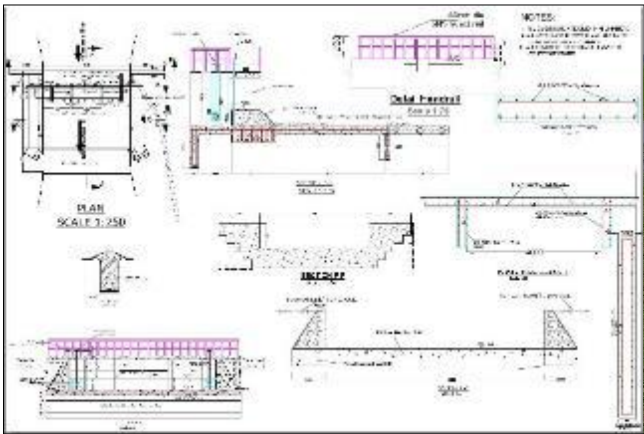
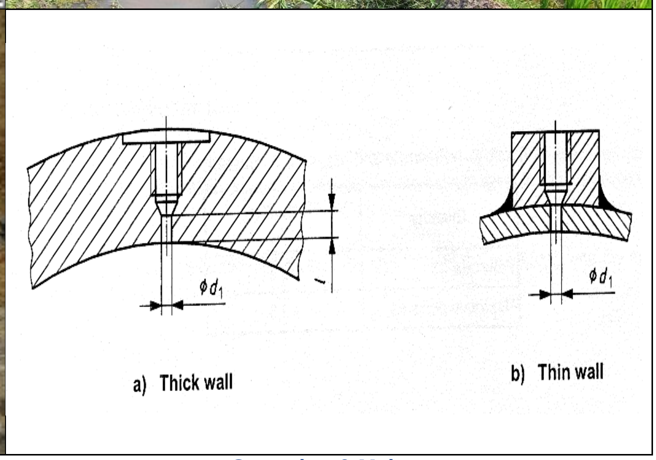
MINISTRY OF AGRICULTURE, IRRIGATION AND WATER DEVELOPMENT

DEPARTMENT OF IRRIGATION

IRRIGATION CODE OF PRACTICE AND EQUIPMENT STANDARDS





Design
Construction

Operation & Maintenance
Standards

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List of abbreviations/acronyms

ASWAp	Agriculture Sector Wide Approach
CSO	Civil Society Organizations
DoI	Department of Irrigation
EU	European Union
GBI	Green Belt Initiative
ICoP	Irrigation Code of Practice
ID	Inside Diameter
ISO	International Organization for Standardization
MBS	Malawi Bureau of Standards
MoAIWD	Ministry of Agriculture, Irrigation and Water Development
NAO	National Authorising Officer
NKE	Non Key Expert
O&M	Operation and Maintenance
OD	Outside Diameter
STE	Short Term Expert
TA	Technical Assistance
TL	Team Leader
ToR	Terms of Reference
WD	Working Day

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PART 1: DESIGNING IRRIGATION SYSTEMS

CODE OF PRACTICE FOR DESIGNING IRRIGATION SYSTEMS

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CHAPTER 1: INTRODUCTION

1.1. Purpose of the Irrigation Design Code of Practice

1.1.1. The goal of developing irrigation systems is the efficient and sustainable use of water, energy, labour and capital in the irrigation industry.

1.1.2. This design code of practice shall provide the guidance on design of irrigation systems in an economic and environmentally sustainable manner, in order to achieve the irrigation industry's expectation of acceptable levels of irrigation design practices to irrigation designers, owners, and operators.

1.1.3. In some circumstances practices and equipment other than those suggested in the code may be equally relevant in meeting irrigation industry standards.

1.1.4. The code is mandatory, and is intended to draw authority from all areas of legislative responsibility within the irrigation industry.

1.2. Context of Design Code of Practice

1.2.1. The Irrigation Design Code of Practice describes the procedures that irrigation designers must follow to meet the required performance standards.

1.3. Technical Standards

1.3.1. Standards from other Codes of Practice that are referenced within this Code of Practice are overseen by the relevant issuing authority.

1.3.2. The International Organisation for Standardisation (ISO) has responsibility for the International Standards published under its name.

1.4. Registration

1.4.1. Requirements

1. No person shall be allowed to practice as an irrigation engineer unless and only when registered with the Malawi Irrigation Board and the Malawi Board of Engineers or equivalent institution as a registered member, (Irrigation Act 2001, Articles 39 and 41; and Board of Engineers Act 1972, Articles 38 and 40).
2. No firm, contractor, or consultant shall practice as specialised in irrigation services unless and otherwise registered with the National Construction Industry Council (NCIC) (NCIC Act 1996, Part VI, Article 20 (1 – 3).

1.4.2. Penalties

1. Any person, firm, contractor, consultant, or their employees that shall contravene the requirements of registration as stipulated in the relevant Acts described in Article 1.4.1 (a-b) above shall be liable to penalties as provided for in the particular Acts.

1.4.3. Access to registers

1. Irrigators shall have access to registers of registered engineers and firms that provide irrigation services, maintained by the Irrigation Board, Board of Engineers and NCIC towards implementing their intended irrigation services.

1.5. How the Code of Practice should be used

1.5.1. The Code of Practice includes practices that must be followed by designers in the design of irrigation systems to ensure acceptable performance standards. Specific technical data are provided to help in this respect, with reference to other technical Standards.

1.6. Normative references

1. MS 4:1993 Unplasticized Polyvinyl Chloride (upvc) Type 1, Pressure Pipes and Fittings (for Cold Water Services) – Specification (Second edition)
2. MS 5:1993 Unplasticized Polyvinyl Chloride (upvc) Pipes and Pipe Fittings for use above ground in drainage installations – Specification (Second Edition)
3. MS 7:1980 Unplasticized Polyvinyl Chloride (upvc) Pipes Installation – Code of Practice
4. MS 785-1:2008 Steel for the Reinforcement of Concrete Part 1: Plain bars
5. MS 785-2:2008 Steel for the Reinforcement of Concrete Part 2: Ribbed bars
6. MS 785-3:2008 Steel for the Reinforcement of Concrete Part 3: Welded fabric
7. MS 838:2011 Concrete Works - Code of Practice for Minor Works (First edition)
8. IS0 8779:2010, Plastic piping systems – Polyethylene(PE) pipes for irrigation - Specifications
9. MBS 324:1992, Black Polyethylene Pipes for the Conveyance of liquids – Specification-Part 1: Low density polyethylene pressure pipes
10. MBS 617-3:1998, Pipes and Fittings made of unplasticized poly-vinly chrolide (PVC-U) for water supply –Specification-Part 3: Fittings and joints
11. DMS 838:2009, Concrete works – Code of practice for minor works
12. ISO 21500:2012, Guidance on project management
13. SABS 0164-1:1980, Structural use of masonry - Part 1: unreinforced masonry walling
14. ASAE EP400.2T: 1997, Designing and Constructing Irrigation Wells
15. ASAE EP260.4: 1997, Design and Construction of Subsurface Drains in Humid Areas

CHAPTER 2: DEFINITIONS

2.1. **Adequacy of irrigation:** A measure of the proportion of the target area for which the soil is restored to a level that equals or exceeds a set level, or target soil water content

2.2. **Application depth:** The mean application depth (mm) applied by an irrigation event during periods of peak irrigation demand. In some applications, such as for annual crops, the system may be required to meet a range of application depths to match progressive stages of crop development

2.3. **Application efficiency:** The percentage of applied water that is retained in the root zone, or in the target area, after an irrigation event

2.4. **Application rate:** The mean precipitation rate of the irrigation system, expressed in millimetres depth of water applied per hour.

2.5. **Application uniformity:** The spatial variability of application, defined in a variety of ways; the most common being distribution uniformity (DU), coefficient of uniformity (CU) and emission uniformity (EU).

2.6. **Available water holding capacity:** The difference in moisture content between field capacity and permanent wilting point, expressed in millimetres depth of water over a specified depth of soil within the effective root zone (usually equal to the expected effective root depth of a crop during periods of maximum water demand).

2.7. **Back flow preventer:** A device or devices installed in a pipeline to prevent water flowing in reverse through the system.

2.8. **Capital cost:** The overall system investment cost ($) or cost per unit area ($/ha) as total or annualised cost. For the purposes of economic analysis, annualised capital cost may also be expressed as cost per unit volume ($\$/m^3$) based on mean annual irrigation demand.

2.9. **Crop factor:** The ratio of the water requirements of a particular crop to that of a reference crop (usually average grass pasture).

2.10. **Design area:** The specific land area in hectares, which the supplier (or designer) and the irrigation system purchaser mutually understand is to be irrigated by the irrigation system.

2.11. **Design system capacity:** The mean daily flow of water per hectare of irrigated area used in the design of the system.

2.12. **Distribution efficiency:** A measure of how much of the water supplied to the Property reaches the application system. It is a function of losses incurred in the conveyance or distribution system, from the point of water abstraction or entry to the Property (in the case of irrigation schemes) to the application system.

2.13. **Drainage depth:** The potential drainage volume based on peak irrigation demand. This is typically expressed as volume per unit area (m^3/ha) or an equivalent depth per unit area (mm/ha).

2.14. **Effective root depth:** The depth of soil profile that has enough rooting density for extraction of available water, if needed. Roots may be found at depths greater than this value but do not contribute significantly to water extraction.

2.15. **Evapotranspiration rate (ET):** The rate of water loss from a combined surface of vegetation and soil. It includes evaporation of water from the soil surface, from free water on plants and transpiration by plants.

2.16. **Field capacity:** The soil water content of well-drained soils after drainage from initially saturated soils has become negligible. The macro pores of the soil are filled with air and the micro pores hold water by capillary action.

2.17. **Headworks efficiency:** A measure of the hydraulic performance of the intake structure, pump and headworks (excluding pump pressure and elevation differences) to indicate the extent of pressure loss in the water supply system between the water supply point and the mainline entry.

2.18. **Hydraulic efficiency:** A measure of the system hydraulic performance; it gives an indication of how much pressure is lost between the delivery (mainline entry) and discharge points (machine entry, hydrant, or take-off in drip-micro systems), excluding variations in elevation.

2.19. **Infiltration rate:** The rate at which the soil can absorb water, which changes according to the wetness of the soil. Infiltration rate is usually expressed in units of mm/hour.

2.20. **Irrigation scheme types**

2.20.1. **Basin:** Water is supplied in a field which has been subdivided into flat areas of land surrounded by earth bunds. Water entering the basin is ponded until it infiltrates into the soil.

2.20.2. **Border strip:** Resembles basin irrigation in that the land is divided into strips by small earth bunds, however, the field usually slope uniformly away from the field channel.

2.20.3. **Centre Pivot and Lateral Move:** These are self-propelled irrigation systems which apply water to pasture or crop, generally from above the canopy. They are anchored at one end and rotate around a fixed central point. Lateral systems are not anchored and both ends of the machine

move at a constant speed up and down a paddock.
Centre Pivot and Lateral Move systems require an energy source to move water from the source to the plant as well as energy to move the machine on farm.

2.20.4. **Dam:** An irrigation scheme whose water source is a reservoir formed by constructing a dam across a river, a stream, or a valley. Reservoirs can be on-stream or off-stream depending upon their location.

2.20.5. **Drip:** Drip irrigation (low volume/micro-irrigation) is where water is delivered on a slow, frequent and accurate basis directly to the root zone of the plant. The root zone is kept moist but never saturated with water. The end result is that the plant always maintains the ideal balance between water and air.

2.20.6. **Furrow:** Irrigation water is confined to narrow channels (furrows) between crop rows. The shape of the furrow depends upon soil type, stream size, and crops being grown. This method is widely used irrigating row crops.

2.20.7. **Gravity:** An irrigation scheme in which water is supplied to the agricultural land with gravity force only

2.20.8. **Groundwater:** An irrigation scheme in which the water source is a shallow well, a borehole, or other groundwater storage. Water abstraction could be by centrifugal pumps, submersible pump, treadle pump, solar powered pump, or other pump mechanism.

2.20.9. **Localised:** This form of irrigation aims at applying water at the plant root zone, using such devices as nozzles, micro-tubes, porous pipes, orifices.

2.20.10. **Pump (lake/pond):** An irrigation scheme whose water source is a lake or pond and water is abstracted by pumping.

2.20.11. **Pump (river):** An irrigation scheme whose water source is a river and water is abstracted by pumping.

2.20.12. **Rainwater harvesting:** An irrigation scheme that subsistence farmers themselves have introduced using simple rainwater harvesting techniques to artificially control the availability of water for crops. This type includes flood recession schemes.

2.20.13. **Sprinkler:** This system comprises a network of pipes with sprinklers attached for spraying water under pressure over the land surface. There are three types of sprinkler systems: portable, semi-permanent, and permanent. The systems are connected to a main line normally supplied by a pumping unit.

2.20.14. **Surface:** These are schemes whereby water is applied onto the crops on the ground surface and allowed to percolate to roots by gravitational forces.

2.21. **Irrigation system:** This comprises all of the equipment required to transfer water from the water source to the crops in the design area.

2.22. **Irrigator:** An individual, community, or institution that seeks to develop agricultural land into an irrigation scheme.

2.23. **Leaching:** Removal of salts and loss of nutrients beyond the root zone of plants due to deep percolation of water.

2.24. **Mainline:** A pipeline within the distribution system that transports water from the water source to sub units or zone control valves in a system.

2.25. **Maximum allowable deficit (MAD):** The percentage of available water that is accepted to be depleted before irrigation is required. Often known as stress point or critical deficit.

2.26. **Mean Annual Flood (MAF):** The flood which is estimated to occur in a river whose magnitude is based on a probability of occurrence or non-exceedance. In case of ungauged rivers, the following parameters apply in determining MAF: MAF_{ug} (ungauged river), MAF_g (gauged river), MAF_o (observed).

2.27. **Operating system capacity:** The mean daily flow of water per hectare the system is able to provide the way it is being managed.

2.28. **Permanent wilting point:** The soil moisture content at which a plant will die from drought stress. For practical purposes, it is the soil water content at a soil tension of 15 bar (1500 kPa).

2.29. **Planning stage:** A period in the irrigation project development process which covers activities related to the initiation of the project by the client or irrigators under the guidance of professional registered irrigation services providers.

2.30. **Potential system capacity:** The mean daily flow of water per hectare the system is able to provide in the time available.

2.31. **Productivity:** The marginal increase in income resulting from the irrigation system. It is generally expressed as the increase based on mean annual irrigation demand per unit area ($/ha, may also be expressed as $/mm/ha), though for economic analysis, maximum and minimum values may also be of interest.

2.32. Pump terminologies

2.32.1. **Cavitation** is the formation and collapse of vapour bubbles in the liquid.

The reason is in most of the cases is a too low static suction head. The suction valve should be submerged in the liquid to a depth greater than the minimum recommended by manufacturers so that no air is sucked in through vortices when the pump is in operation. Cavitation causes pitting corrosion at the impeller, pressure drops resulting in a drop in pump performance.

2.32.2. **Diaphragm pumps** use a positive displacement design and will deliver a specific amount of flow per stroke, revolution or cycle. Engine-powered versions are the most common.

2.32.3. **Dynamic Discharge Head** is the static discharge head plus the friction in the discharge line. Also referred to as Total Discharge Head.

2.32.4. **Dynamic Suction Head** is the static suction lift plus the friction in the suction line. Also referred to as Total Suction Head.

2.32.5. **Head** refers to gains or losses in pressure caused by gravity and friction as water moves through the system. It is most commonly listed in metres of water. Depending on how the measurement is taken suction lift and head may also be referred to as **static or dynamic head**.

2.32.6. **High-pressure centrifugal pumps** are designed for high-discharge pressures and low flows. Typically, these pumps will discharge around 10 litres per second and produce heads in excess of 90 metres. These pumps by design are not capable of handling any types of solids or even sandy water.

2.32.7. **Maximum suction lift** is the practical suction lift, at sea level, which is specified by most pump manufacturer. It is set at 7.5 metres.

2.32.8. **Net positive suction head (NPSH)** is defined as absolute pressure (rather than gauge pressure) that is required at the pump inlet for satisfactory operation. The NPSH of the pump is determined by measurements carried out on the suction and delivery side of the pump. This value is to be read from the pump characteristic curve and is indicated in meter (m). The NPSH of the pump is called NPSH required, and that of the system is called NPSH available. The $NPSH_{avl}$ should be greater than the $NPSH_{req}$ in order to avoid cavitation. NPSH required ($NPSH_R$) depends on the design of a particular pump, and is specified by the pump manufacturers. For safety reasons another 0.5 m should be integrated into the calculation, i.e.: $NPSH_{avl} > NPSH_{req} + 0.5m$

2.32.9. **Performance** of a pump is measured in volume as litres per second and in pressure as head.

2.32.10. **Required flow rate (Q)** is equal to the design flow rate for the irrigation system. In situations where there is more than one design flow rate, the designer shall consider using a single or multiple pumps, or a variable speed drive unit or other control methods.

2.32.11. **Standard centrifugal pumps** common models are in the 50 mm to 100 mm range with flows from 10 to 35 litres per second and heads in the range of 25 to 35 metres, used in clear water applications only. They will only pass spherical solids ¼ the diameter of the suction inlet.

2.32.12. **Static Discharge Head** is the vertical distance from the discharge outlet to the point of discharge or liquid level when discharging into the bottom of a water tank.

2.32.13. **Static Suction Lift** is the vertical distance from the water line to the centreline of the impeller.

2.32.14. **Submersible pumps** have a compact and streamlined design which makes them ideal for wells and other jobs where space is limited. They work in the water source being pumped.

2.32.15. **Total Dynamic Head** is the head that the pump is required to impart to a fluid in order to meet the head requirement of a particular system. The total dynamic head is made up of static suction lift or static suction head, static discharge head, total static head, required pressure head, friction head and velocity head.

2.32.16. **Trash centrifugal pumps** can handle large amounts of debris and are preferred by contractors for desilting at construction sites. The most common sizes are in the 50 mm to 150 mm range producing flows from 15 to 120 litres per second and heads up to 380 m. They will generally handle spherical solids up to ½ the diameter of the suction inlet, and up to 25% suspended solids by volume.

2.33. **Readily available water holding capacity:** The difference in moisture content between field capacity and the stress point (equal to a soil suction of 200-500 kPa), expressed in millimetres depth of water over a specified depth of soil (usually equal to the expected effective root depth of a crop during periods of maximum water demand).

2.34. **Readily system capacity:** The mean daily flow of water per hectare required to meet the demands of the crop at Peak ET after accounting for the duration that water is available.

2.35. **Return interval:** The interval between successive irrigation cycles during periods of peak demand and no rainfall.

2.36. **Return on water use:** The marginal change in returns resulting from the irrigation system. It is generally based on mean annual irrigation demand, and incorporates cost and productivity elements above. Values can be expressed as returns per unit area or volume of water ($/ha or $/m^3). Values can be positive or negative, dependent on system costs, productivity and crop returns.

2.37. **Scheduling coefficient:** A ratio to indicate how much additional water above the mean application needs to be applied to adequately overcome non-uniform applications.

2.38. **Size of irrigation schemes:**

≤ 10ha: Mini Irrigation Schemes
11 – 50 ha: Small Scale Schemes
51 – 500ha: Medium Scale Schemes
≥ 501ha: Large Scale Schemes

2.39. **Soil texture:** refers to the particle size or the relative amounts of sand, silt and clay in the soil.

2.40. **Surface runoff:** An assessment of the potential surface runoff (volumetric) proportion from the system operating during periods of peak irrigation demand. Generally, such considerations are limited to surface irrigation systems and some spray systems.

2.41. **System capacity:** A measure to assess the ability of a system to meet total system requirements; crop irrigation demand and losses due to non-uniformity of application and distribution losses.

2.42. **Uniformity coefficient (Christiansens):** A measure that defines the variability of individual application depths from the mean and, therefore, the impact of overall uniformity. It has most commonly been used in the description of sprinkler application uniformity, but can be equally useful in defining field and system uniformity.

2.43. **Water holding capacity:** The maximum amount of water that can be held in the soils that is available for plant growth. For practical purposes, it is the difference between field capacity and permanent wilting point.

CHAPTER 3: KEY PERFORMANCE INDICATORS

3.1. Requirements

1. The designer shall provide quantifiable key performance indicators which shall be the basis for the evaluation of the performance of the system, for comparison with industry benchmarks and between systems and system types.
2. The designer shall provide quantifiable key performance indicators specific for each system, some of which shall be selected from the list given in Annex 1.
3. The designer shall provide the following in the design report in order to comply with this Code of Practice:
   - Explicitly state what *kpi* values will be achieved using the determined design, if the system is installed correctly; and
   - Give sufficient details on what, where, and how to measure, throughout the irrigation system, in order to verify that the system is achieving the expected *kpi* values.
4. The following are some of the key performance indicators:
   a. Water use efficiency: measurements of discharge at the intake, at distribution boxes, and at the fields, determining losses within the entire distribution system; measurement of application rates, irrigation intervals in order to meet the crop demand related to the maximum allowable deficit, flows into drains, leakages, and all areas that relate to water from abstraction to drainage from crop fields. This can also be related to the crop yield.
   b. Energy use efficiency: related to pumped irrigation systems, measurements of energy consumption in providing the designed discharges, cost of providing and maintaining the required energy levels. These measurements can also be related to crop yields.
   c. Labour efficiency: related to use of labour for the operation and maintenance services.
   d. Capital efficiency: related to the profitability of the enterprise as regards investment in management, construction, operation, maintenance, and other infrastructure compared to the output from the enterprise.
   e. Environmental performance: which is related to the stream or river yield from the catchment, the stream or river discharges to sustain the planned and developed irrigation system, drainage efficiency monitoring stagnation of water in places and rise in groundwater levels that might result in salinization.

CHAPTER 4: DESIGN PROCESS

The design process can be conveniently divided into five key components:

a) Planning
b) Pre-feasibility studies
c) Feasibility studies
d) Detailed design

4.1. Planning Stage

4.1.1. Preparatory activities

1. The designer shall undertake several preparatory activities assessing the needs of the irrigators and the adequacy of the land and water resources, the environmental considerations, and any other issues that need to be considered before significant resources are committed to the project.
2. These activities shall apply to all sizes of irrigation schemes.

4.1.2. Site visit

1. The irrigator shall have a plan for the proposed irrigation development which shall be the basis for further assessments.
2. The designer shall visit the site in order to confirm the suitability of the site for the intended development.
3. The designer should prepare beforehand a checklist of issues to be investigated. Some of the information to be obtained is given in Annex 2.
4. The designer shall hold discussions with the irrigators and land owners to assess the proposed irrigation development with regard to water source, land, crops and cropping pattern, livestock, markets, value addition, organisation for operation and maintenance.
5. The irrigator shall provide all necessary information regarding the site and the intended development.
6. Should there be several sites that offer options to the desired site, the irrigator shall guide the designer to all the proposed sites to assess their suitability for the intended purpose. The designer shall select out of all the sites the best option for development, and this shall be discussed with the irrigators.

4.1.3. Identification

1. The designer shall obtain consensus during all consultations with the irrigators or clients to confirm the suitability of the site and acceptability of the intended irrigation development. This shall form the basis for further studies leading to the development of the project.
2. The designer shall conduct site visits as appropriate to obtain more data and get more familiar with the site – catchment, water source, proposed intake, irrigation land, the community, soils, crops, topography.
3. The designer must not:
    a. Promise something that cannot be delivered;
    b. Force or coerce the client into making decisions;
    c. Offer to design an irrigation system without visiting the project area; nor
    d. Attempt to design a system that clearly will not meet the needs of the client.
4. The designer shall, jointly with irrigators, clients, and stakeholders, prepare a plan of action for pre-feasibility and feasibility studies

leading to the preparation of the irrigation project on the agreed site, once the proposal for irrigation development has been deemed feasible.

5. The designer shall refer to all available land laws relevant to the proposed irrigation development, and get consensus with the developers before further action.

4.2. Pre-feasibility Stage

4.2.1. Data collection

1. The designer shall access all data that the client has on the intended project.
2. The designer shall obtain data from other sources that shall include and not be limited to the following:
   - (i) Maps of Malawi (1:250000 for project site location), topographical maps (1:50000), aerial photographs and GIS data – Department of Surveys
   - (ii) Hydrological and hydrogeological data – Department of Water Resources
   - (iii) Soil classification, land classification and capability maps – Department of Land Resources Conservation.
   - (iv) Climatological data – Department of Meteorology and Climate Change
   - (v) Environment and Catchment Management – Environmental Affairs Department.
   - (vi) Agronomic data – Department of Crops and Department of Agricultural Extension Services.
   - (vii) Sociological data – National Statistics Office.
   - (viii) Water abstraction – Water Resources Board.
   - (ix) Land issues – The Department of Lands
3. Some of the data to be collected is proposed as in Annex 3.
4. Access to other sources of data shall be facilitated by the Department of Irrigation.
5. Where water rights permits have been granted on the watercourse, the designer shall obtain a copy of the permit and ensure that the design takes into account all these existing permits before confirming the availability of water for irrigation. The client should be encouraged to obtain their own permit for the water to be abstracted to ensure availability of water.

4.2.2. Assessments

1. Pre-feasibility, feasibility and detailed design, shall be done dependent upon the size of the intended irrigation scheme. For mini and small scale irrigation schemes, it would be sufficient to do pre-feasibility studies leading to detailed design. However, for medium scale and large irrigation schemes, all three stages must be done because of the scale of the effects of development.
2. The designer shall carry out pre-feasibility studies on the agreed project proposal in consultation with the client, irrigators, and other stakeholders.
3. The designer shall prepare a checklist derived from the preparatory stage that should guide the conduct of the assessments.
4. The designer shall collect and review all pertinent data on the project from various sources in the process of designing the project. The designer shall resort to other methods of generating data where such data is not available. The methods of generating such data shall be clearly described.

5. [1]In the case of irrigation development where the water resources are from ungauged rivers and therefore no river flow data is available, the designer shall determine hydrological data by using an analogue catchment to modify the MAF whose selection is based on the following criteria:
   (i) Catchment characteristics should be comparable
   (ii) Catchment areas should differ by less than a factor of 5
   (iii) The distance between the centroids of the catchments should be less than 50 km
   (iv) At least 10 years of annual maximum flood data available

   The procedure for adjusting the MAF at the ungauged site if annual maximum flood data are available from a suitable analogue catchment is as follows:
   (i) Apply the appropriate regional MAF equation to estimate the MAF at the ungauged site (MAFug)
   (ii) Apply the same regional MAF equation to estimate the MAF at the gauged site (MAFg)
   (iii) Analyze the annual maximum flood series at the gauged site to determine the observed MAF (MAFo)
   (iv) Adjust MAFug by the ratio MAFo/MAFg
6. The designer shall conduct an environmental screening of the proposed project and identify all environmental and social impact issues, and propose remedial measures. The outcome of the screening shall be a recommendation of whether or not to go into a full environmental and social impact assessment.
7. The designer shall assess the project and provide options on the development of the project. The options shall provide details of pros and cons of development approaches and strategies, and costs and benefit analyses that will be presented to and discussed with the client, irrigators, stakeholders to decide on the best option that will be subject to further investigations (feasibility studies).
8. Further assessments on the proposed area for development into an irrigation scheme shall cease when the pre-feasibility study deems the site unsuitable for development.

4.3. Feasibility Stage

[2]The feasibility study goes into more detail of the aspects investigated during the pre-feasibility stage, and results in options of development out of which the most viable one would be selected for detailed design leading to eventual implementation.

4.3.1. Data collection

1. The designer shall collect and review data as required in addition to that already collected during pre-feasibility studies, in order to fill in the identified data gaps.

4.3.2. Assessments

1. The designer shall conduct feasibility studies as an integral part of project preparation, examining the social, technical, financial, and

[1] More details can be obtained from the publication "Hydrological Design of Small Earth Dams in Malawi, Volume 1 – Guidelines for Flood Assessment and Estimation of Reservoir Yield for Small Ungauged Catchments" (February, 1999)

[2] Additional details on the contents and conduct of feasibility studies for irrigation projects can be obtained in the publication *FAO Irrigation Manual Vol. 1, Module 1: Irrigation Development: a Multifaceted Process*

environmental feasibility of the project, to enable irrigators and financiers make an investment decision. Some of the issues to be assessed are presented in Annex 4.

2. The designer shall conduct feasibility studies on the option selected and agreed upon by the client, irrigators, and stakeholders, as the most viable during the pre-feasibility studies.
3. The designer shall conduct feasibility studies utilising the integrated water resources management (IWRM) approaches. More information on steps of IWRM approaches is presented in Annex 5.
4. Feasibility and detailed design, shall be done dependent upon the size of the intended irrigation scheme. For mini and small scale irrigation schemes, it would be sufficient to do feasibility studies leading to detailed design. However, for medium scale and large irrigation schemes, all three stages must be done because of the scale of the effects of development.
5. The designer shall present several options on approach and strategies of implementing the project selected and agreed during the pre-feasibility stage. The options shall provide details of pros and cons of development approaches and strategies, and costs and benefit analyses that will be presented to and discussed with the client, irrigators, stakeholders to decide on the best option that will be subject to further investigations (detailed design studies).
6. The designer or an independent specialist shall conduct a full environmental and social impact screening in order to assess the magnitude of the impacts whether or not a full environmental and social impact assessment would be required in compliance with the Malawi Environmental Management Act 1996 and the Water Resources Act 2013, Articles 4(b) and 6. The screening form is presented as Annex 6.

4.3.3. Irrigation Scheme Layout Design [3]

Design process

1. The designer shall prepare designs of the irrigation system consisting of a (main) intake structure or (main) pumping station, a conveyance system, a distribution system, a field application system, and a drainage system (Figure 1), taking into consideration the topography and topographical features of the land.

[3] Some software that can be used in irrigation system design is presented in Annex 14.

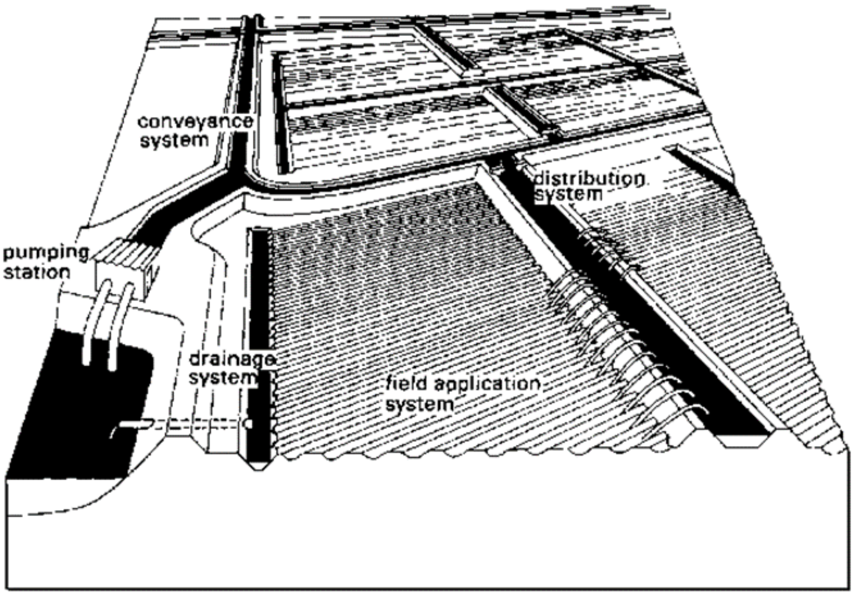

Figure 1 Example of an irrigation system

2. The designer shall design the layout of the irrigation system with the objective of minimising the construction cost of the scheme.
3. The designer shall provide a complementary drainage network to remove excess surface water (caused by rainfall and/or irrigation), and, if necessary, a field drainage network to control the ground water levels.
4. The designer shall provide for flood protection measures where the irrigation infrastructure is likely to be inundated by floods.
5. The designer shall provide for a field application system based on crops, topography, soil characteristics, and efficiency of application.

4.3.4. Main Intake Structure Design

Design process

1. The designer shall provide for a main intake of a type depending upon the source of water and method of abstraction (river diversion, pumping, tubewell, shallow well, or reservoir). A perfect offtake structure should have the following characteristics:
   - (i) Deliver the water a farmer needs to meet the water requirements of a cropping pattern;
   - (ii) Deliver accurately the amount of water required (within 5%);
   - (iii) Minimal hydraulic losses;
   - (iv) Water delivery which is independent from fluctuations in the upstream and/or downstream water levels in the tertiary canal;
   - (v) Practical and economical;
   - (vi) Easy to adjust for varied discharges; and
   - (vii) Sturdy and tamper proof, not possible to adjust it illegally.
2. The designer shall provide for a direct run-of-the-river abstraction mechanism on rivers with a stable base flow and a high enough water level throughout the year in relation to the bed level of the intake canal.
3. For run-of-the-river abstraction, the designer shall locate the intake structure at a straight reach of the river, placed on the outside of a

bend, in order to minimise silt intake. Bank protection shall be provided for where the river channel banks are unstable.

4. Where the base flow water level fluctuates greatly over the year and the water level gets below the gate opening to the offtake structure, the designer shall consider the following options:
   (i) Select an offtake site further upstream, mindful of the costs due to the increased length of the canal and site conditions.
   (ii) Construct a cheap temporary earthen dam and temporary diversion structure, where high expenses for a permanent structure are not warranted because of the danger of the river changing its course.
   (iii) Construct a permanent diversion dam or structure (weir or gate) across the river, where the design elevation of the weir should relate to the design water level in the conveyance canal.
5. In the case of a **weir**, the designer shall locate the weir in a stable part of the river where the river is unlikely to change its course. The designer shall observe the following:
   (i) The weir should be kept as low as possible but high enough to fulfil command requirements.
   (ii) The selected location should have firm, well defined banks to prevent wash-away during floods. Where possible, the site should have good bed conditions, such as rock outcrops.
   (iii) The weir height shall match the design water level in the conveyance canal, and the weir length shall allow the design flood to safely discharge over the weir.
   (iv) The design flood, which is the maximum flood for which the weir has to be designed, shall be determined. If data are available, a flood with a return period of 50 or 100 years could be selected, depending upon the size of the river. If sufficient data are not available, the designer shall either generate data using approved hydrological methods, or check flood marks, upon which the cross-sectional area can be determined and used, together with the gradient of the river, to calculate the flood discharge. The general equation for all weir types is:

$$Q = C_1 \times C_2 \times B \times H^{3/2}$$

where:

Q = Discharge (m^3/sec)

C_1 = Coefficient related to condition of submergence and crest shape

C_2 = Coefficient related to crest shape

B = Weir length, i.e. the weir dimension across the river or stream (m)

H = Head of water over the weir crest (m)

For values of the coefficients, refer to *FAO Irrigation Manual Module 7 Volume II: Planning, Development, Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation*.

(v) The designer shall provide for protection of the downstream side of the weir by using a stilling basin to dissipate the energy of the dropping water. The parameters used in the design of a stilling basin are shown in Figure .2

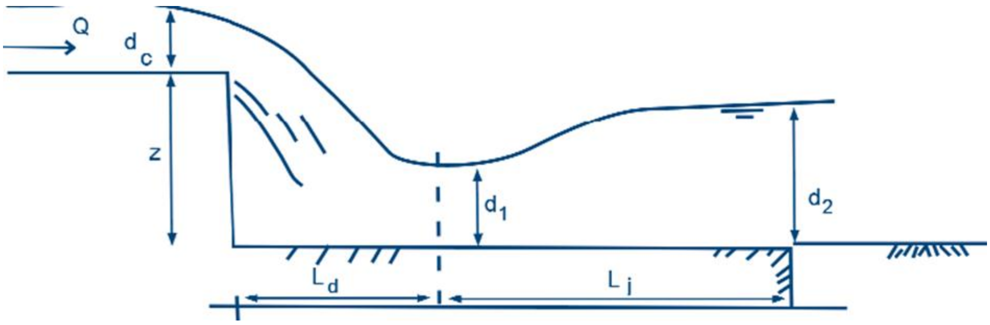

Figure 2 General parameters of a stilling bassin

The empirical formulae to use for the design of a stilling basin (apron) are:

$$D = q^2\left(g \times z^3\right) \qquad \frac{L_d}{z} = 4.30 \times D^{0.27}$$

$$L_j = 6.9x\left(d_2 - d_1\right)$$

$$\frac{d_1}{z} = 0.54 \times D^{0.425} \qquad \frac{d_2}{z} = 1.66 \times D^{0.27}$$

Where:

D = Drop number (no limit)

q = Discharge per metre length of the weir (m^2/sec)

g = Gravitational force (9.81 m/sec^2)

z = Drop (m)

L_d = Length of apron from the drop to the point where the lowest water level d_1 will occur (hydraulic jump) (m)

d_1 = Lowest water level after the drop (m)

d_2 = Design water level after the apron (m)

L_j = Length of apron from the point of lowest water level to the end of the apron (m)

The apron floor shall have sufficient thickness to counterbalance the uplift hydrostatic pressure and shall be sufficiently long to prevent piping action.

6. The designer shall incorporate in the intake as well as in the main conveyance system appropriate sediment extraction systems to minimise sediments being transported into the field conveyance system.
7. In the case of the intake being a **pumping station**, the designer

shall observe the following:

(i) Firstly, the designer should confirm the reliability of the river flow or, in case of a reservoir, whether the amount of water stored is enough to fulfil the annual irrigation requirements for the proposed cropping programme.

(ii) Secondly, in the case of river abstraction the designer shall check the maximum flood level of the river and locate the pumping station outside the flood level, using either a portable pumping station or a permanent pumping station, depending upon the reliability and variability of the river flows.

(iii) Thirdly, the abstraction point shall not be located in a river bend where sand and silt deposition is predominant, to prevent clogging of both the suction pipe and pump.

(iv) Fourthly, where water is to be pumped from a dam or weir, the abstraction site shall be located outside the full supply level in case of upstream abstraction, and shall neither be too close to nor in line with the spillway in the case of downstream abstraction.

(v) Finally, as a rule, before a final decision is made on the location of the pumping station, the designer shall visit the site to verify the acceptability of the site, with the help of the local people, taking into consideration the above requirements.

(vi) The designer shall select a pump that that is most efficient and matches the design.

4.3.5. Pump Selection

Design process

1. When selecting a pump, the designer shall observe the following:
   - (i) By looking at the various manufacturers' pump curves the designer shall identify a pump that can provide the discharge and head required at the highest possible efficiency.
   - (ii) The designer shall not select a pump when the required Q and H combination falls outside the performance curve or when it falls at the fringes of the performance curve.
   - (iii) The designer shall also take into consideration motor efficiencies of the various pumps, which are in the range of 0.88 - 0.92. Motors of 7.5 kW or less have motor efficiencies usually below 0.88. For motors of 75 kW or larger the efficiency is 0.9 - 0.92. Hence, the tendency is to use 0.88 for motor efficiency in small size irrigation schemes.
   - (iv) The designer shall also consider the speed of the pump in order to determine the type of drive employed (e.g. direct coupled electric, belt drive).
   - (v) If the required Q and H combination falls between two impeller sizes, the designer shall prefer to use the larger impeller, but may have to have it trimmed down by the manufacturers so that it matches the required Q and H.
   - (vi) The designer shall consider all dependent factors when determining allowable suction lift, (such as atmospheric pressure, water vapour pressure, pressure losses, the required inlet pressure of the particular pump, elevation (height above sea level) and water temperature).
   - (vii) For centrifugal pumps, the designer should consider the following:
     - a. Suction lift should be kept to a realistic minimum;
     - b. Actual net positive suction head (NPSH) should be calculated and be less than the required NPSH recommended by the pump manufacturer; and
     - c. The system must be designed in accordance with manufacturers' performance guidelines.
   - (viii) The designer shall consider the net positive suction head (NPSH) of the pump provided in the manufacturers' pump characteristic curves and is indicated in meter (m). The NPSH of the pump is called NPSH required, and that of the system is called NPSH available. The $NPSH_{avl}$ should be greater than the $NPSH_{req}$ in order to avoid cavitation. The absolute pressure available at the inlet is determined by adding up the available pressure and subtracting any pressure used up by losses prior to water arriving at the pump inlet, i.e. *NPSHA = Atmospheric pressure +/- any static head – friction head (Including minor losses) – Velocity head – vapour pressure of water at operating temperature*

Table 1 Variation of vapour pressure with water temperature

Temp. ^{0}C	0	5	10	15	20	25	30	35	40	45	50
Vapour press. Of water (m)	0.06	0.09	0.13	0.17	0.24	0.32	0.43	0.58	0.76	0.99	1.28

(ix) The designer shall note that pump performance diminishes with higher elevations, whereby atmospheric pressure is decreased reducing suction lift. For this reason, the pump should be located as close to the water source as possible. At high altitudes, atmospheric pressure is less than at sea level, practical suction limit decreases by 1 m for every 1000 m of altitude.

(x) The designer shall also note that higher elevations affect engine performance as well. A rule of thumb is that gasoline and diesel engines will lose 3% of their power for every 300 metres of elevation. This is due to the "thinner air" or lack of oxygen at higher altitudes. The reduced engine speed results in reduced flow and head.

Table 2 Performance loss at various elevation

Altitude	**Discharge Flow**	**Discharge Head**
Sea Level	100%	100%
610 m	97%	95%
1,220 m	95%	91%
1,830 m	93%	87%
2,440 m	91%	83%
3,048 m	88%	78%

4.3.6. Solar pump systems design

Design process

1. A typical solar powered pumping system contains the following equipment: a solar array, which converts sunlight into electricity; system controllers, which control the array and the pump; an electric motor, which drives the pump; and a water pump, which moves the water from a source to its delivery point, as shown in Figure .3.

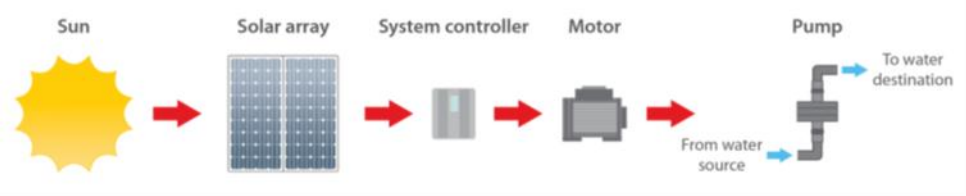

Figure 3 Configuration of solar power system

Source: Solar-powered Pumping in Agriculture: A guide to System Selection and Design, NSW Farmers, Aug, 2014

2. The designer shall follow the following sequence when designing solar powered systems:

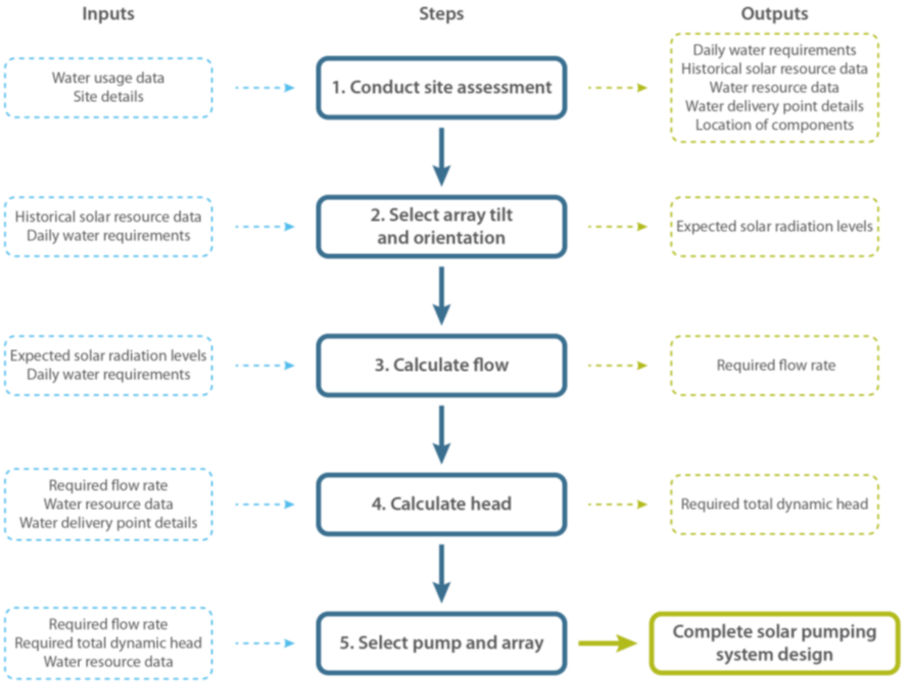

Figure 4 The steps involved in designing a solar pumping system

Source: Solar-powered Pumping in Agriculture: A guide to System Selection and Design, NSW Farmers, Aug, 2014

4.3.7. Irrigation canal network design

Design process

1. The designer shall consider all the head losses that occur in the system starting from the tail of the field canals to the source of irrigation water. The minimum acceptable difference between water level in the field canals and the field level, is usually between 15 to 20 cm. This should be valid at both the head and tail of the field canals.
2. The designer shall start by determining the minimum required water level in the field canals, proceed progressively to the tertiaries, secondary and main canals, and finally determine the minimum required water level at the canal head regulator. Further steps in design are described in Annex 7.
3. The designer shall calculate channel dimensions and longitudinal slope, whether for irrigation or drainage, through iterations with the Manning's formula or other similar formulae.
4. The designer shall define a trapezoidal channel as the preferred channel geometry, with side slopes set at 45 or 60 degrees. Other channel geometry types can be used depending upon the prevailing site conditions.
5. The designer shall provide embankment width such that they are stable enough against slope failure and that seepage line is kept well within the embankment. A recommended relationship between the bed width and water depth in earth canals for discharges up to 15 m^3/s is:

   $D = 0.50\sqrt{B}\,;\; B = 4D^2$. Both B and D are in metres

   For discharges greater than 15m^3 /s, Varsheny recommends the relationship given in Table 3

   .

Table 3 Recommended depth of water in open channels

Q (m^3/s)	D (m)	
15	1.70	$D = 1.103Q^{0.175}$ R = 0.93
30	1.85	
75	2.30	
150	2.60	
300	3.00	

The same author has constructed a curve to relate B/D to the canal discharge, Q. Its regression yields the following equation with a regression coefficient r = 0.98.

$$B/D = 3.92\ Q^{0.272}$$

6. The designer shall define canal side slopes based on soil stability, as is the usual practice. The indicative side slopes to be used are given in Table 4

Table 4 Recommended side slope for unlined canals

Type of soil	**Side slopes (H:V)**
1. Very light loose sand to average sandy soil	1.5:1 to 2:1 in cut 2:1 to 3:1 in fill
2. Sandy loam, black cotton soil and similar soils	1:1 to 1.5:1 in cut 2:1 in fill
3. Sandy soil or gravel	1:1 to 2:1
4. Hard soil	0.75:1 to 1.5:1
5. Rock	0.25:1 to 0.5:1

Source: Irrigation Design and Practice by Bruce Withers and Stanley Vipond

7. The designer shall determine canal freeboard in small and medium sized earth canals from the following relationship:

$$F = C\sqrt{D}$$

where F = freeboard in metres
D = water depth in metres
C = a coefficient defined below
C = 0.46 for Q = 0.60 m^3/s
C = 0.8 for discharges of up to 0.5 m^3/sec
C = 0.76 for Q = 0.85 m^3/s
C = 1.35 for discharges up to 80 m^3/sec
or
[4] $F = 0.20 + 0.15\ Q^{1/3}$

[4] F should be within 50 – 60% of water depth, with a minimum of 0.15 m. For lined canals, $F=0.15*Q^{0.35}$, whereby F ranges from 0.40 m for discharges less than 0.5 m^3/sec up to 1.20 m for discharges of 50 m^3/s or more. For very small lined canals, with discharges of less than 0.5 m^3/sec, the freeboard depths could be reduced to between 0.05-0.30 m.

where, the freeboard F is in metres and discharge Q in m^3/s.

Q (m^3/sec)	0.70	0.7 – 1.4	1.4 – 8.5	> 8.5
F (m)	0.46	0.61	0.76	0.92

The width of the canal berm should not be less than 0.5 m.

8. The designer shall prescribe the recommended road widths presented in Table 5 where canal banks shall incorporate roads for operation and maintenance services and crop extraction. However, under no circumstances shall canal embankments be less than 0.50 m wide, and the minimum cover over the saturated line should not be less than 0.50 m. The water line is assumed to have a gradient of 1:4 to 1:6.

Table 5 Recommended canal bank and field road width

Q (m^3/sec)	**> 30**	**30 -10**	**10 - 5**	**5 - 1**	**1 – 0.30**	**< 0.30**
Bank width (m)	5	3.5	2.0	1.5	1.0	0.6
Road width (m)	6	5	3.5	3.5	1.5 if needed	1.5 if needed
Depth of cover over saturation line (m)	1.0	0.75	0.5	0.50	0.5	0.5

9. The designer shall ensure that the maximum permissible velocity in earthen channels shall not cause erosion of bottom and side slopes, neither induce settlement of sediment, nor allow weed growth. The average and range of suggested maximum velocities for different soil types and materials are presented in Table 6.

Table 6 Maximum water velocities in different earth materials

Earth material	Velocity (m/s)
Sand	0.5 (0.3 – 0.7)
Sandy loam	0.6 (0.5 – 0.7)
Clay loam	0.75 (0.6 – 0.9)
Alluvial silt	0.8
Loam	0.9
Clay	1.2 (0.9 – 1.5
Gravel	1.2 (0.9 – 1.5)
Concrete cast-in-place	2.0 (1.5 – 2.5)
Concrete precast	1.75 (1.5 – 2.0)
[5]Bricks	1.5 (1.2 – 1.8)

Source: Surface Irrigation by L.J. Booher, FAO, 1974

10. The designer shall take into account seepage losses in channels when determining field water requirements. Normally, the discharge is increased to compensate for these losses by dividing it by the conveyance efficiency. Indicative seepage loss values given in Table 7 can be used in the absence of more accurate data.
11.

Table 7 Seepage losses in canals

Type of soil	Losses in m^3/m^2 of wetted perimeter/day
1. Impervious clay loam	0.07 – 0.10
2. Medium clay loam with impervious layer below not exceeding 900mm in depth	0.10 – 0.15
3. Clay loam, silty soil	0.15 – 0.23
4. Clay loam with gravel, sandy clay loam	0.23 – 0.30
5. Sandy loam	0.30 – 0.45
6. Sandy soil	0.45 – 0.55
7. Sandy soil with gravel	0.55 – 0.75
8. Pervious gravelly soil	0.75 – 0.90
9. Gravel with some earth	0.90 – 1.80

Source: Irrigation Design and Practice by Bruce Withers and Stanley Vipond

12. The designer shall take into account losses at canal structures in order to achieve the command over the agricultural area. For

[5] The bricks referred to for lining of channels shall be not be of baked clay. Use should be made of other types of bricks such as soil-stabilised (SSB) or cement bricks.

preliminary design the following values can be adopted, but for the final design the assumed values must be verified

- Canal offtake: 10 – 15 cm
- Diversion box: 5 – 15 cm for quaternary canals
  10 cm for tertiary canals
  5 cm for large boxes
- Culvert: 5 cm
- The water level in the quaternary canals must be between 15 and 30 cm higher than ground level for most of the canal length
- The water level in the canal at 70% of the design discharge should command the cultivated area

13. The designer shall determine a non-scouring, non-silting velocity for the terrain through which the canal is constructed when designing the longitudinal profile of an earth canal. The gradient in main earth canals usually ranges between 7.5 to 15 cm/km, and in secondary canals between 12 to 25 cm/km. The recommended maximum slope for field canals is 1:300.
14. In the event that the earth channels have to be lined, the designer shall refer to the recommended thickness of lining as given in Table 8.

Table 8 Recommended thickness of lining in lined canals

Velocity (m/s)	Thickness of lining (mm)
V < 2.5	70
2.5 < V < 2.75	80
2.75 < V < 3.10	100
V > 3.10	Reinforced concrete t = 1.10 mm

Source: Irrigation Design and Practice by Bruce Withers and Stanley Vipond

Some of the different types of lining are: clay, stone masonry, concrete, brick, and sand-cement. The selection of a lining method depends mainly on the availability of materials, the availability of equipment, the costs and availability of labour for construction.

4.3.8. Closed conduits design

Design process

1. The designer should consider the following when designing pipelines: friction losses, flow velocities, soil conditions for buried pipelines, environmental conditions for surface pipelines, scheme or pipeline longevity, capital and system operating costs.
2. The designer shall consider friction losses of the outlet pipe and the conveyance pipe that they shall not exceed the difference in elevation between the lowest drawdown level and the top of the scheme or the block of fields. The friction losses (H_L) through a pipe can be calculated using the Hazen-Williams equation:

$$Hf_{100} = \frac{K \times \left(\frac{Q}{C}\right)^{1.852}}{D^{4.87}}$$

Where:

Hf_{100} = Friction losses over a 100 m distance (m)
K = Constant 1.22 x 1 012, for metric units
Q = Flow (l/s)
D = Inside diameter (mm)
[6]C = Coefficient of retardation

3. When both canal and drain meet more or less at the same level, the designer may consider passing the drain through an aqueduct (Figure 5) or inverted siphon underneath the canal. Silt ejectors and trash racks shall be incorporated at the upstream to minimise siting and deposition of floating debris in the aqueduct. The velocity of water through the aqueduct should be at least twice the canal velocity to discourage deposition of sediment, but generally should not exceed 3.0 m/s.

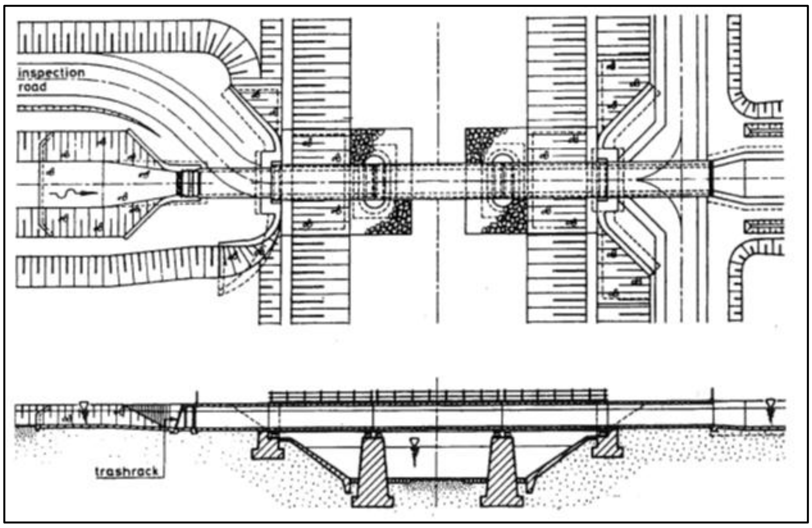

Figure 5 An aqueduct

4. An inverted siphon (Figure .6) shall be designed for a low head loss. Normally, the velocity in the siphon should be at least twice the normal canal velocity and, not less than 1.5 m/s. Maximum velocity should not exceed 3 m/s. The depth of submergence of the siphon entrance depends on the slope and the size of the barrel, and can be taken at 1.5 times of the entrance loss, with a minimum of 0.15m. The level at siphon exit should be below the entrance level. 'Trash racks' have to be installed at the entrance of siphons as to avoid the involuntary entrance by persons or animals and to avoid clogging by floating debris.

[6] The values of "C" are based on the pipe material as follows: (C = 120, 130, and 140 for galvanized steel, cast iron, and new asbestos cement respectively, and 140 – 150 for uPVC)

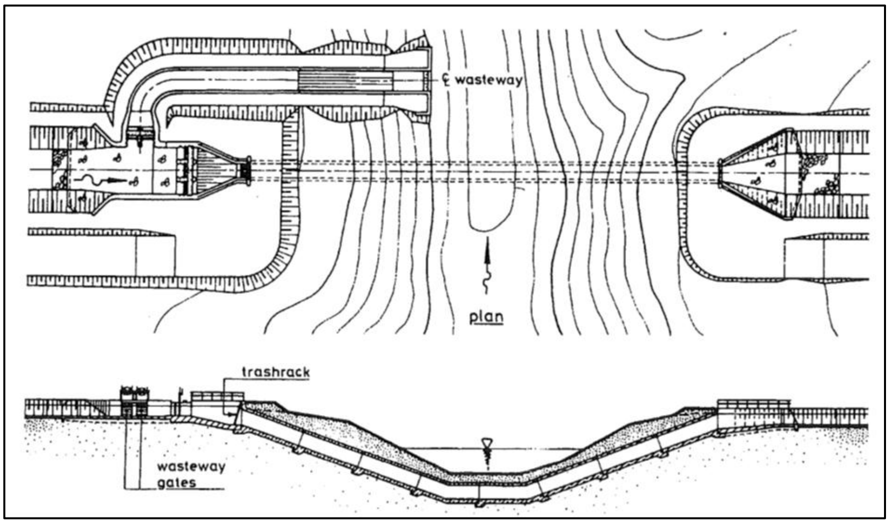

Figure 6 An inverted siphon

5. The designer may opt for the use of siphons to convey irrigation water by gravity and under pressure over an obstacle or canal bank into the field. The discharge through a siphon is determined by the following relationship:

$$Q = C * A * \sqrt{2gh}$$

Where:

Q = discharge in m^3/s,
h = the energy loss over the siphon,
C = discharge coefficient (is approximately 0.5)

The head (h), is approximately equal to the drop in water level between the upstream and downstream level.

6. The designer may opt for the use of a culvert where a canal crosses a natural channel with a skew (Figure 7). The design of culverts is based on the head loss calculation for tail water control. The velocity in the wet cross sectional area of the culvert may range from 0.5 to 2.0 m/s, and determines the head loss over the structure. The designer should also note the following:
   (i) S1 should be much steeper than critical slope.
   (ii) S2 is usually 0.005 to facilitate dissipation of energy by hydraulic jump in the pipe without being flat enough to permit sedimentation in the pipe. The pipe should be under canal prism with at least 600 mm below the invert of an earth section canal, and at least 150 mm below the lining of concrete lined canal.

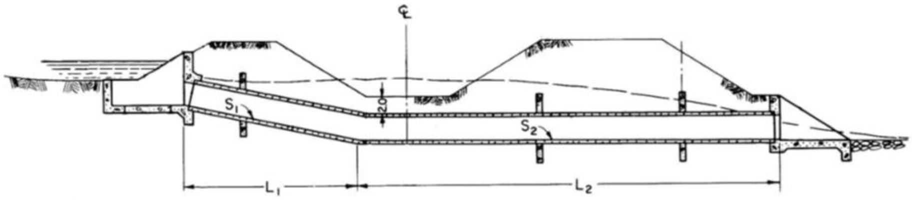

Figure 7 Section of a culvert of siphon

4.3.10. Drop structures

1. The designer shall incorporate appropriate drop structures, including chutes, in steep channels to dissipate energy and to avoid damage of unlined canals.

4.3.11. Tail-end structures

1. The designer should provide a tail-end structure at the end of the canal so that excess water can flow safely into the drain.

4.3.12. [7]Discharge measurement structures

1. The designer shall incorporate discharge measurement structures in the water conveyance system for the purpose of maintaining proper delivery schedules, determining amount of water to be delivered into channels or fields, detecting origin and quantity of water losses, and to ensure efficient water distribution.
2. [8]The designer shall determine the type of measuring structure appropriate for the size of canal and discharge from a selection including weirs (sharp- and broad-crested, Romijn, and Cipoletti, rectangular contracted, and v-notch), and flumes (Parshall Flume).

4.3.13. Design capacity of canals

1. The designer shall design the tertiary canals for continuous flow for economic reasons, and design the quaternary canals on a rotation basis, since most farmers do not irrigate more than 8 - 10 hrs a day. Where irrigation is restricted to daytime only, the designer shall incorporate night storage in order to avoid losing night-time water.
2. Whenever possible, the designer shall ensure that irrigation canals and drains do not run adjacent to each other. Canals and drains should always be sufficiently far apart to keep the hydraulic gradient below 1:4.
3. The designer shall locate secondary canals on a ridge, irrigating areas on both sides of the canal, as far as the bordering drainage channels.
4. As much as possible, the designer shall avoid irrigating directly from the main canal.

4.3.14. Drainage system and flood control

1. The designer shall provide for a drainage system to dispose of excess irrigation water or rainfall, and where the water table is high, to control the groundwater level. The designer shall thus determine the amount excess rainfall that needs to be drained per unit area of land, known as the drainage modulus. Annex 9 shows an example

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[7] More details on the Romijn weir and other weirs and canal structures can be found in *FAO Irrigation Manual Module 7 Volume II: Planning, Development, Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation.*

[8] For discharge characteristics, refer to Annex 8.

of determining the drainage modulus in a rice field.

2. The designer shall be guided by the following probability percentages of non-exceedance when designing flood control structures.

Component	%	T
Top abutment of headworks	0.1	1000
Headworks and nearby works	1	100
Road bridges	2	50
Cross drainage work, river diversion	4	25
Internal project drainage work	20	5
Where the primary irrigation canal could be damaged by a river flood, the probability percentage of non-exceedance should be < 4%, sometimes down to 1%	< 4%	

3. The designer shall prepare a Flood Control Plan from the basin-wide view point, and requires proper coordination with the other plans such as Irrigation development plan, Road network/bridge plan, and Environmental management plan.
4. The designer shall consider the effect/influence of other development plans in the formulation of flood control plan. For example, the height of levee will affect the design height of bridge. Likewise, the design riverbed profile will affect the design of the irrigation intake/canal and other related facilities.

4.3.15. Irrigation scheme selection

1. [9]To select an irrigation method, the designer as well as the user must know the advantages and disadvantages of the various methods, and which method suits the local conditions best.

4.3.16. Soil - Crop - Water Relationships

1. [10]When choosing and designing an irrigation system, the designer should obtain the necessary soil, crop, and climate data to ensure that the irrigation system can be designed to match appropriate soil-crop conditions within the prevailing climatic environment.
2. The designer can also use computer software such as CROPWAT, CLIMWAT, AQUACROP, in determining soil-crop-water relationships.
3. The designer shall determine soil water holding capacities following these steps:
    - Obtain local expert advice from institutions that have specific knowledge about the soils on the property; or
    - Refer to GIS soil maps or other soil maps of the region; or

[9] More information can be obtained in the FAO Irrigation Manual, Vol.II, Module 7, Surface Irrigation Systems Planning, Design, Operation and Maintenance.

[10] More details can be accessed in the FAO Irrigation Manual Module 4, Crop Water Requirements and Irrigation Scheduling

- Take soil samples and measure water holding capacities (standard techniques such as oven drying can be used); or
- If no specific information is available, use the estimated soil water holding capacities of various soils given below:

Soil class	**WHC (mm/m)**
Clay loam	175-190
Silt loam, no stones or gravel	155-165
Silt loams, approx. 30% gravel by volume	110-120
Sandy loam	65-110
Sand	45-55

Source: NZ Irrigation Code of Practice

4. The designer shall ensure that the depth of soil over which water holding capacity has been determined is known and adjusted for effective crop rooting depths.
5. [11]The designer shall access information on the effective root zone depths of various crops in order to determine the depths of water application to facilitate scheduling of water application. As a rule, for most field corps 40% of the water uptake takes place from the first quarter of the total rooting depth, 30% from the second quarters, 20% from the third quarter and 10% from the fourth quarters (FAO, 1984).

   Rainbird International provides the following guide for the position of the majority of plant feeder roots of several plants, the effective root zone depths. Thus, knowing the crop water requirements, the type of soil and the root zone depth, the designer shall calculate the readily available moisture for the crop, which is the amount of water that can be extracted by the crop in the root zone without suffering water stress.

Crop	**RZD (mm)**	**Crop**	**RZD (mm)**	**Crop**	**RZD (mm)**
Banana	50	Grain	60-75	Strawberry	30-45
Bean	60	Sorghum	75	Sugarcane	150
Beet	60-90	Nuts	90-180	Sweet potato	90
Cabbage	45-60	Onion	45	Tobacco	75
Carrot	45-60	Groundnut	45	Tomato	30-60
Cassava	50	Pea	75	Soybean	60
Maize	75	Potato	60	Citrus, peach, pear, etc.	90-150
Cotton	125	Safflower	150		

Source: Rainbird International

[11] Information on effective root zone depths and allowable soil water depletion of various soils can be obtained from FAO Irrigation Manual Module 4, Crop Water Requirements and Irrigation Scheduling.

6. The designer shall determine the design flow of the irrigation system, by taking into consideration the available moisture, the root zone depth, the allowable moisture depletion, the net peak water requirements, the irrigation frequency and cycle, and the irrigation efficiencies.
7. The designer shall determine the **net depth of water application (dnet)**, which is the amount of water in millimetres that needs to be supplied to the soil in order to bring it back to field capacity, from this relationship:

   dnet = (FC - PWP) x RZD x P

   Where:

   dnet = Net depth of water application per irrigation for the selected crop (mm)
   FC = Soil moisture at field capacity mm/m)
   PWP = Soil moisture at the permanent wilting point (mm/m)
   RZD = The depth of soil that the roots exploit effectively (m)
   P = The allowable soil water depletion
8. The designer shall determine the **Gross depth of water application (dgross)** per irrigation using the following relationship:

   dgross = dnet/E

   where E is the application efficiency
9. The designer shall determine the **volume of water** to be delivered per farm per turn based on the area of the farm and the depth of water to be supplied, **Vol = 10 * Af *dgross.** The designer shall then calculate the **design flow** of the irrigation system by dividing the volume of water with irrigation duration.

4.4. Detailed design stage

4.4.1. Investigations

1. The designer shall conduct a thorough and detailed assessment of the parameters investigated during the feasibility study stage, on the selected and approved option, culminating in final designs and construction drawings, final cost estimates of the project expressed in the bills of quantities, preparation of bidding and tender documents to facilitate financing and construction of the project.
2. The designer shall include in the investigations, but not be limited to, the following:
   a. Assessment of the proposed irrigation area, including description, prevailing land use, land tenure, cultural practices
   b. Assessment of available resources, including hydrological investigations, water quality, abstraction permits, catchment conditions, human resources, construction materials
   c. Topography
   d. Soil investigations for agricultural use and construction
   e. Detailed design of the irrigation and drainage infrastructure,

including cropping pattern and crop water requirements, irrigation system operation and maintenance, all structures from the intake to the field, conveyance structures, water application system, drainage and flood control

f. Institutional set up and capacity to operate and maintain the irrigation infrastructure and cropping system including disposal of produce
g. Preparation of bidding and contract documents for construction and supervision of construction respectively
h. Preparation of costs estimates, normally known as engineering estimates of the project

3. The designer shall prepare the Operation and Maintenance Manual for the irrigation scheme, which shall be the basis for capacity building of the operation and maintenance service providers.

4.4.2. Environmental and social impact assessment

1. [12]An independent Environmental and social impact assessment shall be conducted as an integral part of the investigations being done by the designer. Mitigation measures shall be incorporated into the technical design of the scheme. The process of conducting and approving an environmental and social impact assessment is presented in Annex 10.
2. The designer or an independent specialist shall prepare an environmental and social management and monitoring plan (ESMP), a resettlement policy framework (RPF), and/or a resettlement action plan (RAP) (where necessary) which shall provide the guidelines for monitoring the implementation of the recommendations from the environmental and social impact assessment. An example of the environmental and social management plan (ESMP) is shown in Annex 11.

[12] For complete details of how to conduct the environmental and social impact assessment, refer to National Environment Management Act, No. 23 of 1996, the National Environmental Policy 1996, and the EIA Guidelines for Irrigation and Drainage Projects published by the Environmental Affairs Department.

4.4.4. Permits and licenses applicable to irrigation development projects

1. The developer is required to obtain an EIA Certificate before any development operations can commence on the land.
2. The designer shall ensure that consultations have been made with the relevant authorities as regards permits and licenses that might have an effect on the design of the irrigation project. Table 9 shows some of the applicable permits and licenses, depending on the nature of the activities included in the irrigation development project.

Table 9 Other applicable permits and licenses

Act, Regulation or Byelaw	Permit or Licence	Requirements	Implementing Agency
Water Resources Act CAP72.03	Water Right	Permit is required to use and/or abstract water, build dams	National Water Resources Authority: Water Abstraction Control Sub-committee
Environment Management Act, No 23 of 1996, s.42	Air Pollution Licence	Licence is required to emit any gas or other pollutants into the atmosphere	EAD
Environment Management Act, No 23 of 1996, s.38	Waste Licence	A licence is required to handle, store, transport, classify or destroy waste other than domestic waste, or operate a waste disposal site	EAD

CHAPTER 5: DESIGN PRACTICES FOR SURFACE IRRIGATION SYSTEMS

5.1. Basin irrigation systems

Description

1. A basin is a horizontal area of land surrounded by earthen bunds and totally flooded during irrigation. Flooding should be done using a large stream size that advances quickly in order for water to spread rapidly over the basin. The advance time should not exceed a quarter of the contact time, so as to reduce difference in contact time on the different sections of the basin

5.1.1. Soils

1. It may be used on a wide variety of soil textures; though fine-textured soils are preferred. As the area near the water inlet is always longer in contact with the water, there will be some percolation losses, assuming the entire root zone depth is filled at the bottom of the field. Coarse sands are not generally recommended for basin irrigation as high percolation losses are expected at the areas close to water intake

5.1.2. Land slope

1. The soil surface within each basin should be horizontal. Basins can be as large as the stream size and soil type can allow on level land. On steep slopes, the removal of the topsoil and the associated land levelling costs may be limiting factors for the basin size

5.1.3. Basin size

1. The size of basin is critical in the design of this irrigation method and depends on the following factors: Soil type, Stream size, Irrigation depth, Field size and shape, Land slope, and Farming practices

2. The following criteria are generally used for determining basin size:

Criteria	**Basin size small**	**Basin size large**
Soil type	Sandy	Clay
Stream size	Small	Large
Irrigation depth	Small	Large
Land slope	Steep	Gentle or flat
Field preparation	Hand or animal traction	Mechanized

Source: FAO Irrigation Manual 1992

5.1.4. Basin width

1. Typically, terrace width varies from about 2 m for 4% land slopes up to 150 m for 0.1 % land slopes. Table 10 below provides some guidelines on the possible width of a basin, in relation to the land slope

Table 10 Approximate values for the maximum basin width (m)

Slope (%)	Maximum width (m)	
	Average	Range
0.2	45	35-55
0.3	37	30-45
0.4	32	25-40
0.5	28	20-35
0.6	25	20-30
0.8	22	15-30
1.0	20	15-25
1.2	17	10-20
1.5	13	10-20
2.0	10	5-15
3.0	7	5-10
4.0	5	3-8

Source: FAO Irrigation Manual 1992

5.1.5. Field size and shape

1. Basins are best adapted to regular field shapes (square or rectangular). Irregular field shapes necessitate adapting basins.
2. Although a regular shape is favourable, basins can be shaped to follow contours. These are contour basins or terraces, which are seen mainly on steep slopes used for rice.

