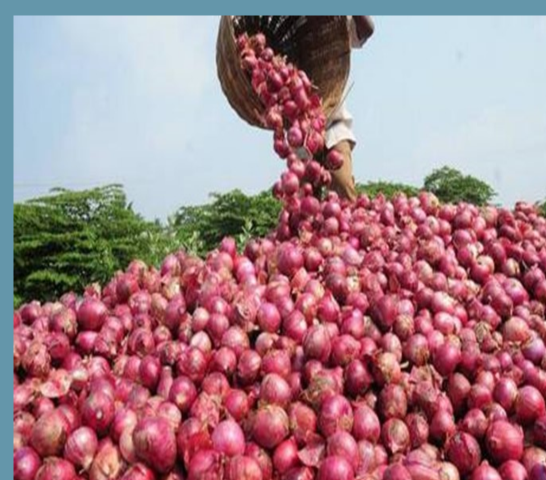
SSIGL 17

NATIONAL GUIDELINES

For Small Scale Irrigation Development in Ethiopia

Sprinkler Irrigation System Study and Design



November 2018

Addis Ababa

MINISTRY OF AGRICULTURE

National Guidelines for Small Scale Irrigation Development in Ethiopia

SSIGL 17: Sprinkler Irrigation System Study and Design

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FORWARD

Ministry of Agriculture, based on the national strategic directions is striving to meet its commitments in which modernizing agriculture is on top of its highest priorities to sustain the rapid, broad-based and fair economic growth and development of the country. To date, major efforts have been made to remodel several important strategies and national guidelines by its major programs and projects.

While efforts have been made to create access to irrigation water and promoting sustainable irrigation development, several barriers are still hindering the implementation process and the performance of the schemes. The major technical constrains starts from poor planning and identification, study, design, construction, operation, and maintenance. One of the main reasons behind this outstanding challenge, in addition to the capacity limitations, is that SSIPs have been studied and designed using many ad-hoc procedures and technical guidelines developed by various local and international institutions.

Despite having several guidelines and manuals developed by different entities such as MoA (IDD)-1986, ESRDF-1997, MoWIE-2002 and JICA/OIDA-2014, still the irrigation professionals follow their own public sources and expertise to fill some important gaps. A number of disparities, constraints and outstanding issues in the study and design procedures, criteria and assumptions have been causing huge variations in all vital aspects of SSI study, design and implementation from region to region and among professionals within the same region and institutions due mainly to the lack of agreed standard technical guidelines. Hence, the SSI Directorate with AGP financial support, led by Generation consultant (GIRDC) and with active involvement of national and regional stakeholders and international development partners, these new and comprehensive national guidelines have been developed.

The SSID guidelines have been developed by addressing all key features in a comprehensive and participatory manner at all levels. The guidelines are believed to be responsive to the prevalent study and design contentious issues; and efforts have been made to make the guidelines simple, flexible and adaptable to almost all regional contexts including concerned partner institution interests. The outlines of the guidelines cover all aspects of irrigation development including project initiation, planning, organizations, site identification and prioritization, feasibility studies and detail designs, contract administration and management, scheme operation, maintenance and management.

Enforceability, standardization, social and environmental safeguard mechanisms are well mainstreamed in the guidelines, hence they shall be used as a guiding framework for engineers and other experts engaged in all SSI development phases. The views and actual procedures of all relevant diverse government bodies, research and higher learning institutions, private companies and development partners has been immensely and thoroughly considered to ensure that all stakeholders are aligned and can work together towards a common goal. Appropriately, the guidelines will be familiarized to the entire stakeholders working in the irrigation development. Besides, significant number of experts in the corresponding subject matter will be effectively trained nationwide; and the guidelines will be tested practically on actual new and developing projects for due consideration of possible improvement. Hence, hereinafter, all involved stakeholders including government & non-governmental organizations, development partners, enterprises, institutions, consultants and individuals in Ethiopia have to adhere to these comprehensive national guidelines in all cases and at all level whilst if any overlooked components are found, it should be documented and communicated to MOA to bring them up-to-date.

Therefore, I congratulate all parties involved in the success of this effort, and urge partners and stakeholders to show a similar level of engagement in the implementation and stick to the guidelines over the coming years.

H.E. Dr. Kaba Urgessa
State Minister, Ministry of Agriculture

SMALL SCALE IRRIGATION DEVELOPMENT VISION

Transforming agricultural production from its dependence on rain-fed practices by creating reliable irrigation system in which smallholder farmers have access to at least one option of water source to increase production and productivity as well as enhance resilience to climate change and thereby ensure food security, maintain increasing income and sustain economic growth.

ACKNOWLEDGEMENTS

The preparation of SSIGLs required extensive inputs from all stakeholders and development partners. Accordingly many professionals from government and development partners have contributed to the realization of the guidelines. To this end MOA would like to extend sincere acknowledgement to all institutions and individuals who have been involved in the review of these SSIGLs for their comprehensive participation, invaluable inputs and encouragement to the completion of the guidelines. There are just too many collaborators involved to name exhaustively and congratulate individually, as many experts from Federal, regional states and development partners have been involved in one way or another in the preparation of the guidelines. The contribution of all of them who actively involved in the development of these SSIGLs is gratefully acknowledged. The Ministry believes that their contributions will be truly appreciated by the users for many years to come.

The Ministry would like to extend its appreciation and gratitude to the following contributors:

- Agriculture Growth Program (AGP) of the MoA for financing the development and publication of the guidelines.
- The National Agriculture Water Management Platform (NAWMP) for overseeing, guidance and playing key supervisory and quality control roles in the overall preparation process and for the devotion of its members in reviewing and providing invaluable technical inputs to enrich the guidelines.
- Federal Government and Regional States organizations and their staff for their untiring effort in reviewing the guidelines and providing constructive suggestions, recommendations and comments.
- National and international development partners for their unreserved efforts in reviewing the guidelines and providing constructive comments which invaluably improved the quality of the guidelines.
- Small-scale and Micro Irrigation Support Project (SMIS) and its team for making all efforts to have quality GLs developed as envisioned by the Ministry.

The MOA would also like to extend its high gratitude and sincere thanks to AGP's multi development partners including the International Development Association (IDA)/World Bank, the Canada Department of Foreign Affairs, Trade and Development (DFATD), the United States Agency for International Development (USAID), the Netherlands, the European Commission (EC), the Spanish Agency for International Development (AECID), the Global Agriculture and Food Security Program (GAFSP), the Italy International Development Cooperation, the Food and Agriculture Organization (FAO) and the United Nations Development Program (UNDP).

Moreover, the Ministry would like to express its gratitude to Generation Integrated Rural Development Consultant (GIRDC) and its staff whose determined efforts to the development of these SSIGLs have been invaluable. GIRDC and its team drafted and finalized all the contents of the SSIGLs as per stakeholder suggestions, recommendations and concerns. The MoA recognizes the patience, diligence, tireless, extensive and selfless dedication of the GIRDC and its staff who made this assignment possible.

Finally, we owe courtesy to all national and International source materials cited and referred but unintentionally not cited.

Ministry of Agriculture

DEDICATIONS

The National Guidelines for Small Scale Irrigation Development are dedicated to Ethiopian smallholder farmers, agro-pastoralists, pastoralists, to equip them with appropriate irrigation technology as we envision them empowered and transformed.

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ACRONYMS

A	Total Area to be irrigated
a1	Area to be irrigated per day
a2	Area to be irrigated per shift
AGP	Agricultural Growth Program
as	Area covered by each sprinkler
BDU	Basic Design Unit
BS	British Standard
C	Friction coeffiecient
CU	Consumptive Use
Cu	Coefficient of Uniformity
CUp	Peak Consumptive Use
D	Internal diameter of pipe
d	Gross depth of irrigation
DN	Nominal Diameter
dn	Net depth of irrigation
drz	Depth of root zone
ECe	Electrical Conductivity of the soil saturation extract
ECw	Electrical Conductivity of Water
Em	Efficiency of the motor driving the pump
EP	Efficiency of a pump
ETc	Crop Evapotranspiration
F	Christansen correction factor
f	Irrigation frequency
FAO	Food and Agriculture Organization
FC	Field capacity
Fi	Irrigation interval
g	Acceleration due to gravity
GI	Galvanized iron
GIRDC	Generation Integrated Rural Development Consultant
HDPE	High density polyethylene

hf	Frictional head loss of pipe
hfL	Frictional head loss in the lateral line
hl	Local head loss
HL	Inlet pressure head of lateral
Hm	Inlet pressure head of main
Ho	Operating pressure head of sprinkler
HP	Horse power
Hr	Height of rizer pipe
Hsm	Inlet pressure head of submain
HzL	Elevation head of the ground
I	Application rate of sprinkler nozzle
ID	Internal diameter
ISO	International standard Organization
J	The head loss gradient
L	Length of pipe
Lpm	Liter per minute
LR	Leaching Requirement
MAD	Maximum Allowable Deficit
MOANR	Ministry of Agriculture and Natural Resource
MOWIE	Ministry of Water, Irrigation and Electricity
NGOs	Non-Governmental Organizations
NL	Number of laterals in a submain line
NRV	Non-Return Valve
Ns	Number of sprinklers operating simultaneously
ns	Number of sprinkler system shifts per day
Nsm	Number of submains on the main line
OD	Outer diameter
PE	Polyethylene
PN	Nominal Pressure
PRV	Pressure Regulating Valve
PVC	Polyvinyl chloride
PWP	Permanent Wilting Point

Q	System discharge
qL	Inlet discharge of lateral
qm	Inlet discharge of main
qs	Operating discharge of sprinkler
qsm	Inlet discharge of sub-main
SL	Lateral spacing on submain or main line
SP	Sprinkler spacing on a lateral
SSID	Small Scale Irrigation Development
SSIGL	Small Scale Irrigation Guideline
SSIP	Small Scale Irrigation Project
SSIS	Small Scale Irrigation Scheme
T	Time of application
TAW	Total available water
TP	Time of pumping
TS	Time required for shfting
uPVC	Un-plasticized polyvinyl chloride
UV	Ultraviolet light
V	Velocity of water flow
WHP	Water horse power
ρ_b	Dry bulk density

PREFACE

While irrigation development is at the top of the government's priority agendas as it is key to boost production and improve food security as well as to provide inputs for industrial development. Accordingly, irrigated land in different scales has been aggressively expanding from time to time. To this end, to enhance quality delivery of small-scale irrigation development planning, implementation and management, it has been decided to develop standard SSI guidelines that must be nationally applied. In September 2017 the Ministry of Agriculture (MoA) had entrusted Generation Integrated Rural Development Consultant (GIRDC) to prepare the National Small-scale Irrigation Development Guidelines (SSIGLs).

Preparation of the SSIGLs for enhancing development of irrigated agriculture is recognized as one of the many core initiatives of the MoA to improve its delivery system and achieve the targets in irrigated agriculture and fulfill its mission for improving agricultural productivity and production. The core objective of developing SSIGLs is to summarize present thinking, knowledge and practices to enable irrigation practitioners to properly plan, implement and manage community managed SSI schemes to develop the full irrigation potential in a sustainable manner.

As the SSIGLs are prepared based on national and international knowledge, experiences and practices, and describe current and recommended practice and set out the national standard guides and procedures for SSI development, they serve as a source of information and provide guidance. Hence, it is believed that the SSIGLs will contribute to ensuring the quality and timely delivery, operation and maintenance of SSI schemes in the country. The SSIGLs attempt to explain and illustrate the important concepts, considerations and procedures in SSI planning, implementation and management; and shall be used as a guiding framework for professionals engaged in SSI development. Illustrative examples from within the country have been added to enable the users understand the contents, methodologies presented in the SSIGLs.

The intended audiences of the SSIGLs are government organizations, NGOs, CSOs and the private sector involved in SSI development. Professionally, the SSIGLs will be beneficial for experienced and junior planners, experts, contractors, consultants, suppliers, investors, operators and managers of SSI schemes. The SSIGLs will also serve as a useful reference for academia and researchers involved and interested in SSI development. The SSIGLs will guide to ensure that; planning, implementation and management of SSI projects is formalized and set procedures and processes to be followed. As the SSIGLs provide information and guides they must be always fully considered and applied by adapting them to the local specific requirements.

In cognizance with the need for quality SSIGLs, the MoA has duly considered quality assurance and control during preparation of the guidelines. Accordingly, the outlines, contents and scope of the SSIGLs were thoroughly discussed, reviewed and modified by NAWMP members (senior professionals from public, national and international stakeholder) with key stakeholders in many consultative meetings and workshops. Moreover, at each milestone of SSIGL preparation, resource persons from all stakeholders reviewed and confirmed that SSIGLs have met the demands and expectations of users.

Moreover, the Ministry has mobilized resource persons from key Federal, National Regional States level stakeholders and international development partners for review, validation and endorsement of the SSIGLs.

Several hundreds of experienced professionals (who are very qualified experts in their respective fields) from government institutions, relevant private sector and international development partners have significantly contributed to the preparation of the SSIGLs. They have been involved in all aspects of the development of SSIGLs throughout the preparation process. The preparation process included a number of consultation meetings and workshops: (i) workshop to review inception report, (ii) workshop on findings of review of existing guidelines/manuals and proposed contents of the SSIGLs, (iii) meetings to review zero draft SSI GLs, (iv) review workshop on draft SSI GLs, (v) small group review meetings on thematic areas, (vi) small group consultation meetings on its final presentation of contents and layout, (vii) consultation mini-workshops in the National States on semi-final versions of the SSIGLs, and (viii) final write-shop for the appraisal and approval of the final versions of SSIGLs.

The deliberations, concerns, suggestions and comments received from professionals have been duly considered and incorporated by the GIRD Consultant in the final SSIGLs.

There are 34 separate guidelines which are categorized into the following five parts concurrent to SSI development phases:

Part-I. Project Initiation, Planning and Organization Guideline which deals with key considerations and procedures on planning and organization of SSI development projects.

Part-II. Site Identification and Prioritization Guideline which treats physical potential identification and prioritization of investment projects. It presents SSI site selection process and prioritization criteria.

Part-III. Feasibility Study and Detail Design Guidelines for SSID dealing with feasibility study and design concepts, approaches, considerations, requirements and procedures in the study and design of SSI systems.

Part-IV. Contract Administration and Construction Management Guidelines for SSI development presents the considerations, requirements, and procedures involved in construction of works, construction supervision and contract administration.

Part-V. SSI Scheme Management, Operation and Maintenance Guidelines which covers SSI Scheme management and operation.

Moreover, Tools for Small Scale Irrigation development are also prepared as part of SSIGLs.

It is strongly believed and expected that; the SSIGLs will be quickly applied by all stakeholders involved in SSI development and others as appropriate following the dissemination and familiarization process of the guidelines in order to ensure efficient, productive and sustainable irrigation development.

The SSIGLs are envisioned to be updated by incorporating new technologies and experiences including research findings. Therefore, any suggestions, concerns, recommendations and comments on the SSIGLs are highly appreciated and welcome for future updates as per the attached format below. Furthermore, despite efforts in making all types of editorial works, there may still errors, which similarly shall be handled in future undated versions.

UPDATING AND REVISIONS OF GUIDELINES

The GLs are intended as an up-to-date or a live document enabling revisions, to be updated periodically to incorporate improvements, when and where necessary; may be due to evolving demands, technological changes and changing policies, and regulatory frameworks. Planning, study and design of SSI development interventions is a dynamic process. Advancements in these aspects are necessary to cope up with the changing environment and advancing techniques. Also, based on observation feedbacks and experiences gained during application and implementation of the guidelines, there might be a need to update the requirements, provisions and procedures, as appropriate. Besides, day-by-day, water is becoming more and more valuable. Hence, for efficient water development, utilization and management will have to be designed, planned and constructed with a new set up of mind to keep pace with the changing needs of the time. It may, therefore, be necessary to take up the work of further revision of these GLs.

This current version of the GLs has particular reference to the prevailing conditions in Ethiopia and reflects the experience gained through activities within the sub-sector during subsequent years. This is the first version of the SSI development GLs. This version shall be used as a starting point for future update, revision and improvement. Future updating and revisions to the GLs are anticipated as part of the process of strengthening the standards for planning, study, design, construction, operation and management SSI development in the country.

Completion of the review and updating of the GLs shall be undertaken in close consultation with the federal and regional irrigation institutions and other stakeholders in the irrigation sub-sector including the contracting and consulting industry.

In summary, significant changes to criteria, procedures or any other relevant issues related to technological changes, new policies or revised laws should be incorporated into the GLs from their date of effectiveness. Other minor changes that will not significantly affect the whole nature of the GLs may be accumulated and made periodically. When changes are made and approved, new page(s) incorporating the revision, together with the revision date, will be issued and inserted into the relevant GL section.

All suggestions to improve the GLs should be made in accordance with the following procedures:

I. Users of the GLs must register on the MOA website: Website: www.moa.gov.et
II. Proposed changes should be outlined on the GLs Change Form and forwarded with a covering letter or email of its need and purpose to the Ministry.
III. Agreed changes will be approved by the Ministry on recommendation from the Small-scale Irrigation Directorate and/or other responsible government body.
IV. The release date of the new version will be notified to all registered users and authorities.

Users are kindly requested to present their concerns, suggestions, recommendations and comments for future updates including any omissions and/or obvious errors by completing the following revisions form and submitting it to the Ministry. The Ministry shall appraise such requests for revision and will determine if an update to the guide is justified and necessary; and when such updates will be published. Revisions may take the form of replacement or additional pages. Upon receipt, revision pages are to be incorporated in the GLs and all superseded pages removed.

Suggested Revisions Request Form (Official Letter or Email)

To: ---
From: ---
Date: ---
Description of suggested updates/changes: Include GL code and title, section title and # (heading/subheading #), and page #.

GL Code and Title	Date	Sections/ Heading/Subheading/ Pages/Table/Figure	Explanation	Comments (proposed change)

Note that be specific and include suggested language if possible and include additional sheets for comments, reference materials, charts or graphics.

GLs Change Action

Suggested Change	Recommended Action	Authorized by	Date

Director for SSI Directorate**: _________________________Date: _________________**

The following table helps to track initial issuance of the guidelines and subsequent Updates/Versions and Revisions (Registration of Amendments/Updates).

Revision Register

Version/Issue/Revision No	Reference/Revised Sections/Pages/topics	Description of revision (Comments)	Authorized by	Date

1 BASICS ON SPRINKLER IRRIGATION SYSTEM

1.1 DEFINITION OF SPRINKLER SYSTEM

Sprinkler system is one of the broad classes of pressurized irrigation methods. It is a system in which water is applied from a pipe network to crops above the ground in the form of sprays somewhat resembling rainfall. Since the water is applied through overhead spraying, the system is also known as overhead irrigation system. Sprinkler system generally requires a pumping device to drive water from the source to the pipe network. However, in some cases, if sufficient head is available, sprinkler systems may be pressurized by gravity and therefore pumping plants may not be required.

1.2 OBJECTIVES AND PRESENTATION STRUCTURES OF THE GUIDELINE

This guideline is a guide for planning, design, operation and maintenance of s*prinkler irrigation system.* The main objective of the guideline is to have standard sprinkler irrigation systems design in Ethiopia mainly for small scale level irrigation practices. The material has been prepared with emphasis given to the practical aspects of sprinkler irrigation. It starts with definition, components and concepts of pipe line hydraulics in pressurized system. Then, it deals with the detail planning and design procedures of the system which are illustrated by practical examples. Finally, the installation, specification, operation and maintenance aspects of the system are presented in a more simplified manner.

1.3 PRINCIPLES OF OPERATION OF SPRINKLER SYSTEM

In sprinkler system, water is conveyed from the source to the field by network of pipes. Sufficient head (gravity) or pump is required for the water to flow in the pipes under pressure. The pressure causes the water to flow out through small opening (sprinkler nozzle) and fly through the air and falls onto the soil surface. Hence, the system distributes water by spraying it over the fields.

The pipes used in sprinkler system are called main, submain and lateral pipes. These pipes differ in their sizes. The main pipe is a single largest size pipe line in the network. It takes water from the supply pipe, which is short pipe connected to the source or pump. The next smaller pipes which are connected at regular spacing on the main pipe are the submain pipes. They provide water to lateral pipes which are the smallest pipes in the system. Sufficient number of such pipes is connected to the sub-main pipe at regular spacing. Finally, there are short vertical pipes called riser pipes; one end of which are connected to the lateral pipe at regular spacing while the other ends are connected to a device is called sprinkler nozzle. It is through this nozzle or small opening that water is applied or sprayed onto the field.