5.1.6. Efficiency of basin irrigation systems

1. It is possible to achieve field application efficiencies of 80% on properly designed and managed basins, although a more common figure used for planning varies between 60 – 65%.

5.2. Furrow irrigation systems

5.2.1. Field size and shape

1. For the system to operate at the level of efficiency earmarked by the designer, the field shape of each farmer's plot should be regular and the length of run uniform for all farmers. This would facilitate uniform water delivery throughout the field and scheme

5.2.2. Furrow lengths

1. Table 11 summarizes the main factors affecting the furrow length and the suggested practical allowable furrow lengths. The data given in this table are appropriate for large-scale and fully mechanized conditions.

Table 11 Furrow lengths in metres as related to soil type slope stream size and irrigation depth

Soil type		**Clay**		**Loam**			**Sand**		
		Average irrigation depth (mm)							
Furrow slope (%)	**Maximum stream size (l/sec)**	**75**	**150**	**50**	**100**	**150**	**50**	**75**	**100**
0.05	3.0	300	400	120	270	400	60	90	150
0.10	3.0	340	440	180	340	440	90	120	190
0.20	2.5	370	470	220	370	470	120	190	250
0.30	2.0	400	500	280	400	500	150	220	280
0.50	1.2	400	500	280	370	470	120	190	250
1.00	0.6	280	400	250	300	370	90	150	220
1.50	0.5	250	340	220	280	340	80	120	190
2.00	0.3	220	270	180	250	300	60	90	150

Source: FAO Irrigation Manual 1992

2. Table 12 provides more realistic data for smallholder irrigation. The soil variability in most smallholders' schemes, combined with the small size of holdings, makes the scheme more manageable when shorter furrows are used. The figures in both tables should only be used as a guide in situations where it is not possible to carry out field tests.

Table 12 Practical values of maximum furrow lenghts in metres depending on soil type slope, stream size and irrigation depth for small scale irrigation

Soil type		**Clay**		**Loam**		**Sand**	
		Net irrigation requirements (mm)					
Furrow slope (%)	**Maximum stream size per furrow (l/sec)**	**50**	**75**	**50**	**75**	**50**	**75**
0.0	3.0	100	150	60	90	30	45
0.1	3.0	120	170	90	125	45	60
0.2	2.5	130	180	110	150	60	95
0.3	2.0	150	200	130	170	75	110
0.5	1.2	150	200	130	170	75	110

Source: FAO Irrigation Manual 1992

5.2.3. Furrow shape

1. The furrows are generally V-shaped or U-shaped in cross-section and are 15-30 cm deep and 25-40 cm wide at the top. The shape of the furrow depends on the soil type and the stream size.
2. Soils with low infiltration rates have usually shallow wide parabolic or U-shaped furrows to reduce water velocity and to obtain a large wetted perimeter to encourage infiltration.
3. Sandy soils, on the other hand, require more or less V-shaped

furrows to reduce the wetted perimeter through which water infiltrates.

5.2.4. Furrow spacing

1. The spacing between furrows depends on the water movement in the soil, on the crop agronomic requirements as well as on the type of equipment used in the construction of furrows.
2. When water is applied to a furrow, it moves vertically under the influence of gravity and laterally by capillarity. Clay soils have more lateral movement of water than sandy soils because of their small pores, which favour capillary action. In this regard, larger spacing can be used in heavier soils than in light soils.
3. In general, a spacing of 0.3 m and 0.6 m has been proposed for coarse soils and fine soils respectively. For heavy clay soils up to 1.2 m has been recommended.

5.2.5. Furrow slope

1. Furrows should be put on proper gradients that allow water to flow along them and at the same time allow some water to infiltrate into the soil.
2. Furrows put on steeper slopes can be longer because water moves more rapidly. However, with slopes steeper than 0.5% (0.5 m drop per 100 m length), the stream sizes should normally be reduced to avoid erosion, thus shorter furrows have to be used.
3. Under smallholder conditions the maximum slope of 0.5% should not be exceeded.

5.2.6. Stream size

1. In order to wet the root zone as uniformly as possible and to have minimum percolation losses at the top end of the field and minimum runoff at the bottom end of the field an appropriate stream size has to be chosen.
2. Usually the advance is slower than the recession because water infiltrates quicker in dry soil. Therefore, the top end of the field usually receives more water than the bottom end of the field and water will be lost through deep percolation.
3. The stream size should not exceed the maximum non-erosive stream size. The following equation provides guidance in selecting stream sizes for field trials.

$$Q_{max} = K/So$$

   Where:

   Qmax = Maximum non-erosive stream size (l/min)

   So = Furrow slope in the direction of flow (%)

   K = Unit constant (= 40)

4. Furrow stream sizes are sometimes selected on the basis of the one-quarter rule. This rule states that the time required for water to advance through a furrow till the end should be one quarter of the total irrigation time (contact time).

5.2.7. Discharge through siphons

1. The discharge through siphons depends on the diameter of the siphon and the head, refer to Table 13
2. For drowned or submerged discharge, the head is the difference between the water level in the canal and the water level in the field.
3. For free discharge, the head is the difference between the water level in the canal from where the siphon takes the water and the outlet from the siphon.
4. Discharge can be altered by a change in pipe diameter or a change in the head.

Table 13 Discharge through siphons, depending on pipe diameter and head

Pipe diameter (cm)	Head (cm)			
	5	10	15	20
2	0.19	0.26	0.32	0.73
3	0.42	0.59	0.73	0.84
4	0.75	1.06	1.29	1.49
5	1.17	1.65	2.02	2.33

5.2.8. Efficiency of furrow irrigation systems

1. Furrow irrigation could reach a field application efficiency of 65% when it is properly designed, constructed and managed. The value ranges from 50-70%.
2. Losses will occur through deep percolation at the top end of the field and runoff at the bottom end.

5.3. Border strip irrigation systems

Characteristics

1. Border strips are strips of land with a downward slope but are as horizontal as possible in cross-section. A horizontal cross-section facilitates an even rate of water advance down the longitudinal slope. Border strips can vary from 3-30 m in width and from 60-800 m in length. They are separated by parallel dykes or border ridges (levées).
2. Normally water is let onto the border strip from the canal through intakes, which can be constructed with gates on the wall of the canal or, when unlined canals are used, by temporarily making an opening in the canal wall. The latter is not recommended since it weakens the walls of the canal, leading to easy breakage.
3. Other means used for the same purpose is the insertion of short PVC pipes (spiles) through the canal wall. The short pipes are usually equipped with an end cup, which is removed when irrigation is practiced. Some farmers use cloth or plastic sheet to close and open the pipe.
4. The most appropriate method of supplying water from the canal to the field, however, is the use of siphons.

5.5. Surface irrigation systems and types of crops

Surface irrigation system	Basin	Furrow	Border strip
Type of crops	a) Rice grown on flat lands or in terraces on hillsides. b) Trees, where one tree is usually located in the middle of a small basin, e.g. citrus, banana; c) Crops which are broadcast, such as cereals d) Pastures, e.g. alfalfa, clover e) To some extent row crops such as tobacco. f) In general, this system is suitable for crops that are not affected by standing in water for long periods.	a) Row crops such as maize, sunflower, sugarcane, soybean; b) Crops that would be damaged by inundation, such as tomatoes, vegetables, potatoes, beans; c) Fruit trees such as citrus, grape; d) In general, this system is suitable for all row crops and for crops that cannot stand in water for long periods.	a) Close growing crops such as pasture or alfalfa are preferred

CHAPTER 6: DESIGN PRACTICES FOR OVERHEAD IRRIGATION SYSTEMS

6.1. Sprinkler irrigation systems

Description

1. Sprinkler irrigation is a method of applying irrigation water which is similar to natural rainfall.
2. Water is distributed through a system of pipes usually by pumping. It is then sprayed into the air through sprinklers so that it breaks up into small water drops which fall to the ground.
3. The pump supply system, sprinklers and operating conditions must be designed to enable a uniform application of water.

6.1.1. Classification of sprinkler systems

General

1. Sprinkler systems can be classified in such ways as portability, field layout, equipment used, and type of system being irrigated.
2. Some researchers have found portability as a useful criterion for describing the available sprinkler irrigation systems. Under this classification, a system is fully portable when all of the system components can be moved and fully permanent when none of them can be moved.

Solid-set system

3. Solid-Set System is a sprinkler system which remains in a single location during an irrigation season and supplied by a fixed network of pipes.
4. There are two basic types of pipe components - aluminium and plastic. Aluminium piping is laid along the ground surface and collected to provide access for cultivation farming practices. Plastic pipes, usually uPVC, are always buried permanently because sunlight deteriorates the pipe. If LDPE pipes are used instead of uPVC pipes, they can be installed on the surface.
5. Solid-set systems irrigate the entire field with a single set of components and are, therefore, costlier than most other sprinkler systems.
6. Labour and maintenance requirements are minimal, but cultural operations such as cultivation, spraying, planting and harvesting may be restricted. As a result, solid-set systems are mostly applicable for crops with minimum cultural practices requirements.

Move-stop system

7. Move-stop System is a system whose lateral pipelines are designed to move from set to set in order to reduce equipment needs and minimise interference with other farming operations.
8. The movement itself can take on any form, from the hand-moved lateral to the tractor-towed lateral to the motor-moved lateral; hence, the common use of names like hand move, end tow and side-roll sprinkler systems.
9. The drag-hose sprinkler system falls within this category. Main and laterals are buried uPVC pipes: one lateral covers three positions. Sprinklers on risers carried by skids are attached to the laterals through hoses (similar to garden sprinklers). Only the skid with the sprinkler has to be moved from one position to another, which is an

easy task.

10. Move-stop systems require more labour and maintenance than solid-set systems, but are less expensive to purchase and install. Energy requirements are approximately equivalent.
11. The major disadvantage is the need to move the system from wet to dry areas which not only increases the necessary capacity of the network but also tends to reduce crop yields by damaging the crops

Continuous-move system

12. Continuous-Move System is a sprinkler system that covers the irrigated area by continuously moving, thus reducing labour, maintenance, and down-time problems experienced with move-stop systems.
13. Centre-pivot, linear move, and big gun systems are typical examples of the continuous move concept.
14. Although the equipment must be automated and made mobile, some reduction in pipe lengths and pipe sizes are possible to offset higher equipment costs.
15. The major advantage of the continuous-move system is laboursaving. On a smaller scale, the sweeping action tends to improve irrigation uniformities.
16. One major problem is high precipitation rates leading to excessive field runoff and high energy requirements. Nevertheless, the continuous move systems are the most popular and most widely used sprinkler systems in agricultural applications.

6.1.2. Advantages and disadvantages

Advantages

1. Sprinkler irrigation systems are recommended and used on practically all types of soils, topographic conditions, and on almost all kinds of crops.
2. It is flexible and efficient in water control and therefore can be applied on a wider range of soils that are suited to surface water application methods.
3. In instances where usually there is no rain at exactly the right time in the required quantity, sprinkler irrigation has been used to provide supplemental irrigation. A timely irrigation at a critical crop growth stage, applying only a few centimetres of water, can more than double the yield.
4. On some saline soils, sprinklers are recommended for better leaching and crop germination.
5. Sprinklers are especially desirable where soils have a high permeability and/or low water holding capacity. However, they have been used effectively in dense soils with low permeability.
6. In areas where labour and water costs are high, sprinklers can be the most economical way to apply water.
7. Sprinklers have been shown to increase yield, such as in the fresh vegetables and fruit market where colour and quality are very important.
8. Sprinklers can be used for irrigation, crop cooling, frost control, and

the application of pesticides, herbicides and fertilizers.

9. In modern farming practices which require large equipment and large fields for economical farming operations, sprinklers have been used with no reduction in efficiency.

Disadvantages

1. Damage to some crops has been observed when poor quality irrigation water is applied to the foliage by sprinklers.
2. Poor quality water can leave undesirable deposits or colouring on the leaves or fruit of the crop.
3. Sprinklers are also capable of increasing the incidence of certain crop diseases such as fire blight in pears, fungi or foliar bacteria.
4. A major disadvantage of sprinklers is the relatively high cost, especially for solid-set systems, in comparison to surface irrigation methods.
5. When gravity cannot supply sufficient head to operate the system, sprinklers can require large amount of energy to supply the necessary pressure.

6.1.3. Suitable crops

1. Sprinkler irrigation is suited for most row, field and tree crops and water can be sprayed over or under the crop canopy.
2. However, large sprinklers are not recommended for irrigation of delicate crops such as lettuce because the large water drops produced by the sprinklers may damage the crop.

6.1.4. Suitable slopes

1. Sprinkler irrigation is adaptable to any farmable slope, whether uniform or undulating.
2. The lateral pipes supplying water to the sprinklers should always be laid out along the land contour whenever possible. This will minimize the pressure changes at the sprinklers and provide a uniform irrigation.

6.1.5. Suitable soils

1. Sprinklers are best suited to sandy soils with high infiltration rates although they are adaptable to most soils.
2. Sprinklers are not suitable for soils which easily form a crust. If sprinkler irrigation is the only method available, then light fine sprays should be used. The larger sprinklers producing larger water droplets are to be avoided.
3. The average application rate from the sprinklers (in mm/hour) is always chosen to be less than the basic infiltration rate of the soil so that surface ponding and runoff can be avoided.

6.1.6. Suitable irrigation water

1. A good clean supply of water, free of suspended sediments, is required to avoid problems of sprinkler nozzle blockage and spoiling the crop by coating it with sediment.

6.1.7. Efficiency of pumping systems

1. The efficiency of a pumping system depends on number of factors such as:
   a) The pipe being too small in diameter or having many bends in the conveyance manifold.
   b) Putting the discharge of water considerably above the necessary level.
   c) The drive or coupling between pump and prime mover may not be an efficient unit.
   d) Mismatch of power requirement between a pump and prime mover. Correct matching of pump, motor/engine and drive is very important for efficient utilization of energy, thus bringing down the irrigation operational costs.
2. Efficiency will also be reduced by elevation, temperature, accessories, and continuous operation. The details of efficiency estimated for design purpose are as indicated in Table 14.

Table 14 Efficiency of pumping systems

Parameters	**Decrease in Efficiency (%)**
Elevation from sea level, 3% for each 300 meters, assuming elevation of 450 meters.	4.5
For each 6º operating air temperature above 16ºC, decrease of 1% is encountered; assuming 45ºC maximum temperature.	5.0
For accessories, using heat exchangers.	5.0
For continuous load operation	20.0
Drive losses (0-15 %)	5.0 for motor 10.0 for engine
Radiator, fan	5.0

Source: Handbook of Sprinkler Irrigation Systems in Pakistan

3. The overall efficiency for pumping systems recommended for sprinkler irrigation is:
   - Electric motor operated systems = 60 %
   - Diesel engine operated systems = 50 %

6.1.8. Design practices

1. For comprehensive information on the design of overhead systems, please refer to the FAO Publication *Irrigation Manual Module 8 – Sprinkler Irrigation Systems Planning, Design, Operation and Maintenance*.
2. Comprehensive design guide can also be obtained from the *Technical Handbook on Pressurised Irrigation Techniques by A. Phocaides*, published by FAO. The manual and handbook also contain design information for centre pivot systems.

3. The computer programme EPANET 2.0 can be used for design and dimensioning of pipes (pipeline systems).

6.2. Centre pivot systems

General description

1. Centre Pivot and Lateral Move systems are self-propelled continuous move type of sprinkler irrigation systems which apply water to pasture or crop, generally from above the canopy.
2. Centre Pivot systems are anchored at one end and rotate around a fixed central point. However, Lateral Move systems are not anchored, but both ends of the machine move at a constant speed up and down a paddock.
3. Centre Pivot and Lateral Move systems require an energy source to move water from the source to the plant as well as energy to move the machine on farm.

Components

4. Centre Pivot or Lateral Move systems consist of the following components:
    a) A span, which is the pipe and framework between two towers
    b) A tower supports the spans and contains drive mechanisms and wheels
    c) Outlets are the points at which water exits the main pipes
    d) Emitters are attached at outlets either directly or on rigid or flexible droppers. Water is applied to the plants through emitters
    e) Droppers are rigid or flexible small diameter pipes that allow emitters to be placed closer to the ground
5. Lateral Move systems share similar technology to pivots and are suited to large rectangular areas - up to 200 ha.

6.2.1. Advantages and disadvantages

Advantages

1. **Precise application:** The systems are able to apply a prescribed volume of water to match crop water requirements. It reduces the opportunity for surface runoff or deep percolation if the system is designed to match soil infiltration characteristics.
2. **Reduced variability:** The reported application efficiencies for new well designed machines are generally in the 80-95% range, compared to 50-90% for surface irrigation systems.
3. **Lower labour requirements:** Labour requirements are generally lower than surface irrigation but depends on the system and\ or the degree of automation of the machine.
4. **Opportunities for fertigation:** Fertigation allows the targeted application of small quantities of nutrients, with a reasonable uniformity of application and less risk of nutrient losses. The irrigation system may also be used to apply herbicides and pesticides.
5. **Less landforming:** The system can work on rolling topography. However, there might be a need for some landforming for surface drainage or rainfall induced runoff.

Disadvantages

6. **Cost:** The systems have a relatively high capital cost compared to surface irrigation systems, unless substantial landforming is required for optimum performance of the surface system. The running costs can also be significant and need to be evaluated during the design process.

6.2.2. Energy requirements

1. These systems require some form of energy source (electric or diesel) to operate.

6.2.3. Water quality

1. Water may need to be filtered before use to prevent system blockages with sediments. Poor water quality can affect longevity of irrigation infrastructure.

6.2.4. Skill requirement

1. Operation and maintenance of these systems will require different skills to those required for surface irrigation systems.

6.2.5. Planning considerations

1. The following aspects need to be considered at the planning stage:
   a) Physical location (area, shape, topography, soil type)
   b) Water supply (flow rate, supply location, quality and quantity)
   c) Irrigable area (area to be developed, system capacity)

6.2.6. Land area

1. A typical centre pivot system has a span of 300 to 400 meters long and irrigates 28 to 50 ha. However, they can be as short as a single-span 35-metre unit or as long as 800 metres with 18 to 20 towers

irrigating approximately 200 ha.

2. The large systems have high average application rates at the outside of the circle that may exceed the infiltration rate of the soil and consequently cause run-off.

6.2.7. Land shape

1. Centre Pivot systems irrigate a circle, which covers 78% of a square.
2. End guns used on Centre Pivots to irrigate square properties are not recommended.
3. Lateral Move systems can be an option to irrigate rectangular areas.

6.2.8. Land slope

1. Centre Pivots can irrigate significantly undulating land.
2. Some minor earthmoving may be needed to connect depression areas and provide drainage for run-off from rainfall events.

6.2.9. Soil type

1. Centre Pivots are able to irrigate any soil type. However, sprinklers should be selected to suit soil infiltration characteristics, as excessive average application rates can cause runoff.
2. It is desirable the pivot irrigates one soil type or soil types with similar infiltration characteristics.

6.2.10. Water supply

1. These systems often require more frequent, but lower flow rates over a longer period of time.
2. The designer should note that the distance from the water source to the Centre Pivot may impact on capital and running costs.

6.2.11. Water quality

1. The physical, chemical and biological characteristics of irrigation water can affect pivot performance.
2. Filtration may be required to prevent nozzle blockage.

6.2.12. Design practices

1. The designer should refer to system manufacturers who will advise what data to provide in order for the manufacturers to design and deliver the system. Possible suppliers are:
   a) Valley Irrigation, USA (valleyirrigation.com)
   b) Nelson Irrigation Corporation (nelsonirrigation.com)
2. Each supplier has their own design software and design data sheets for inputting into their computer programmes.

CHAPTER 7: LOCALISED IRRIGATION SYSTEMS (DRIP OR TRICKLE)

7.1 Drip / Trickle irrigation systems

Description

1. Drip Irrigation, also commonly referred to as micro-irrigation, trickle irrigation, low volume irrigation or xerigation, is a method of irrigation which efficiently delivers water to the soil surface or the root zone by having water drip slowly from emission devices, most commonly called “drip emitters” or “drippers”.

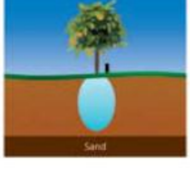
7.2 Advantages

Advantages

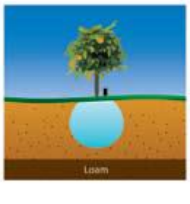
1. **Water Conservation -** Drip irrigation allows efficient watering by supplying water where it is needed – at the very roots of the plants. This significantly reduces the chances for evaporation and run off.
2. **Reduce Weed Growth -** Since drip irrigation applies water to the root zone of plants, the spaces in between plants remain dry. This greatly inhibits weed seed germination.
3. **Reduce Plant Stress -** When plants get deep, consistent watering, they thrive, promoting healthy growth and disease resistance in plants. Inefficient, shallow watering can contribute to plant stress.
4. **Extremely Flexible Application -** It is a versatile watering system which can easily be installed on hillsides or flat terrains. Drip is the perfect irrigation method for oddly shaped landscapes and windy areas. Drip systems are also suitable for crops grown under greenhouses, where drip and spray nozzles can be used.
5. **Save Money -** Drip irrigation systems use less water to irrigate. Automation eliminates the need for a large labour force. With the reduction of plant disease and unwanted weeds, maintenance costs drop considerably

7.3 Soil types

1. **Clay soils** have densely packed particles that have little space for water or air. Water is absorbed very slowly and runoff can occur if water is applied too quickly. When wet, water tends to move outward, away from the drip emitter. Clay soils will hold water very well and can stay wet for several days. Drip emitter spacing tends to be further apart.



2. **Sandy soils** are very loose and have plenty of space for water or air. Water is absorbed very quickly and runoff usually doesn’t occur. When wet, water tends to move straight down through the soil. Sandy soils do not hold water very well and can dry out very quickly. Drip emitter spacing tends to be closer together.



3. **Loam soils** are an ideal in-between mix of clay and sandy soils. The absorption rate is greater than that of clay soil but not as fast as sandy soil. When wet, water will move outward and down more evenly. Loam soils

will hold water well and dry out at a medium rate.

7.4 Planning and Designing the system

7.4.1 Planning the layout

1. The designer shall start by **making a sketch of the areas that need to be irrigated**. Include and label all plant types, including shrubs, trees, ground cover, flower beds, vegetable gardens and containers. Identify all the site watering sources, what type they are, and any existing connections.
2. The designer shall d**raw out each run of drip mainline** tubing and any laterals that will be needed to supply water to each planting area. For plants that are away from the mainline, draw out runs of micro tubing to cover each plant. Working from a good plan will help when making a materials list and is essential in designing an efficient drip irrigation system.
3. The designer shall **group plant types** of similar sizes and growth habits, which generally have water requirements that are much the same. Always try to group watering zones by plant moisture needs and local climate conditions (shade, partial shade, full sun). Consider the following:
    a) Plants that need frequent, shallow watering, like annual flowers and ground cover, should be grouped separately from those needing less frequent, deep watering, like trees.
    b) Seasonal plantings like crops or vegetable gardens should be kept separate from permanent plantings like shrubs. Install inexpensive flow control valves to shut off these areas when not in use.
    c) Create separate zones for plants in the shade versus hot, sunny spots.
4. The designer shall ensure that container plants are watered separately from plants in the ground. They have confined root systems and may dry out more quickly.

7.4.2 Designing the system

1. [13]Design parameters include the following:
   a) Area to be irrigated, type of plants, plant spacing and number of plants per unit area
   b) Peak water requirement of crop or plant
   c) Selection of emitter type, number of emitter per plant and amount of water discharge per hour through each emitter
   d) Water required to be pumped from the source. If the source is a well, apart from crop water requirements, yield of the well also could be a limiting factor.
   e) Layout of the system considering topography, field shape and location of the water source
   f) Calculating sectional flow based on number of emission devices and their discharge against known pressure
   g) Design of main and lateral drip lines. This depends upon friction head losses
   h) Selection of filters and other equipment
   i) Energy specification of the pump set. This depends on discharge and the total head including friction losses over which water is to be lifted/pumped
2. Figure 8 shows a typical drip irrigation installation. However, installation differ depending upon water source, size of land to be irrigated, incorporation of fertigation and pest control, availability of resources, and other factors.

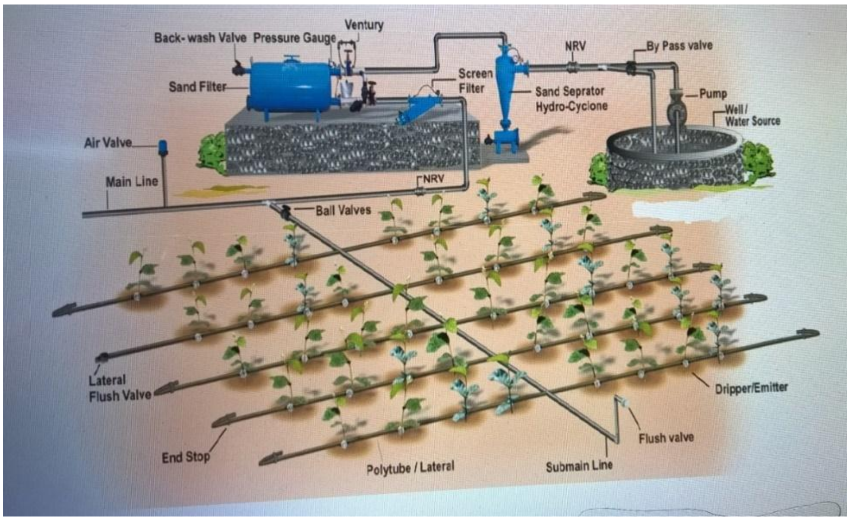


Figure 8 Typical layout for drip irrigation system

[13] The designer shall refer to the following publications which contain comprehensive information: FAO Irrigation Manual Module 9: *Planning, Design, and Operation and Maintenance of Localised Irrigation Systems*. Other references are: *Design of Drip Irrigation Systems* by Dr. Muhammad Ashraf of International Centre for Agricultural Research in Dry Areas (ICARDA), and drip irrigation systems manufacturers, such as Irrigation Direct (irrigationdirect.com), Agrifim of NDS Inc. (agrifimusa.com), and Sprinkler Warehouse (sprinklerwarehouse.com). For irrigation equipment for pressurised systems, the designer should refer to FAO Manual Module 10.

CHAPTER 8: RIVER IMPROVEMENT

8.1 Objectives

Objectives

1. The objectives of river improvement works are to aid navigation, to prevent flooding, to reclaim or protect land or to provide water supply for irrigation, hydropower development or domestic and industrial use.
2. The design of river improvements works in general should be based on fluvial geomorphology and wider river engineering aims.
3. It is extremely important in river training to adopt a holistic approach and to incorporate environmental impact assessment and socio-economic considerations in any design.

8.2 Principal methods

Principal methods

1. **River improvement** works include river regulation and dredging. Flow improvement is done by reservoir construction and operation.
2. In planning river improvement works, both the upstream situation and historical factors have to be taken into account; a good design should assess this evolution even if the purpose of the improvement works is to stabilize the situation at least over the life of the design.
3. In **river regulation or training** the river may be encouraged to pursue its natural course or it may be straightened; the latter requires great sensitivity and should be used only with caution and due regard to environmental constraints.
4. In the upstream reaches the main problem is the short-term and seasonal variation of flow, high velocity, channel instability and shoal formation.
5. In the middle and lower reaches, it is often necessary to raise river banks and carry out works reducing the channel width, e.g. groynes, longitudinal training walls etc.
6. Dredging, using mechanical or suction dredgers, is the most effective means of estuarine river regulation, but its impact is often only temporary.
7. An efficient river training system will try to maintain and improve the natural sequence of bends of a meandering river, while preserving sufficient depth (e.g. for navigation) at low flows and suppressing unduly sharp bends and excessive velocities. This is mainly achieved by groynes, jetties, longitudinal dykes, and embankments and ground sills.
8. In designing works to fulfil this function, the designer must ensure that:
    a. The impact on surrounding lands, properties and communities is minimised
    b. In particular, that problems of flooding are not introduced upstream of the works
    c. The condition of the natural channel downstream of the works is unaffected by the operation of the works.
9. It is the responsibility of the designer to assess the nature of sediment regime of the watercourse concerned. The hydraulic

design must ensure that there will be no long term problems of sedimentation or erosion that affect the performance of the structure or in some way present a risk to the integrity of the area or facility being protected.

10. The arrangements must be properly interfaced with flood control measures. Where the introduction of new infrastructure leads to the need for additional flood control measures in such communities these works shall be properly identified.
11. The hydraulic design must be based upon adequate topographic data. The topographic survey conducted must be consistent the needs of the hydraulic design.

8.2.1 Groynes

1. Groynes are small jetties, solid or permeable, constructed of timber, sheet piling, vegetation, and stone rubble, etc. (Figure 9). They usually project into the stream perpendicularly to the bank, but sometimes are inclined in the upstream or downstream direction.
2. The main purpose of groynes is to reduce channel width and to remove the danger of scour from the banks; their ends in the stream are liable to scour, with sediment accumulation between them.
3. As their effect is mainly local, the spacing between groynes should not exceed about five groyne lengths. A spacing of about two lengths results in a well-defined channel for navigation; the larger the ratio of groyne spacing to river width, the stronger the local acceleration and retardation, and thus the greater the hindrance to shipping.

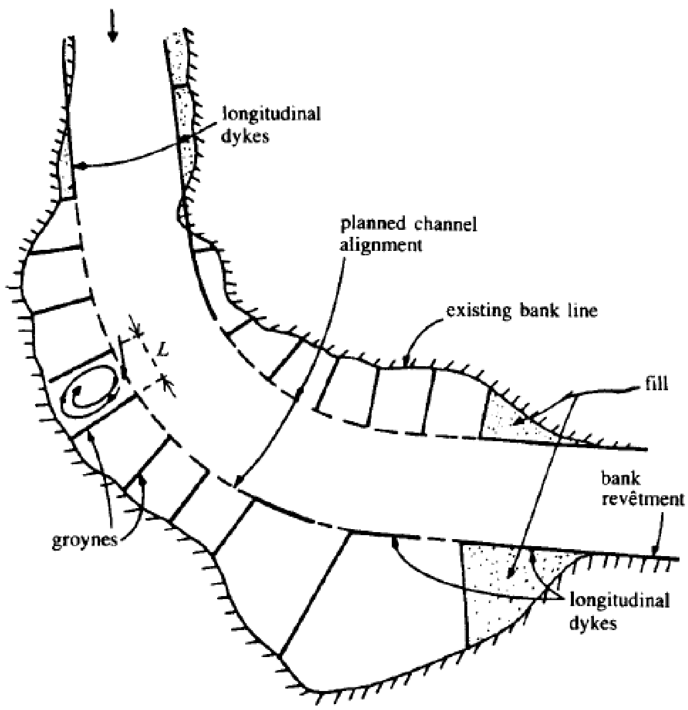


Figure 9 River training by groynes

8.2.3 Training walls

1. Longitudinal **dykes (training walls)** (Figure 10) are usually more economical than groynes and – if properly positioned – equally or even more effective. The material used is again rubble, stone, or fascine work (on soft river beds).
2. Training walls may be single – on one side of the channel, or double – on both sides of the channel.

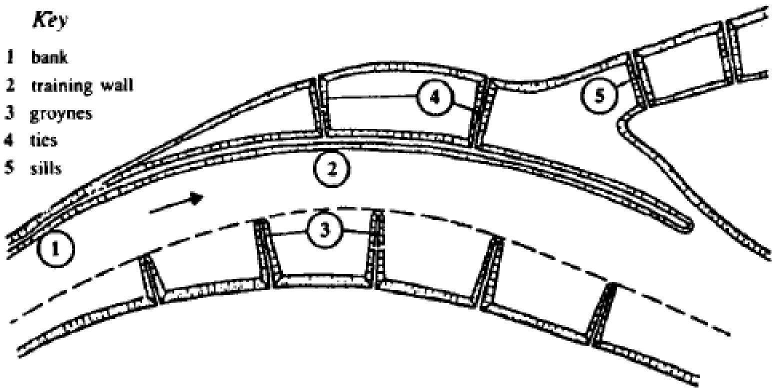


Figure 10 River training with groynes and training wall

8.3 Flood protection[14]

1. Flood protection works include high-water river training (mainly by dykes), diversion and flood-relief channels with or without control structures, and flood-control reservoirs.
2. Flood protection schemes require a careful cost–benefit analysis to determine a suitable design discharge which depends on the type of land, structures and property to be protected and the processes involved.
3. The return period of the design discharge may range from 1 to 100 years and in very special cases (large settlements, ancient historic monuments, nuclear installations, etc.) may be substantially higher.
4. The designer shall have a basic understanding and follow these basic steps for planning of flood embankments:
   a) **Classification –** An embankment is designated as low, medium or major (according to its height above natural surface level (NSL),
   b) **Data for planning of an embankment –** Topographical data, Hydrological data, History of past floods,
   c) **Degree of protection –** The degree of protection which gives the optimum Benefit Cost Ratio shall be adopted for embankments for predominantly agricultural areas, and for townships or areas having industrial installations
   d) **Alignment & spacing of embankment –** Aligning the

[14] More information on th design of dykes/flood embankments can be accessed in the publication *Handbook for Flood Protection, Anti-erosion, & River Training Works* by Sh K.N. Keshri et al, Flood Management Organisation, Central Water Commission, Government of India, June 2012.

embankment on the natural bank of the river, where land is high and soil available for the construction of embankments, and spacing the embankment with respect to its vulnerability to the river and the rise of high flood levels on account of reduction in flood plain storage by construction of the embankment.

e) **Types –** whether homogenous, zoned or diaphragm type.
f) **Design High Flood Level –** which can be obtained from gauge discharge relationships, or from flood frequency analysis for corresponding return period.
g) **Free board –** The top of the embankment should be so fixed that there is no danger of overtopping, even with the intense wave wash or any other unexpected rise in water level due to sudden change in river course or aggradations of river bed or settlement of embankment.
h) **Top width –** which should be sufficient enough to accommodate the vehicular traffic.
i) **Hydraulic gradient –** the line of seepage which can be determined from the following guidelines: Clayey soil: 4H:1V; Clayey sand: 5H:1V; Sandy soil: 6H:1V
j) **Side slope –** dependent upon the material and height of the embankment. The side slope should be flatter than the angle of repose of the material of the embankment. The river side (R/S) slope should be flatter than the under-water angle of repose of the material. The country side slope should be 2H:1V from the top up to the point where the cover over HGL is 0.6 m after which a berm of suitable width, with country side slope of 2H:1V from the end of the berm up to the ground level should be provided.
k) For **drainage purposes**, longitudinal drains on the berm and cross drains at suitable places should be provided to drain out the water.
l) In order **to provide communication** from one side of embankment to another side, ramps in a slope of 40H:1V at suitable places and all village paths should be provided as per requirement.

8.4 Bank protection

1. Bank protection is carried out by planting, mattresses, rubble, stone pitching, gabions, bagged concrete, concrete slabs, asphalt slabs, prefabricated concrete interlocking units with or without vegetation, articulated concrete mattresses, soil–cement blocks, asphalt and asphaltic concrete, geotextiles (woven and non-woven fabrics, meshes, grids, strips, sheets and composites of different shapes and constituents), used tyres, etc., all used with or without membrane linings (e.g. nylon, rubber, polythene, etc.).
2. The choice of material is influenced by the extent of the area to be protected, hydraulic conditions, material availability, material and labour costs, access to the site, available mechanization, soil conditions, design life, required impermeability, robustness, flexibility, roughness, durability, environmental requirements, among other effects.

3. Figure 11 shows an example of bank protection using gabion baskets and mattresses.

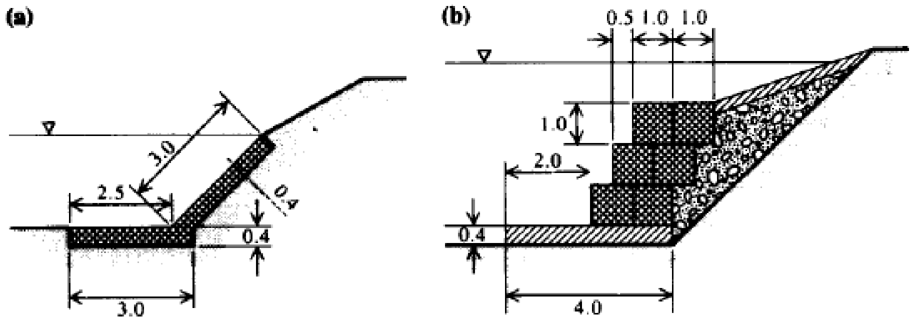


Figure 11 Bank protection with gabions, dimensions in metres

CHAPTER 9: DRAWINGS

1. [15]The designer shall provide drawings with appropriate notations, symbols, orthogonal views, in appropriate scales and paper sizes for each component of the irrigation system (layouts, profiles, and structures).
2. Standard drawings for major structures are presented in Annex 12.
3. Standard Bills of Quantities for all systems are presented in Annex 13.

[15] Comprehensive information on drawings can be obtained from the FAO publication *Irrigation Manual Module 6: Guidelines for Preparation of Technical Drawings*.

ANNEXES

Annex 1: Key Performance indicators associated with irrigation schemes development

Key performance indicator	Unit(s)	Associated information
	Water Use Efficiency	
Irrigation crop demand	mm/d m^3/ha/week	• Crop type, crop factors, soil type • Climate (rainfall and evapotranspiration) • Level of risk of not meeting soil water deficits
System capacity (based on 24 hours)	ℓ/s/ha mm/day	• Flow rate of irrigation system • Irrigated area • Actual hours of pumping per day
Maximum allowable deficit (MAD)	mm %	• Soil water holding capacity in root zone during peak design period • % of available water that is accepted to be depleted before recharge (irrigation) is required
Application depth	mm	• Gross depth of water applied
Return interval	days hours	• For larger systems • For some mini/small scale irrigation systems
Application rate	mm/hr	• Gross depth of water applied • Time (hours) taken to apply water
Infiltration rate	mm/hr	• Soil infiltration rate characteristics • Slope • Crop cover • Time to apply water
Adequacy of irrigation		• The ratio of the mean low quarter depth applied, to the mean target depth required across the field as a whole.
Potential application efficiency	%	• The single event potential application efficiency is estimated from field distribution uniformity and surface losses due to runoff and leakages.
Distribution efficiency	%	• Water supplied to the scheme • Water discharged from application system
Headwork efficiency	%	• Pressure loss through headworks components net of elevation differences • Actual abstraction compared with expected abstraction
Supply reliability	days	• The number of days when supplies will not be available in a 1:5 or a 1: 10 year drought
	Energy Use Efficiency	
System energy rating	kW	• Size of pumps in kW
System pumping efficiency	%	• Energy consumed to (volume of water moved and pressure increase)
Energy per unit volume	kWh/m^3 (based on meter readings)	• Seasonal volume of water pumped • Seasonal kWh of energy used
	Labour Efficiency	
Hours per hectare per year used for operation	hr/ha	• Time spend on operating irrigation system

Key performance indicator	Unit(s)	Associated information
		• Effective area irrigated
Hours per hectare per year used for maintenance	hr/ha	• Time spend on maintaining irrigation system • Effective area irrigated
Hours per mm applied	hr/mm	• Time spend on operating and maintaining irrigation system • Seasonal depth of water applied
Capital Efficiency		
Capital cost per hectare	$/ha	• Total cost of irrigation system • Effective area irrigated
Operating cost/volume applied	$/mm/ha $/ML	• All running costs of irrigation system • Effective area irrigated • Effective depth of water applied
Annual operating cost per hectare	$/ha	• All running costs of irrigation system • Effective area irrigated
Total annual cost per hectare	$/ha	• Capital cost per hectare • Annual cost per hectare • Cost of finance (rate, term)
Environmental Performance		
Average system efficiency	%	• Water supplied to the property • Water beneficially used
Drainage index	m^3/ha/yr	• Volume of water draining through profile • Area irrigated (ha)
Redistribution index	m^3/ha/yr	• Volume of water reaching target area • Total volume of water applied

Explanation of the components forming these indicators is given in the *Definitions* section (Section 2).

Although most of the KPI's are generic in that they apply to all types of irrigation systems, some are not. Where they apply, they should be included. Where they don't, they can be left out.

Annex 2: Some of the information to be obtained from site visits

Item	Description
Site layout/shape	Fixed boundaries, permanent features, roads, other obstructions
Map	Can a copy of a site map be obtained? Include map of Malawi and area map to define location of site
Design area	What area is intended to be irrigated? Is there a priority? Demography, number of beneficiaries. Proximity to villages.
Elevation	Elevations, slope, hills, gulleys, flood risk.
Topology	Catchment health, trees, streams, water races, buildings, power pylons, obstructions.
Land restrictions	Protected areas, covenants on titles. Land rights. Availability of land for the intended purpose
Shelter	What natural or artificial wind breaks will be present or required?
Animals	What and how many stock will be grazed in the irrigated area? Proximity to game reserves should be indicated
Fencing	What fencing arrangement will be used, how will it affect shifting? How will it affect animals?
Water supply location	Is it fixed, or will it be determined in the design?
Water quantity	What is available or approximately what will be required? Existing abstraction rights, other uses.
Water supply reliability	What restrictions could the supply be subjected to? Is storage needed? Storage on-farm, in the catchment, or both? What is the risk imposed by other users of the catchment and catchment degradation?
Water quality/chemistry	Is the quality physically and chemically suitable for the proposed irrigation system?
Soil water holding capacity	What are the soil type, plant available water and readily available water?
Soil infiltration capacity	How quickly will the soil absorb water? Are there any soil pans? Is soil erosion likely to be a problem?
Drainage	Potential drainage problems. Existing natural drainage. Flood risk
Crops	What crops are to be grown short-term and long-term? Any markets or potential for value addition before sales?
Contracts	What conditions do crop contracts impose with respect to irrigation?
Other needs	Is water required for other purposes (e.g. tobacco/tree nursery germination, domestic, leaching of salts, animal watering)?
Risk preference	How much risk of not meeting demand is the client prepared to accept? What are the other risks to development, management, operation and maintenance?
Precipitation (Rainfall)	Are rainfall records available? If not, where is the nearest record? Any other meteorological data source and availability
Evapotranspiration	Where is the nearest record?
Wind	Which is the prevailing wind? When does it blow, and at what strength? Who keeps records?
System 'catchup'	What requirements for "catching up" after restrictions will be

Item	Description
ability[16]	needed?
Energy source	If power is required, where is it going to come from? What supply limitations are there? Power options: grid or solar
Future flexibility	Is there a need to consider a future change in method? Additional development that will need more abstraction from the water source, and the associated requirements
Labour	What labour and skill level is available to operate and maintain the system?
Management, operation and maintenance	How has the irrigator organised management of all operations of the scheme? Capacity and skills for management functions. Willingness to pay fees.
Health & safety	What health and safety issues could arise? Sanitation and hygiene issues? Disease vectors?
Price limits	How much money is the client prepared to spend and how? How much contribution in-kind shall be made?
Delivery	When does the system have to be operational?
Personal preferences	Does the client have any personal preferences for systems?
Restrictions	Are there any restrictions regarding installing and operating the system (e.g. dependence on subcontractors)?
Resource Management Acts	Have the necessary consents been obtained and under what conditions? (e.g. water abstraction rights, user rights, land leases, EIA)
Special conditions	Are there any special conditions relating to the taking and using of land, water and other resources?
Vandalism	What is the likelihood of vandalism?
Other	Any other issues relevant to the client?

Adapted from the New Zealand Code of Practice

[16] Water supply may also be subject to seasonal restrictions, whether they are due to changing stream flows or changing groundwater levels. Due account should be taken of possible changes in water availability or restrictions in determining irrigation system capacities, irrigation components, area irrigated and risk of shortfalls. It may be necessary to increase overall system capacity to provide a 'catchup' ability to minimise the effect of shortfalls or build in extra capacity in pumps to lift water from greater depths.

Annex 3: Data to be collected during pre-feasibility studies

The designer shall source maps and data required for the technical planning and design of the irrigation system that shall include the following:

- Map of Malawi (1:1000 000) and area maps (1:250 000) to define the location of the irrigation project site. Map of the entire project area;
- The physical, environmental, economic and human conditions to such a scale/detail that the actual situation and future changes can be studied to a sufficient extent;
- Administrative data: organisations, laws (water abstraction rights, environmental, land tenure arrangements);
- Topographical maps and/or aerial photographs and /or GIS data, on a scale according to level of needed detail;
- Aerial maps: scale 1:50,000
- Soil maps and/or land classification and land capability maps to appropriate scales; information on soil properties and soil conservation;
- Climatological data: rainfall, temperature, humidity, wind and radiation are the more important ones;
- Hydrologic data: quantity and quality; floods events,
- Sociological data such as available labour and experience, and available management at the various levels;
- Construction conditions and materials in the project area;
- Agronomic data: actual and possible crops and cropping patterns; crop water, irrigation and drainage requirements;
- Information to support financing arrangements; and
- Economic and financial data: expected costs and benefits at all levels.

Annex 4: Some of the issues to be assessed during feasibility studies

a) Natural conditions: topography, meteorology, hydrology, geology, soil mechanics, soil science and type of vegetation
b) Land use conditions: land use pattern and land ownership
c) Accessibility of the project to utilities (roads, electricity & water)
d) Agricultural practices: current situation and projected: cropping patterns & rotation
e) Availability of markets
f) Selection of irrigation method
g) Determination of possible crop production economic gains
h) Crop and Irrigation water requirements
i) Topographical Surveys
j) Geotechnical Surveys
k) Soil Surveys
l) Water Resources Surveys, including availability of water abstraction rights
m) Environmental and Social Impacts (ESIA/ESMP), which involve considering
    (i) National Regulations (Environmental Affairs Department)
    (ii) International Regulations (WB, AfDB, EU)
    (iii) Environmental Scoping
    (iv) Environmental Assessments
    (v) Environmental Assessment Requirements
    (vi) Environmental Safeguards
    (vii) Catchment Conservation
    (viii) Social Aspects of Environmental Conservation
n) Socio-economic Surveys
o) Community/Owner Participation
p) Determination of the most viable option through financial and economic analyses
q) Preliminary design and cost estimates

Annex 5: IWRM Approaches to conducting Feasibility Studies

IWRM is a participatory planning and implementation **process**, based on sound **science**, which brings together **stakeholders** to determine how to meet society's long-term needs for water and coastal resources while maintaining essential **ecological** services and **economic** benefits. The method emphasizes the key concepts of *Integration*, *Decentralization*, *Participation*, and *Economic and Financial Sustainability*.

Integration - a holistic approach that emphasizes the three goals of economic development, social welfare, and environmental protection and that integrates management of all *horizontal and vertical* sectors that use and/or affect water (Figure 1). IWRM advocates creating and empowering basin-level organizations to direct water resource management efforts in a hydrological boundary.

Decentralization - places responsibility for water resource management at the lowest effective administrative level, seeking to strike a balance between top-down and bottom-up management.

Participation – aims at strengthening community-based organizations, water user associations, and other stakeholders to enable them to take a greater role in management decisions. IWRM emphasizes broad-based capacity building and support for the formation of user groups and representative associations.

Economic and Financial Sustainability – emphasises on giving proper attention to the ***economic value of water***. To achieve long-term economic sustainability, water must be priced at its full cost, accounting for the cost of withdrawing and delivering the water, as well as the opportunity cost and both economic and environmental externalities associated with using that water. To achieve financial sustainability of water service delivery, user fees should at a minimum cover O&M costs of service provision.

SADC has also developed guidelines for local level IWRM which require an integrated and demand-driven development approach that supports and emphasises participatory planning processes by local government, multi-sectoral government line agencies, Non-Governmental Organizations, Community-Based Organizations and private firms and contractors, who together form the 'supportive environment' to improve the livelihoods of their constituencies.

There are three conditions for applying these guidelines. With sufficient decentralization of decision-making on the allocation of financial, technical and institutional resources, local structures can usually meet these conditions. Otherwise, these conditions need to be negotiated gradually within government and the donor community.

- **the aim of improving livelihoods**, especially for the vulnerable members of the community, using water as a catalyst for development;
- **the ability to provide a range of potential appropriate technologies and interventions**, varying from individual technologies to small dams and reservoirs, and interventions to augment the benefits from water use.
- **funding and time** conditions of the specific project (or 'loop') that allow for a **participatory planning phase** during which communities can partake in the detailed

project design and budgeting, and a phase in which selected activities are implemented.

The guidelines assume that the local authority has basic demographic, social and water resource availability information.

Responsible Organization	Phases	Steps	Steps
Creating a supportive environment			**Continuous 'Step' Seven:** Do participatory monitoring and evaluation and impact assessment for follow-up
Local authorities and support agencies	Initial	**Step One:** Mobilize support	
		Step Two: Select communities	
Participatory planning, implementation and monitoring			
Communities facilitated by local structures and support agencies	Participatory planning	**Step Three:** Understand the community and build capacity	
		Step Four: Create a vision and select activities to fulfil it	
		Step Five: Compile action plans	
	Implementation	**Step Six:** Implement the action plans	

Figure 1: Overview of responsibilities, phases and steps

The guidelines, which are summarized in Figure 2, consist of two parts. The first part concerns the creation of a sustainable supportive environment for local-level IWRM. This is the responsibility of the local authorities and the intermediate and national level tiers of their organizations, as well as of collaborating government line agencies, private service providers and NGOs and CBOs. This supportive environment should allow for implementing community-based water resource management.

The second part of these guidelines concerns a particular community and the step-wise participatory process in that community. This consists of five steps: *three*) understanding the community and building capacity; *four*) creating a vision and selecting activities; *five*) compiling action plans; *six*) implementing the action plans; and *seven*) participatory monitoring and evaluation and impact assessment. The last 'step' is continuous. The steps concern one 'loop' or one cycle of improvements. Any next intervention can build on the improvements realized and the lessons learned. Thus, community-based water resource development and management becomes a continuous process, which can be oral or written as 'village water development plans'.

The steps and their components in the guidelines are more or less chronological and not rigid at all. Every step has a value and purpose and none of these steps should be skipped. For example, once sites of new infrastructure have been selected, the potential beneficiaries have also largely been determined. However, for other issues, such as the technical feasibility assessment, it may well be necessary to go back to earlier steps once or twice or even more often to adjust the process because of unforeseen events and new information. Also, the different activities in one project are often staggered and in different phases. Early implementation of some smaller 'successes' can encourage in pursuing the planning process of a complex, longer-term activity.

Step One: Mobilize support

- Strengthen existing development plans.
- Compile integrated support.
- Define targeting procedures.
- Establish horizontal, integrated service delivery structures.
- Ensure vertical national support.

Step Two: Select communities

- Develop selection criteria within time and funding frames.
- Communicate widely and test for compliance.
- Select.

Step Three: Understand the community and build capacity

- Build trusting relationships and communicate the project concept.
- Do contextual profiling.
- Train the community and select community mobilizers.

Step Four: Create a vision and select activities to fulfil it

- Do participatory situational diagnosis and problem analysis.
- Create a vision of new ways to manage water.
- Rank opportunities and needs.
- Select activities for implementation.

Step Five: Compile detailed action plans

- Create and train community structures.
- Specify actions, roles and budgets.
- Sign off.

Step Six: Implement the action plans

- Construct communal infrastructure and develop the capacity to operate and maintain it.
- Create management structures and develop their capacity.
- Implement the accompanying interventions and develop the capacity to maintain them.
- Ensure sustainability when exiting.
- Operate and maintain infrastructure and continue capacity development.

Continuous 'Step' Seven: Do participatory monitoring and evaluation, and livelihood impact assessment for follow-up

- Monitor planning, implementation and use.
- Monitor the impacts on livelihoods.
- Identify follow-up plans for community-based water resource management.

Figure 2: Project steps in local-level IWRM

Annex 6: Environmental and Social Impact Assessment Screening Form

PART A: GENERAL INFORMATION

Project Name	**Estimated Cost (MK)**
Project Site	Funding Agency
Project Objectives	Proposed Main Project Activities:
Name of Evaluator	Date of Field Appraisal

PART B: BRIEF DESCRIPTION OF THE PROPOSED ACTIVITIES

Provide information on the type and scale of the construction/rehabilitation activity (e.g. area, land required and approximate size of structures).

Provide information on the construction activities including support/ancillary structures and activities required to build them, e.g. need to quarry or excavate borrow materials, water source, access roads etc.
Describe how the construction/rehabilitation activities will be carried out. Include description of support/activities and resources required for the construction/rehabilitation.

PART C: ENVIRONMENTAL BASELINE INFORMATION OF THE PROJECT SITE

CATEGORY OF BASELINE INFORMATION	BRIEF DESCRIPTION
GEOGRAPHICAL LOCATION a. Name of the Area (District, T/A, Village) b. Proposed location of the project (Include a site map of at least 1:10,000 scale)	
LAND RESOURCES a. Topography and Geology of the area b. Soils of the area **c.** Main land uses and economic activities	
WATER RESOURCES a. Surface water resources (e.g. rivers, lakes, etc) quantity and quality b. Ground water resources quantity and quality	
BIOLOGICAL RESOURCES a. Flora (include threatened/endangered/endemic species) b. Fauna (include threatened/endangered/endemic species) c. Sensitive habitats including protected areas e.g. national parks and forest reserves	
CLIMATE a. Temperature b. Rainfall	

PART D: SCREENING CRITERIA

	AREAS OF IMPACT			IMPACT EVALUATION						POTENTIAL MITIGATION MEASURES
				Extent or coverage (on site, within 3km - 5km or beyond 5km)			Significance (Low, Medium, High)			
1.	Is the project site/activity within and/ or will it affect the following environmentally sensitive areas?									
		No	Yes	On Site	Within 3-5 km	Beyond 5km	Low	Medium	High	
1.1	National parks, Wildlife and game reserve									
1.2	Wet-lands									
1.3	Productive agricultural /grazing lands									
1.5	Areas with rare or endangered flora or fauna									
1.6	Areas with outstanding scenery/tourist site									
1.7	Within steep slopes/mountains									
1.8	Dry tropical forest s such as Brachsystegia woodland									
1.9	Along lakes , along beaches, riverine									
1.10	Near industrial sites									
1.11	Near human settlements									
1.12	Near cultural heritage sites									
1.13	Within prime ground water recharge area									
1.14	Within prime surface run off									

SCREENING CRITERIA FOR IMPACTS DURING IMPLEMENTATION AND OPERATION										
2.0	Will the implementation and operations of the project activities within the selected site generate the following externalities /costs /impacts?									
		No	Yes	On Site	Within 3-5 km	Beyond 5km	Low	Medium	High	
2.1	Deforestation									
2.2	Soil erosion and siltation									
2.3	Siltation of watercourses, dams									
2.4	Damage of wildlife species and habitat									
2.5	Increased exposure to agro-chemical pollutants									
2.6	Nuisance - smell or noise									
2.7	Reduced water quality									
2.8	Increase in costs of water treatment									
2.9	Soil contamination									
2.10	Loss of soil fertility									
2.11	Stalinization or alkalinisation of soils									
2.12	Reduced flow and availability of water									
2.13	Long term depletion of water resource									
2.14	Incidence of flooding									
2.15	Changes in migration patterns of animals									
2.16	Introduce alien plants and animals									
2.17	Increased incidence of plant and animal diseases									
SCREENING CRITERIA FOR SOCIAL AND ECONOMIC IMPACTS										
3.0	Will the implementation and operation of the project activities within the selected site generate the following socio-economic costs/impacts?									
		No	Yes	On Site	Within 3-5 km	Beyond 5km	Low	Medium	High	
3.1	Loss of land for human settlement, farming, grazing									

3.2	Loss of property- houses ,agricultural produce etc.									
3.3	Loss of cultural sites, graveyards, monuments									
3.4	Disruption of social fabric									
3.5	Interference in marriages for local people by workers									
3.6	Spread of STIs and HIV and AIDS, due to migrant workers									
3.7	Increased incidence of communicable diseases									
3.8	Health hazards to workers and communities									
3.9	Changes in human settlement patterns									
3.10	Conflicts over use of natural resources e.g. water, land, etc.									
3.11	Conflicts on land ownership									
3.12	Disruption of important pathways, roads									
3.13	Increased population influx									
3.14	Loss of cultural identity									
3.15	Loss of income generating capacity									

OVERALL EVALUATION OF THE SCREENING PROCESS ON THE SITE AND PROJECT ACTIVITY

The result of the screening process would be either: (a) the proposed project would be permitted to proceed on the site or (b) the proposed project would need an EIA. The basis of these options is listed in the table below:

The Proposed Project Activity Can Be Exempted From EIA and/or RAP Requirements On The Following.	The Proposed Project Activity Needs Further Compliance With EIA Requirements On The Following Observations.
a. Screening indicates that the site of the project will not be within environmentally–sensitive areas .e.g. protected areas	a. Field appraisals indicate that the project site is within environmentally –sensitive areas, protected areas.
b. No families will be displaced from the site	b. Cause adverse socio-economic impacts
c. Identified impacts are minor, marginal and of little significance	c. Significant number of people, families will be displaced from site
d. Mitigation measures for the identified impacts are well understood and practiced in the area	d. Some of the predicted impacts will be long term, complicated, extensive
e. The stakeholders have adequate practical experiences in natural resource conservation and management.	e. Appropriate mitigation measures for some predicted impacts are not well known in the area

Completion by Environmental District Officer	
Is This Project Likely To Need An EIA	YES/ NO
List A/B Paragraph Numbers	
Date Exempted	
Date Forwarded To DEA Head Office	
Name & Signature of EDO	

Completion by Director of Environmental Affairs	
Date Received from District Assembly:	
Dated Reviewed:	
Date of Submission of Project Brief	
Date of Submission of EIA Reports	
Date of Approval/Rejection	

NOTES:

- Once the Environmental and Social Screening Form is completed it is analysed by experts from the District Environmental Sub-Committee who will classify it into the appropriate category based on a predetermined criteria and the information provided in the form.
- All projects' proponents exempted from further impact assessment must be informed to proceed with other necessary procedures.
- All projects recommended for further impact assessment will have to follow procedures outlined in section 24 and 25 of the Environmental Management Act, and the Malawi Government's Guidelines for Environmental Impact Assessment Appendix C, page 32

Annex 7: Some steps in the design of irrigation canals

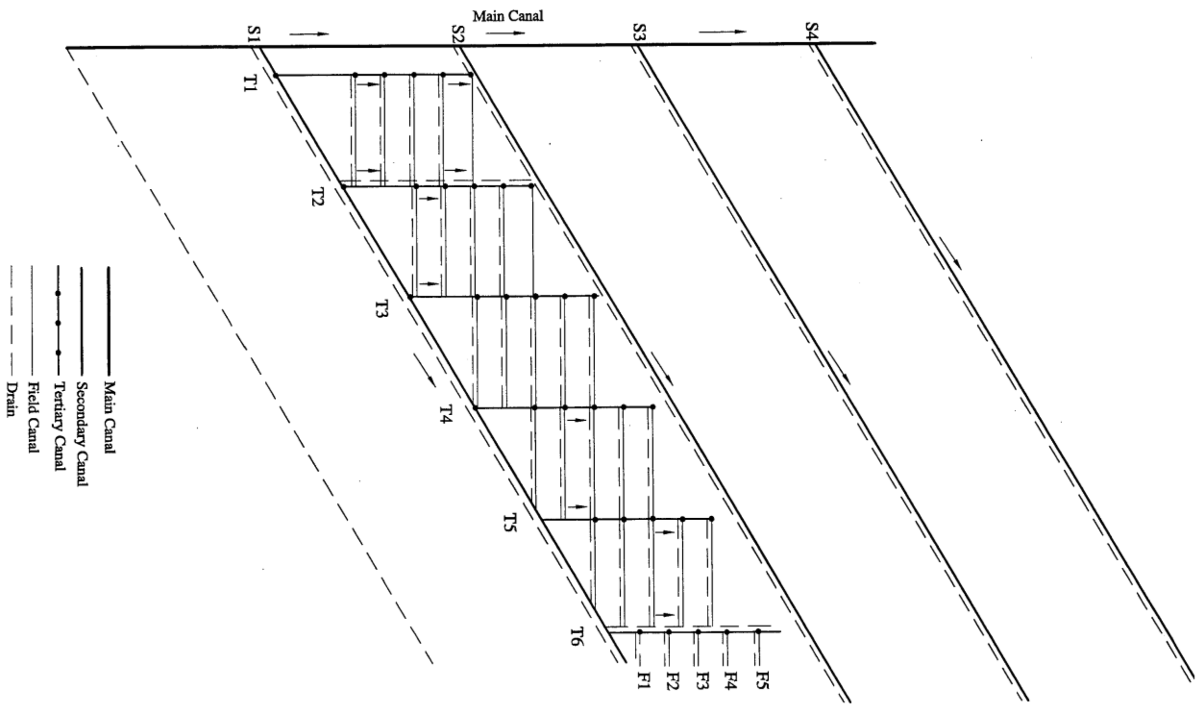


Figure 1: Typical layout of an irrigation canal network

Figure 1 shows a typical layout of a canal network with the main components of an irrigation project. To design such a system, the designer should implement the following steps:

Step 1

On the contour map of the proposed irrigation project try to locate the best alignment for the canals, taking into consideration the following factors.

1. The canal gradient is down the slope, to allow for gravity flow.
2. The canals should be aligned on high ground to command the greatest irrigable area.
3. Main canals crossing the contours at right angles should be avoided to reduce excavation and earthwork.
4. The management of the system must be considered, when the canal network is designed. For example, a block which is served by a tertiary canal should command an area which is manageable, and can be administered by the farmers' irrigation committee. A tertiary block will usually be about 25 to 30 ha. in area.
5. To avoid excessive losses by seepage in the field canals, it is recommended that the field canals should not be longer than one kilometre. The maximum area irrigated by a field canal should generally not exceed 7.5 ha.

Step 2

Determine the minimum acceptable water level at the tail and head of the field canals by adding about 20 cm to the field level at these two locations. The ground level and the minimum acceptable water level (mwlf) is then drawn. The line which connects mwlf at the head and the tail of a canal should represent the water surface, if the gradient is acceptable. The acceptable gradient is the gradient which gives a flow velocity in the canal less than the maximum permissible velocity. If the gradient of the assumed water surface is too steep, drop structures can be introduced as necessary along the canal.

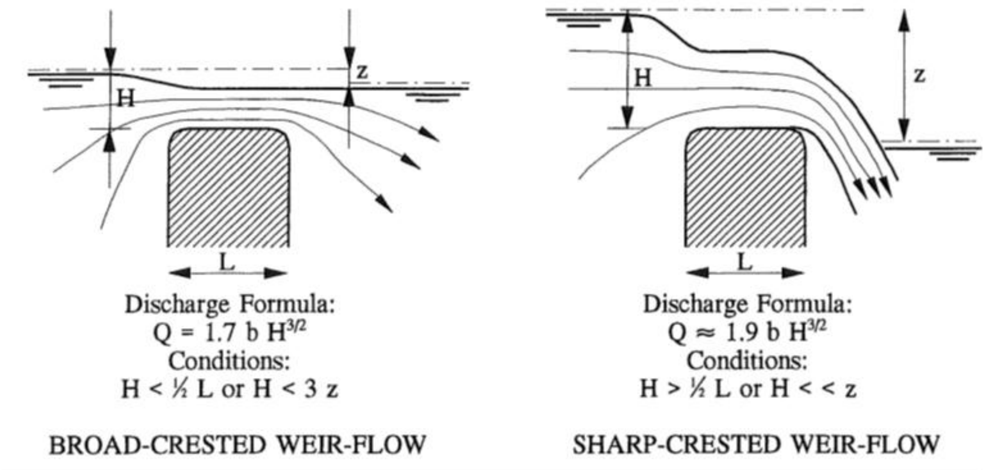
Step 3

The same procedure as given in Step 2 is repeated for other field canals and the minimum acceptable water level in the tertiary canals (mwlt) at the location of the field canals is calculated. The mwlt is equal to the mwlf plus head losses through the turnout, which is about 5 cm for a simple gate to about 10 cm for short pipes. For the preliminary design, these figures can be adopted, but they should be checked later once the structure type has been decided. The water surface in the tertiary canals must be at or higher than the mwlt at the location of the field canals. At this stage the need for drop structures will become apparent.

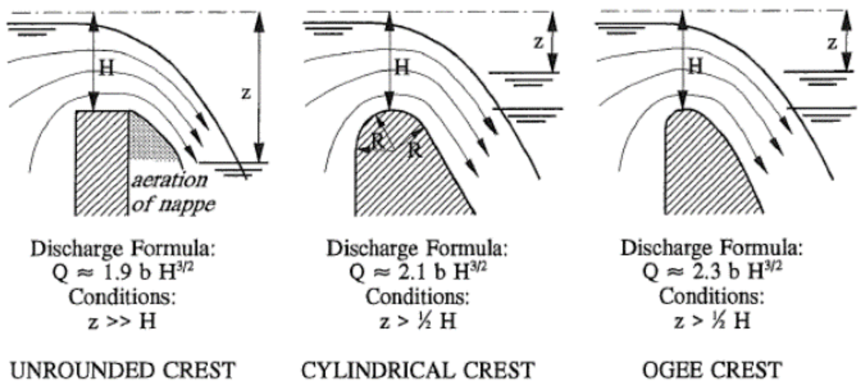
Step 4

1. Calculate the water level at the head of the tertiaries and add the head losses through the turnouts to obtain the minimum water level in the secondary canals (mwls).
2. The water surface in the secondary canals must be at or higher than the mwls. Introduce drop structures as needed to fulfil the design hydraulic criteria, as explained in Section 3 of this chapter.
3. Add an estimated value of the head loss at the turnouts and division boxes to obtain the minimum required water level in the main canal (mwlm).
4. The water surface in the main canal must be at or higher than the mwlm.
5. Determine the water level at the head of the main canal and confirm that the water source has enough head to supply the design discharge. If there is insufficient head, a weir or a pumping station may be required.

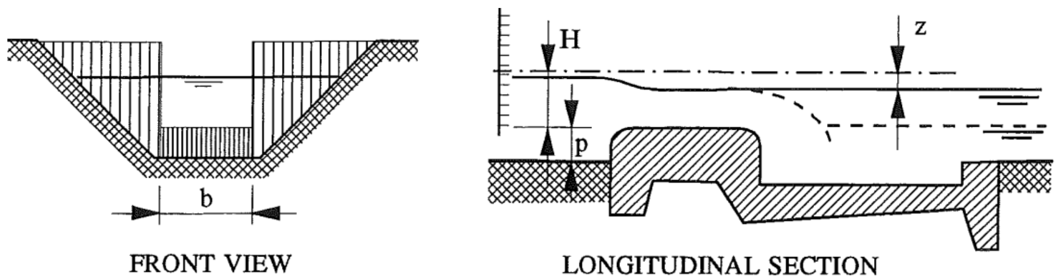
Annex 8: Discharge characteristics of some measuring weirs



Discharge characteristics of broad- and sharp-crested weirs



Types of sharp-crested weirs



Hydraulic parameters of the broad-crested weir for discharge measurement.

Discharge coefficient: The discharge coefficient depends on the curve of the streamlines above the crest, and amounts to = 1 for the broad-crested weir. Thus, weir coefficient of the broad-crested weir is c = 1.7 $m^{½}$/s. Thus, the hydraulic design equation of a broad-crested weir with a rectangular control section is often simplified into: $Q = c\ b\ H^{1.5}$ with c = 1.7 $m^{½}$/s.

The Romijn broad-crested weir

One of the most commonly used broad-crested weirs for discharge measurements is the Romijn weir, which was developed in Indonesia for use in relatively flat areas and where the water demand is variable because of different requirements during the growing season. The discharge equation for the Romijn broad-crested weir is written as:

$$Q = \tfrac{3}{2}\ x\ C_v\ x\ C_d\ x\ \left(\tfrac{3}{2}g\right)^{\frac{1}{2}}\ B_t\ x\ H_{crt}^{\frac{3}{2}}$$

Where:

Q = Design discharge over the weir (m^3/sec)
C_d = Discharge coefficient
C_v = Approach velocity coefficient
g = Acceleration due to gravity (= 9.81 m/sec2)
B_t = Width (or breadth) of the weir across the direction of flow (m)
H_{crt} = Design upstream water depth over the weir (m)

For field structures with concrete abutments, it is advisable to use an average value of C_d = 1.00. The value of the approach velocity coefficient, C_v, ranges between 1.00 and 1.18, depending on H_{crt}. Where both C_d and C_v are considered to be 1.00, substituting these values and the value for g gives:

$$q = 1.7\ x\ B_t\ x\ H_{crt}^{\frac{3}{2}}$$

Rectangular contracted weir

A rectangular contracted weir is a thin-plate weir of rectangular shape, located perpendicular to the flow. To allow full horizontal contraction of the nappe, the bed and sides of the canal must be sufficiently far from the weir crest and sides. Many practical formulae have been developed for computing the discharge, amongst which are the following:

Hamilton-Smith formula:

$$Q = \left[0.616\ x\left(1 - \frac{0.1h}{b}\right)\right] x\ \frac{3}{2}\ x\ (2g)^{\frac{1}{2}}\ x\ b\ x\ h^{\frac{3}{2}}$$

Francis formula:

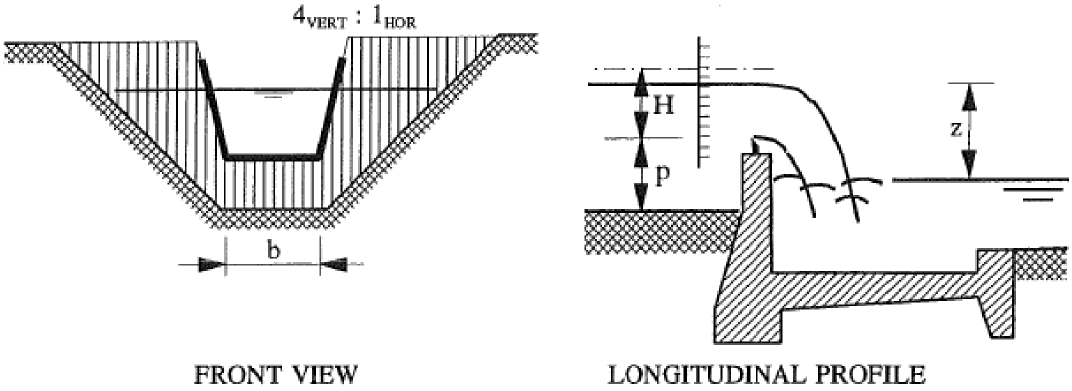
$$Q = 1.838\ x\ (b - 2h)\ x\ h^{\frac{3}{2}}$$

Where:

Q = Design discharge over weir (m3/sec)
b = Length of weir crest (m)
h = Design water depth measured from the top of the weir crest (m)
Table gives discharge data related to length of crest, b, and water head, h, over a weir.

Trapezoidal (Cipoletti) weir

The Cipoletti weir is a trapezoidal weir with the sides having an outward sloping inclination of $1_{Horizontal}$:$4_{Vertical}$. This side slope is such that the water depth-discharge relationship is the same as that of a full width rectangular weir, Figure below..



Hydraulic parameters of the Cipoletti weir for discharge measurement

The hydraulic design equation of a Cipoletti weir is:

$$Q = 1.9\ bH^{1.5} \quad \text{or} \quad Q = 1.859 \text{ x } b \text{ x } h^{\frac{3}{2}}$$

where Q is the discharge in m^3/s, H is the energy head upstream in m, b is the width of the crest in m.

Where:

Q = Design discharge over weir (m3/sec)
b = Length of weir crest (m)
h = Design water depth measured from the top of the weir crest (m)

V-notch weir

The V-notch weir is an accurate discharge-measuring device, particularly for discharges less than 30 l/sec, and it is as accurate as other types of sharp-crested weirs for discharges from 30 to 300 l/sec. To operate properly, the weir should be installed so that the minimum distance from the canal bank to the weir edge is at least twice the head on the weir. In addition, the distance from the bottom of the approach canal to the point of the weir notch should also be at least twice the head on the weir. The general and simple discharge equation for a V-notch weir is:

$$Q = 1.38 \text{ x } \tan\left(\tfrac{1}{2} \text{ x } \theta\right) \text{ x } h^{\frac{5}{2}}$$

Where:

Q = Design discharge over the weir (m3/sec)
θ = Angle included between the sides of the notch (degrees)
h = Design water depth (m)

Parshall Flumes

The upstream head-discharge (ha-Q) relationship of Parshall flume of various sizes, as calibrated empirically, is represented by an equation, having the form

$$Q = Kh^u,$$

where K denotes a dimensional factor which is a function of the throat width. The power u varies between 1.522 and 1.60. Values of K and u for each size of flume are given in the following figure. In the listed equations Q is the modular discharge in m^3/s, and ha is the upstream gauge reading in metres.

The flumes cover a range of discharges from 0.09 l/s to 93.04 m^3/s and have overlapping capacities to facilitate the selection of a suitable size

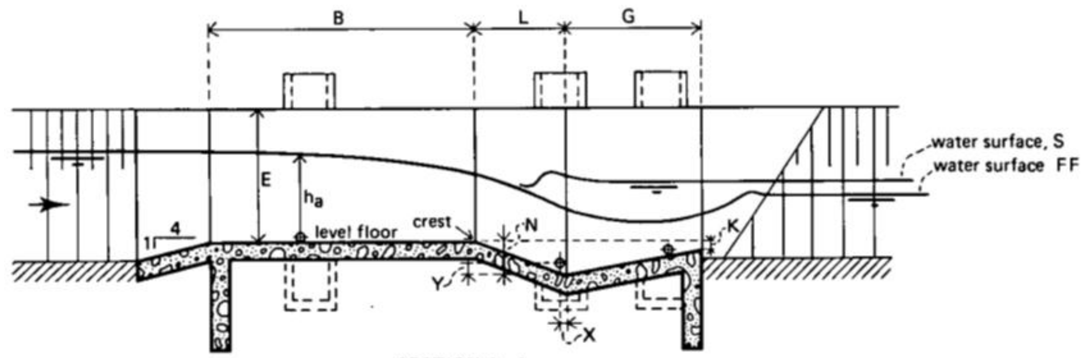
Throat width b_c in feet or inches	Discharge range in $m^3/s \times 10^{-3}$		Equation $Q = K h_a^u$ (Q in m^3/s)	Head range in metres		Modular limit h_b/h_a
	minimum	maximum		minimum	maximum	
1″	0.09	5.4	$0.0604\ h_a^{1.55}$	0.015	0.21	0.50
2″	0.18	13.2	$0.1207\ h_a^{1.55}$	0.015	0.24	0.50
3″	0.77	32.1	$0.1771\ h_a^{1.55}$	0.03	0.33	0.50
6″	1.50	111	$0.3812\ h_a^{1.58}$	0.03	0.45	0.60
9″	2.50	251	$0.5354\ h_a^{1.53}$	0.03	0.61	0.60
1′	3.32	457	$0.6909\ h_a^{1.522}$	0.03	0.76	0.70
1′6″	4.80	695	$1.056\ h_a^{1.538}$	0.03	0.76	0.70
2′	12.1	937	$1.428\ h_a^{1.550}$	0.046	0.76	0.70
3′	17.6	1427	$2.184\ h_a^{1.566}$	0.046	0.76	0.70
4′	35.8	1923	$2.953\ h_a^{1.578}$	0.06	0.76	0.70
5′	44.1	2424	$3.732\ h_a^{1.587}$	0.06	0.76	0.70
6′	74.1	2929	$4.519\ h_a^{1.595}$	0.076	0.76	0.70
7′	85.8	3438	$5.312\ h_a^{1.601}$	0.076	0.76	0.70
8′	97.2	3949	$6.112\ h_a^{1.607}$	0.076	0.76	0.70
	in m^3/s					
10′	0.16	8.28	$7.463\ h_a^{1.60}$	0.09	1.07	0.80
12′	0.19	14.68	$8.859\ h_a^{1.60}$	0.09	1.37	0.80
15′	0.23	25.04	$10.96\ h_a^{1.60}$	0.09	1.67	0.80
20′	0.31	37.97	$14.45\ h_a^{1.60}$	0.09	1.83	0.80
25′	0.38	47.14	$17.94\ h_a^{1.60}$	0.09	1.83	0.80
30′	0.46	56.33	$21.44\ h_a^{1.60}$	0.09	1.83	0.80
40′	0.60	74.70	$28.43\ h_a^{1.60}$	0.09	1.83	0.80
50′	0.75	93.04	$35.41\ h_a^{1.60}$	0.09	1.83	0.80

Discharge characteristics of Parshall flumes

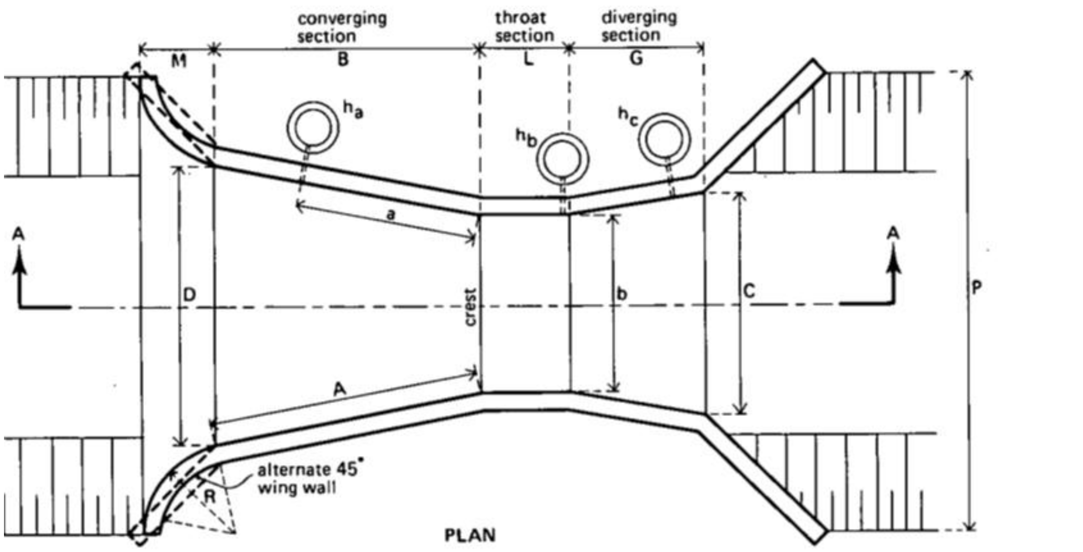
Source: FAO Irrigation Manual Module 7 Volume II.

Sizes of Parshall flumes

All dimensions are in millimetres.



SECTION A–A



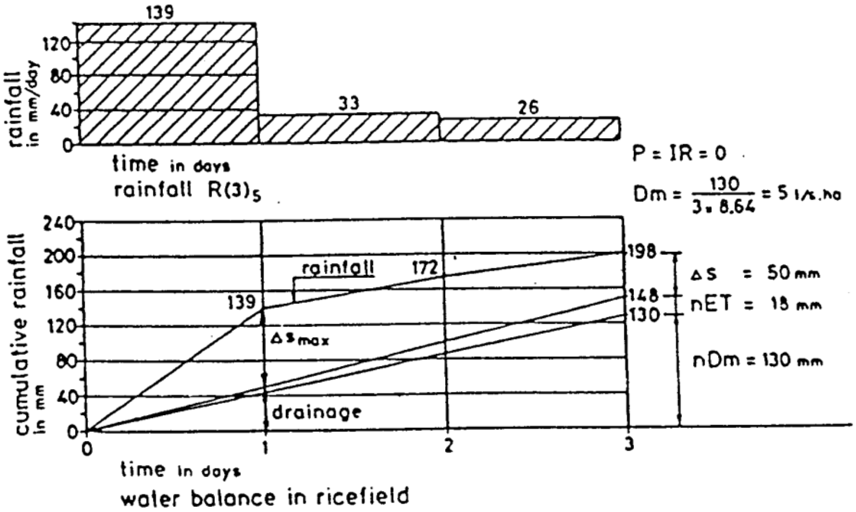
PLAN

	b_c	A	a	B	C	D	E	L	G	H	K	M	N	P	R	X	Y	Z
1"	25.4	363	242	356	93	167	229	76	203	206	19	–	29	–	–	8	13	3
2"	50.8	414	276	406	135	214	254	114	254	257	22	–	43	–	–	16	25	6
3"	76.2	467	311	457	178	259	457	152	305	309	25	–	57	–	–	25	38	13
6"	152.4	621	414	610	394	397	610	305	610	–	76	305	114	902	406	51	76	–
9"	228.6	879	587	864	381	575	762	305	457	–	76	305	114	1080	406	51	76	–
1'	304.8	1372	914	1343	610	845	914	610	914	–	76	381	229	1492	508	51	76	–
1'6"	457.2	1448	965	1419	762	1026	914	610	914	–	76	381	229	1676	508	51	76	–
2'	609.6	1524	1016	1495	914	1206	914	610	914	–	76	381	229	1854	508	51	76	–
3'	914.4	1676	1118	1645	1219	1572	914	610	914	–	76	381	229	2222	508	51	76	–
4'	1219.2	1829	1219	1794	1524	1937	914	610	914	–	76	457	229	2711	610	51	76	–
5'	1524.0	1981	1321	1943	1829	2302	914	610	914	–	76	457	229	3080	610	51	76	–
6'	1828.0	2134	1422	2092	2134	2667	914	610	914	–	76	457	229	3442	610	51	76	–
7'	2133.6	2286	1524	2242	2438	3032	914	610	914	–	76	457	229	3810	610	51	76	–
8'	2438.4	2438	1626	2391	2743	3397	914	610	914	–	76	457	229	4172	610	51	76	–
10'	3048	–	1829	4267	3658	4756	1219	914	1829	–	152	–	343	–	–	305	229	–
12'	3658	–	2032	4877	4470	5607	1524	914	2438	–	152	–	343	–	–	305	229	–
15'	4572	–	2337	7620	5588	7620	1829	1219	3048	–	229	–	457	–	–	305	229	–
20'	6096	–	2845	7620	7315	9144	2134	1829	3658	–	305	–	686	–	–	305	229	–
25'	7620	–	3353	7620	8941	10668	2134	1829	3962	–	305	–	686	–	–	305	229	–
30'	9144	–	3861	7925	10566	12313	2134	1829	4267	–	305	–	686	–	–	305	229	–
40'	12191	–	4877	8230	13818	15481	2134	1829	4877	–	305	–	686	–	–	305	229	–
50'	15240	–	5893	8230	17272	18529	2134	1829	6096	–	305	–	686	–	–	305	229	–

Annex 9: How to determine the drainage modulus in a rice field

To determine the modulus for a rice field the following steps may be followed: -

1. Obtain data on rainfall, for as many years as possible and calculate for each year the maximum 3 days' rainfall during the growing season;
2. Analyse the data to obtain a maximum 3 days' rainfall which has a return period of say 5 to 10 years. In rice fields 5 years return period is usually taken;
3. Draw the data as it is shown below assuming that at the end of the 3 days only 50 mm water is accumulated;



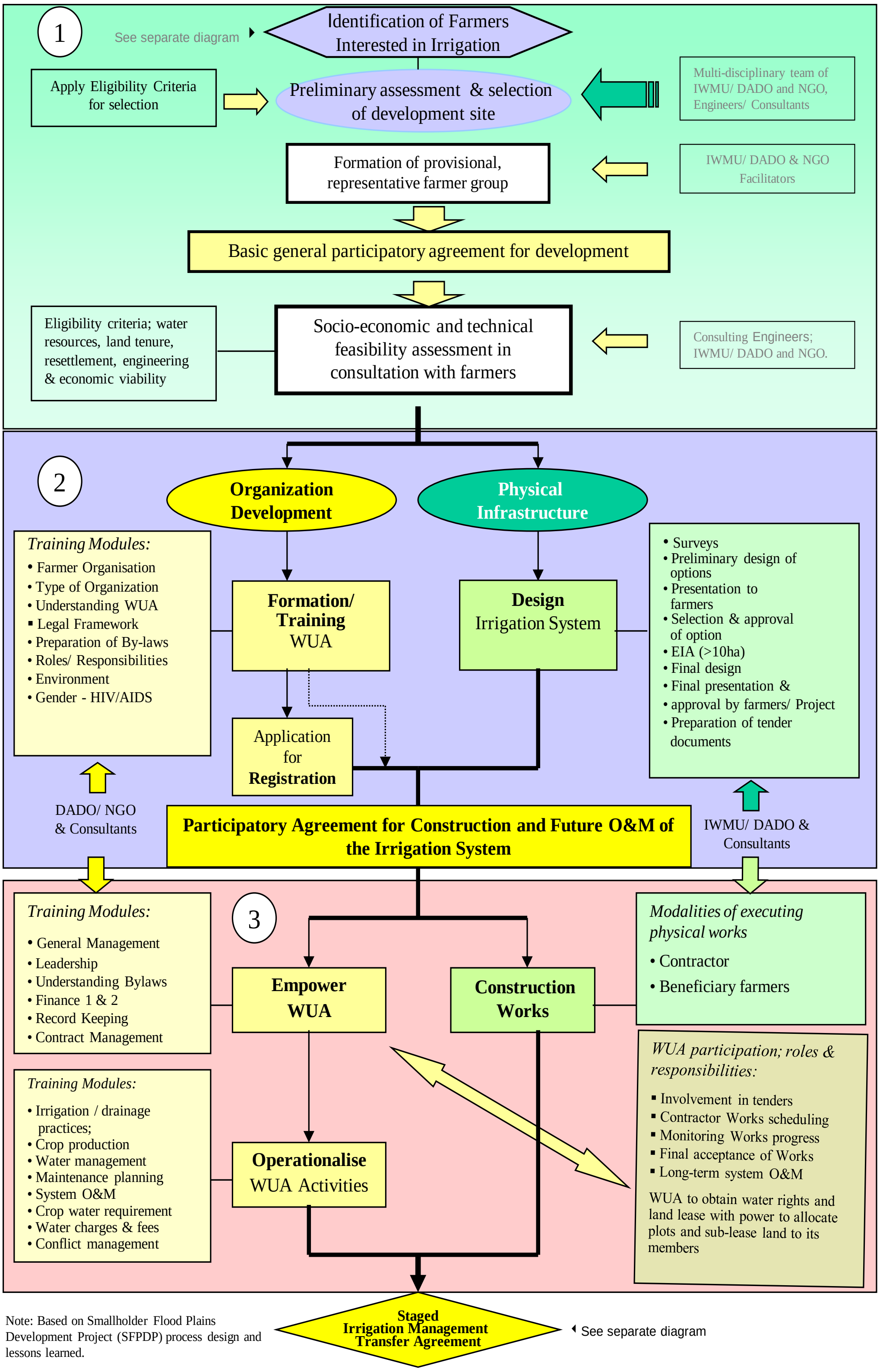
4. Subtract evapotranspiration and percolation losses from the accumulated water, to obtain the maximum drainage modulus (D3 days);
5. The mean drain capacity in l/s/ha is calculated as follows:

$$q = \frac{D_3}{3 \, x \, 8.64} = l/s/ha$$

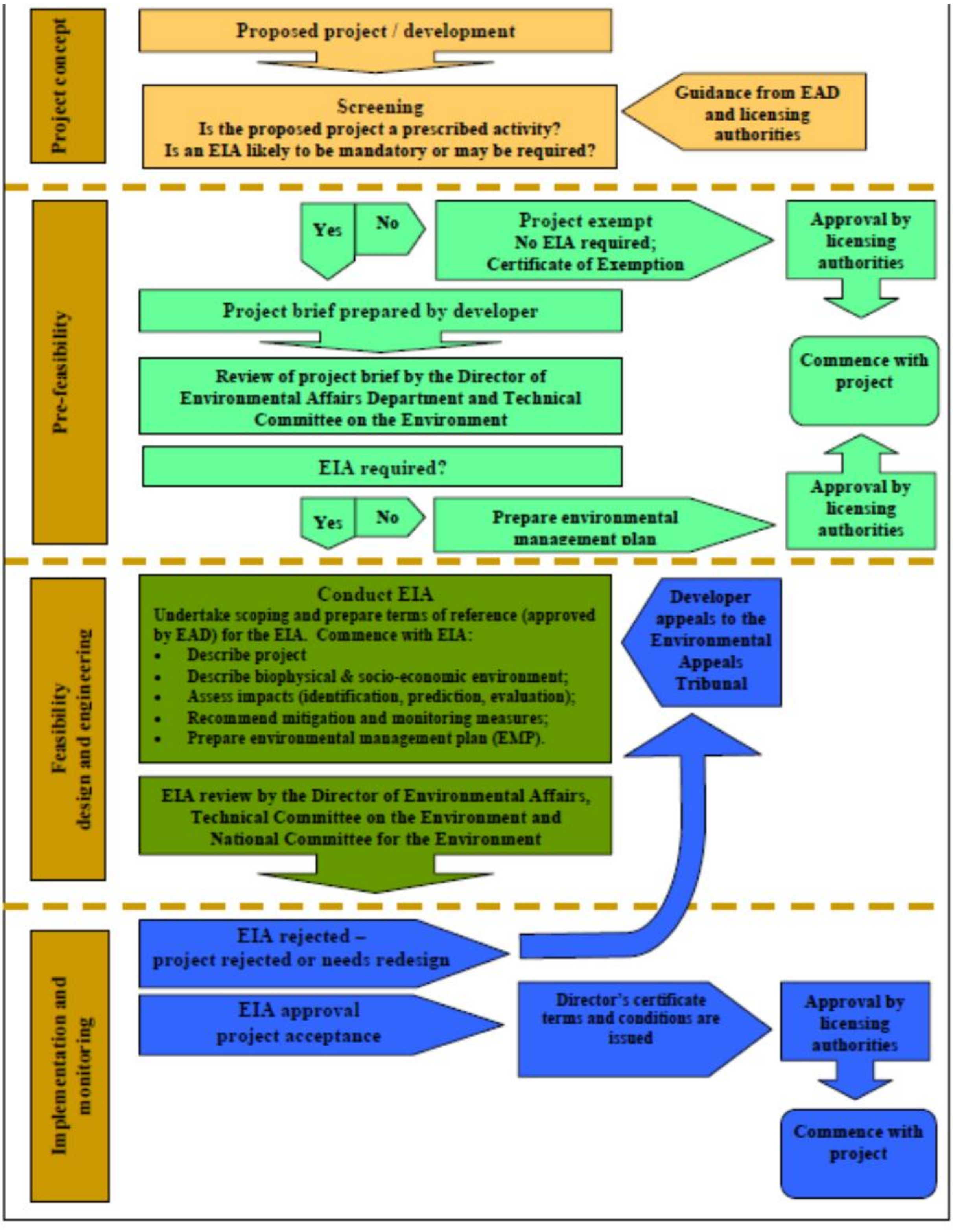
Drain capacity Q_d = q. Litres/sec should be used. For larger areas, the drainage channel cross section should be adjusted to the discharge value.

Annex 10: Process of formation and approving an environmental and social impact assessment

WUA Formation Process - New Irrigation Schemes



Note: Based on Smallholder Flood Plains Development Project (SFPDP) process design and lessons learned.


Project concept
Proposed project / development
Screening
Is the proposed project a prescribed activity?
Is an EIA likely to be mandatory or may be required?
Guidance from EAD and licensing authorities
Pre-feasibility
Yes
No
Project exempt
No EIA required;
Certificate of Exemption
Approval by licensing authorities
Project brief prepared by developer
Review of project brief by the Director of Environmental Affairs Department and Technical Committee on the Environment
Commence with project
EIA required?
Yes
No
Prepare environmental management plan
Approval by licensing authorities
Feasibility design and engineering
Conduct EIA
Undertake scoping and prepare terms of reference (approved by EAD) for the EIA. Commence with EIA:
Describe project
Describe biophysical & socio-economic environment;
Assess impacts (identification, prediction, evaluation);
Recommend mitigation and monitoring measures;
Prepare environmental management plan (EMP).
Developer appeals to the Environmental Appeals Tribunal
EIA review by the Director of Environmental Affairs, Technical Committee on the Environment and National Committee for the Environment
Implementation and monitoring
EIA rejected – project rejected or needs redesign
EIA approval project acceptance
Director's certificate terms and conditions are issued
Approval by licensing authorities
Commence with project

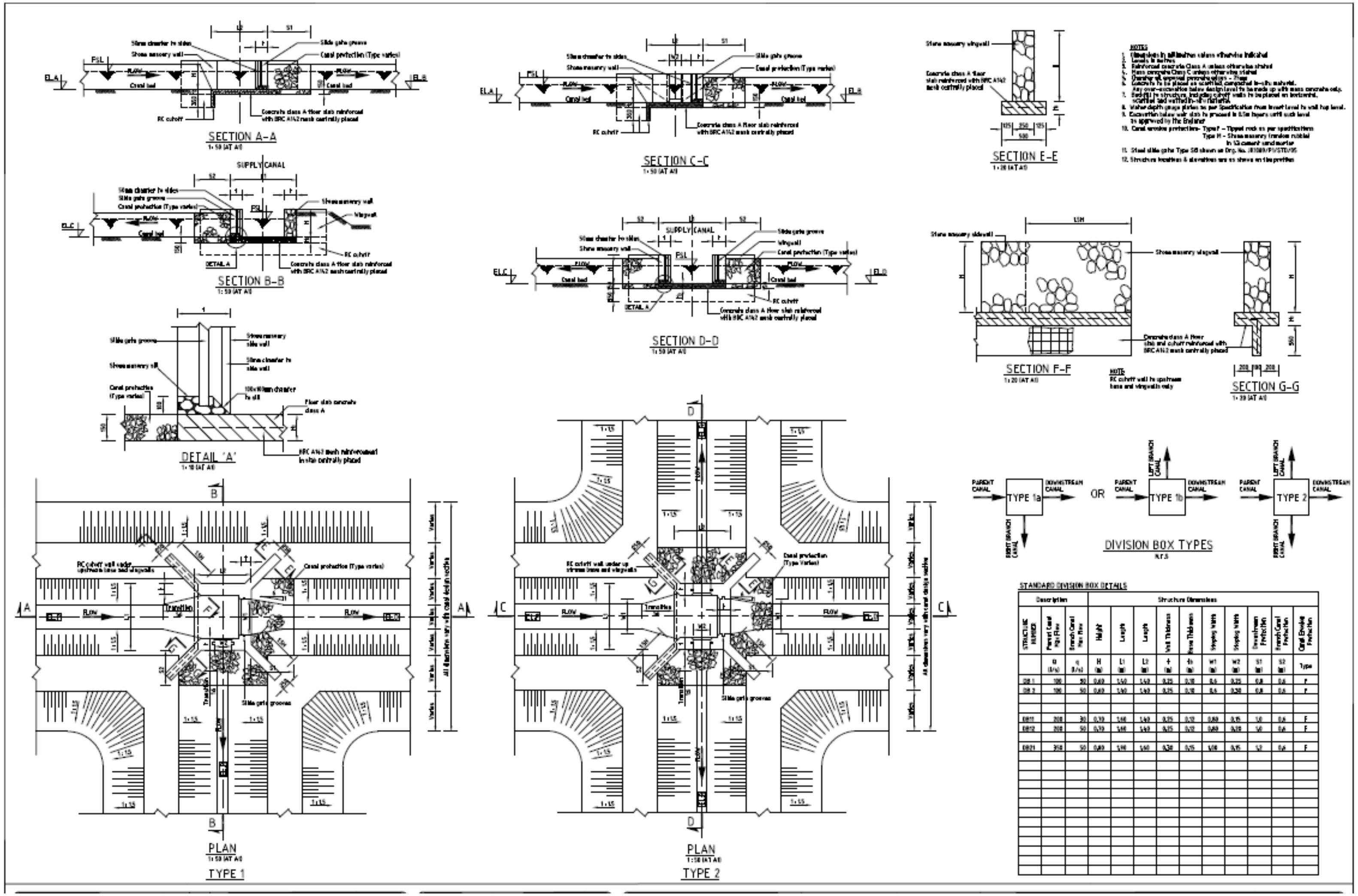
Annex 11: Example of the Environmental and Social Management Plan (ESMP)

Environmental / social impact	Proposed mitigation and aspects for monitoring	Implementation arrangements		Frequency of monitoring C – Construction O – Operation	Cost
		Execution	Supervision		
Soil erosion	- Control earthworks. - Install irrigation canals and drainage structures as per design. - Install erosion control measures. - Landscape embankments and re-vegetate borrow sites with grass and indigenous shrubs. - Ensure management of excavation activities. - Manage irrigation to avoid erosion.	PM/RE, Contractor. Farmer	AEDO	Random (c). Twice a year to cater for seasonal variation (o). Random (o)	
Borrow sites	- Inform community living at/near the sites that the areas have been selected for exploitation. - Arable lands should not be used as borrow sites whenever possible. For new borrow sites the topsoil (30cm) should be put aside and used for reinstatement after construction is over to minimise the impact on ecosystem and agriculture. - Plan access to borrow sites. - Control and restrict access to borrow sites (e.g. by fencing). - Control earthworks. - Proper management of excavation activities. - Landscape, terrace and if necessary grass sites. Replace trees that are removed during excavation.	PM/RE, Contractor. PM/RE, Contractor.		Once after site selection (c). Monthly (c).	
Vegetation loss	- Control clearing of vegetation. - Avoid clearing using herbicides. - Replant areas where vegetation is unnecessarily removed. - Undertake agroforestry in the schemes.	Contractor, PM/RE. Farmers.	AEDO. AEDO.	Random (c,o).	

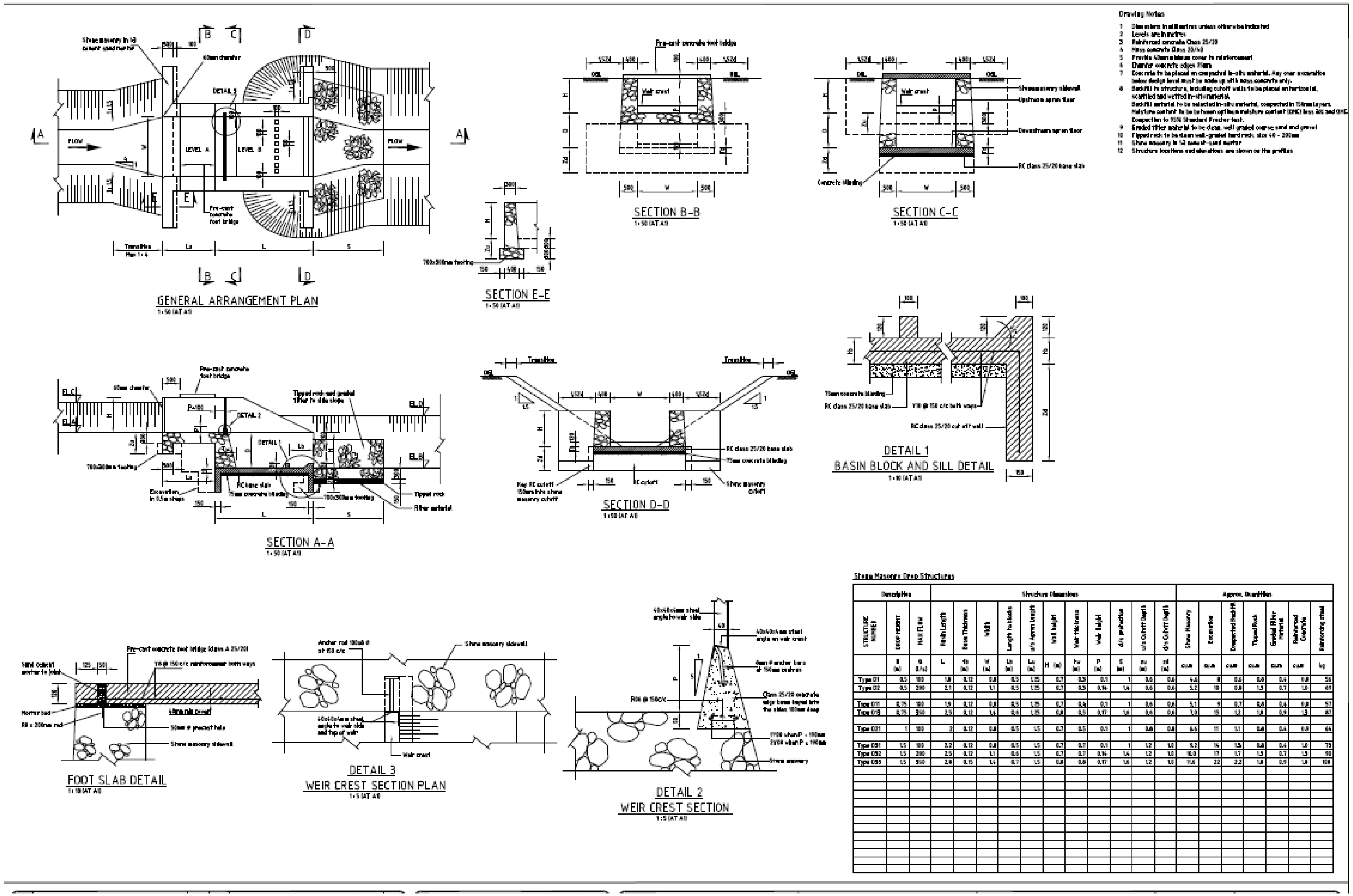
Environmental / social impact	Proposed mitigation and aspects for monitoring	Implementation arrangements		Frequency of monitoring C – Construction O – Operation	Cost
		Execution	**Supervision**		
	- Landscape and plant trees or grass at all disturbed areas (borrow pits, embankments etc). - Care for trees / plants.	Farmers.	AEDO.		
Construction campsites	- Sufficient measures should be taken at the construction camps i.e., provision of garbage bins and sanitation facilities. If septic tanks are installed, waste must be cleared out periodically. - Special attention should be paid to the sanitary condition of camps. - Garbage should be disposed of periodically.	Contractor, PM/RE.		Daily (c)	
Air pollution	- Prohibit idling of construction vehicle engines. - Water should be sprayed during the construction phase on excavated areas and access roads leading to borrow pits, and the Project sites to minimise dust.	Engineer, Contractor, PM/RE.		Daily (c)	
Noise pollution	- Supervise construction traffic. - Maintain construction equipment according to manufacturers' specifications. - Workers in the vicinity of high level noise to wear safety & protective gear.	PM/RE and Contractor.			
Oil pollution	- Ensure proper storage, handling and disposal of oil and oil wastes. - Maintain construction equipment according to manufacturers' specifications. - Maintenance of construction vehicles should be carried out in the Contractor's camp.	Engineer, PM/RE, Contractor. PM/RE, Contractor.		Daily (c). Twice a year (o).	
Public health and occupational safety	- Sensitisation campaign on STDs in the communities around the schemes. - Monitor solid and liquid waste disposal and collection facilities.	Contractor, PM/RE.	Public Health Officer,	Twice a year (c,o).	

Environmental / social impact	Proposed mitigation and aspects for monitoring	Implementation arrangements		Frequency of monitoring C – Construction O – Operation	Cost
		Execution	Supervision		
	- Place warning signs during construction. - Consult with the beneficiary community and health workers.				
Water Sources	- Manage water usage during construction so as not to disrupt beneficiary community. - Plan works schedule according to water availability. - Construct appropriate stream / river crossings where none exist. - Do not bulldoze soil into stream / rivers. - Minimise areas to be disturbed around water resources. - Install erosion protection works to prevent siltation. - Ensure pit latrines are located away from water resources. - Ensure appropriate agricultural practices and control of agro-chemical inputs.	Contractor, PM/RE. Farmer	 AEDO	Daily (c) Random (o)	
Fuel	- Energy sources should be identified so as not to put a strain on the local resources. - Discourage use of firewood/charcoal by providing alternatives such as kerosene and gas.	Contractor.		Daily (c).	

Annex 12: Standard Drawings of Major Structures



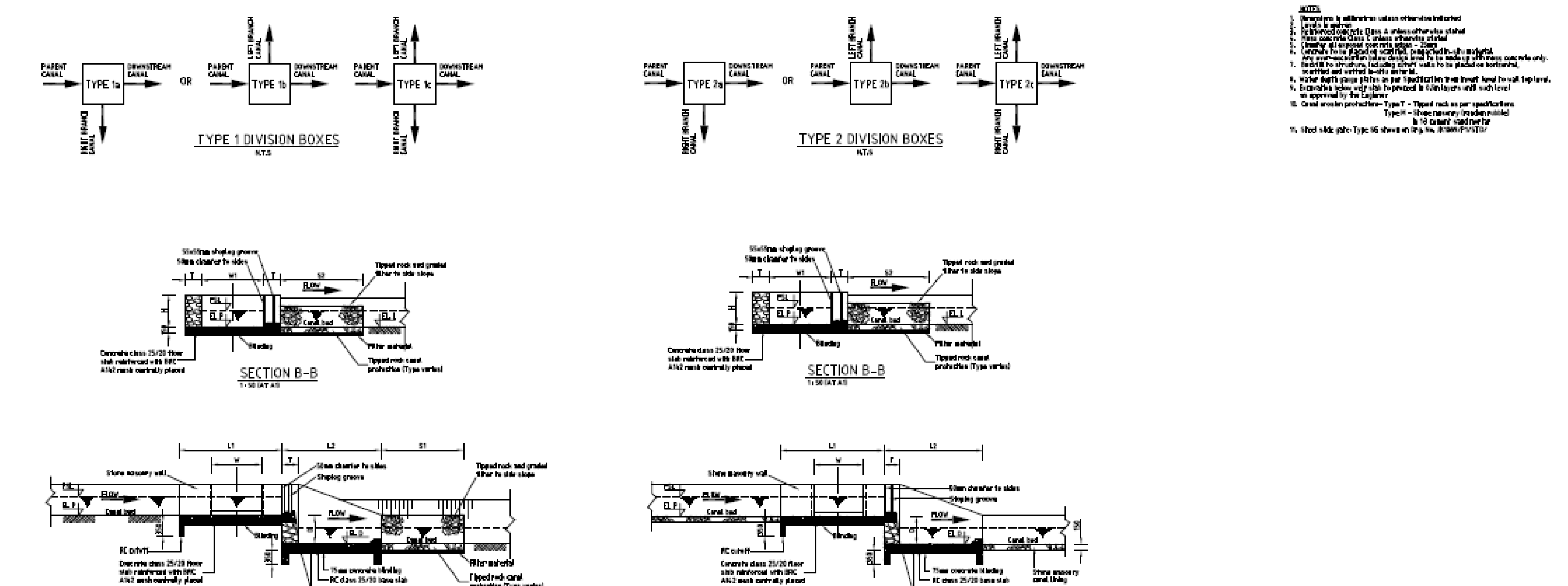
Standard Division Box Details

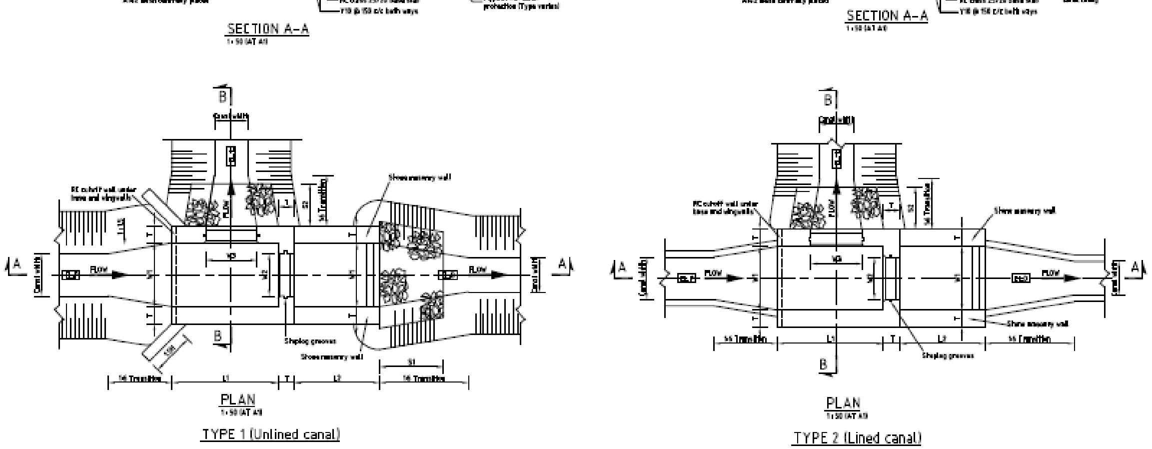


Stone Masonry Drop Structures

Description			Structure Dimensions											Approx. Quantities						
STRUCTURE NUMBER	DROP HEIGHT	MAX FLOW	Basin Length	Base Thickness	Width	Length to blocks	u/s Apron Length	Wall height	Weir thickness	Weir height	d/s protection	u/s Cutoff Depth	d/s Cutoff Depth	Stone Masonry	Excavation	Compacted Backfill	Tipped Rock	Graded Filter Material	Reinforced Concrete	Reinforcing steel
	(m)	Q (l/s)	L	tb (m)	W (m)	Lb (m)	Lu (m)	H (m)	tw (m)	P (m)	S (m)	zu (m)	zd (m)	cu.m	cu.m	cu.m	cu.m	cu.m	cu.m	kg
Type D1	0.5	100	1.8	0.12	0.8	0.5	1.25	0.7	0.3	0.1	1	0.6	0.6	4.8	8	0.6	0.8	0.4	0.8	56
Type D2	0.5	200	2.1	0.12	1.1	0.5	1.25	0.7	0.3	0.14	1.4	0.6	0.6	5.2	10	0.8	1.5	0.7	1.0	69
Type D11	0.75	100	1.9	0.12	0.8	0.5	1.25	0.7	0.4	0.1	1	0.6	0.6	5.1	9	0.7	0.8	0.4	0.8	57
Type D13	0.75	350	2.5	0.12	1.4	0.6	1.25	0.8	0.5	0.17	1.6	0.6	0.6	7.0	15	1.2	1.8	0.9	1.3	87
Type D21	1	100	2	0.12	0.8	0.5	1.5	0.7	0.5	0.1	1	0.8	0.8	6.6	11	1.1	0.8	0.4	0.8	66
Type D31	1.5	100	2.2	0.12	0.8	0.5	1.5	0.7	0.7	0.1	1	1.2	1.0	9.2	14	1.5	0.8	0.4	1.0	75
Type D32	1.5	200	2.5	0.12	1.1	0.6	1.5	0.7	0.7	0.14	1.4	1.2	1.0	10.0	17	1.7	1.5	0.7	1.3	90
Type D33	1.5	350	2.8	0.15	1.4	0.7	1.5	0.8	0.8	0.17	1.6	1.2	1.0	11.6	22	2.2	1.8	0.9	1.8	108

Standard Stone Masonry Drop Structure

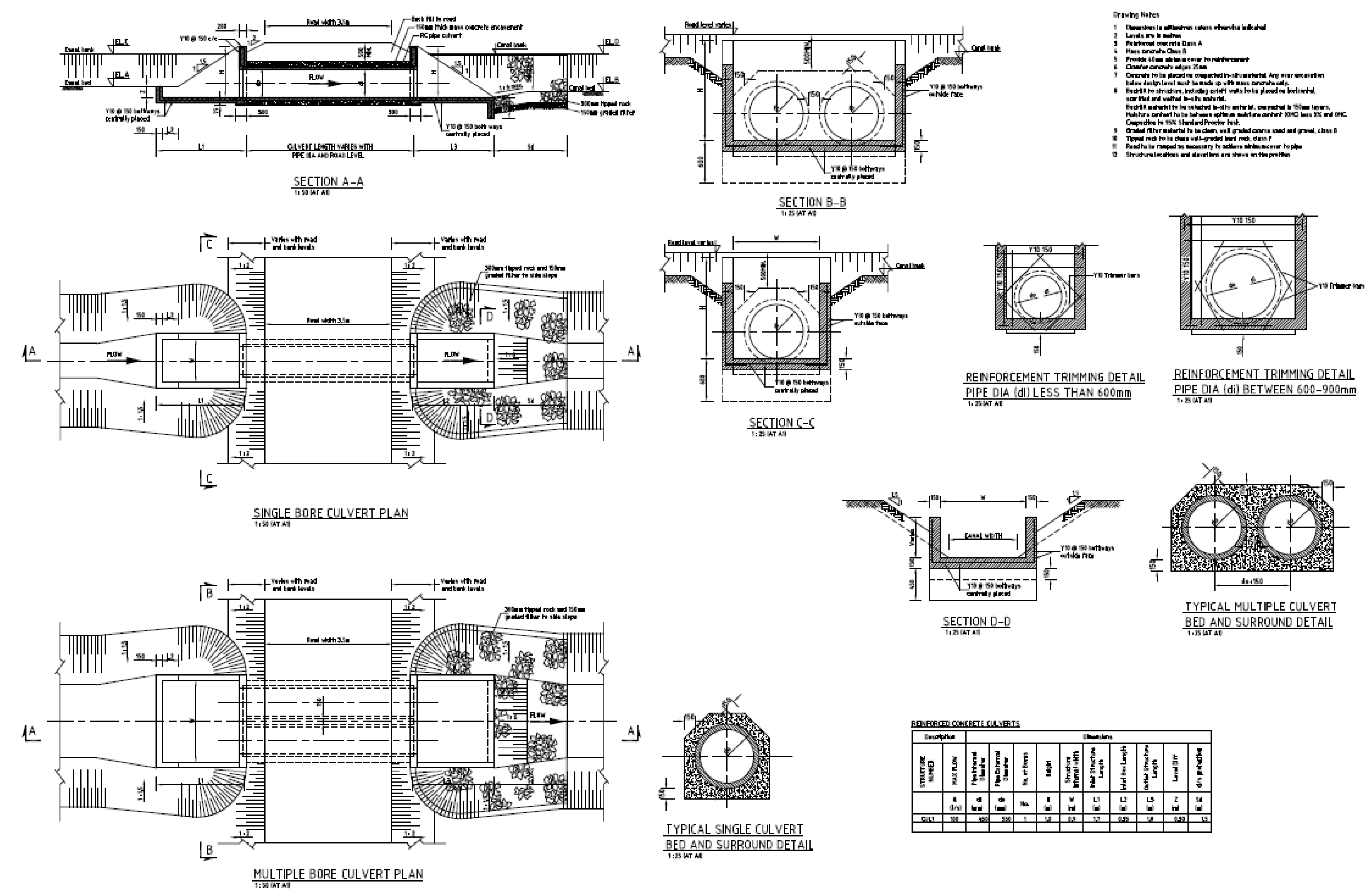




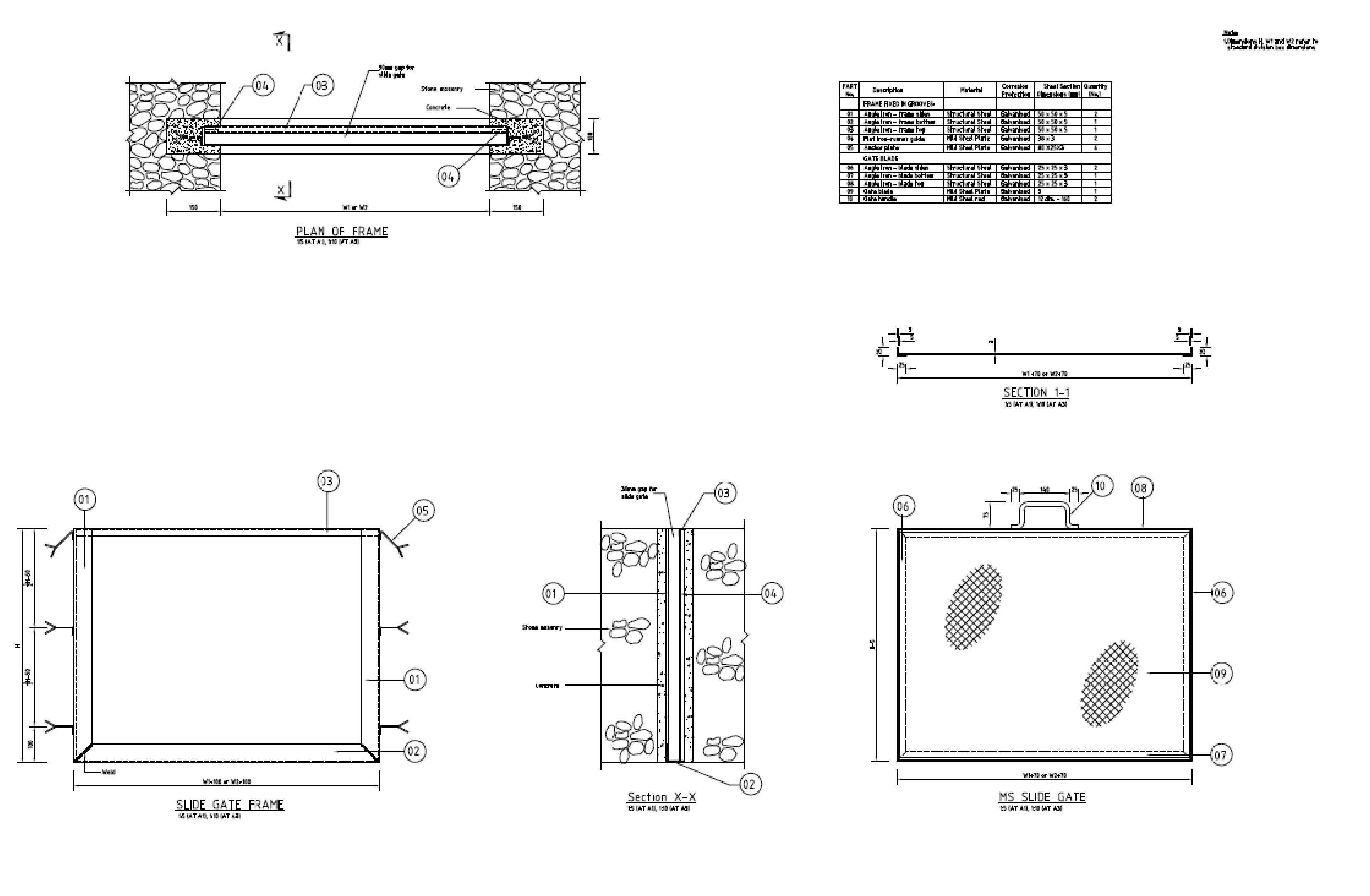
Standard Division Boxes With modified Drop Details

Description	Height	Box Length	Drop Length	Wall Thickness	Drop depth	Box Width	Parent Canal Sloping width	Branch Canal Sloping width	Downstream Protection	Branch Canal Protection	Canal Erosion Protection
Structure Type / Name	H (m)	L1 (m)	L2 (m)	T (m)	D (m)	W1 (m)	W2 (m)	W3 (m)	S1 (m)	S2 (m)	Type
DB1/HCD11	0.6	1.4	1.6	0.5	0.5	0.8	0.6	0.25	1.0	0.6	T
DB1/HCD11	0.6	1.4	1.6	0.3	0.75	0.8	0.6	0.25	1.0	0.6	T
DB1/HCD31	0.6	1.4	2.0	0.35	1.0	0.8	0.6	0.25	1.0	0.6	T
DB1/HCD51 (?)	0.6	1.4	2.2	0.55	1.5	0.8	0.6	0.25	1.0	0.6	T
DB11/HCD12	0.7	1.6	2.2	0.35	0.75	0.8	0.6	0.25	1.4	0.6	T
DB11/HCD22	0.7	1.6	2.5	0.55	1.0	0.8	0.6	0.25	1.4	0.6	T
DB11/HCD52 (?)	0.7	1.6	2.5	0.35	1.5	0.8	0.6	0.25	1.4	0.6	T
DB2/HCD31	0.6	1.4	2.2	0.55	1.5	0.8	0.6	0.25	1.0	0.6	T
DB21/HCD23 (?)	0.8	1.6	2.4	0.55	0.5	1.2	1.0	0.15		0.6	T
DB21/HCD38 (?)	0.8	1.6	2.6	0.35	1.5	1.2	1.0	0.25	1.6	0.6	T

Standard Division Box combined with modified Drop Structure

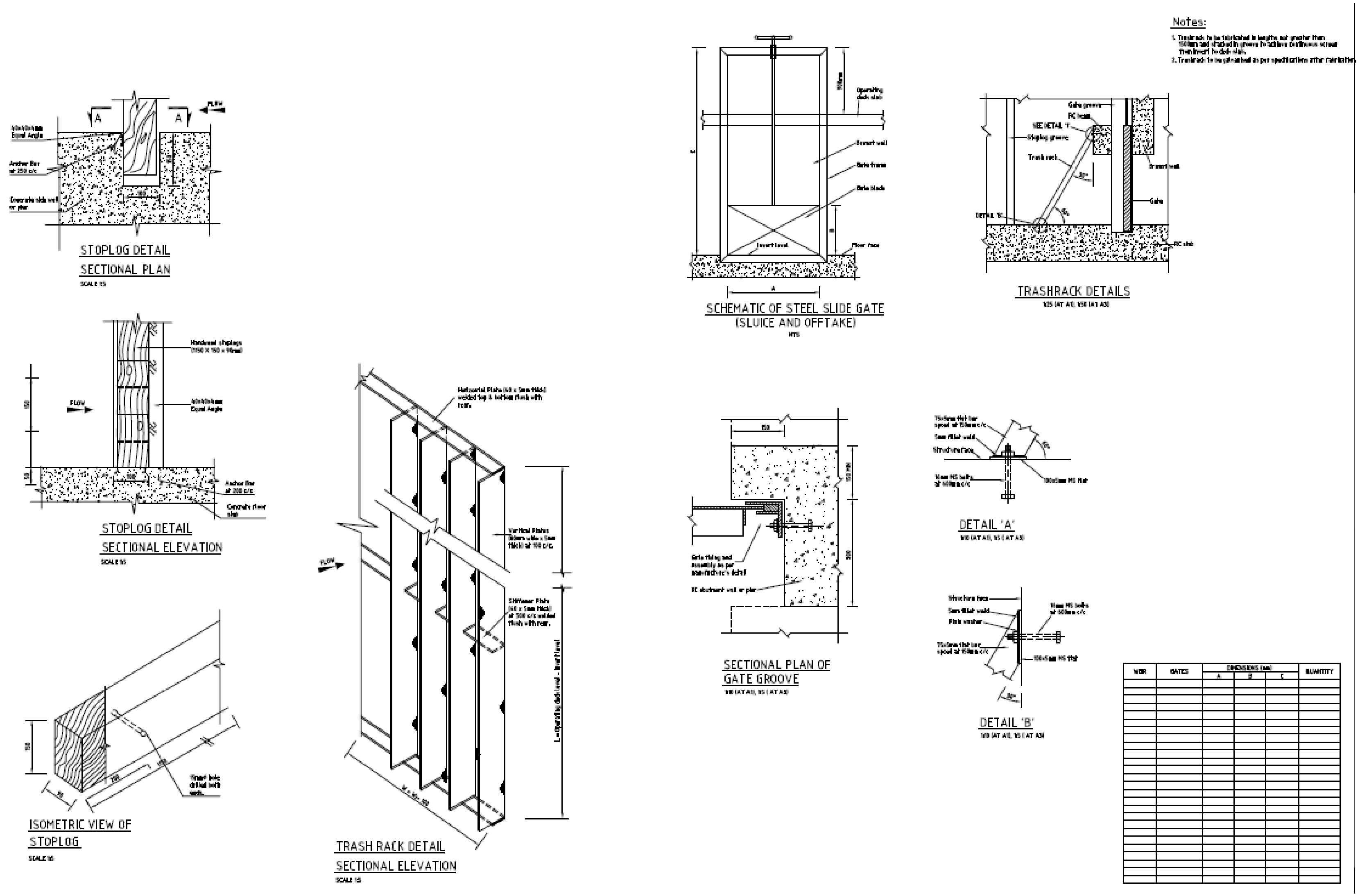


Standard Culvert Details

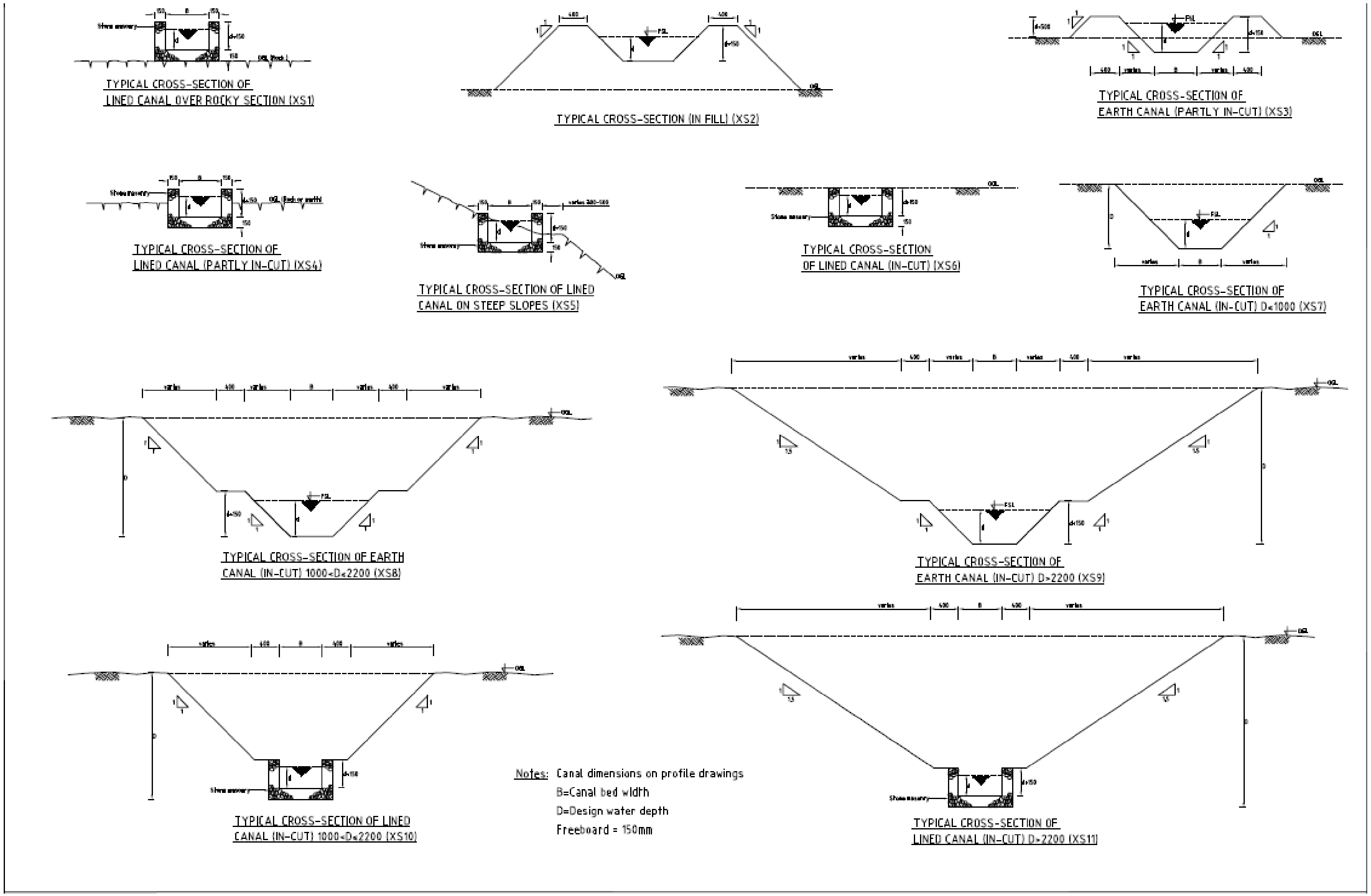


PART No.	Description	Material	Corrosion Protection	Steel Section Dimensions (mm)	Quantity (No.)
	FRAME FIXED IN GROOVES				
01	Angle Iron – frame sides	Structural Steel	Galvanised	50 x 50 x 5	2
02	Angle Iron – frame bottom	Structural Steel	Galvanised	50 x 50 x 5	1
03	Angle Iron – frame top	Structural Steel	Galvanised	50 x 50 x 5	1
04	Flat Iron–runner guide	Mild Steel Plate	Galvanised	38 x 3	2
05	Anchor plate	Mild Steel Plate	Galvanised	80 X 25 X 3	6
	GATE BLADE				
06	Angle Iron – blade sides	Structural Steel	Galvanised	25 x 25 x 3	2
07	Angle Iron – blade bottom	Structural Steel	Galvanised	25 x 25 x 3	1
08	Angle Iron – blade top	Structural Steel	Galvanised	25 x 25 x 3	1
09	Gate blade	Mild Steel Plate	Galvanised	3	1
10	Gate handle	Mild Steel rod	Galvanised	12 dia. - 180	2

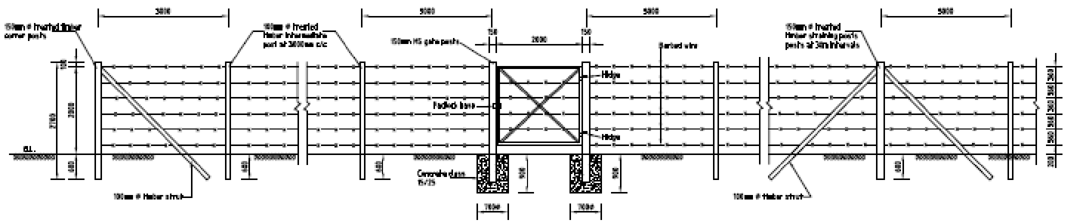
Standard Gate Details (Type: Slide Gate)



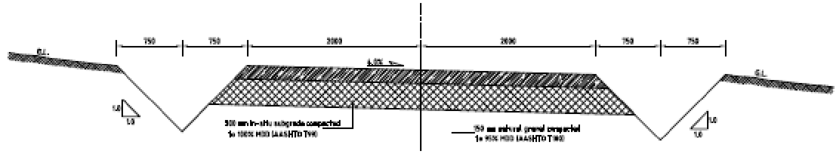
Standard Gate, Trash Racks, and Stop Logs Details



Typical Canal Cross Sections

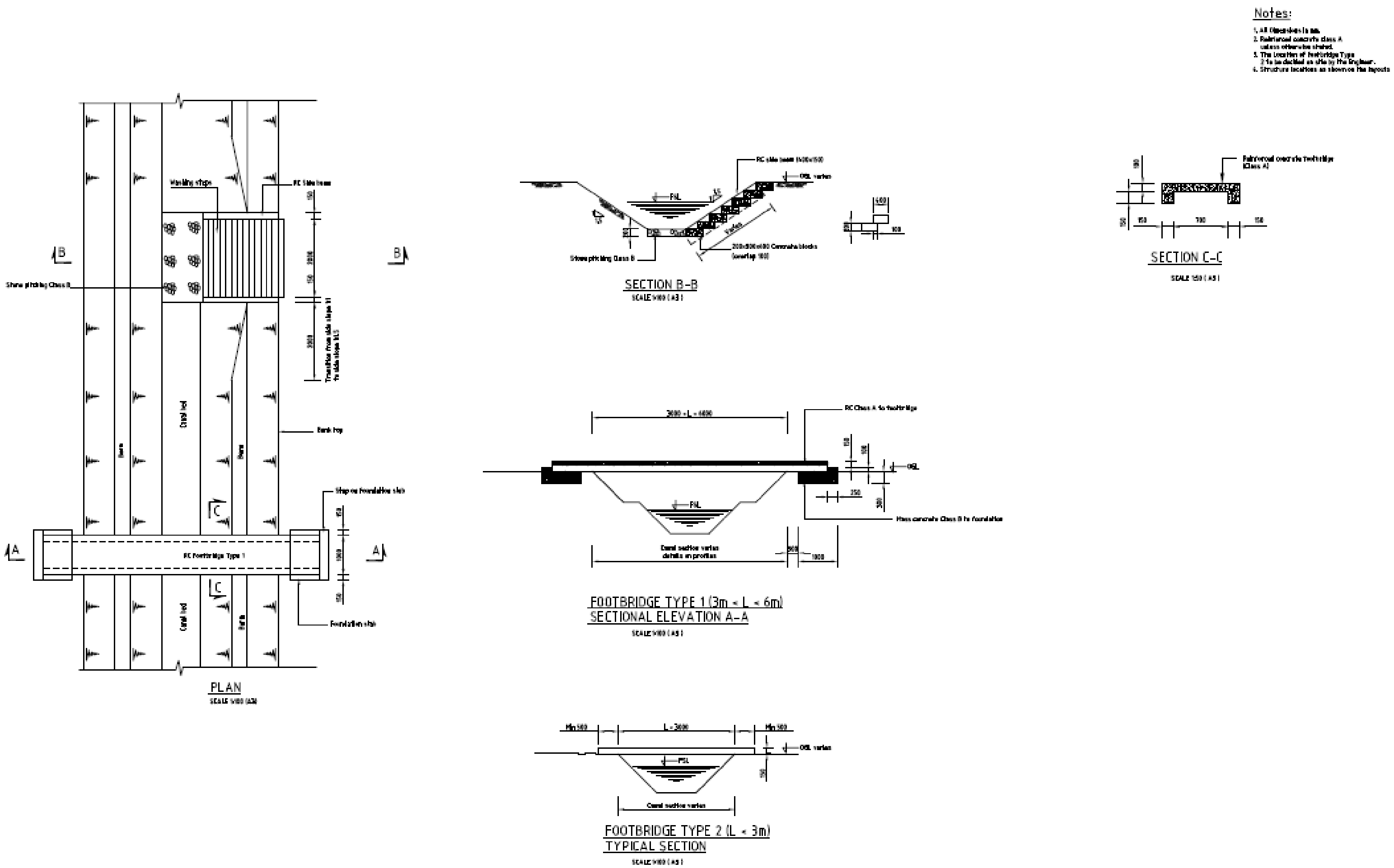


DAM OF PERIMETER FENCE AND GATE DETAIL

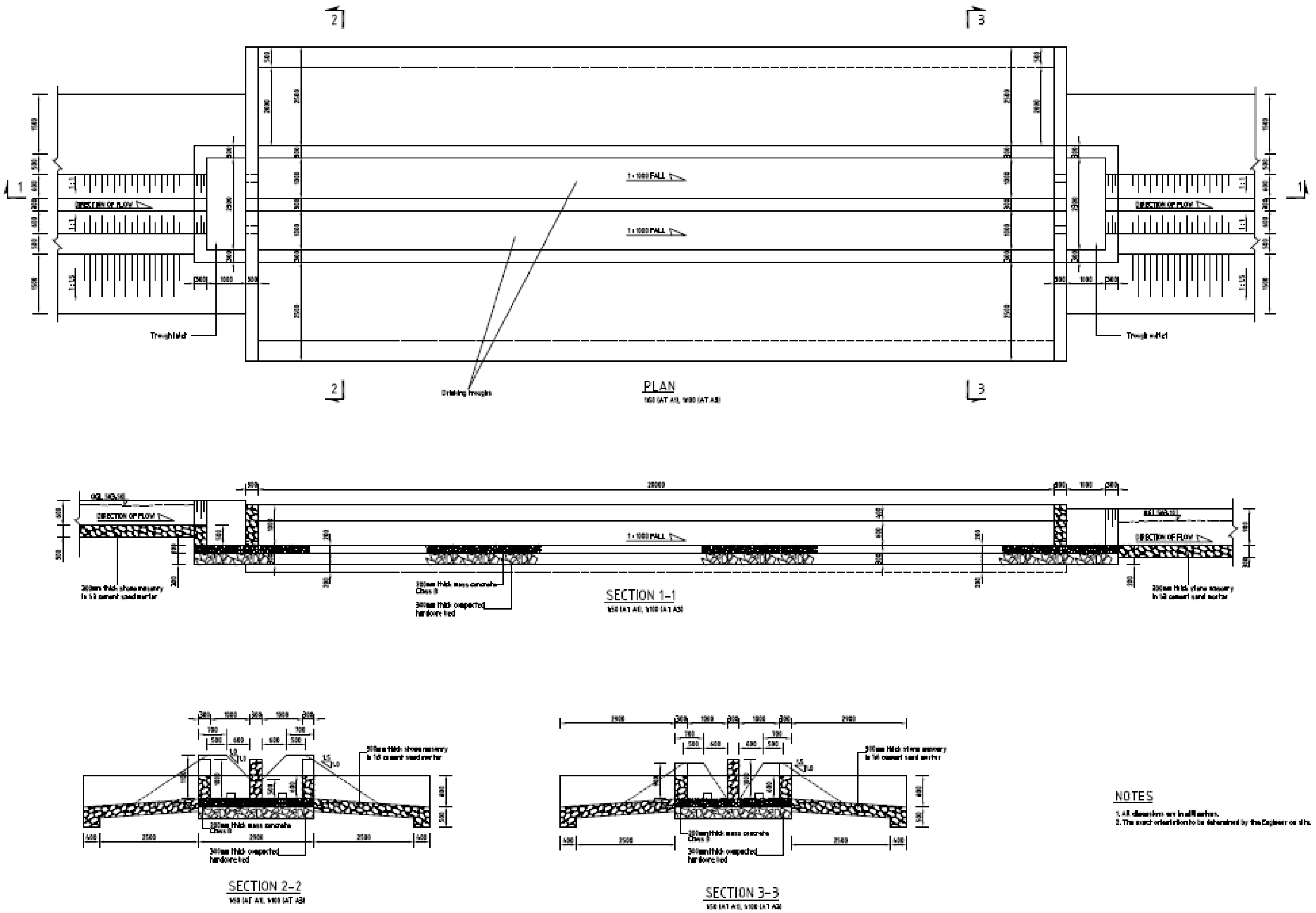


TYPICAL GRAVEL FIELD ROAD SECTION

Fence Details and Typical Road and Mitre Drain Cross Section



Typical Washing Steps and Footbridge Details



Standard Cattle Trough Details

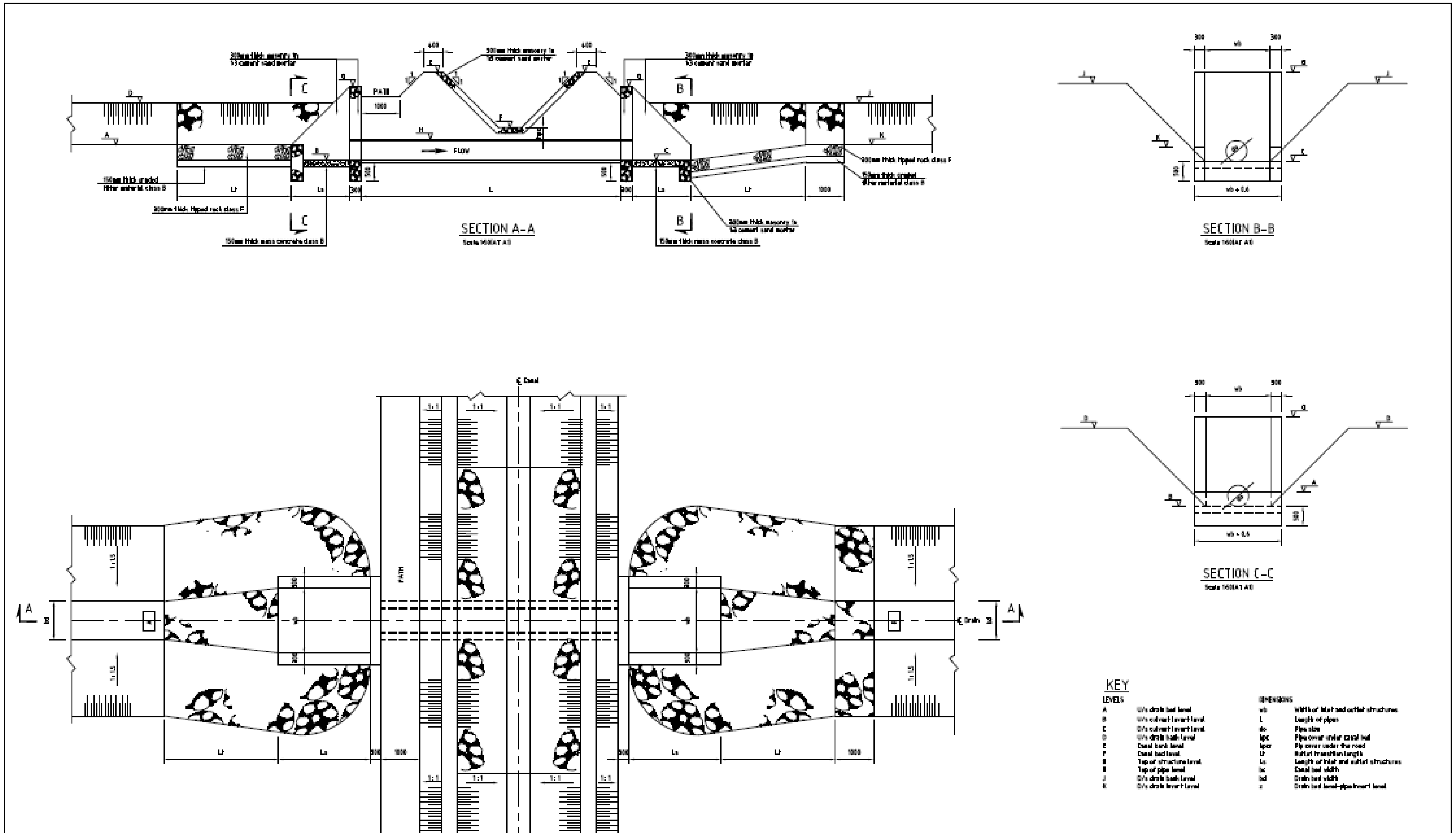
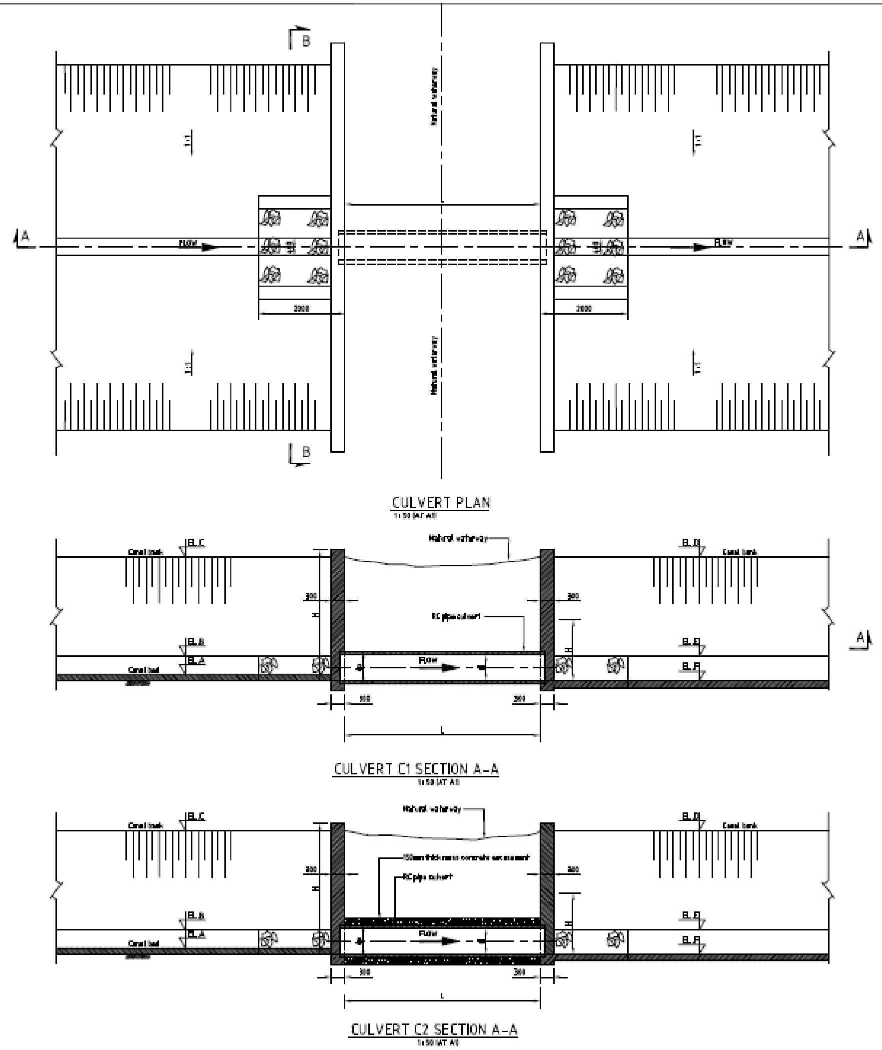
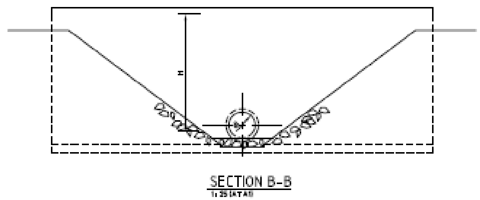