As water is coming out from the system through small openings on the sprinkler heads, the system relatively requires clean water. It might result in clogging of the openings by the debris in the water source, otherwise. Therefore, additional component such as water filter of some kind might be used depending upon the level of debris in the water. If the source of water is particularly river with high level of sediments, it might be desirable to divert water first to an artificial basin for de-silting purposes. The relatively clean water will then be pumped to the system directly from the basin. Apart from the pipe networks, accessories such as valves, fittings, couplers, water and pressure metering devices, etc. and ancillary units like liquid fertilizer applicator (if needed) are included for proper operation of the system.

1.4 THE BENEFITS AND LIMITATIONS OF SPRINKLER SYSTEM

1.4.1 Benefits

The major benefits of using sprinkler system are:

- It can be applied on irregular topography and steep slopes of up to 20% that cannot be irrigated by surface irrigation without producing runoff or erosion.
- It can be used on soils with low water holding capacity such as sandy soils which is difficult under surface irrigation due to high infiltration rate.
- It can be applied on proper irrigation of problem soils with intermixed textures and profiles or the irrigation of shallow soils that cannot be graded without detrimental results.
- It is suited to irrigate most row, field and tree crops
- It delivers water uniformly throughout the field and at high water use efficiency.
- Effective use of water from various sources such as small, and continuous streams of water, such as from springs and small tube or dug wells.
- System operation is simple and labour requirement is low. Labour is only needed for a short time each day for pipe moving during operation.
- Since water is transported through pipes, no contamination of the irrigation water during transport and avoids water losses.
- The system is also known to modify the micro climate (hot and freezing conditions)
- Light and frequent irrigations are so easily managed by using the system, in many situations such as for shallow rooted crops, and germination of new plants.
- As field channels are not required in the system, more areas become available for crop production.

1.4.2 Limitations

Although sprinkler system has many benefits as mentioned above, it has the following limitations:

- System installation cost is relatively high.
- As the water is applied in the form of sprays, they are easily drifted away under high wind conditions.
- System operation interfere farm activities like cultivation
- Since the whole area is wetted, it promotes weed growth.
- Pump is required for the system if sufficient head is not available. This will be extra cost of the energy consumed for creation of water pressure.
- Overhead application may induce leaf diseases as some crops are sensitive to wet conditions.
- As sprinkler nozzles are small, it might be blocked by suspended sediments.
- Planning and design of the system requires good technical know-how and its operation needs great attention.

1.5 THE CURRENT STATUS OF SPRINKLER SYSTEM AND ITS PROSPECTS IN ETHIOPIA

1.5.1 Current status

There are no well-organized and nationally accepted data on the current sprinkler system practice in Ethiopia. But the system is known to use for growing horticultural crops around Ziway area. Gravity sprinkler system is used on 9000ha for sugarcane plantation at Finchaa. There is a development of 10,700ha at Wolenchiti for sugar plantation under Wonji-Shoa sugar factory. A 2000ha drag hose sprinkler system is developed at Sunuta area, Ewa woreda, Afar regional state and 4000ha is developed in Siti zone Harawa and Kulen area in Somali Regional State. And, 3000ha is under development in Welkayt Sugar factory in Tigray; similarly 13,000ha is developed in Tana Beles, Amhara Region. Detail design was done for development of 2700ha at Alaydege in Afar regional state. For small land holding farmers of the Raya and Kobo Valleys, alternative sprinkler and drip irrigation systems have been started for the development of 26,100ha.

1.5.2 Future prospects

Irrigation development is given greater attention ever in Ethiopia as integral part of overall development of water resources. It is known that surface irrigation has been widely practiced in the country by the local irrigators due to its simplicity in operation and maintenance. However, given the undulating and steep topography of wide arable areas of the country; the marginal soils of peripheral regions of the country; shallow soils with low water holding capacity at the arid and semi-arid regions, extensive use surface irrigation is not possible. Such condition rather favors an irrigation system like sprinkler irrigation. Besides this, the increasing demand for improved utilization of water due to sever water shortage, and intensification and diversification of production in time of climate change calls for the application of improved irrigation methods like sprinkler system.

In addition, one of the major hurdles to irrigation development in the country is the underperformance of existing surface irrigation schemes. This urges to opt for other efficient method of irrigation such as sprinkler system as the application of this system produces a drastic change in irrigation management practices at farm level. Unlike the old days, the local production of plastic pipes, and availability of pressurized system kits for small farms coupled with the development of hydroelectric power and the continuous reduction of cost of system components is also a boost for the farmers to adopt the system in the near future.

1.6 TYPES OF SPRINKLER SYSTEM

There are many types of sprinkler systems. However, they are broadly categorized on the basis of portability of the system components as fixed or solid set system, semi-portable or periodic move system, and fully-portable or continuous move system.

Solid set system: Here, all the system components are not movable. It consists of permanently laid mains, submains, laterals and stationary water sources with pumping plant. The mains, submains and laterals are usually buried below plough depth. The system has enough laterals to cover the entire field at the same time. Sprinklers are permanently located onto short vertical pipe called as riser. Thus, to irrigate, the sprinklers are only needed to be cycled on and off. These systems are good for irrigating tree crops and turfs, for frost protection and crop cooling. A typical example of this is pop-up sprinklers which are commonly used in irrigating lawn grasses. The sprinklers, which are attached on the lateral, are at equal level to the ground when they are not operational and they pop-up from the ground to irrigate the field.

Figure 1-1: Pop-up sprinkler system

Semi-portable system: Here, the water source and the pumping plants are fixed and the mains and submains are usually buried with valve outlets at various spacing for the portable laterals. As the laterals are periodically shifted from place to place, the system is also known as periodic-move system. This system includes:

a) **Hand move system:** It is very common type of sprinkler system. It relatively costs cheap per unit area but requires relatively large amount of labour. The system consists of portable laterals which were previously aluminum (6 to 12m long) with quick coupling which are strong enough but light to carry. Currently, the aluminum pipes are being replaced by HDPE pipes. Sprinklers are mounted on short galvanized iron (GI) riser pipes, which are connected to the pipe couplings on each of the lateral pipelines. The lateral lines are assembled and operated in one area, and are then disassembled and moved to another area to apply water. It is a system more convenient to irrigate almost all type of crops.

b) **End tow (drag hose) system:** It is similar to hand move system but as pipes are rigidly connected, a tractor is used to drag the lateral from position to position. Pipes are protected from wear during dragging by mounting it on skid plates or small wheels.

c) **Side roll system:** It consists of lateral mounted on wheels and the lateral is also acting as the axle for the wheels. It uses motorized units to roll the lateral, which are mounted in middle or at ends. The side roll sprinkler system is best adapted for rectangular fields.

Figure 1-2: Side roll system

d) **Side move system:** It is similar to side roll system but lateral pipe is not axle rather it is mounted on a steel frame with two wheels at each end.

e) **Perforated pipe system:** This method consists of systematically placed drilled holes along the length of the lateral pipe through which water is sprayed under pressure. The holes are uniformly spaced along the top and sides of the lateral pipe and are typically 1.6 mm in diameter. The system is usually designed for relatively low operating pressures. The application rate ranges from 1.25 to 5cm/hr for various pressures and spacing. The laterals are shifted from place to place manually. This system is mainly used on home lawns and is generally suited to coarse textured soils because of its high water application rates.

Figure 1-3: Perforated sprinkler system

Fully-portable system: It is a continuous move system in which all the component parts of the system including the pumping unit are movable. Typical examples of this system include:

a) **Traveler or gun sprinkler:** It consists of sprinklers with big nozzle (gun sprinkler) of discharge 300 to 1800 lpm mounted on long flexible hose which is usually reeled on a wheel frame. The system pumps water from open ditch. Water is delivered to the system by a hose hooked up to a water supply. Traveling gun systems usually produce large droplets and high application rates, so they are best suited for coarse soils with high intake rates. It is commonly used to irrigate pasture.

b) **Center pivot system**: It consists of wheels mounted on large steel frame which rotates about a center where the source of water is located. The system has a pipe lateral mounted on steel towers. The fixed end of the lateral, the pivot, is connected to a water supply. The pipe carries different sizes of impact, spinner or spray sprinklers. The typical lateral length is from 35 to 400m which are mounted on the frame about 3m above the ground. The system requires no labor and can operate on very undulating topography. This system is getting substantial attention in Ethiopia due to its increasing innovation, low cost per ha and being best for irrigating larger areas like sugar farms. There are quite a lot of such systems in operation, covering areas as little as 3 hectares, and as large as 60ha or more.

c) **Linear move system:** It is similar to the center pivot, because they are both made up of series of aluminum pipe towers with sprinklers attached and equipped with wheels. However in this system, instead of the water being supplied from a central point and the lateral rotating around that point, a water supply system, such as an open channel or hose, is provided over the whole length, along which the lateral travels. Therefore, the lateral travels linearly as it irrigates. As a result this system irrigates rectangular fields. The fields, however, have to be free of obstructions. The system is driven either by the water pressure, diesel or electric engine. The water inlet is usually located at the pipe end and water is supplied by pumping directly from a canal along the field border.

Figure 1-4: Linear move system directly pumping water from canal

But, of all the methods mentioned above, the most suitable and easily manageable system for small land holding is the semi-portable hand move sprinkler system. This system is most widely adopted and least expensive but labor intensive system for irrigating small to medium-sized farms as it works with a low (<20bars) to medium (2.0-4.0 bars) operating pressures. They can also be adapted to irregular field shapes and fairly steep topographies, and are suitable for irrigating most field crops.

The semi-portable hand move sprinkler system is known to have portable lateral pipes while other pipe systems (main and submain pipes) are fixed and are generally buried. Submains are with valve outlets (hydrants) at various spacing for connecting to the portable laterals. The laterals are made of aluminum or HDPE tubing with quick couplers, risers and sprinklers. The couplers are connectors for quick coupling and decoupling of the lateral pipes.

As the laterals are periodically shifted from place to place, the system is also called as *periodic-move system*. In this system, the lateral pipe lines are running parallel to the cropped rows. The sprinkler nozzles, which are connected on the laterals through the riser pipes, rotate such that each nozzle wets in a circular pattern. The uniformity of application comes from the overlapping of these circular patterns both along the sprinkler line and between successive positions of the lateral lines.

Figure 1-5: Periodic move sprinkler system

1.7 COMPONENTS OF SEMI-PORTABLE HAND MOVE SPRINKLER SYSTEM

A typical semi-portable sprinkler irrigation system consists of pumping unit, control unit, the pipe network (mains, submains and laterals), sprinkler head, and other accessories such as couplers, valves, risers, and fittings. These components are briefly presented hereunder. A complete illustration is given in fig. 1.19 below.

a) **Pumping unit –**Water is carried in the pipe network under pressure. A pump may be required to create this pressure (to provide sufficient head) for the system to operate. The pump is selected depending upon the required discharge and pumping water head. Centrifugal pump is generally used if the water source is from irrigation ditches, lakes, ponds, river channels, shallow wells or surface reservoirs. Debris screen or strainer is provided on the water source end of the suction pipe to fliter out any large debris from entering into the system.

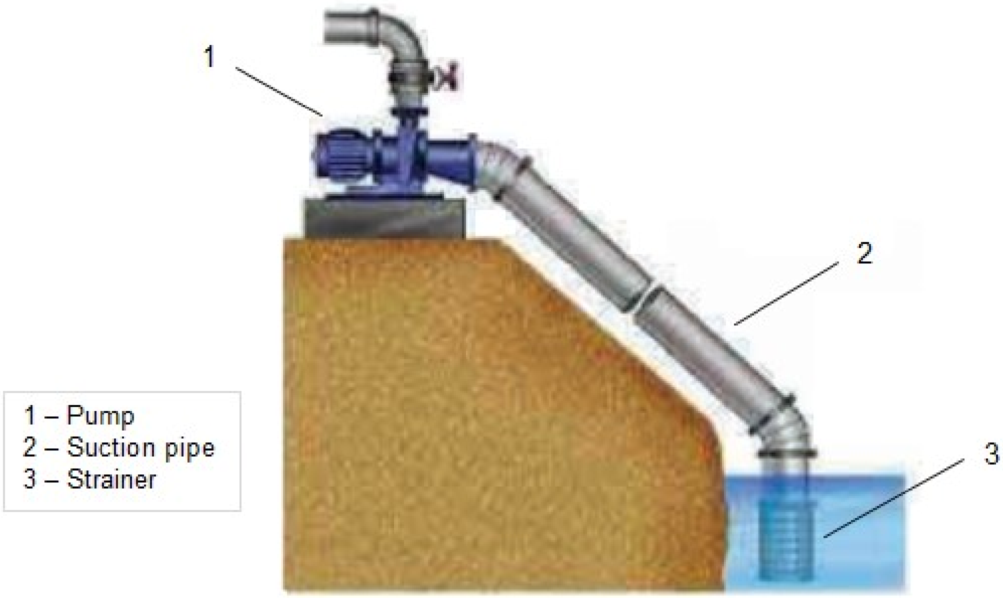
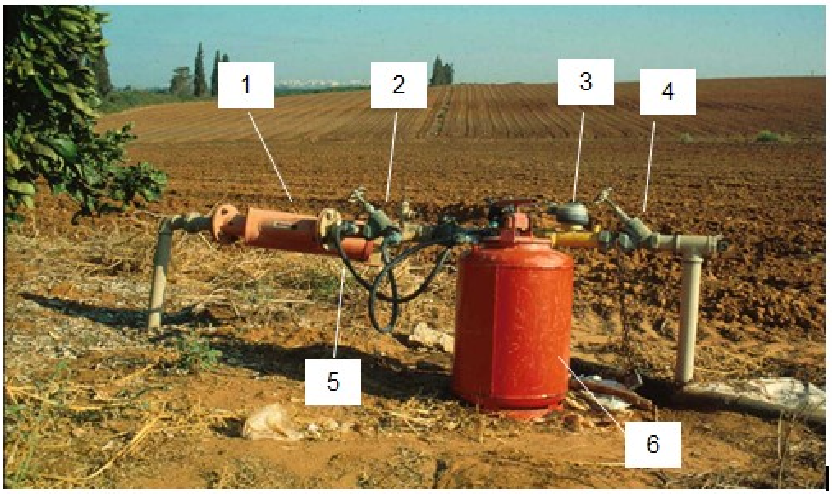


Figure 1-6: Typical centrifugal pump installation

b) **The head control unit -** It consists of majorly short supply pipeline; the shut-off, and check (non-return) valves, fertilizer connections and tank, and water filter.The supply pipe is a rigid galvanized steel pipe installed horizontally at a minimum height of 60cm above ground.

For small land holdings, the control unit can be as simple as possible. The fertilizer injector is not always needed, as many farmers prefer to apply solid fertilizer manually. Where a filter is needed, it is installed at the beginning of the supply pipe.



1 – Filter
2 – NRV
3 – Water meter
4 – PRV
5 – Fertilizer hose
6 – Fertilizer tank

Figure 1-7: The head control unit

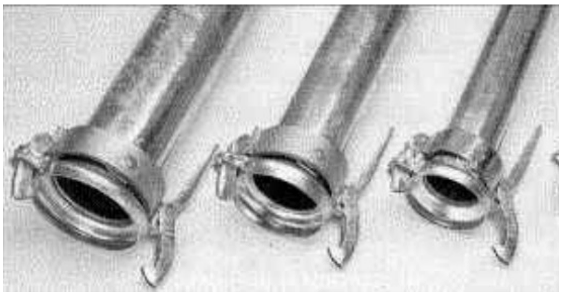
c) **Pipe network –** It comprises generally of three types: main, submain and laterals as brifly indicated in section 1.2.

Main and submain pipe lines are laid permanent or buried below ground. They are commonly buried at about 45 to 65cm below ground level so as to be out of the way of farming operations and to protect from temperature changes. Main and submain pipe lines are made of plastic (rigid PVC or HDPE) with Class 4, 6, 8 or 10. The class of the pipe implies that the pipes can resist upto a nominal pressure (PN) of 4, 6, 8 or 10bars (or, a working pressure head of 40m, 60m, 80m or 100m) which otherwise get damaged. This variation is due to the thickness of the pipes (see Appendix V& VI).

The lateral pipes are always laid as portable ones.They are usually made of aluminium pipe or plastic pipe (HDPE) of Class 4 or 6 and are generally equipped with quick coupling devices. This is to enable shifting of the pipes very quickly during operation.

(a) uPVC pipe

(b) HDPE pipe



(c) Aluminium pipes with quick coupling

Figure 1-8: Pipe line types used in sprinkler system

d) Sprinkler head –It is a device with a nozzle mounted on a short riser pipe to spray water onto the field. They are usually rotating type with two-nozzle heads (long and short range)**.** The long range nozzle is to irrigate at long distance from the sprinkler and the short range nozzle is to apply the area under and near the sprinkler.

Sprinklers are available in various nozzle sizes, flow discharges, operating pressures and wetted diameters. Most agricultural sprinklers have a hammer-drive slow-rotating or revolving mechanism and use a low (<20 bars) to medium operating pressure (2.0-4.0 bars). They are made of brass or high engineering plastics with internal or external threaded connections.

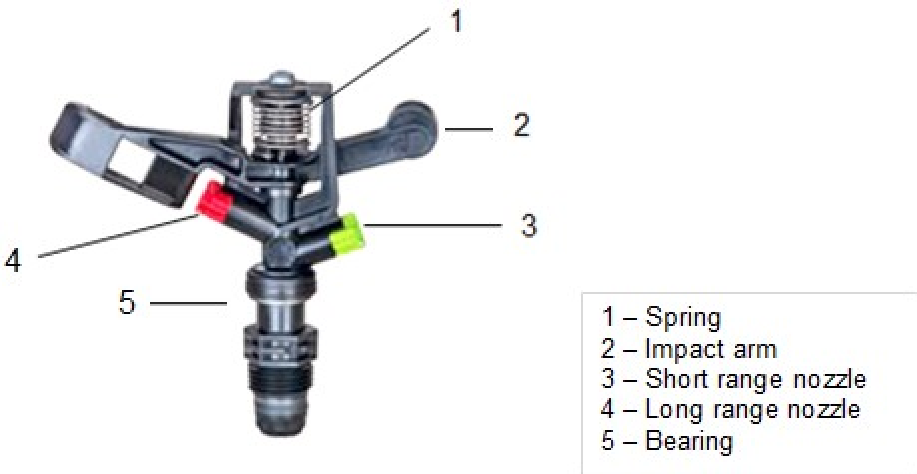


Figure 1-9: Typical rotating two nozzle sprinkler head

e) Accessories – These include risers, couplers, valves, water meter, pressure guage, bends, plugs, and fittings.

i. Risers – Theyare short galvanized iron (GI) vertical pipes which are placed at a regular spacing on laterals on top of which sprinklers are connected. They supply water from lateral to the sprinklers. They are fastened into a saddle fitting, mounted straight on a lateral. The height of the riser pipe is recommended to be at least 60cm above the height of the growing crops.

Figure 1-10: Sprinkler system clearly showing tripod supported riser pipes

ii. **Quick couplers –** A coupler provides connection between two pipes and between pipes and fittings. For hand move laterals, couplers provide flexible connection that facilitate fast disconnecting of the riser from the laterals. They are light in weight, non-corrosive, strong and durable. They are either made of polyperolyene or aluminium alloy. They are manufactured in nominal diameter of 2 to 6 inches.

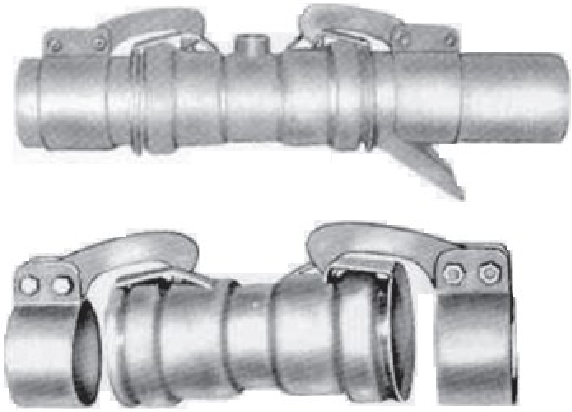


Figure 1-11: Quick couplers for aluminum pipes

iii. **Valves –** They control the flow of water in irrgiation systems. They are used for closing and opening of the water flow (take off/gate valve or ball valve), regulation of pressure (reducing, sustaining and controling valves) and flow rate (globe valve), prevention of back flow (check valves) and prevention of water hammer or protection of pipe damage by trapped air in the system (air release valves) or from collapse due to a vacuum (vaccum brakers). Air/vaccum valves are installed on riser pipes, at high points of the system after the pump, and at the beginning and the end of long branch pipelines.