TABLE OF LEVELS AND DIMENSIONS

CANAL	CHAINAGE (m)	DRAIN	CHAINAGE (m)	LEVELS (m)										DIMENSIONS (m)								
				A	B	C	D	E	F	G	H	J	K	wb	L	do	hpc	Lt	bc	bd	z	Ls
Lilasi HC	407.87	Lilasi HD4	115.68	543.36	543.08	542.08	543.44	544.37	543.27	543.74	542.55	542.82	542.32	1.80	6.50	0.45	0.74	2.00	0.80	0.80	0.30	1.70
Lilasi sc1	178.23	Lilasi HD2	98.42	540.85	540.49	540.49	541.49	542.03	541.43	541.71	541.19	541.30	540.46	0.60	4.50	0.45	0.44	2.00	0.50	0.30	0.20	1.40
Mahalani MC2	354.832	Mahalani MD2	435.602	497.38	497.12	497.12	498.34	498.54	497.97	498.04	497.57	498.06	497.28	0.60	4.10	0.45	0.40	2.00	0.40	0.30	0.20	1.50

Typical Cross Drainage Structure Type 1 Details

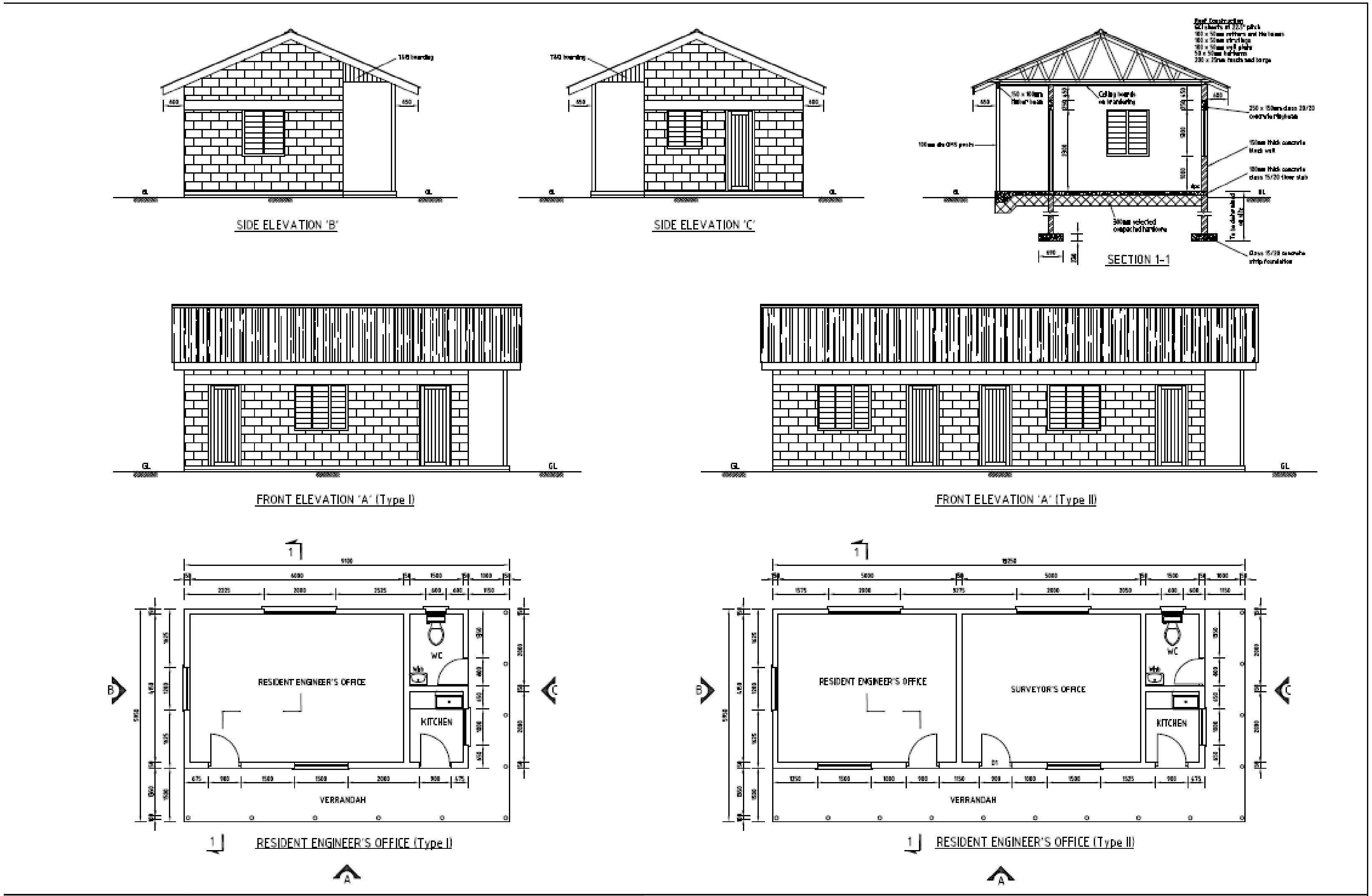




REINFORCED CONCRETE CULVERTS

CANAL	STRUCTURE NUMBER	CHAINAGE (m)	FLOW (l/s)	PIPE DIAMETER (mm)	No. OF BORES	HEIGHT (m) H	CULVERT LENGTH L (m)	ELEVATIONS (m)					
								A	B	C	D	E	F
SEFWA MAIN CANAL	C1	107	50	450	1	1.1	16	1638.26	1638.60	1634.06	1634.27	1634.27	1633.35
SEFWA MAIN CANAL	C2	386.75	50	450	1	1.25	22	1638.02	1635.56	1635.56	1634.08	1634.08	1633.00
SEFWA MAIN CANAL	C1	450	50	450	1	1.31	15	1630.96	1638.31	1638.97	1634.10	1634.10	1632.96
SEFWA MAIN CANAL	C2	509	50	450	1	1.47	18	1632.91	1635.26	1636.08	1635.50	1635.50	1632.91
SEFWA MAIN CANAL	C1	1520	50	450	1	1.67	28	1626.66	1625.27	1625.66	1625.66	1625.66	1624.66

Typical Cross Drainage Structure Type 2 Details



Typical Resident Engineer's Offices Details

Annex 13: Standard Bills of Quantities

TYPICAL BILL OF QUANTITIES FOR WEIR BASED SURFACE IRRIGATION SCHEME

Bill No. 2 DIVERSION WEIR

ITEM	DESCRIPTION	UNIT	QUANTITY	RATE (MK)	AMOUNT (MK)
2.1	**Earthworks**				
2.1.1	Site clearing for the weir body, apron & cut-off wall, divide wall, gabion, wing wall and dyke	m^2			
2.1.2	Strip 150mm top soil for the weir body, apron & cut-off wall, divide wall, gabion, wing wall and dyke	m^2			
2.1.3	Excavation of earth for the weir body, apron & cut-off wall, divide wall, gabion, wing wall and dyke	m^3			
2.1.4	Compacted backfill at the back of wing wall	m^3			
2.1.5	Embankment fill for the dyke	m^3			
	Subtotal - 1				
2.2	**Structural Work**				
2.2.1	***Masonry Work***				
2.2.1.1	Wet masonry for the weir body, apron & cut-off wall, wing wall (1:3)	m^3			
2.2.1.2	Plaster the required parts of masonry for weir body, apron & cut-off wall and wing wall	m^2			
2.2.2	***Concrete Work***				
2.2.2.1	Reinforced concrete for divide wall , breast wall, deck slab, box culvert (C-25)	m^3			
2.2.2.2	Blinding concrete for divide wall and box culvert (C-15 and t = 75mm)	m^2			
2.2.2.3	Concrete for toe wall in the dyke (C-15)	m^3			
2.2.2.4	Steel reinforcement for divide wall, breast wall, deck slab and box culvert	kg			
2.2.2.5	Formwork for divide wall, breast wall, deck slab and box culvert	m^2			
2.2.3	***Miscellaneous Work***				
2.2.3.1	Gabion (Protection work) in the river bed as specified in the design	m^2			
2.2.3.2	Supply, install and fix galvanised steel gate for the intake as specified in the design	nr			
2.2.3.3	Supply, install and fix galvanised steel gate for under-sluice bay as specified in the design	nr			
2.2.3.4	Stone pitching (rip rap) for U/S face	m^3			

ITEM	DESCRIPTION	UNIT	QUANTITY	RATE (MK)	AMOUNT (MK)
	of the dyke				
2.2.3.5	Gravel under the pitching in the dyke	m^3			
	Subtotal - 2				
2.3	Allow for diversion of river and reinstate on completion plus all associated temporary works necessary to construct the weir	LS			
	Subtotal - 3				

Bill No. 3 CANAL EARTHWORKS

3.1	**Main Canal - Lined (100m)**				
	Chainage 0 to 100m				
3.1.1	Site clearance	m^2			
3.1.2	Strip top soil (Provisional)	m^2			
3.1.3	Excavation in soft material	m^3			
3.1.4	Fill and compact the embankment as specified	m^3			
3.1.5	Wet stone masonry	m^3			
3.1.6	Compacted Granular backfill	m^3			
	Subtotal				
3.2	**Main Canal - Earthen (311m)**				
	Chainage 100 to 411m				
3.2.1	Site clearance	m^2			
3.2.2	Strip top soil (Provisional)	m^2			
3.2.3	Excavation in soft material	m^3			
3.2.4	Fill and compact the embankment as specified	m^3			
	Sub total				
3.3	**Tertiary Canal**				
3.3.1	Site clearance	m^2			
3.3.2	Strip top soil (Provisional)	m^2			
3.3.3	Excavation in soft material	m^3			
3.3.4	Fill and compact the embankment as specified	m^3			
	Subtotal				
3.4	**Other minor canals (may not be contracted out)**				
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**RATE (MK)**	**AMOUNT (MK)**
3.4.1	Field canals	m			
3.4.2	Field drains	m			
	Subtotal				
3.5	**Tertiary Drain**				
3.5.1	Excavation in soft material	m^3			
3.5.2	Fill and compact the embankment as specified	m^3			
	Subtotal				

3.6	**Flood Protection**				
3.6.1	Strip top soil under embankment (75mm thick)	m^2			
3.6.2	Forming earthen dykes with excavated material scrapped from adjacent lands across old river course	m^3			
	Subtotal				
3.7	**Land Levelling**				
3.7.1	Stripping in soft material from upper part of each plot/field and placing on lower side of it to make a level surface or as directed	m^3			
	Subtotal				

BILL No. 4 STANDARD IRRIGATION STRUCTURES

4.1	**DIVISION BOXES**				
4.1.1	**Main Canal**				
	Division Box (2 No.)				
4.1.1.1	Excavation for structure in soft material	m^3			
4.1.1.2	Excavation for structure in rock	m^3			
4.1.1.3	Backfilling and compaction with selected fill to structure (0.84 m^3 per division box)	m^3			
4.1.1.4	Class C25/ reinforced concrete to base	m^3			
4.1.1.5	Wet stone masonry to gate sill (0.02m^3 per division box)	m^3			
4.1.1.6	Brick walls in 1:3 mortar, plastered on both sides, thickness greater than 330 mm	m^3			
4.1.1.7	Concrete capping Class C20 to brick walls (5cm)	m^2			
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**RATE (MK)**	**AMOUNT (MK)**
4.1.1.8	Steel fabric reinforcement A142 to floor slab (6.8 Kg per division box)	kg			
4.1.1.9	Tipped rock, Class F to canal base and sides (0.7 m^3 per division box)	m^3			
4.1.1.10	Supply, install galvanised slide gates complete with all fixing iron mongery as per drawings	No			
4.1.1.11	Provide and install staff gage (0.70 m)	No			
	Subtotal				
4.2	**STANDARD FOOT BRIDGES**				
4.2.1	**On main canal and tertiary drain**				
4.2.1.1	Excavation for structure in soft material (1 m^3 per drop)	m^3			
4.2.1.2	Class 25/ Reinforced concrete to footbridge (0.6m^3 per drop)	m^3			
4.2.1.3	High yield steel reinforcement (36 kg per cu. m RC)	kg			
4.2.1.4	Class 20/ mass concrete to foundation footings (0.8 m^3 per structure)	m^3			
	Subtotal				
4.3	**OVERFLOW SECTION**				
4.3.1	Excavation for structure in soft material (1 m^3 per drop)	m^3			
4.3.2	Masonry lining	m^2			
	Subtotal				

4.4	**MEASURING STRUCTURE**				
4.4.1	Common excavation	m^3			
4.4.2	Reinforced concrete Class C20	m^3			
4.4.3	Brick walls	m^3			
4.4.4	Backfilling	m^3			
	Subtotal				
4.5	**CROSS DRAINAGE STRUCTURE**				
4.5.1	Excavation for structure in soft material	m^3			
4.5.2	Excavation for structure in rock (Provisional)	m^3			
4.5.3	Backfilling and compaction with selected fill to structure	m^3			
4.5.4	Graded filter material Class A	m^3			
4.5.5	Tipped rock, Class F 300mm thick	m^3			
4.5.6	Class C15/ Blinding concrete, 75mm thickness	m^3			
ITEM	**DESCRIPTION**	**UNIT**	**QUANTITY**	**RATE (MK)**	**AMOUNT (MK)**
4.5.7	Class 20/ mass concrete	m^3			
4.5.8	Wet stone masonry thickness greater than 400 mm	m^2			
4.5.9	600 mm concrete pipe	m			
	Subtotal				

BILL NO. 5 ACCESS ROAD

5.1.1	Site clearance	m^2			
5.1.2	Strip 150 mm top soil as specified, and grade road to design slope	m^2			
5.1.3	Fill low spots as directed by the Engineer and compact with selected material, and grade road to design slope.	m^3			
5.1.4	Provide road drains as per drawing	m			
	Note: The quantities for the road works are provisional and are for spot improvement of access road. These will only be undertaken when instructed by the Project Manager.				
	TOTAL BILL CARRIED OVER TO SUMMARY SHEET				

TYPICAL BILL OF QUANTITIES FOR MOTORISED SURFACE IRRIGATION SCHEME

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
2	**Pump**				
2.0.1	Supply, test and install 8HP Motorised pumps (Q=23l/s, H=15m)				
2.1	**Fabricate portable steel plate mounting for pump and construct pump store for the scheme**				
2.1.1	Fabricate and supply (10 No) portable steel plate mountings for the pumps, to include bolts, nuts and washers as detailed in standard pump mounting base plate Drawing No JK1306/STD/07	No.			
3	**Construct pump store**				
3.1.0	Excavate and backfilling for structure	cu.m			
3.1.4	50mm hardcore	cu.m			
3.1.3	Class C20/C20 mass concrete to floor as specified	cu.m			
3.1.1	230mm clay burnt brickwork to walls reinforced with brickforce wire at every 5 courses	sq.m			
3.1.2	19mm Plaster to brickwork to walls	sq.m			
3.1.5	Supply and fix 100mm X 75mm timber rafters to roof as specified in the Pump store drawing	m			
3.1.6	Supply and fix 50mm x 50mm timber purlins to roof as specified	m			
3.1.7	Supply and fix 230mm x 15mm nutec fascia board to roof as specified	m			
3.1.8	Supply and fix 100mm x 50mm wall plate to roof as specified	m			
3.1.9	Supply and fix 28 gauge IBR sheets	sq.m			
3.1.10	Supply and fix breeze blocks as specified on drawing	sq.m			
3.1.11	Supply and fix standard hardwood double door as specified on the drawing complete with frame including all ironmongery	no.			
3.1.12	Supply and fix double steel grilled door as specified on the drawing complete with frame including all ironmongery	no.			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
4	**Supply and Installation of pipes and related fittings to suction lines for pumps**				
4.1.0	Reinforced Flexible Suction Pipe,75mm diameter , with Clips 6 m long	no.			
4.1.1	Foot valve and Strainer (75mm diameter)	no.			
4.1.2	75mm Diameter Steel Tee piece with a steel Plug	no.			
4.1.3	75mm Diameter Brass Barrel Nipple	no.			
4.1.4	NIFV Barrel Nipple,3/4 inch	no.			
4.1.5	75mm Diameter Non-return Valve	no.			
4.1.6	125mm X 75mm UPVC Reducer	no.			
4.1.7	140mm X 75mm UPVC Reducer	no.			
4.1.8	200mm X 75mm UPVC Reducer	no.			
4.1.9	250mm X 75mm UPV Reducer	no.			
4.1.10	Fabricate, Supply and install manifold as specified in drawing	no.			
5	**Supply and Installation of UPVC pipes and related fittings to delivery lines**				
5.1.0	125mm Diameter PVC RRJ class 4 Pipe	no			
5.1.1	125mm Diameter NIFV Barrel Nipple	no			
5.1.2	140mm Diameter PVC RRJ class 4 Pipe	no			
5.1.3	200mm Diameter PVC RRJ class 4 Pipe	no			
5.1.4	250mm Diameter PVC RRJ class 4 Pipe	no			
5.1.5	125mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.6	140mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.7	200mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
5.1.8	250mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.9	125mm Diameter class 6 uPVC 113 Degree Long Radius Bend	no			
5.1.10	140mm Diameter class 6 uPVC 141 Degree Long Radius Bend	no			
5.1.11	250mm Diameter class 6 uPVC 153 Degree Long Radius Bend	no			
5.1.12	250mm Diameter class 6 uPVC 90 Degree Long Radius Bend	no			
6	**Earthworks to pipe lines**				
6.1.0	Excavate up to 0.75m deep X 0.6m wide Trench (including backfilling) for Pipelines	cu.m			
7	**Supply and Install Fittings for Hydrants / Discharge Chambers**				
7.1.0	125mm Diameter Gate Valve with flange adaptors	no			
7.1.1	125mm Diameter Class 6 uPVC 90 Degree Elbow	no			
7.1.2	140mm Diameter Gate Valve with Two Flange Adaptors	no			
7.1.3	140mm Diameter Class 6 uPVC 90 Degree Elbow	no			
7.1.4	200mm Diameter Gate Valve with Flange Adaptors	no			
7.1.5	200mm Diameter Class 6 uPVC 90 Degree Elbow	no			
7.1.6	250mm Diameter Gate Valve with two Flange Adaptors	no			
7.1.7	250mm Diameter Class 6 uPVC 90 Degree Elbow	no			
7.1.8	140mm Diameter class 6 uPVC Tee Piece	no			
7.1.9	250mm Diameter class 6 uPVC Tee Piece	no			
8	**Type 1 (Hydrant with Single outlet)**				
8.1.0	Excavation and backfilling for structures	cu.m			
8.1.1	50mm Hardcore	cu.m			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
8.1.2	Concrete foundation slab	cu.m			
8.1.3	Concrete thrust blocks to hold inlet pipe for hydrants as specified on drawings	cu.m			
8.1.4	Brickwork in cement sand mortar as specified	sq.m			
8.1.5	19mm Plaster to brickwork in cement sand mortar	sq.m			
9	**Type 2 (Hydrant with Double outlets)**				
9.1.0	Excavation and backfilling for structures	cu.m			
9.1.1	50mm Hardcore	cu.m			
9.1.2	Concrete foundation slab	cu.m			
9.1.3	Concrete thrust blocks to hold inlet pipe for hydrants as specified on drawings	cu.m			
9.1.4	Brickwork in cement sand mortar as specified	sq.m			
9.1.5	19mm Plaster to brickwork in cement sand mortar	sq.m			
9.2	**Type 3 (Hydrant with Triple outlet)**				
9.2.0	Excavation and backfilling for structures	cu.m			
9.2.1	50mm Hardcore	cu.m			
9.2.2	Concrete foundation slab	cu.m			
9.2.3	Concrete thrust blocks to hold inlet pipe for hydrants as specified on drawings	cu.m			
9.2.3	Brickwork in cement sand mortar as specified	sq.m			
9.2.4	19mm Plaster to brickwork in cement sand mortar	sq.m			
10	**Valve Chambers as Shown in Drawing No.**				
10.1.0	Excavation and backfilling for structures	cu.m			
10.1.1	50mm Hardcore	cu.m			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
10.1.2	Concrete foundation slab	cu.m			
10.1.3	Brickwork in cement sand mortar as specified	sq.m			
10.1.4	19mm Plaster to brickwork in cement sand mortar	sq.m			
10.1.5	Valve Chamber Cover 980mm X 980mm X50mm Hardwood Cover with 2 Handles	no			
11	**Field canals-lined secondary canals and unlined tertiary canals (Total length)**				
11.1.0	Site clearance	sq.m			
11.1.1	Excavate suitable fill material as directed by the engineer and place in embankment, haulage not exceeding 300m	cu.m			
11.1.2	Fill and compact to 98% MDD, the embankment with suitable fill material	cu.m			
11.1.3	Excavate canal section to specified grade and profile	cu.m			
11.1.5	Clay-burnt bricks lining in cement ,sand mortar as specified	sq.m			
11.1.6	19 mm plaster to brickwork in cement sand mix 1:3 in all canals	sq.m			
12	**Footbridges**				
12.1.0	Excavate for structures	cu.m			
12.1.2	Class C25/20 Reinforced concrete to deck slab and supports as shown in the drawing	cu.m			
12.1.3	Class C20/20 Mass concrete to foundation footings	cu.m			
13	**Distribution boxes**				
13.1.0	Type 2 (Double outlets)	no			
14	**Drainage Channels**				
14.1.0	Excavate to form drains to specified levels and shape as shown on relevant drawings	m3			
15	**Drop Structures for Canals and Drainage Channels**				

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
15.1.0	Construct 0.236m drop structures at locations specified on Drawing No. STD	No.			
15.1.1	Construct 0.250m drop structures at locations specified on Drawing No. STD	No.			
15.1.2	Construct 0.300m drop structures at locations specified on Drawing No. STD	No.			
15.1.3	Construct 0.400m drop structures at locations specified on Drawing No. STD	No.			
15.1.4	Construct 0.450m drop structures at locations specified on Drawing No. STD	No.			
15.1.5	Construct 0.500m drop structures at locations specified on Drawing No. STD	No.			
16	**Siphons**				
16.1.0	63mm diameter siphons, each 1.5m long at 60^0	No.			
	TOTAL BILL TO SUMMARY				

TYPICAL BILL OF QUANTITIES FOR SPRINKLER IRRIGATION SYSTEM

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
2	**Pump (fixed or portable, depending upon system)**				
2.0.1	Supply, test and install 8HP Motorised pumps (Q=23l/s, H=15m)				
2.1	**Fabricate portable steel plate mounting for pump and construct pump store for the scheme**				
2.1.1	Fabricate and supply portable steel plate mountings for the pumps, to include bolts, nuts and washers as detailed in standard pump mounting base plate Drawing No	No.			
3	**Construct pump store**				
3.1.0	Excavate and backfilling for structure	cu.m			
3.1.4	50mm hardcore	cu.m			
3.1.3	Class C20/C20 mass concrete to floor as specified	cu.m			
3.1.1	230mm clay burnt brickwork to walls reinforced with brickforce wire at every 5 courses	sq.m			
3.1.2	19mm Plaster to brickwork to walls	sq.m			
3.1.5	Supply and fix 100mm X 75mm timber rafters to roof as specified in the Pump store drawing	m			
3.1.6	Supply and fix 50mm x 50mm timber purlins to roof as specified	m			
3.1.7	Supply and fix 230mm x 15mm nutec fascia board to roof as specified	m			
3.1.8	Supply and fix 100mm x 50mm wall plate to roof as specified	m			
3.1.9	Supply and fix 28 gauge IBR sheets	sq.m			
3.1.10	Supply and fix breeze blocks as specified on drawing	sq.m			
3.1.11	Supply and fix standard hardwood double door as specified on the drawing complete with frame including all ironmongery	no.			
3.1.12	Supply and fix double steel grilled door as specified on the drawing complete with frame including all ironmongery	no.			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
4	**Supply and Installation of pipes and related fittings to suction lines for pumps**				
4.1.0	Reinforced Flexible Suction Pipe,75mm diameter , with Clips 6 m long	no.			
4.1.1	Foot valve and Strainer (75mm diameter)	no.			
4.1.2	75mm Diameter Steel Tee piece with a steel Plug	no.			
4.1.3	75mm Diameter Brass Barrel Nipple	no.			
4.1.4	NIFV Barrel Nipple,3/4 inch	no.			
4.1.5	75mm Diameter Non-return Valve	no.			
4.1.6	125mm X 75mm UPVC Reducer	no.			
4.1.7	140mm X 75mm UPVC Reducer	no.			
4.1.8	200mm X 75mm UPVC Reducer	no.			
4.1.9	250mm X 75mm UPV Reducer	no.			
4.1.10	Fabricate, Supply and install manifold as specified in drawing	no.			
5	**Supply and Installation of UPVC pipes and related fittings to delivery lines**				
5.1.0	125mm Diameter PVC RRJ class 4 Pipe	no			
5.1.1	125mm Diameter NIFV Barrel Nipple	no			
5.1.2	140mm Diameter PVC RRJ class 4 Pipe	no			
5.1.3	200mm Diameter PVC RRJ class 4 Pipe	no			
5.1.4	250mm Diameter PVC RRJ class 4 Pipe	no			
5.1.5	125mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.6	140mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.7	200mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
5.1.8	250mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.9	125mm Diameter class 6 uPVC 113 Degree Long Radius Bend	no			
5.1.10	140mm Diameter class 6 uPVC 141 Degree Long Radius Bend	no			
5.1.11	250mm Diameter class 6 uPVC 153 Degree Long Radius Bend	no			
5.1.12	250mm Diameter class 6 uPVC 90 Degree Long Radius Bend	no			
6	**Earthworks to pipe lines**				
6.1.0	Excavate up to 0.75m deep X 0.6m wide Trench (including backfilling) for Pipelines	cu.m			
7	**Supply and Install Fittings for Hydrants / Discharge Chambers**				
7.1.0	125mm Diameter Gate Valve with flange adaptors	no			
7.1.1	125mm Diameter Class 6 uPVC 90 Degree Elbow	no			
7.1.2	140mm Diameter Gate Valve with Two Flange Adaptors	no			
7.1.3	140mm Diameter Class 6 uPVC 90 Degree Elbow	no			
7.1.4	200mm Diameter Gate Valve with Flange Adaptors	no			
7.1.5	200mm Diameter Class 6 uPVC 90 Degree Elbow	no			
7.1.6	250mm Diameter Gate Valve with two Flange Adaptors	no			
7.1.7	250mm Diameter Class 6 uPVC 90 Degree Elbow	no			
7.1.8	140mm Diameter class 6 uPVC Tee Piece	no			
7.1.9	250mm Diameter class 6 uPVC Tee Piece	no			
8	**Type 1 (Hydrant with Single outlet)**				
8.1.0	Excavation and backfilling for structures	cu.m			
8.1.1	50mm Hardcore	cu.m			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
8.1.2	Concrete foundation slab	cu.m			
8.1.3	Concrete thrust blocks to hold inlet pipe for hydrants as specified on drawings	cu.m			
8.1.4	Brickwork in cement sand mortar as specified	sq.m			
8.1.5	19mm Plaster to brickwork in cement sand mortar	sq.m			
9	**Type 2 (Hydrant with Double outlets)**				
9.1.0	Excavation and backfilling for structures	cu.m			
9.1.1	50mm Hardcore	cu.m			
9.1.2	Concrete foundation slab	cu.m			
9.1.3	Concrete thrust blocks to hold inlet pipe for hydrants as specified on drawings	cu.m			
9.1.4	Brickwork in cement sand mortar as specified	sq.m			
9.1.5	19mm Plaster to brickwork in cement sand mortar	sq.m			
9.2	**Type 3 (Hydrant with Triple outlet)**				
9.2.0	Excavation and backfilling for structures	cu.m			
9.2.1	50mm Hardcore	cu.m			
9.2.2	Concrete foundation slab	cu.m			
9.2.3	Concrete thrust blocks to hold inlet pipe for hydrants as specified on drawings	cu.m			
9.2.3	Brickwork in cement sand mortar as specified	sq.m			
9.2.4	19mm Plaster to brickwork in cement sand mortar	sq.m			
10	**Laterals, risers, and sprinkler heads**				
10.1.0	Excavation and backfilling for laterals (for fixed system)	cu.m			
10.1.1	Supply and install lateral pipes (uPVC or Aluminium – specify diameter)	m			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
10.1.2	Supply and install sub-lateral pipes (uPVC or Aluminium – specify diameter)	m			
10.1.3	Supply and install riser pipes (specify length, diameter)	m			
10.1.4	Supply and install sprinkler heads (specify size or type)	no			
10.1.5	Supply and install end-stops (related to size of laterals and sub-laterals)	no			
11	**Drainage Channels**				
11.1.0	Excavate to form drains to specified levels and shape as shown on relevant drawings	m^3			
	TOTAL BILL TO SUMMARY				

TYPICAL BILL OF QUANTITIES FOR DRIP IRRIGATION SCHEME

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
2	**Pump**				
2.0.1	Supply, test and install Motorised pumps (Q=23l/s, H=15m)				
2.1	**Fabricate portable steel plate mounting for pump, filter, and construct pump store for the scheme**				
2.1.1	Fabricate and supply portable steel plate mountings for the pumps, to include bolts, nuts and washers as detailed in standard pump mounting base plate Drawing No JK1306/STD/07	No.			
3	**Construct pump store**				
3.1.0	Excavate and backfilling for structure	cu.m			
3.1.4	50mm hardcore	cu.m			
3.1.3	Class C20/C20 mass concrete to floor as specified	cu.m			
3.1.1	230mm clay burnt brickwork to walls reinforced with brickforce wire at every 5 courses	sq.m			
3.1.2	19mm Plaster to brickwork to walls	sq.m			
3.1.5	Supply and fix 100mm X 75mm timber rafters to roof as specified in the Pump store drawing	m			
3.1.6	Supply and fix 50mm x 50mm timber purlins to roof as specified	m			
3.1.7	Supply and fix 230mm x 15mm nutec fascia board to roof as specified	m			
3.1.8	Supply and fix 100mm x 50mm wall plate to roof as specified	m			
3.1.9	Supply and fix 28 gauge IBR sheets	sq.m			
3.1.10	Supply and fix breeze blocks as specified on drawing	sq.m			
3.1.11	Supply and fix standard hardwood double door as specified on the drawing complete with frame including all ironmongery	no.			
3.1.12	Supply and fix double steel grilled door as specified on the drawing complete with frame including all ironmongery	no.			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
4	**Supply and Installation of pipes and related fittings to suction lines for pumps**				
4.1.0	Reinforced Flexible Suction Pipe,75mm diameter , with Clips 6 m long	no.			
4.1.1	Foot valve and Strainer (75mm diameter)	no.			
4.1.2	75mm Diameter Steel Tee piece with a steel Plug	no.			
4.1.3	75mm Diameter Brass Barrel Nipple	no.			
4.1.4	NIFV Barrel Nipple,3/4 inch	no.			
4.1.5	75mm Diameter Non-return Valve	no.			
4.1.6	125mm X 75mm UPVC Reducer	no.			
4.1.7	140mm X 75mm UPVC Reducer	no.			
4.1.8	200mm X 75mm UPVC Reducer	no.			
4.1.9	250mm X 75mm UPV Reducer	no.			
4.1.10	Fabricate, Supply and install manifold as specified in drawing	no.			
5	**Supply and Installation of uPVC pipes and related fittings to delivery lines**				
5.1.0	125mm Diameter PVC RRJ class 4 Pipe	no			
5.1.1	125mm Diameter NIFV Barrel Nipple	no			
5.1.2	140mm Diameter PVC RRJ class 4 Pipe	no			
5.1.3	200mm Diameter PVC RRJ class 4 Pipe	no			
5.1.4	250mm Diameter PVC RRJ class 4 Pipe	no			
5.1.5	125mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.6	140mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.7	200mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
5.1.8	250mm Diameter Reinforced Flexible Pipe 6m long with Clips	no			
5.1.9	125mm Diameter class 6 uPVC 113 Degree Long Radius Bend	no			
5.1.10	140mm Diameter class 6 uPVC 141 Degree Long Radius Bend	no			
5.1.11	250mm Diameter class 6 uPVC 153 Degree Long Radius Bend	no			
5.1.12	250mm Diameter class 6 uPVC 90 Degree Long Radius Bend	no			
5.1.13	Supply and install non-return valves				
5.1.14	Supply and install by-pass valve				
5.1.15	Supply and install sand separator (hydrocyclone)				
5.1.16	Supply and install pressure gauge				
5.1.17	Supply and install sand filter				
5.1.18	Supply and install back-wash valve				
6	**Earthworks to pipe lines**				
6.1.0	Excavate up to 0.75m deep X 0.6m wide Trench (including backfilling) for Pipelines S1,S2,S3,S4,S5 and S6	cu.m			
7	**Supply and Install Fittings for irrigation system**				
7.1.0	Supply and install PE pipes as main line	m			
7.1.1	Supply and install PE pipes as sub-main lines	m			
7.1.2	Supply and install lateral lines (poly tubes)	m			
7.1.3	Supply and install drippers / emitters	no			
7.1.4	Supply and install end-stops	no			
7.1.5	Supply and install flush valves	no			
7.1.6	Supply and install air valves	no			

ITEM	DESCRIPTION	UNIT	QTY	RATE (MK)	AMOUNT (MK)
7.1.7	Supply and install ball valves	no			
	TOTAL BILL TO SUMMARY				

Annex 14: Some software used in irrigation design

a. Simple on Excel
b. AutoCad
c. LandCad
d. Surfer
e. Drainmod
f. EPANET 2.0 – design and dimensioning of pipeline systems
g. CROPWAT
h. CLIMWAT
i. Model Maker
j. Civil Designer
k. AquaCrop
l. ArcGIS
m. MAQUA for design of river training works

Annex 15: Bibliography

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PART 2: OPERATING AND MAINTAINING IRRIGATION SYSTEMS

IRRIGATION OPERATION AND MAINTENANCE CODE OF PRACTICE

Table of contents

CHAPTER 1: INTRODUCTION

1.1. Purpose of the Irrigation Operation and Maintenance Code of Practice

Goal and purpose

1. The goal of developing irrigation systems is the efficient and sustainable use of water, energy, labour and capital in the irrigation industry.
2. This operation and maintenance code of practice shall provide the guidance on operation and maintenance of irrigation systems in an economic and environmentally sustainable manner, in order to achieve the irrigation industry's expectation of acceptable levels of irrigation operation and maintenance practices to irrigation owners, and operators.
3. In some circumstances practices and equipment other than those suggested in the code may be equally relevant in meeting irrigation industry standards.
4. The code is mandatory, and is intended to draw authority from all areas of legislative responsibility within the irrigation industry.

1.2. Context of the Irrigation Operation and Maintenance Code of Practice

Context

1. The Irrigation Operation and Maintenance Code of Practice describes the procedures that irrigation managers and operators must follow to meet the required performance standards.

1.3. Technical Standards

Alignment with Standards

1. Standards from other Codes of Practice that are referenced within this Code of Practice are overseen by the relevant issuing authority.
2. The International Organisation for Standardisation (ISO) has responsibility for the International Standards published under its name.
3. Where Malawi Standards exist, these shall apply to the implementation of this Code of Practice.

1.4. How to use the Irrigation Operation and Maintenance Code of Practice

1. The Code of Practice includes practices that must be followed by managers and operators in the operation and maintenance of irrigation systems to ensure acceptable performance standards.
2. Specific technical data are provided to help in this respect, with reference to other technical Standards.
3. The Operation and Maintenance Manual should be translated into local languages to facilitate its implementation by the communities at irrigation scheme level.

CHAPTER 2: DEFINITIONS

2.1. **Adequacy of irrigation:** A measure of the proportion of the target area for which the soil is restored to a level that equals or exceeds a set level, or target soil water content

2.2. **Application depth:** The mean application depth (mm) applied by an irrigation event during periods of peak irrigation demand. In some applications, such as for annual crops, the system may be required to meet a range of application depths to match progressive stages of crop development

2.3. **Application efficiency:** The percentage of applied water that is retained in the root zone, or in the target area, after an irrigation event

2.4. **Application rate:** The mean precipitation rate of the irrigation system, expressed in millimetres depth of water applied per hour.

2.5. **Application uniformity:** The spatial variability of application, defined in a variety of ways; the most common being distribution uniformity (DU), coefficient of uniformity (CU) and emission uniformity (EU).

2.6. **Available water holding capacity:** The difference in moisture content between field capacity and permanent wilting point, expressed in millimetres depth of water over a specified depth of soil within the effective root zone (usually equal to the expected effective root depth of a crop during periods of maximum water demand).

2.7. **Back flow preventer:** A device or devices installed in a pipeline to prevent water flowing in reverse through the system.

2.8. **Capital cost:** The overall system investment cost ($) or cost per unit area ($/ha) as total or annualised cost. For the purposes of economic analysis, annualised capital cost may also be expressed as cost per unit volume ($\$/m^3$) based on mean annual irrigation demand.

2.9. **Crop factor:** The ratio of the water requirements of a particular crop to that of a reference crop (usually average grass pasture).

2.10. **Design area:** The specific land area in hectares, which the supplier (or designer) and the irrigation system purchaser mutually understand is to be irrigated by the irrigation system.

2.11. **Design system capacity:** The mean daily flow of water per hectare of irrigated area used in the design of the system.

2.12. **Distribution efficiency:** A measure of how much of the water supplied to the Property reaches the application system. It is a function of losses incurred in the conveyance or distribution system, from the point of water abstraction or entry to the Property (in the case of irrigation schemes) to the application system.

2.13. **Drainage depth:** The potential drainage volume based on peak irrigation demand. This is typically expressed as volume per unit area (m^3/ha) or an equivalent depth per unit area (mm/ha).

2.14. **Easily Available Water (EAW)** refers to the amount of water that is easily available to the plant, being 50% of the Plant Available Water. The easily available water in the soil is determined as follows: Easily Available Water (mm) = Plant Available Water (mm/m) x Effective Root Depth (m) x 50% or **EAW = PAW x ERD x 50% .**

2.15. **Effective root depth:** The depth of soil profile that has enough rooting density for extraction of available water, if needed. Roots may be found at depths greater than this value but do not contribute significantly to water extraction.

2.16. **Environmental and Social Impact Assessment:** An assessment of factors ensuing from the implementation of the project that would impacts (negative or positive) on the social welfare of the people as well as the environment. Identified mitigation measures are incorporated into the design of the project.

2.17. **Evapotranspiration rate (ET):** The rate of water loss from a combined surface of vegetation and soil. It includes evaporation of water from the soil surface, from free water on plants and transpiration by plants.

2.18. **Field capacity:** The soil water content of well-drained soils after drainage from initially saturated soils has become negligible. The macro pores of the soil are filled with air and the micro pores hold water by capillary action.

2.19. **Field Water Capacity (FWC)** is the volume of water, measured in millimetres, that is required per meter of soil to saturate the soil and all free water has drained. This is regarded as the full point of the water reserve in the soil.

2.20. **Headworks efficiency:** A measure of the hydraulic performance of the intake structure, pump and headworks (excluding pump pressure and elevation differences) to indicate the extent of pressure loss in the water supply system between the water supply point and the mainline entry.

2.21. **Hydraulic efficiency:** A measure of the system hydraulic performance; it gives an indication of how much pressure is lost between the delivery (mainline entry) and discharge points (machine entry, hydrant, or take-off in drip-micro systems), excluding variations in elevation.

2.22. **Infiltration rate:** The rate at which the soil can absorb water, which changes according to the wetness of the soil. Infiltration rate is usually expressed in units of mm/hour.

2.23. **Irrigation cycle** refers to the number of days before a block is irrigated again. For example, if the cycle for a block is three days, it will be irrigated for instance on Mondays and Thursdays.

2.24. **Irrigation scheme types**

2.24.1. **Basin:** Water is supplied in a field which has been subdivided into flat areas of land surrounded by earth bunds. Water entering the basin is ponded until it infiltrates into the soil.

2.24.2. **Border strip:** Resembles basin irrigation in that the land is divided into strips by small earth bunds, however, the field usually slope uniformly away from the field channel.

2.24.3. **Centre Pivot and Lateral Move:** These are self-propelled irrigation systems which apply water to pasture or crop, generally from above the canopy. They are anchored at one end and rotate around a fixed central point. Lateral systems are not anchored and both ends of the machine move at a constant speed up and down a paddock.
Centre Pivot and Lateral Move systems require an energy source to move water from the source to the plant as well as energy to move the machine on farm.

2.24.4. **Dam:** An irrigation scheme whose water source is a reservoir formed by constructing a dam across a river, a stream, or a valley. Reservoirs can be on-stream or off-stream depending upon their location.

2.24.5. **Drip:** Drip irrigation (low volume/micro-irrigation) is where water is delivered on a slow, frequent and accurate basis directly to the root zone of the plant. The root zone is kept moist but never saturated with water. The end result is that the plant always maintains the ideal balance between water and air.

2.24.6. **Furrow:** Irrigation water is confined to narrow channels (furrows) between crop rows. The shape of the furrow depends upon soil type, stream size, and crops being grown. This method is widely used irrigating row crops.

2.24.7. **Gravity:** An irrigation scheme in which water is supplied to the agricultural land with gravity force only

2.24.8. **Groundwater:** An irrigation scheme in which the water source is a shallow well, a borehole, or other groundwater storage. Water abstraction could be by centrifugal pumps, submersible pump, treadle pump, solar powered pump, or other pump mechanism.

2.24.9. **Localised:** This form of irrigation aims at applying water at the plant root zone, using such devices as nozzles, micro-tubes, porous pipes, orifices.

2.24.10. **Pump (lake/pond):** An irrigation scheme whose water source is a lake or pond and water is abstracted by pumping.

2.24.11. **Pump (river):** An irrigation scheme whose water source is a river and water is abstracted by pumping.

2.24.12. **Rainwater harvesting:** An irrigation scheme that subsistence farmers themselves have introduced using simple rainwater harvesting techniques to artificially control the availability of water for crops. This type includes flood recession schemes.

2.24.13. **Sprinkler:** This system comprises a network of pipes with sprinklers attached for spraying water under pressure over the land surface. There are three types of sprinkler systems: portable, semi-permanent, and permanent. The systems are connected to a main line normally supplied by a pumping unit.

2.24.14. **Surface:** These are schemes whereby water is applied onto the crops on the ground surface and allowed to percolate to roots by gravitational forces.

2.25. **Irrigation system:** This comprises all of the equipment required to transfer water from the water source to the crops in the design area.

2.26. **Irrigator:** An individual, community, or institution that seeks to develop agricultural land into an irrigation scheme.

2.27. **Leaching:** Removal of salts and loss of nutrients beyond the root zone of plants due to deep percolation of water.

2.28. **Mainline:** A pipeline within the distribution system that transports water from the water source to sub units or zone control valves in a system.

2.29. **Maximum allowable deficit (MAD):** The percentage of available water that is accepted to be depleted before irrigation is required. Often known as stress point or critical deficit.

2.30. **Mean Annual Flood (MAF):** The flood which is estimated to occur in a river whose magnitude is based on a probability of occurrence or non-exceedance. In case of ungauged rivers, the following parameters apply in determining MAF: MAF_{ug} (ungauged river), MAF_{g} (gauged river), MAF_{o} (observed).

2.31. **Operating system capacity:** The mean daily flow of water per hectare the system is able to provide the way it is being managed.

2.32. **Osmotic Pressure:** Osmotic Pressure refers to the pressure required by plant roots to draw water from the soil.

2.33. **Permanent wilting point:** The soil moisture content at which a plant will die from drought stress. For practical purposes, it is the soil water content at a soil tension of 15 bar (1500 kPa). It is the volume of water, measured in millimetres per meter soil, where most plants will wilt permanently, i.e. where plants will not recover in twelve hours after being watered again. This is regarded as the empty point of the water reserve in the soil.

2.34. **Planning stage:** A period in the irrigation project development process which covers activities related to the initiation of the project by the client or irrigators under the guidance of professional registered irrigation services providers.

2.35. **Plant Available Water (PAW)** is defined as the difference between Field Water Capacity and Permanent Wilting Point, i.e. **PAW = FWC – PWP.**

2.36. **Potential system capacity:** The mean daily flow of water per hectare the system is able to provide in the time available.

2.37. **Precipitation**: Precipitation refers to the increase in the water content of the soil as a result of irrigation or rain, and is measured in millimetres (mm). Precipitation is calculated as follows: Precipitation (m) = Volume of water (m^3) / Area of land (m^2) : **P = V / A** or Precipitation (mm) = Volume of water (m^3) x 1,000 / Area of land (m^2).

2.38. **Productivity:** The marginal increase in income resulting from the irrigation system. It is generally expressed as the increase based on mean annual irrigation demand per unit area ($/ha, may also be expressed as $/mm/ha), though for economic analysis, maximum and minimum values may also be of interest.

2.39. **Pump terminologies**

2.39.1. **Cavitation** is the formation and collapse of vapour bubbles in the liquid. The reason is in most of the cases is a too low static suction head. The suction valve should be submerged in the liquid to a depth greater than the minimum recommended by manufacturers so that no air is sucked in through vortices when the pump is in operation. Cavitation causes pitting corrosion at the impeller, pressure drops resulting in a drop in pump performance.

2.39.2. **Diaphragm pumps** use a positive displacement design and will deliver a specific amount of flow per stroke, revolution or cycle. Engine-powered versions are the most common.

2.39.3. **Dynamic Discharge Head** is the static discharge head plus the friction in the discharge line. Also referred to as Total Discharge Head.

2.39.4. **Dynamic Suction Head** is the static suction lift plus the friction in the suction line. Also referred to as Total Suction Head.

2.39.5. **Head** refers to gains or losses in pressure caused by gravity and friction as water moves through the system. It is most commonly listed in metres of water. Depending on how the measurement is taken suction lift and head may also be referred to as **static or dynamic head**.

2.39.6. **High-pressure centrifugal pumps** are designed for high-discharge pressures and low flows. Typically, these pumps will discharge around 10 litres per second and produce heads in excess of 90 metres. These pumps by design are not capable of handling any types of solids or even sandy water.

2.39.7. **Maximum suction lift** is the practical suction lift, at sea level, which is specified by most pump manufacturer. It is set at 7.5 metres.

2.39.8. **Net positive suction head (NPSH)** is defined as absolute pressure (rather than gauge pressure) that is required at the pump inlet for satisfactory operation. The NPSH of the pump is determined by measurements carried out on the suction and delivery side of the pump. This value is to be read from the pump characteristic curve and is indicated in meter (m). The NPSH of the pump is called NPSH required, and that of the system is called NPSH available. The $NPSH_{avl}$ should be greater than the $NPSH_{req}$ in order to avoid cavitation. NPSH required ($NPSH_R$) depends on the design of a particular pump, and is specified by the pump manufacturers. For safety reasons another 0.5 m should be integrated into the calculation, i.e.: $NPSH_{avl} > NPSH_{req} + 0.5m$

2.39.9. **Performance** of a pump is measured in volume as litres per second and in pressure as head.

2.39.10. **Required flow rate (Q)** is equal to the design flow rate for the irrigation system. In situations where there is more than one design flow rate, the designer shall consider using a single or multiple pumps, or a variable speed drive unit or other control methods.

2.39.11. **Standard centrifugal pumps** common models are in the 50 mm to 100 mm range with flows from 10 to 35 litres per second and heads in the range of 25 to 35 metres, used in clear water applications only. They will only pass spherical solids ¼ the diameter of the suction inlet.

2.39.12. **Static Discharge Head** is the vertical distance from the discharge outlet to the point of discharge or liquid level when discharging into the bottom of a water tank.

2.39.13. **Static Suction Lift** is the vertical distance from the water line to the centreline of the impeller.

2.39.14. **Submersible pumps** have a compact and streamlined design which makes them ideal for wells and other jobs where space is limited. They work in the water source being pumped.

2.39.15. **Total Dynamic Head** is the head that the pump is required to impart to a fluid in order to meet the head requirement of a particular system. The total dynamic head is made up of static suction lift or static suction head, static discharge head, total static head, required pressure head, friction head and velocity head.

2.39.16. **Trash centrifugal pumps** can handle large amounts of debris and are preferred by contractors for desilting at construction sites. The most common sizes are in the 50 mm to 150 mm range producing flows from 15 to 120 litres per second and heads up to 380 m. They will generally handle spherical solids up to ½ the diameter of the suction inlet, and up to 25% suspended solids by volume.

2.39.17. **Water Hammer** occurs when water flow is stopped abruptly, e.g. the column of pumped water stops and flows backwards towards the pump. This can cause major pipe damage.

2.40. **Readily available water holding capacity:** The difference in moisture content between field capacity and the stress point (equal to a soil suction of 200-500 kPa), expressed in millimetres depth of water over a specified depth of soil (usually equal to the expected effective root depth of a crop during periods of maximum water demand).

2.41. **Readily system capacity:** The mean daily flow of water per hectare required to meet the demands of the crop at Peak ET after accounting for the duration that water is available.

2.42. **Return interval:** The interval between successive irrigation cycles during periods of peak demand and no rainfall.

2.43. **Return on water use:** The marginal change in returns resulting from the irrigation system. It is generally based on mean annual irrigation demand, and incorporates cost and productivity elements above. Values can be expressed as returns per unit area or volume of water ($/ha or $/m^3). Values can be positive or negative, dependent on system costs, productivity and crop returns.

2.44. **Scheme Committee** refers to a body of persons elected by the farmers responsible for the management, operation, and maintenance of the scheme.

2.45. **Scheduling coefficient:** A ratio to indicate how much additional water above the mean application needs to be applied to adequately overcome non-uniform applications.

2.46. **Size of irrigation schemes:**

≤ 10ha: Mini Irrigation Schemes
11 – 50 ha: Small Scale Schemes
51 – 500ha: Medium Scale Schemes
≥ 501ha: Large Scale Schemes

2.47. **Soil texture:** refers to the particle size or the relative amounts of sand, silt and clay in the soil.

2.48. **Stand-Time** is the period (in hours) that a block is irrigated.

2.49. **Surface runoff:** An assessment of the potential surface runoff (volumetric) proportion from the system operating during periods of peak irrigation demand. Generally, such considerations are limited to surface irrigation systems and some spray systems.

2.50. **System capacity:** A measure to assess the ability of a system to meet total system requirements; crop irrigation demand and losses due to non-uniformity of application and distribution losses.

2.51. **Transpiration** reffers to the loss of water by means of evaporation from a plant's surface through minute pores on the leaf surface, called stomata.

2.52. **Uniformity coefficient (Christiansens):** A measure that defines the variability of individual application depths from the mean and, therefore, the impact of overall uniformity. It has most commonly been used in the description of sprinkler application uniformity, but can be equally useful in defining field and system uniformity.

2.53. **Water holding capacity:** The maximum amount of water that can be held in the soils that is available for plant growth. For practical purposes, it is the difference between field capacity and permanent wilting point.

2.54. **Water User Association:** Water User Associations (WUA) are formally registered organizations of the people, for the benefit of the people set up to do the functions of operation and maintenance of the irrigation system

2.55. **Water User Group:** Water User Group (WUG) are organizations of the people, for the benefit of the people set up to do the functions of operation and maintenance of the irrigation system, which has not been formally registered.

CHAPTER 3: OPERATION AND MAINTENANCE MANUAL

3.1. Definition

1. Operation and maintenance procedures rely very much on the designer's concept of the irrigation scheme. The designer made some assumptions and decisions that have been incorporated in the design of the irrigation scheme. The designer, therefore, has a very important role in guiding and determining the way the scheme should be operated and maintained.
2. The designer should provide a description of the irrigation and drainage system including proposed crops and cropping patterns. A clear picture should be presented on the flow of water from the water source to the drainage system, highlighting the different components that exist in the scheme layout. These instructions should be presented in operation and maintenance manuals that should be prepared by the designers for each scheme. This underscores the need to involve of stakeholders and beneficiaries in the entire process of planning and design of the irrigation schemes.
3. The designer should produce scheme specific manuals clearly specifying how each part of the infrastructure should be operated and maintained to ensure sustainability. In these manuals, capacities and capabilities of the operators at each level should be described to ensure efficiency of the system. As a guide, the following are some of the issues to be described in the manuals

3.2. Intake

Requirements

1. The following should be specified concerning operation and maintenance of the intake:
   a. How many days per week the intake should be operated;
   b. How many hours per day the intake should be operational;
   c. What flow should pass through the intake at any given time and how the flow should be measured and controlled;
   d. Depending upon the type of intake, what are the critical areas of operation and maintenance to maintain the efficiency of the structure;
   e. What the maintenance procedures should be followed regarding all components of the intake.

3.3. Pumping Station

Requirements

1. The designer should specify the following:
   a. The type of pump(s) that will be installed and used in the entire irrigation system (axial, centrifugal, submersible, solar);
   b. Pump position and location (if variable). A mention should be made of the condition of the base where the pump will be positioned;
   c. How the pump should be primed;
   d. What operation procedures should be followed for each type of pump installed in the irrigation system;
   e. What the sequence of operations should be when switching on and off the pump so as to prevent water hammer;
   f. How long the pump should be operated per day;
   g. Number of pumps operating at a time;
   h. The type of fuels to be used for pumps and an estimate of how much would be required for a single operation. Likewise,

if an electric pump is to be used what consumption should be expected;

i. Necessity of referring to pump manual by users;

j. What maintenance procedures should be followed for each type of pump installation;

k. How pumps should be installed and operated in order to avoid problems of cavitation, and pumping of sediments.

2. Specific Speed

i. Specific speed as a measure of the geometric similarity of pumps - Specific speed (Ns) is a non-dimensional design index that identifies the geometric similarity of pumps. It is used to classify pump impellers as to their type and proportions. Pumps of the same Ns but of different size are considered to be geometrically similar, one pump being a size-factor of the other.

ii. Specific speed is defined as the speed in revolutions per minute at which a geometrically similar impeller would operate if it were of such a size as to deliver one gallon per minute flow against one-foot head.

iii. The understanding of this definition is of design engineering significance only, however, and specific speed should be thought of only as an index used to predict certain pump characteristics.

iv. Specific speed as a measure of the shape or class of the impellers – Specific speed determines the general shape or class of the impellers. As the specific speed increases, the ratio of the impeller outlet diameter, D2, to the inlet or eye diameter, D1, decreases. This ratio becomes 1.0 for a true axial flow impeller. Radial flow impellers develop head principally through centrifugal force. Radial impellers are generally low flow high head designs. Pumps of higher specific speeds develop head partly by centrifugal force and partly by axial force. A higher specific speed indicates a pump design with head generation more by axial forces and less by centrifugal forces. An axial flow or propeller pump with a specific speed of 10,000 or greater generates its head exclusively through axial forces. Axial flow impellers are high flow low head designs.

v. Specific speed identifies the approximate acceptable ratio of the impeller eye diameter (D1) to the impeller maximum diameter (D2) in designing a good impeller.
Ns: 500 to 5000; D1/D2 > 1.5 - radial flow pump
Ns: 5000 to 10000; D1/D2 < 1.5 - mixed flow pump
Ns: 10000 to 15000; D1/D2 = 1 - axial flow pump

vi. Specific speed is also used in designing a new pump by size-factoring a smaller pump of the same specific speed. The performance and construction of the smaller pump are used to predict the performance and model the construction of the new pump.

vii. Specific speed as a measure of the safe operating range – Suction specific speed (Nss) is commonly used as a basis for estimating the safe operating range of capacity for a pump. The higher the Nss is, the narrower is its safe operating range from its BEP. The numbers range between 3,000 and 20,000.

Most users prefer that their pumps have Nss in the range of 8000 to 11000 for optimum and trouble-free operation.

3.4. Water Conveyance Channels

Requirements 1. The designer should specify the following:

a. The flow expected in the conveyance or main channel;
b. How many days the channel will operate per week;
c. How many secondary turnouts the channel should feed at any given time and what their discharges and water levels are;
d. How the flow into secondary channels should be controlled;
e. Need for removing pipes and provision of end caps during the rainy season where necessary;
f. How to manage sediments in channels, drains, and all other structures along conveyance channel;
g. How to operate channels in order to avoid failure of the side walls or slopes;
h. How to operate channels and drains in order to minimise maintenance operations;
i. How to maintain channels and drains in order not to compromise their operational efficiencies;
j. In case of siphons (inverted or otherwise) and other conveyance structures, how these should be operated and what protective measures should be undertaken in order to minimise sedimentation and other maintenance needs;
k. Use of conveyance systems for human and livestock (animal) use, and the resultant safety measures and maintenance needs.

3.5. Water Distribution Structures

Requirements 1. The designer should specify the following:

a. The flow is expected in the secondary and tertiary channels;
b. How many tertiary channels should operate at any given time and the operation time for each channel;
c. The sequence of operation for the tertiary channels i.e. which channel operates first;
d. How the flow should be controlled in each channel;
e. How to operate the channels in order to minimise maintenance operations;
f. How to maintain the channels so that they do not compromise their conveyance efficiencies.

3.6. Water Application Structures

Requirements 1. The designer should specify the following:

a. The method used for application of irrigation water (basin, furrow, border strip, sprinkler, dripper, centre pivot);
b. How many basins, furrows, border strips, sprinklers, drippers should be used per given time or the irrigation time for each method, similarly for centre pivots;
c. The application aides that should be used (spiles, siphons, gates, hydrants), their sizes and how many of each per given time;
d. How long each application aide should operate;
e. How to control the water level in the field canals to ensure delivery of the design discharge;

f. How to operate these application aides without destroying the channels, and thus compounding maintenance needs;
g. When to operate the application aides and for how long to meet the irrigation demand of the time;
h. What precautions should be taken before, during, and after operation of the operation aides;
i. Maintenance needs and storage measures that will enhance the length of life of the application aides.

3.7. Water Measuring Devices

Requirements

1. The designer should specify the following:
    a. The position of all water measurement devices in the scheme and their types;
    b. How and when to read each water measurement device;
    c. How to maintain the data thus collected;
    d. How to use the data collected from each water measurement device;
    e. Maintenance needs of the structures;

2. Stage-discharge relationships
    i. The empirical, or also theoretical, relationship existing between the water-surface stage (i.e. the water level) and the simultaneous flow discharge in an open channel is known as *stage-discharge relation* or *rating curve,* or also just *rating*. These expressions are synonymous and they can be used interchangeably.
    ii. The rating curve is a very important tool in surface hydrology because the reliability of discharge data values is highly dependent on a satisfactory stage-discharge relationship at the gauging station.
    iii. Although the preparation of rating curves seems to be an essentially empiric task, a wide theoretical background is needed to create a reliable tool to switch from measured water height to discharge.
    iv. The rating curve is extensively used to estimate the discharge in natural and/or artificial open channel. It is common practice to measure the discharge of streams at suitable times, usually by a current meter or other methods Meanwhile, the corresponding stage is also measured; a curve of discharge against stage can then be built by fitting these data with a power or polynomial curve, looking like the one in Figure 12. The traditional and simple way to gather information on current discharge is then to measure the water level with gauges and to use the stage-discharge relationship to estimate the flow discharge.

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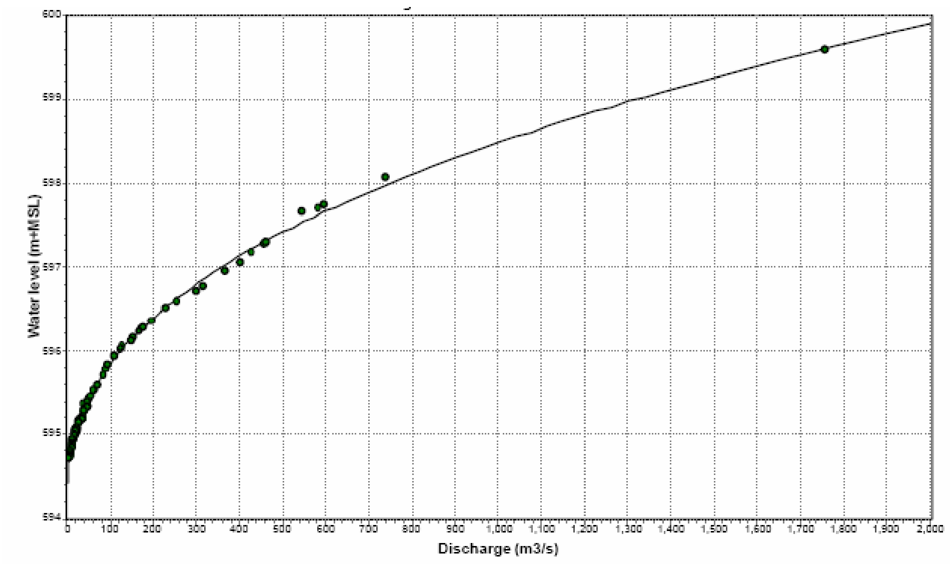

Figure 12 An example of a rating curve

v. For new gauging stations, many discharge measurements are needed to develop the stage discharge relation throughout the entire range of stream flow data. Generally, periodic measurements are needed to validate the underlying stage-discharge relationship and to track changes or shifts in the rating curve.

3.8. Flood Protection Structures

Requirements 1. The designer should specify the following:

a. How the structures have been designed to operate;
b. How the structures should be maintained, and the frequency of the maintenance operations;
c. Safety measures that have been incorporated into the design that need to be enforced;

vi.

3.9. Night Storage Reservoirs and Dams

Requirements 1. The designer should specify the following:

a. How the structures should be operated in order to complement the discharges into the water delivery system;
b. How to operate the structures in order to maintain the stability of the structure;
c. How long the structure should be operated;
d. Maintenance services that are needed for the structure to maintain its design efficiency;
e. Safety measures that have been incorporated into the design that need to be enforced;
f. Frequency of maintenance operations.

3.10. Silt Ejectors

Requirements 1. The designer should specify the following:

a. How the structures have been designed to operate;
b. Operation procedures and frequency of operation;
c. Safety measures incorporated into the design that need enforcing;
d. Maintenance needs and frequency.

3.11. The End User

Requirements 1. The role and responsibilities of the end user should be clearly indicated in the Manual. The development of the Manual should be done with full involvement and participation of the end users so that these roles and responsibilities are outlined and included upon consensus.

3.12. Irrigation Water Management

Definition The process of determining and controlling the volume, frequency and application rate of irrigation water in a planned, efficient manner.

3.12.1. Purpose

1. The purpose for irrigation water management is to:
    a) Manage soil moisture to promote desired crop response
    b) Optimize use of available water supplies
    c) Minimize irrigation induced soil erosion
    d) Decrease non-point source pollution of surface and groundwater resources
    e) Manage salts in the crop root zone
    f) Manage air, soil, or plant micro-climate
    g) Proper and safe chemigation or fertigation
    h) Improve air quality by managing soil moisture to reduce particulate matter movement

2. The designer and the Operation Service manager shall develop an "Irrigation Water Management Plan" to assist the irrigator or decision-maker in the proper management and application of irrigation water.

3.12.2. Irrigator Skills and Capabilities

1. Proper irrigation scheduling, in both timing and amount, control of runoff, minimizing deep percolation, and the uniform application of water are of primary concern.
2. The irrigator or decision-maker shall possess or obtain the knowledge and capability to accomplish the purposes which include:

A. GENERAL

i. How to determine when irrigation water should be applied, based on the rate of water used by crops and on the stages of plant growth and/or soil moisture monitoring.
ii. How to determine the amount of water required for each irrigation, including any leaching needs.
iii. How to recognize and control erosion caused by irrigation.
iv. How to measure or determine the uniformity of application of an irrigation.
v. How to perform system maintenance to assure efficient operation.
vi. Knowledge of "where the water goes" after it is applied considering soil surface and subsurface conditions, soil intake rates and permeability, crop root zones, and available water holding capacity.
vii. How to manage salinity and shallow water tables through water management.
viii. The capability to control the irrigation delivery.

B. SURFACE SYSTEMS

i. The relationship between advance rate, time of opportunity, intake rate, and other aspects of distribution uniformity and the amount of water infiltrated.
ii. How to determine and control the amount of irrigation runoff.
iii. How to adjust stream size, adjust irrigation time, or employ techniques such as "surge irrigation" to compensate for seasonal changes in intake rate or to improve efficiency of application.

C. SUBSURFACE SYSTEMS

i. How to balance the relationship between water tables, leaching needs, and irrigation water requirements.
ii. The relationship between the location of the subsurface system to normal farming operations.
iii. How to locate and space the system to achieve uniformity of water application.
iv. How to accomplish crop germination in arid climates and during dry periods.

D. PRESSURIZED SYSTEMS

i. How to adjust the application rate and/or duration to apply the required amount of water.
ii. How to recognize and control runoff.
iii. How to identify and improve uniformity of water application.
iv. How to account for surface storage due to residue and field slope in situations where sprinkler application rate exceeds soil intake rate.
v. How to identify and manage for weather conditions that adversely impact irrigation efficiency and uniformity of application.

3.12.3. System Capability

1. The irrigation system must be capable of applying water uniformly and efficiently and must provide the irrigator with adequate control over water application.

3.12.4. Managing Soil Water to Promote Desired Crop Responses

1. The following principles shall be applied for various crop growth stages:
   i. The volume of water needed for each irrigation shall be based on plant available water-holding capacity of the soil for the crop rooting depth, management allowed soil water depletion, irrigation efficiency and water table contribution.
   ii. The irrigation frequency shall be based on the volume of irrigation water needed and/or available to the crop, the rate of crop evapotranspiration, and effective precipitation.
   iii. The application rate shall be based on the volume of water to be applied, the frequency of irrigation applications, soil infiltration and permeability characteristics, and the capacity of the irrigation system.
   iv. Appropriate field adjustments shall be made for seasonal variations and field variability.

3.12.5. Optimising Use of Water Supplies

1. Limited irrigation water supplies shall be managed to meet critical crop growth stages.
2. When water supplies are estimated to be insufficient to meet even the critical crop growth stage, the irrigator or decision-maker shall modify plant populations, crop and variety selection, and/or irrigated acres to match available or anticipated water supplies.

3.12.6. Minimising Irrigation Induced Soil Erosion

1. Application rates shall be consistent with local field conditions for long-term productivity of the soil.

3.12.7. Decreasing Non-Point Source Pollution of Surface and Groundwater Resources

1. Water application shall be at rates that minimize transport of sediment, nutrients and chemicals to surface waters and that minimize transport of nutrients and chemicals to groundwater.

CHAPTER 4: OPERATION PROCEDURES

4.1. Personnel and Organisation

Definition

1. Water User Associations (WUA) are organizations of the people, for the benefit of the people set up to do the functions of operation and maintenance of the irrigation system. Membership is comprised of participating farmers in the irrigation schemes.

4.2. Structure of WUA

WUA Structure and functions

1. The WUA has the following structure:

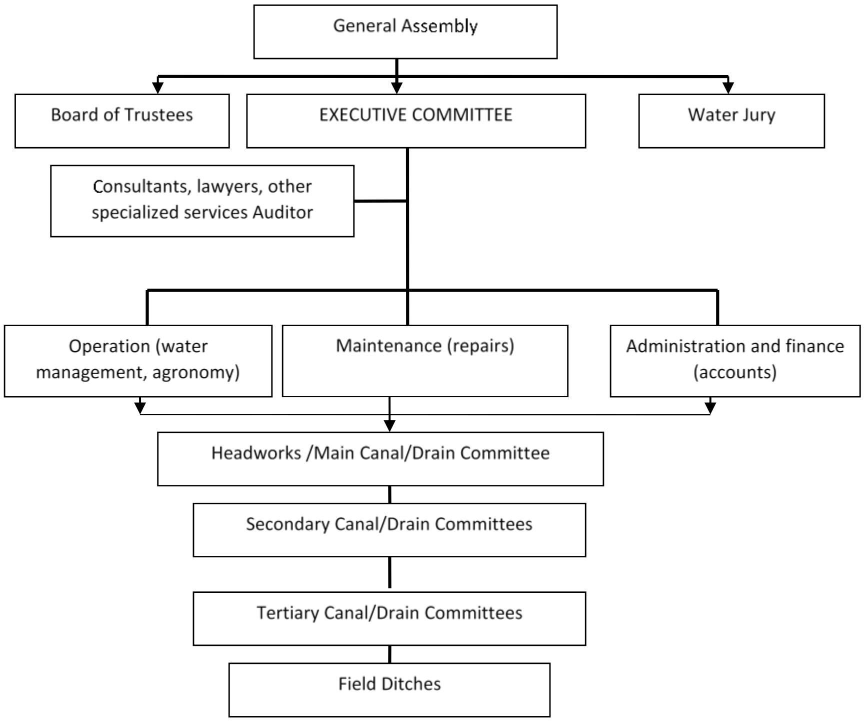

Figure 13 structure of WUA

Source: WUA Manual

i. *The General Assembly:* composed of all the farmers of the association. It is the highest authority. Its main roles and functions are as follows:
   - a) To select their representatives (Board of Trustees);
   - b) To elect the members of the Executive Committee.
   - c) To hear and pass upon the reports of the Executive Committee and officers of the Association.
   - d) To make a final decision regarding any drastic change in financial policies.
   - e) approve or disapprove the management plans.
   - f) To elect and remove trustees, officers and committee members for just cause.
   - g) To adapt or amend the Articles of Incorporation and by-laws of the Association.
   - h) To act and exercise final authority in all matters affecting the Association except those delegated to the Executive Committee.

i) To dissolve the Executive Committee for just cause and to constitute a new one.

ii. *The Executive Committee:* This is the highest executive body comprising a President, Vice President, Secretary, Vice Secretary, Treasurer and three committee members. The number of Executive Committee members may be increased according to the need and in accordance with the law. The Executive Committee of the Association shall exercise all the powers and accept all the duties laid down in this constitution and in particular shall have all duties listed below:

a) The Executive Committee shall protect the Constitution of the Association.
b) To be responsible for planning, co-ordination and implementation to ensure the efficient distribution and use of irrigation water.
c) Assist the Irrigation Committee in the preparation of an annual operation and maintenance plan.
d) To be responsible for joint or group actions of members in the proper operation and maintenance of the irrigation system.
e) To closely co-ordinate irrigation activities in the area including cropping patterns, irrigation scheduling and water distribution.
f) To formulate and implement rules and regulations for the management of the affairs of the Association and for the guidance of the Associations officers and members.
g) To hold Annual General Meetings as required by the Constitution.
h) To ensure true and accurate records of all transactions of the Association are kept by the Treasurer and audited annually.
i) To appoint employees who may not be members of the Association and fix their remuneration.
j) To submit to the General Assembly, the financial statement of the Association.
k) To decide on the disposition of any surplus funds in case of dissolution and/or liquidation of the Association with the concurrence of two thirds of the general membership present at a regular or special meeting for the purpose.
l) To act on the withdrawal from membership.
m) To ensure safe custody of the Association property.
n) To enter into contracts on behalf of the Association.
o) To ensure that resolutions of the General Meeting are complied with and implemented.
p) Land allocation
q) To apply for water rights on behalf of the Association
r) To ensure that the health and hygiene practices within the scheme are appropriate
s) To ensure that members are conversant with current agronomic practices in irrigated farming.
t) To encourage users to make the best use of natural resources and protect the environment.
u) To ensure that all water fees are collected by an

agreed time and remitted to the Treasurer of the Association.

v) To prepare an annual budget and get approval from the General Assembly.

w) To perform other duties as agreed by the AGM.

iii. *The Standing Committees:* comprising the Irrigation Committee and the Finance Committee. The specific functions and responsibilities of each of the standing committees are as follows:

a) ***Irrigation Committee*** **–** responsible for the day to day management of the irrigation system including:
- Ensure the proper distribution and use of irrigation water;
- Consolidate the list of irrigated and planted areas.
- Evaluate and recommend ways and means for efficient water delivery and distribution.
- Evaluate and recommend policies and procedures in managing water crises.
- Evaluate and recommend policies and procedures for in-season maintenance.
- The preparation of an annual operation and maintenance plan.
- Evaluate O&M plans before and after each cropping season and identify problems and formulate procedures to solve them;
- Supervise O&M work;
- Supervising any irrigation staff employed by the Association.
- Recommend policies and procedures in settling irrigation related conflicts.

b) ***Finance Committee*** **–** responsible for all financial matters of the Association including:
- Formulate policies and procedures regarding the business affairs and improvement in the finances of the association.
- Evaluate and recommend policies and procedures for defective irrigation service fee collection.
- Study proposed income producing projects/activities and recommend appropriate actions to the Executive Committee
- Consolidate list of members with back-accounts.
- Consolidate actual receipts and expenditures of the Association and renders monthly report to the Executive Committee.

iv. *The Water Jury:* established by the General Assembly, to administer all water related conflicts in the scheme. The Water

Jury is responsible for settling disputes amongst members, ensuring that there is order and discipline in the scheme as well as at all WUA meetings, ensuring that all bye-laws are being followed by all committees and bringing offenders to book, ensuring that all scheme infrastructure is well protected and maintained and recommend punishments and fines.

4.3. Coordination with Supporting Agricultural Services

Coordination 1. Coordination with the agricultural and irrigation services is at the level of the Board of Directors of the association where they are included as special members, or are invited to the decision-making meetings of the concerned institutions.

4.4. Main Characteristics of WUA

Characteristics 1. The most outstanding characteristics of the WUA are:

i. They secure farmers' participation in decision-making for the irrigation schemes. The democratic process of selecting farmers' representatives guarantees such participation.
ii. They are non-political in nature. However, political influences pose a challenge to the nature of the associations.
iii. Farmers are personally interested in their own organization and this sometimes permits them to do the same job cheaper and faster. They reduce the need for a heavy public bureaucracy to run the irrigation schemes. Civil servants utilised in the development of an irrigation scheme can be moved to a new scheme, instead of remaining as permanent employees of the developed scheme.
iv. The recovery of water fees is more effectively carried out.
v. Rules and regulations are respected better since the punishment of faults is effective and quick.
vi. The relations between those distributing the water (water masters and water guards) and the farmers receiving it are much more friendly and cooperative than when the same job is undertaken by personnel of the administration.
vii. They provide an excellent communication channel between the administration and the farmers. When they do not exist, communication tends to be one-sided from the top to the bottom.
viii. The Board of Directors and often the appointed Manager himself are farmers of the irrigation scheme and continuation in their jobs will depend largely on their performance. This is indeed an important incentive to carry out their jobs in the best possible way.

Limitations 2. Despite the WUA being the highly desirable way of managing an irrigation scheme, there are also some limitations to consider:

i. The water distribution system utilized frequently leads to considerable operational water losses.
ii. There is little capability for undertaking responsibilities outside the operation and maintenance field. Most of the people running the WUA are from the farmers' community and are unlikely to have technical and managerial skills, thus tending to limit their sphere of competence to problems that they themselves can easily handle.
iii. Long periods of considerable effort are required to get the WUA established and working properly

4.5. Size of WUA

WUA Size

1. The size of the WUA is predetermined by the physical size of the scheme.
2. In larger schemes, the possibility of subdividing them into irrigation sections, each having its own WUA, or having a large association for the whole scheme, is frequently debated.
3. The larger the WUA the more difficult becomes communication between the individual farmers and the executive body.
4. On the other hand, small WUAs facilitate communications; but the administrative costs are greater and therefore place more of a burden on the farmers.

4.6 Responsibilities of WUA

WUA Responsibilities

1. The WUA is responsible for the management of operation and maintenance functions at the scheme.
2. The aim of good irrigation management is to obtain a correct flow division within the canal network and over the fields in order to achieve sufficient and equitable delivery of water to the fields. This means that infrastructure must be maintained to provide optimum service after construction, and that operation activities are done to maintain the designed discharges in order to meet the demand for water from the farms, without disputes.
3. The WUA therefore establishes an Irrigation Committee comprising three separate executing units in order to achieve these functions, namely:
   - i. A committee for operation of the irrigation network
   - ii. A committee for maintenance of the irrigation infrastructure
   - iii. A committee for dealing with disputes, the Water Jury
4. An administration unit ensures that these activities are done in accordance with rules and regulations set out in the Constitution of the WUA.
5. In general, the following are the responsibilities of the WUA in order to ensure efficient operation and maintenance of the scheme:
   - i. plan, co-ordinate and implement the efficient distribution and use of irrigation water.
   - ii. prepare an annual operation and maintenance plan and budget. This should include the following:
     - a) silt clearance
     - b) weed clearance
     - c) repairs to structures
     - d) maintenance of service roads and bridges
     - e) environmental protection
   - iii. facilitate joint or group action by farmers in the proper operation and maintenance of the irrigation system.
   - iv. ensure a consolidated list of irrigated and planted areas is prepared for planning purposes and determining water requirements.
   - v. evaluate and recommend policies and procedures in managing water crises.
   - vi. evaluate and recommend policies and procedures for in-season maintenance.
   - vii. evaluate operation and maintenance plans before and after each cropping season and identify problems and formulate

procedures to solve them.

viii. appoint suitable personnel and contractors for operation and maintenance.
ix. ensure that there are always sufficient funds for operation and maintenance.
x. evaluate the overall performance of the irrigation system.
xi. to supervise Operation and Maintenance work.
xii. to supervise any irrigation staff or contractors employed by the Association.
xiii. to collect and deposit irrigation fees.
xiv. to prepare an Annual Report showing the water received and water utilized; and the area irrigated under different crops.

CHAPTER 5: THE OPERATION SERVICE

5.1. Main Objectives

Objectives

1. The main objective of an Operation Service is the timely delivery of the irrigation water necessary to satisfy crop water requirements. The accomplishment of this objective implies the following main activities:
   i. Planning the Operation (preparation of the so-called Irrigation Plans)
   ii. Implementation of the Plan (actual water distribution)
   iii. Monitoring of the Operation (collection of data related to water use and preparation of the corresponding reports).
2. To undertake these tasks different kinds of personnel are required with specific qualifications depending on the type of water distribution system and other local characteristics.

5.2. Planning the Operation

Planning

1. The objective of this activity is to match supply with demand as closely as possible. As water is a scarce resource in irrigation schemes, the importance of this planning process cannot be overemphasized, but unfortunately there are too many occasions when this process is not carried out even in its most elemental form.
2. The planning exercise may be a complex and laborious undertaking, or just a simple meeting where farmers are informed of the amount of water available and the times when it will be distributed.
3. The planning process is essential because it promotes two-way communication with the farmers.
4. The planning process culminates in the development of an Irrigation or Crop Plan. The preparation of an Irrigation or Crop Plan implies the following main steps:
   i. Estimating future water supply
   ii. Estimating water demand of the expected cropping pattern
   iii. Matching supply and demand.

5.2.1. Estimating Future Water Supply

Water Supply

1. The estimation of the future water supply depends upon several factors such as the characteristics of the dry and wet season, the type of water storage utilized, the reliability of climatic data, or the effective rainfall during the irrigation season.
2. Simple cases of determination of the water supply are: (a) pumping or diversion from a river, with an average flow much greater than the one pumped; (b) pumping from fairly abundant aquifers; (c) dam storage where the season for filling the reservoir does not coincide with the irrigation season during which hardly any water contribution can be expected. In all these cases the available water resources should be known precisely at the beginning of the irrigation season.
3. However, where there are cases of uncertainty in the availability of the water resources, it is important to have alternative plans which can be adopted according to changing climatic conditions, which can be modified according to changes in the weather.

5.2.2. Estimating Future Water Demand

Future water demand

1. The water demand is determined by the expected cropping pattern and the irrigation efficiencies at the farm and project level.

i. **Cropping pattern**

a) The difficulty of foreseeing the expected cropping pattern on an irrigation scheme varies according to the degree of freedom allowed to farmers in their choice of crops and the timing of their cultivation activities.
b) Alternatively, demand can be controlled by means of differential control over the water supply pattern (permitting certain highly water-consuming crops to be grown only in certain designated areas which will be the only ones to receive sufficient water).
c) There can also be a free choice of cropping, when response to market demand is the main determining factor.
d) In irrigation schemes where the management has recognized authority over the cropping pattern, a series of negotiations can be made in order to keep a balance between the cropping pattern desired by the farmers and the management.
e) Where management has no authority over the cropping pattern, information gathered from previous years and a study of the trends in relation to expected prices of different crops could be a guide.

ii. **Irrigation efficiencies**

a) In order to complete the evaluation of the demand, the efficiency of the water distribution system and of application must be known.
b) This is usually the weakest point in estimating the demand, because such evaluations are rarely made in the field as they are time-consuming and the qualified staff needed to undertake them are frequently not available.

5.2.3. Matching Supply and Demand

Supply and demand

1. The main cases that are encountered in trying to match supply and demand are as follows:

i. **Irrigation schemes where water supply is greater than or equal to the demand**

a) This is the most favourable situation from the management point of view.
b) Although systems with relatively abundant water are easier to operate, they are likely to be less efficient in terms of returns per unit of water distributed.
c) In technically well designed schemes, supply and demand should match fairly equally. However, when the supply is smaller than the peak month demand, the usual corrective measure is to advance the planting dates of some of the crops in order to avoid coincidence of peak demands.

ii. **Irrigation schemes with a moderate water deficit**

a) A moderate water deficit (10-20 percent of the water supply available) is often encountered in irrigation schemes.
b) This can either be a periodic situation found only in "dry"

years or recurrent every year.

c) Whichever the case may be, these irrigation systems offer the best potential for maximizing the returns from the water that is available.

iii. Irrigation schemes with a large water deficit

a) There are some irrigation schemes which command an area much larger than can actually be irrigated. The water deficit is often greater than 50 percent of the available supply.

b) However, these schemes may not have been designed to irrigate the whole command area at cropping intensities of 100-200 percent. Many of these schemes were designed with the important social objective of benefiting as many people as possible; others were merely the result of an under evaluation of crop water requirements.

c) Whatever the reason, these projects have frequently yielded less than expected. Production per hectare is low. Some of the reasons for such a state of affairs could be:
   - that although the efficient use of water was essential, the farmers were not assisted in preparing their lands (land levelling, grading) for efficient use when water supplies were limited;
   - that the water distribution network was much longer than it should have been; therefore, losses were bound to be greater.

d) These problems do not only occur in irrigation systems with large water deficits; they can also happen in any of the others, and are likely to have more damaging effects.

e) Where water supplies are extremely scarce in "socially designed projects", it is possible to obtain high returns from water, provided good management (i.e. ensuring regular and predictable water supplies) is ensured, suitable technical designs are implemented and the farmer is assisted to use water efficiently.

5.2.4. Restrictive Measures to Match Supply and Demand

Restrictions to Supply and Demand

1. Several restrictive measures and water distribution practices can be utilized to reduce the gap between supply and demand.
2. The measures that can be taken to reduce the water deficit are related to the cropping pattern, the water distribution practices, and the water fees. They are not mutually exclusive and a combination can usually be applied.

i. Measures related to the cropping pattern

There are three main measures that can be undertaken to reduce water demand: (a) changing the planting time; (b) changing the existing crops for others with lower water requirements; and (c) reducing the irrigation area. Of all the possible measures these are the most effective to reduce water deficit but they are also the most difficult to implement.

a) By suitable regulation of the **planting time** and other cultivation activities large reductions can be attained during the peak demand of an irrigation scheme. Careful planning allows controlled staggering of cultivation activities between different sections of the same irrigation system leading to a more rational use of available machinery and manpower.

b) **Changing the existing crops for others** is an effective measure to reduce water demand, e.g. sorghum for maize, etc. However, the condition must be met that the two crops have similar characteristics or end purposes. Otherwise there is the risk of introducing crops which may have very low water requirements but that are not financially attractive to the farmer.

c) **Reducing the irrigated area** is the most expedient way of reducing the demand, but it is difficult to implement. Rather than physically reducing the irrigated area, the usual measure is to reduce the water allocation which in turn should lead to a reduction in the area irrigated by the, farmer.

d) Other methods of reducing the cropped area are:
   - eliminating the areas furthest from the distribution point;
   - giving water to certain sections of the command area only, with the sections being rotated from season to season. This is only feasible where irrigation is supplementary and farmers in sections not receiving irrigation water are able to grow rainfed crops in the season concerned.

ii. Measures related to water distribution practices

There are only two measures that can be used to lessen the water deficit: reducing the water allocation but keeping the same water distribution method, and changing the water distribution method to a more efficient one.

a) **Reducing the water allocation** can be effected in three different ways:

***Allocating water to preferential crops*:** This is common where high value crops (fruit trees, nursery produce, vegetables) are grown near to less valuable ones. In such cases, the regulation is sometimes established that the valuable crops must receive their necessary allocation and whatever is left can be utilized for the other crops. This kind of measure is easy to implement provided that the interests of the farmers and the management are the same, which is generally the case.

***Decreasing the amount of water given per irrigation*:** This can be done in a manner proportional to the deficit with no regard to the possible effects on the crop yield or, on the contrary, by trying to decrease the amounts in such a way that the effect on crop production is minimized. The first alternative is the most commonly adopted because of its simplicity, but the second one offers much better possibilities, where it can be applied. This method can be extremely effective in irrigation schemes concerned with one single crop, but its effectiveness decreases with the number of crops grown because the intervals that fit one crop well may not necessarily do so for others.

Extending the interval between irrigations is the measure most commonly used to cope with water deficits. There is also the possibility of irrigating at times when the crop can make best use of the water. Similarly, the effectiveness of the method is reduced by an increase in the number of crops grown in the scheme.

b) **Changing the water distribution method**: Among the different water distribution methods, it is expected that some will be more efficient (assuming comparable situations of management and technical design) than others. The possibilities of changing the water distribution method are very limited since a certain method is normally linked with a specific technical design. In most cases, changing the method also means changing the physical system to some extent. However, even in cases where there is no need to alter the physical system, a switch is difficult to introduce because farmers have been used to a particular system for many years.

iii. Measures related to water fees

Increases in the water fees tend to decrease the amount of water used. However, this measure should be exercised with great care and only where the preconditions for its use exist.

One precondition is that the water distribution system must be equipped with water measuring devices at the farm level, in order that prices of water can be associated with the volumes received.

Another important requirement is that the farmer must have some understanding of the soil-plant-water relationship, otherwise he will continue to use the same amount of water as before and simply pay more for it.

5.3. Distribution of Water

1. The main water distribution methods are:
   i. **On-demand**: Water is available to the farmer any time that the intake or hydrant is opened. Therefore, the amounts to be used are not limited but water consumption is usually metered and paid for.
   ii. **Semi-demand**: Water is made available to the farmer within a few days (generally 2-7 days) of his request. The amount is often limited to a certain volume per hectare.
   iii. **Canal rotation and free demand**: Secondary canals receive water by turns, for example every 7 days, and once the canal has water farmers can take the amount they need at the time they wish.

iv. **Rotational system**: Secondary canals receive water by turns and the individual farmers within a given canal area receive the water at a pre-set time and generally in a limited quantity.
v. **Continuous flow**: Throughout the irrigation season, the farmer receives a small but continuous flow that compensates the daily crop evapotranspiration.

2. The water distribution method is normally linked to the design of the conveyance system; therefore, once a water distribution method has been selected there is little possibility to change it.
3. The selection of the water distribution method is thus an important matter where social, technical and economic characteristics must be taken into consideration.

5.3.1. On Demand Distribution

1. On-demand irrigation systems are generally designed with high-level technology.
2. The degree of human intervention is minimal since they operate on automatic principles, i.e. when the water level or pressure drops in a canal or pipe due to the opening of an inlet, the level or pressure is immediately reinstated by an automatic device which calls for a greater supply, provided by automatic gates or valves.
3. The efficiency of these systems is very high (up to 90 percent) particularly when using pipes for the distribution.
4. The great advantage of this method is that it allows the farmer to use the water when it is most necessary for the crops.
5. The main disadvantages are high costs and the need for a high level of technology in the construction, operation, and maintenance of the systems.

5.3.2. Semi-Demand Distribution

1. This is perhaps the most common system of water distribution due to its simplicity.
2. A farmer requests the water from the water guard, who passes the information up to the water master.
3. He makes the necessary calculation to accommodate it with the demands of the other farmers within the limited capacity of the canal. If the demand can be met, the information is passed back through the water guard to the farmer with an indication of the exact time of his turn.
4. In irrigation systems where the canals have been designed with a certain flexibility, the request is usually met within a short time (2-3 days), although sometimes 6-7 days can elapse in the case of canals with little flexibility and high demand.
5. The amount to be supplied to the farmer is usually fixed in relation to the number of hectares.
6. This form of distribution requires a well-designed and constructed irrigation system since the flows delivered by the canals should be well-known, and the intakes should also be capable of delivering the requested flow.
7. Another advantage of this system is that when the need arises (peak month) or during exceptionally dry years, it can also function on a fixed rotation.
8. The only disadvantage of this distribution system is its low efficiency at times of low demand, because the opening and closing of canals for a few farmers could imply considerable losses. However, the

problem is mitigated since at times of low demand water losses are not so relevant.

5.3.3. Canal Rotation and Free Demand Distribution

1. The main feature of this system is that canals receive water in turns.
2. The duration of the turns is generally the result of experience in the area.
3. When the number of crops grown in the irrigation scheme is fairly large, there is not much opportunity for rationalizing the duration of the turns. However, where the number of crops is limited or some crops clearly prevail, the duration of the turns can be determined in a rational way.
4. When it is their turn, the farmers take the water from canals on free demand or they may eventually establish some kind of rotation among themselves.
5. Since farmers take the water on free demand, which is the more frequent, the canal must be designed to cope with a concentration of demand at any time.

5.3.4. Rotational System Distribution

1. In this system all canals receive water by turns and farmers on the tertiary canals receive water at a pre-set time and in the allowed quantity.
2. This system is an improvement on the previous one where the rotation is not only of the main canals receiving water but also of the farms.
3. It is a highly efficient system from the operational point of view and socially fair since it gives an equal chance to everyone.
4. There are several ways in which a rotational system can be implemented:
   i. The water is distributed by turns of equal duration throughout the irrigation season. The farmer receives the water on a fixed day for an amount of time that is always constant, regardless of the crops that he may plant.
   ii. The water is distributed by turns of different duration, longer at the beginning and end of the irrigation season and shorter in the middle, according to crop demand. The order of distribution within each turn is always the same and the amount delivered is constant throughout the season.
   iii. The water is distributed by turns of different durations and the amount delivered also changes throughout the season. The amount delivered is calculated according to the actual crop water requirements.
5. The degree of technicality increases from method (i) to (iii) and this not only refers to the actual calculation of the amounts of water to be delivered but also to the design of the irrigation network. For instance:
   a) Method (i) can only be applied if the irrigation network has water measuring devices for each farm. It is the simplest of the three and perhaps the most widely used. It is a fair method, since it gives every user an amount of water proportional to the amount of land.
   b) Method (ii) requires a little more technical knowledge as the intervals must be adapted more to the actual needs of the crops.
   c) Method (iii) technically offers the best opportunity to meet crop

water requirements and achieve greater water efficiency. However, it is difficult to implement.

i. First of all, water measuring devices are needed at the farm level in order to measure the amount of water that must be delivered.
ii. Secondly, the management must have an excellent communication system in order to inform the farmers well in advance about their turns.
iii. Thirdly, since the calculations for the amounts of water to be delivered are made by the management and change from one irrigation to the next, the system is very vulnerable to malpractice.
iv. Fourthly, the calculation procedures are quite complicated and lengthy, needing qualified staff for their execution.

d) As a result of all these requirements, this method is rarely used, in spite of its theoretical advantages.

5.3.5. Continuous Flow Distribution

1. Continuous flow is perhaps the simplest water distribution system, but it is also the least efficient because delivery is generally from field to field, resulting in large evaporation losses.
2. These are inevitable since the water moves from top to bottom in a thin, but extensive layer. Under this system, water losses by deep infiltration and excessive runoff are high.
3. Where water is scarce, the continuous flow system can lead to considerable social unrest because farmers on higher land get the water needed while those lower down get very little or nothing.
4. In areas of water shortage, continuous flooding is gradually being replaced by "intermittent irrigation". With this system, any field can be filled or drained at will by the farmer within the restrictions imposed by the irrigation and drainage network. This system also helps plant growth through periodic drainage and reduces any tendency for fertilizer to be leached. The term "intermittent irrigation" means the intentionally controlled supply of water to fields by the farmer.

5.4. Operation of Structures

5.4.1. Headworks

1. A headwork has to safeguard the inflow to an irrigation scheme, to secure a sufficient and reliable supply of water to the irrigation scheme, and must be sufficiently solid to resist high floods and other damaging forces.
2. It requires skill and high investments and the design is never standardised but adapted to the specific conditions of the site.
3. Most common head works are:
   i. Reservoir dam
   ii. Pumping station
   iii. Diversion weir
4. The headwork is operated to supply the scheme irrigation demand regardless of the distribution method that is applicable at the time.

5.4.2. Spillway

1. A spillway is a structure in a headwork that guides excess water safely to the drainage system.
2. Water levels in irrigation canals changes depending on the inflow and outflow of the canal section concerned. The water level may rise if the gate of an intake structure is open instead of being closed, or if field intakes are closed instead of open.
3. The rising water may pass the free board level, reach the crest of the canal embankment, and start overtopping, resulting in destruction of the bank.
4. To avoid this problem, a small section of the canal bank is lowered and is reinforced with concrete or with masonry. As this is the lowest part of the canal bank, rising water will spill over here. This water will be guided to the drainage system.
5. No particular operational procedures are required for spillways.

5.4.3. Intakes

1. Intakes are constructed at the head of canals mostly in combination with a regulator in the on-going canal. The regulator could be any of the following:
   i. Slide gate for flow regulation and shut-off of canal or canal section
   ii. Avio gate for flow regulation with slide gate for shut-off of canal or canal section
   iii. Distributor for flow regulation
2. Regulators are operated in such a way as to provide the required amount of water to the field in line with the irrigation demand of the day.

5.4.4. De-silting Basin and Sediment Trap

1. A de-silting basin is mostly constructed just behind the headworks, with an outlet back to the river, for the deposit and removal of solids, sand/silt.
2. Sediment traps are constructed in the irrigation system soon after the offtake in order to trap and remove solids and suspended load from the irrigation water to prevent them settling in main and secondary canals. Special sections are included where the velocity of the flowing water is reduced (< 0.5 m/s) and the sediments are separated from the water by gravity.
3. The sediment trap has to be cleaned regularly and all solids, sand, and silt removed.

5.4.5. Stilling Basin

1. A stilling basin, constructed with protected walls and floor, is filled with water in order to dissipate the energy of fast flowing water, so that the flow enters the canal downstream of the basin at low velocity (non-silting and non-eroding velocity).
2. Stilling basins are required downstream of structures where flow velocities are high, such as intake structures, off-takes, culverts, weirs, or drop structures.

5.4.7. Night Storage Reservoirs

1. These are storages constructed at the head of secondary or tertiary units when night irrigation is not possible.
2. They store water during the night, which is available to distribute into canals when irrigation activities commence in the morning together with the daytime flow.
3. They supplement canal discharges where reliance on canal flow alone would not be sufficient to meet the irrigation demand within the desired time of application.

5.4.8. Canal Outlets (Offtakes)

1. These are structures with gates for releasing and controlling the amount of water that should be delivered into field canals.
2. There are two types normally used, an over-flow gate, similar to a weir, or an under-flow gate.
   i. Over-flow gates are usually rectangular box-like structures with grooves in the sidewalls into which flashboards can be placed. The over-flow section is similar to a weir crest, the height of which can be adjusted by adding or removing boards. When the boards are higher than the water surface in the canal, the structure serves as a gate to stop the flow.
   ii. Under-flow gates may be similar, except that a solid wood or metal gate is raised or lowered to control the flow under the gate.
3. Another type makes use of a pipe placed through the ditch bank with a sliding control gate on the inlet end. The pipe should be slightly lower than the bottom of the canal into which the water is released. Having the outlet submerged will help dissipate the energy of the moving water as it leaves the pipe, reducing erosion in the canal.
4. Operation of these gates assists in maintaining a constant water level, and therefore constant discharge entering that canal. It also minimises the risk of overtopping in tertiary canals.

5.4.9. Division Boxes

1. Division boxes are generally concrete box-like structures with two or more outlets, constructed to provide a fixed or variable proportional division of flow in the main or secondary canals. The width of each outlet is in proportion to the division of water that is to be made.
2. Their function is to distribute irrigation water proportionately, dividing the flow in proportions between two or more smaller canals. The flows are proportional to the areas to be irrigated by each canal. Gates are required for closing or regulating the flow into each separate canal.
3. In some division boxes the division of the flow is fixed and cannot be changed. This means that if the flow in the source canal changes, the flow in the branch canals will also change, but the flows remain proportional to the respective command areas of the branch canals.
4. The type of division box chosen depends on:
   i. the accuracy that is required,
   ii. the number of off-take canals at the same distribution point,
   iii. the local topography.
5. A division box is an ideal instrument to enable farmers to manage their own scheme. The outlets in the division box should be fixed with no moveable parts, as these are likely to break down or change the

proportional division.

6. The water level in the division box determines the output through fixed outlets.
7. Division boxes are sometimes combined with other structures, such as drop structures or culverts.

5.4.10. Drop Structures

1. Irrigation water may need to be transported over steeply sloping land. If a canal had the same slope as the surrounding steeply sloping field, the flow velocity in the canal would be very high. The canal is therefore given a slope that is less than the field slope in order to avoid unacceptably high flow velocities.
2. Canals on land with considerable slope require drop structures. These permit the canal to be constructed as a series of relatively flat canals, each at a different elevation.
3. The water is lowered from one section to the next by means of drop structures. They are generally spaced so that the difference in elevation at each drop does not exceed 50 cm.
4. The main function of a drop structure is to dissipate the energy of falling water so that it does not erode the canal. They also provide for the safe dissipation of surplus energy when combined with a stilling basin.
5. A stilling basin or a concrete or rock apron is generally used to absorb this energy.

5.4.11. Farm Turnouts (Farm Intake)

1. The entrance of water from the field channel to the farmer's field is called the field intake or the farm turnout.

Table 15 Farm turnouts characteristics

Item	**Breach**	**Gated intake**	**Siphon**	**Spile**
Operational Activity	Opening and closing by hand and shovel	Gate setting – responsibility of one farmer	Starting or priming the siphon	None or opening/ closing by plug
Problems	Bank erosion; Channel damage; Poor control	Cost	Cost; Head loss in the Siphon (high Water level required in the channel); Difficult to prime.	Cost Blocked openings.
Discharge regulation	Possible, but not accurate	Manipulating the gate	Number & diameter of pipes	Number & diameter of pipes

2. The discharge through the turnout depends on the area of the opening through which water enters the field, and the difference in water level between the channel and the field.

3. It is possible to control the flow by manipulating the water level in the field channel, by using check structures. The higher the water level is in the field channel, the greater will be the discharge. Lowering the water level in the field channel reduces the discharge into the field.
4. The opening of the intake can be adapted to supply the required discharge: breaches can be made smaller or larger; gates can be opened partly or fully; and the number of siphons or spiles and their diameter can be reduced or increased.
5. The difference in water level between the channel and the field also affects the flow rate through the field intake, and can also be adapted to meet the need of water intake.
6. Farm turnouts are compared in Table 15 with regard to the operational activities involved, problems, and quality of discharge regulation of the various options for water intake to the field.

5.4.12. Check Structures

1. A check structure obstructs the flow in the canal and consequently raises the water level.
2. Check structures can be permanent or temporary.
    i. Permanent check structures can be made of concrete, wood etc. Removable flash boards, usually made of wood, are used to change the water level in the canal.
    ii. Temporary checks can be made of plastic, canvas, cloth etc. In small canals, the use of sandbags is also a well-known method for raising the water level.
    iii. The decision to choose permanent or temporary check structures depends on:
        (a) The function of the check
        (b) The need to raise the water level (a few centimetres or 10 to 20 cm)
        (c) Whether the check is in a lined or unlined canal
        (d) Whether the check Is needed regularly
        (e) Whether the place of installation is fixed
3. When flash boards in a check structure are down, when gates are closed, the water level upstream of the structure concerned will rise. This higher water level allows higher flow rates through field intake structures. As a result, the discharge in the field channel downstream of the check is seriously reduced or may even become zero.
4. Water in a field channel is most commonly distributed among the farmers in rotation. Check structures can be very useful, because the farmer whose turn it is can be given the full channel discharge. The discharge downstream of the check in such cases can be zero.
5. When the discharge in a field channel is large, several farm plots can be irrigated simultaneously.

5.5. Emergency Operation

1. Emergency works require immediate action by the WUA, to prevent or reduce the effects of unexpected events such as:
    i. Breach or overtopping of canal embankment or protection bund, causing flooding
    ii. Critical failure of pumps or head-works, causing interruption of irrigation water supply
    iii. Natural disasters such as floods.
2. System operators must be trained so that they know what to do as soon as they arrive, such as cutting off the power to an overheated

pump, and closing the head-works in case of a canal breach.

5.5.7. Emergency Procedures

1. An emergency action plan should be developed for all facilities for which failure or malfunction could cause:
    i. danger to human life
    ii. substantial property damage
    iii. loss of production
    iv. disruption to other community activities
2. The plan should outline the response and procedures to be taken during an emergency, with particular reference to a flood. The plan should indicate:
    i. action to be taken to minimise damage or risk to structures
    ii. action to minimise danger to life or other property
    iii. canal shut-down procedure
    iv. procedure to be followed to inform affected members
    v. reporting processes to be followed (who should be informed and how)
    vi. notices to be given to the community
3. The Water Users Association should keep a sufficient store of materials to be available for rapid repair. This should include shovels, spades, sandbags, cement, wheelbarrows, among other materials and equipment.
4. The WUA should also keep a list of persons that should be contacted in an emergency.

5.5.8. Flood Emergency Criteria

1. Criteria should be established for different stages of emergency with regard to different water levels in the river or at the headworks.
2. Relationships should be developed between flood levels and threats of flooding of housing areas, isolated houses and fields.
3. Procedures and regulations should be laid down and followed.

5.6. Monitoring the Operation

It is important and essential to maintain a record of water discharges at every critical point in the irrigation system because this will assist in decision making concerning water management and system improvements in successive seasons. Monitoring should include:

- how and how much water is available in the system per season
- how the available water is utilised in the season.

This entails the measurement of discharges and keeping appropriate records.

5.6.7. Flow Measurement

1. It is important to know the discharges in the canals in order to supply the required amounts of water to the crops and to avoid waste by supplying too much.
2. Measurements should be taken at various points in the system and at farmers' intakes, for the following reasons:
    i. efficient water distribution: if the amount of water each part of the system receives is known, it becomes possible to manage the water and prevent losses; on top of that locations where the excessive losses take place are visible and action may then be taken to prevent these losses;

   ii. water charges: if farmers have to be charged for the water they receive, the amount of water that they have received has to be measured and recorded;
   iii. disputes over water: if a conflict over water between farmers or between farmers and the system management occurs, it, again, is necessary to know the amount of water each has received;
3. From the above, the locations for measurement follow logically:
   i. at the outlet: here the farmer takes water from the supply channel to irrigate his fields, measurements here can be the basis for water charges and solving disputes;
   ii. at the beginning [head] of the distribution canal: measurements taken here can be used for solving disputes and making management decisions;
   iii. at the beginning of the main canal: measurements taken here give information about how much water is available for the system and can be used for making management decisions.
4. In an ideal system, discharges should be measured at all these points continuously. In most systems, therefore, measurement of discharges is limited to the main canal and distributor heads once or twice a day because of human resource issues and costs.
5. The following procedures are used for flow measurement.
   i. **Flow estimation procedure:** Float method: one throws a floating object into water and measures the time it takes to cover a specified distance, e.g. 10 meters. This is repeated several times and similar answers and average time is computed. The velocity is the distance divided by time. The method is not very precise but it is simple and gives a good indication.
   ii. **Current meters:** This method uses propellers, which are held perpendicular to the direction of flow; and the number of revolutions made corresponds with a certain speed. For small channels the propeller is held halfway the depth of the channel, for larger discharges, speeds are measured on 0.2 and 0.8 of the depth of the channel, taking the average of these as the speed of the water.
   iii. **Weirs:** Weirs are sharp- or broad-crested overflow structures that are built across open canals. They can measure the discharge accurately when correctly installed. However, it is important that the water level downstream is always below the weir crest, otherwise the discharge reading will be incorrect.
   The water level upstream of the structure is measured using a measuring gauge installed at a specified distance from the crest of the weir. The difference in elevation between the water level and the crest of the weir is termed the head and marked 'H'. The discharge corresponding to that water level is then read from a table that is specific for the size and type of weir being used. This implies that the weir should be calibrated and a discharge curve developed specific to the weir. Critical dimensions that should be recorded are:
      a) the level of the weir crest relative to the channel bottom

b) the horizontal distance between the measuring gauge and the weir
c) the level of the gauge relative to the level of the crest of the weir.

iv. **Flumes:** Flumes consist of a narrowed canal section with a particular, well-defined shape. The advantage of flumes over weirs is the small drop in water level (head loss), and so flumes can be used in relatively shallow canals with flat grades. The drop in water level is only one quarter of the drop needed to be able to use a weir, for the same discharge under similar conditions. Because of this, smaller flumes can easily be used as portable measuring devices. Like measurements with weirs, the water level upstream of the flume is a measure of the discharge through the flume, and when the head has been measured the discharge can be obtained by reading the value on a diagram that is specific for the flume being used.

5.7. Operation of Irrigation Systems

5.7.7. Basin Irrigation

1. The basic principle is that water is released into a basin that is reasonably level.
2. The water is retained or ponded inside the basin by means of bunds or small banks of earth, 20 to 40 cm high.
3. The amount of water corresponds to the required water demand at the time.
4. Where basins come in series, such as terraces, one after the other, with the next one on a lower level than the previous one, water is let in the highest basin and if the desired level is attained, the basin overflows and starts filling the next one. This applies to both flat basins and ridged basins in which plants that cannot tolerate standing in water are planted on top or on the side of the ridge.

5.7.9. Furrow Irrigation

In furrow irrigation system, planting may be done on top or on the sides of the ridges.

In ponded furrows, the furrow is ponded with water to the required water depth, and then the flow is diverted to the next furrow. The dead water layer in the furrow slowly infiltrates the soil. Ponded furrows are most suitable on land with slopes of over 2 %.

In the case of other types of furrows, water is let into the furrow at the top and infiltrates to a certain depth before the water reaches the soil furthest away from the inlet. This depth should not be too much in order to attain an even distribution of water over the furrow. The depth depends on the infiltration rate of the soil and the discharge into the field.

Selection of the size of stream flow depends upon the length of furrow, the optimum furrow length, and the optimum non-erosive stream flow. As a rule of thumb, the stream size must be large enough to reach the end of the furrow in approximately one quarter of the contact time. This is called the one-quarter rule.

In order to minimise runoff losses at the end of the furrow, the flow is usually reduced once or twice during an irrigation, such that runoff remains small. The flow could be reduced by taking out siphons from the furrow. Table 16 shows discharge rates through spiles, while Table 17 shows discharge rates through siphons of different sizes.

Table 16 Rates of discharge through spiles

Diameter of pipe (cm)	**Pressure head (cm)**				
	5	**10**	**15**	**20**	**25**
20	18.7	26.4	32.3	37.3	41.7
25	29.2	41.3	50.5	58.3	65.2
30	42.0	59.4	72.8	84.0	93.9
35	57.2	80.9	99.0	114.4	127.8

Source: FAO Irrigation Manual Module 7 Vol. II

Table 17 Discharge for iphons for different head and pipe diameter (l/sec)

Diameter of pipe (cm)	**Head (cm)**						
	5	**7.5**	**10**	**12.5**	**15**	**17.5**	**20**
4	0.75	0.91	1.06	1.18	1.29	1.40	1.49
5	1.17	1.43	1.65	1.85	2.02	2.18	2.33
6	1.68	20.6	2.38	2.66	2.91	3.14	3.36
7	2.29	2.80	3.24	3.62	3.96	4.28	4.58
8	2.99	3.66	4.23	4.72	5.18	5.59	5.98
9	3.78	4.63	5.35	5.98	6.55	7.07	7.56
10	4.67	5.72	6.60	7.38	8.09	8.73	9.34

Source: FAO Irrigation Manual Module 7 Vol. II

5.7.11. Border strip Irrigation

1. Border irrigation entails the guiding of a layer of water down the slope by means of two bunds on either side of a strip. Strips can be 3 to 30 meters wide and 100 - 800 meters long.
2. As in the case of furrow irrigation, it is important to use the right stream size for the soil and land slope and to stop the flow at the right time so that just enough water infiltrates into the soil to satisfy the required irrigation depth. As a rule of thumb, the water supply is stopped when the waterfront reaches between 2/3 and 3/4 of the border strip length. Table 18 gives a general guideline to decide when to stop the flow.

Table 18 Guidelines to determine when to stop the water supply onto a border strip

Soil Type	Stop the flow when advance reaches the following portion of border strip
Clay	Two thirds of total length
Loam	Three quarters of total length
Sand	Almost end of border strip

Source: FAO Irrigation Manual Module 7 Vol. II

Where possible, it is recommended to carry out field tests to determine the best border strip length.

5.7.12. Overhead Irrigation (Sprinkler or Centre Pivot)

1. Overhead irrigation is the application of water to the soil through the air. The simplest ways to do this are the watering can and the water hose. A more complicated method is sprinkler and centre pivot irrigation.
2. A basic sprinkler system consists of:
   - a pump to supply water under pressure,
   - a supply pipe, which is called main line,
   - pipes that supply water from the main line to the sprinkler heads, which we call laterals,
   - the sprinkler head itself. This is often placed on a riser, a pipe between the lateral and the sprinkler-head, to enable the release of water above a matured crop.
3. The sprinkler head can be just a hole in the lateral but the most common one is the rotary sprinkler head. A rotary sprinkler has either one or two nozzles. A single nozzle sprinkler is used at lower application rates and pressures. The two-nozzle sprinkler is used at application rates and higher pressures, the main nozzle being similar to the single nozzle sprinkler and the second nozzle, located at the opposite side of the sprinkler head, irrigating the area close to the sprinkler.
4. The design of a sprinkler system includes a layout of the system, application rate, operating pressure, nozzle diameter, discharge per sprinkler head and the spacing between the sprinklers.
5. The basic infiltration rate of the soil is used as a guide to select a sprinkler with a precipitation rate lower than the infiltration rate.
6. The time of application corresponds to the irrigation need at the time.
7. Table 19 gives the maximum precipitation rates on level ground, which can be adjusted on the basis of the slope of the terrain as shown in Table 19 Table 20 shows the suggested maximum

sprinkler application rates for average soil, slope, and tilth.

Table 19 Maximum precipitation rates to use on level ground

Soil type	Maximum precipitation (mm/hr)*
Light sandy soils	18 - 12
Medium textured soils	12 - 6
Heavy textured soils	6 - 2.5

** Rates increase with adequate cover and decrease with land slope and time*

Source: FAO Irrigation Manual Module 8 Vol. III

Table 20 Precipitation rates reduction on sloping ground

Slope	Percent reduction
0 - 5%	0
6 - 8%	20
9 - 12%	40
13 - 20%	60
> 20%	75

Source: FAO Irrigation Manual Module 8 Vol. III

Table 21 Suggested maximum sprinkler application rates for average soil, slope and tilth

Soil texture and profile	Slope			
	0 – 5%	5 – 8%	8-12%	12 – 16%
	Maximum application rate			
	mm/hr	mm/hr	mm/hr	mm/hr
Coarse sandy soil to 1.8 m	50	38	25	13
Coarse sand soils over more compact soils	38	25	19	10
Light sandy loams to 1.8 m	25	20	15	10
Light sandy loams over more compact soils	19	13	10	8
Silt loams to 1.8 m	13	10	8	5
Silt loams over more compact soils	8	6	4	2.5
Heavy textured clays or clay loams	4	2.5	2	1.5

Source: FAO Irrigation Manual Module 8 Vol. III

5.7.13. Localised Irrigation Systems (Drip)

1. The success of a localised irrigation system is based on proper operation and a regular maintenance programme.
2. Considerations in the application of water to the crops are similar to what has been discussed for overhead systems (sprinkler and centre pivot).
3. Problems and suggested solutions in the operation of localised systems are presented in Table 22.

Table 22 Problems and suggested solutions in the operation of localized irrigation system

Potential problem	**Suggested solution**
Too low pressure at the pump outlet	• Check the suction screen and clean from dirt. • Check the volute and impeller of the pump and clean from dirt. • Check for pipe breakage especially the main line. • Check and ensure that the number of blocks under irrigation does not exceed the number specified in the designs.
Too low pressure at the main filter outlet	• If the pressure at the filter inlet is as specified in the designs and the pressure at the outlet is low, then cleaning of filters is required.
Too low pressure at the block inlet	• Check for pipe breakage in the system and rectify. • Check for open laterals at the block level and close them. • Check for number of blocks in operation and do not exceed design number.
Too low pressure in the laterals	• Check block filter and clean. • Check for open laterals and close. • Check block inlet pressure; if low follow earlier recommendations.
Too high pressure at the filter outlet	• Check number of blocks under irrigation. It could be that less blocks than the recommended number are in operation. • Check filter for ruptures and rectify.
Too high pressure at the block inlet	• Check the number of blocks in operation and rectify.
Lack of knowledge on the time required for the fertilizer to exit the system	• Using an electrical conductivity (EC) bridge, measure the EC of the water. Proceed with injection of fertilizer solution at a specified pressure differential. Measure the EC at the outlet of the furthest emitter of a block. The EC will increase and then decrease to the level measured before connecting the injector. The time taken for the injected solution to reach the EC of the water is recorded and used in the future with the same pressure differential.
Clogged emitters	• Flush the manifold and laterals one at a time until clean water comes out. • Chlorinate. • Use acids.

Flow rate after the main filters has been declining over the past few months.	• Gradual clogging of emitters. Use chlorine and/or acids. • Regularly flush manifold and laterals.
Leaking laterals	• Cut the leaking portion and connect the two ends with a connector.
Leaking grommet	• Excavate soil around the manifold. Identify leaking grommet and replace the rabble ring and the grommet, if needed

Source: FAO Irrigation Manual Module 9 Vol. IV

5.8. Monitoring the Operation Service

Purpose and functions

1. This activity has two main purposes: (i) short-term: acting as a means of management control - comparing the actual pattern of water distribution with what it should have been and helping to identify reasons for divergences; and (ii) long-term: amassing information on water supply, demand and performance etc. in past seasons as a guide to planning and implementation in forthcoming seasons.
2. The functions to be performed by this service include the following:
    i. Day-to-day activities in relation to water distribution
    ii. Preparation of the annual Irrigation or Crop Plan; and
    iii. Preparation of the Annual Report covering the irrigation season to account for the water distribution affairs throughout the season.
3. It is essential that only relevant information (for the purposes of performance evaluation and future planning) should be included.
4. It is also important that the accuracy of the data should be regularly checked; this means checks not only on equipment (e.g. measuring gauges) but also on the junior staff who do the recording.
5. A monitoring and planning unit should be established that would be monitoring the behaviour of the system, including problems of drainage, water supply, water distribution, discharge measuring devices, flooding and sedimentation, and water quality.
6. The establishment of agro-meteorological stations within the area of an irrigation scheme is most advisable in medium or large schemes to provide data for sound calculation of crop water requirements and water balance studies. The systematic collection of these data is essential for the proper operation of the system.

5.8.8. Staffing the Operation Service

1. To function adequately an Operation Service requires the following personnel:
   i. **Water Guards** – sometimes known as ditchriders, or water bailiffs, are the main communication channel between the scheme management and the farmer, so the success of a smooth relationship between the two parties depends on their capabilities and honesty. Their main activities are as follows:
      a) distribute and control the flows that each intake must deliver
      b) open and close intake gates or valves
      c) collection of the water requests
      d) preparation of the daily forms for the water delivery
      e) communication to the master water guard of the request for water
      f) control of the canals and watercourses to avoid unauthorized use of water
      g) compilation of agricultural and water data as needed
      h) delivery of water bills.
      i) they also supervise works related to cleaning of the irrigation canal and ditches, small repairs in the small hydraulic works (intakes, siphons, joints, etc.), major repairs, and repairing and maintaining gates.

   ii. **Operators of large structures** (main canal gates and intakes and dam gates) – these operators are responsible for the operation of flow regulating hydraulic structures. Normally, each operator is responsible for the structures in a given stretch of canal. A main intake may require one or more operators depending on its complexity and hours of work. Their main activities include:
      a) reading of water levels in the canal, river or reservoir
      b) transmitting data to Head Water Master who passes it on to the main office for computation and feedback
      c) manipulating gates and structures as indicated by main office
      d) receiving data from master guards as to the required amount of water, and transfer data to the main office
      e) reporting to the Head Water Master any malfunctioning of gates and structures, who passes on the information to the main office

f) controlling and reporting on the state of maintenance of the stretch of canal for which each is responsible

Main canal operators are frequently given round-the-clock responsibility and should therefore live in proximity to the stretch for which they are responsible.

iii. **Pump-set Operators –** pump operators are needed where pump-sets are used either for lifting groundwater or surface water. Their main activities are as follows:

a. start and stop engines and motors
b. operate engines or motors under the most suitable conditions
c. provide for the regular maintenance of pump and engines/motors
d. check the well discharge regularly check the number of hours that the pump is utilized by each farmer or group of farmers (where applicable)
e. ensure the requisite supplies of fuel oil and grease are available.

They are particularly liable to abuse their positions because they have monopoly control over distribution within the areas commanded by their pumps. Effective management control systems are especially important to keep this situation in hand.

iv. **Water Masters** – also known as "water foremen", supervise water guards and canal operators and are the main channel of communication with the head of the operation service. Such an appointment is only necessary when the group of water guards to be supervised is larger than 12-15. For most of the existing irrigation schemes, the standard is one water master for each 6-12 water guards. Their main activities are as follows:

a) receive the water request from the water guards transmit the water request to the Chief of the Operation Service
b) coordinate, with the canal operators, the operation of the main canal gates
c) transmit operational orders to the water guards according to instructions received from the head of the operation service
d) supervise that the orders transmitted to the water guards are executed accurately.
e) Where the Operation Service is entrusted with maintenance responsibilities during the off-season, the water master supervises major and

minor maintenance work.

Optimally, one water master should be responsible for one or several hydraulically independent sections served by a single canal.

v. **Service Head of the Operation Service** – also called Irrigation Supervisor is responsible for the operation of the whole scheme. His main function is to collect the information provided by the water guards, process it, and issue the operational orders to be executed. Main activities are as follows:
   a) responsible for the preparation of the annual irrigation plan
   b) contribute as required to the preparation of the annual report
   c) schedule the operation as planned
   d) supervise all the aspects related to the operation of the scheme
   e) impose fines and penalties on farmers breaking the rules as adopted in the rules or regulations of the scheme
   f) control operational expenses
   g) ensure the supply of materials necessary for continued operation.

vi. **Auxiliary Staff** – such as drivers, bookkeepers, clerical staff, etc., should be limited to the minimum indispensable to undertake the necessary work. When possible, these services should be provided by a pool serving the other units (maintenance, administration, etc.).

2. Staffing varies greatly depending on the technical characteristics of the irrigation system (number of control structures, complexity of information required about farmers' demands, etc.) and the social attributes of the farmers (educational level, size of holding, etc.).
3. Staffing requirements are also affected by the nature of local transport facilities and telecommunications.

5.8.9. Equipment

1. Little equipment is needed for the operational activities. The following are usually needed:
   i. for the Water Guards: portable water measuring devices can be used to check water flows when the irrigation system is not equipped with water measuring structures. Bicycles or motorcycles help to improve the service.
   ii. for the Canal Operators: radio or telephone for communicating with the main office. They should also have good transport facilities.

iii. for the Pump Operators: adequate mechanical tools for their maintenance work. Transport of fuel, oil and grease should be arranged by the main office.

iv. for the Main Office: small desk calculators and desk computers are necessary for medium-scale schemes. The value of using desk computers or larger ones depends on the complexity of the water distribution methods being used.

CHAPTER 6: THE MAINTENANCE SERVICE

6.1. Scope

1. The irrigation network is perhaps the costliest element of an irrigation scheme and is designed to last a long time. However, all too often one finds that irrigation schemes not long constructed bear little resemblance to the original construction and design. Silt deposition, weed infestation, malfunctioning of structures and other undesirable situations make it practically impossible to control the flow in these canals. As a result, the system is unable to deliver the necessary water and distribute it equitably. On the other hand, with proper maintenance and cooperation among farmers in this task, irrigation systems may last much longer than their original designers or constructors ever envisaged.

6.2. The Vicious Cycle of Maintenance

1. The main purpose of forming a WUA is to ensure efficient operation and maintenance of the irrigation system in a sustainable way for continuous agricultural production so that members can achieve their economic and social goals. When maintenance services are not done efficiently, the following circle results, causing more deterioration of the system:
   i. Poor maintenance leads to siltation of canals, excessive growth of vegetation, seepage, resulting in reduced canal capacity and lack of water.
   ii. The lack of water can lead to late planting, stress on plants and, as a consequence, yields will be reduced.
   iii. With the reduced yields, the farmers' income may be reduced and may not be sufficient to pay the annual operation and maintenance dues.
   iv. This lack of funds for O&M and reduced income leads to poor maintenance and a further deterioration in the system.
2. There are several "external" factors that can also affect the situation. Some of them, such as climate and disasters, cannot be influenced. However, others which can be influenced, such as:
   i. Poor catchment conditions – farmers can discuss with upland farmers how to improve conservation measures in the catchment.
   ii. Poor collection of O&M fees- the WUA can ensure collection of funds.
   iii. Poor crop management- the WUA can assist farmers with training and advice on good crop management practices.
3. Figure 14 shows how the interconnection between main issues that affect and result from inadequate maintenance services.

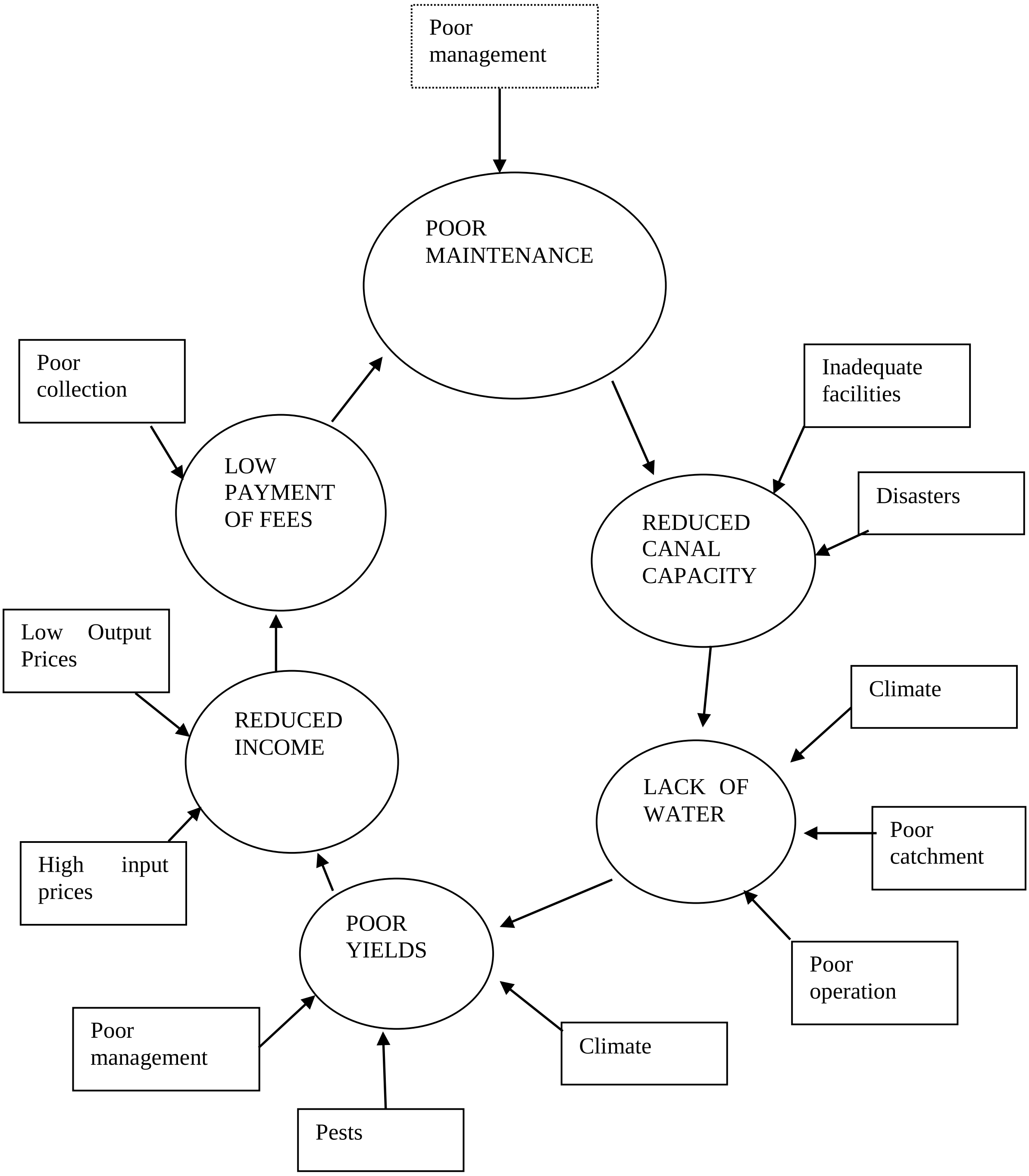

Figure 14 vicious cycle of maintenance (adapted from WUA Manual)

6.2.2. Reasons for Poor Maintenance

1. There are several reasons for poor maintenance, the most important are:
   i. insufficient funds made available to the management, which could be due to prioritising other activities;
   ii. lack of interest by the farmers in participating or collaborating in the maintenance work, which could be due to not realise the importance of maintenance work, not knowing how to do it, feeling that his work benefits others rather than himself, or not identify the irrigation system as his own system;
   iii. poor organization of the work; and
   iv. degree of completion of construction works, i.e. handing over the irrigation system to farmers in an incomplete state of construction hoping that completion shall be done during the period of operation and maintenance.
2. It has been observed that the need for maintenance is greater in "low-cost technology" constructed irrigation schemes than in "high-cost technology". Thus, when using low-cost technologies, special attention should be paid to the maintenance problem if the scheme is to work properly.
3. Where there is little hope that maintenance will be satisfactory, the choice of a high-cost technology design may be justified, but keeping in mind that, although the maintenance requirements of such schemes are smaller in terms of manpower, they require highly specialized personnel.

6.3. Main Functions of the Maintenance Service

1. The Maintenance Service is entrusted with the overall responsibility for keeping the irrigation and drainage systems working in a satisfactory manner, within the limitations imposed by the initial design.
2. The main functions to be undertaken by the Maintenance Service are:
   i. Planning the maintenance activities within the limited resources available;
   ii. Ensure maintenance of head works and main canal;
   iii. Overall supervision of maintenance work in the scheme;
   iv. Ensure adequate water supply in main canal;
   v. Process water rights;
   vi. Registration of all membership;
   vii. Take inventory of structures at the heard works and main canal;
   viii. Process land lease;
   ix. Land allocation;
   x. Periodical system inspection for rehabilitation or regular major maintenance;
   xi. Reporting to Board of Trustees;

xii. Arrange for contractors on works which they cannot afford and supervise accordingly;
xiii. Evaluating and recommending policies and procedures in managing water crises;
xiv. Evaluating and recommending policies and procedures for in-season maintenance;
xv. Preparing an annual operation and maintenance plan;
xvi. Evaluating O&M plans before and after each cropping season and identify problems and formulate procedures to solve them;
xvii. Implementing the maintenance activities planned and those unforeseen;
xviii. Monitoring the above mentioned activities.

3. Maintenance activities can be more easily undertaken in the off-season, when labour from the farming community is normally plentiful. Furthermore, if farmers are engaged in maintenance work on their own land for their own benefit, they are more likely to work willingly. Operational personnel are more free at that time of the year and can be engaged to supervise or execute part of the maintenance work themselves.
4. A Maintenance Service requires data for good and realistic planning, which can be obtained by regular monitoring. A project should endeavour to have its own data based on the specific conditions of the area.

6.4. Types of Maintenance

1. There are three main types of maintenance, namely:
   i. ***routine or normal maintenance*** which includes all work necessary to keep the irrigation system functioning satisfactorily and is normally done annually. Table 23 gives a simplified typical maintenance management programme.

Table 23 Sample maintenance management programme

Component	Maintenance	Effectiveness
Concrete-lined field canal	• Hoeing within canal • Slashing/hoeing sides 2-3 times per year	• Up to 4 weeks • Slashing 4 weeks; hoeing 6-8 weeks
Concrete-lined main canal	• Slashing canal shoulders 3 times per year	• Up to 4 weeks
Night storage reservoirs	• Desilting every 5	• Every 5 years

	years	
Infield drains	• Slashing within drain	• Up to 4 weeks in wet season
Main drains	• Slashing 2 times per year • Hoeing and re-profiling once a year	• Up to 3-4 months in the dry season • Up to 6 months; up to 1 year
Underground pipes for sprinklers	• No maintenance but replace when tractor operator knocks down hydrant valve	• Long lasting
Isolation valves on sprinklers	• Check every month by opening and closing	• Long lasting
Above ground components of sprinkler systems	• Can last up to 15 years before replacement	• Long lasting
Rubber rings in aluminium couplings	• Replace every 2 years	• Up to 2 years and replace
Hoses for sprinkler systems	• Can last up to 8 years before replacement	• Replace when damaged
Rubber flaps on the riser assembly	• Can last up to 5 years before replacement	• Depends upon quality
Garden tap rubber or leather seal	• Can last up to 5 years before replacement	• Depends upon quality
Sprinkler nozzles	• Replace every 2 years	• To maintain correct flow and water distribution

Component	Maintenance	Effectiveness
Sprinkler assembly	• Take to suppliers every 5 years	• Overall check-up (springs, plastic components)
Pressures	• Check that pump and block pressures are within prescribed limits	• Daily
Pump operation	• Check that pump operation is within prescribed parameters	• Weekly
Pump motor	• Pump motor must be greased as prescribed	• Monthly

ii. ***special maintenance*** including repairs of damage caused by major disasters, such as floods, earthquakes and typhoons. The unforeseeable nature of such natural phenomena make it very difficult to take specific preventive action, although general safeguards can be installed in particularly prone areas, e.g. large drainage dykes in flood areas;

iii. ***deferred maintenance*** including any work necessary to regain the lost flow capacity in canals, reservoirs and structures when compared to the original design. In particular cases the system is allowed to deteriorate to a certain level, beyond which it would not operate well, before it is restored to its design operational level. It often includes large modifications to the canal system and structures arising from important changes (cropping patterns, drainage problems, erosion of canal banks) that have occurred in an irrigation scheme. In practice, it is difficult to differentiate between so-called 'deferred maintenance' and a 'rehabilitation programme'. The difference is mainly of a financial nature, because 'deferred maintenance' is normally undertaken with funds from the national budget allocated to operation and maintenance while rehabilitation programmes are considered as an investment and the funds come from a different source (e.g. loans, national development banks).

6.5. Maintenance Activities

Requirements

1. The maintenance activities for which the Maintenance Service is responsible should be clearly spelled out in the by-laws of the irrigation scheme.
2. While some activities are clearly a responsibility of the Service (silt removal in canals, weed clearing, etc.), there are others not so precisely defined, for instance, rural roads, ancillary works, buildings, the cleaning of the drainage system.

6.5.1. Dams and Reservoirs

1. Maintenance activities in a reservoir itself comprise:
   i. controlling aquatic weeds;
   ii. removing large debris (e.g. tree trunks) floating in the water that may damage hydraulic works;
   iii. monitoring the water quality: not only from the salt content point of view but also from a biological standpoint in order to detect possible sources of pollution;
   iv. grass cutting and removing all trees and shrubs growing on the embankment;
   v. surveying the solid deposition in the bottom of a reservoir;
   vi. Inspection and filling of the embankment for any signs of weakness, cracks, animal burrows, leakages due to piping, that may result in failure of the dam;
   vii. Any signs of erosion at the spillway that may lead to collapse of the structure and failure of the dam.

2. The most common water weed in reservoirs in semi-tropical and tropical areas is the water hyacinth (Eichhornia crassipes). This plant forms an ideal environment for mosquito larvae and has evaporation several (2.2 to 13.4) times greater than an open water surface. The plant has a very fast rate of growth: two plants can produce enough offspring to cover one acre in less than eight months.
3. Another frequent problem is eutrophication (over-abundance of nutrients in the water bodies) resulting in high production of blue-green algae and the associated phenomenon of lack of dissolved oxygen in the water. The main consequence is that of increasing vegetation in the irrigation canals and greater weed infestation.
4. The main maintenance activities for an irrigation dam are: lubrication of gates, anti-corrosion treatment, cleaning of debris, control of filters, and some other minor work. Earth dams require greater maintenance, especially the upstream slope where weed control is necessary once or twice a year.
5. The electro-mechanical system of a dam must also receive proper maintenance, particularly electric engines, head gates, and the lighting system. The maintenance of these elements is rather specialized and the manufacturers of the equipment usually provide

detailed instructions

6.5.2. Night Storage Reservoirs

1. Night storage reservoirs should not stay dry for a long time as this allows cracks to develop in the clay in the core, embankment, and bed.
2. It is necessary, however, to empty the reservoirs from time to time in order to clear them of weeds. Weeds, besides harbouring snails, tend to reduce the capacity of night storage reservoirs.
3. It is also recommended to allow the water level in the reservoirs to fluctuate to control snails.

6.5.3. Headworks

1. The main problems with the headworks are leakages.
2. Regular desilting is also necessary and removal of blockages.
3. Damaged gates and other metal components should be repaired or replaced immediately.