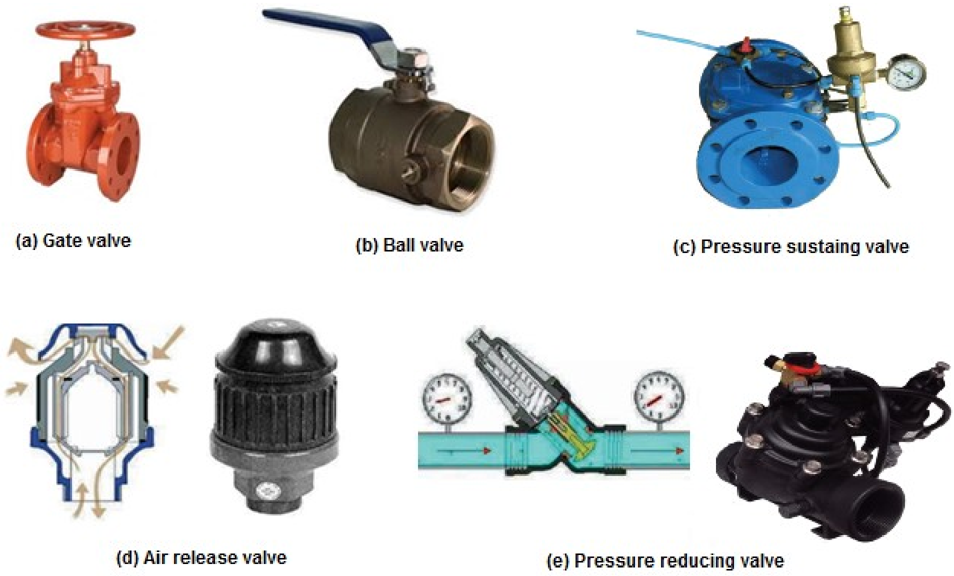


Figure 1-12: Different types of valves used in sprinkler system

iv. **Water meter –** It is used to measure the volume of water delivered. The common flow meter consists of a casing containing a horizontal or vertical impeller. The impeller is rotated by the flowing water and transmits its rotational motion to a measuring scale mounted on top of the casing. The flow meter visually displays the readings of the delivered water amount. They are manufactured in various designs, with the body made of cast iron.

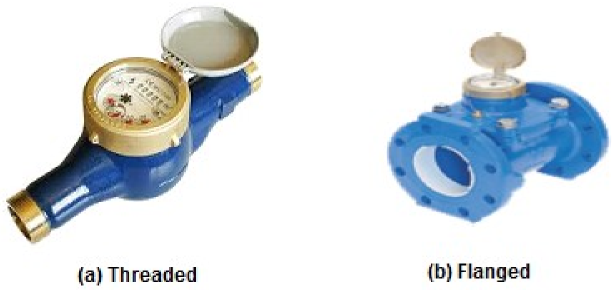


Figure 1-13: A water meter

v. **Pressure gauge –** It is used to measure and monitor the pressure under which sprinkler is working in order to deliver the water uniformity. The most common pressure gauge used is the Bourdon gauge. A portable gauge can be used by an operator to read the sprinkler pressure at the sprinkler nozzle which is in use.

Figure 1-14: A Bourdon type pressure gauge

vi. **Filters –** as adequate filteration of irrigation water is essential in pressurized system, different filter types are used depending upon the level of impurities of the water. If the level impurities are high primary filters (sand and hydrocyclone) are preferred. For instance, sand or media filters are primarily suitable when irrigating with water containing high organic loads. Hydro-cyclones are used if the water is having sands. Otherwise, secondary filters (screen or disk filters) are used. Screen filters are suitable to water with inorganic impurities, whereas disk filters are suitable to water containing mixed impurities – inorganic solid particles and organic debris.

(a) Hydro-cyclone filter

(b) Media filter

Figure 1-15: Primary filters

(a) screen filter **(b) disc filter**

Figure 1-16: Secondary filters

vii. **Fittings –** Different types of fittings such as flanges, adapter and nipples are used for facilitating proper connections of pipes.

Figure 1-17: Different types of PVC fittings

Figure 1-18: Different types of PE fittings

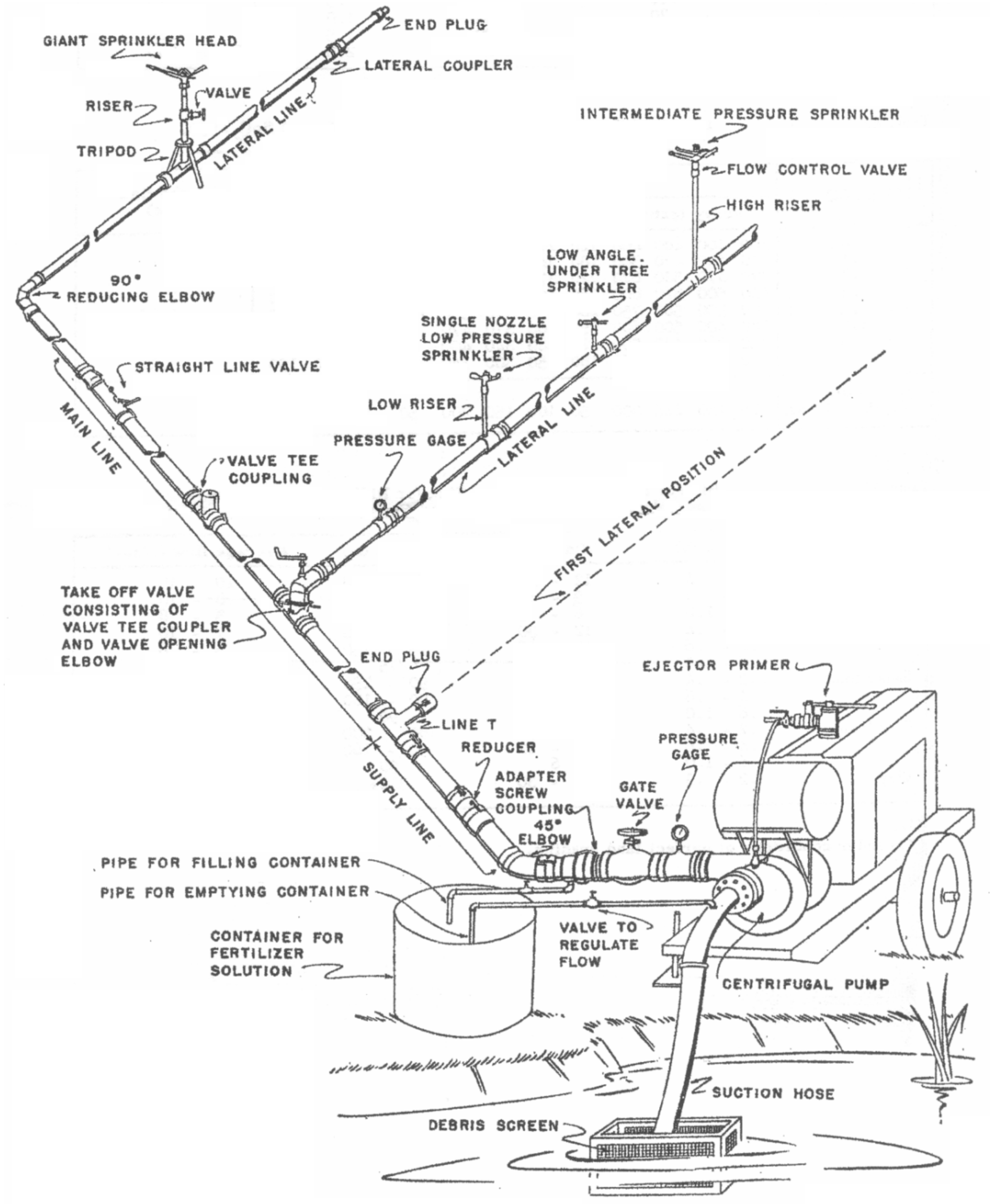


Figure 1-19: Typical components of sprinkler irrigation system

2 DESIGN OF SPRINKLER SYSTEM

Proper planning and correct design of sprinkler irrigation system is required to obtain a system that provides satisfactorily uniform application of water with a minimum annual operation and maintainance cost. Specifically, it is essential to provide sufficient flow to meet the irrigation demand, ensure that the least irrigated plant receives adequate water, and ensure that the water is uniformly distributed.

2.1 THE DESIGN PROCESS

The design of a simple semi-portable sprinkler system requires the following two stage process:

- Preliminary design steps
- Detail design steps

The step-by-step procedure in the planning and design of a sprinkler irrigation system at the two stages is summarized in the flowchart shown in Figure 2.1 below. The details of the steps are enumerated in the subsequent sections. Further, design template is prepared in spreadsheet which can be found in the accompanied CD.

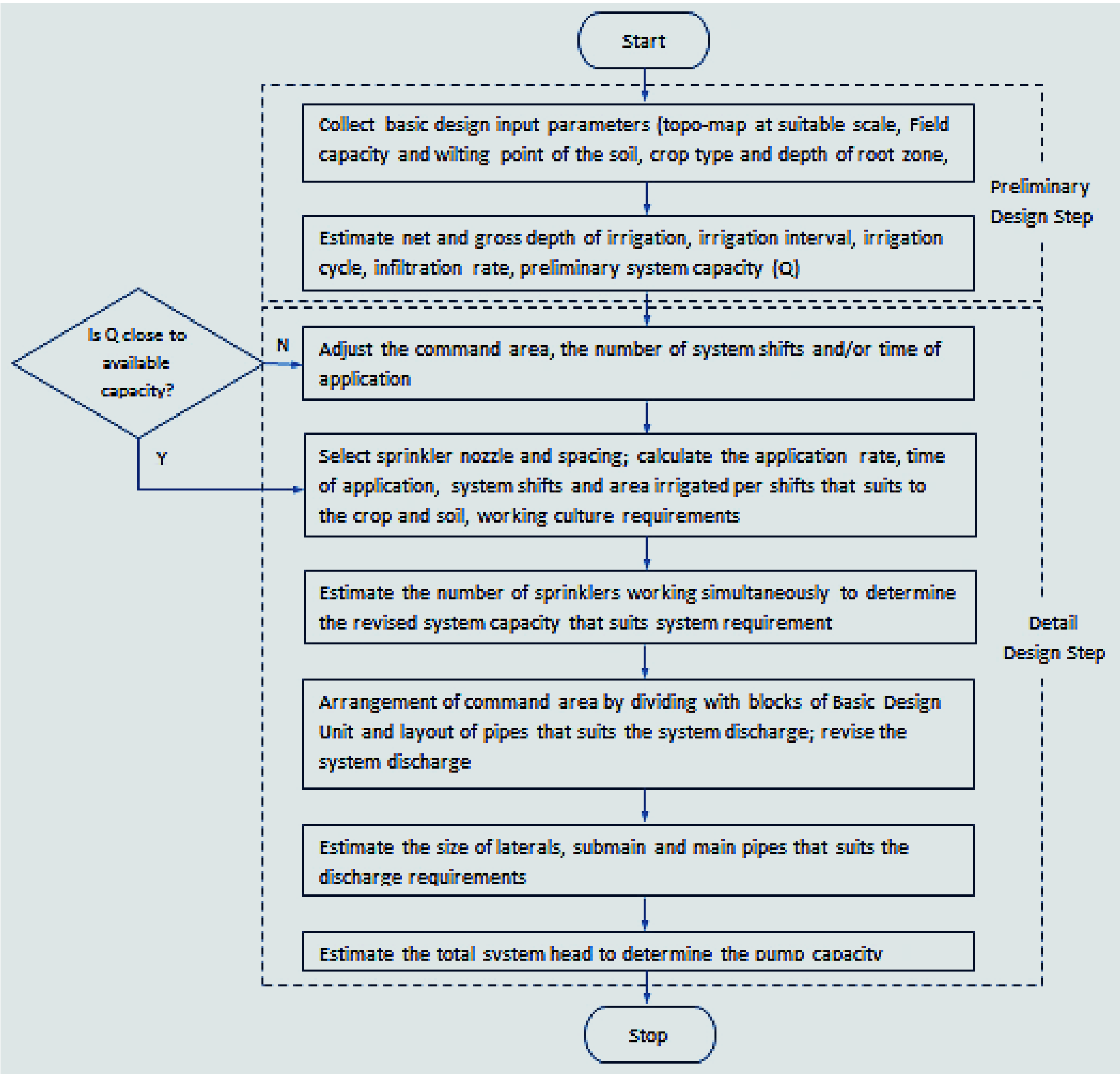


Figure 2-1: Design process for a portable hand-move sprinkler system

2.1.1 Preliminary design of sprinkler system

It is an important step for system design. It is the stage of field data collection,and determination of basic design parameters that will be needed as inputs in the detail design stage.

2.1.1.1 Field data collection

The first step in the design of sprinkler system is to make the resource inventory and operating conditions of the area by document review and by having field visit, and collect basic information for design. This includes:

a) Topographic map of the area at a scale that shows all the features including the land use plan for delinating commandable area and for layout of the system. The typical scale of map required for system layout is 1:1000 to 1:2500.
b) Water source (quantity, quality, period of availability). The available head, maximum available flow rate at the supply points and supply hours have to be defined. The quality of water shall be suitable for irrigation. Particularily, the level of salinity has to be defined to decide on the requirement for leaching of salts accumulated in the root zone of the soil.
c) Crops to be grown and their characterstics such as effective root zone, peak consumptive use rate and the allowable moisture deficit.
d) Soil charactrestics such as infiltration rate and water holding capacity (field capacity and permanent wilting point).The former is required to decide the maximum rate of water application by a sprinkler while the latter is required to decide the depth of application.
e) Climate such as wind speed and general direction of blow.

Note: Data may be collected using the data collection form shown in Appendix III

2.1.1.2 Determination of basic design parameters

With the above mentioned data at hand, the following basic parameters to suit to the detail sprinkler system design and operation will be determined.

- Net depth of irrigation
- Gross depth of irrigation
- Irrigation Interval
- Irrigation cycle
- Application rate
- Application time
- Preliminary system capacity

i. **Net depth of irrigation:** It is the depth of water to be applied to the soil that is readily available for the crop to absorb. It is a function of the water holding capacity of the soil (total available water) and the root system of the selected crop. The toal available water (TAW) or the water which is considered as available to plant is the amount between the field capacity (FC) and the permanent wilting point (PWP). But it is only a fraction of this soil moisture is easily absorbed by the plants (without any stress that results in yield reduction). This fraction is called as the maximum allowable depletion (MAD). The net depth of irrigation application is, therefore, a product of TAW multiplied by MAD.

$$d_n = MAD\left(\frac{FC - PWP}{100}\right) \times \rho_b \times drz = MAD \times TAW \times drz$$

---- (2.1)

Where,

dn = Net depth of irrigation, mm
MAD = Maximum allowable deficit
FC = Field capacity on dry weight basis, %
PWP = Permanent wilting point on dry weight basis, %
ρ_b = Dry bulk density, g/cm^3
drz = The depth of rootzone, mm

The MAD value differs according to the root depth, the climatic conditions and the irrigation techniques. Values for MAD vary from 0.25 in shallow rooted, sensitive crops to 0.70 in deep rooted tolerant crops. However, for most crops, it is considered that 3/4 th of their root depth is effective to absorb 2/3rd of the available water. Thus, as a thumbs rule, the soil water which is readily available to most crops is half of the total available water. Practically, it means that for maximum result from the crop, irrigation water is recommended to apply when half of the total available water is depleted. That is, MAD is considered to have a value of 0.50. This value of MAD can also serve as a safety factor because many values (soil data, crop data, climate data, etc.) are not precisely known.

Key Note: *The details about the concept of FC, PWP, TAW, MAD, root zone, and sensitive crops can be referred from GL 8: Irrigaton Agronomy and Agricultural Development Plan Guideline for SSID.*

Worked example 1: Compute the net depth of irrigation for sprinkler system with the following crop and soil data.

- Location: Raya Valley
- Area to be irrigated: 30ha
- Soil
  - Texture: Deep clay loam
  - Total available water(TAW): 150mm/m
- Infiltration rate: 15mm/hr
- Crop: vegetable (small vegetables and tomato)
- Average Root zone depth: 0.85m
- Maximum allowable depletion: 50%

Solution:

The net depth of irrigation is computed based on eqn. 2.1:

$$d_n = MAD\left(\frac{FC - PWP}{100}\right) \times \rho_b \times drz = MAD \times TAW$$

Since TAW is: $TAW = \left(\frac{FC - PWP}{100}\right) \times \rho_b$, the d_n can be expressed as:

$$d_n = MAD \times TAW \times drz = 0.50 \times 150 \times 0.85m = 63.75mm, \; say \; 64mm$$

ii. **Gross depth of irrigation, d –** it is the actual depth of irrigation to apply onto the field which is obtained by considering the efficency of water application and the leaching requirement. Irrigation application efficiency for sprinkler system varies with climate. The FAO recommendation for different climate is shown in Table 2-1. The reader may adopt these values when no information is available in the area.

Table 2-1: Application efficiencies for sprinkler irrigation in different climates

Climate	Application Efficiency, Ea (%)
Cool	80
Moderate	75
Hot	70
Desert	65

Source: FAO, 2001

The leaching Requirment(LR) is the water applied in excess of the required depth to flush out salts from the root zone. Leaching is necessary if the irrigation water and/or the saturation extract of the soil contains excess salts or LR is greater than 0.1. The leaching requirement, LR under sprinkler irrigation is determined by:

$$LR = \frac{EC_w}{5EC_e - EC_w} \quad \text{---- (2.2)}$$

Where,

LR= Leaching requirment
ECw = The electric conductivity of the irrigation water, dS/m or mmho/cm
ECe = The electric conductivity of the soil saturation extract, dS/m or mmho/cm

Salinity of the soil extract, ECe, is measured by taking a soil sample to the laboratory, adding pure water until the soil is saturated, then measuring the electrical conductivity.

Thus, the gross depth of irrigation water, d is calculated by

For LR<0.1, $d = \frac{d_n}{E_a}$ ---- (2.3a)

For LR≥0.1, $d = \left(\frac{1}{1-LR}\right)\frac{d_n}{E_a}$ ---- (2.3b)

Where,

d = Gross depth of irrigation, cm
Ea = Application efficiency, %

Worked example 2: If the net depth of irrigation is 64mm, compute the gross depth of irrigation for sprinkler system with the following data:

- Location: Raya
- Climate: Moderate
- Water source: Borehole and good quality for irrigation

Solution:

Since the water is good quality, it doesn't require leaching. As the climate is moderate, the application efficiency may be taken as 75%. Thus, the gross depth of irrigation is:

$$d = \frac{d_n}{E_a} = \frac{64}{0.75} = 85.3mm$$

iii. **Irrigation interval, F (days) –** The irrigation interval is the time period in days between two successive irrigation applications. It is expressed as:

$$F = \frac{d_n}{CU_p} \qquad \text{---- (2.4)}$$

Where,

F = Irrigation interval, days
d_n = net depth of irrigation,cm
CU_p = Peak consumptive use, mm/day

The actual irrigation interval should be the value of F rounded to the nearest whole number of days. The net application depth will then be adjusted according to the newly adjusted value of F.

Worked example 3: If the net depth of irrigation required for sprinkler irrigation is 64mm, compute the irrigation interval formaximum daily consumptive use of 5.4mm/day.