6.5.4. Irrigation Canals

1. Concrete-lined Canals
   i. Concrete-lined canals should require little maintenance, provided that they have been properly constructed and any potential problems studied (sub-pressure, gypsum soils, swelling clays, etc.) and adequate technical solutions provided. One of the main reasons for constructing concrete-lined canals is precisely to reduce maintenance operations.
   ii. The routine activities include: replacement of joints, replacement of damaged concrete slabs, weed control in joints and on the surface of concrete slabs, control and treatment of filters, control and removal of silt. In the case of concrete flumes, chemical sterilization is also needed around the supporting structures.
   iii. Under normal conditions, the silting in concrete-lined canals is not an important problem since water velocity is high and sand traps and silting basins are often provided to reduce the solid content of the water. Heavy rain may cause deposition of solid materials if the berms are not properly formed.
   iv. Removal of silt from concrete-lined canals is an expensive operation because it is mainly manual. In some irrigation schemes, the technique of flushing "quick water" through the canal is used to remove silt from one place and concentrate it in another where it can be more easily removed or disposed of. For this purpose, the canal should be run at its maximum capacity to reach the highest possible velocity.
   v. Weed control should not be a major problem in lined canals, although aquatic weeds must be periodically removed.
   vi. The main problem in concrete - lined canals is cracking of the lining and eventual eruption of concrete slabs due to sub-

pressure.

vii. Apart from repairing the damaged lining, corrective action must be taken. Usually the installation of sub-pressure valves is enough to relieve the pressure, but this involves major work. An alternative measure can be the construction of a subsurface drainage system to lower the water level.

2. Clay-lined Canals
    i. If a sufficient volume of clay soil can be found in the vicinity of the scheme, clay lining might be the cheapest method to use to reduce seepage losses.
    ii. The clay should be well spread in the canal and well compacted.
    iii. However, clay lining is susceptible to weed growth and possible soil erosion. Maintenance should be done as soon as the defect has been observed.

3. Polythene-lined Canals
    i. Polyethylene plastic sheeting can be used for lining canals. The sheets should be covered with well-compacted soil, since the plastic deteriorates quickly when exposed to light.
    ii. Furthermore, tools such as shovels and slashers can easily damage it during maintenance works.
    iii. Weed growth and soil erosion could also cause problems in the canal.

4. Sand-Cement-lined Canals
    i. If coarse aggregates are not available for the preparation of concrete, the method of sand-cement lining could be considered.
    ii. A strong mixture is either placed in-situ on the canal sides and bed or is precast (thickness 5-7 cm). A mix of 1:4 (cement : river sand) is recommended.
    iii. Cracks should be filled as soon as possible to prevent damage to the lining.
    iv. Weed growth should be prevented as this will tend to weaken the lining.

5. Brick-lined Canals
    i. If good clayish soils, suitable for producing good quality burnt bricks, are found near the scheme area, brick lining could be considered.
    ii. Cement is required for mortar and plastering.
    iii. A disadvantage of this lining method is the large amount of firewood needed to burn the bricks. In this regard, and for the sake of environmental conservation, bricks should be either sand/cement or soil stabilised.

iv. Plastering with cement mortar is usually done in order to provide additional strength and durability.

v. Cracks may develop due to pore pressure where the canal depth is 1.0 m or more. Weep-holes should be provided at regular intervals to relieve the pore pressure in the canal side slopes.

vi. Regular inspection of the lining should be maintained, and maintenance and repair should be done after every irrigation season.

6. Earth Canals

i. <u>Silting</u>

a) Excessive sedimentation is perhaps the most common problem affecting the performance of earth canals. The following are some causes for canal siltation:

1. excessive silt entry at the main canal intake
2. disproportionate withdrawal by branches
3. prolonged heading up at control points
4. drifting sand
5. inadequate transport capacity of channels
6. re-entry of excavated material by rain and wind action
7. malfunctioning of intakes
8. haphazard sediment excavation
9. excessive weed growth
10. wrong channel regulation.

b) Causes 1 to 5 indicate defective design. Corrective measures for defective design are difficult to implement since they require major physical changes which imply heavy investments. However, the effects of defective design can be reduced by proper maintenance.

c) Causes 6 to 9 indicate inefficient maintenance, while 10 denotes improper channel operation.

d) Canals carrying a heavy load of material in suspension should not be allowed to run at less than three quarters of their capacity since at lower capacities the velocity decreases inducing silting.

e) Abrupt shutting of gates, causing rapid changes in flow velocity, may induce bank erosion near the gates.

ii. <u>Weed infestation</u>

a) Weed infestation can seriously impede the flow of canal water.

b) *<u>earth weeds</u>*: they root in the soil and their habitat is not the water; they proliferate on the canal slopes and in the banks, benefiting from favourable soil moisture conditions;

c) *aquatic weeds*: they can either root in the water or the earth but their habitat is in the water. Robson (1976) classifies them as follows:
   - emergent plants - these are plants growing in the water and whose foliage emerges above the surface, e.g. the common read (Phragmites communis);
   - floating leaved plants - there are two sub-groups with floating leaves: in one, the plants are rooted in the mud and their leaves float flat on the surface, in the other, plants are not rooted but free-floating on the surface;
   - submerged plants - this group consists of plants whose foliage is totally submerged; a number of them produce flowers which emerge above the surface; one or two plants are free-floating, but most are rooted in the mud;
   - algae - this group consists of a variety of algae of various forms, including unicellular algae and the large filamentous forms.

d) Some of these weeds, such as nutgrass (Cyperus rotundus), are not only a problem in the operation of the canals but can become a menace for the farmers when water transports them into fields. There they reproduce rapidly and become a serious problem because of the difficulty of eradicating them.

e) Another hazard of weed infestation is the shelter and good breeding conditions they offer for vectors (mosquitoes, snails, etc.) of debilitating diseases.

iii. Water infiltration

a) Water leaks through canal banks can be caused by burrowing small crabs and water rats or by rotting plants and roots which were not removed from the canal bank seat during construction. Ants are also known to be a problem even in concrete-lined canals.

b) These leaks can be repaired by following the path of the leak through the bank either by hand digging or hydraulic backhoe if available and once the path has been found, the trench must be carefully backfilled and compacted.

c) Canal leaks, if not repaired in time, can result in major breaches in banks causing far greater inconvenience and most costly repairs.

d) Water seepage through porous soils may also be a major concern. Seepage through banks can be considerably reduced by trenching them and burying a plastic membrane or thick slurry made from the excavated material. The trench is backfilled with sand after the barrier has been interred.

iv. Erosion of banks

a) Canal banks can be eroded by heavy rainfall or wind, improper canal operation, animal grazing or passage by drinking animals, and the transit of vehicles.
b) Heavy rainfall or wind can cause serious damage to unprotected banks.
c) Seeding of grasses in the unwetted part of the canal is a cheap and effective protective measure. Short growing varieties (e.g. Agropyron riparium (streambank wheat-grass), Psathyrostachys juncea (Russian wildrye), Festuca ovina (sheep fescue) and Phleum bertolonii (dwarf timothy)) give good results.
d) Abrupt and rapid shutting off of canal water may also contribute to erosion of the banks.
e) The practice of leaving a canal empty during the rainy season will contribute considerably to erosion of canal slopes.
f) Cattle, goats and sheep damage the channel banks in different ways (Swales 1976). Cattle tend to push the moist bank material at the waterline into the waterway when they drink. Goats and sheep, however, graze the banks bare thereby allowing wind and rain to wash away the bank material.
g) Erosion of canals can be repaired by mechanical means or manually by re-building the worn canal banks. However, care should be taken to construct a proper join between the old and the new part, otherwise the canal will deteriorate at the same place.
h) The most effective measures are of a preventive nature: such as seeding grass mentioned earlier, fencing the canals, and constructing special places for animal watering and bathing.

6.5.5. Pipelines and Sprinklers

1. As a rule, the underground components of the system require no maintenance. However, at times, because of careless errors during cultural practices (for example tractor operators knocking down valve hydrants), pipes have to be replaced in order for the system to operate at the designated pressure.
2. Isolation valves, when unused for long periods, get stuck to the opening position and cannot be closed any more for the purpose of isolating the areas of breakages from other areas. This causes the whole system to be down, until repairs are made for minor breakages. It is therefore necessary that once a month all isolation valves are checked by opening and closing as well as lubricated.
3. The above ground components of the system, if carefully operated and maintained, are expected to last for about 15 years. This would require careful movement of aluminium pipes, after each riser and sprinkler have been disconnected from the pipe to facilitate ease of movement to the next position.
4. Portable aluminium pipes are connected through couplings with rubber rings in order to ensure watertight connections. These rings have a life of about two years and need to be replaced accordingly.

5. The hoses used for sprinkler systems are rated at 7 metres pressure and are reinforced. Their life expectancy is about eight years. However, at times perforations or cuts occur during cultivation. In this case, line joiners can be used to repair the hoses.
6. Another item that requires replacement is the rubber flap of the riser assembly which, depending on quality, can last about five years. The same holds true for the garden tap rubber or leather seal.
7. With respect to the sprinklers, it is necessary that all nozzles are replaced at least every two years (four seasons), in order to maintain the correct flow and distribution of water from the sprinkler. This is particularly important when surface water with high load of suspended solids is used for irrigation.
8. The tension of the sprinkler spring and the wear of some of the plastic seals also require attention. It is therefore, necessary that every four to five years the sprinklers are taken to the supplier for an overall check-up.

6.5.6. Drainage Network

1. The need for proper maintenance is especially important during the first two years after a ditch is constructed.
2. It is desirable to establish adapted grass for erosion control on the ditchbanks as soon as possible since they are susceptible to the growth of undesirable woody vegetation.
3. The most common problem with drains is weed growth. Weeds should be frequently removed so as to maintain the design capacity of the drains.
4. Maintenance work includes control of vegetation by mowing, pasturing, or chemicals, timely removal of sediment bars as they form, removing sediment after a few years' accumulation, repairing structures, and doing such other work as necessary to retain the original effectiveness of the systems. If ditches are allowed to be overgrown with brush and small trees they may have only one-half to two-thirds of the designed capacity.
5. Maintenance must be carried out effectively for the drainage system to operate as planned. Guidelines in Table 23 also apply.
6. The retention in good working order of open drains includes the following operations:
   - light deforestation
   - weed control in the canal section
   - seeding grass in the canal section
   - maintenance of flow gauges and other measuring devices
   - removal of silt
   - maintenance of pumping stations where water cannot be evacuated by gravity.
7. For practical purposes, the maintenance of open drains is very similar to that of earth irrigation canals. However, all too often drainage networks receive much less attention than the irrigation ones. The

result is that during heavy rain, when they are much needed, they do not work as they should.

8. Drainage maintenance should always be programmed from downstream to upstream, and as far as possible completed within an irrigation season. The intervals in regular maintenance should not exceed periods of 2-3 years between two consecutive cleanings.
9. Methods of maintenance include the following:
   i. ***Using construction equipment for maintenance.*** - Usually the same equipment used in construction can be employed economically for removal of sediment and reshaping of spoil at intervals as needed after construction. Effective maintenance work by hand tools and with manual labour could pause some problems.
   ii. ***Mowing.*** - Mowing is effective in most locations for controlling brush and encouraging grass on ditchbanks, travelways and spoil disposal areas. Use of appropriate equipment could enhance the maintenance work to be more effective.
   iii. ***Pasturing.*** - Controlled pasturing is one of the most economical and effective methods of maintaining ditches. In some locations pasturing is not practical because of the type of farming adjoining the ditches. Pasturing should be controlled to keep cattle off ditchbanks especially during wet weather. Pigs should be kept out of ditches
   iv. ***Burning undesirable vegetation.*** - In sane locations controlled burning in the winter is useful to remove dead weeds, tall grass and small brush. This type of maintenance should be limited to channels through open areas and must comply with local antipollution regulations.
   v. ***Chemical control of vegetation.*** - Chemicals to control undesirable vegetative growth are effective. Caution should be used in their application to prevent damage from the drifting chemicals and poisoning. The most up-to-date information available, including data on new herbicides, should be followed.

6.5.7. Scheme Road Network

1. Scheme roads are of vital importance in irrigation schemes, especially at harvest time. Maintenance of these roads should be included in the responsibilities of the Maintenance Service.
2. These roads are best grassed to avoid eroded soils being deposited in the adjacent drains or canals.
3. Any anthills growing on the roads must be removed as quickly as they have been noticed.
4. Care should be taken not to dump road maintenance debris into channels or canals.
5. If possible, these roads must be passable by light vehicles or tractors all year round. They are not made to sustain heavy traffic. Refilling and compaction of potholes and gullies should be done immediately.

6. Dust roads deteriorate rapidly in rainy conditions and become unusable without proper maintenance.
7. Unfenced roads can also be damaged by livestock using the tracks.
8. Repairs and maintenance can be greatly reduced by keeping the shoulder drains in good condition to evacuate excess water quickly.

6.5.8. Berms, Embankments, Dykes

1. Maintenance of the berms of canal banks or flood protection bunds (dykes) is similar to that for dust roads.
2. The common problems of embankments are erosion, leakages and weed growth. Refill and soil compaction should be done when repairing embankments.
3. Weeds and shrubs should be slashed. Trees must not be allowed to grow; they should be uprooted as soon as recognised.
4. Preventive measures, such as prohibition of traffic on banks and berms which are not supposed to be used by heavy machinery (trucks, tractors, etc.) may considerably reduce the maintenance needs.
5. Flood protection dykes can be badly damaged in severe flood conditions and as such situations cannot be anticipated, their repair must be by so-called special maintenance, for which special budget allocations are needed.

6.5.9. Land Levelling

1. After the initial land levelling during project construction, it is necessary to periodically level the fields in order to maintain the desired field slope. This can be done by machinery or manually.
2. If levelling is done manually, it is still recommended that after every two to four seasons farmers use machinery, such as a land plane.

6.5.10. Structures

1. The common maintenance problems with structures are siltation, leakages caused by cracking and weed growth. They should be maintained accordingly.

6.5.11. Gates

1. Gates can have problems of rusting or sticking over time and leaking. They should be painted to prevent rusting.
2. Any movable parts should be greased or oiled to prevent sticking. Replacing warn-out water seals, if there are any, can minimize leaking.

6.5.12. Pump Stations

1. Pumping stations for irrigation schemes may be:
    a. main irrigation lift-pump stations (surface water or groundwater);
    b. booster-pump stations for additional lifts in the main or branch canals;

c. drainage-pump stations.

The first two are usually of medium to high lift, required to pump forecasted quantities of water for long continuous periods. The last is usually for low lift with much larger quantities of water and required to operate intermittently.

2. The irrigation pumps are usually manually controlled whereas the drainage station is frequently float controlled to ensure automatic starting once drainage levels in the scheme begin to rise above a pre-set level. A manual operator should also be on call even with an automatic control.
3. Operation and maintenance tasks for electric pump stations are comparatively simple, those for diesel operated a little more complex. The operators must be given clear instructions on safety measures, on the methods of starting the pump motors and the way in which they must be brought into full operation. Electric motors sometimes require to be stepped up in speed manually at a strictly controlled rate. Also canals may be damaged if all pumps come rapidly into full operation.
4. Operators must also be given a programme of irrigation quantities to be pumped i.e. 1, 2 or 3 etc. pumps to be operating simultaneously.
5. Where 24-hour pumping is not provided, account must be taken of the rate of rise and fall of canal levels in the irrigated area. It is of little use with a 12-hour pumping schedule if canals do not fill up until late in the morning and still remain full long after dark.
6. In case of an emergency, there must be some system for easy communication between the pump house operator and the officer in charge - either telephone or signal or runner.
7. In Table 24 are some general causes of pump malfunctioning and their remedies that can be used for on-spot trouble-shooting when pump problems are encountered. Annex 7 gives a general troubleshooting list for the maintenance of pumps.

Table 24 Pump problems, causes and corrections

Symptoms	Causes	Corrections
Failure to pump	1. Pump not properly primed	1. Prime pump correctly
	2. Speed too low or high	2. Check speed, check calculations, consult with manufacturer
	3. Not enough head to open check valve	3. Check speed, check calculations, consult with manufacture
	4. Air leak	4. Check and rework suction line
	5. Plugged section	5. Unplug section
	6. Excessive suction lift	6. Check NPSH and consult manufacturer
Rapid wear of	7. Misalignment	7. Align

coupling cushion	8. Bent shaft	8. Replace
Reduced performance	9. Air pockets or small air leaks in suction line	9. Locate and correct
	10. Obstruction in suction line or impeller	10. Remove obstruction
	11. Insufficient submergence of suction pipe	11. Extend suction line to deeper water to the extent that NPSH allows you or excavate and deepen the area where the suction basket is located
	12. Excessively worn impeller or wear ring	12. Replace impeller and/or wear ring
	13. Excessive suction lift	13. Calculate NPSH, consult with manufacturer
	14. Wrong direction of rotation	14. Ask contractor to rectify
Driver overloaded	15. Speed higher than planned	15. Reduce speed
	16. Water too muddy	16. Raise suction
	17. Too large an impeller diameter	17. Trim impeller
	18. Low voltage	18. Consult power authority
	19. Stress in pipe connection to pump	19. Support piping properly
	20. Packing too tight	20. Loosen packing gland nuts
Excessive noise	21. Misalignment	21. Align all rotating parts
	22. Excessive suction lift	22. Check NPSH, consult with manufacturer
	23. Material lodged in impeller	23. Dislodge obstruction
	24. Worn bearings	24. Replace bearings
	25. Impeller screw loose or broken	25. Replace
	26. Cavitation	26. Check NPSH, correct suction piping
	27. Wrong direction	27. Ask contractor to rectify

	of rotation	
Premature bearings failure	28. Worn wear ring	28. Replace
	29. Misalignment	29. Align all rotating parts
	30. Suction or discharge pipe not properly supported	30. Correct support
	31. Bent shaft	31. Replace shaft
Electric motor failure	32. High or low voltage	32. Check voltage and consult power authority
	33. High electric surge	33. Monitor voltage and consult power authority
	34. Poor electric connection	34. Turn power off, clean and check connections
	35. Overloads	35. Check amperage, do not exceed full load amperage
	36. Bearing failure	36. Change motor bearing
	37. Cooling vent plugged (rodent, dirt, leaves)	37. Install proper screen
	38. Moisture or water in motor	38. Send for blow-dry and protect from environment

Source: FAO Irrigation Manual Module 5

6.5.13. Solar System

1. A very minimal effort is required for maintenance of the panels including their regular cleaning.
2. Solar panels are required to be cleaned, particularly in dry areas or where panel tilt is minimal as, dust and other substances, such as bird droppings, can build up over time and impact the amount of electricity generated by a panel.
3. Air pollution, dust, fallen leaves and even bird droppings block sunlight falling on the solar panel surface. Grime and bird droppings do not need to cover an entire panel to have an effect. Experience suggests that dirty solar panels, which have not been cleaned for a week, lead to a drop in power generation by as much as 25 - 30 percent. Hence, it is absolutely necessary to clean the solar panels to ensure maximum power output and water discharge rate.
4. Before commencing cleaning, ensure that procedures are followed that are described in the operation manual which is provided by the manufacturer/supplier.
5. For safety reasons, it is also advisable to clean solar panels from the ground itself, wherever possible. A good quality soft brush and a squeegee with a plastic blade on one side and a cloth covered sponge on the other side, with a long extension is an adequate tool to

perform solar panel cleaning from the ground level itself.

6. Solar panels can also be cleaned using a hose with a suitable nozzle to allow a stream of water to reach the panels.
7. Training is provided for maintenance and cleaning by the company installing the pump. Village personnel can easily be trained to take care of the pump and solar panels.
8. Solar panels when properly maintained continue to produce electricity for the pump for even longer than 25 years.

6.5.14. Ancillary Works

1. The hydraulic structures in an irrigation scheme include: gates, inlets, spillways, outlets, dividers, siphons, jumps, check dams and other minor structures.
2. Maintenance of such items, when they are constructed in concrete, is restricted to the removal of silt and obstructions.
3. The mechanical elements require periodic greasing. Iron elements require antirust treatment. The same applies to structures in drainage networks (e.g. culverts, drainage outlets) and those in road networks (e.g. bridges, culverts, crossings).
4. Administrative buildings and some other special installations (e.g. stores, workshops, warehouses) require a certain amount of upkeep and should not be overlooked.

6.6. Planning Maintenance Activities

1. In order to be able to formulate a maintenance programme, the following steps must be taken:
   i. make an inventory of all the works that require maintenance;
   ii. determine the volume of maintenance activities to be undertaken annually;
   iii. establish the optimum cycle of maintenance for each type of work;
   iv. determine the machinery and manpower requirements to undertake the maintenance;
   v. budgeting and establishing the maintenance priorities.

6.6.1. Inventory of the Works

1. Most irrigation schemes already have maps available, also lists of the main works and structures, but for maintenance purposes it is necessary to group the latter into types with similar characteristics. In this way, calculations can be simplified and machinery utilized to the optimum. The grouping is specific to each irrigation scheme. An example of grouping by canal type is as follows:

Table 25 Example of grouping by canal

Canal Type	Width of base (m)	Height of water (m)
A	10 – 20	> 3.0
B	8 – 10	2.5 – 3.0
C	4 – 6	1.8 – 2.4
D	2 – 4	1.3 – 1.7
E	1 – 2	< 1 – 1.2

2. Other works (roads, structures, lined canals, etc.) can be grouped similarly.

6.6.2. Volume of Maintenance Works

1. In order to prepare a maintenance programme, the amount of work to be undertaker under each category of maintenance must be known.
2. A detailed list of maintenance works should be prepared for the main elements in the irrigation canal network, the drainage system, and for work concerning roads, buildings and workshops.
3. The extent of work to be undertaken shall be determined by visual inspection, followed by detailed measurement of the volume, area, or unit lengths of each task. The most complex estimate is generally that of silt clearance, since owing to variations in the sections of the canal and consequent differences in water velocity, the silt is deposited unevenly.
4. In order to determine the amount of silt to be removed, a topographical survey is made by taking the sections every 50 or 100 m according to the required degree of precision. With the data obtained the area of the sections is calculated. The volume of sediment (Vp) for each stretch of length will be:

$V_p = ½(A_1 + A_2)\ l$

where A_1 and A_2 are the transversal section of the sediment and l the length of the section, and therefore for a canal of constant section:

$V_p = \{½(A_1 + A_n) + A_2 + A_3 + ...A_{n-1}\}\ l$

5. Once all the measurements of the maintenance activities are complete, they should be grouped according to activity in order to determine the manpower and machinery requirements.

6.6.3. Optimum Cycle of Maintenance

1. The optimum cycle of maintenance is the time that can safely elapse between two consecutive maintenance operations of a constructed element (canal, road, drain, etc.) without that element failing and disrupting the efficient operation of the whole.
2. A certain degree of malfunctioning (10-20 percent reduction in absolute efficiency with respect to the design) is normally acceptable between the two consecutive maintenance operations.
3. The optimum maintenance cycle is determined by local factors such as climate, length of irrigation season, quality of the water, quality of

the construction, etc., and it should be based on experience gained in the particular project or in other irrigation schemes with similar conditions in the country.

6.6.4. Machinery and Manpower Requirements

1. The first decision is whether maintenance should be manual or mechanical.
2. In general, preference is given to machinery in high cost technology projects because the original reason for constructing them in that way was influenced by the scarcity of labour and the availability of technically skilled personnel.
3. Low cost technology projects should rely as far as possible on manual labour. As far as technically and economically feasible, maintenance should be by local labour and only where it is not possible should resort be made to machinery, particularly since most of the irrigation projects are in areas where labour is plentiful.
4. In some cases, there may not be sufficient labour to undertake the requisite amount of work in the time available and thus the use of machinery becomes unavoidable.
5. As there are many maintenance activities, it is not always possible to have the ideal machine for each specific activity. Therefore, versatile machinery is preferable to highly specialized.
6. The machinery or manpower requirements can easily be calculated once the output of the machinery or labour for a given maintenance task and the amount of work to be done are known.
7. **Silt clearance –** Silt is still removed manually in many parts of the world, provided that the water levels in the canals can be lowered sufficiently or, even better, the canals dried for several days. This method is quite effective, although the actual organization of the work can be a problem.

    i. Where water-borne diseases are known to be prevalent, the use of labour should be restricted to those canals that can be dried completely for several days, otherwise mechanical means should be adopted.
    ii. Productivity of labour is generally low due to the muddy conditions in which they often work. Output therefore varies widely from 2 to 8 m^3/man-day, depending on several factors such as working conditions, tools, lifting and hauling distance.
    iii. Several types of machines are utilized for silt removal and canal reshaping. The productivity depends largely on how well suited the machine is to the particular work. Annex 2 rates the productivity of machinery most commonly used for removing canal silt and reshaping, but most of these machines can do a certain amount of weed clearance at the same time, which affects their productivity. The given rates are applicable to medium or small size canals and

refer mostly to dry working conditions. The output will be reduced by 20-30 percent under wet conditions except for the machines (dredgers) specially designed to work in running water.

iv. The selection of machinery is mainly influenced by its reach and working conditions: wet or dry, accessibility, amount and type of work, weed infestation, etc.

v. A combination of labour and machinery is particularly frequent in lined canals, where silt is removed and accumulated at certain points by labour and then removed by mechanical means.

8. **Control of canal vegetation** – Weeds are normally removed by cutting, mowing or dredging.

i. Emergent and submerged weeds are best cut near the base of the stem, leaving roots and rhizomes undisturbed.

ii. Weeds need cutting at regular intervals throughout the season and the interval varies according to the environmental conditions and species.

iii. The stage of growth at which the plant is cut affects the rate of growth; cutting at an early growth stage tends to be more effective than at a later one.

iv. Four main methods are used to control canal vegetation, (a) manual, (b) mechanical method depends weed species, (c) chemical, and (d) biological. The choice primarily depends upon the availability of labour, the predominant environmental and economic conditions.

a) <u>Manual</u>

Much of what has been said for the manual removal of silt applies to this method of weed control. However, since it requires a little more skill, the choice of an appropriate hand tool is more important and will lead to relatively, high productivity. Annex 3 illustrates some of the characteristics of these hand tools and their related productivity.

b) Mechanical

There are many types of specially designed machines available for specific weed control purposes. In some cases, it is preferable to adapt a regular farm, tractor for use with different attachments. Rubber wheeled 40-60 hp farm tractors can travel along channel banks with a maximum slope of 1:3 percent using the PTO (power take-off) for the implement. This operation requires neither specialized operator nor training nor equipment. For slopes steeper than 1:3 percent, hydraulically operated machines are available. Tractor-dragged chains are more effective on steeper slopes. Two 60 hp tractors can easily handle channels 6 m wide. Mower and cutter attachments are used mainly for grass and reeds on banks of watercourses, while buckets are more appropriate for emergent and submerged weeds. Launches can be used for mowing and cutting emergent weeds on banks, if the size of the channel permits their passage. Details and productivity of the different types of machinery are given in Annex 4.

c) Chemical
Chemicals have been developed which can control weeds effectively and safely, provided that adequate precautions are taken. They also offer an economic system of weed control in certain circumstances. The use of herbicides should, however, be limited because of their possible adverse effects on the environment. It is known that some herbicides may affect the quality of water to the extent that it becomes harmful to humans, animals and crops. Therefore, they should be selected with care. Where their use may prove hazardous, it may be necessary to limit or even prohibit them. Annex 1 gives a summary of some available herbicides and their use.

d) Biological
Biological control may become more important in the future in view of the disadvantages of other methods (high costs, danger to the environment). The most common method is the introduction of an animal, fish or insect which feeds especially on the problem plant. Recently, attention has been given to the use of the grass carp (Ctenopharyngodon idella) for the control of submerged weeds and, in some cases, it appears to be an economical and effective way of control.

The introduction of competing plants (grasses) has been tried but this is not appropriate in watercourses where the flow must be unobstructed.

v. Sometimes weed growth can be prevented by fluctuations in the water regime, for example, holding a canal dry for 3-6 days is most effective in the control of algae. However, the success of this method depends on the weed species.

9. **Road maintenance** – Scheme road maintenance work is well best done by labour. There are several useful combinations of labour and

machinery that depend on the local wages and availability of machinery. Table 26 gives some generalized information on the machines most commonly adopted for road maintenance. Motor graders, complemented with a water bowser and roller, are particularly useful for remodelling macadam and dust roads. Tipper trucks combined with loaders are normally used to haul base material for distances over 500 m, which is usually the case. The scraper is more suitable for short distances but there is rarely opportunity for its use in road maintenance work. Medium size bulldozers are also useful in some of the remodelling work before a grader can be used efficiently.

Table 26 Machinery used for road maintenance and land grading

Type	**Productivity**	**Optimum hauling distance**
Bulldozer (130-150 HP)	400 m^3/day	100 m
Grader	1000 m/day	50 m
Tipper truck[2]	300m^3/day	500 m or more
Loader/shovel (1.2 m^3 bucket)	300 m^3/day	20 m
Scraper towed (12.0 m^3 bowl)	1100-1200 m^3/day	100-250 m
Motor scraper (12.5 m^3 bowl)	1100-1200 m^3/day	250-500 m
Tyre or sheep foot roller	800-1000 m^3/day	
Water bowser	1000 m^3/day	

[1] Productivity figures are only an approximation; precise indications can be obtained from dealers when working conditions are known.
[2] Used in combination with loader or shovel.
Source: FAO Irrigation and Drainage Paper No. 40

6.6.5. Costing and Establishing Maintenance Priorities

1. Costing the intended maintenance programme is an easy operation because the amount of work to be done has been determined and the basic unit prices are known.
2. It may be important to present a detailed justification for some of the intended works emphasizing the consequences (financial and social) if they are not carried out.
3. It is also advisable to earmark some funds for unexpected repairs. About 10-20 percent of the total budget for this purpose is generally accepted.
4. As in any budgeting operation, the initial estimates may have to be reconsidered and curtailed in relation to the finances available. This is often the case where allocated funds are considerably lower than those requested. At this point, the establishment of priorities is an important exercise in which all the units of the water management organization should participate.
5. The maintenance programme is usually adversely affected by this kind of budgeting exercise because the effect of reducing the level of upkeep is not apparent in the short run.

6. The establishment of maintenance priorities depends on many factors such as reduction of manpower and machinery, etc., and is therefore site specific.
7. A sample budget is provided in Annex 5.

6.7. Implementing the Maintenance Programme

1. The implementation of maintenance activities is highly site specific in nature, but some general management principles can be applied, the most relevant of which are as follows:
    i. Good planning is particularly important in maintenance work since the time and resources available for its execution are limited. The use of planning techniques such as critical path methods and bar diagrams, is helpful, though rarely put into practice.
    ii. Monitoring the output productivity is essential, not only to feed back the planning process with realistic data but also to control the progress of the work planned.
    iii. Farmers' participation in maintenance work should be encouraged. In some irrigation schemes the contribution of a number of man-days per farmer is spelled out in the by-laws of the scheme. In other cases, the responsibility may be for specific studies of irrigation ditches. The Maintenance Service should provide technical guidance, organize and control the work.
    iv. Maintenance work on a voluntary basis is customary in some old irrigation associations but it is difficult to obtain in public irrigation schemes. In this latter case, the use of incentives such as food and transportation, is advisable and work should be restricted to special repairs that need unexpected large human resources.
    v. Whenever unskilled labour is required, use should be made of the human resources of the farming community of the project.
    vi. Subcontracting part of the maintenance work may be advisable in certain circumstances and should be more frequently adopted. It reduces the number of permanent staff in a maintenance unit and is a system that can be adapted to maintenance conditions that change from one year to another. It is highly suitable for specialized jobs such as maintenance of electro-mechanical equipment of gates and remote control devices, placing and removing deep well pumps, etc. Irrigation schemes having few vehicles and machines should also consider the possibility of subcontracting their maintenance rather than having a poorly equipped workshop where maintenance may be of low standard.
    vii. A sample maintenance schedule has been included as Annex 6.

6.8. Catchment Management

Definition

1. Precautionary actions, procedures or installations undertaken to prevent or reduce harm to the environmental integrity of drainage areas used to catch water, such as reservoirs or basins.
2. Defining the objectives: Addressing questions such as why the water catchment protection activities should be initiated, what is the aim of the water catchment protection activities, how will it be implemented and what will be the expected outcome of the water catchment protection activities.
3. Check any policies that address catchment management and its implementation.
4. Define actual or potential locations for water catchment protection.
5. Check activities currently being undertaken within the catchment and composition any existing catchment management committees and their influence.
6. Sensitise all stakeholders who will be affected by the water catchment protection activities or have an interest in the water catchment protection activities.
7. Identify size and place of the area to be protected.
8. Identify the necessary protective measures and discuss to consensus with all affected stakeholders for their implementation. Agree on a catchment conservation plan and its implementation.
9. Implement and monitor the catchment conservation plan.

ANNEXES

Annex 1: Selected herbicides for control of aquatic weeds

Type	Use	Dose	Safety interval[1]	Remarks[2]
Aromatic solvents	Submerged weeds	40-80 ppmv[3]	-	Inject under water. Toxic to fish. Distasteful in water
Acrolein	Submerged weeds	4-7 ppmv	-	Inject under water. Very toxic to aquatic fauna
Amitrole-T	Floating + emergent weeds	1-1.5 kg/ha	-	Spray on foliage. In USA can only be used in drainage canals
2,4-D amine salt	Broad leaved plants near water	2-4 kg/ha	3 weeks	Spray on foliage, especially for water hyacinth
2,4,5-T	Ditch bank control (woody vegetation)	4 kg/ha	-	Spray on plants
Dalapon	Aquatic grasses + cat-tail	10-25 kg/ha	5 weeks	Spray on foliage, repeat applications. Safe to fish
Diquat	Submerged + floating weeds	1-1.5 kg/ha	10 days	Spray on foliage. Considered safe at recommended dosages
Dichlobenil	Submerged + some floating weeds	1 mg/1	4 weeks	Spray on foliage. No adverse effect on wild life. At high concentrations can be toxic to fish
Copper sulphate (CSP)	Algae	1.0 ppmw[4]	-	Toxic to fish, distasteful in water when suggested dose exceeded
Sodium arsenite	Submerged + floating weeds	4 ppmw	-	Inject or spray, highly toxic (0.02 g may kill a man) to mammals. Its use is discouraged
Endothall	Submerged weeds	1.5-4 ppmw	7-25 days	Inject underwater. Some of the salts (long chain type) are toxic to fish and mammals

[1] Before use of water for irrigation

[2] Time to spray one hectare: Hand operated back sprayer, 10 litres capacity - 9 hours
Back mounted power sprayer - 6.5-7 hours
Tractor mounted boom sprayer - 4-5 hours

[3] ppmv = parts per million by volume

[4] ppmw = parts per million by weight

Annex 2: Machinery for canal cleaning

Type	Productivity	Characteristics of use	Remarks
Dragline excavators:			
(a) small (0.3 m^3)	80 m/day[1/]	• works from the canal banks on dry or running channel	Versatile machine adaptable to several jobs and working conditions.
	120 m/day[2/]	•	Spoil can be dumped clear of canal banks.
	300 m/day[3/]	• reach: 9-10 m	Care needed to avoid damage on compacted bed channels.
		•	To be used when desilting job smaller than 3000 m^3/km of canal.
(b) large (1 m^3)	100 m/day[1/]	• works from canal banks on dry or running channel	Similar to small dragline excavator.
	160 m/day[2/]	• reach: 18-20 m	Suitable for jobs greater than 3000 m^3/km.
	500 m/day[3/]	•	
Hydraulic excavators:			
(a) back-actor type	800-1000 m/day[4/]	• digging depth: 5-6.5 m	They are normally crawler mounted and all hydraulically operated.
		• reach: 6-8 m	
		• works from canal bank for maintenance work or from the rear in construction of new canals	
		• a great variety of buckets can be fitted	More appropriate for construction of new canals.
		• can be used for desilting or weeding jobs	Those mounted on rubber tyres require firm ground conditions.
Hydraulic excavators:			
(b) telescopic boom (Gradall Type)	1000 m^3/day[5/]	• digging depth: 6-7.5 m	Can handle several jobs but highly suitable for excavating new drains or canals and heavy maintenance work.
		• reach: 9-11 m	
		• bucket can be rotated	Compares favourably with

Type	Productivity	Characteristics of use	Remarks
		hydraulically	the small dragline.
		• tilt capacity is often 90° (other types only 45°)	
Hydraulic backhoes:			
(a) tractor mounted	300-600 m/day[2/]	• digging depth: 3.5-4.5 m	More powerful and robust than trailer type.
		• reach: 5.5-6.5m	Suitable for construction and maintenance work.
		• slew: 180°	Normally associated with a front- end loader attachment.
			The most common type is the side shift which can be mounted at each side of the tractor.
			Can be used effectively for excavation, desilting and weeding jobs.
			Needs good footing.
(b) trailer mounted	200-400 m/day[2/]	• digging depth: 2.8-4.0 m	
		• reach: 4.5-6.0 m	Highly suitable and economic for maintenance work.
		• slew: 180-190°.	
		• hydraulic pump of the hoe is driven by the drive-shaft of wheel tractor	Can work in difficult positions, while prime mover remains on level standing.
Dredges	100-200 m/day[6/]	• good for use in marshy ground or canals that cannot be cleaned from banks. Also good for removal of soft weeds	Highly specialized machine.
		• maximum depth: depends on model but for small dredges 2 m	Useful for concrete-lined canals since no damage is produced when fitted with suitable skid plates.
		• spoil (slurry) on nearest bank or collected in special pontoons	Difficult to transport and to move in and out of canals.
		• cable and winch system for locomotion needs	

Type	Productivity	Characteristics of use	Remarks
		strong anchorage points along banks	
Flatbed ditchers (Briscoe type)	3000-5000 m/day[7/]	• operates within the waterway, towed by tractors from each side; therefore can only work on dry canals	Needs powerful crawler tractors for towing (D6, D7).
	12000 m/day[8/]	• bed width: 1.2-4.2 m	Most ditchers have their own engine and hydraulic system.
			Experienced operator needed.
			More suited for construction of new canals or reconstruction work.
Rotary digger	400-600 m/day[8/]	• bed width: 0.4-1.0 m	
		• operates within the canal	Powered by PTO of wheeled tractor.
		• suitable for quick removal of light siltation and soft weeds	Works canal bed and batters simultaneously.
Bulldozer	300-400 m/day[9/]	• spreading of excavated material.	Also used for road maintenance, light deforestation and rough land levelling.
		• used as prime mover of attachments mentioned above	
Grader	500-800 m/day	• finishing of canal banks and spoils	Better suited to road maintenance work and levelling jobs.

Source: FAO Irrigation and Drainage Paper No. 40

Notes:

[1/] With standard bucket and for heavy excavation.

[2/] With light-weight bucket and for removal of silt and vegetation.

[3/] With the weed bucket but does not include any cleaning of the batters.

[4/] Refers to remodelling of badly silted canals,

[5/] Equipped with the 2.4m wide bucket.

[6/] Desilting of 1.5m wide canal. Rates for soft weeds are much higher,

[7/] For normal cleaning operations towed by a D6 crawler tractor.

[8/] Light cleaning operation, with wheeled tractor.

[9/] Refers to spreading of excavated material with a -medium size machine (D6).

NB: The equipment listed is the most commonly used but many specialized machines are also available on the market.

Annex 3: Hand tools for control of canal vegetation

Type	Use	Dimension of Canal	Productivity
Scythe	Submerged weeds + grass and reeds on banks	Small canals up to 0.6-0.8 m depth	15-25 m^2/hour
Sickle, grass hook	Submerged weeds + grass and reeds on banks	Small canals up to 0.75-1.25 m depth	8-12 m^2 hour
Rake, fork	Removing cut material, lifting floating weeds, removing algae	-	Highly variable depending on weed species and vegetation density
Chain knives and chain scythes	Submerged weeds + grass and reeds on banks	up to 6 m width	4-60 m^2/hour (two or three labourers)

Source: FAO Irrigation and Drainage Paper No. 40

Annex 4: Special characteristics of power moved tools for control of canal weeds

Type	Attachment	Use	Outreach	Productivity	Remarks
Tractor powered attachments or trailers	Oscillating grass cutter Bar	Emergent weeds	3-6 m	1-2.5 km/hr[1]	Machines can only work on one side of the canal at a time (crossing places Industrial tractors (70-150 hp) increase outreach to 8 m.
	Rotary cutter	Emergent weeds	"	1-2.5 km/hr[1]	needed to complete operation).
	Flail mower	Emergent weeds	"	1-2.5 km/hr[1]	
	Chain, harrow	Submerged + emergent	Width: 2 m	0.5-3 km/hr	
Hydraulic excavator with attachments	Oscillating grass cutter bar	Emergent weeds	horizontal outreach; 6-12 m depth: 3-5m	800-1200 m/day[1]	Wheeled machines 1 metre less effective outreach than tracked machines.
	Rotary cutter	Emergent weeds	"	0,1 ha/hr	Can work on both sides of canal at same time.
	Flail -mower	Emergent weeds	"	0,1 ha/hr	
	Mud bucket	All types	"	400-600 m/day[2]	
	Weed cutting bucket	All types	"	600-800 m/day[2]	
Dragline	Weed rake Mud bucket	Submerged + algae +emergent	9-21 m (dragline throw)	500 m/day[2]	Max. channel width depends on access and configuration of channel
Large boats C10-15 hp)	Oscillating rigid knives Modified (T type) grass cutters Wilder 'D' shaped cutter	Bank weeds + floating leaved plants + emergent weeds + algae	Width; 6-10m	1-4 km/hr with a width of cut of 1.5-2.8 m	Max. depth of cut: 1.5-2.8 m$ min. depth of cut: 0.5-1.0 m;-max. river flow velocity: 2.5 km/hr.

Type	Attachment	Use	Outreach	Productivity	Remarks
Small boats C4-5 hp)	Oscillating knives grass cutter	"	Width; 5-6 m	1.4 km/hr with a width of cut of 1.0-1,8 m	Max. depth of cut: 1.0-1.8 m; min depth of cut: 0.5-1,75 m; max. river flow velocity: 2.5 km/hr.

[1] Covering a swathe of 1,5-2 m,

[2] Refers to the complete cleaning of medium sized canals (5-6 m width),

Source: FAO Irrigation and Drainage Paper No. 40

Annex 5: Sample Operation and Maintenance Budget

Operation Service

Description	Unit	Quantity	Unit Rate	Amount (MK)	Totals (MK)
Personnel					
Head Operation Service	No.				
Water Master	No.				
Water Guards	No.				
Pump Operators	No.				
Operators (Structures)	No.				
Auxiliary Staff	No.				
Driver	No.				
Bookkeeper	No.				
Clerical Staff	No.				
Office Assistant	No.				
Sub-Total					
Equipment					
Slashers	No.				
Timer	No.				
Bicycle	No.				
Panga Knife	No.				
Rake	No.				
Notepad	No.				
Pen / Pencil	No.				
Umbrella	No.				
Raincoat	No.				
Gumboots	No.				
Other Protective Clothing	No.				
Portable water measuring device	No.				
Telephone	No.				
Mechanical Tools (Toolbox)	No.				
Oils and Grease	No.				
Computer and Printer	No.				
Calculators	No.				
Photocopier	No.				
Tape Measure	No.				
Sub-Total					
Totals					

Maintenance Service

Description	Unit	Quantity	Unit Rate	Amount (MK)	Totals (MK)
Personnel					
Head Maintenance Service	No.				
Water Guards	No.				
Water Master	No.				
Casual Labour	No.				
Artisans	No.				
Sub-Total					
Equipment					
Slashers	No.				
Hoes	No.				
Shovels	No.				
Steel brushes	No.				
Panga Knives	No.				
Axes	No.				
Rake	No.				
Cement	No.				
Aggregate	No.				
Paints	No.				
Welding Equipment	No.				
Protective Clothing	No.				
Tractor	No.				
Mower and Cutter attachments	No.				
Drag Chains	No.				
Herbicides	No.				
Wheelbarrows	No.				
Tractor Trailer	No.				
Tape Measure	No.				
Sub-Total					
Totals					

Annex 6: Sample Maintenance Schedule

Maintenance Schedule

No.	Job	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1.0	[17]Headworks												
2.0	[18]Main Canal												
3.0	[19]Secondary Canals												
4.0	[20]Tertiary Canals												
5.0	[21]Main Drain												
6.0	[22]Secondary Drain												
7.0	[23]Tertiary Drain												
8.0	[24]Collector Drain												
9.0	[25]Conveyance Structures												
10.0	[26]Distribution Structures												
11.0	[27]Measuring Structures												
12.0	[28]Access Roads												
13.0	Catchment Management												

[17] Headworks maintenance include daily inspection, especially during the wet season to remove floating debris, and repairs and desilting during the dry season.
[18] Maintenance of main canal includes daily inspection for weaknesses and shrubs growing on the embankments, and repairs and desilting during the dry season.
[19] Similar schedules as for the main canal.
[20] Similar schedules as for the main canal.
[21] Maintenance schedules include inspections for damages during the wet season, and repairs during the dry season.
[22] Secondary drains should be cleaned weakly and repairs should be done during the dry season.
[23] Tertiary drains should be inspected and cleaned daily.
[24] Collector drains should be cleaned weekly to prevent excessive weed growth.
[25] There are many types of conveyance structures. All of them should be inspected daily for any blockages that would affect the flow of water. Repairs should be done during the dry season.
[26] These structures should be treated similarly as conveyance structure
[27] Measuring structures should be inspected and cleaned daily to ensure efficiency and correctness of readings or measurements.
[28] Repairs to access roads should be done during the dry season. Routine maintenance should be done every quarter, depending upon severity of use.

Annex 7: Troubleshooting Checklist for Pump Maintenance

PROBLEM	CAUSE	REMEDY
Pulsation	Valve stuck open	Check all valves, remove foreign matter
Low pressure	Worn nozzle	Replace nozzles, use proper size
	Belt slippage	Tighten or replace; use correct belt
	Air leak in inlet plumbing	Disassemble, reseal and reassemble
	Relief valve stuck, partially plugged or improperly adjusted, valve seat down	Clean, adjust relief valve; check for worn or dirty valve seals. Kit available.
	Inlet suction strainer clogged or improperly sized	Clean, use adequate size. Check more frequently
	Worn packing, abrasives in pumped fluids or severe cavitation. Inadequate water	Install proper filter. Suction at inlet manifold must be limited to lifting less than 20 feet of water or 8.5 PSI
	Fouled or dirty inlet discharge valves	Clean discharge and valve assembly
	Worn inlet, discharge valve blocked or dirty	Replace worn valves, valve seats and/or discharge hose
	Leaky discharge hose	
Pump runs extremely rough, pressure low	Restricted inlet or air entering the pump	Proper size inlet plumbing; check for air tight seal plumbing
	Inlet restriction and/or air leaks. Stuck inlet or discharge valve	Replace worn cup or cups, clean out foreign material, replace worn valves
Water leakage from under manifold. Slight leakage	Worn packing	Install new packing
	Cracked plunger	Replace plunger(s)
Oil leak between the crankcase and plumbing section	Worn crankcase piston rod seals O-ring on plunger retainer worn	Replace crankcase piston seals. Replace O-rings
Oil leaking in the area of the crankshaft	Worn crankshaft seal or improperly installed oil seal O-ring	Remove oil seal retainer and replace damaged O-ring and/or seals
	Bad bearings	Replace bearing and any spacer or cover damaged by heat
Excessive play in the area of the crankshaft pulley	Worn main bearing from excessive tension on the belt	Replace crankshaft bearing and/or tension drive belt
Water in crankcase	May be caused by humid air condensing into water inside the crankcase	Change oil intervals. Use non-detergent oil
	Worn packing and/or piston rod sleeve O-ring on plunger retainer worn	Replace packing. Replace O-ring
	Cracked plunger	Replace plunger(s)
Oil leaking at underside of crankcase	Worn crankcase piston rod seals	Replace seals
	scored piston rod	Replace piston rod
Oil leaking at the rear portion of the crankcase	Damaged crankcase, rear cover O-ring, drain plug O-ring; or sight glass O-ring	Replace cover O-ring, drain plug O-ring, or sight glass O-ring
Loud knocking noise in pump	Pulley loose on crankshaft	Check key and tighten set screw
	Broken or worn bearing or rod(s)	Replace bearing or rod(s)
	Valve stuck open or shut, or not opening enough	Replace bad valve
	Inadequate water supply to pump inlet	Check inlet feed conditions and adjust accordingly
Frequent or premature failure of the packing	Scored, damaged or worn plunger	Replace plunger(s)
	Over pressure to the inlet manifold	Reduce inlet pressure
	Abrasive material in the fluid being pumped	Install proper filtration on pump inlet plumbing
	Excessive pressure and/or temperature offluid being pumped	Check pressure and fluid inlet temperature; be sure they are within specified range
	Overpressure of pump	Reduce pressure
	Running pump dry	DO NOT run pump without water
	Upstream chemical injection	Use downstream chemical injection

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5. FAO Irrigation Manual Module 8, Volume III, Sprinkler Irrigation Systems, Planning, Design, Operation and Maintenance, 2001
6. FAO Irrigation Manual Module 9, Volume IV, Localised Irrigation Systems, Planning, Design, Operation and Maintenance, 2002
7. Frequently Asked Questions on Solar Powered Irrigation Pumps by Dr. Harald Richter et al., GIZ Gmbh
8. WUA Manual, Department of Irrigation

PART 3: CONSTRUCTING IRRIGATION SYSTEMS

IRRIGATION CODE OF PRACTICE FOR CONSTRUCTING IRRIGATION SYSTEMS

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CHAPTER 1: INTRODUCTION

1.1. Foreword

This code of practice provides guidance on the irrigation industry's expectation of acceptable levels of irrigation construction works. The code is aligned to statutes, regulations, legal requirements and industry standards which are used in the construction sector for Malawi. It must be utilized in construction activities associated with the irrigation sector as it provides essential guidance on construction of irrigation systems in an economic and environmentally sustainable manner.

This code of practice is intended for all stakeholders involved in construction projects for irrigation systems. It is expected that this Code of Practice will be utilized as a guide in all construction projects within the irrigation sector in Malawi

1.2. Notice

This Code of Practice shall be revised whenever it is necessary so as to have a document that is relevant to prevailing developments in the construction sector for irrigation works at all times

1.3. Scope

This Code of Practice covers best construction practices for irrigation development including procurement cycle, construction plan, construction materials, construction works and evaluation of construction projects

1.4. Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this code of practice. All standards are subject to revision and, since any reference to a standard is deemed to be a reference to the latest edition of the standard, parties to agreements based on this code of practice are encouraged to take steps to ensure that they use the most recent editions. Information on currently valid national and international standards can be obtained from the Malawi Bureau of Standards.

MS 842:2010, *Aggregates from natural sources-Aggregates for concrete*

IS0 8779:2010, *Plastic piping systems-Polyethylene (PE) pipes for irrigation - Specifications*

ISO 4064-2:2005, *Measurement of water flow in fully charged closed conduits- Meters for cold portable water and hot water-Part 2: Installation Requirements*

MBS 324:1992, *Black Polyethylene Pipes for the Conveyance of liquids –specification-Part 1: Low density polyethylene pressure pipes*

MBS 617-3:1998, *Pipes and Fittings made of un-plasticized poly-vinyl chloride (PVC-U) for water supply –Specification-Part 3: Fittings and joints*

ANSI-PMI 08-001-2012, 2013: *A Guide to the Project Management Body of Knowledge (PMBOK Guide).*

DMS 838:2009, *Concrete works – Code of practice for minor works*

ISO 21500:2012, *Guidance on project management*

SABS 0164-1:1980*, Structural use of masonry - Part 1: unreinforced masonry walling*

ASAE EP400.2T: 1997, *Designing and Constructing Irrigation Wells*

ASAE EP260.4: 1997, *Design and Construction of Subsurface Drains in Humid Areas*

MBS 88:1986, *Solvent cement for assembly of uPVC pipe fittings- specifications*

BS 1881:1983, *Testing Concrete- Part 102: Method for determination of slump*

BS 812:1989, *Testing Aggregates-Part 110: Methods for determination of Aggregate Crushing Value (ACV)*

BS 812:1989, *Testing Aggregates-Part 103.2: Method for the determination of particle size distribution*

CHAPTER 2: DEFINITIONS

2.1. Technical terms

2.1.1. **Aggregate Crushing Value (ACV) test** – this is a test which gives a relative measure of the resistance of an aggregate crushing under gradually applied compressive load

2.1.2. **Air Pumping** – a well development method that utilizes the pressure of air from a pumping device

2.1.3. **Aquifer** - underground layer from which groundwater can be extracted and can be in form of water-bearing permeable rock, rock fractures or unconsolidated materials (gravel, sand, or silt)

2.1.4. **Backfilling** – a construction activity whereby an earlier excavated area is refilled with either with the material that was dug out of it or imported material

2.1.5. **Batching** - the measurement of the quantities of the materials (cement, sand, stone and water) and introducing them into the mixing plant

2.1.6. **Bid Evaluation** – a process through which a procuring entity undergoes after bid submissions to come up with a successful bidder

2.1.7. **Bid Data Sheet** – a section within the bidding document that provides general information in the instructions to bidders such as submission deadlines, evaluation procedures, regulations, adjudicator etc.

2.1.8. **Bidding forms** – a section in the bidding documents which includes the forms for the Bid Submission, Price Schedules and Bid Security to be submitted with the Bid

2.1.9. **Bills of Quantities** – document used in tendering whereby activities/materials/labour and their corresponding costs are itemised

2.1.10. Borrow material –earth material imported from elsewhere for use during earthworks

2.1.11. **Certificate of Practical Completion** – a certificate issued by the Engineer to the Contractor following substantial completion of works as stipulated in the contract

2.1.12. **Certificate of Final Completion** – a certificate issued by the Engineer to the Contractor following expiry of the Defects Liability Period

2.1.13. **Code of practice** – a set of written regulations issued by a professional association or an official body that explains how people working in a particular profession should behave

2.1.14. **Cohesive concrete** - concrete that is sticky enough to prevent coarse aggregate from separating from the rest of the mixture when it is being transported, placed and compacted

2.1.15. **Concrete** – construction material formed from sand, coarse aggregate and cement when mixed with water

2.1.16. **Concrete bleeding**- the process where water rises to the surface when concrete is setting as the other mixture materials are heavier than water

2.1.17. **Concrete compressive strength test** – test carried out to assess the capacity of concrete to withstand compressive load

2.1.18. **Construction programming software** – software that is used for construction management activities during construction

2.1.19. **Concrete Durability**- the ability of concrete to resist weathering action, chemical attack and abrasion while maintaining its desired engineering properties

2.1.20. **Contingency Reserves –** sum of money allocated to a project to manage identified risks such as those resulting in scope variations

2.1.21. **Contract forms –** a section in the bidding document which includes the form for the Agreement, which, once completed, incorporates corrections or modifications to the accepted bid that are permitted under the Instructions to Bidders, the General Conditions of Contract, and the Special Conditions of Contract

2.1.22. **Contract management** – process of managing contract creation, execution and analysis with the objective of achieving the targeted deliverables on time, within budget and to expected quality standards

2.1.23. **Contract duration –** time allocated to a contract from its start date to expiry date

2.1.24. **Control chart** – a graphical analysis quality tool used to assess how measurements deviate from the expected measurement as work progresses

2.1.25. **Commissioning** – a milestone activity in construction projects that marks the official commencement of operations for the built infrastructure

2.1.26. **Defects Liability Period** – period after completion of a construction project during which the Contractor has the obligation to remedy construction defects

2.1.27. **Demobilization** - removal of Contractor's human, material and equipment resources away from the construction site following either termination of the contract or satisfactory completion of the works

2.1.28. **Dimensional Control –** execution of activities meant at ensuring that the constructed structures are matching with the engineering drawings

2.1.29. **Earthworks –** a construction activity associated with movement, excavation and compaction of earth material

2.1.30. **Elevation control** – execution of activities aimed at ensuring that the structure is being constructed as per the specified elevations

2.1.31. **Environmental and Social Management Plan (ESMP)** – a site specific document which describes predicted impacts, recommended mitigation measures / enhancement measures and a schedule for implementing these measures

2.1.32. **Falsework** – temporary works during construction which are carried out to support the main work until such work has achieved sufficient capability to support itself

2.1.33. **Form of bid** - this is a section within the bidding document in which the contractor declares his intent to carry out the works as per the contract

2.1.34. **Formwork** – temporary or permanent moulds into which concrete or similar materials are poured

2.1.35. **Flexural Bond Strength** – highest stress of a material at its point of yielding in a flexure test

2.1.36. **Gantt chart** – a horizontal bar chart developed as a project management tool for planning, coordination and tracking specific tasks in a project

2.1.37. **General Conditions of Contract –** this is a section within the bidding document that sets out the minimum expected performance of the Contractor in the contract

2.1.38. **Geotechnical tests –** tests aimed at determining physical properties of soil and rock material

2.1.39. **Gabions** - Gabions are a form of retaining wall which is produced from individual rectangular, wire mesh boxes that are partitioned inside

2.1.40. **High tensile bars** – round, ribbed surface steel bars with a yield tensile strength of 450N/mm2 or higher

2.1.41. **Irrigation** – artificial application of water to plants

2.1.42. **Instruction to bidders** - section in a bidding document that provides information to assist Bidders' preparations

2.1.43. **Large schemes** - irrigation schemes with irrigation area of more than 500 hectares

2.1.44. **Maximum Dry Density (MDD)** - the highest dry density on the dry density-moisture content graph as recorded in a Modified Proctor test

2.1.45. **Medium schemes –** irrigation schemes with irrigation area of more than 50 hectares but less than 500 hectares

2.1.46. **Mini-schemes** – irrigation schemes with net irrigable area of less than 10 hectares

2.1.47. **Mobilization** - preparation of camp site, transportation and delivery of plant, equipment, personnel and construction materials for use during the construction works

2.1.48. **Mortar** – a construction material formed from a mixture of sand and cement in water which is used for bonding in brickwork and concrete block work

2.1.49. **Mild steel bars** – round, smooth surfaced steel bars with a yield strength of 250N/mm^2

2.1.50. **Optimum Moisture Content (OMC) –** the moisture content at which fill material exhibits highest dry density in a Modified Proctor test

2.1.51. **Organic Content Test** – a test carried out on sand to assess the content of organic material present

2.1.52. **Pre-bid conference** - a conference conducted at least two weeks after the first advertisement which gives an opportunity to aspiring contractors/consultants to seek clarifications on both technical and administrative matters in the bidding document

2.1.53. **Procurement –** process of finding, acquiring services or works from external sources

2.1.54. **Qualification and Evaluation Criteria** - section in the bidding document that describes the minimum expected requirements for a Contractor to be considered for the contract

2.1.55. **Rip rap** - protection that is provided with broken rock or large stones of thickness between 250 mm and 500 mm depending upon erosive forces such as wave

2.1.56. **Schedule of requirements** - section in the bidding document which describes the List of Goods and Related Services, the Delivery and Completion Schedules, the Technical Specifications and the Drawings that describe the Goods and Related Services to be procured

2.1.57. **Site Handover** – function whereby the Client gives the Contractor authority to work on the site which he/she has been awarded

2.1.58. **Small schemes –** schemes with irrigation area of 10 to 50 hectares

2.1.59. **Special Conditions of Contract –** conditions in the bidding document that are peculiar to a specific contract

2.1.60. **Strength control** - execution of activities aimed at ensuring that the structure achieves the specified strength

2.1.61. **Standard gauge box** – a 150mm x 150mm x 150mm box with handles usually made from timber and is used as the standard measuring tool for construction materials such as sand, cement and coarse aggregate

2.1.62. **Statistical sampling** – a quality control and assurance method that utilizes representative samples from construction products in order to establish whether the delivered product has met the required specifications

2.1.63. **Setting –** the change of concrete property from plastic to hardened state due to the occurrence of hydration between cement and water

2.1.64. **Sand** - Fine aggregate that consists of 90-100% of its particles passing through a square aperture of nominal size 4.75mm

2.1.65. **Stress rapture test** - a pipe test whereby a pipe sample is exposed to a hoop stress of 420 bars at 200^{o}C for a duration of 1 hour

2.1.66. **Stress Relief test –** a pipe test whereby a pipe sample is placed in an oven at 1500C then cooled

2.1.67. **Sand Cone Test –** a test conducted to establish relative density of a compacted material

2.1.68. **Soil Stabilization** – a chemical or physical earthworks technique used to improve properties of soil

2.1.69. **Setting out** – execution of activities that enable transfer of dimensional and elevation properties of a structure from an engineering drawing on paper to the actual site

2.1.70. **Stone pitching** - type of erosion protection works that gives a fairly smooth surface by firmly packed stones which are secured in place by mortar at the joints

2.1.71. **Soding –** type of erosion protection works which involves planting of grass

2.1.72. **Thrust blocks** - concrete structures constructed at the end of the pipeline, where the pipeline changes direction and where the pipe branches into two or more pipelines in order to resist the load due to additional pressure exerted at these points.

2.1.73. **Work Programming –** production of a schedule of works to be done in a construction project whereby activities are identified, logically sequenced and realistic durations determined based on available resources

CHAPTER 3: PROCUREMENTS OF IRRIGATION WORKS

3.1. Procurement Cycle

The procurement process to be adopted shall be aligned to the Public Procurement and Disposal of Assets Act of 2017.In some cases especially donor-funded projects, the funding agency may demand for additional procurement steps. The following are the key stages in the procurement cycle that shall be adopted:

3.1.1. Budget and Procurement Plan

A detailed procurement plan and its corresponding budget shall be prepared and approved by management before commencement of the actual procurement

3.1.2. Purchase requisition filled with clear specifications/terms of reference/scope of works/bills of quantities

The designer(s) of the targeted irrigation system(s) shall ensure that the specifications/terms of reference/scope of works/bills of quantities are very clear

3.1.3. Review of specifications/terms of reference/scope of works/bills of quantities

A Senior or Independent Design Engineer, in collaboration with the Designer(s) who produced the specifications/terms of reference/scope of works/bills of quantities, shall conduct a thorough review to ascertain their clarity and conduct modifications where necessary

3.1.4. Review of procurement method

The Procurement Expert(s), in consultation with Engineers responsible for the construction project, shall determine the most suitable procurement method to be adopted.

3.1.5. Supply Sourcing

The Procurement Expert(s), in consultation with Engineers responsible for the construction project, shall ensure availability of potential contractors on the targeted market

3.1.6. Ascertain availability of funds

The Engineer(s) responsible for the construction project shall confirm with management that funds for both procurement activities and the actual construction works are available

3.1.7. Preparation of bidding documents

The Procurement Expert(s) shall prepare the bidding document in consultation with the Engineer(s) responsible for the targeted construction project

3.1.8. Approval of the bidding document

Before an invitation to tender is done, the prepared bidding document should be approved by:

- The Engineer responsible for the project and
- Management and/or Internal Procurement Committee

3.1.9. Invitation to tender

3.1.9.1. Advertisement in the form of either Request for Proposals (RFP) or Request for Quotation (RFQ) shall be conducted.

3.1.9.2. Requests for clarifications from potential bidders shall be made to the procuring entity through emails, letters or verbally during a Pre-bid conference

3.1.10. Receipts and opening of bids

The bids shall be received and opened at locations and times which are specified in both the invitation to tender and bidding document

3.1.11. Evaluation of bids

The bids shall be evaluated in accordance with the evaluation criteria specified in the bidding document. The key areas stages in the evaluation process shall include administrative compliance, technical compliance, mathematical checks and corrections and ranking of responsive bids

3.1.12. Review of Evaluation Report

Management/Internal Procurement Committee shall review and approve the evaluation report presented by representatives of the evaluation team

3.1.13. Offer of Contract

Successful bidders shall be offered contracts following approval of the Evaluation Report

3.1.14. Contract Negotiations

The Client and Successful bidder shall conduct negotiations regarding terms of the contract centring on technical and administrative issues

3.1.15. Contract Signing

3.1.15.1. Prior to signing of the contract, often during contract negotiations, the successful bidder shall be informed of any adjustments/ corrections which have been made to his/her original bid including its impact upon the final contract sum.

3.1.15.2. The contract shall be signed by at least one representative from both the Client and the successful bidder

3.1.16. Publish the Award

The contract award shall be published in the media recommended in the procurement plan

3.1.17. Performance Rating

The Engineer responsible for the construction project in collaboration with the Procurement Expert(s) shall assess the performance of the Contractor in the contract

3.2. Public-private partnership arrangement(ppp)

Where financing for irrigation development is either limited or non-existent, the Government shall engage with the private sector to jointly execute the targeted project. PPP arrangement shall be implemented using any of the following approaches for irrigation infrastructure development:

- DBOM (Design, Build, Operate, Maintain)
- BOOT(Build., Own, Operate and Transfer)
- BOT (Build. Operate and Transfer)

3.3. Contract management

3.3.1. Site Handover

3.3.1.1. Once the Contractor and Client have agreed on the contractual issues, a date shall be set for site handovers

3.3.1.2. This activity should take place at the site targeted for construction works with representatives of all key stakeholders of the project in attendance. During the function, roles and responsibilities for each key stakeholder must be clearly explained so as to avoid conflicts that may arise due to lack of understanding on contractual obligations for all parties involved.

3.3.1.3. The Supervising Engineer must provide all relevant engineering drawings, corrected bills of quantities and contract document either during or before this function.

3.3.2. Mobilisation

3.3.2.1. The Engineer shall ensure that mobilization has been carefully planned. Timing regarding when to deliver these resources is crucial as delays may lead to failure to commence the works for which they are to be used for. Equally, bringing plant and equipment too early before their scheduled use may lead to unnecessary increase in idle time

3.3.2.2. Mobilization shall be planned as an activity within the construction programme.

3.3.2.3. Mobilization shall include establishment of camp site, transportation and delivery of plant, equipment, personnel and construction materials for use during the construction works.

3.3.3. Site establishment

3.3.3.1. The need for site establishment should always be catered for in the Preliminaries and General (P&G) section of the bills of quantities. Site establishment shall include:

- Identification of land or property for use as site office –
- contractors/consultants office
- Setting up of storage place for construction materials
- A laboratory where the site is far away from the laboratory testing centres
- Identification of water supply

3.3.3.2. When setting up a camp, the Engineer shall ensure that the Contractor has taken the following into consideration:

- Compliance with all legal and regulatory issues - all legal issues relating to the planned camp site as well as local, state and national government regulations must be strictly adhered to
- Water supply – water of right quality and quantity must be made available to meet the needs of both the site personnel and construction works
- Electricity – electricity for security of the camp, running of equipment and machinery and general lighting for personnel must be provided for
- Residential houses or camp – workers must be allocated proper accommodation with adequate sanitary and hygiene facilities
- First Aid facilities – these must be provided for in case of injury. Furthermore, workers must be provided first aid trainings
- Camp security - shall be seriously considered to deter outsiders from

tampering with construction facilities and workers from stealing.

- Fuel storage – where there will be need to set up fuel tanks on site, security of the tanks and prevention of fire accidents must be seriously taken into consideration.
- Sufficient space for car parking, stocking of materials and storage of plant and equipment
- Safety measures – warning signs, directive signage
- Accessibility – camp should be accessible and there should be enough service roads

3.3.4. Ferrying and Storage of Construction Materials

Ferrying and storage of construction materials shall be done before the scheduled time for utilization of the materials

3.3.4.1. The assessment of material needs during construction planning shall include the type and quantities of materials available within the vicinity of the project area, including their haulage distances. This information shall assist the Contractor in determining and scheduling quantities of materials to be brought to the site in order to maintain the flow of the construction works and reduce downtime.

3.3.4.2. As much materials as possible shall be brought to the site early, mindful of the storage requirements, in order to reduce risks of downtime due to transport breakdowns or adverse weather conditions.

3.3.4.3. The Engineer shall ensure that the following materials are transported and stored as follows:

- Sand - Tippers, trucks, tractors and flat lorries shall be used to ferry sand from the source to the construction site where it is stored in heaps. The heaps shall be made on areas free from organic matter and as close as possible to the batching plant
- Cement - Tippers, trucks, tractors and flat lorries shall be used to ferry cement from the source to the site. Cement shall be stored off the floor in a waterproof shed. Cement pockets shall be closely stacked to a height of not more than 12 pockets and shall not be stacked against the walls of the shed. Bulk supplies of cement shall not be permitted unless all cement is used before 3 months. All cement must be used in the order in which it was received. Cement for use in construction of irrigation systems should not be older than three months after its date of manufacturing. This is because cement which has stayed more than three months reduces in strength.
- Coarse aggregate - Tippers, trucks, tractors and flat lorries shall be used to ferry sand from the source to the construction site where it is stored in heaps. In hot weather that is above 300C, coarse aggregate shall either be stored in a shade or sprayed with water to keep it cool.
- Timber - Tippers, trucks, tractors and flat lorries shall be used to ferry timber from the source to the construction site Timber should be protected from exposure to rain before use on site.
- Pipes - Pipes and fittings shall be carefully packed to protect them against damage during transportation. They shall not come into contact with sharp objects, nor project beyond the body of the vehicle transporting them but shall be well secured along their full length. Rubber joint rings shall not be contaminated with either oil or grease. Before uPVC pipes are delivered to the construction site, they must be stacked to a maximum height of 1.5 m high (or about 7 pipe layers) under a covering on pipe racks. Pipe racks must provide support to the full length of the pipe. Pipes with different diameters shall be stacked together by inserting smaller diameter pipes inside the larger diameter pipes. Once on site, the uPVC pipes shall be stored on level ground that is free of sharp objects and stacked not more than 1 m high in a stack, formed by cross formation of pipes. Pipes must be stored under a shed.Pipes must be delivered, unloaded, stored and handled in dry, weatherproof, waterproof condition in a manner that prevents damage, breakage, deterioration, intrusion, ignition, and vandalism.
- Steel reinforcement - Tippers, trucks, tractors and flat lorries shall be used to transport steel reinforcement. Steel reinforcement shall be kept in a dry storage place which is free from dust and oil.

3.3.5. Drawings

3.3.5.1. The Engineer shall confirm that the benchmark elevations shown on all layout drawings are a true reflection of their measured values on the ground before commencement of setting out of the works

3.3.5.2. Any noted discrepancy between these two sets of data shall be reported to the Supervising Engineer for necessary corrections and/or adjustments. In addition, during setting out, any mismatch between the drawing and the actual situation on the ground shall be reported to the Supervising Engineer.

3.3.5.3. The drawings to be used shall, at a minimum, comprise the following:

- Be prepared to standard, for example British Standard (BS 308) or any other applicable standard
- Be listed on the drawing schedule
- Have a unique reference number
- Have any amendments clearly indicated and dated
- Have a title block with the name of the Client, Engineer, Draughts person, as well as the drawing scale and date

3.3.5.4. Construction shall be based on approved construction drawings evidenced by an Engineer's signature and stamp.

3.4. Contract administration

3.4.1. General

3.4.1.1. The Contract shall be administered by the Engineer responsible for the construction project in collaboration with the Procurement Expert under the leadership of the Project Manager.

3.4.1.2. The Engineer shall monitor progress to ensure that all contractual obligations are being adhered to.

3.4.2. Variation orders

The Engineer shall assess the essence of changing the expected cost/duration/quality parameters as proposed by the Contractor or Client or other key stakeholders. Where such a proposal is deemed acceptable by the Client through its Project Manager, the Engineer shall formally issue a written Variation Order on the same to the Contractor

3.4.3. Use of contingency reserves

The Engineer shall issue a request to use contingency reserves to the Client through its Project Manager. Only Client-approved amounts of the contingency reserves shall be used.

3.4.4. Presence of key personnel

. The Engineer shall always ensure that key personnel incorporated in the bidding document are available on site as per the labour resource calendar. Incoming personnel as replacement shall be of higher or similar experience and qualifications to the one being replaced unless there is a revision to the scope of works. The Engineer shall suspend the works whenever absence of key personnel is discovered during the execution of construction works

3.4.5. Work programming

3.4.5.1. The Contractor shall provide a tentative programme of works in his bid submission which should be updated at the commencement of the construction works.

3.4.5.2. The Engineer shall instruct the Contractor to provide a revised work programme whenever a significant variation to the prevailing version has occurred (see Annex A for a description of how a work programme can be produced using a Gantt chart).

3.4.6. Contract duration

3.4.6.1. The Engineer shall ensure that physical progress is in tandem with the work programme .Where the Contractor has delayed in some of the activities being implemented, countermeasures to prevent delays shall be made by the contractor through updating the work programme and resource calendar

3.4.6.2. The Engineer shall enforce the liquidated damages' clause if the Contractor has been found to be at fault in delivering within the contract duration

3.4.7. Progress Reports

The Engineer shall ensure that the Contractor submits monthly progress reports with the following information as a minimum: progress charts in the form of Gantt chart, comparison of actual versus planned progress, cash flow forecasting, detailed descriptions of progress, materials on site, Contractor's photographs showing progress on the site, test results, payments honoured by the Client, list of correspondences made in the month, challenges and countermeasures

3.4.8. Site meetings

The Engineer shall ensure that site meetings are conducted as follows:

- Weekly site meetings – to be attended by site staff representing all parties to the contract
- Fortnightly meetings – to be attended by site team from all parties and District Council representatives
- Monthly Site Meetings – to be attended by high level representatives with the authority to make decisions, including those who attend both fortnightly and weekly meetings.

3.4.9. Communication Channels

3.4.9.1. The Engineer shall ensure that written communication is used when giving or issuing the following: Approvals, certificates, consents, determinations, notices, requests and discharges. Minutes of site meetings shall also be in written form.

3.4.10. Record keeping

The Engineer shall ensure that all records pertaining to delivery of the construction project are kept safe for future reference. Such records include: climatic data, daily personnel and plant availability, work performed, materials used, materials remaining on site and information about site visitors on daily basis.

3.4.11. Site Instructions

The Engineer shall issue instructions and additional or modified drawings which may be necessary for the execution of the Works and the remedying of any defects. Instructions from the Engineer, or from an assistant to whom the appropriate authority has been formally delegated shall be deemed valid by the Contractor for his/her action.

3.4.12. Checking material and equipment availability

The Engineer shall ensure that approved construction materials and equipment for the work that has been planned are available before approving commencement of such works.

3.4.13. Demobilization

The Engineer shall ensure that the Contractor has addressed the following issues before certifying payment for demobilization:

- All known defects have been rectified
- All equipment including broken down equipment have been removed
- Spoil disposed off and all unused materials have been removed
- All outstanding wages and debts have been paid by the Contractor in accordance with the prevailing labour laws of Malawi
- All access areas have been restored to the same condition prior to the start of the work.
- As-built drawings have been produced and submitted to the Client
- Backfilling of borrow pits

3.4.14. Testing and Commissioning of an irrigation system

4.4.14.1 The Engineer shall approve execution of site handover tasks by the Contractor when the constructed structures have been tested in terms of functionality and confirmed to be in conformity with the requirements as per the approved designs. The checks on functionality and operational aspects of the system shall include the following key tasks:

- Checks on possible faults on control gates
- Verification of accuracy of gauges for water measurements
- Checks on possible leakages within the system
- Check on whether the designed irrigation methods and procedures are in tandem with the built irrigation system

3.4.14.1. The Engineer shall ensure that there is involvement of the targeted end-users for the system during both interim and final checks upon the system to ensure that they get acquainted with the system and also confirm that the system is working as per the expectations.

3.4.14.2. Commissioning of the irrigation system shall be done after site handovers from the Contractor to the Client have been conducted

3.4.15. Site inspection

The Engineer shall conduct site inspections to assess work progress, quality and safety measures during construction. The Engineer shall deploy Site Inspectors to assist in day-to-day supervision and monitoring of works.

3.4.16. Retention

The Engineer shall ensure that five percent (5%) of the amount certified as due to the Contractor is retained by the Client on each interim certificate. An amount equivalent to 2.5% of the total retention money shall be released to the Contractor after issuance of Certificate of Practical Completion. The remainder shall be released after the expiry of defects liability period and issuance of Certificate of Final Completion.

3.4.17. Defects remedy

The Contractor shall be responsible for the cost of completing outstanding works and the remedying of defects which fall under his/her responsibility.

3.4.18. As-built drawings

The Contractor shall prepare and submit as-built drawings upon completion of the construction project. The Engineer shall check and approve the As-built drawings.

3.5. Closing procurements

3.5.1. The Contractor shall submit the final certificate once the expected deliverables as agreed in the contract have been accepted by the stakeholders

3.5.2. The Engineer shall ensure that all outstanding payment issues are addressed in the final certificate so that the Contractor is neither overpaid nor underpaid.

3.5.3. The Engineer shall ensure that all documents related to the contract are kept safe for reuse, referencing or audit purposes in future. This includes all files in both hard copy and digital form.

CHAPTER 4: CONSTRUCTION PLAN

4.1. General

Construction of irrigation schemes in Malawi shall take place in three main forms supervised by the Engineer. These include:

i. Construction by farmers.
ii. Construction by local artisans.
iii. Construction by a hired, registered contractor

Strategies (i) and (ii) are normally deployed in mini-schemes, small and medium. Strategy (iii) is mainly used in medium to large schemes and the scope of work is substantial. In all cases, planning for construction is crucial because meeting quality, cost and time targets for construction, is always the goal for such projects.

4.2. Quality Management

4.2.1. Three aspects of quality management

Quality management has three components: Quality Planning, Quality Control and Quality Assurance

4.2.1.1. The Engineer shall ensure that the three aspects of quality management are being put to practice before, during and after construction. These include Plan quality management, Perform quality assurance and Control Quality.

4.2.2. Quality planning

4.2.2.1. The Engineer overseeing construction works must thoroughly understand the quality requirements set by the designer of the irrigation system. Each expected quality target for the structures and construction material components as specified in drawings, technical specifications and bills of quantities shall be noted during planning stage. Some of the aspects of quality targets for irrigation structures are tabulated below:

Table 27 Key quality parameters for iirigation system components

No.	Structure	Quality parameters
1	Canals	Maximum dry density for compacted canal embankment, canal slope, canal width, canal side slope, canal depth , material for finished surface area , etc
2	Pipes	Pipe material, operating pressure, length, diameter
3	Pipe fittings	Operating pressure, fitting type
4	Pump	Pump horsepower, pump type(mobile or immobile, fossil fuel powered or electric powered or solar-powered, manual pumps, submersible or surface pumps)
5	Gates valves	Gate type, operating pressure, Gate size
6	Weir	Weir type, weir material composition, type of river bank protection works, apron size and material composition
7	Water measuring devices	Devices type, maximum and minimum measurement, material composition

4.2.2.2. The Engineer shall ensure that construction materials have the expected specifications that must be taken into consideration during planning. Key parameters of specifications for construction materials commonly used in irrigation and other structures are as shown in Table 28 below:

Table 28 Commonly used construction materials in irrigation

No.	Construction Material	Quality parameters
1	Coarse aggregate	Aggregate crushing value, flakiness index,
2	Sand	Organic content, material grade
3	Cement	Type
4	Concrete	Compressive strength at 28 days, size of coarse aggregate, sand-cement-coarse aggregate mix ratio
5	Pipes	Pipe type, operating head, diameter , length
6	Mortar	Sand-cement mix ratio
7	Fill material	Maximum dry density , liquid limit , plasticity index , material grade

4.2.2.3. Based on information highlighted in 5.2.2.1 and 5.2.2.2, the Engineer shall determine:

- Required quantities for construction materials
- Required construction equipment
- Methodologies to be adopted during construction in order to meet the quality, time and cost targets
- Personnel with expertise to deliver according to the set requirements
- Quality-related measurements to be taken during construction

4.2.2.4. The Engineer shall use the information in 5.2.2.3 as basis for supervision of works and provision of technical and administrative advice to the Contractor.

4.2.3. Quality Control

The Engineer shall ensure that Quality control is being carried out to assess whether quality targets are being achieved as the construction plan is being executed. This shall involve monitoring and recording results as devised in the quality plan. The Engineer or his/her delegated representative shall witness the quality tests**.**

4.2.3.1. Quality control in canal construction

4.2.3.1.1. Strength control *in canal construction*

The Engineer shall ensure that the concrete mix design, compressive strength of concrete lined canals, mortar mix for stone masonry canals and specified maximum dry density for fill material in canal embankment are meeting the technical specifications described in the drawings and other relevant design documents

4.2.3.1.2. Dimensional control in canal construction

The Engineer shall check through measurements that the constructed canal has met the specified length, width and depth of canal under construction. This shall be executed by checking these dimensions with a measuring tape using the following intervals:

- Every 5m for a canal of maximum length of 50m
- Every 10m for a canal with length more than 50m and less than 200m
- Every 25m for a canal with length of more than 200m

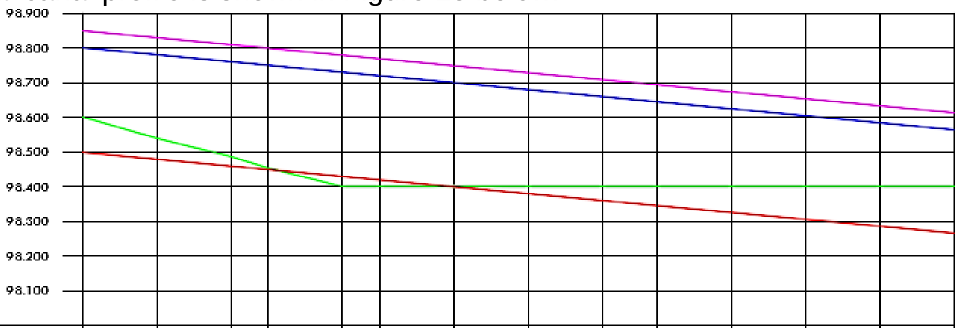
(Note: these dimensions are for quality control checks after completion of the canal in question. During construction, the regular chainage can be ignored. Instead, random checks at irregular chainages must be considered)

4.2.3.1.3. Elevation control in canal construction

4.2.3.1.3.1. The Engineer shall ensure that the bed slopes for constructed canals are as per the specified gradient in the relevant canal profile drawing. Thus, at each point, the following elevations are either shown on canal profile drawing or can be calculated:

- Canal bed elevation
- Designed water level
- Top Embankment/Cut level

A typical canal profile is shown in Figure 15 below:



CHAINAGE (m)	0	20	40	50	70	80	100	120	140	155	175	195	215	235
EXISTING GROUND LEVEL (m)	99.600	99.541	99.488	99.456	99.400	99.400	99.400	99.400	99.400	99.400	99.400	99.400	99.400	99.400
BED LEVEL (m)	99.500	99.480	99.460	99.450	99.430	99.420	99.400	99.380	99.360	99.340	99.320	99.300	99.280	99.265
WATER LEVEL (m)	99.800	99.780	99.760	99.750	99.730	99.720	99.700	99.680	99.660	99.640	99.620	99.600	99.580	99.565
EMBANKMENT LEVEL (m)	99.850	99.830	99.810	99.800	99.780	99.770	99.750	99.750	99.710	99.690	99.670	99.650	99.630	99.615

Figure 15 Typical canal profile

4.2.3.1.3.2. The Engineer shall check the elevations through the use of any of the following survey equipment:

- RTK GPS
- Dumpy level
- Total station and
- Theodolite

4.2.3.2. Quality control in pipe laying

4.2.3.2.1. Elevation control in pipe laying

4.2.3.2.1.1. The Engineer shall refer to design drawings, especially the pipeline profile drawings, in ensuring that the following elevations are set out correctly. The elevations that are provided shall include*:*

4.2.3.2.1.2. The Engineer shall ensure control of elevations during construction through the use of any of the following survey equipment:

- RTK GPS
- Dumpy level
- Total station and
- Theodolite

4.2.3.2.1.3. At any given chainage, the Engineer shall ensure that elevations between designed values as shown on engineering drawings and the actual values are matching.

4.2.3.2.2. Pipe joining control

There are two main types of joining techniques for uPVC pipes: use of injection mould adhesive and pipes with rubber ringed sockets.

4.2.3.2.2.1. Where injection mould adhesives are to be used as a pipe joining technique, the Engineer shall ensure that the required pipe joining processes as per the instructions on the adhesive package are strictly followed to ensure high quality joints.

4.2.3.2.2.2. Where joining of pipes using rubber ring sockets has been specified, the Engineer shall visually check that the rubber rings are visible when viewing the pipe internal details at the socket end

4.2.3.2.3. Water tightness check

The Engineer shall ensure that pressure testing for the pipeline is conducted before burying the pipes to ensure that there are no leakages at joints along the pipeline. The test shall be carried out by conveying water along the targeted section using pressure that does not exceed one and a half times of its maximum operating pressure. Inspections shall be carried out at all joints.

4.2.3.2.4. Backfilling control

4.2.3.2.4.1. The Engineer shall ensure that the width of trench accommodates the targeted method of compaction when backfilling. Where either a hand rammer or pedestrian roller will be used, the width of the trench shall accommodate their sizes and required working space for the operator of these equipment. Thus, for a hand rammer with diameter of 30cm, at least 50cm space on either side of the laid pipe will suffice. As for a pedestrian roller, a working width of at least 650mm on either side of the laid pipe is adequate. Backfilling using a portable hand rammer shall be carried out by simultaneously compacting fill material in layers of 75mm. Thereafter , when fill material has been compacted up to 10cm above the crown level of the pipe, layers should be increased from 75 to 150mm until completion of the backfilling process.

4.2.3.2.4.2. The Engineer shall ensure that trench backfilling is done up to 50mm above the original ground level to avoid formation of a depression along the trench line once settlement of the fill material has occurred.

4.2.3.2.5. Stability of thrust blocks

4.2.3.2.5.1. The Engineer shall ensure that thrust blocks are constructed at the end of the pipeline, where the pipeline changes direction and where the pipe branches into two or more pipelines.

4.2.3.2.5.2. When constructing thrust blocks, the Engineer shall check that the right concrete mix proportions as specified in the design are being used.

4.2.3.2.5.3. The Engineer shall check the stability of the constructed thrust blocks during pressure testing of the pipelines

4.2.3.3. Quality control in other irrigation-related structures

The Engineer shall ensure that elevation and horizontal dimensions being used during construction of irrigation structures are being maintained as indicated in the construction drawings. Checks on elevation and horizontal dimensions shall therefore be conducted during setting out, as construction is in progress and after completion of construction

4.2.3.3.1. Mortar and concrete mix control

4.2.3.3.1.1. The Engineer shall ensure that mortar for joints of construction materials and concrete for the structure being built are as specified in their relevant construction drawings

4.2.3.3.1.2. The Engineer shall ensure that only Standard Gauge boxes measuring 300 mm x 300mm x 300mm are being used when mixing either mortar or concrete components

4.2.3.4. Quality tools irrigation scheme construction

The Engineer shall utilise Control charts and statistical sampling as the two main tools that in the analysis of results for compaction test and concrete compressive test (see Annex B for descriptions of the tools).

A typical example of a control chart is displayed in Figure 16:

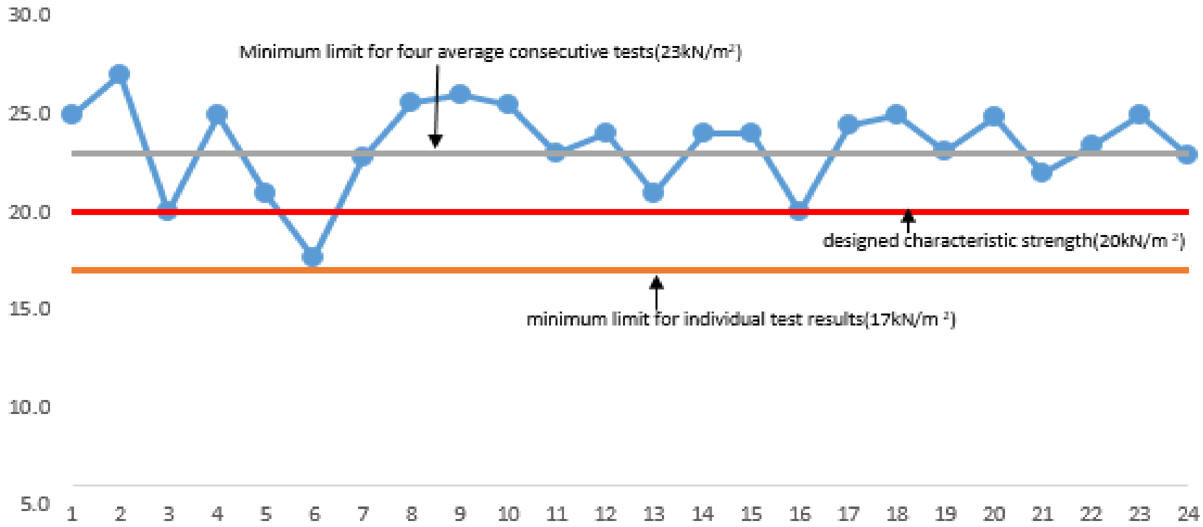


Figure 16 Control chart for concrete in line with BS 5323 requirements for concrete test results

4.2.4. Quality Assurance

The Engineer shall confirm quality control outcomes and determine trends and countermeasures to address occurrences of non-conformity of constructed structures. Records obtained from quality control activities shall be used to perform quality assurance which is more of an audit on how quality standards are being adhered to.

4.2.5. Cost Management

4.2.5.1. The Engineer shall ensure that that the total project cost also includes contingencies which may be put to use when unforeseen developments eventuate

4.2.5.2. The Engineer shall ensure that the Contractor produces a planned cost analysis(S-curve) for the project which is in line with his/her programme of works (see Annex A for a description on how this can be produced).The S-curve for actual costs shall be superimposed on the S-curve for the planned costs

4.2.5.3. The Engineer shall ensure that the Contractor's progress report comprises a section in which progress of costs and their forecasts in the project are explained to a greater detail

4.2.5.4. The Engineer shall ensure that cost changes in the project undergo a due process as described in the contract document .Involvement of the Project Manager and other key stakeholders when making decisions for cost changes shall be required as a means of ensuring transparency and accountability in the project.

4.2.6. Environmental and Social Management in Irrigation Development

4.2.6.1. Relevant legal instruments, policies and Acts

Any form of construction brings about positive and negative impact upon the environment and social status within the communities around the site. Environmental and Social Management issues pertaining to construction of irrigation schemes is governed by the following relevant instruments, legislations, and policies:

- The Malawi Constitution, 1994
- Environmental Management Act (EMA), 1996
- National Environmental Policy, 2004
- Water Resources Act, 2013 and National Water Policy, 2005
- National Irrigation Policy (NIP) , 2016
- Irrigation Act, 2001
- Local Government Act, 1998
- Occupational Safety, Health and Welfare Act (1997)
- The Malawi National Health Policy (2012)
- Town and Country Planning Act, (1988)

4.2.6.1.1.1. The Engineer shall ensure that the Contractor adheres to the implementation of the project's Environmental and Social Management Plan (ESMPs) during the entire project period. A sample of key construction related points in the ESMP is in Annex C

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CHAPTER 5: CONSTRUCTION

5.1. Construction Materials

5.1.1. Individual construction materials

5.1.1.1. Cement

There are different types of cement depending on raw materials and additives used. These additives may be incorporated to improve properties such as setting times, durability, strength, working conditions and permeability. Most commonly used is Ordinary Portland Cement (OPC). Other types include Sulphate- resisting Portland cement, Blast furnace slag cement and Portland limestone cement.

5.1.1.1.1. The Engineer shall ensure that the appropriate cement is being used during construction as specified

5.1.1.2. Fine aggregate

These are mainly obtained from three possible sources:

- Natural disintegration of rock
- Mechanical crushing or milling of rock
- A composite mixture of the two sources

5.1.1.2.1. The Engineer shall ensure that fine aggregates comprise at least 90% of its particles that can pass through a 4.75 x 4.75mm hole on a sieve. Sand must be free from organic content, too much dust or any other chemical that may cause damage to concrete or steel reinforcement.

5.1.1.2.2. The Engineer shall ensure that key geotechnical tests to assess suitability of sand for use in construction are conducted prior to use in accordance with BS 812 .The tests shall include Organic Content test and Particle Size Distribution test (see Annex E for descriptions of the tests).

5.1.1.3. Coarse aggregate

The common coarse aggregate nominal sizes for irrigation construction works are 9.5mm, 19mm and 40mm.

5.1.1.3.1. The Engineer shall ensure that two of the key tests to determine suitability of coarse aggregate namely particle size analysis and aggregate crushing value are conducted prior to use (Refer to Annex E for descriptions of the tests).

5.1.1.4. Steel products

The main products made from steel that are used in works within an irrigation scheme include reinforcement, steel sections and steel sheets.

5.1.1.4.1. Steel reinforcement

Steel reinforcement provides tensile strength as concrete is only strong in compression.

5.1.1.4.1.1. The Engineer shall ensure that bar bending schedules for steel reinforcement is incorporated

A typical bar bending schedule is shown in Figure 17.

Member	Bar Mark	Type and Size	No. in each	Total No.	Total Length (mm)	Bending (mm)
Operating Deck Slab (Total No. 1)	01	Y10	10	10	20600	80 1900 80
Operating Deck Slab (Total No. 1)	02	Y10	20	20	21200	80 900 80

Figure 17 A typical bar bending schedule

Steel reinforcement is in two main forms:

- Mild steel bars – these have a smooth surface texture and their yield tensile strength (strength at which steel loses its elasticity) is 250N/mm2. Mild steel bars can also come in form of wire mesh for smaller diameters which are used for reinforcement of concrete slabs
- High tensile bars –these have a ribbed surface texture with yield strength of 450N/mm2 or more. These are produced in 12m lengths.

5.1.1.4.1.2. The Engineer shall reject the steel reinforcement is rusty, dusty or oily as these disturbs the bonding capability between reinforcement and concrete.

All steel reinforcement come with a mill certificate from the factory which shows the steel properties such as tensile strength, elasticity and ultimate tensile strength.

5.1.1.4.1.3. The Engineer shall check the information on the mill certificates to confirm whether the steel reinforcement's properties provided are matching with the ones specified in the structural drawings and specifications.

5.1.1.4.2. Steel sections

Steel sections are used as beams for roofing and small footbridges. They are also used as handles for structures such as steel gates and guard rails at inspection gates for large headworks. Common steel sections include I-sections, U-sections, angles, and hollow sections.

5.1.1.4.2.1. The Engineer shall check the information on the mill certificates to confirm whether the steel section's properties provided are matching with the ones specified in the structural drawings and specifications.

5.1.1.4.3. Steel sheets

Steel sheets for construction work are usually galvanized (i.e. coated with zinc) during production to prevent corrosion. Steel sheets may be corrugated or in inverted box ridge (IBR) form for roofing purposed or flat for use in irrigation control structures such as sluice gates. Thickness of steel sheets required for construction works is usually specified in the drawings or bills of quantities (26 gauge, 28 gauge, etc).

5.1.1.4.3.1. The Engineer shall check the information on the mill certificates to confirm whether the steel sheet's properties provided are matching with the ones specified in the structural drawings and specifications.

5.1.1.5. Timber

Timber can be used in small structures for irrigation systems such as canal gates and rarely division boxes. Other uses of timber include partitioning, roofing and formwork during construction of concrete structures. Hardwood timber is recommended for use in making canal gates for irrigation systems.

5.1.1.5.1. The Engineer shall ensure that timber protection from damage due to rotting, termites or wood borers has been conducted through the use of wood preservatives

5.1.1.6. Pipes and fittings

The most common pipes used in irrigation are un-plasticized polyvinyl chloride (uPVC) and polyethylene (PE) pipes. Pipes can be subjected to and withstand any given operating pressure, provided they are manufactured to withstand that pressure.

5.1.1.6.1. The Engineer shall ensure that the pipes to be used have the manufacturer's trade name or trade mark, the class of the pipe, the nominal size of the pipe and batch identification whereas fittings shall in addition have the size, shape and form of the thread in the case of threaded adapter bushes. Adhesives for use in joining pipes shall also have the manufacturer's trade name or trade mark of product suitable identification of the product, date of manufacture, words such as 'FLAMMABLE' and batch identification.

5.1.1.7. Fill material

Fill material in construction of irrigation infrastructure is mostly required during embankment formation for a canal in fill. Soils for fill can be sourced from cuts onsite or borrow pits located offsite.

5.1.1.7.1. The Engineer shall ensure that the fill material is suitable for embankment formation by confirming that the following geotechnical parameters are met by the sample of the proposed fill.

Table 29 Requirements for suitable fill material

No.	Test	Requirement
1	Sieve analysis	No particle shoul be more than 100mm in size
		40% should be the maximum percentage of soil particles passing through 0.075mm sieve
2	Plasticity index	Plasticity index should not be more than 30%
3	Maximum Dry Density(MDD)	MDD should not be less than 1500kg/m3

5.1.2. Composite construction materials

Composite construction products are made from a mix of individual construction materials. Such products include concrete and mortar.

5.1.2.1. Concrete

Concrete is formed from a mixture of specified proportions of cement, fine aggregate (sand), coarse aggregate (crushed stone or natural pebbles) and water. It is the most preferred construction material because it can be formed into almost any shape when it is still fresh, and when hardened it can achieve the strength required for most types of structural work.

5.1.2.1.1. Properties and components

Concrete has three main constituents namely, cement, fine aggregate and coarse aggregate. These are mixed using water.

5.1.2.1.1.1. The Engineer shall ensure that water used for making concrete is clean and as a rule, water suitable for drinking is suitable for concreting

5.1.2.1.1.2. The Engineer shall disallow concreting without using a concrete mixer

5.1.2.1.1.3. The Engineer shall ensure that a vibrating poker is being used when casting concrete to ensure high quality concrete.

5.1.2.1.2. Batching, concrete mixtures and mixing

5.1.2.1.2.1. The Engineer shall direct the Contractor to carry out trial mixes for concrete classes required in the project prior to the actual construction of the structures in order to ensure that the quality of concrete is not compromised in the construction works. This shall normally be done during the mobilization period in the presence of the Engineer and/or Site Inspector. The Engineer shall only approve the mixes that meet the strength requirements for use in the construction works.

5.1.2.1.2.2. The Engineer shall ensure that batching is being done correctly as it affects the workability, strength and cost of concrete. The quantities for construction materials shall either be measured by volume or by mass.

The most common used concrete mixes and their estimated 28 day strengths are as shown in Table 30:

Table 30 Common concrete mix proportions

Cement:Sand:Agg Ratio	Approx. strength at 28 days (N/mm2)
1:1:2	35
1:2:3	25
1:2:4	20
1:3:6	15
1:4:8	10

Concrete shall be properly mixed to the required workability which depends on the amount of water. The correct cement/water (c/w) ratio depends on the concrete grade, nominal stone size and type of compaction used. Time between addition of water to the mix and placing shall not exceed 60 minutes.

Loading of the material shall start with stone and most of the water followed by cement, sand and water to make up to the required volume and mixing shall be long enough to get the proper mixture normally 1.5 to 2 minutes. As a guideline, the approximate time required for one mix of concrete in a small mixer with a capacity of up to 500 litres is as follows:

Table 31 Approximate time for handing concrete

Activity	Time
filling	3 minutes
mixing	2 minutes
offloading	3 minutes
Extra	2 minutes

The Contractor shall avoid overloading the concrete mixer and make sure that the mixer is cleaned at the end of a shift. The concrete mixture shall not be allowed to dry out. The entire batch shall be discharged from the mixer before recharging.

5.1.2.1.3. Transporting, placing, compacting and curing concrete

5.1.2.1.3.1. The Engineer shall ensure that concrete is transported as quickly as is possible so that the quality of the concrete is not affected by:

- drying up
- losing workability
- contamination by soil or dust
- dilution with water
- segregation of the components

5.1.2.1.3.2. The Engineer shall not allow concrete placing to take place under the following conditions:

- When temperature is below 5 degrees Celsius or above 30 degrees Celsius
- When it is raining .If the rains started whilst concreting was in progress, the area where concrete has already been poured must be covered by plastic sheets to prevent rain water from increasing water content in the concrete. Concreting must only re-start after the rains have stopped
- When there are strong winds blowing

5.1.2.1.3.3. The Engineer shall ensure that the newly placed concrete is cured properly by covering the concreted area with a wet sack cloth or by continuous application of water for at least 2-4 weeks.

5.1.2.1.3.4. The Engineer shall ensure that any cavities in the concrete surface, caused by form ties, minor honey combs, broken corners or other defects are thoroughly cleaned, saturated with water for at least an hour and filled with mortar of 1:1 mix.

5.1.2.1.3.5. The Engineer shall ensure that concrete undergoes both slump test and compressive strength tests (see Annex 13 for descriptions of the tests).

5.1.2.1.4. Removal of formwork and falsework

The Engineer shall ensure timely removal of both formwork and falsework for concrete works. As a guide, the minimum days from date of casting concrete to the date for removal is as follows:

- Beam sides, walls and unloaded columns: 1 day
- Slabs with props left in place: 4 days
- Beam soffits with props left in place: 7 days
- Slab props: 10 days
- Beam including beam cantilever props: 14 days

5.1.2.2. Mortar

The Engineer shall ensure that the mortar mix being used during construction matches the specifications on construction drawings and bills of quantities

5.1.2.2.1. Properties of mortar

Mortar has two distinct, important sets of properties: those in the plastic state and those in the hardened state. The plastic properties help to determine the mortar's compatibility with brick and its construction suitability and include workability, water retention, initial flow and flow after suction. Properties of hardened mortar help to determine performance of the finished blockwork and include flexural bond strength, durability, extensibility and compressive strength.

5.1.2.2.1.1. The Engineer shall ensure that mortar is used within 2½ hours after initial mixing

5.1.2.2.2. Common mortar mixes

Sand and cement shall be mixed dry, before adding water. Common mortar mixes by volume are:

Table 32 Common mortar mixes by volume

Mortar Mix	Cement Bags	Fine Aggregate
	(1 bag of 50 kg = 40 litres)	m^3
1:2	14	1.12
1:3	10	1.2
1:4	8	1.28
1:5	7	1.4
1:6	6	1.44

5.1.2.3. Soil Stabilized Blocks (SSBs) and Concrete/Cement blocks

Burnt bricks, SSBs and Concrete/Cement blocks shall be used for building vertical walls for irrigation structures. A desirable soil for use in production of SSBs must consist of gravel, sand, silt and clay. The recommended range of the fines content is from 20-30%.Concrete blocks are made from a mixture of sand and cement. The blocks are compacted and cured properly.

5.1.2.3.1. The Engineer shall ensure that prior to mass production, samples of cement blocks and SSBs to be used in the works meet the minimum expected compressive strengths as specified in the drawings and other relevant documents.

5.2. Construction works

5.2.1. Earthworks

5.2.1.1. General

Earthworks involve operations such as excavations, preparation of surfaces, embankment or fill construction and compaction. However, there are other activities that may be performed before earthworks construction begin such as clearing and removal of top soil. Earthwork operations shall take into consideration all archaeological, governmental, religious, cultural and environmental issues.

5.2.1.2. Clearing

The Engineer shall ensure that clearing has been carefully planned and executed with particular attention to both short and long term effects that may be brought about due to soil erosion. From the start of the construction works, attention should be paid to the effects of the construction works upon the surrounding landscape. The haphazard bulldozing or dumping of cleared vegetation should be prohibited. Unwarranted damage of vegetation around the construction site should not be allowed. This also applies to the management of borrow areas.

5.2.1.3. Removal of Topsoil

The top 150mm of top soil is considered as agricultural soil with organic content from roots of plants. This soil is not suitable for construction works.

5.2.1.3.1. The Engineer shall ensure that top soil up to the depth of 150mm is removed and stockpiled for reuse at a later stage at both the construction site and borrow pits

5.2.1.3.2. Volume of stripped top soil shall be measured jointly between the Contractor and the Engineer to avoid disagreements on the quantities. The stripped soil volume shall generally be established by multiplying the area stripped by the average depth of stripped soil. Where other methods for calculation of volume have been indicated in the technical specifications, the Engineer shall use them.

5.2.1.4. Excavation Operations

5.2.1.4.1. The Engineer shall ensure that the Contractor is handling fill material during excavation as specified in the bills of quantities. Where this is not clearly stated in the bills of quantities, the Engineer shall determine the most economical option to be used

The following are the options used when handling fill material during construction:

- Cut to fill - where the material excavated can be re-used within the project site
- Cut to spoil - where the material excavated is not suitable for the re-use, and must be disposed of in the most appropriate way
- Cut to stock pile - where the material excavated can be re-used on a later date.

5.2.1.4.2. The Engineer shall ensure that the excavated materials are correctly classified as either rock or common excavation.

: These two classes are described below:

- Rock excavation- excavation in material which requires drilling and blasting or use of hydraulic or pneumatic jackhammers to be loosened and to be loaded for transportation to disposal, fill or stockpile.
- Common excavation-excavation in all materials other than rock as defined above

5.2.1.5. Protection of excavated pits and trenches from collapsing

The Engineer shall ensure that bracings to support excavated sides against collapsing through the use of planks and props is being carried out during construction. Alternatively, excavating trenches with battered/slanting sides must be used.

5.2.1.6. Drainage

The Engineer shall ensure that all necessary precautions are taken to secure the site against the introduction of surface water, sub-surface of groundwater where earthworks are being done. This operation frequently entails the temporary diversion of natural drainage water or pumping away from the site works. Precautions shall be taken to ensure that control of surface water within the construction site does not interfere with or disrupt the water supply to downstream users.

5.2.1.7. Identification of suitable Borrow material

Borrow material as per the required quantities and geotechnical parameters shall be identified at borrow pits and where possible, within the site where cuts will be essential. Recommended geotechnical tests for samples of earth material have been covered under Annex E. These tests shall be done to ensure that only suitable earth material is being used in the construction works.

5.2.1.7.1. The Engineer shall approve the borrow areas, indicating specific requirements for working limits, access restraints, working method and final shape characteristics.

5.2.1.7.2. The Engineer shall ensure timely acquisition of resource permits and approvals to avoid unacceptable delays on the contract.

5.2.1.7.3. The Engineer shall ensure that the borrow areas conform to the adjoining landform when finally restored

5.2.1.8. Dimensions of Cuts or Excavations

5.2.1.8.1. The Engineer shall ensure that dimensions of cut or excavations are in accordance with details on the drawings which may be amended by an instruction from the Engineer. In rock cuts or excavations, the rock shall be excavated to the level that will allow the construction of the subsequent top layers for the fill or embankment.

5.2.1.8.2. The Engineer shall order all cuts made outside the specified line of cut or below the specified level without his/her approval to be backfilled with approved material. This shall be compacted to the Engineer’s satisfaction and re-trimmed.

5.2.1.8.3. The Engineer shall ensure strict control of levels on site to avoid unnecessary costs.

5.2.1.9. Undercutting

The Engineer shall ensure that all unsuitable material are excavated and replaced by suitable material. The removal of unsuitable foundation material from areas where filling is to be placed is classed as undercutting. Such unsuitable foundation materials shall include materials which contain a high percentage of organic matter (i.e. peat and soft plastic clays).

5.2.1.10. Construction plant/equipment for earthworks

The Engineer shall ensure that the plant/equipment earmarked for use are in good working condition. Where this is not the case, the Engineer shall order either replacement or repair of the plant/equipment

5.2.1.11. Filling

The Engineer shall ensure that fill material is being handled, laid and compacted in manner that the specified compaction and shape requirements on the finished product can be achieved.

5.2.1.12. Cut to Stockpile Material

The Engineer shall ensure that excavated material undergoes geotechnical tests to ascertain its suitablitiy as fill material. Where the material is technically declared as being suitable for fill material, it should be used as such. Excavated material that is unsuitable should be used as backfill.

5.2.1.13. Fill Compaction

Soil compaction increases the unit weight of soil through application of either dynamic or static load. The load reduces air and water in the voids thereby forcing solids into a tighter state. In any soil, there is a specific moisture content that makes it to possess the maximum unit weight. This optimum moisture content and its corresponding maximum dry density are determined through Modified Proctor test in the laboratory (see Annex E). For canal embankment formation, granular, well graded fill material is the most suitable soil that produces best results. In irrigation canal embankments, 95% of the maximum dry density is the recommended minimum for granular fill material.

5.2.1.13.1. The Engineer shall order a trial run for compaction works before the actual compaction programme commences. The results of the trial run shall be used as basis for compaction methodology to be used during construction. Annex E describes compaction and trial run procedures

5.2.1.14. Material improvement

Earthworks material with the required properties may not always be available to meet the required specifications. As such, existing material shall be improved to make it suitable through soil stabilization.

5.2.1.14.1. The Engineer shall determine the soil stabilization technique to be used whenever need arises.

The two main soil stabilization techniques namely mechanical and chemical stabilization are described below:

- Mechanical Stabilization -improves soil properties by adding missing components whereby insitu soil is mixed with imported materials and compacted.
- Chemical Stabilization - Improves the properties by mixing with materials such as cement or lime. Mixing can be done either by dynamic machines such as grader or stationary plant such as a concrete mixer.

5.2.1.15. Canal construction

5.2.1.15.1. Setting out canals

The Engineer shall approve the setting out of the designed elevations, vertical and horizontal alignments. Survey instruments such as dumpy level, total station, RTK GPS and theodolites shall be used. Measuring tapes should also be used to measure distances. Prior to approval, the Engineer shall check that the following have been executed:

- Survey point intervals of not more than 20m have been established along the canal alignments so that important details are not missed out. In small farms, this interval shall be limited to 10m.
- Significant changes in elevation along the canal location have been marked as key chainages even if their corresponding chainage do not coincide with the chosen interval.
- The pegs at the established chainages have been painted to show the embankment finish level.
- Transversely, pegs have been installed to show the extent of embankment bottom width at each established chainage.

5.2.1.15.2. Canal construction

5.2.1.15.2.1. The Engineer shall ensure that clearing and stripping off of unacceptable material is done along the canal route. The strip shall be as wide as the bottom width of the canal embankment.

5.2.1.15.2.2. Embankment formation shall be done either manually or mechanically depending on either the specifications or direction from the Engineer. This shall be achieved by using a grader/hoes/scraper when moving fill material and compacting equipment when compaction is taking place.

5.2.1.15.2.3. After canal embankment formation is complete, the Engineer shall ensure that excavation for the canal section is being done with control of wooden profiles and/or survey equipment to achieve specified vertical and horizontal dimensions. Excavation shall be done either manually using hoes or mechanically using an excavator with a special bucket which can excavate to required canal shapes. This process of excavating canal sections also applies to canals in cut.

5.2.1.15.2.4. Blinding

The Engineer shall ensure that the specified thickness and required sand properties are being used during blinding

5.2.1.15.2.5. Concrete Lining

Lining canals improves durability and efficiency as it prevents seepage losses, scour and erosion, excessive aquatic weed growth, reduction of maintenance cost and allow for increased curvature. Concrete/stone masonry / earth material shall be used for lining. In cases where weep holes have been incorporated in the design, these and their filters shall be put in place before lining is done.

Concrete lining shall be either cast in-situ or precast concrete

5.2.1.15.2.5.1. The Engineer shall recommend either in-situ lining where the canal sides are not too steep and water is available for curing or precast concrete lining where access to water along the targeted canal locations may be challenging.

5.2.1.15.2.5.2. For Pre-cast lining, the Engineer shall recommend size of slabs that are easy to handle (3m maximum length). Formwork that is recommended for precast slabs is either steel or timber. The ratio of cement/sand/stone for concrete shall be as specified in the design.

5.2.1.15.2.5.3. The Engineer shall ensure that concrete canal panels shall be laid in alternate bays. Construction of the middle panels must done at least after 24 hours.

5.2.1.15.2.5.4. After curing, the Engineer shall ensure that joints between concrete panels are filled up with bitumen or any other recommended joint seal to avoid leakage.

5.2.1.15.2.5.5. The Engineer shall ensure that a layer of 50mm thick sand blinding is used over a compacted canal base to protect the canal lining from cracking in cuts occurring along sections comprising clayey soils.

5.2.1.15.2.6. Stone masonry lining

5.2.1.15.2.6.1. The Engineer shall ensure that stones selected for canal lining are dense, smooth faced, durable and abrasion resistant.

5.2.1.15.2.6.2. The Engineer shall ensure that the mortar mix ratio and thickness of stone masonry canal as specified in the drawings and bills of quantities are being used

5.2.1.16. Pipe laying

5.2.1.16.1. Setting out Pipelines

5.2.1.16.1.1. The Engineer shall approve the setting out of pipeline prior to commence of excavation. The Engineer shall check that the following have been done before approval:

- Centreline pegs for the pipeline including offsets indicating the extent of excavation have been installed
- The centre line pegs of trenches match with coordinates indicated on the horizontal alignment profile drawings
- The extent of trench excavation is to a width that can accommodate pipe diameter and adequate working space (at least 0.5m).

5.2.1.16.1.2. The Engineer shall check the vertical alignment of invert levels for the pipeline by referring to pipeline profiles.

5.2.1.16.2. Trenching

Trenches shall be dug either manually by using picks and shovels or mechanically by using an excavator.

5.2.1.16.2.1. The Engineer shall order blasting where rock outcrops are encountered during excavations and it is still deemed imperative to remove the outcrops. Local techniques may also be considered by the Engineer when dealing with rock outcrops, like heating and fast cooling to weaken the rocks and then hitting them with a hammer.

5.2.1.16.3. Bedding

The Engineer shall ensure that the bottom of the trench is level or of a uniform slope so as to accommodate the full length of the pipe. Where an uneven trench bottom is encountered, especially in rocky or hard ground, a 10 cm (or at least one third of nominal diameter) fine back-fill or bedding should be provided. This layer shall be back-filled, using suitable bedding material such as free-draining coarse sand, gravel, loam or a soil of friable nature, and be levelled. In the case of fittings, excavation in the back-fill shall be made to accommodate the fitting.

5.2.1.16.4. Pipe laying

For uPVC piping less than 200 mm in diameter, either an injection-mould adhesive type of fitting or an integral rubber ring is be used. For sizes larger than 250 mm diameter, a rubber ring end socket is used. Larger diameter pipes shall be mechanically jointed.

5.2.1.16.4.1. The Engineer shall ensure that the pipes to be joined are clean of dirt.

5.2.1.16.4.2. The Engineer shall ensure that all the solvent cleaners, adhesives and lubricants used in joining pipes are those recommended by the manufacturer of the pipe or fitting. Caution shall be taken on the handling of solvent cleaners and adhesives because they are highly volatile.

5.2.1.16.4.3. When joining pipes using adhesives, the Engineer shall ensure that the lubricant have been applied up to the witness groove and the alignment of the pipe up to the coupling. Where jointing is not done immediately, the pipes must be temporarily closed in order to avoid the entrance of animals or dirt and temporary closures shall be opened on re-commencement of pipe laying.

5.2.1.16.5. Back-filling

The Engineer shall ensure that side filling is being done in 75 mm thick layers, using fine material for the fill after checking that the levels of all joints are correctly set out. The layers must be tamped, ensuring that the joints are left exposed. Tamping shall be done simultaneously on both sides of the pipe, in order to avoid misalignment. This must continue up to a height of two thirds of the pipe diameter, or up to 10 cm above the crown when the material is spread over the whole length of the pipeline except the joints. Beyond that, the rest of the back-filling shall be done in layers of 15-30 cm. The trenches shall be over-filled to allow for settlement. The space between the joints must be backfilled after the pipeline has been pressurized and the joints inspected to confirm that that there are no leaks. All pipes shall be backfilled once they are installed in order to prevent them from floating due to either rainwater or groundwater.

5.2.1.16.6. Pressure testing and flushing of the system

5.2.1.16.6.1. The Engineer shall ensure that testing of pipelines is done to ensure that the pipe joints are water-tight and that the permanent concrete thrust blocks are capable of resisting the load. Normally, at least 7 days shall be allowed after constructing the last thrust block before the system is tested. By this time, the last thrust block should be able to withstand the load.

5.2.1.16.6.2. When pressure testing, the Engineer shall ensure that the pressure being used does not exceed one and half times the maximum working pressure. Valves and all other outlets shall be opened and closed slowly.

5.2.1.16.6.3. The Engineer must ensure that flushing, which is intended to remove all the dirt that inevitably gets into the system during pipe laying is done for a couple of hours with the flush valves at the end of the lateral lines open. The flushing process shall be stopped once clean water starts coming out of the valves.

5.2.1.17. Water Storage, Control and distribution structures

5.2.1.17.1. General

Water storage, control and distribution structures commonly used in irrigation schemes include dams, night storage reservoirs, weirs, energy dissipating chambers, distribution boxes, and spillway and drop structures.

Before any construction of water storage, control and distribution structures, proper setting out must be done to avoid both horizontal and vertical dimension errors. Pegs and survey equipment such as RTK GPS, Total Station, Dumpy level and theodolites are used.

5.2.1.17.2. Dam embankment

5.2.1.17.2.1. The Engineer shall ensure that setting out commences with pegging along the proposed location for embankment centerline, top and bottom widths. Where the dam has been designed to have a key trench, its key dimensions in plan must be also be set out to guide on the extent of excavations.

5.2.1.17.2.2. The Engineer shall ensure that excavation of key trench is carried out to depths and sectional shape as provided in the drawings for the designed dam .In most cases, mechanically operated machines such as excavators are used.

However, manually digging the trench is also acceptable for very small dams.

5.2.1.17.2.3. The Engineer shall ensure that filling of key trench and the construction of dam embankment is done as explained in 6.2.1.22 and Annex E where fill material handling and compaction is discussed.

5.2.1.17.2.4. The Engineer shall ensure that the upstream side of the dam embankment is protected with grass or stone pitching works or any other specified protective measure to prevent erosion. The downstream side requires stone pitching to avoid scouring of the embankment.

5.2.1.17.3. Water control and distribution structures

5.2.1.17.3.1. The Engineer shall ensure correct setting out so that the elevation and location of the built structure matches with the specifications in the relevant drawings for both the structure and entire system layout. Elevation and location of these structures is critical as they are set to satisfy design requirements of the operational aspects for the irrigation system.

5.2.1.17.3.2. The Engineer must ensure that care is being taken on selection and handling of the materials as well as skill of the mason.

5.2.1.17.3.3. The Engineer shall ensure that the following steps are taken during construction of infield water control and distribution structures such as division boxes, tail end structures, drop structures, manholes and flumes:

- Setting out - The proposed site for the structure shall be set out to mark the designed exact location, dimensions and elevations.
- Clearing and stripping off top soil-The area on which the structure is to be constructed shall be cleared from existing vegetation and/or rubble. Stripping off of top soil from the site shall be conducted thereafter.
- Construction of foundation -The foundation shall be laid as specified in the drawings supplied by the Engineer. Foundation details shall include foundation size, blinding, hard core, reinforcement and material requirements. In cases where there are significant discrepancies between the design details and the actual site conditions, the Engineer shall determine the required modifications that should not negatively affect the functional requirements of the structure.
- Walls -Walls shall be constructed following completion of foundation. The walls shall be constructed as per the design specifications for material type, mortar or concrete mix proportions, size and height.
- Plastering - Where plastering has been specified in the drawings, walls shall be plastered using mortar mix proportions provided in drawings and/or bills of quantities
- Curing - Plaster and concrete portions of the walls and foundation shall be allowed to cure properly. This shall be achieved by covering concrete/plastered wall with a wet sack cloth or by continuous application of water for at least 2-4 weeks. Floor slabs shall be overlaid with 50mm thick sand and frequently watered.
- Gates and Valves - For structures with gates and/or valves, installation shall be based on their instruction manual

5.2.1.17.4. Erosion Protection Works

5.2.1.17.4.1. Stone Pitching

This type of protection gives a fairly smooth surface by firmly packed stones which are secured in place by mortar between the stone joints.

5.2.1.17.4.1.1. The Engineer shall ensure that the stones are laid perpendicular to the slope with the thickness that has been specified in the drawings.

5.2.1.17.4.2. Rip rap

This is protection that is provided with broken rock or large stones of thickness between 250 mm and 500 mm depending upon erosive force such as wave. The individual stone pieces weighing between 5 and 25 kg shall be placed loosely on top of the slope.

5.2.1.17.4.2.1. The Engineer shall ensure that before the stones are laid, at least 100 mm thick layer of well-graded gravel is provided underneath the rip-rap when there is a danger that fines may be washed away from the embankment material through wave action.

5.2.1.17.4.3. Soding works

Erosion protection works also include seeding of grass, which is a cheap and effective protective measure. Short growing or creeping varieties give good results (e.g. star grass).

5.2.1.17.4.3.1. The Engineer shall ensure that at least 100mm thick top soil is laid before seeding grass, particularly when poorly weathered sub-soil material is placed in the embankment

5.2.1.17.4.4. Gabions

Gabions are a form of retaining wall produced from individual rectangular, wire mesh boxes that are partitioned inside.

5.2.1.17.4.4.1. The Engineer shall ensure that gabion boxes are stacked in a stretcher bond fashion as in brickwork and placed in layers against the surface which is being retained.

A typical gabion placement arrangement is shown in Figure 18 below

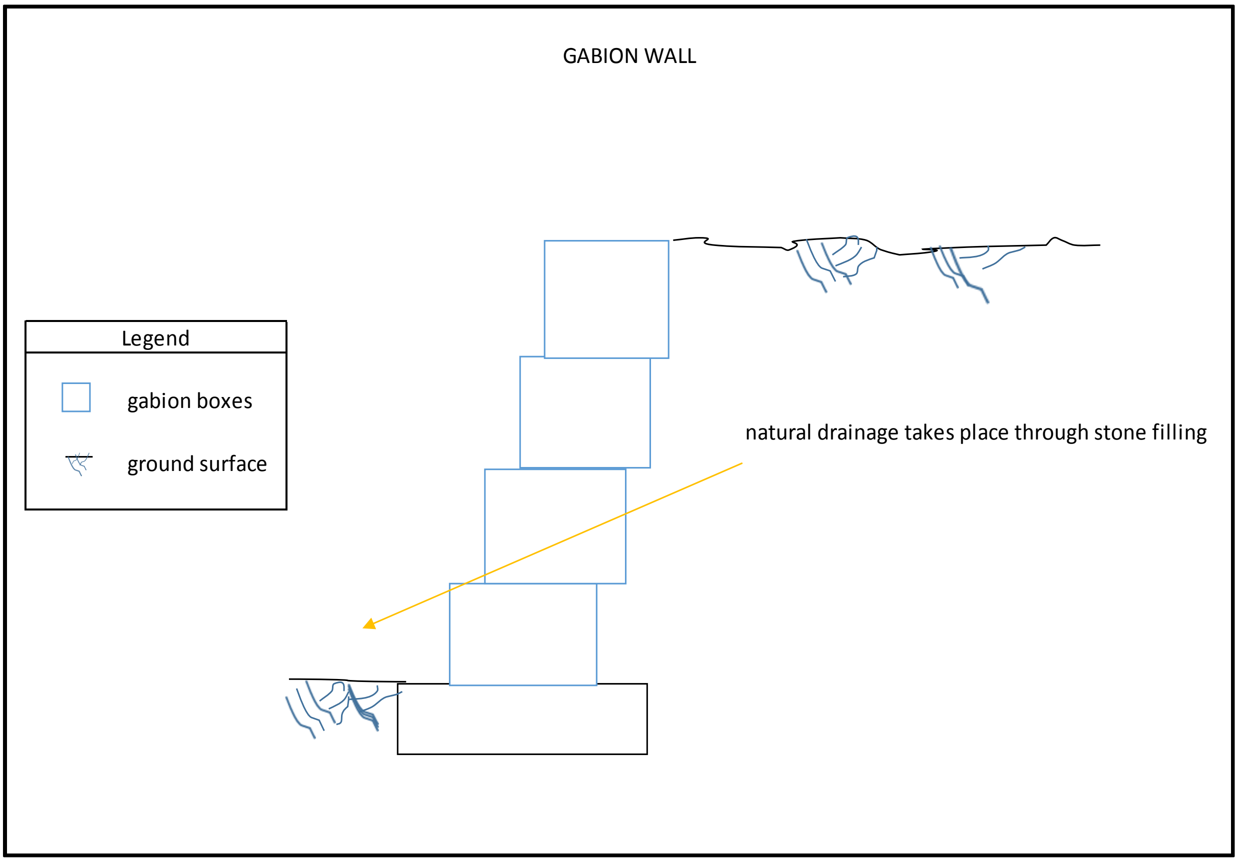


Figure 18 General gabion placement arrangement

5.2.1.17.4.5. Reno mattresses

Reno mattresses are similar to gabions except the fact that they have lesser thickness, smaller mesh and stone sizes. They are mainly used on surfaces that are not very steep. Mattresses shall be mostly used next to water channels where scour protection is essential.

5.2.1.17.4.5.1. The Engineer shall ensure that reno mattresses are stacked in a stretcher bond fashion as in brickwork and placed in layers against the surface which is being retained.

A typical reno mattress placement arrangement is shown in Figure 19 below

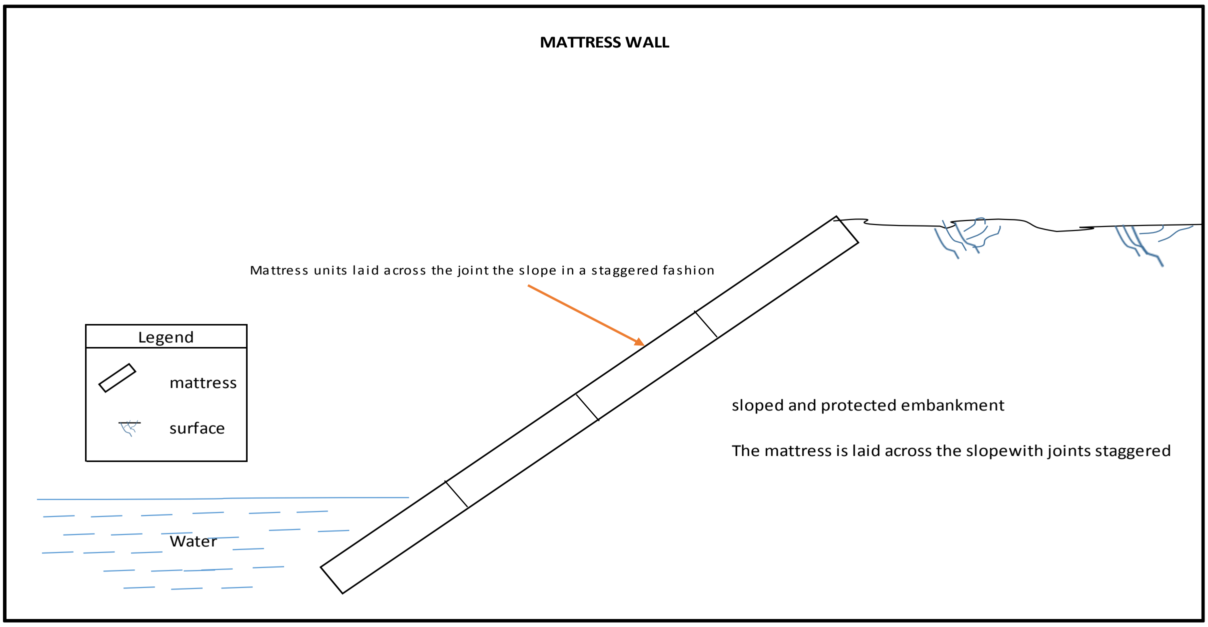


Figure 19 General Reno mattress placement arrangement

5.2.1.17.5. Drainage Works

5.2.1.17.5.1. The Engineer shall ensure that drainage works are implemented on sites that are potentially at risk from progressive drainage problems.

Such sites are characterized by the following:
- Poorly drained soils
- Flat surface gradients
- A water table which is close to the surface
- An underlying impermeable layer.

There are two main types of drains: surface and sub-surface drains:

5.2.1.17.5.2. Surface drains

These are drains that are constructed on the surface in order to:
- Prevent water from ponding on land surfaces or in surface drains that are crossed by farm equipment
- Remove excess water in time to prevent damage to crops
- Accomplish the above without excess erosion.

5.2.1.17.5.2.1.

The Engineer shall ensure that setting out of surface drains is conducted in a similar manner as setting out of canals as described in under 6.2.1.15.1.

5.2.1.17.5.2.2. The Engineer shall ensure that construction of surface drains is conducted in a similar manner as construction of unlined open canals as described in 6.2.1.15.1 and 6.2.1.15.2.3 and leaving out the scope on construction of embankment

5.2.1.17.5.2.3. The Engineer shall ensure that the gradient, elevation and dimensions of the drains are matching those provided in the specifications of the design.

5.2.1.17.5.3. Sub-surface drains

Subsurface drains are drains constructed below the ground. These drains are preferred in fields with high water table. These drains are made from perforated PVC pipes, reeds, rocks amongst others.

5.2.1.17.5.3.1. During setting out of sub surface drains, the Engineer shall ensure that the drain route is marked longitudinally with pegs.

5.2.1.17.5.3.2. The Engineer shall ensure that vertical alignment for the drain is controlled at design grade by utilizing grading devices i.e. survey equipment and wooden profiles.

5.2.1.17.5.3.3. The Engineer shall check the final trench levels by using a minimum of four targets that are set along any given line of continuous grade. Each target shall be set for depth of cut as indicated by its respective grade stake. Alternatively, manual grade control with visual sight bars and targets can be used for trenching operations. To govern alignment, direction and grade stakes shall be set 30 m or less apart on straight lines and 15 m or less on curves for all drain lines to be constructed. They shall also be set at all intersections of mains and points of grade change.

5.2.1.17.5.3.4. The Engineer shall ensure that the trench width is the minimum required to permit installation of the drains and provide bedding conditions that are suitable to support the load on the drain. If the trench is excavated below the designed grade, it shall be filled with gravel and tamped sufficiently to provide a firm foundation. The bottom of the trench shall be shaped to grade. A width of 500mm is appropriate to provide for working space of installation personnel.

5.2.1.17.5.3.5. In unstable or fluid soil conditions, the Engineer shall ensure that bracings have been provided to protect the sides of the trench from collapsing until the drain has been properly laid and blinded. Excavation of these drains shall start from the downstream end for easy drainage during construction.

5.2.1.17.5.3.6. Soon after excavation is complete, the Engineer shall ensure that drainage installation begins immediately with proper bedding. In the case of perforated PVC-piping, a layer of sand of 150mm shall be laid from trench bottom to the design levels. These bedding finish levels shall be checked to ensure conformance to design specifications. The following is the chronological order of the subsequent steps to be followed:

- Commencement of back filling to avoid pipes floating in the water logged conditions
- Covering of pipes with another layer of sand with minimum thickness of 150mm coarse grained material
- If tubing is used, inspection boxes shall be incorporated to clean blockages at specified intervals.
- If rocks are used for the sub surface drainage, a filter (an impervious mat) specified in the design shall be used to wrap around them to avoid soil clogging up the system.
- A sand and gravel envelope designed as a filter may be used. Where this type of filter material is not available, artificial prefabricated filter material shall be used.
- Where fiber glass filter material is used, it should be the type that is manufactured from borosilicate-type glass and it shall be certified suitable for underground use. The fibers shall be of variable size, with some larger fibers intertwined in the mat in a random manner. Any damaged areas shall be replaced before backfilling.

- Backfilling up to the finished level specified in the designs.

5.2.1.17.6. River Training Works

A stable section of the river is normally identified as the most suitable site for constructing water abstraction structures. However, some interventions are required in order to guide the river to flow within the channel, improve the flow characteristics, without causing erosion of the banks.

River training shall be done in order to provide good flow characteristics through a water abstraction structure. River bank protection is required upstream and downstream of the structure.

These protection works include gabions and Reno mattresses which have been discussed earlier

5.2.1.17.7. Irrigation Well

Irrigation well construction consists of the drilling operation, installing the well inlet, and casing, packing material, and protecting the quality of the aquifer.

5.2.1.17.7.1. Placement of equipment and materials.

The Engineer shall ensure that all equipment and materials placed in the well are installed in a manner which meets design specifications, unless some good and sufficient reason is encountered during construction to deviate from design specifications. Any change shall first be approved by the Engineer in form of a variation order.

5.2.1.17.7.2. Borehole

The Engineer shall ensure that the borehole is round, plumb, straight, and of adequate diameter to permit satisfactory and proper installation of the inlet, well casing, and pack material.

5.2.1.17.7.3. Inlet

The Engineer shall ensure that the screen or perforated sections are handled carefully and placed at the correct depths to match the desired formations. When the well is to be packed, the entire length of the inlet shall be centered in the borehole by the placement of centering guides at vertical intervals of about 6 m to insure that the pack material will fill the entire intake area uniformly. The centering guides shall be placed 90 degrees apart circumferentially.

5.2.1.17.7.4. Casing

The Engineer shall ensure that the casing is relatively plumb and straight to permit installation and operation of the pump. The usual requirement for plumbness of casing and screen is that it shall not deviate from the vertical by more than two-thirds the casing diameter per 30 m of depth as determined by gaging. The deviations shall be reasonably consistent regarding direction. A normal standard for straightness requires that a 12 m long bucket (bailing bucket or pipe) with a diameter of 25 mm less than the casing be lowered freely to the total depth of the well or to the deepest possible pump setting.

5.2.1.17.7.5. Pack material

The Engineer shall ensure that pack material is placed carefully to prevent separation and bridging. The use of a tremie will help prevent layering of material caused by different rates of settling, bridging of pack materials, and non-uniform placement of pack material in the intake area. Thin packs that are uniform in size shall be added from the surface if done very slowly.

5.2.1.17.7.6. Drilling fluid additives

The Engineer shall ensure that unconsolidated formations are sealed in order to prevent excessive loss of drilling fluids. Natural clays shall be placed in the drilling fluid to temporarily seal the pores in the borehole walls. However, these introduced materials shall be removed during the development process.

5.2.1.17.7.7. Aquifer protection

The Engineer shall ensure that the upper 3 to 6 m of the annular space between the borehole and the well casing is carefully filled with material that does not contain potentially harmful bacteria or chemicals. A cement grout shall be used in this space to prevent surface water entering the aquifer through the area around the well casing. If the natural water level in the ground is less than 6 m, the cement grout shall extend down to the static water level. Surface casing is appropriate for additional protection. State regulations shall be consulted for additional requirements regarding aquifer protection.

5.2.1.17.7.8. Construction certification.

The Engineer shall issue a certification that the well was constructed in such a manner as to satisfy all original design specifications. Any modifications of the original specifications shall be included in the certification.

5.2.1.17.7.9. Well development

It is necessary to develop the well to obtain its maximum capacity for a given drawdown. The developing process removes fine material from the formation near the well screen, thereby opening the passages so that the water can enter the well more freely. The process is accomplished by forcing water in and out of the screen openings.

5.2.1.17.7.9.1. The Engineer shall ensure that all fine material pulled into the well during the developing operation has been removed from the well before installing the test pump.

5.2.1.17.7.10. Well development methods

Often, more than one method is used to successfully develop a well. The method used to develop a well shall be selected based upon the geological makeup of the aquifer.

- Development by surge block or swab- After the casing and filter pack (if required) have been installed, the well is thoroughly surged or swabbed. The surge block is alternated with the use of a bailer to keep the screen and casing clean.
- Development by bailing-Although not a highly recommended method, the bailer alone shall be used in a similar manner as that of a surge block in wells with diameters greater than 200 mm. The bailing unit shall have a line speed of at least 2.5 m/s during hoisting (5 m/s is recommended) and free-fall during lowering of the bailer. The bailer shall fit closely inside the casing being no less than 50 mm smaller than the well inlet. The bailing unit shall be capable of removing at least 2 L/s continuously for 1 hour from 200 mm diameter well to 8 L/s from 400 mm diameter wells.
- Development by pumping- Development by pumping shall be employed as an additional or final development step when used in conjunction with other methods. It is not recommended as a singular method of development. A pump shall be supplied for this method and may be the same pump used for the well test. The suggested procedure for pump development is to begin pumping at about one-fourth or one fifth of the desired yield of the well and to continue pumping until the water becomes clear. Then the well shall be surged by turning off the pump, allowing the water to run back into the well, and then

pumped again. This process of alternating pumping and not pumping continues until no sand is pumped at the first discharge rate. The process is repeated at 50, 75,100 and if possible 125% of the desired well yield.

- Development with chemicals-Numerous chemicals are used to aid in well development. Several polyphosphates are available to disperse clays and mud cakes. Acid may be used in limestone formations to enlarge openings and improve production.
- Development by jetting -Development by high-pressure hydraulic jetting shall be required to remove the foreign material and fines that accumulate in the formation during the drilling process. If practical, the well shall be pumped during the jetting process to remove the fine particles.
- Development by air pumping- Air pumping shall be accomplished by injecting a high volume of compressed air in the well which causes an uplift action which provides a surging effect. A more effective air pumping method utilizes a double-packer tool to selectively develop the well inlet.

5.2.1.17.7.11. Well testing

The Engineer shall ensure that the well is adequately tested for discharge and drawdown characteristics with a test pump after the well is developed and the discharge is free of sand.

5.2.1.17.7.12. Static water level

The Engineer shall ensure that the static water level in the well is measured with an air pressure device, wetted tape, or a standard electrical depth device prior to test pumping. The measurement shall be made at least 12 hours after any work has been done on the well that may have disturbed the water level.

5.2.1.17.7.13. Pumping water level

For test pumping purposes, the Engineer shall ensure that the water level is lowered substantially below the desired or anticipated production pumping level. The lowest level normally attempted is that which results from a rate equal to 125% of the desired pumping rate after equilibrium is reached.

5.2.1.17.7.14. Pumping rates

5.2.1.17.7.14.1 Several patterns of pumping rates can be used in pump testing a well. The Engineer shall ensure that the pattern selected is based on the type of information desired such as aquifer constants, degree of well development, maximum discharge within permissible drawdown, and acceptable discharge for pump selection. It is important that the pumping test provides adequate data for efficient pump selection. The required data include:

i. Maximum discharge -If problems in the continuity of the water supply are not anticipated, the one flow rate which gives the lowest allowable pumping water level is the maximum discharge rate. This flow rate shall be maintained until the drawdown remains stable for a minimum of 1 hour, and the entire test shall never be less than 8 hours. However, test periods of 24 hours or more are preferred, especially in aquifers with low permeability.

ii. Decreasing step-drawdown test-This pattern of pumping rates is suitable for determining the range of acceptable discharges for selecting the permanent pump. The first pumping rate and pumping time is described in 4.7.5.3(i). At the end of the first pumping period the rate is reduced to approximately 80% of the initial pumping rate. This rate is continued until the discharge and pumping water level in the well remain constant for at least 30 min. Then the process is repeated for pumping rates of 60, 40, and 20% of the initial pumping rate. Each pumping rate shall continue until the discharge and pumping water level remain constant for at least 30 min.

iii. Constant discharge test- A constant rate test may be specified to determine certain aquifer characteristic coefficients. The well is pumped at the established rate or other specified rate criterion without substantial variations in rate for the time period required. Periodic measurement of pumping rate shall be recorded during the test period.

5.2.1.17.7.14.2 The Engineer shall ensure that pumping water levels are being measured and recorded.

The following are the two recommended time schedules that can be used:

i. Regular intervals - Water level measurements shall be made every 5 min for the first 30 min of pumping, every 10 min for the next hour, every 30 min for the next 4.5 hours, then every hour for the duration of the test measured in the same time sequence for at least 50% of the elapsed pumping time.

ii. Logarithmic intervals- Pumping water levels shall be measured with sufficient frequency so at least 10 data points are located throughout each logarithmic graph cycle. For example, depth is measured at approximately 1, 1.2, 1.5, 2, 2.5, 3, 4, 5, 6, 7, and 8 min after the start of the test. Then measurements are continued at all succeeding decimal multiples of these intervals to the end of the test, e.g., 10, 12, 15, 20, 25, 30, 40, 50, 60, 70, 80, 100, 120, 150 min.

5.2.1.17.7.15. Continuity

The Engineer shall ensure that the pump is not stopped during the pumping test period. If the pump is stopped for less than 1 hour, the test may be resumed, but measurements shall not be recorded until the water level in the well has remained steady for 1 hour. If a constant rate test is being conducted the test shall not be resumed until a sufficient recovery period has allowed the static water table to return to its original level. The complete test shall then be restarted.

5.2.1.17.7.16. Data recording

The Engineer shall ensure that the flow rates (discharge) and pumping water levels are being measured accurately and recorded for each pumping rate test. The rate shall be measured with a standard orifice, flow meter, or other measuring device with an error of less than 5%. Water level measurements shall be accurate to 30 mm, if possible.