Solution:
The irrigation interval, F_i for d_n=64mm and CU_P = 5.4mm/day is:

$$F_i = \frac{d_n}{CU_P} = \frac{64}{5.4} = 11.85 days, \; say \; 12 days$$

So, the net depth of irrigation need to be adjusted:

$$d_n = F_i \times CU_P = 12 \times 5.4 = 64.8mm$$

Similarly, the gross depth in example 2 shall be adjusted to:

$$d = \frac{d_n}{Ea} = \frac{64.8}{0.75} = 86.4mm$$

The peak consumptive use, CU_p is nearly the evapotranspiration need of the crop during the peak demand, which depends on the crop type and climate of the project area. Several methods available for determination of crop water requirment. This is covered in detail in irrigation agronomy guideline. The reader is advised tosee this guideline.

iv. **Irrigation cycle, f (days) –** The period in days required to complete irrigating the design command area. Irrigation cycle shall be less than or equal to the irrigation interval. It is given by:

$$f = \frac{A}{a} \qquad \text{---- (2.5)}$$

Where,

f = Irrigation Cycle, days
A = Total command area, ha
a = Area irrigated per day,ha/day

Worked example 4: Compute the area irrigated per day if 30ha of land is to be irrigated in 12 days.

Solution:

The irrigation cycle is 12days which is taken as equal to the irrigation interval calculated in worked example 3. Thus, the area to be irrigated per day is:

$$f = \frac{A}{a} \rightarrow a = \frac{A}{f} = \frac{30}{12} = 2.5ha$$

If the average land holding size of a farmer is 0.50ha, then 5 farmers can irrigate their lands simultaneously per day.

v. **Water intake rate of the soil, I –** it is the rate at which water infiltrate into the soil. It is a fundamental parameter in the design and operation of irrigation systems. It indicates how fast, in mm/hr, water infiltrates into the soil. The intake rate of the soil decreases over time during irrigation application. Table 2.2 shows the steady infiltration rate of the typical soil types. The values may be taken as a rough guideline but field tests should be done for determination of actual steady state infiltration as these are highly location specific. Various methods are used for determining the intake rate of the soil on the field. The double ring infiltrometer is a widely used method of infiltration test used in many applications. This is covered in GL 5: Soil Survey and Land Suitability Evaluation Guideline for SSID. The reader is advised to see this guide.

Table 2-2: Typical intake rates of soil

Soil type	Steady Infiltration rate (mm/hr)
Clay	1-7
Clay Loam	7-15
Silt Loam	15-25
Sandy Loam	25-40
Sand	>40

(Source: FAO, 2001)

vi. **Preliminary Capacity of Sprinkler System, Qs –** It is the initial estimate of flow rate required by the system which can be determined by:

$$Qs = \frac{A \times d}{f \times N_S \times T} \quad \text{---- (2.6)}$$

Where,

Qs = System capacity, m^3/hr
A = Design area of irrigation, ha
d = Gross depth of irrigation, mm
f = Irrigation frequency, days
Ns = Number of shifts per day
T = Time of irrigation per shift, hr

Worked example 5: Calculate the preliminary system capacity of a sprinkler system with the following data:

- Safe yield of the well (water source): 108m^3/hr
- Command area, A = 30ha
- Gross depth of irrigation, d = 86.4mm
- Irrigation frequency, f = 12days
- Maximum working hours per day, Td = 17hrs

Solution:
The maximum working hours per day is the total time taken for irrigation application which may be given as:

Ta = Number of shifts per day x the time of irrigation per shift
Therefore, the system capacity of the sprinkler system is:

$$Q_s = \frac{A \times d}{f \times N_S \times T} = \frac{A \times d}{f \times T_a} = \frac{(30 \times 10000) \times (86.4/1000)}{12 \times 17} = 135 m^3/hr$$

Since the available safe yield of the system is 108m^3/hr, the command area has to be reduced or if the farmers on 30ha is required to be benefited, farmers should be advised to extend their working time per day. Thus, taking the second option, Ta will be:

$$T_a = \frac{A \times d}{f \times Q_s} = \frac{(30 \times 10000) \times (86.4/1000)}{12 \times 108} = 20 hrs$$

Since each farmer is irrigating every 12 days, it won't be difficult to extend to this time.

2.1.2 Detail design of sprinkler system

After the basic design parameters are determined, the actual or detail design of sprinkler irrigation system will take place.

2.1.2.1 Important terminologies

For detail design, the following terminologies associated to pressurized irrigation system need to be clear first.

Pressure: a force required to push water in a given size of pipe, expressed in units of kg/cm^2, bar or atmosphere.

Pressure head: the pressure of water which is expressed in depth of water column. The common unit of pressure head is meter. A head of 10m is equivalent to 1 atm.or 1 bar.

Water discharge (flow rate): the amount of water that flows through a certain cross-section of pipe per unit time. The common units of discharge in metric units is m^3/hr or lit/hr.

Wetting diameter: the diameter of the soil surface wetted by a certain sprinkler, which is twice the wetting radius of the sprinkler expressed in meter.

Sprinkler spacing: the regular spacing between the sprinklers along the sprinkler laterals.
Wind velocity: the rate at which wind blows in a given direction expressed in meter per second or kilometer per hour.

Nominal pipe diameter: the diameter of steel pipes up to 10inch, which is expressed as the internal diameter, measured in inches. Wider diameters, as well as the diameter of aluminium,and plastic pipes are expressed as the external diameter, measured in inches in aluminium pipes and in mm in plastic pipes.

2.1.2.2 Detail design procedures

The detail design of a semi-protable hand move sprinkler system that suits small land holdings requires:

- Selection of sprinkler and spacing (type, nozzle size, operating presure, discharge and spacing)
- Determination of design discharge of the system
- Layout of the field and system
- Sizing of pipes
- Determination of pump capacity

I. Selection of Sprinkler and Spacing

The selection of sprinkler nozzle and its spacing on the laterals and between laterals are a function of infiltration rate of the soil, field slope and wind conditions.

a. **Sprinkler application rate for different soils and surface slopes** – The discharge of the sprinkler system would vary with the characterstics of the soil and its surface slope. Normally, the sprinkler application rate shall be less than the infiltration rate of the soil. Table 2.3 may be used as information to decide on water application rates for different soils and surface slopes if no information is available on the soil characterstics of the area.

Table 2-3: 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 1.8m depth	50	38	25	13
Coarse sandy soil over more compacted soils at shallow depth	38	25	19	10
Light sandy loams to 1.8m depth	25	20	15	10
Light sandy loams over more compacted soils at shallow depth	19	13	10	8
Silt loams to 1.8m depth	13	10	8	5
Silt loams over more compacted soils at shallow depth	8	6	4	2.5
Heavy textured clays or clay loams	4	2.5	2	1.5

(Source: FAO, 2001)

b. **Selection of sprinkler nozzle–**. After application rate is decided in (a), the sprinkler nozzle will be selected. There are hundreds of sprinkler designs and variations from several manufacturers. The specifications of the sprinkler nozzle shall include model of sprinkler nozzle, nozzle size, diameter of throw, application rate, discharge of the nozzle and discharge-pressure relationship. Manufacturers provide recommended spacings and pressures. In the absence of manufacturers or suppliers information, table 2.4 may be taken as a guide for selection of the nozzle size.

Table 2-4: Performance of some sprinkler nozzles

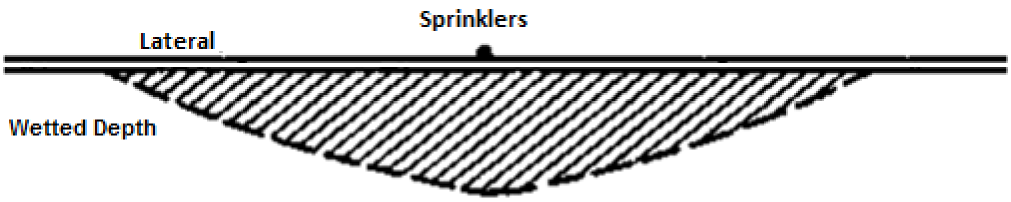
Sprinkler specifications				**Sprinkler precipitation rate (mm/hr)**						
				Sprinkler Spacing (mxm)						
Nozzle size (mm)	**Pressure (m)**	**Discharge (m^3/hr)**	**Wetted Dia. (m)**	**9x12**	**9x15**	**12x12**	**12x15**	**12x18**	**15x15**	**18x18**
3.0	25	0.57	25.00	5.28	4.22	3.96				
3.0	30	0.63	25.60	5.83	4.67	4.38				
3.0	35	0.68	26.20	6.30	5.04	4.72				
3.5	25	0.75	26.85	6.94	5.56	5.21	4.17			
3.5	30	0.82	27.60	7.59	6.07	5.69	4.56			
3.5	35	0.89	28.35	8.24	6.59	6.18	4.94			
4.0	30	1.08	28.60		8.00	7.50	6.00	5.00	4.60	
4.0	35	1.16	30.50		8.59	8.06	6.44	5.37	5.16	
4.5	30	1.32	30.95			9.17	7.33	6.11	5.87	
4.5	35	1.42	32.00			9.86	7.89	6.57	6.31	
4.5	40	1.52	33.05			10.56	8.44	7.04	7.56	
5.0	30	1.70	33.00				9.44	7.87	8.18	5.25
5.0	35	1.84	34.30				10.22	8.52	8.18	5.68
5.0	40	1.96	35.60				10.89	9.07	8.71	6.05

Nozzle size indicates the diameter of the orifice of the nozzle
Pressure is the sprinkler operating pressure at the nozzle
Discharg indicates the flow rate of the sprinkler at given operating pressure
Wetted diameter is the diameter of the circular area wetted by sprinkler when opertaing at a given pressure and no wind
The sprinkler spacing shows the pattern in which the sprinklers are laid onto the irrigated area. For example, a 12mx18m spacing implies that sprinklers are laid at a spacing of 12m along a lateral and 18m between laterals.

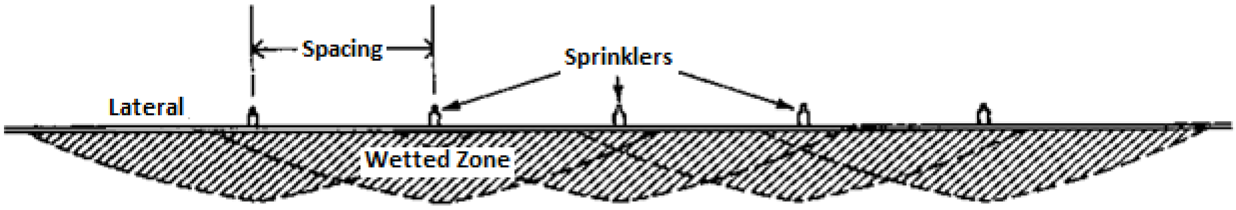
(Source: FAO, 2001)

c. **Spacing of sprinkler –**After preliminary decided the spacing for a suitable nozzle in (b) above, to achieve uniform sprinkling of water, it is necessary to overlap water spread area of sprinklers. The overlap increases with the increase in wind velocity. But, the reader is advised to check manufacturers' technical data to enable sufficient overlapping of the water sprays from nozzles considering sprinklers application rate and wetting diameter to maintain good distribution uniformity.

Table 2.5 and 2.6 may be used as a guide for sprinkler spacing under different wind conditions and pattern. A square pattern is prefered if there is no defined direction of wind, and rectangular pattern, otherwise.



(a) Wetted pattern of a single sprinkler



(b) Wetted pattern of overlapped sprinklers

Figure 2-2: Overlapping effect of sprinklers

Table 2-5: Maximum sprinkler spacing as related to wind velocity, rectangular pattern

Average win speed (km/hr)	Spacing as % of Wetted Diameter (D)
Upto 10	40% between sprinklers 65% between laterals
10-15	40% between sprinklers 60% between laterals
Above 15	30% between sprinklers 50% between laterals

(Source: FAO, 2001)

Table 2-6: Maximum sprinkler spacing as related to wind velocity, square pattern

Average wind speed (km/hr)	Spacing as % of Wetted Diameter (D)
Upto 5	55% between sprinklers
6 -11	50% between sprinklers
13 -19	45% between sprinklers

(Source: FAO, 2001)

Worked example 6: Select sprinkler and lateral spacing for a sprinkler system with the following data:

- Location: Raya
- Soil type: Caly loam (infiltration rate = 15mm/hr)
- Wind speed: 10km/hr and usually to N-S direction
- Slope: nearly flat (Average 2.25%)
- Maximum working hours: 20hrs
- Gross depth of application: 86.4mm

Solution:

As the wind blows N-S direction, a rectangular pattern is preferred.

Since there is no detail information about the locally available size of sprinklers, size of sprinklers and spacing will be chosen from recommendations by FAO.

Since the basic infiltration rate of the soil is 15mm/hr, a sprinkler with application rate less than 15mm/hr can be selected.

The maximum working hours available is 20hrs. The nozzle size that can be chosen to apply irrigation demand of 86.4mm is the one with application rate of 4.32mm/hr(=86.4/20). But it is not economical to irrigate the whole area at once. Since the application rate is far less the infiltration rate of the soil, it allows us to increase it until 15mm/hr.

However, from table 2.4, the rectangular pattern only allows us to apply in two shifts. Thus, to be economical and to effectively use the available working time, a rectangular pattern with nozzle size of 5.0, working pressure of 30m, discharge of 1.70m^3/hr and a wetting pattern of 33m is chosen. It has an application rate of 9.44mm/hr at a spacing of 12x15 is selected.

But the spacing is a function of wind. Thus, based on the wind velocity and wetting diameter, from table 2.5,

The sprinkler spacing, Sp = 0.40xwetted dia. = 0.40x33 = 13.2m, say 12m
The lateral spacing, Sl = 0.60xwetted dia. = 0.60x33 = 19.8m, say 18m

II. Determination of design discharge of the system

The next step is calculation of design discharge of the system. For determination of the design discharge, the number of simultanously operating sprinklers shall be known.

a. **Number of simultaneously operating sprinklers –** The number of sprinklers operating at a time is calculated as:
Application rate of sprinkler nozzles (I, cm/hr):

$$I = \frac{360 \times q_s}{S_p \times S_L} \qquad \text{---- (2.7)}$$

Where,

I = Application rate of sprinkler nozzle, cm/hr
q_s = Sprinkler discharge, lps
S_p = Sprinkler spacing on a lateral, m
S_L = Lateral spacing on submain or main line, m

Key Note:
The application rate of sprinkler shall be less than or equal to the basic infiltration rate of the soil so as to avoid runoff during irrigation application.

The time needed to apply the required depth of irrigation water by the sprinkler system:

$$T = \frac{d}{I} \qquad \text{---- (2.8)}$$

Where,

T = Time of application, hr
d= gross depth of irrigation, cm

Number of sprinkler system shifts per day (n):

$$n_s = \frac{T_P}{T + T_S} \qquad \text{---- (2.9)}$$

Where,

n_s= Number of sprinkler system shifts per day
T_P = Time of pumping, hr
T_s = Time required for shfting, hr (usually 0.5hr)

Area to be irrigated per day, a_1:

$$a_1 = \frac{A}{f} \quad \text{---- (2.10)}$$

Where,

a_1 = Area to be irrigated per day, ha
A = Total area to be irrigated, ha
f = Irrigation frequency, days

Key Note:
Irrigation frequency may be taken as one day less than the irrigation interval to consider off-day. Otherwise, it may be taken as equal to the irrigation interval. Since the system designed for small holders is to irrigate their land in turn, they have sufficient time for cultivation and other activities. Thus, the irrigation cycle can practically be taken as equal to irrigation interval.

Area to be irrigated per shift, a_2:

$$a_2 = \frac{a_1}{n_s} \quad \text{---- (2.11)}$$

Where,

a_2 = Area to be irrigated per shift, ha
n_s = Number of shifts per day

Finally, the number of sprinklers per shift (operating simultanously), which is rounded to next higher integer:

$$N_s = \frac{a_2}{a_s} \quad \text{---- (2.12)}$$

Where,

N_s = Number of sprinklers operating simultaneously
a_2 = Area to be irrigated per shift, ha
a_s = Area covered by each sprinkler

Worked example 7: Compute the number of sprinklers operated simultaneously per shift with the following information:

- Sprinkler spacing x Lateral spacing (S_P x S_L) = 12mx18m
- Sprinkler nozzle discharge, q_s = 1.70m^3/hr
- Gross depth of application, d = 86.4mm
- Command area, A=30ha
- Time of pumping, T_P = 20hrs
- Irrigation interval, f=12 days
- Maximum working=20hrs

Solution:
First calculate the effective application rate of sprinkler, I :

$$I = \frac{360 \times q_s}{S_p \times S_L} = \frac{360 \times 0.472}{12 \times 18} = 0.79 cm/hr \ or \ 7.9 mm/hr$$

Area covered by each sprinker:

$$a_s = S_P \times S_L = 12m \times 18m = 216m^2 \ or \ 0.0216 ha$$

The time needed to apply the required depth of irrigation water by the sprinkler system:

$$T = \frac{d}{I} = \frac{86.4}{7.9} = 10.93 hrs$$

Number of system shifts per day (n) if the time for shifting of lateral pipes is taken as 0.5hrs:

$$n_s = \frac{T_P}{T + T_S} = \frac{20}{10.93 + 0.5} = \frac{20}{11.43} = 1.7 shifts$$

If the number of shifts adjusted to 2shifts, the pumping time required is:

$$T_P = 11.43 \times 2 = 22.86 hrs$$

Now, area to be irrigated per day, a_1:

$$a_1 = \frac{A}{f} = \frac{30 ha}{12 days} = 2.5 ha/day$$

Area to be irrigated per shift, a_2:

$$a_2 = \frac{a_1}{n_s} = \frac{2.5}{2} = 1.25 ha/shift$$

Therefore, the number of sprinklers operating per shift (operating simultanously), which is rounded to next higher integer:

$$N_s = \frac{a_2}{a_s} = \frac{1.25}{0.0216} = 57.87, \; say\; 58 sprinklers$$

b. **Discharge of sprinkler system –** The total discharge, Q (lps) is given by:

$$Q = q_s \times N_s \qquad \text{---- (2.13)}$$

Where,

Q = System discharge per shift, m^3/hr
q_s = Dischrge of a sprinkler, m^3/hr

Worked example 8: Compute the discharge of a sprinkler system if the number of sprinklers operated simultaneously are 58 and each sprinkler has a discharge of 1.70m^3/hr

Solution:

The system discharge is computed as:

$$Q = q_s \times N_s = 1.70 \times 58 = 98.6 m^3/hr$$

Here it is important to note that the system discharge may again be adjusted to meet layout conditions.

III. Layout of the system

The next step is layout of the system to suit to the system discharge. For that, the topographical map at suitable scale will be prepared and the general layout will be decided upon, and the network of the system will be drawn on the map. The field layout of sprinkler system shall be developed according to topographic nature of the area, location of water sources and the scheme of movement of lateral lines per day. The layout refers to the direction of laying of main, submain and lateral lines.

The general rule in layout of the system is main and submain pipes are laid orthagonal to each other and using the shortest route as possible. Main line is typically running across the slope where as the submain lines are laid along the slope. Lateral pipes should be laid across slope (along the general contour line) as far as possible to minimize pressure variation. Otherwise, it is advantageous to run laterals downhill, if possible, because the gain in energy due to elevation change will allow longer laterals. But, if the slope is too steep, pressure regulators or flow control nozzles may be desirable. It is usually not recommendable to run laterals in an uphill direction. In this case, both friction loss and elevation are working to reduce pressure toward the end of the lateral. However, for small slopes, running laterals uphill may be required to reduce the total length of the mainline pipe.

In small landholdings, the layout usually have blocks of command area, which can get water from submains called basic design unit (BDU). The BDU will further be sub-divided into small operation units are called subunits. The size of the subunit will be determined based on the minimum land-holding size or based on the future manageable size arrangement, and the regional irrigation landholding policy. The average landholding size in Ethiopia is 0.5ha, and this can be taken as the subunit in sprinkler system design. Access roads of 1m and 2m are provided between the subunits and BDUs, respectively. A 4m access road is desired to be provided along the submain line. The typical layout of the field and the sprinkler system for small land holding is shown in fig. 2-3.

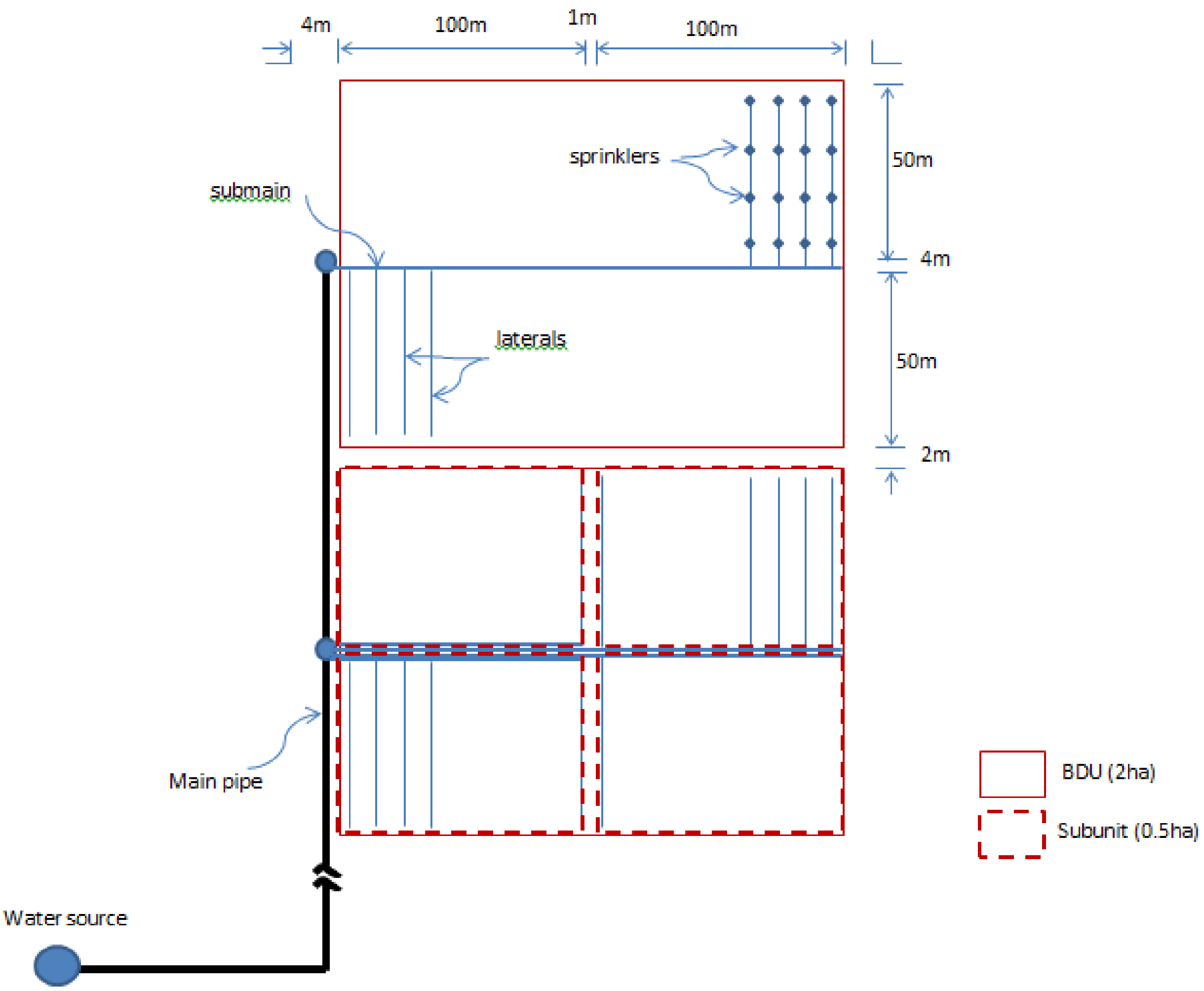


Figure 2-3: Typical sprinkler system layout for smallholdings

Key Note:
The field layout boundaries are laid out to suit to the prevailing soil and topographical condition. Depending on the topographic conditions, the nature of the field layouts can be fragmented, i.e. there could be a variation of laterals length.

IV. Sizing of pipes

Next, the sizes of the pipes in the system are decided in such a way that a satisfactory discharge uniformity between all the sprinklers operating at a time are achieved while minimizing the cost of the system and its operation. This requires first a good understanding of the pipe hydraulics, which is briefly discussed below. Then, the sizes of laterals, submains and main pipes are decided based on recommended design guides.

a. Pipe hydraulics in pressurized irrigation system

When water is flowing in pipes, it loses energy from friction of water with pipe walls and other components of the irrigation system such as fittings. These frictional losses are classfied into two categories. The frictional losses which occur due to the friction of the water with the pipe walls is called as pipe friction or longitudinal friction loss, whereas losses which occur due to the turbulence of flow by other components of the system is referred as local losses. The local losses are minor losses but should be taken into account in design.
The frictional head losses in pipes are commonly found by Hazen-William's equation or Darcy-Weisbach equation.

i) Hazen-William's Equation:

$$J = \frac{h_f}{L/100} = K\left(\frac{Q}{C}\right)^{1.852} D^{-4.87}$$ ---- (2.14)

ii) Darcy-Weisbach Equation:

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75}$$ (for small pipe, D<125mm) ---- (2.15a)

$$J = \frac{h_f}{L/100} = K_2 Q^{1.83} D^{-4.83}$$ (for large pipe, D≥125mm) ---- (2.15b)

Where,

J = The head loss gradient, m per 100m length of pipe
L = Length of pipe, m
Q = Flow rate in the pipe, m^3/hr
D = Internal diameter of pipe, mm
K = Conversion constant = $1.131x10^{11}$
C = Friction coeffiecient, which is a function of pipe material characterstics
K_1 = Conversion constant = $8.38x10^6$
K_2 = Conversion constant = $9.19x10^6$

Table 2-7: Typical values of C for use in the Hazen-Williams equation

Pipe material	C
Plastic pipes	150
Galvanized steel pipes	135
Aluminum pipes	130
Steel pipes (new)	130

The Hazen-Williams equation was originally developed for pipes larger than 75mm in diameter. The user can employ this equation for such size of pipes but Darcy-Weisbach equation estimates better the head loss for all size of pipes. The user is advised to use equation 2.15a for plastic pipes less than 125mm in diameter and equation 2.15b for larger plastic pipes where the diameter is wider than 125mm. In this guide, the Darcy-Weisbach equation is used.

Use of the above head loss equations might be tedious work unless a computer is used. Alternatively, the reader may use slide rules, nomographs or head loss charts which are presented in Appendices VII, VIII and IX, respectively.

Now, the reader needs to understand that flow of water through a closed /blind pipeline of a given diameter and length like the case in water supply system causes more friction loss than does flow through a pipeline with a number of equally spaced outlets which is the case inpressurized irrigation system. The reason for this reduction in friction loss is that the volume of flow decreases each time an outlet is passed.
Therefore, for computing head losses in multioutlet pipes, the friction head loss is done in two steps as follows.

- First, the head loss is calculated by assuming that the pipe is plain (without considering the outlets) using either equation 2.14 or equation 2.15.
- Then, it is multiplied by a factor called Christansen correction factor, F whose value can be read from table 2.8 for given number of outlets or can be calculated using equation 2.17.

Or simply, the head loss h_f in a pipe with uniform spaced outlets is given by:

$$h_f = JF\frac{L}{100}$$ ---- (2.16)

Key Note: *For the number of outlets greater than 30, F value of 0.36 may practically be adopted*

Table 2-8: Correction factor, F for friction losses in pipes with multiple outlets

Number of outlets	Plastic Laterals			Aluminum Laterals		
	F_1	F_2	F_3	F_1	F_2	F_3
2				0.639		0.520
3				0.535		0.440
4				0.486		0.410
5	0.469	0.337	0.410	0.457	0.321	0.396
10	0.415	0.350	0.384	0.402	0.336	0.371
12	0.406	0.352	0.381	0.393	0.338	0.367
15	0.398	0.355	0.377	0.385	0.341	0.363
20	0.389	0.357	0.373	0.376	0.343	0.360
25	0.384	0.358	0.371	0.371	0.345	0.358
30	0.381	0.359	0.370	0.368	0.346	0.357
40	0.376	0.360	0.368	0.363	0.347	0.355

Number of outlets	Plastic Laterals			Aluminum Laterals		
	F_1	F_2	F_3	F_1	F_2	F_3
50	0.374	0.361	0.367	0.361	0.348	0.354
100	0.369	0.362	0.366	0.356	0.349	0.352

F1 to be used when the distance from the lateral inlet to the first outlet is the regular outlet spacing S meters
F2 to be used when the first outlet is just by the lateral inlet
F3 to be used when the distance from the lateral inlet to the first outlet is S/2 meters

(Source: Keller and Blisener, 1990)

Alternative to Table 2.8, the first sprinkler is being located at a distance equal to the sprinkler spacing from the lateral inlet, the Christansen correction factor, F based on the number of outlets in the pipe, N can also be calculated from:

$$F = \frac{1}{b+1} + \frac{1}{2N} + \frac{(b-1)^{0.5}}{6N^2}$$

---- (2.17a)

Where,
F = Chritansen correction factor
b = Flow exponent of the flow equation, for example b=1.852 in Hazen-William's equation
N = Number of outlets in a pipe

If the first sprinkler is located at a distance of less than or equal to the sprinkler spacing, Se from the lateral inlet, the Christansen correction factor, F based on the number of outlets in the pipe, N can also be calculated from:

$$F(\alpha) = \frac{NF - (1-\alpha)}{N - (1-\alpha)}$$

---- (2.17b)

Where, $0 \le \alpha \le 1$

Many sprinkler systems have the first sprinkler at a distance of ½Se from the lateral inlet (α = 0.5), when laterals run in both orthogonal directions from the mainline. Under such condition, the Christansen correction factor, F based on the number of outlets in the pipe, N can be derived as:

$$F = \frac{2N}{2N-1}\left(\frac{1}{b+1} + \frac{(b-1)^{0.5}}{6N^2}\right)$$

---- (2.17c

Worked example 9: Compute the friction head loss in a sprinkler Aluminum lateral diameter of 2inch (50.8mm) and length of 42m using Hazen Williams equation (C=150). Sprinklers with discharge of 1.70m^3/hr are spaced at 12m and the first sprinkler is at half the regular spacing of sprinklers.

Solution:

The inlet discharge of the lateral is calculated by multiplying the number of sprinklers with the discharge of each sprinkler, q_s. The number of sprinklers is a function of the length of lateral L and spacing between sprinklers, S_P.

First, the number of sprinklers is:

$$L = (N-1)S_P + \frac{S_P}{2} \rightarrow N = \frac{\left(L - \frac{S_P}{2}\right)}{S_P} + 1 = \frac{\left(42 - \frac{12}{2}\right)}{12} + 1 = 4\ sprinklers$$

Now the inlet discharge of the lateral is:

$$Q = N \times q = 4 \times 1.70 = 6.8 m^3 / hr$$

To find the head loss, the hydraulic gradient J for 100m length pipe is determined using eqn. 2.14:

$$J = \frac{h_f}{L/100} = K\left(\frac{Q}{C}\right)^{1.852} D^{-4.87} = 1.131 \times 10^{11} \times \left(\frac{6.8}{150}\right)^{1.852} \times 50.8^{-4.87} = 1.81 m\ per\ 100 m$$

Then, for N=4 from table 2.8, F = 0.369. Thus, for L=50m lateral, the friction head loss hf using eqn. 2.16 is:

$$h_f = JF\frac{L}{100} = 1.81 \times 0.410 \times \frac{42}{100} = 0.31m$$

In addition to the frictional head losses in a pipe, there are local head losses due to a local disturbance in water flow. This disturbance in water flow happens anywhere equipment is attached to the system, such as a valve, filter, and pressure regulator and also in elbow and connection junctions. The local head loss is proportional to the velocity of flow and is calculated as follows:

$$h_l = K\frac{V^2}{2g} \quad \text{---- (2.18)}$$

Where,

h_l = Local head loss, m

K = a constant provided by the manufacturer

V = Velocity of water flow, m/s

g = Accleration due to gravity, m/s^2

Worked example 10: A 6 inch valve (K=2.5) is installed in 1000m long pipe (12 inch, C=130). What is the total head loss due to the valve and the pipe when the water flow rate is 10 m^3/hr.

Solution:

The cross-sectional area of the pipe is determined from its diameter, d (=12 x 0.0254m):

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (12 \times 0.0254)^2}{4} = 0.07 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{100}{0.07} = 1428.57 m/hr\ or\ 0.39 m/\sec$$

The local head loss using eqn.2.18 is computed as:

$$h_l = K\frac{V^2}{2g} = 2.5 \times \frac{0.39^2}{2 \times 9.81} = 0.02m$$

For friction loss in a pipe, first compute J for Q=100m^3/hr and D=12inch (304.8mm)

$$J = \frac{h_f}{L/100} = K\left(\frac{Q}{C}\right)^{1.852} D^{-4.87} = 1.131\times10^{11}\times\left(\frac{100}{130}\right)^{1.852}\times304.8^{-4.87} = 0.06m\ per\ 100m$$

For L=1000m pipe, the friction head loss h_f is:

$$h_f = J\frac{L}{100} = 0.06\times\frac{1000}{100} = 0.6m$$

The total head loss = $h_f + h_l$ =0.60+0.02=0.62m

K is a constant and its value depends on the way the equipment is made of. The reader need to see this value from the manufacturer's catalogue. In the absence of any information, the values indicated in Appendix VI for some common types of equipment may be used. Sometimes, the manufacturers may give fittings in equivalent length of pipes and the head loss for the length is calculated by the appropriate friction head loss equation. However, from experience, the local losses due to fittings of pipes are usually taken as 2 percent of the operating pressure head of the sprinkler.

b. Selection of size of pipelines

As next step of design, the sizes of the pipes in the system are decided in such a way that a satisfactory discharge uniformity between all the sprinklers operating at a time are achieved. The sizes of main line, submain lines and lateral lines are selected as per the discharges carried through them and the friction head loss corresponding to these discharges.

$$q_l = q_s \times N_s \qquad \text{---- (2.19)}$$

$$q_{sm} = q_l \times N_{sm} \qquad \text{---- (2.20)}$$

$$Q = q_{sm} \times N_{sm} \qquad \text{---- (2.21)}$$

Where,

- Q = Discharge through main line or system discharge, lps
- q_{sm}= Discharge through submain line, lps
- q_l = Discharge through lateral line, lps
- q_s = Sprinkler discharge, lps
- N_s = Number of sprinklers in a lateral line
- N_L = Number of laterals in a submain line
- N_{sm} = Number of submains on the main line

Lateral sizing:

The general guideline for sizing of lateral pipes is to keep the friction loss in lateral lines within 20% of the sprinkler operating pressure head or to keep discharge variation between sprinklers in the system within 10% of the nominal sprinkler discharge while at the same time keep the velocity of flow in the pipe lines between 1.5 – 2.5 m/sec to prevent pipe failure due to water hammer. The friction head loss are calculated with the help of equation 2.14 or 2.15 for the given discharge, available market size, length of pipe line and number of sprinklers used on the line. A sutiable F factor should be used to compute head loss for laterals.

The step-by-step procedure for selection of lateral line size is given below.

Step 1. Select a given commercially available size of pipe (for HDPE pipe see Appendix IV).

Step 2. Assume the flow in the pipe through the entire length without sprinklers and determine the friction head loss.
Step 3. Multiply the friction head loss as in step 2 above by the correction factor obtained corresponding to the number of sprinklers on the lateral line.

Step 4. To step 3 above, add the elevation difference if the lateral goes uphill or subtract if it goes downhill.

Step 5. Check whether the head loss computed in step 4 is within the allowable limit of 20% of the operating head of sprinklers. If it is within the limit, the size of the pipe diameter selected in step 1 above is acceptable. Otherwise, another value for the diameter of the pipe is selected and the steps 1 through 5 are repeated. When the value of head loss as obtained in step 4 is far less than the allowable value, then the next smaller size of pipe, from among the commercially available sizes, is considered. Otherwise, the next larger size is adopted and repeat the procedure until the condition is satisfied.

Then, the required pressure head at inlet of lateral is calculated by:

$$H_L = H_o + 0.75h_{fL} + H_r \pm 0.5H_{zL} \quad \text{---- (2.22)}$$

Where,

- H_L = Required pressure head at inlet of lateral, m
- H_o = Operating pressure head of sprinkler, m
- h_{fL} = Frictional head loss in the lateral line, m
- H_r = Height of rizer pipe, m
- H_{zL}= Elevation head of the ground (+ve for upslope and –ve for downslope), m

Key Note: *Laterals can be designed with multiple diameters to accomdate desirable pressure distribution but in practice hand move systems have only one size lateral pipe to simplify handling during set changes. Thus, in this guideline design with different sizes of laterals is avoided.*

Worked Example11: In a sprinkler system, laterals are laid on a level ground and are connected to submain which is installed 0.6m below the ground. They are connected to the submain through riser pipes at a spacing of 18m. Each lateral has a discharge of 6.8m^3/hr and a length of 42m. Each lateral has sprinklers connected at spacing of 12m (the first sprinkler being connected at half the regular spacing). The operating pressure head of sprinklers is 30m and is mounted on 1m riser pipe. What is the suitable size of lateral?

Solution:
As per the design criteria, the discharge variation of sprinklers on a lateral shall be kept within 10% (or, pressure variation of 20%). Thus, the maximum allowable head loss is 20% of the operating pressure head of sprinkler.

0.20*30m= 6m

Now, the number of sprinklers on the lateral is:

For N=4, the correction factor F from table 2.8 is 0.410.

If HDPE lateral is used, select commercially available size, say class 6 HDPE size of 32mm(ID= 27.9mm) and compute hf.

Using Darcy-Weisbach equation for small plastic pipes for Q=6.8m^3/hr,

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (6.8)^{1.75} \times 27.9^{-4.75} = 32.62m \ per \ 100m$$

Then, the head loss h_f for L=42m and F=0.410 is:

$$h_f = JF\frac{L}{100} = 32.62 \times 0.410 \times \frac{42}{100} = 5.62m$$

The head loss is less than the allowable pressure head. Thus, the selected diameter is accepted.

Now, the Now, the inlet pressure head of the lateral is:

$$H_L = H_o + 0.75h_{fL} \pm 0.5H_{zL} + Hr = 30 + 0.75 \times 5.62m + 0 + 1 = 35.22m$$

Main and submain sizing:

The main and submain pipes are sized based on the flow velocity rather than the friction loss. The velocity should be between 1.5 – 2.5 m/sec to prevent pipe failure due to water hammer. Main and submains may take different sizes of pipes (tellescopic).

Therefore, the diameter of each segment of main and submain line can be fixed from the relation:

$$q_{sm} = V\frac{\pi D^2}{4} \quad \rightarrow V = \frac{4q_{sm}}{\pi D^2} \qquad \text{---- (2.23)}$$

Where,

- q_{sm} = discharge of submain/main line, m^3/s
- V = Allowable velocity of flow, m/s
- D = Diameter of submain/main line, m

The step-by-step procedure for selection of main or submain size is given below.

Step 1. Select a given commercially available size for a given length of pipe (for PVC pipe class 6 see Appendix IV).

Step 2. From discharge capacity of the pipe calculate the velocity using eqn. 2.23.

Step 3. Check whether the velocity is within the allowable limit. If it is within the limit, the size of the pipe diameter selected in step 1 above is acceptable. Otherwise, another value for the diameter of the pipe is selected and the steps 1 through 5 are repeated. When the velocity as obtained in step 3 is far less than the allowable value, then the next smaller size of pipe, from among the commercially available sizes, is considered. Otherewise, the next larger size is adopted and repeat the procedure until the condition is satisfied.

Step 4. Calculate the frictional head loss using equation 2.14 or 2.15.

Step 5. If the frictional head loss is judged to be too high, the size selected in step 3 will be changed to the next larger size.

Step 6. Compute the velocity for the new size of pipe. If the velocityis found too low from the allowable lowest range, reject the size. Otherwise, accept and calculate the new friction head loss.