5.2.1.17.7.17. Aquifer protection

During and after all testing work, the Engineer shall ensure that the well is properly protected to prevent the entry of foreign material and contaminated water from any source. This would include capping the well casing, covering the well bore, and grading the land surface to prevent surface water entry.

CHAPTER 6: EVALUATION OF A CONSTRUCTION PROJECT

6.1. General

Evaluation of project performance is conducted after completion of the project as this is a very important aspect of ensuring continuous improvement by every implementer.

6.2. Review and Analysis of construction project data

6.2.1. Review and Analysis sessions

6.2.1.1. The Engineer shall facilitate the review sessions aimed at reviewing how the project has performed at any point in time.

Six main areas of focus on how the construction project has performed at any given period are:

- Cost – how the actual costs varied with planned costs during the project period and the causes of the variations
- Schedule – how planned schedule varied with actual progress and the causes of the variations
- Cash flow – how planned cash flow varied with actual cash flow and the causes of the variations
- Quality – patterns of quality data, frequency of failed tests, etc. and causes of variations between planned and actual quality of deliverables
- Safety – how the frequency of occurrences of injury incidences faired during project implementation
- Stakeholder satisfaction- the extent to which achieving expected results excellently has delighted the Client, targeted end users and other key stakeholders

6.2.1.2. The Engineer shall ensure that data related to these key areas of focus is well managed and stored during the entire project period. Most of the key sources for such data have been discussed in this document. These include:

Table 33 Sources of project data for performance review

Source	Data
Work programme	schedule data (both actual and planned)
Cash flow S-curve	Cost data –actual versus planned, cumulative actual versus cumulative planned
Control charts	Quality data – test results and patterns
Site diary	Safety incidences ,
Questionnaire survey	Client/End-user/other key stakeholders' level of satisfaction
Monthly Progress Reports	All relevant information can be retrieved from these reports

6.3. Documentation of lessons learnt

Findings and observations made during the review of project performance shall be recorded. Recommendations made from these findings and observations shall form basis for formulation of lessons learned document. A lessons learned document enables the team undergoing its production, extract key points which have proven to be practices worth adopting during construction. These shall become the best practices for construction in the subsequent projects.

6.4. Project Completion Report

6.4.1. Report format

6.4.1.1. The Engineer shall prepare a comprehensive report regarding the ended project which should have the following sections as a minimum:

- Executive summary – this is the summary of the report
- Review and analysis – this is a section that discusses issues described in 7.2.1.1 and 7.2.1.2
- Recommendations – this section deals with presentation of major improvement actions following review and analysis of the project data
- Lessons learned – description of lessons learned during execution of the project as stated in 7.3
- Appendix – this section incorporates back up data or details of analysis that other may wish to follow up

6.5. Project Technical Audit

6.5.1. General

The objective of a Technical Audit is to assess the performance of both the Engineer and Contractor towards delivery of their services to the Client. It aims at establishing the extent to which the Engineer and Contractor conducted themselves in alignment with their contractual obligations. The technical audit must be conducted by an Independent, Qualified and Experienced Registered Engineer. In this Project Technical Audit Section, the term “Engineer” shall mean an Independent, Qualified and Experienced Registered Engineer who has been assigned to undertake the Technical Audit.

6.5.2. Timing of conducting a Project Technical Audit

6.5.2.1. The Engineer shall ensure that the Technical Audit is conducted in a timely manner and in accordance with his/her contractual obligations. The audit can be done during the following stages, depending on the needs of the Client:

- Early stages of the construction period, after the Contractor has established on site
- Around midway through the construction period, when the construction works are at a maximum rate of production
- At the end of the project, at least four weeks before issuance of a Certificate of Substantial Completion

6.5.2.2. The Engineer shall acquaint himself/herself in project related documentation by undertaking the following actions:

- Read project documents to thoroughly understand the scope of works
- Carefully study tender documents, bills of quantities and tender evaluation report
- Review contract documentation including the contract, drawings, technical specifications, materials reports, test records, measurement and payment data, site correspondence, minutes, monthly progress reports, construction programme and its updates etc
- Conduct site visits to inspect how the works are being executed
- Assess the Consultant’s quality assurance procedures including the laboratory equipment , test methods and other general procedures

6.5.2.3. Based on findings obtained under 7.5.2.2, the Engineer shall analyse them and produce recommendations

6.5.2.4. The Engineer shall produce a Technical Audit Report that describes the objectives, methodology, findings and recommendations

6.5.2.5. The Engineer shall acknowledge and confirm to the Client that the Contractor and Consultant have addressed the issues raised in the report before the Client issues a Certificate of Substantial Completion to the Contractor.

ANNEXES

Annex 1: Description of Gantt chart and a Demonstration on basics of how a construction programme is built

General

A work programme is the backbone for monitoring construction progress and must therefore be planned properly. The essence of a work programme is to ensure that:

- Timing for completion is being targeted as a key priority
- Cash flow requirements are planned and met in advance to avoid unexpected delays due to financial problems
- Sequencing of activities is logical and realistic
- A baseline to determine whether good or bad progress is being attained in the course of the project

In Malawi, construction programmes are generally produced in form of a Gantt/Bar chart. In this code of practice this tool is recommended for construction activities due to its ease in being integrated within simple computer programmes such as excel. Other tools such as PERT and Network diagrams require advanced commercial software such as Microsoft Projects and Prima Vera which may not be legally accessible to most organizations involved in irrigation projects in Malawi.

Formulation of a Gantt Chart

Gantt Chart production undergoes the following major steps: Activity identification, Activity Duration Estimates and Resource Needs Estimates and Production of a Gantt Chart

Activity Identification

Identification of activities that must be carried out to come up with any constructed facility requires technical know-how as well as practical experience. Therefore, an Irrigation Engineer needs exposure to every form of construction activity that is carried out on site. With such experience and technical know-how, the Engineer determines the list of activities that need to be done to achieve the project objectives. This also includes knowing about the logical sequencing of the activities that have been identified.

Activity Duration Estimates

The Irrigation Engineer must be capable of estimating the time that each activity identified will take. This information is very important as it helps in the determination of the realistic duration for the project. Experience from similar projects or other technocrats who have been involved in same kind of projects plays a pivotal role towards producing realistic estimates. Furthermore, most plant and machinery have performance data which is incorporated in their specification. Some of the general performance data for selected plant and machinery relevant to construction of irrigation system can be accessed in Annex D.

Resource Needs Estimates

The Engineer must determine manpower, material , plant and equipment needs for each activity in the project. This includes the time that each resource will be required for the activities to be accomplished. Quality targets as specified upon the activities to be done is also the main determinant factor when resource selection is being conducted.

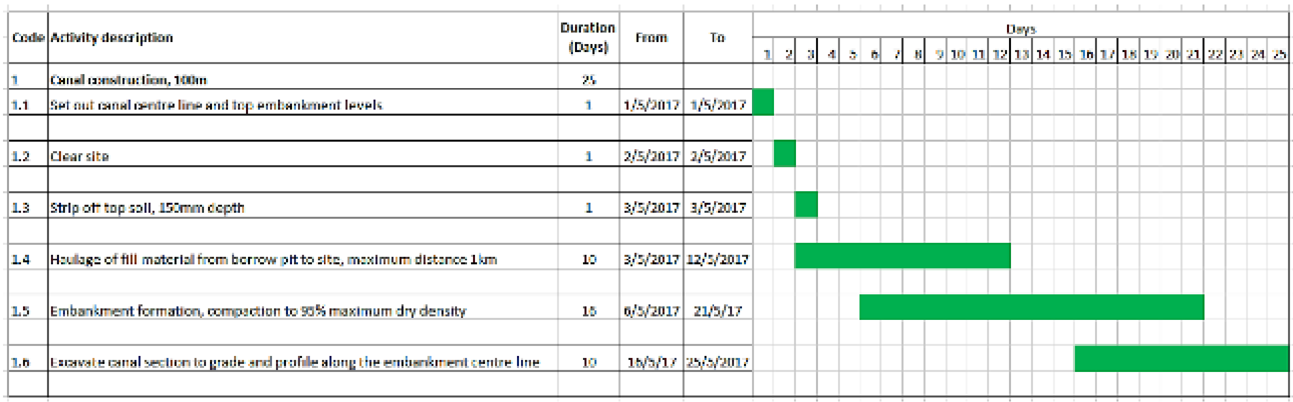
Production of a Gantt Chart

Once the above data has been produced by the Engineer, a Gantt Chart can be drawn.

The chart, comprises the following key sections:

- Activity Code on the first row from the left side of the chart
- Activity Description on the second row from the left side of the chart
- Bars depicting the duration for each activity

A typical Gantt Chart is shown in Figure below:



Gantt Chart

Example:
An Irrigation Engineer has been given a quick assignment to produce a work programme for a small project aimed at extending a secondary canal in fill by 100m in order to increase the net area for irrigation in the scheme. The budget that is available is MK5, 000,000.00 and the following are the unit rates for available resources for the assignment.

Table 1 Available resource date

Resource	Unit	Rate(MK)	Maximum number available
Chainman	person day	900	2
Surveyor	person day	5,500	1
Labourer	person day	750	15
Materials technicians	person day	3,000	2
D3 dozer & operator	day	90,000	1
7 tonne tipper and operator	day	75,000	3
Handbomag and operator	day	30,000	3

Note: The rates used above are for illustration purpose only and not the actual rates to be used

Solution:
Step 1: Production of a Gantt chart to ensure activities are logically sequenced
With the experience and knowledge on how a canal is constructed, the Irrigation Engineer identifies a list of key activities that are done for this to be achieved. Duration estimates for completing each activity are determined and these are represented by horizontal bars. These are then incorporated in the Gantt chart as shown in Figure above.

Step 2: Identification of resource needs per activity
Once the first draft of the Gantt chart has been produced as above, the Engineer must ascertain the resource needs per activity shown in the chart. The resource needs include man power, plant, equipment and construction materials to be used. For each activity, a realistic estimate for the magnitude of each resource must be determined. Such data may be available from past experience from similar projects as well as plant and equipment performance data. The data for resource needs is plotted directly below the Gantt chart in the form of a histogram as in Figure below.:

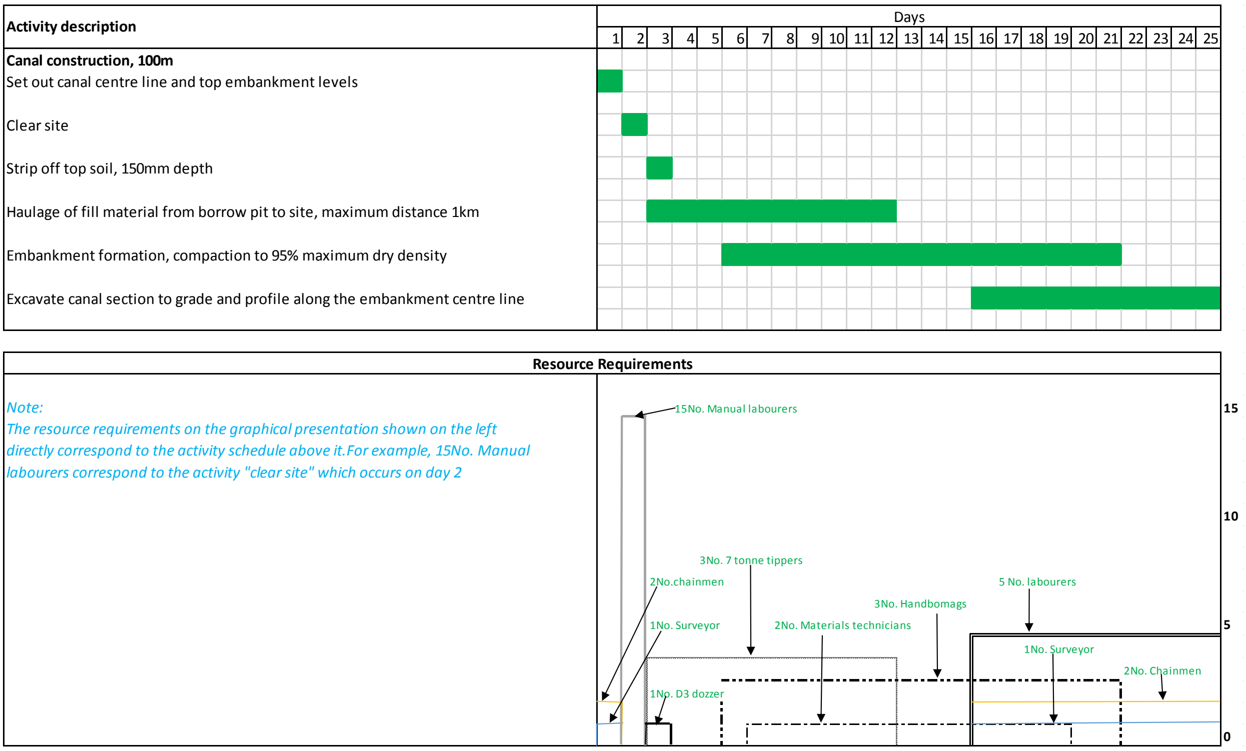


Figure 1Gantt chart and histogram for resource needs

As shown in the resource needs histogram, the vertical axis on the far right of the graph represents quantities for the resources.

Step 3: Based on the duration, quantities and type of resources required for each activity, cost per activity and cost per unit time (e.g. Cost per day) is calculated as displayed in Table 2

Table 2 Activity costing table

Activity Code	Activity	Activity Duration (days)	Cost per activity(MK)							Total cost(MK)	Activity cost per day
			Chainman	Surveyor	Labourer	Materials Technician	D3 dozer & operator	7 tonne tipper and operator	Handbomag and operator		
1	**Canal construction**										
1.1	Set out canal centre line and top embankment levels	1	1,800.00	5,500.00	-	-	-	-	-	7,300.00	7,300.00
1.2	Clear site	1	11,250.00	-	-	-	-	-	-	11,250.00	11,250.00
1.3	Strip off top soil, 150mm depth	1	-	-	-	-	90,000.00	-	-	90,000.00	90,000.00
1.4	Haulage of fill material from borrow pit to site, maximum distance 1km	10	-	-	-	-	-	2,700,000.00	-	2,700,000.00	270,000.00
1.5	Embankment formation, compaction to 95% maximum dry density	16	-	-	-	78,000.00	-	-	1,440,000.00	1,518,000.00	94,875.00
1.6	Excavate canal section to grade and profile along the embankment centre line	10	18,000.00	55,000.00	37,500.00	-	-	-	-	110,500.00	11,050.00
	Total cost estimate		31,050.00	60,500.00	37,500.00	78,000.00	90,000.00	2,700,000.00	1,440,000.00	**4,437,050.00**	

Step 4: Cost Activities
Having calculated daily cost per activity in the last column for Table 2, the Gantt chart bars produced in Table must be replaced with its corresponding calculated daily cost. From this data, an S-curve depicting the pattern of costs during the entire project period of 25 days can be produced. Table 3 shows the cumulative cost patterns (on next page); a corresponding graph has been produced here just below (Figure 2):

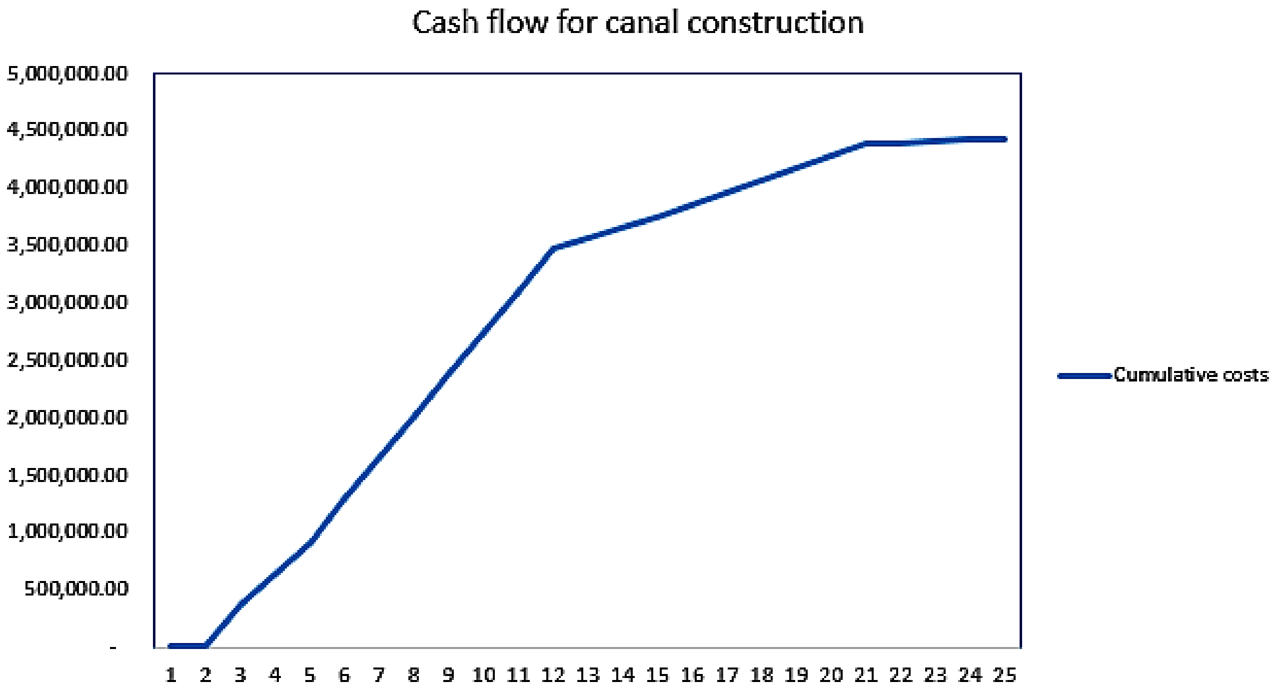


Figure 2 S-curve for project cumulative costs

As shown above, the project will begin at a slow pace then get intensified around midway. Thereafter, the cost gradually decrease. This curve is termed as S-curve.

Once the Irrigation Engineer is satisfied that the construction programme will ensure project delivery within the set cost, quality and time targets, it must be adopted as the plan to be followed and will thus be a progress monitoring tool. The set schedule, time and cost aspects in the construction plan become the baseline for monitoring and controlling the project.

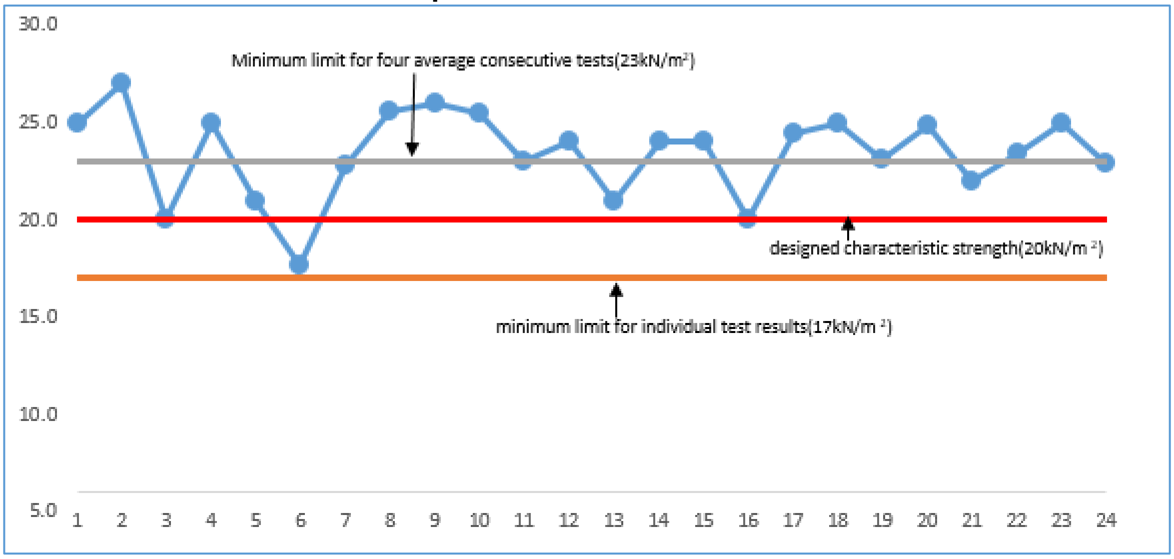
Table 3 Cash flow for planned canal construction project

Code	Activity Description	Days																								
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	**Canal construction**																									
1.1	Set out canal centre line and top embankment levels	7,300.00																								
1.2	Clear site		11,250.00																							
1.3	Strip off top soil, 150mm depth			90,000.00																						
1.4	Haulage of fill material from borrow pit to site, maximum distance 1km			270,000.00	270,000.00	270,000.00	270,000.00	270,000.00	270,000.00	270,000.00	270,000.00	270,000.00	270,000.00													
1.5	Embankment formation, compaction to 95% maximum dry density						94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00	94,875.00				
1.6	Excavate canal section to grade and profile along the embankment centre line																11,050.00	11,050.00	11,050.00	11,050.00	11,050.00	11,050.00	11,050.00	11,050.00	11,050.00	11,050.00
	Daily total cost	7,300.00	11,250.00	360,000.00	270,000.00	270,000.00	364,875.00	364,875.00	364,875.00	364,875.00	364,875.00	364,875.00	364,875.00	94,875.00	94,875.00	94,875.00	105,925.00	105,925.00	105,925.00	105,925.00	105,925.00	105,925.00	11,050.00	11,050.00	11,050.00	11,050.00
	Cumulative total cost	7,300.00	18,550.00	378,550.00	648,550.00	918,550.00	1,283,425.00	1,648,300.00	2,013,175.00	2,378,050.00	2,742,925.00	3,107,800.00	3,472,675.00	3,567,550.00	3,662,425.00	3,757,300.00	3,863,225.00	3,969,150.00	4,075,075.00	4,181,000.00	4,286,925.00	4,392,850.00	4,403,900.00	4,414,950.00	4,426,000.00	4,437,050.00

Annex 2: Analysis of Control Chart Data for Concrete compressive tests

Control charts are graphical presentations of how measurements deviate from the expected measurement as specified in the design.
It shows maximum and minimum acceptable values for measurements as horizontal line and each individual measurement is recorded along a time scale on the horizontal axis.

Control chart for concrete compressive tests



BS 5323 states that a passed compressive test for concrete shall meet these two conditions:

- The average strength determined from any group of four consecutive test results exceed the specified characteristic strength by:
- 3N/mm2 for concrete with characteristic strength of 20N/mm2 and above
- 2N/mm2 for concrete with characteristic strength of 15N/mm2 and below

The compressive strength from any individual result must not be less than the specified characteristic strength by:

- 3N/mm2 for concrete of 20N/mm2 and above
- 2N/mm2 for concrete of 15N/mm2 and below

Analysis of test results using the chart

Figure above shows how each individual test result relates to the minimum acceptable test result of 17 N/mm2 (i.e 3N/mm2 less than the specified strength of 20 N/mm2).The chart shows that all individual test are above the line corresponding to the minimum acceptable strength. This means that all individual tests passed the second criteria.
Figure above shows 24 test results captured consecutively in a project. In this project, the specified concrete strength for a particular structure is 20N/mm2.This means that to meet the first condition in BS 5323, the average test of any four consecutive test results must be 23N/mm2 or above (i.e 3N/mm2 more than the specified characteristic strength).
Table 1 below shows the pattern of these averages. This Table 1 shows that average tests corresponding to sample numbers 6, 7, 8 and 16 as the last sample in the four consecutive results failed to meet these criteria.

Table 1: Analysis of test results

Test Sample No	Compressive test result(kN/m²)	Designed characteristic strength(N/mm²)	Minimum limit for four average consecutive tests (N/mm²)	Minimum limit for individual test result(N/mm²)	Averages for four consecutive tests
1	25.0	20	23	17	
2	27.0	20	23	17	
3	20.0	20	23	17	
4	25.0	20	23	17	24.3
5	21.0	20	23	17	23.3
6	17.7	20	23	17	20.9
7	22.8	20	23	17	21.6
8	25.6	20	23	17	21.8
9	26.0	20	23	17	23.0
10	25.5	20	23	17	25.0
11	23.0	20	23	17	25.0
12	24.0	20	23	17	24.6
13	21.0	20	23	17	23.4
14	24.0	20	23	17	23.0
15	24.0	20	23	17	23.3
16	20.0	20	23	17	22.3
17	24.5	20	23	17	23.1
18	25.0	20	23	17	23.4
19	23.1	20	23	17	23.2
20	24.9	20	23	17	24.4
21	22.0	20	23	17	23.8
22	23.4	20	23	17	23.4
23	25.0	20	23	17	23.8
24	22.9	20	23	17	23.3

From this analysis, it is clear that some of the tests failed to meet the first criteria. In such cases the Engineer has the following options:

- Assess the strength requirements for the deficient part of the structure regarding its capacity to still perform properly at a reduced strength
- Strengthen the concerned part
- Order demolition of the affected part

Ordering demolition is considered as the best option as it makes the Contractor realize how serious it is when quality is compromised. The Contractor will obviously get serious on quality matters in all subsequent constructions.

The Control chart can also be used to carry out investigations regarding the pattern of the test results. Finding out unique things that happened on the days during which the low and high concrete strengths were produced helps to make improvements upon the quality.

Annex 3: An extract of an ESMP for irrigation scheme construction

Table 1: Sample of ESMP table for irrigation scheme construction

Environmental component No.	Impact identified	Recommended enhancement/mitigation/management measure	Responsible organization	Estimated Cost (MWK)	Timeframe
Positive Impacts Construction phase					
1	Creation of employment opportunities	Employ as many locals as possible to maximise project benefits to the local communities, and in particular look to include women and vulnerable groups	Contractor/ Supervision Committee/DC	Included in the project budget	During construction
2	Creation of business opportunities	Purchase as many local materials as possible during the construction phase such as quarry, cement, sand from approved sites, bricks etc	Contractor/ Supervision Committee/DC	Included in the project budget	During construction
		Encourage members to take advantage to expand their business activities	Community members Supervision Committee	N/A	
Negative Impacts Construction Phase					
1	Spread of	Conduct awareness meetings	Contractor/DC/S	Included in	During

	HIV/aids/sexually transmitted diseases	Distribution of condoms to workers Development of and strict adherence to Code of Conduct for workers	upervision Committee	the project budget	construction period
2	Generation of wastes	Siting and establishment of camps will be done in consultation with Supervision Committee Designate specific places for the disposal of waste in consultation with the district council	Contractor/Supervision Committee	Included in the project budget	During construction period

Annex 4: General Performance data for selected plant for construction

The manufacturer provides the data pertaining to the performance of a particular make of machinery. A big difference can occur between the performance quoted by the supplier and the actual performance. This can be attributed to a number of factors, such as the skilfulness of the operator, availability of a continuous supply of spare parts, lubricants, fuel, maintenance and repair, climatic factors and site conditions among others. These ultimately have a bearing on the efficiency of the equipment.
As a guide, the following formula is used to estimate the anticipated output of plant and equipment:

Anticipated output = Optimum output x Task efficiency factor x Operator efficiency factor

Note: *Optimum output and task efficiency factor are provided by the manufacturer. The operator efficiency factor is generally estimated at about 75%.*

Since time is needed for re-fuelling, repairs and other maintenance work on the machines, it can be assumed that the actual working time per machine is 5 machine hours per shift of 8 hours. Use of efficient machinery reduces downtime and therefore maintenance and servicing of machinery is very important.

Bulldozer:
For an average dozing distance of 50 m, the performance would be:

- Average soil (loose): 60 m3/machine hour
- Average gravel: 40 m3/machine hour

Scraper:
The capacity of scrapers per load may vary from 6 m^3 for a model 613B to 30 m^3 for a model 851B, thus the performance will also vary.

Grader:
With a relatively experienced operator, a grader can level approximately 1 ha per working day, assuming a cut and fill of up to 20 cm. The required time depends on the soil type and the distances of soil movement. It is estimated that 50 m of 1.5 m wide field drains together with 50 m of 2.5 m wide infield roads can easily be done per hour.

Dragline:
Table 1 gives estimates of excavation quantities for draglines:

Table 1: Estimates for excavation volume by dragline

Description	**Bucket Size (Litres)**	**Excavation per Machine Hour (m^3)**
Digging or clearing of drainage channels with heavy weed infestation in wet conditions and dumping soil sideways.	350	20
Digging or clearing of drainage channels with heavy weed infestation in wet conditions and dumping soil sideways.	700	35
Digging channel in average soil in dry conditions and dumping soil sideways	350	30
Digging channel in average soil in dry conditions and dumping soil sideways	700	50

It must be noted that there is need to be economical on selection of bucket size. The size must correspond to the extent of the required excavation. For example, there is no need to use a large dragline bucket for the excavation of a small channel.

Excavator:

An excavator can be slightly more efficient than a dragline, but it has a smaller reach. A CAT215 excavator could perform as follows:

- Excavating and loading on a dump-cart or lorry: 45 m3/machine hour
- Excavating and side dumping of soil: 65 m3/machine hour

Front-end loader with backhoe:
The performance of a front-end loader with a backhoe depends on the power of the machine. The buckets of a tractor-powered machine shall be much smaller than the ones of a large caterpillar 992C wheel loader with a bucket of up to 10.3 m^3. Typical performance of a caterpillar 931B track-type with a backhoe is as follows:
If using the front-end loader:

- Loading stockpiled average soil: 33 m3/machine hour
- Loading stockpiled gravel: 28 m3/machine hour

If using the backhoe:

- Excavating canal and loading tipper: 13 m3/machine hour
- Excavating canal and dumping soil sideways: 18 m3/ machine hour

Tipper:
The performance of tippers to carry materials such as soil depends very much on the distance between the pit and the construction site, the road condition, etc. Under field conditions on dirt roads, the average carrying capacity of a 7- ton tipper is 3.5 m3 and the average speed is approximately 15 km/hr loaded and 30 km/hr empty.

Annex 5: Descriptions of tests

Sand

Organic Content test:

In this test, the objective is to check whether the fine aggregate is has traces of organic content. In the test, sand is filled in a 250ml cylinder up to the 90ml graduation on the cylinder. A 3% sodium hydroxide is applied to the cylinder until it reaches 140ml gradation. After thorough mixing of the sand and sodium hydroxide to facilitate complete mixing, the sample is left for 24 hours. After expiry of the 24 hour period, the colour of the sample is observed.

- Where the colour of the sample has become darker than the standard colour of sodium hydroxide, the sand contains organic impurities. Such sand is unsuitable for concrete work.
- Where the colour of the sand is not darker than the standard colour of sodium hydroxide, the sand does not contain organic impurities. Such sand is suitable for construction

Particle size distribution test:

Fine aggregate that consists of 90-100% of its particles passing through a square aperture of nominal size 4.75mm is suitable for concrete works. Any sand falling below this composition is not suitable.

Coarse Aggregate

Particle size distribution test:

Coarse aggregate that consists of 85-100% of the nominal size particles passing through a square aperture of its nominal size is suitable for concrete works. Any coarse aggregate falling below this composition is not suitable.

Table 1 is an extract of coarse aggregate grading requirements for the common nominal sizes.

Table 1: Grading requirements for commonly used coarse aggregate

1	2	3	4
Property	Requirement Nominal size of aggregate mm		
Grading , mass percentage of material that passess sieves of nominal aperture size, mm	37.5	19	9.5
53	100		
37.5	85-100		
26.5	0-50	100	
19	0-25	85-100	
13.2	0-5	0-50	100
9.5		0-25	85-100
6.7		0-5	0-50
4.75			0-25
2.36			0-5

Aggregate crushing value (ACV) test:

This test aims at assessing the strength of coarse aggregate towards resisting from a gradually applied compressive load. This test is done for coarse aggregate with nominal sizes ranging from 10 to 29mm.

The test commences with drying the sample of the aggregate in an oven. It is then let to cool down before being placed and tamped with a road to make it well compacted. The sample is thereafter compressed in a compression testing machine to a maximum force of 400kN in 10minutes.

A 2.36mm sieve is used to separate particles finer than 2.36mm from the main sample. The aggregate crushing value (ACV), expressed as a percentage of fines emanating from the crushed sample is calculated using the formula below:

ACV = (Mass emanating from the crushed sample/initial mass of sample) x 100

Concrete

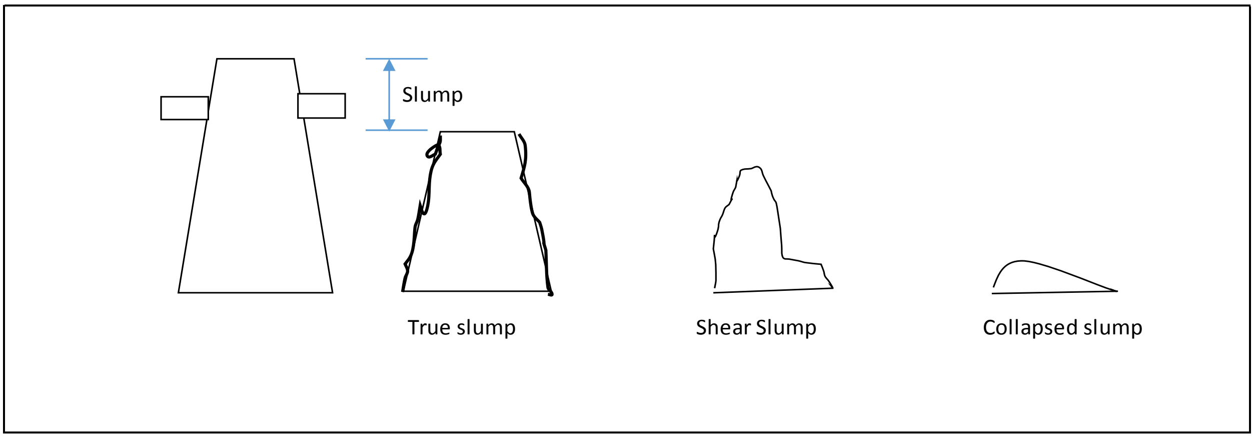
Slump test:

This is a concrete test aimed at assessing workability of concrete which is being cast. In a slump test, a conical mould is used. The mould is placed on a flat surface then filled with concrete in three layers. After filling each layer, a tamping road is used to stroke the layer 25 times. The last layer get levelled at the top of the mould using the rod.

The mould is then carefully removed from the concrete sample by lifting it upwards. Slump is the difference in height between the mould and the self-supporting sample which is measured in millimetres.

Figure below shows the slump types that may occur when this test is carried out.

Possible slump test results



True slump indicates a cohesive and highly workable mix. A shear slump indicates inadequate mortar content. A collapsed slump indicates very wet mix with very high probability of leading to segregation of concrete as it is a poor mix. Whenever, a shear or collapsed slump occurs, the test needs to be re-done. If the result remains the same, it must be recorded and reported to the Supervising Engineer.

Table 2 shows some of the expected slump values for some of the common concrete strengths:

Table 2: Slump values for true slump in common concrete grades

Concrete strength	Slump (mm)		Concrete strength	Slump (mm)
15N/mm2	75		25N/mm2	70
20N/mm2	75		30N/mm2	70

Concrete Compressive strength test:

The test is used to determine the concrete strength achieved at 7, 14 and 28 days after production. Samples are made using 150mm x 150mm x 150mm cubes during casting of concrete. The cubes are let to cure in a curing tank after 24 hours of being placed in the moulds. Each test requires a set of three cubes that are crushed in the compressive test machine at 7, 14 and 28 days of their age. The compressive strengths at which the three cubes fail are recorded and the average value gives the sample compressive strength.

Blocks, Cement blocks and Soil Stabilised Blocks (SSBs)

Compressive Test:

Burnt bricks, Cement blocks and SSBs must undergo compressive test to assess their strengths. Those with an average compressive strength of 5N/mm^2 from a sample of 12 randomly selected brick/blocks are suitable for load bearing wall. Bricks/Blocks with compressive strength of more than 3.5N/mm2 but less than 5N/m^2 may be used only for non-load bearing walls such as partitioning and fencing. Bricks/blocks with strength below 3.5N/mm^2 are not suitable.

Absorption test:

This test is only applicable for burnt bricks. Twelve bricks are selected randomly then oven dried at 110^{0}C with the loss in water content being measured. The bricks are taken out of the oven when the successive mass loss is less than 0.1%. The last mass measured is regarded as dry mass.
Once the dried 12 bricks have been air cooled for at least 2 hours, a 24 hour immersion in water takes place. The bricks are removed and immediately weighed to get their wet mass. Water Absorption percentage is obtained using the equation below:
Water absorption percentage = (Wet mass – Dry Mass)/Dry Mass) x 100
Any absorption rate more than 7% renders the bricks unsuitable for construction.

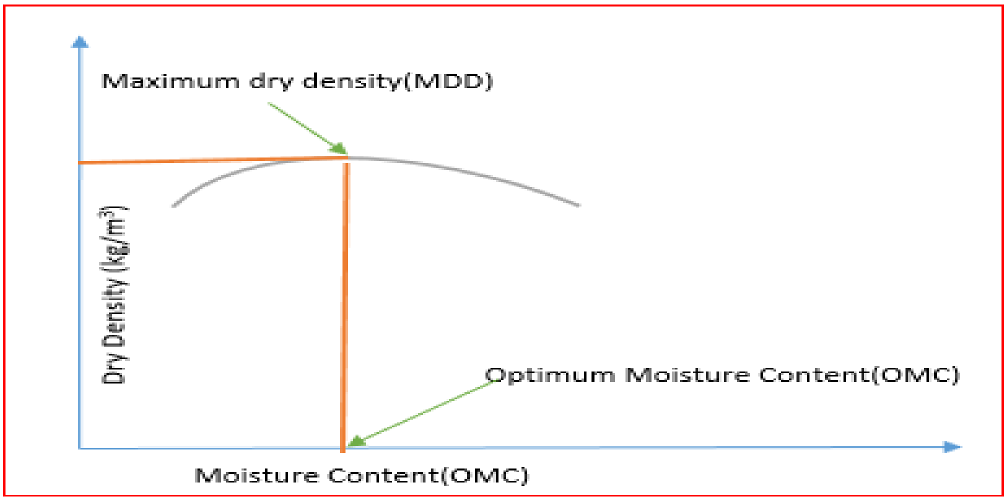
Pipes:
Before proliferation of several pipe manufacturers as well as fake products, pipe testing was not seriously considered. This was the case because it was obvious that the few well known ISO-certified manufacturers will be producing pipes to the required standards. These days, it is recommended that pipes should be tested to check their suitability for the construction works as a quality assurance strategy. Two types of tests are recommended for pipes. These are stress rapture test and stress relief test.

Stress Rapture test:
In stress rapture test, a pipe sample is exposed to a hoop stress of 420 bars at 20^{0}C for a duration of 1 hour. Where the pipe does not break or crack, the pipe is rendered suitable. A pipe that ends up cracking or breaking after this test is not suitable.

Stress Relief test:
In a stress relief test, a pipe sample is placed in an oven at 150^{0}C then cooled. A failed pipe test will result in the pipe sample exhibiting excessive blisters, cracking or splitting.

Fill Material
Soil Compaction test:
The laboratory procedure for the test according to BS 1377 involves selection of a sample from the proposed borrow pit. The sample is initially air dried and separated into four to six samples. The moisture content for each sample is adjusted by adding water in 3%-5% increments. The soil is placed in a 100mm diameter mould and compacted in three layers. Each layer receives 25 blows from a 2.5kg hammer. The sample is then removed and tested for moisture content. Using results from all samples, a graph of dry unit weight versus moisture content is produced. The highest dry density on the plotted graph is the maximum dry density and its corresponding water content is the optimum moisture content. This is illustrated in Figure below.

Typical graph from Modified Proctor test results



Insitu dry density test:

The *insitu* dry density test used to determine the extent of compaction is sand cone test. In this test, the surface of the compacted area to be tested is well levelled then excavated to the depth of 10cm and diameter of the hole for the soil plate which is an apparatus for this test. Sand of known density and weight is poured into the hole to establish the volume of the hole. Once the excavated soil's mass has been measured, its density (i.e. mass of soil/hole volume) can be established.
Relative density for compacted soil is determined using the following formula:
Relative density = field density/laboratory density x 100

Trial Run:
In the trial run, a section for embankment (at least 25m) is selected. The proposed granular fill is laid and spread as the first layer above the stripped section to prepare it in readiness for compaction. The proposed compaction equipment is then allowed to make passes along the trial section. After each pass, the relative density for the compacted section is determined using sand cone test and the results from the Modified Proctor test of the sample. The number of passes is also counted until the pass at which the specified relative density has been achieved. This number of passes becomes the recommended number of passes to achieve the desired level of compaction. This principle can also be applied where hand rammers are being used .In this case, the number of blows become the required measure to achieve desired compaction.

PART 4: IRRIGATION EQUIPMENT STANDARDS

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CHAPTER 1: INTRODUCTION

1.1. Importance

The irrigation sector in Malawi uses irrigation equipment which are imported and those manufactured locally. Some equipment parts modified locally during installation and maintenance. Any piece of equipment should perform at an acceptable level regardless of its origin. The same applies to modified equipment or parts.

Standards form the fundamental building blocks for product development by establishing consistent protocols that can be universally understood and adopted. This helps fuel compatibility and interoperability and simplifies product development. Standards also make it easier to understand and compare competing products. The irrigation standards provide people and organizations with a basis for mutual understanding. They are used as tools to facilitate communication, measurement, commerce and manufacturing

It is only through the use of standards that the requirements of interconnectivity and interoperability can be assured. Standards also disseminate knowledge in industries where products and processes supplied by various providers must interact with one another. Standardization is a voluntary cooperation among industry, consumers, public authorities, researchers and other interested parties for the development of technical specifications based on consensus. They thus form a basis for trust among the different stakeholders in the irrigation sector.

CHAPTER 2: IRRIGATION EQUIPMENT STANDARDS

2.1. Pipes and pipe fittings

A pipe is a tubular section or hollow cylinder, used mainly to convey substances which can flow — liquids and gases (fluids), slurries, powders and masses of small solids. In irrigation pipes are used to convey water and chemicals. The words pipe and tube are usually interchangeable, but in industry and engineering, the terms are uniquely defined. A pipe is specified by a nominal diameter with a constant outside diameter (OD) and a schedule that defines the thickness. A tube is specified by the OD and wall thickness, but may be specified by any two of OD or inside diameter (ID), and wall thickness. Pipes are generally manufactured to one of several international and national industrial standards. Tubes on the other hand are made to custom sizes and a broader range of diameters and tolerances. Many industrial and government standards exist for the production of pipes and tubing.

The manufacture and installation of pipes are regulated by the available national standards. Pipe installation requires the use and application of a variety of specialized tools, techniques, and parts. Table 34 presents available international standards. They are used to regulate pipes and tubes of different types.

Table 34 Pipes and fitting standards

Std No.	Title	Year
ISO 3183:2012	Petroleum and natural gas industries - Steel pipe for pipeline transportation systems	2012
ISO 11678:1996	Agricultural irrigation equipment -Aluminium irrigation tubes	1996
ISO 14617-3:2002	Graphical symbols for diagrams - Part 3: Connections and related devices	2002-09
ISO 559:1991	Steel tubes for water and sewage	1991-03
ISO 13460-1:2015	Agricultural irrigation equipment - Plastics saddles - Part 1: Polyethylene pressure pipes	2015
ISO 16149:2006	Agricultural irrigation equipment -PVC above-ground low-pressure pipe for surface irrigation -Specifications and test methods	2006
ISO 16438:2012	Agricultural irrigation equipment - Thermoplastic collapsible hoses for irrigation - Specifications and test methods	2012-12
ISO 8224-1:2002	Traveller irrigation machines - Part 1: Operational characteristics and laboratory and field test methods	2002
ISO 8224-2:1991	Traveller irrigation machines - Part 2: Softwall hose and couplings - Test methods	1991
ISO 8779:2010	Plastics piping systems - Polyethylene (PE) pipes for irrigation – Specifications	2010-03
ISO 8796:2004	Polyethylene PE 32 and PE 40 pipes for irrigation laterals - Susceptibility to environmental stress cracking induced by insert-type fittings - Test method and requirements	2004-06
ISO 1401:2016	Rubber hoses for agricultural spraying	2016
ISO 10508:2006	Plastics piping systems for hot and cold water installations - Guidance for classification and design	2006
ISO 13783:1997	Plastics piping systems - Unplasticized poly(vinyl chloride) (PVC-U) end-load-bearing double-socket joints - Test method for leak tightness and strength while subjected to bending and internal pressure	1997
ISO 13846:2000	Plastics piping systems - End-load-bearing and non-end-load-bearing assemblies and joints for thermoplastics pressure piping - Test method for long-term leak tightness under internal water pressure	2000-10
ISO 1452-1:2009	Plastics piping systems for water supply and for buried and above-ground drainage and sewerage under pressure - Unplasticized poly(vinyl chloride) (PVC-U) - Part 1: General	2009
ISO 1452-3:2009	Plastics piping systems for water supply and for buried and above-ground drainage and sewerage under pressure - Unplasticized poly(vinyl chloride) (PVC-U) - Part 3: Fittings	2009
ISO 1452-4:2009	Plastics piping systems for water supply and for buried and above-ground	2009

Std No.	Title	Year
	drainage and sewerage under pressure - Unplasticized poly(vinyl chloride) (PVC-U) -Part 4: Valves	
ISO 1452-5:2009	Plastics piping systems for water supply and for buried and above-ground drainage and sewerage under pressure - Unplasticized poly(vinyl chloride) (PVC-U) - Part 5: Fitness for purpose of the system	2009
ISO 15874-1:2013	Plastics piping systems for hot and cold water installations - Polypropylene (PP) - Part 1: General	2013
ISO 15874-2:2013	Plastics piping systems for hot and cold water installations - Polypropylene (PP) - Part 2: Pipes	2013
ISO 15874-3:2013	Plastics piping systems for hot and cold water installations - Polypropylene (PP) - Part 3: Fittings	2013
ISO 15874-5:2013	Plastics piping systems for hot and cold water installations - Polypropylene (PP) - Part 5: Fitness for purpose of the system	2013-02
ISO 28921-1:2013	Industrial valves - Isolating valves for low-temperature applications - Part 1: Design, manufacturing and production testing	2013-05
ISO 10522: 1993	Agricultural irrigation equipment -Direct-acting pressure-regulating valves	1993
ISO 7714:2008	Agricultural irrigation equipment - Volumetric valves - General requirements and test methods	2008-09
ISO 9635-1:2014	Agricultural irrigation equipment - Irrigation valves - Part 1: General requirements	2014 - 11
ISO 9635-2:2014	Agricultural irrigation equipment - Irrigation valves - Part 2: Isolating valves	2014 - 11
ISO 9635-3:2014	Agricultural irrigation equipment - Irrigation valves -Part 3: Check valves	2014-11
ISO 9635-4:2014	Agricultural irrigation equipment - Irrigation valves -Part 4: Air valves	2014-11
ISO 9635-5:2014	Agricultural irrigation equipment -Irrigation valves -Part 5: Control valves	2014-12
ISO 9644:2008	Agricultural irrigation equipment - Pressure losses in irrigation valves - Test method	2008-07
ISO 9911:2006	Agricultural irrigation equipment - Manually operated small plastics valves	2006
ISO 13693-1:2013	Irrigation equipment -Safety devices for chemigation - Part 1: Small plastics valves for chemigation	2013
ISO 13693-2:2015	Irrigation equipment - Safety devices for chemigation - Part 2: Chemigation valve assemblies from DN 75 (3") to DN 350 (14")	2015
ISO 11738:2000	Agricultural irrigation equipment -Control heads	2002
ISO 12374:1995	Agricultural irrigation - Wiring and equipment for electrically driven or controlled irrigation machines	1995
ISO 15873:2002	Irrigation equipment - Differential pressure Venturi-type liquid additive injectors	2002
ISO 16399:2014	Meters for irrigation water	2014-05
ISO 9912-3:2013	Agricultural irrigation equipment - Filters for micro-irrigation - Part 3: Automatic flushing strainer-type filters and disc filters	2013-10
ISO 9912-1:2004	Agricultural irrigation equipment - Filters for micro-irrigation - Part 1: Terms, definitions and classification	2004
ISO 9912-2:2013	Agricultural irrigation equipment - Filters for micro-irrigation - Part 2: Strainer-type filters and disc filters	2013-11

2.2. Pump and Pump Fittings

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action. Pumps can be classified into three major groups according to the method they use to move the fluid: direct lift, displacement, and gravity pumps.

Pumps operate by some mechanism (typically reciprocating or rotary), and consume energy to perform mechanical work by moving the fluid. Pumps operate via many energy sources, including manual operation, electricity, wind or solar power among others. Pumps come in many sizes, from microscopic for use in medical applications to large industrial pumps. Mechanical pumps serve in a wide range of applications.

Pumps may be classified on the basis of the applications they serve, the materials from which they are constructed, the liquids they handle, and even their orientation in space. All such classifications, however, are limited in scope and tend to substantially overlap each other. A more basic system of classification defines the principle by which energy is added to the fluid, goes on to identify the means by which this principle is implemented, and finally delineates specific geometries commonly employed.

Under this system, all pumps may be divided into two major categories:
(i) dynamic, in which energy is continuously added to increase the fluid velocities within the machine to values greater than those occurring at the discharge such that subsequent velocity reduction within or beyond the pump produces a pressure increase, and
(ii) displacement, in which energy is periodically added by application of force to one or more movable boundaries of any desired number of enclosed, fluid-containing volumes, resulting in a direct increase in pressure up to the value required to move the fluid through valves or ports into the discharge line.

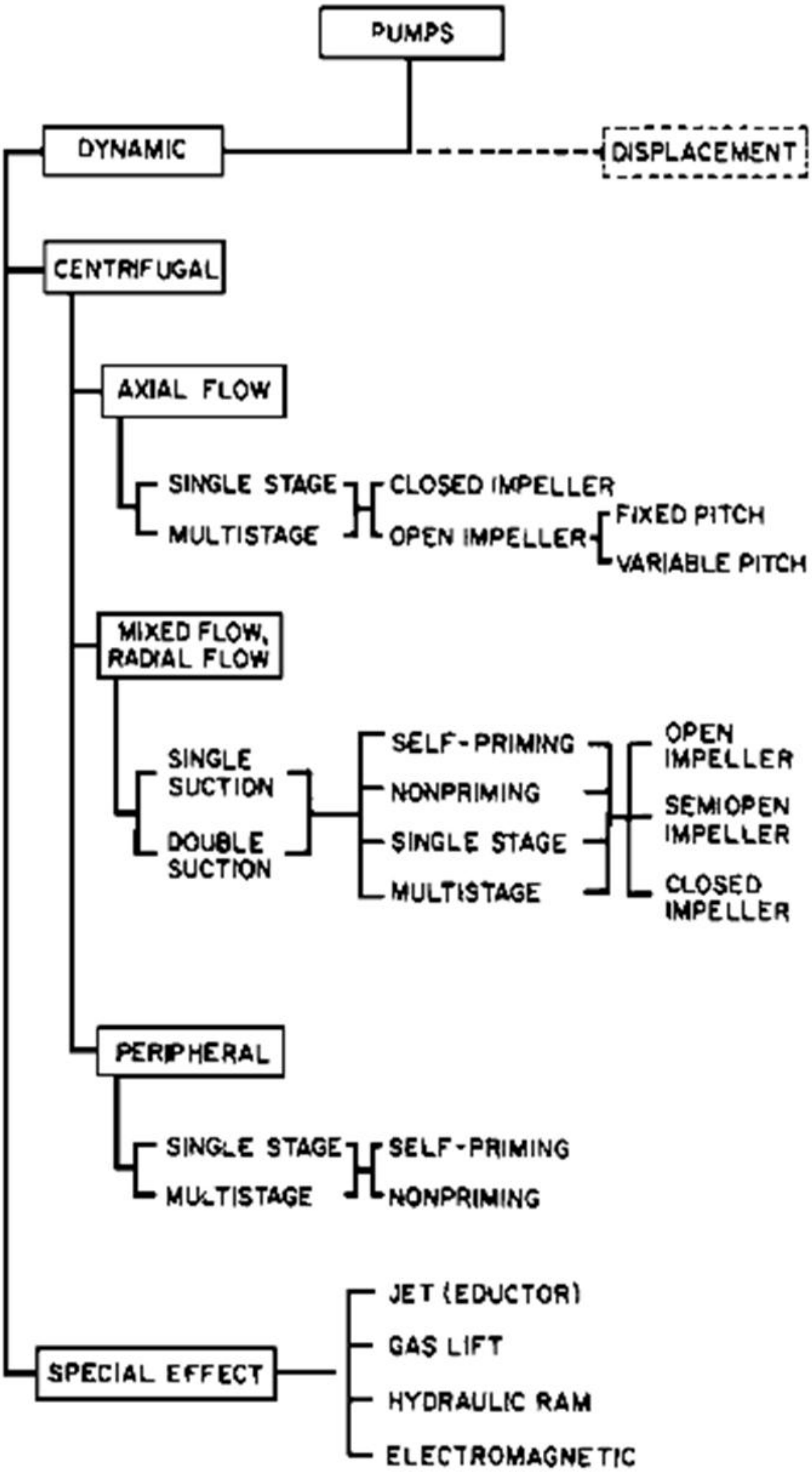

Figure 20 Classification of dynamic pumps

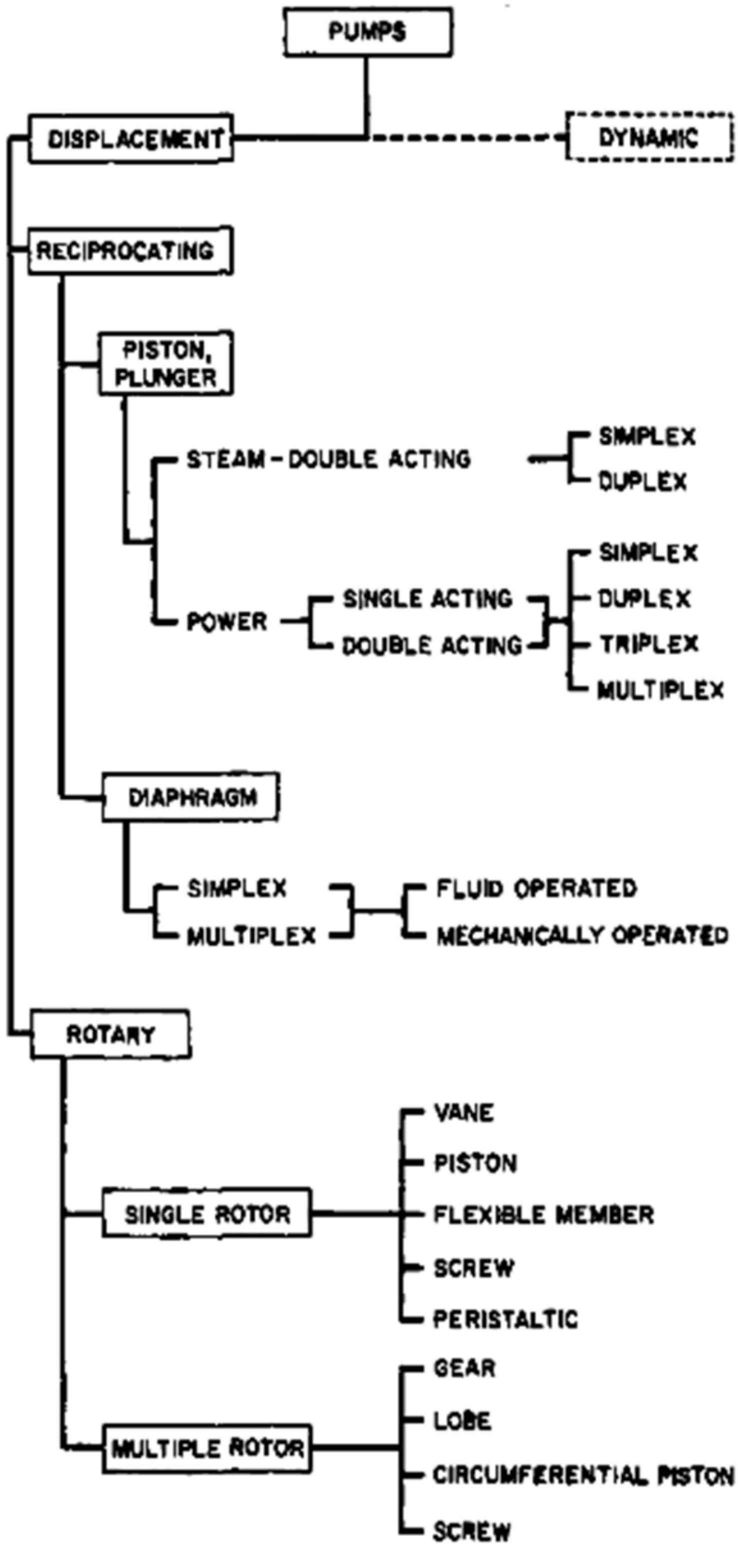

Figure 21 Classification of displacement pumps

ISO standards for pumps and pump fittings are preferred. Where ISO standards are not available other international standards are used. Table 38 shows the list of relevant ISO pump standards that have been published and whether or not are currently available in Malawi.

Table 35 Pumps and fittings standards

Std No.	Title	Year
ISO 14617-9:2002	Graphical symbols for diagrams - Part 9: Pumps, compressors and fans.	2002-09
ISO 14847:1999	Rotary positive displacement pumps -Technical requirements	1999-04
ISO 15783:2002	Seal-less rotodynamic pumps -Class II -Specification	2002-02
ISO 15783:2002/Amd 1:2008	Seal-less rotodynamic pumps -Class II –Specification (Amendment)	2008-11
ISO 16330:2003	Reciprocating positive displacement pumps and pump units - Technical requirement	2003-05
ISO 17769-1:2012	Liquid pumps and installation - General terms, definitions, quantities, letter symbols and units - Part 1: Liquid pumps	2012-07
ISO 17769-2:2012	Liquid pumps and installation - General terms, definitions, quantities, letter symbols and units - Part 2: Pumping system	2012-07
ISO 20361:2015	Liquid pumps and pump units - Noise test code -Grades 2 and 3 of accuracy	2015-06
ISO 21049:2004	Pumps - Shaft sealing systems for centrifugal and rotary pumps	2004-02
ISO 21630:2007	Pumps -Testing -Submersible mixers for wastewater and similar applications	2007-08
ISO 2858:1975	End-suction centrifugal pumps (rating 16 bar) - Designation, nominal duty point and dimensions	1975-02
ISO 3069:2000	End-suction centrifugal pumps -Dimensions of cavities for mechanical seals and for soft packing	2000-11
ISO 3661:1977	End-suction centrifugal pumps – Base plate and installation dimensions	1977-02
ISO 5198:1987	Centrifugal, mixed flow and axial pumps -Code for hydraulic performance tests - Precision grade	1987-07
ISO 5199:2002	Technical specifications for centrifugal pumps - Class II	2002-03
ISO 9905:1994	Technical specifications for centrifugal pumps - Class I	1994-05
ISO 9905:1994/Amd 1:2011	Technical specifications for centrifugal pumps - Class I (Amendment)	2011
ISO 9905:1994/Cor 1:2005	Technical specifications for centrifugal pumps–Class I (Amendment)	2005
ISO 9906:2012	Rotodynamic pumps- Hydraulic performance acceptance tests- Grades 1, 2 and 3	2012
ISO 9908:1993	Technical specifications for centrifugal pumps - Class III	1993-11
ISO 9908:1993/Amd 1:2011	Technical specifications for centrifugal pumps - Class III	2011
ISO/ASME 14414:2015	Pump system energy assessment	2015-04
ISO/ASME 14414:2015/Amd	Pump system energy assessment	2016

Std No.	Title	Year
1:2016		
ISO/DIS 21049	Pumps - Shaft-sealing systems for centrifugal and rotary pumps	2004
ISO 5198:1987	Centrifugal, mixed flow and axial pumps -Code for hydraulic performance tests-Precision grade	1987
ANSI/HI 9.6.6-2016	Rotodynamic Pumps for Pump Piping	2016
ANSI/HI 11.6 – 2012	Procedures for performance of submersible pumps	2014
ANSI/HI 9.6.3-2017	Rotodynamic (Centrifugal And Vertical) Pumps - Guideline For Allowable Operating Region	2017
HI 40.6-2016	Methods for rotodynamic pump efficiency testing	2016
SAC - GB/T 16750.1-97	The types, general parameters and conjunction sizes of electrical submersible pumping equipment	1997-03-04
SAC - GB/T 16750.2-97	Electrical submersible pump-technical specifications	1997-03-04
SAC - GB/T 16750.3-97	The test method for electrical submersible pump	1997-03-04

2.3. Sprinklers

Irrigation systems differ greatly depending on what they are going to be used for. They range from the simple hand watering method used in most home gardens and nurseries to the huge surface and overhead irrigation systems found in large-scale production.

In a sprinkler irrigation system, water is applied above the ground surface as a spray somewhat resembling rainfall. The spray is developed by the flow of water under pressure through small orifices or nozzles. The pressure is usually obtained by pumping, although it may be by gravity if the water source is high enough above the area to be irrigated. A typical sprinkler set includes the sprinkler, the standpipe, the lateral pipe, the main pipe and often the pumping plant.

In order to properly design, install, operate and maintain a sprinkler system, some standards are available for use. Table 36 shows the ISO standards available.

Table 36 ISO Sprinkler standards

Std. No.	Title	Year
ISO 15886-1:2012	Agricultural irrigation equipment - Sprinklers - Part 1: Definition of terms and classification	2012
ISO 15886-3:2012	Agricultural irrigation equipment - Sprinklers -Part3: Characterization of distribution and test methods	2012
ISO 15886-4:2012	Irrigation equipment - Irrigation sprinklers -Part 4: Test methods for durability	2012
ISO 11545:2009	Agricultural irrigation equipment - Centre-pivot and moving lateral irrigation machines with sprayer or sprinkler nozzles - Determination of uniformity of water distribution	2009
ISO 7749-1:1995	Agricultural irrigation equipment - Rotating sprinklers - Part 1: Design and operational requirements	1995-4
ISO 8026:2009	Agricultural irrigation equipment - Sprayers - General requirements and test methods	2009-12
ISO 9261:2004	Agricultural irrigation equipment - Emitters and emitting pipe - Specification and test methods	2005
ISO 15155:2005	Test facilities for agricultural irrigation equipment	2005

CHAPTER 3: AVAILABLE MALAWI STANDARDS

Malawi Bureau of Standards has developed and published a number of standard that are used by various regulatory agencies. Table 37 shows the irrigation-related Malawi Standards that are currently in use.

Table 37 Irrigation Related Malawi Standards

Std No.	Title	Year
MS 3:2004	UNPLASTICIZED POLYVINYL CHLORIDE, (UPVC) SEWER AND DRAIN PIPES AND PIPE FITTINGS – SPECIFICATION (Third Edition) (32 p) M	2004
MS 4:1993	UNPLASTICIZED POLYVINYL CHLORIDE (UPVC) TYPE 1, PRESSURE PIPES AND FITTINGS (FOR COLD WATER SERVICES) – SPECIFICATION (Second edition) (21 p) M	1993
MS 5:1993	UNPLASTICIZED POLYVINYL CHLORIDE (UPVC) PIPES AND PIPE FITTINGS FOR USE ABOVE GROUND IN DRAINAGE INSTALLATIONS – SPECIFICATION (Second Edition) (14 p) M	1993
MS 7:1980	UNPLASTICIZED POLYVINYL CHLORIDE (UPVC) PIPES INSTALLATION – CODE OF PRACTICE (30 p)M	1980
MS 374-1:1992	BLACK POLYETHYLENE PIPES FOR THE CONVEYANCE OF LIQUIDS – SPECIFICATION Part 1: Low Density Polyethylene Pressure Pipes (10 p) M	1992
MS 374-2:1992	BLACK POLYETHYLENE PIPES FOR THE CONVEYANCE OF LIQUIDS – SPECIFICATION Part 2: High Density Polyethylene Pressure Pipes (14p) M	1992
MS 374-3:1992	BLACK POLYETHYLENE PIPES FOR THE CONVEYANCE OF LIQUIDS – SPECIFICATION Part 3: High Density Polyethylene PE 80 Pressure Pipes (14p) M	1992
MS 407:1992	BLACK POLYETHYLENE PIPES FOR THE CONVEYANCE OF LIQUIDS – METHODS OF TEST (20 p) V	1992
MS 414-1:2002	MASONRY CEMENT – SPECIFICATION (10 p) M	2002
MS 456:1993	UNPLASTICIZED POLYVINYL CHLORIDE (UPVC) PIPES AND FITTINGS – METHODS OF TEST (19 p) V	1993
MS 458:2002	RUBBER SEALS – JOINT RINGS FOR WATER SUPPLY, DRAINAGE AND SEWERAGE PIPELINES MATERIAL – SPECIFICATION (13.p) M	2002
MS 617-1:1998	PIPES AND FITTINGS MADE OF UN-PLASTICIZED POLY (VINYL CHLORIDE) (PVC-U) FOR WATER SUPPLY – SPECIFICATION Part 1: General (2 p) M	1998
MS 617-2:1998	PIPES AND FITTINGS MADE OF UN-PLASTICIZED POLY (VINYL CHLORIDE) (PVC-U) FOR WATER SUPPLY – SPECIFICATION Part 2: Pipes (with or without integral sockets) (2 p) M	1998
MS 617-3:1998	PIPES AND FITTINGS MADE OF UN-PLASTICIZED POLY (VINYL CHLORIDE) (PVC-U) FOR WATER SUPPLY – SPECIFICATION Part 3: Fittings and joints (4 p) M	1998
MS 666-1:2002	COMPONENTS OF PRESSURE PIPE SYSTEMS (PVC-U) − SPECIFICATION Part 1: Unplasticized poly (vinyl chloride) (PVC-U) pressure pipes (33 p) M	2002
MS 666-2:2002	COMPONENTS OF PRESSURE PIPE SYSTEMS (PVC-U) − SPECIFICATION Part 2: Modified poly (vinyl chloride) (PVC-M) pressure pipe systems (30 p) M	2002
MS 688:2004	UNPLASTICIZED POLY (VINYL CHLORIDE) (PVC-U) SOIL, WASTE AND VENT PIPES AND PIPE FITTINGS – SPECIFICATION (31 p) M	2004

Std No.	Title	Year
MS 689:2004	THE INSTALLATION OF POLYETHYLENE AND POLY (VINYL CHLORIDE) (PVC-U) AND (PVC-M) PIPES – CODE OF PRACTICE (29 p) M	2004
MS 713:2005	PLASTIC PRODUCTS – GUIDELINES FOR SAFE MANAGEMENT AND DISPOSAL (12 p) M	2005
MS 719:2005	HAZARDOUS WASTE – MANAGEMENT, CLASSIFICATION AND DISPOSAL – CODE OF PRACTICE (59p) M	2005
MS 736:2011	TRANSPORTATION OF DANGEROUS GOODS – INTERMEDIATE BULK CONTAINERS FOR ROAD AND RAIL TRANSPORT (47 p) M	2011
MS 737:2011	INDUSTRIAL EMMISSIONS – EMISSIONS FROM MOBILE STATIONERY SOURCES - SPECIFICATION (30 p) M	2011
MS 779:2007	SOLAR PHOTOVOLTAIC (PV) WIND HYBRID SYSTEM – SPECIFICATION (10 p) M	2007
MS 780:2007	SOLAR PHOTOVOLTAIC (PV) WATER PUMPING SYSTEM – SPECIFICATION (15p) M	2007
MS 877:2011	ENERGY MAMNAGEMENT SYTEMS REQUIREMENTS WITH GUIDANCE FOR USE (22p) V	2011
MS 912-1:2014	PLASTICS PIPING SYSTEMS FOR HOT AND COLD WATER INSTALLATIONSPOLYPROPYLENE (PP) Part 1: General (9p)	2014
MS 912-2:2014	PLASTICS PIPING SYSTEMS FOR HOT AND COLD WATER INSTALLATIONSPOLYPROPYLENE (PP) PART 2: PIPES (first ed) (18p) M	2014
MS 912-3:2014	PLASTICS PIPING SYSTEMS FOR HOT AND COLD WATER INSTALLATIONSPOLYPROPYLENE (PP) PART 3: FITTINGS (first ed) (14p) M	2014
MS 912-5:2014	PLASTICS PIPING SYSTEMS FOR HOT AND COLD WATER INSTALLATIONSPOLYPROPYLENE (PP) PART 5: FITNESS FOR PURPOSE OF THE SYSTEM (first ed) (10p) M	2014
MS 912-7:2014	PLASTICS PIPING SYSTEMS FOR HOT AND COLD WATER INSTALLATIONSPOLYPROPYLENE (PP) Part 7: Guidance for the assessment of conformity (12 p)	2014
MS-ISO/TS 4949:2003	STEEL NAMES BASED ON LETTER SYMBOLS (8 p)	2003
MS-17020:2014	CONFORMITY ASSESSMENT-REQUIREMENTS FOR THE OPERATION OF VARIOUS TYPES OF BODIES PERFORMING INSPECTION (18p) M	2014
MS 17065:2013	CONFORMITY ASSESSMENT –REQUIREMENTS FOR BODIES CERTIFYING PRODUCTS, PROCESSES AND SERVICES (first ed) 27p	2013
MS-IEC 61721	SUSCEPTIBILITY OF A PHOTOVOLTAIC (PV) MODULE TO ACCIDENTAL IMPACT DAMAGE (RESISTANCE TO IMPACT TEST) (M)	
MS-IEC 61724	PHOTOVOLTAIC SYSTEM PERFORMANCE MONITORING – GUIDELINES FOR MEASUREMENT, DATA EXCHANGE AND ANALYSIS (M)	
MS-IEC 61727	PHOTOVOLTAIC (PV) SYSTEMS – CHARACTERISTICS OF THE UTILITY INTERFACE (M)	
MS-IEC 61836	SOLAR PHOTOVOLTAIC ENERGY SYSTEMS – TERMS AND SYMBOLS	