Then, the inlet pressure of the submain is computed as:

$$H_{sm} = H_l + \sum h_{fsm} \pm H_{zsm} + H_{rsm} \quad \text{---- (2.24)}$$

Where,

H_s =	inlet pressure of the submain, m
H_l =	inlet pressure of the lateral, m
$\sum h_{fsm}$ =	total of the friction head loss in each segment of the submain pipe, m
H_{zsm} =	elevation difference between the two ends of the submain (+ for upslope and – for downslope.
H_{rsm} =	Height of riser pipe which connects submain with lateral, m

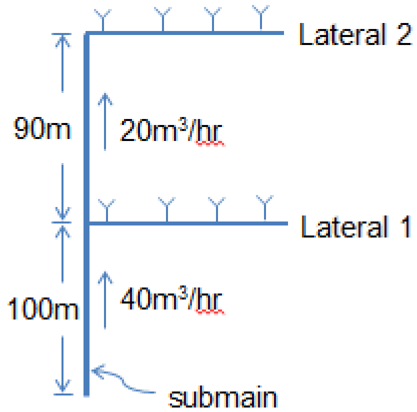
Similarily, the required pressure head at inlet of main is calculated by:

$$H_m = H_{sm} + \sum h_{fm} \pm H_{zm} \quad \text{---- (2.25)}$$

Where,

H_m =	inlet pressure of the main line, m
H_{sm} =	inlet pressure of the submain, m
$\sum h_{fm}$ =	total of the friction head loss in each segment of the main pipe, m
H_{zm} =	elevation difference between the two ends of the main (+ for upslope and – for downslope.

Worked example12: Two laterals are connected to a submain through riser pipes at 90m spacing. The length and inlet discharge of each lateral are 42m and 6.8m^3/hr, respectively. The submain is buried at 0.60m below the ground and connected with the manifold by a riser pipe. What is the suitable size of the submain if the two laterals are operating simultaneously? What is the pressure head required at the inlet of the submain if the inlet pressure head of the lateral is 35.22m?



Solution:

The size of the submain can be computed using the velocity method. As per the criteria, the velocity of flow in the pipe should be b/n 1.5 to 2.5m/s. Thus, starting from the end of the pipe, for the 90m length, the discharge of the pipe is 6.8m^3/hr.

If class 6 PVC pipe of 40mm (ID=34.8mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.0348)^2}{4} = 0.00095\, m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(6.8/3600)}{0.00095} = 1.99 m/\sec$$

Since the velocity is within the desired limit, the size may be taken as suitable for this segment of the pipe.

The next segment of the submain carries the discharge required by both the laterals. Thus, its discharge is 13.6m^3/hr. The length of this part of the submain is 100m.
Now, select class 6 PVC pipe of 50mm (ID=43.6mm). The cross-sectional area of the pipe for this size is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.0436)^2}{4} = 0.0015 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(13.6/3600)}{0.0015} = 2.53 m/\sec$$

Now, the velocity is just greater than the allowable range. Thus, to be on the safest size, better to increase the size.

The next larger commercially available size is 63mm (ID =55mm).

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.055)^2}{4} = 0.0024 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(13.6/3600)}{0.0024} = 1.59 m/\sec$$

Now, the velocity is within the allowable range. Thus, this size is suitable.

To find the inlet pressure of the submain, the head losses in the two segments of the submain have to be worked out. Thus, using Darcy-Weisbach equation for small plastic pipes,
For 90m segment, Q = 6.8m^3/hr and D=34.8mm

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (6.8)^{1.75} \times 34.8^{-4.75} = 11.42 m \; per \, 100 m$$

For L=90m,

$$h_f = J \frac{L}{100} = 11.42 \times \frac{90}{100} = 10.28 m$$

But the head loss is too high and the inlet pressure of the two laterals will be very different other wise. Therefore, increase the size of this segment to 50mm (ID=43.6) and the velocity becomes 1.3m/sec which is not far from the lowest range (=1.5m/sec). With this size the head loss becomes only 3.52m

Similarly, for 100m segment, Q = 13.6m^3/hr and D=55mm

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (13.6)^{1.75} \times 55^{-4.75} = 4.37 m \; per \, 100 m$$

For L= 100m,

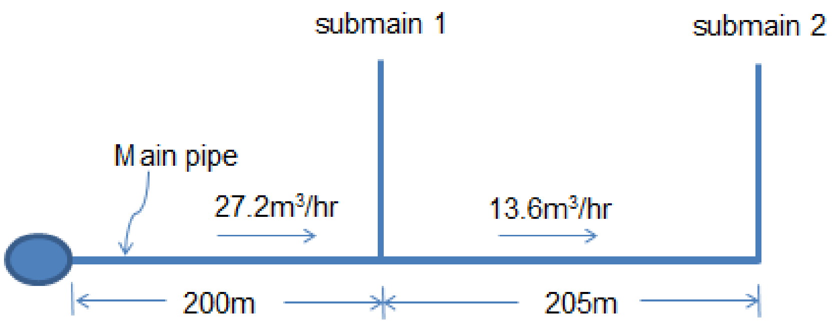
$$h_f = J \frac{L}{100} = 4.37 \times \frac{100}{100} = 4.37 m$$

Thus, the total friction head loss in the submain is 3.52+4.37 = 7.89m

Since the submain is buried at 0.60m below the ground, 0.60m head is required at each connection point of the submain to the manifold. Thus, the inlet pressure head of the submain assuming that it is laid on level ground is:

$$H_{sm} = H_l + \sum h_{fsm} \pm H_{zsm} + H_{rsm} = 35.22 + 7.89 + 0.60m = 43.71m$$

Worked example13: Two submains, each of them carrying a discharge of 13.6m^3/hr and inlet pressure of 43.71m, are connected to a main line at 205m apart. The water source from the inlet point of the first submain is 200m. What are the suitable size and inlet pressure head of the main line if the two submains work simultaneously?



Solution:

The size of the main can be computed using velocity method. As per the criteria, the velocity of flow in the pipe should be between 1.5 to 2.5m/s.

Thus, starting from the end of the pipe, for the 205m length, the discharge of the pipe is 13.6m^3/hr.

If class 6 PVC pipe of 63mm (ID=59mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.059)^2}{4} = 0.0027 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(13.6/3600)}{0.0027} = 1.38 m/\sec$$

The velocity is a few less than the allowable range. Thus, size may be taken instead of taking the next lower size. Otherwise, the head loss will be too large.

For the next 200m length, the discharge of the pipe is 27.2m^3/hr.

If class 6 PVC pipe of 75mm (ID=70.4mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.0704)^2}{4} = 0.0039 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(27.2/3600)}{0.0039} = 1.94 m/\sec$$

This velocity is within the allowable range. Thus, the size is suitable.

Now, the inlet pressure of the main line, the head losses in the two segments of the submain have to be worked out. Thus, using Darcy-Weisbach equation for small plastic pipes, For the first 205m segment, Q = 13.6m^3/hr and D=59mm

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (13.6)^{1.75} \times 59^{-4.75} = 3.13m \; per \, 100m$$

For L=205m,

$$h_f = J\frac{L}{100} = 3.13 \times \frac{205}{100} = 6.41m$$

For the next 200m segment, Q = 27.2m^3/hr and D=70.4mm,

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (27.2)^{1.83} \times 70.4^{-4.83} = 4.55m \; per \, 100m$$

For L=200m,

$$h_f = J\frac{L}{100} = 4.55 \times \frac{200}{100} = 9.09m$$

Thus, the total friction head loss in the main is 9.09+6.41 = 15.5m

Thus, the inlet pressure head of the main assuming that it is laid on level ground is:

$$H_m = H_{sm} + \sum h_{fm} \pm H_{zm} = 43.71 + 15.5 + 0 = 59.21m$$

V. Determination of pump capacity

The size of pumping unit to be selected depends on the total discharge carried through the system and total pressure head. The total pressure head or dynamic head required for the normal operation of the system is the sum of the following pressures:

$$H = H_o + H_f + H_S + H_c + H_r \pm H_z \qquad \text{---- (2.26a)}$$

If inlet pressure head required for main pipe is already computed as shown in the previous steps,

$$H = H_m + H_S + h_f + H_c \qquad \text{---- (2.26b)}$$

Where,

- H = Total pressure head, m
- H_o = Operating pressure head of sprinkler, m
- H_f = The sum of friction head losses in the lateral line, submains, main line and through fittings such as bends, joints, etc., m
- H_s = Total static head (the head difference between the water level at the source and the pump center line including the friction loss of the suction pipe), m
- H_c = Local losses in control unit, m
- h_f= Local losses in fittings, m
- H_r = Height of riser pipe, m
- H_z = Head changes due to elevation of land (+ for downslope, - for upslope), m

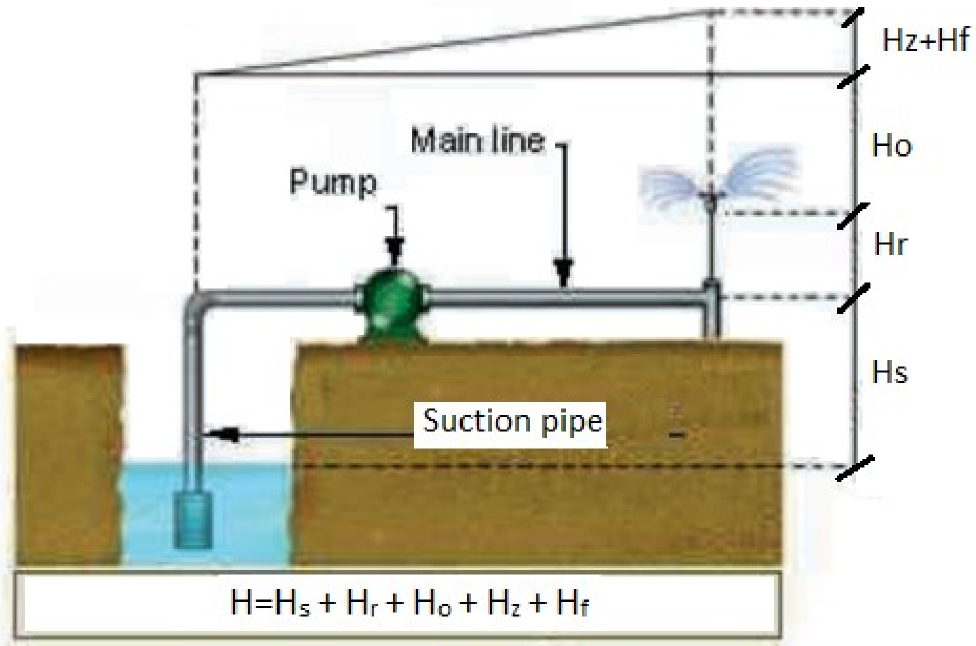


Figure 2-4: Pump size determination

Key Note: *In the absence of any information, the friction head losses in fittings is considered in the order of 2% of the operating head of sprinkler. In addition, the local losses at control unit may be separately considered from 5 to 10m.*

The required capacity of the pump is then calculated as:

$$WHP = \frac{Q \times H}{75} \quad \text{---- (2.27)}$$

$$HP = \frac{WHP}{E_P \times E_m} \quad \text{---- (2.28)}$$

Where,

HP= the required pump capacity, hp
Q = Discharge required for the system
WHP= Water horse power, m
E_p = efficiency of the pump (0.5-0.8)
E_m = efficiency of the motor driving the pump (0.7-0.9)

The reader is advised to read detail about pumps and pump selection in GL 13: Irrigation Pump Facilities Study and Design Guideline.

Worked example 14: Determine the pump capacity for sprinkler system with the following information.

- The water source: Ground water deep well
- Discharge: 27.2m^3/hr or 7.56 lit/sec
- Total Static Head: 20m
- Inlet pressure of main pipe: 59.21m
- Control pressure head losses: 5m
- Take 2% of the operating pressure head of sprinkler for local losses in fittings

Solution:

From the given data, the pumping head is calculated as:

$$H = 59.21 + 20 + 5 + 0.02 \times 30 = 84.81m$$

Now, the pump capacity from eqn. 2.13:

$$HP = \frac{Q \times H}{75 \times E_P \times E_m} = \frac{7.56 \times 84.81}{75 \times 0.70 \times 0.70} = 17.45hp, \; say\; 18hp$$

A complete design example 1 (for cluster of smallholding farmers):

Design a sprinkler irrigation system for small farmers in Raya valley. The average land holding size of each farmer is 0.5ha (subunit). The system is to irrigate vegetable crops. The topographic map of the area (scale 1:2500 and contour interval of 0.5m) is shown below. The basic data collected from the field are the following.

- Location: Raya valley, Tigray Regional State
- Water source : Ground Water (deep Well) labelled as WF0/BH5
  : Safe Yield of the Well: 108m^3/hr (or, 30 lit/s)
- Water quality : good for irrigation (free of salinity)
- Irrigable area: 30ha
- Soil : dominantly deep clay and moderately drained
  : Basic infiltration rate of the soil: 15mm/hr
  : Total Available Water = 150mm/m
- Slope: nearly flat (Average 2.25%)
- Crop : vegetables (small vegetables and tomato)
  : Average depth of root zone = 0.85m
  : Maximum consumptive use = 5.4mm/day
  : Maximum allowable depletion = 0.50
- Climate : Moderate (wind speed = 10km/hr)
- Maximum working hours per day: 17hrs

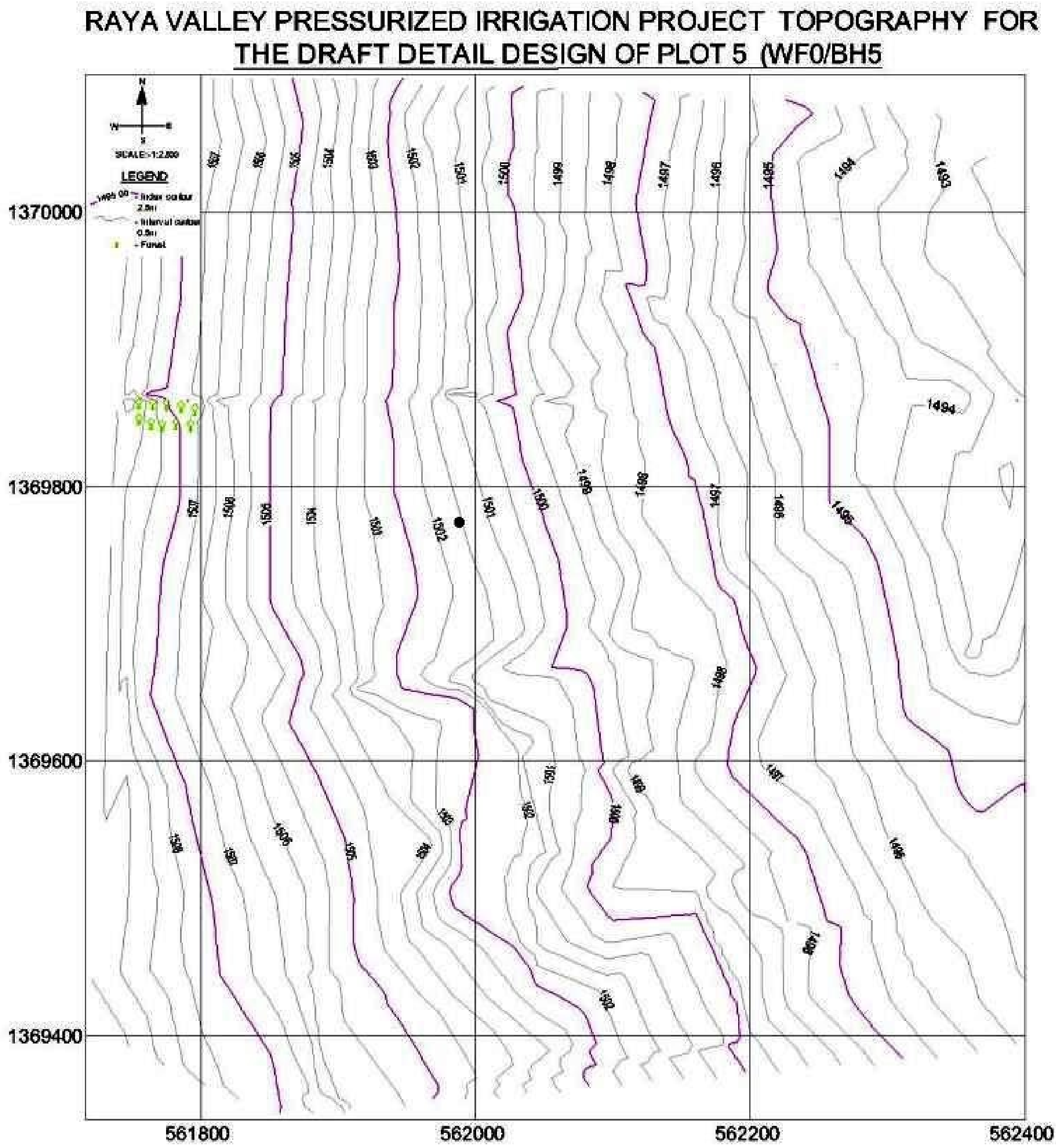


Figure 2-5: Topographic map of the area (scale: 1:2500)

Solution:

I. Determination of basic design parameters

The first step for design is determination of the basic design Parameters based on the given information.

a) ***Net depth of irrigation:*** The net depth of irrigation is computed based on eqn. 2.1:

$$d_n = MAD\left(\frac{FC - PWP}{100}\right) \times \rho_b \times drz$$

Since TAW is: $TAW = \left(\frac{FC - PWP}{100}\right) \times \rho_b$, the dn can be expressed as:

$$d_n = MAD \times TAW \times drz = 0.50 \times 150 \times 0.85m = 63.75mm,\ say\ 64mm$$

b) ***Gross depth of irrigation:*** Since the climate is moderate, the application efficiency may be taken as 75%. Further, as the water quality is good for irrigation, leaching is not required. Thus, the gross depth of irrigation is:

$$d = \frac{d_n}{E_a} = \frac{64}{.75} = 85.3mm$$

c) ***Irrigation interval :*** The irrigation interval, F for dn=64mm and CU_P=5.4mm/day is

$$F = \frac{d_n}{CU_P} = \frac{64}{5.4} = 11.85 days,\ say\ 12 days$$

So, the net depth of irrigation need to be adjusted accordingly:

$$d_n = F \times CU_P = 12 \times 5.4 = 64.8mm$$

Similarily, the gross depth shall be adjusted to:

$$d = \frac{d_n}{Ea} = \frac{64.8}{0.75} = 86.4mm$$

d) ***Irrigation cycle:*** it may be taken as equal to the irrigation interval. Thus, the area to be irrigated per day is:

$$f = \frac{A}{a} \rightarrow a = \frac{A}{f} = \frac{30}{12} = 2.5ha$$

This implies that 5 subunits can be irrigated simultaneously per day.

e) **Preliminary system capacity:**

The maximum working hours per day is the total time taken for irrigation application which may be given as:

Td = Number of shifts per day x the time of irrigation per shift

Therefore, the system capacity is:

$$Qs = \frac{A \times d}{f \times N_S \times T} = \frac{A \times d}{f \times Ta} = \frac{(30 \times 10000) \times (86.4/1000)}{12 \times 17} = 135 m^3/hr$$

Since the available safe yield of the system is 108m^3/hr, farmers should extend their working time per day. Thus, Ta will be adjusted to:

$$Ta = \frac{A \times d}{f \times Qs} = \frac{(30 \times 10000) \times (86.4/1000)}{12 \times 108} = 20hrs$$

Note: Since each farmer is irrigating every 12 days, it won't be difficult to extend to this time. Otherwise, the command area shall be reduced to 24ha.

f) Sprinkler nozzle selection and spacing:

As there is no information about the locally available size of sprinklers, spacing will be chosen from recommendations by FAO.

Since the basic infiltration rate of the soil is 15mm/hr, a sprinkler with application rate less than 15mm/hr can be selected.

The maximum working hours available is 20hrs. The nozzle size that can be chosen to apply 86.4mm is the one with application rate of 4.32mm/hr(=86.4/20). But it is not economical to irrigate the area to be irrigated per day at once. i.e large number of laterals will be required to cover the area. If we increase the application rate, the time of application will be reduced. It is possible to increase it until 15mm/hr. This gives a room the system to be shifted more than one time.

From table 2.4, for any kind of pattern and nozzle, the application ratesare10.89mm/hr or less. This gives time of application of 7.9hr(=86.4mm/10.89mm/hr). With this the maximum number of shifts of the system we can have is only two (20hr/7.9hr=2.5shifts) in 20hrs time. Thus, to be economical in energy use and to use the working time, a rectangular pattern 12x15 with nozzle size of 5.0 and working pressure of 30m is chosen. This nozzle has a discharge of 1.70m^3/hr, a wetting diameter of 33m and an application rate of 9.44mm/hr.

The selected spacing is if the area is calm (or no wind). Otherwise, the spacing is a function of wind. Thus, based on the wind velocity and wetting diameter, from table 2.5,
The sprinkler spacing, S_P = 0.40xwetted dia. = 0.40x33 = 13.2m, say 12m
The lateral spacing, S_L = 0.60xwetted dia. = 0.60x33 = 19.8m, say 18m

Since lateral pipes are manufactured in a length of 3, 6 and 12m, spacing is better be selected in a fraction of 3m. That is the reason to choose the nearest spacings 12m and 18m.

***g)* Number of simultaneously operating sprinklers:**

First calculate the effective application rate of sprinkler, I :

$$I = \frac{360 \times q_s}{S_p \times S_L} = \frac{360 \times 0.472}{12 \times 18} = 0.79cm/hr\ 7.9mm/hr$$

Area covered by each sprinker:

$$a_s = S_P \times S_L = 12m \times 18m = 216m^2 \ or\ 0.0216ha$$

The time needed to apply the required depth of irrigation by the sprinkler system:

$$T = \frac{d}{I} = \frac{86.4}{7.9} = 10.94hrs$$

Now, the number of system shifts per day (n) if the time for shift is taken as 0.5hrs:

$$n_s = \frac{T_P}{T + T_S} = \frac{20}{10.93 + 0.5} = \frac{20}{11.43} = 1.7 shifts$$

If the number of shifts adjusted to 2shifts, the pumping time required is:

$$T_P = 10.94 \times 2 = 21.88 hrs$$

Now, area to be irrigated per day, a_1:

$$a_1 = \frac{A}{f} = \frac{30ha}{12days} = 2.5 ha/day$$

Area to be irrigated per shift, a_2:

$$a_2 = \frac{a_1}{n_s} = \frac{2.5}{2} = 1.25 ha/shift$$

Therefore, the number of sprinklers irrigating per shift(operating simultanously), which is rounded to next higher integer is:

$$N_s = \frac{a_2}{a_s} = \frac{1.25}{0.0216} = 57.87, \ say\ 58 sprinklers$$

h) ***System discharge:*** Now, the design system discharge based on the number of sprinklers operating at a time is computed as:

$$Q = q_s \times N_s = 1.70 \times 58 = 98.6 m^3/hr$$

II. System layout and sizing of pipes

The next step is layingout of the field and the distribution system to suit to the irrigation operation, and then determine the suitable size of the pipe lines.

a) *Layout of the field and the pipe lines:* The first step for design is to layout the arrangement of the field and the pipe lines on the map depending upon the topography and the location of water source with the consideration of non-irrigable features such as villages and other existing facilities. Thus, the layout on the map with consideration of the following is laid out as shown in Fig. 2-6:

- The smallest irrigation unit of the system which is the manageable size of pressurized irrigation system by each farmer is fixed to 0.5ha. A 100m x 50m is adopted to fit the size.
- The BDU is taken as 2ha. So, with a subunit of 0.5ha, four operations selected for the system application. i.e Four farmers are clustered in a BDU but they can manage their own plots.
- Since the number of subunits irrigated per day is 5 (= 2.5ha/0.50ha), to suit the irrigation supply, the area is divided into 5blocks which are supplied by 5 submains each supplying to 3BDUs (3x4=12 subunits or 6ha). Thus, each submain will be irrigating 1 subunit per day and in 12days all the 3 BDUS will be irrigated.
- The directions of the laterals are laid along the contour and the directions of the submains are orthogonal to the laterals and are laid downslope to minimize pressure variation. The submains are connected orthogonal to the mainline.
- The layout is based on the assumption that the irrigable area will be reallocated to farmers as per the manageable size and the beneficiaries will be organized at Tabia level accordingly.

b) **Sizing of pipe lines**:

- Each lateral discharge = Number of sprinklers per lateral xsprinkler discharge

But the number of sprinklers = Maximum length of lateral/sprinkler spacing = width of subunit/Sp
= 50m/12m = 4.16, say 4 sprinklers
Therefore, lateral discharge = 4*1.70 =**6.8m^3/hr**
Thus, Length of lateral (with the first sprinkler at half the regular spacing) = (N-1)Sp+Sp/2
= (4-1)x12+12/2
= 42m

Note: Including half the sprinkler spacing to be wetted at the end of the field, the width of the subunit covered by the system is 48m (=42+6m) or simply 4sprinklers*12m=48m.

- Each submain discharge = Number of laterals working per shift per submain*lateral discharge

But,
Number of laterals per shift per submain = Area covered per shift per submain/Area covered per lat.

But,
Area covered per shift per submain= Area covered per shift/Number of submain = 1.25ha/5= 0.25ha
Area covered per lateral = Number of sprinklers per lateral x Area covered by each sprinkler
= 4 x (12mx18m)
= 864m^2 or 0.0864ha
Number of laterals per shift per submain = Area covered per shift per submain/Area covered per lat.
= 0.25ha/0.0864ha
= 2.89 laterals, say **3 laterals**
If 2 laterals per shift are chosen, it will be covering only 0.17ha (= 2*0.0864) per shift. Thus, 3 laterals is much preferred. It will cover 0.259ha (3*0.0864), which is a bit higher than the desired 0.25ha.

This is practically much tolerable without affecting the layout.

Note: since the width of subunit covered by a lateral is 48m, the length of subunit covered per shift or the three laterals are covering at a time a length of 54m (3laterals*18 m or 0.259ha/18m).

Therefore, the submain discharge = 3 x 6.8m^3/hr = **20.4m^3/hr**

- Now, to suit to the layout, the system discharge will be adjusted.

Adjusted System Discharge = Number of submains in the system*submain discharge
= 5 x 20.4m^3/hr
= 102m^3/hr
Thus, the total number of sprinklers working simultaneously = Q/qs = 102/1.7 = 60 sprinklers
For economic reason, the laterals are preferred to be class 6 HDPE pipes and submains and main line to be class 6 PVC pipes.

Selection of lateral size,

As per the criteria for design, the discharge variation of sprinklers on a lateral shall be kept within 10% (or, pressure variation of 20%). Thus, the maximum allowable head loss is 20% of the operating pressure head of sprinkler.

0.20 x 30m= 6m

If HDPE lateral is used, select commercially available size, say class 6 HDPE size of 32mm (ID= 27.9mm) and compute hf.

Using Darcy-Weisbach equation for small plastic pipes for Q=6.8m^3/hr,

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (6.8)^{1.75} \times 27.9^{-4.75} = 32.62m\ per\ 100m$$

For number of sprinklers per lateral, N=4, the correction factor F from table 2.8 is 0.41

Then, the head loss hf for L=42m and F=0.41 is:

$$h_f = JF\frac{L}{100} = 32.62 \times 0.41 \times \frac{42}{100} = 5.62m$$

As the elevation of the lateral is 0.5m upslope, the net head loss is: 5.62+0.5=6.12m which is above the allowable pressure head. Thus, increasing the diameter to the next larger size, i.e.40mm (ID= 34.8mm),

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (6.8)^{1.75} \times 34.8^{-4.75} = 11.42m\ per\ 100m$$

Then, the head loss hf for L=42m and F= 0.418 is:

$$h_f = JF\frac{L}{100} = 11.42 \times 0.418 \times \frac{42}{100} = 2.00m$$

Now, the net head loss is: 2.01+0.5=2.51m which is less than the allowable pressure head and the size 34.8mm is accepted.

Now, the inlet pressure head of each lateral is:

$$H_L = H_a + 0.75h_{fL} \pm 0.5H_{zL} + Hr = 30 + 0.75 \times 2.00m + 0.5 \times 0.5 + 1 = 32.75m$$

(Note: The average elevation of the lateral is 0.5m upslope as observed from the map; the riser pipe on which the sprinklers are mounted is taken as 1m)

Selection of the submain,

- Discharge of each submain = 20.4m^3/hr
- If application starts from the end of the submain, shifting will be from the end towards the inlet of the submain as indicated on the layout with roman number. At any time and place , the submain carries 20.4m^3/hr. Therefore, each submain will have the same size throughout its length. Thus,

If class 6 PVC pipe of 63mm (ID=59mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.059)^2}{4} = 0.0027m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(20.4/3600)}{0.00095} = 2.07m/\sec$$

Since the velocity is within the desired limit, the size is accepted.
Now, the inlet pressure of the sub mains will be calculated.

The inet pressure of each submain at bock 1, 2, and 3:

Using Darcy-Weisbach equation for small plastic pipes, for each submain on block 1, 2 and 3:
Q=20.4m^3/hr L= 6*100m+3x1m+2x2m(access roads)-9m = 598m

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (20.4)^{1.75} \times 59^{-4.75} = 6.36m\ per\ 100m$$

For L=591m,

$$h_f = J\frac{L}{100} = 6.36 \times \frac{598}{100} = 38.03m$$

However, the head loss is too high and it will increase the energy cost. Thus, increasing the size to the next larger diameter, i.e 75mm(70.4mm),

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (20.4)^{1.75} \times 70.4^{-4.75} = 2.75m\ per\ 100m$$

For L=598m,

$$h_f = J\frac{L}{100} = 2.75 \times \frac{598}{100} = 16.44m$$

Thus, the head loss issubtantially reduced to 16.45m with a new flow velocity of 1.5m/sec, which is within the alllowable limit. Thus, a submain size of 75mm is accepted.

Since the submain is buried at 0.60m below the ground, 0.60m head is required at connection point of the submain to the lateral. Thus, the inlet pressure head of each submain is:

$$H_s = H_l + \sum h_f \pm H_{zm} + Length\ of\ riser\ pipe = 32.75 + 16.44 - 12.5m + 0.60m = 37.29m$$

Average elevation difference = 12.5m downslope (observed from the map)

The inlet pressure of the submain at block 4:

Q=20.4m^3/hr, the maximum length of travel, L= 5*100m+(4m+2m+1m) -9m = 498m

$$h_f = J\frac{L}{100} = 2.75 \times \frac{498}{100} = 13.69m$$

Thus, the inlet pressure head of the submain considering the maximum length of travel is:

$$H_{sm} = H_l + \sum h_{fsm} \pm H_{zsm} + Length\ of\ riser\ pipe = 32.75 + 13.69 - 8m + 0.60m = 39.04m$$

Average elevation difference = 8m downslope (observed from the map)

The inlet pressure of the submain at block 5:

Q=20.4m^3/hr, the maximum length of travel, L= 6*100m+3x2m+2x1m+4m-9m = 603m

$$h_f = J\frac{L}{100} = 2.75 \times \frac{603}{100} = 16.58m$$

Thus, the inlet pressure head of the submain considering the maximum length of travel is:

$$H_{sm} = H_l + \sum h_{fsm} \pm H_{zsm} + Length\ of\ riser\ pipe = 32.75 + 16.58 - 9m + 0.60m = 40.93m$$

Average elevation difference = 9m downslope (observed from the map).
This is the governing pressure for block 4 and 5.

Sizing of main:

Starting from the farthest end to the left of the source:

For segment CD, Q= 20.4 m^3/hr and L = 104m:

If class 6 PVC pipe of 75mm (ID=70.4mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.0704)^2}{4} = 0.0039 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(20.4/3600)}{0.0039} = 1.50 m/\sec$$

Since the velocity is within the recommended limit, 75mm is selected as suitable.

Friction head loss in this segment is:

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (20.4)^{1.75} \times 70.4^{-4.75} = 2.75 m \ per\ 100 m$$

$$h_f = J\frac{L}{100} = 2.75 \times \frac{104}{100} = 2.86 m$$

Inlet pressure at this pipe (which is also the inlet pressure at submain for block 2) is:

$$H_{m1} = H_{sm} + \sum h_{fm} \pm H_{zm} = 37.29 + 2.86 + 0.5 m = 40.65 m$$

Note: elevation is 0.5mupslope

This pressure is greater than the inlet pressure at inlet of submain to block 2 (=37.29m). Therefore, it is the governing pressure.

For the segment BC, Q= 40.8m^3/hr, L=104m:

If class 6 PVC pipe of 90mm (ID=84.4mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.0844)^2}{4} = 0.0056 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(40.8/3600)}{0.0039} = 2.03 m/\sec$$

Since the velocity is now within the recommended limit, 90mm is a suitable size for this segment.

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (40.8)^{1.75} \times 84.4^{-4.75} = 3.91 m \ per\ 100 m$$

$$h_f = J\frac{L}{100} = 3.91 \times \frac{104}{100} = 4.06 m$$

Inlet pressure at this pipe (which is also the inlet pressure at submain for block 3) is:

$$H_{m1} = H_s + \sum h_{fm} \pm H_{zm} = 40.65 + 4.06 + 0.75 m = 45.46 m$$

Note: elevation is 0.75m upslope

This pressure is greater than the inlet pressure at inlet of submain to block 3 (=37.29m).
Therefore, it is the governing pressure.

For the segment AB, Q= 61.2m^3/hr, L=121m:

If class 6 PVC pipe of 110mm (ID=103.2mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.1032)^2}{4} = 0.0084\,m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(61.2/3600)}{0.0039} = 2.03m/\sec$$

Since the velocity is now within the recommended limit, 110mm is a suitable size for this segment.

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (61.2)^{1.75} \times 103.2^{-4.75} = 3.06m\ per\,100m$$

$$h_f = J\frac{L}{100} = 3.06 \times \frac{121}{100} = 3.70m$$

Inlet pressure at point A is:

$$H_{m1} = H_{sm} + \sum h_{fm} \pm H_{z\,m} = 45.46 + 3.70 + 3.5m = 52.66m$$

Note: elevation is 3.5m upslope

For the segment AE to the right of the source, Q= 40.8m^3/hr, L=85+50 = 135m:

If class 6 PVC pipe of 90mm (ID=84.4mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.0844)^2}{4} = 0.0039\,m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(40.8/3600)}{0.0039} = 2.03m/\sec$$

Since the velocity is now within the recommended limit, 90mm is a suitable size for this segment.

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (40.8)^{1.75} \times 84.4^{-4.75} = 3.91m\ per\,100m$$

$$h_f = J\frac{L}{100} = 3.91 \times \frac{135}{100} = 5.27m$$

Inlet pressure at point A is:

$$H_{m1} = H_{sm} + \sum h_{fm} \pm H_{z\,m} = 40.93 + 5.27 + 2m = 48.20m$$

Note: elevation is 2m upslope

The pressure calculated at this point from left of the source is 52.66m whereas to the right is 48.20m. Therefore, the governing head is 52.66m. Pressure regulator is required to the right for 4.46m (52.66-48.20) or the less expensive option is increasing the sizes of the pipes on the right at the expense of velocity of flow.

Thus, if segment CD is 90mm (ID=84.4mm), the head loss will become 1.21m and the inlet pressure at C then is:

$$H_{m1} = H_{sm} + \sum h_{fm} \pm H_{z\,m} = 37.29 + 1.21 + 0.5m = 39.00m$$

If segment BC is 110mm(ID=103.2mm), the head loss will become 1.56m. The inlet pressure at B then is:

$$H_{ma1} = H_s + \sum h_{fm} \pm H_{zm} = 39.00 + 1.56 + 0.75m = 41.31m$$

Now, if the segment AB is kept to have a size of 110mm, the head loss remains to have 3.70m. The inlet pressure at A becomes

$$H_{ma1} = H_s + \sum h_{fm} \pm H_{zm} = 41.31 + 3.70 + 3.5m = 48.51m$$

Now, the inlet pressures from both sides (48.51m and 48.20m) nearly become equal. A head of 48.51m will be the governing head at A.

For the last segment, Q= 102m³/hr and L=83m:

If class 8 PVC pipe of 140mm (ID=129.2mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.1292)^2}{4} = 0.0136 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(102/3600)}{0.0136} = 2.16 m/\sec$$

Since the velocity is now within the recommended limit, 140mm is a suitable size. Friction head loss in this segment is:

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 9.19 \times 10^6 \times (102)^{1.83} \times 129.2^{-4.83} = 2.76m\ per\ 100m$$

$$h_f = J\frac{L}{100} = 2.46 \times \frac{83}{100} = 2.29m$$

Inlet pressure at this pipe is:

$$H_{m3} = H_{m2} + \sum h_{fm} \pm H_{zm} = 48.51 + 2.29 + 0m = 50.80m$$

III. Determination of pump capacity:

If the head loss in the control head is assumed to be 5m, the suction head of the pump is 20m, and the local losses in fittings to be 2% of the operating pressure head of the sprinklers, the total head of the pump is:

$$H = H_{m3} + Hsu + hl = 50.80 + 20 + 5 + 0.02 * 30 = 76.40m$$

Again, if the pump and motor efficiencies are assumed to be 70%, the pump capacity for Q=102m³/hr is:

$$HP = \frac{Q \times H}{75 \times E_P \times E_m} = \frac{(102 \times (1000/3600) \times 76.40}{75 \times 0.70 \times 0.70} = 58.9hp\ say\ 59hp$$

Thus, the salient features of the sprinkler system are:

1. Depth of irrigation : 64mm
2. Irrigation interval : 12 days
3. Sprinklers working simultaneously : 60
4. Sprinkler nozzle size : 5mm
5. Operating head of sprinkler : 30m
6. Discharge of sprinkler : 1.70 m³/hr

7. Spacing of sprinklers on the lateral	: 12m
8. Spacing of laterals on the main line	: 18m
9. Number of sprinklers system settings	: 2 shifts per day
10. Size of lateral	: 32mm (class 6 HDPE.)
11. size of submain pipe	: 63mm (class 6 HDPE)
11. Size of main pipe	: tellescopic (class 6 PVC 75, 90, 110125mm and class 8 PVC 140mm)
12. Length of each lateral	: 42m
13. Total length of laterals	: 630m
14. Length of main line	: 524m (83m of 140mm, 121m of 110mm, 239m of 90mm and 208m of 75mm)
15. System Discharge	: 102m^3/hr
16. Total head	: 76.40m
15. HP of the pump	: 59hp

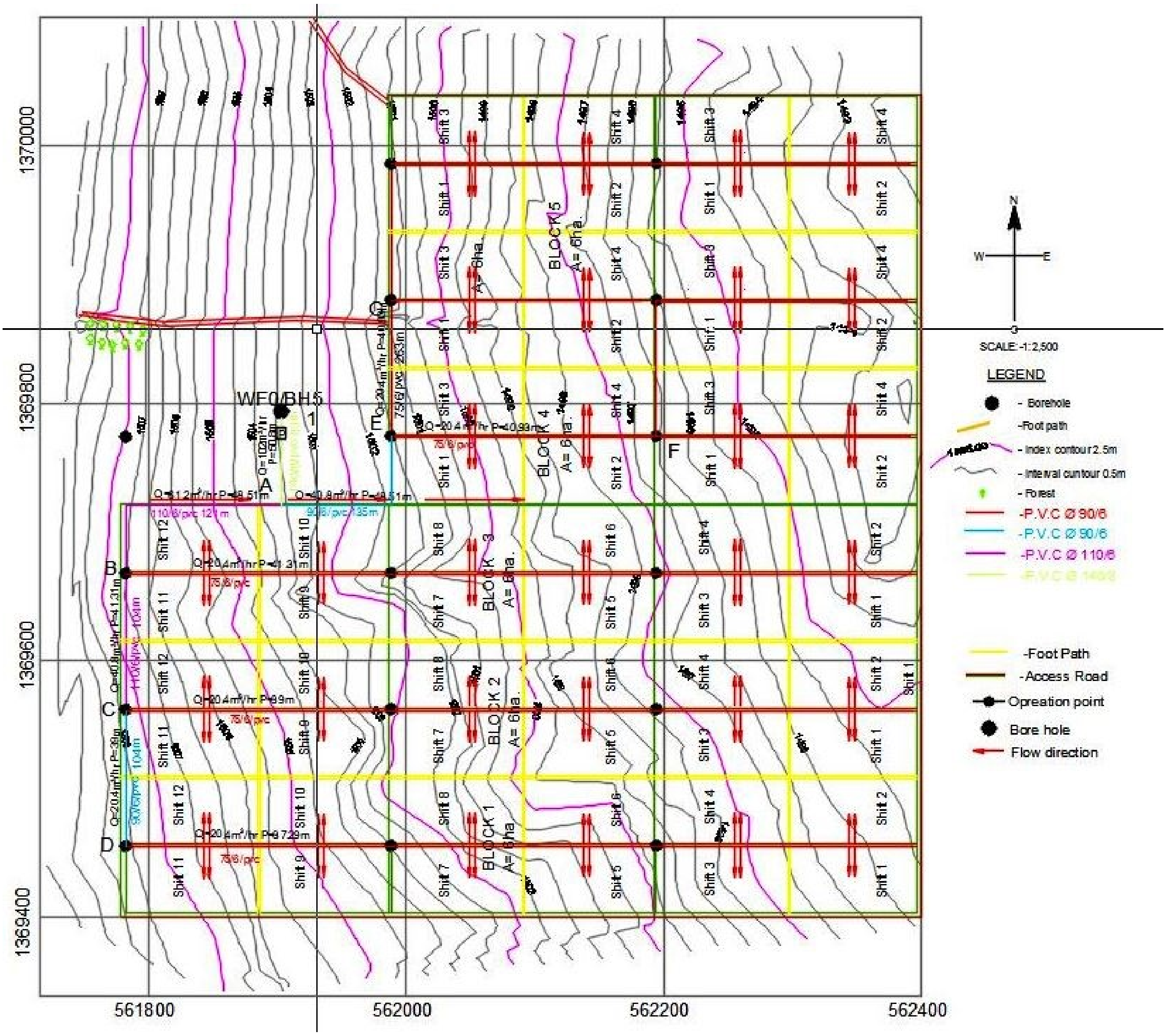


Figure 2-6: Layout of the system (scale: 1:2500)

Complete design example 2: A typical design of sprinkler system(for commercial use by model farmers owningupto 10ha)

Basic data for which the system is to be designed.

Area	: 10ha (Length = 400m x width = 250m)
Topography	: Leveled
Water Source	
Location	: 21m from one corner of the field (along the width)
Capacity	: Adequate
Quality	: Suitable for irrigation
Climate	: Moderate
Average wind speed	: 4km/hr
No. of hours of pumping	: 10hrs/day
Soil Type	: Sandy loam
Infiltration rate	: 2.5cm/hr

Apparent Sp. gravity : 1.5
Field capacity : 14%
Depth of effective root zone : 90cm
Peak rate of daily consumptive use : 4.5mm/day
Permanent wilting point : 6%
Crop: Mustard (leaves sensitive to water)
Application effiecency : 85%

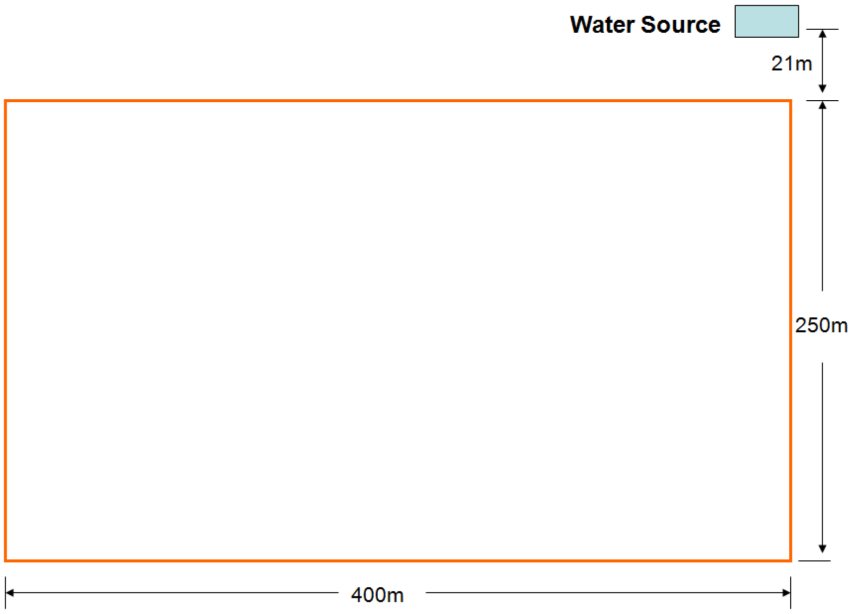


Figure 2-7: Schematic area of the field to be irrigated

Basic design inputs calculations

a) Depth of Irrigation

Net depth of irrigation:

$$d_n = MAD\left(\frac{FC - PWP}{100}\right) \times \rho_b \times drz = 0.50 \times \left(\frac{14-6}{100}\right) \times 1.5 \times 90cm = 5.4cm \; or \; 54mm$$

Gross depth of Irrigation:

$$d = \frac{d_n}{E_a} = \frac{54mm}{0.85} = 63.5mm$$

b)Irrigation interval

$$F = \frac{d_n}{CU_p} = \frac{63.5}{4.5} = 12days$$

c) Irrigation frequency: take equal to irrigation interval

d) Selection of sprinkler:

Normally high pressure (HP) model is used for obtaining finer drop sizes for sensitive crop like mustard. The following high pressure nozzle that is having lower application rate than the given infiltration rate of the soil is recommended as obtained from a manufacturer's catalogue.

Model : HP

Nozzle size : 7.14mm x 3.13mm
Operating pressure : 2.11kg/cm^{2}or 21m
Diameter of throw : 31.4m
Application rate : 2.20cm/hr
Discharge of sprinkler nozzle : 0.88 lps

e)Spacing of sprinkler:

This depends upon the wind velocity. For rectangular pattern **(**Table 2.5), spacing of sprinklers on a lateral for given wind condition is:

Sprinkler spacing = 0.4 * Diameter of throw
= 0.4*31.4
= 12.56 say 12m

f)Spacing of laterals:

This also depends upon the wind velocity. For a wind velocity of up to 10km/hr, lateral spacing is 0.65% of the diameter of throw. Accordingly, the lateral spacing can be taken as:

Lateral spacing = 0.65 * Diameter of throw
= 0.65*31.4
= 20.41 say 18m

Thus, effective area covered per sprinkler is: a_s= 12m x 18m = 216m^2.

g)Number of sprinklers:

Application rate of sprinkler nozzle, cm/hr

$$I = \frac{360 \times q_s}{S_p \times S_L} = \frac{360 \times 0.88}{12 \times 18} = 1.46 cm/hr$$

Time required to apply the required depth of irrigation by the system, hrs

$$T = \frac{d}{I} = \frac{6.35}{1.46} = 4.35 hrs$$

Number of sprinkler system shifts per day

$$n_s = \frac{T_P}{T + T_S} = \frac{10}{4.35 + 0.50} = 2.06, say\ 2 shifts$$

(Note: 0.5 is taken as the time required to shift the lateral pipe.)

Area to be irrigated per day, a_1:

$$a_1 = \frac{A}{f} = \frac{10ha}{12} = 0.83ha$$

Area to be irrigated per shift, a_2:

$$a_2 = \frac{a_1}{n_s} = \frac{0.83ha}{2} = 0.415ha$$

Number of sprinklers per shift (or working simultaneously), Ns:

$$N_s = \frac{a_2}{a_s} = \frac{0.415ha}{0.0216ha} = 19.21\ sprinklers,\ say\ 20$$

h) Total discharge of the sprinkler system:

$$Q = q_s \times N_s = 0.88 \times 20 = 17.60 lps$$

i) Layout of sprinkler system:

The layout of the sprinkler system is as shown in figure below.

To make the system economical, the main line is laid center to the field along its length.
The submain is avoided as the field is taken as one block. Thus, the laterals are directly connected to the main line. The laterals are connected orthagonal to the main line (or along the width).

To suit to irrigation application, the laterals will be moving in the direction indicated on the figure.

There will be two lateral lines each having 10 sprinklers. The sprinklers spacing on the lateral is 12m and lateral to lateral spacing is 18m. Thus,

Length of lateral = [(N-1)*Sp + Sp/2]+[0.5x6m] (Here, the second term is access road along main)
 = (10-1)*12 + 12/2 + 3 = 117m
And, width of the field covered by laterals = (250m-6-2x2)/2=120m (6m along the main line and 2m on the boundary of the field left for access roads).

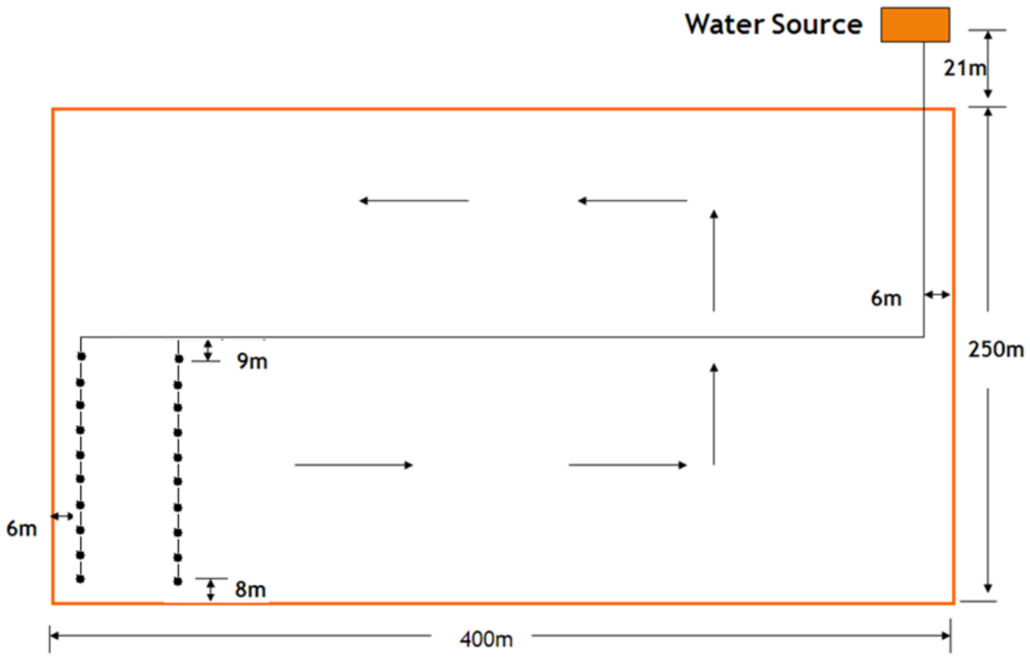


Figure 2-8: Layout of the sprinkler system pipe networks

j) Selection of size of main line and lateral lines and calculation of friction head loss
As the total area is taken as one irrigation block, submain lines are absent. Thus, laterals are directly connected on the mainline.

Discharge through lateral line = 0.88*10 = 8.8 lps
Discharge through main line = 0.88*20 = 17.60 lps

k)Size of lateral line:
Allowable head loss in a lateral line is 20% of operating pressure head of sprinkler
 = 0.20*21m = 4.2m
If HDPE lateral is used, select commercial size, say class 6 HDPE size of 75mm (ID=65.4mm). Using Darcy-Weisbach equation for small plastic pipes for Q=8.8 lps or 31.68m^3/hr, compute hf.

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (31.68)^{1.75} \times 65.4^{-4.75} = 8.43m\ per\ 100m$$

For number of sprinklers per lateral, N=10, the correction factor F from table 2.8 is 0.384

Then, the head loss hf for L=117m is:

$$h_f = JF\frac{L}{100} = 8.43 \times 0.384 \times \frac{117}{100} = 3.79m$$

The head loss is less than the allowable pressure head. Now, to be more economical, select the next lower commercial size. i.e. 63mm (ID=55mm). Total friction head loss is 8.62m which is greater than than the allowble head 4.2m. Thus, the head loss is within the permissible limit if the pipe diameter is 75mm. Hence, the use of 75mm pipe is appropriate.

Now, the inlet pressure head of each lateral is:

$$H_L = H_o + 0.75 h_{fL} \pm 0.5 H_{zL} + H_r = 21 + 0.75 \times 3.79m + 0.5 \times 0 + 1 = 24.84m$$

(Note: No elevation correction is required as the field is a levelled land)

I) Selection of the size of main line

To keep the main line size uniform, we may neglect the head loss in the last segment of the main line as its length is only 18m as compared to the total length and carries only the lateral discharge 8.8lps. Thus, discharge of main line for the longest segment is

= 17.6 lps or 63.36m^3/hr.

If class 6 PVC pipe of 110mm (ID=103.2mm) is selected, the cross-sectional area of the pipe is:

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.1032)^2}{4} = 0.0084 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(102/3600)}{0.0084} = 2.11 m/\sec$$

Since the velocity is now within the recommended limit, 110mm is a suitable size.

Length of main line, L = (400-2x2m access road on the boundary) –2x(lateral spacing/2)+125+21= 400-4-(2*18/2)+125+21 = 524m

Thus, the friction head loss in the main line is:

$$J = \frac{h_f}{L/100} = K_1 Q^{1.75} D^{-4.75} = 8.38 \times 10^6 \times (63.36)^{1.75} \times 103.2^{-4.75} = 3.25m\ per\ 100m$$

Then, the head loss hf for L=524m is:

$$h_f = JF\frac{L}{100} = 3.25 \times 1 \times \frac{524}{100} = 17.01m$$

If more energy saving is required, the next larger size may be selected. i.e. 140mm (ID= 131.4mm). Thus, checking the Velocity of flow,

$$A = \frac{\pi d^2}{4} = \frac{\pi \times (0.1314)^2}{4} = 0.014 m^2$$

Now, the velocity is:

$$V = \frac{Q}{A} = \frac{(102/3600)}{0.014} = 1.3 m/\sec$$

Since the velocity is a bit below the lower range and which is not practically significant. Thus, 140mm may be considered as a suitable size. Now, the friction head loss with this size is reduced to 5.4m

m) Size of pumping unit

Assume total static head	: 6m
Loss in control unit	: 5m
Height of riser	: 1m
Pump efficiency	: 70%
Motor efficiency	: 70%
Total pressure head, H	: Inlet pressure head of lateral + Friction head loss in mainline + Friction head losses in fittings + Elevation head + Static head + local losses in control unit + Height of riser pipe that connects mainline with laterals

$$H_m = H_L + (h_{fm} + h_{fittings}) + H_{zm} + H_s + H_r + H_c + H_{rm}$$
$$H_m = 24.84 + (5.4 + 0.02 * 21) + 0 + 6 + 5 + 1 = 42.66m$$

(Note: The friction head losses in fittings is considered in the order of 2% of the operating head; the main pipe is considered as 1m buried below the ground and is connected to the laterals by riser pipe).

$$HP = \frac{QH_m}{75 \times E_P \times E_m} = \frac{17.60 \times 42.66}{75 \times 0.70 \times 0.70} = 20.43hp,\ say\ 21hp$$

Thus, the salient features of the sprinkler system are:

1. Depth of irrigation	: 6.35cm
2. Irrigation interval	: 12 days
3. Sprinklers working simultaneously	: 20
4. Sprinkler nozzle size	: 7.14 x 3.13mm
5. Operating head of sprinkler	:21m
6. Discharge of sprinkler	:0.88 lps
7. Spacing of sprinklers on the lateral	: 12m
8. Spacing of laterals on the main line	: 18m
9. Number of sprinklers system settings	: 2 shifts per day
10. Size of lateral	:75mm (dia.)
11. Size of main pipe	: 140mm (dia.)
12. Length of each lateral	:117m (Class 6 HDPE, 19 pipes of 6m and 1pipe of 3mlength)
13. Total length of laterals	:234m (Class 6 HDPE 38 pipes of 6m and 2pipes of 3m length)
14. Length of main line	: 524m (class 6 PVC, 88 pipes of 6m length)
15. System Discharge	: 17.6 lps
16. Total head	: 42.66m
17. HP of the pump	:21hp

3 EQUIPMENT SPECIFICATION, BILL OF QUANTITITES & TENDER

3.1 EQUIPMENT SPECIFICATION

With the completion of the design, a detailed list of all the equipment needed (pipes, pipe fittings, etc.) for the installation of the system must be prepared with full descriptions, standards and specifications for every item. That is, in addition to the quantities, it is imperative to determine and specify:

- The size and name of the item (2-in ball valve, 50-mm pipe, etc.);
- The kind of material (brass, uPVC, etc.);
- The pressure rating (PN 16 bars, 6 bars, etc.);
- The type of joints (screw, solvent welded, etc.);
- The standards complied with (ISO 161, 3606, BS 21, ISO 7, etc.).

Three different lists may be prepared: one for the mains, and submains; one for the manifolds and laterals with the sprinklers; and one for the head control.

Should the equipment not comply with any standard, due to many reasons, a full technical description should be given of the material it is made of, the working pressure and the use. The latter is important because the fittings should be made of material recommended for use with the particular pipe.

In addition, the following must be considered in specifying the components of the system.

For Main and sub main lines: Although the low to medium pressure systems are not subjected to the very high pressures created by water hammer, it is advisable to use class 6.0 pipes or more for the main and submain lines.About 5 percent should be added to the design total length of pipelines required.

For laterals: quick coupling aluminum or HDPE pipes are used as surface laterals in theperiodic move sprinkler systems. It is advisable to use class 4.0 pipes.

Head control: All the components of the head control of the system must be determined, i.e. shut-off valves, check valve, air valve, fertilizer injector, filters, pressure regulators, etc. In addition, all the auxiliary fittings must be included, such as the pipe pieces, hoses and fittings needed to assemble the unit, and the pressure gauges and other small devices required.

Pumping unit: A full and detailed description of the pumping unit must be given, including the kind of pump and the capacity and output of the pumping unit, i.e. the water delivery versus the dynamic head.

Table 3-1: Sample Equipment specification (based on Table 3-2 below)

Item No.	Equipment specification
1.1 to 1.4	White PVC pipes, PN 6bars in compliance with ISO standard. Supplied in 6 and 12m lengths
2.1	Black HDPE pipes, PN 6.0 bars in compliance with ISO standard. Supplied in 100m rolls
2.2	Brass made two nozzles sprinkler, size of 5.0mm and working pressure of 30m, discharge of 1.70m^3/hr and wetting diameter of 33m
3.1 to 3.3	Galvanized steel class 6
3.4 to 3.15	PVC connector fittings for use with PVC pipes and to ISO dimensions
4.1 to 4.4	Ball valves, air release valves, etc. made of brass, PN 16bars and to ISO standards
4.5	Filter (strainer), screen type, or grooved disks, 120 mesh/130 micron, epoxy coated metal body or other quality material, PN 10 bars and to ISO standards
5	The trench should be as uniform and level as possible, free of large stones and any other sharp edged materials. Where required it must be filled with embedmentmaterial to a depth of 10cm. Trench dimensions should be 60cm minimum depth for 75mm pipe and above

3.2 BILL OF QUANTITIES

Bill of quantity for each and every item in the design will be prepared. The price will be fixed with +10% of the prevailing average unit rate of the international and local price quotations. The installation cost will be estimated based on the previous experiences in the area with +10% to absorb possible cost variations. An example of bill of quantities is shown in table 3.2 below.

3.3 TENDERS

The purchasing of irrigation equipment or execution of services, such as the installation, operation and maintenance of irrigation networks and/ or pumps, should be effected as per the national procurement rules and regulations. As per Ethiopian Procurement regulation, for equipment and services up to a value of Birr 200,000, the purchase can be effected through ‘quotations’, i.e. written quotations may be asked from a representative number (at least 3) of suppliers. Where the value of the equipment exceeds birr 200,000, their purchase should be effected through public tender. This is done in accordance with the procurement rules and regulations.

Wide publicity should be given to every ‘notice inviting tenders’ (invitation for tenders). This must include the name of the buyer, a brief description of the items for which tenders are invited, the address for delivery of equipment, and the closing date and time of the tenders. Moreover, it should include a statement that the buyer is not bound to accept the lowest or any other tender, and also state to whom the bidders must apply for full particulars.

Table 3-2: Sample bill of quantity for the complete design example 1 case

No.	Description of items	Unit	Quantity	Unit Cost	Total cost(birr)
1	**Main and sub main pipes**				
1.1	∅140 class 6 PVC pipe	m	84		
1.2	∅110 class 6 PVC pipe	m	228		
1.3	∅ 90 class 6 PVC pipe	m	240		
1.4	∅ 75 class 6 PVC pipe	m	1704		
	Subtotal 1				
2	**Lateral pipes and sprinklers**				
2.1	∅ 40 class 6 HDPE pipe	m	630		
2.2	Sprinklers - nozzle size 5mm, 1.7m^3/hr @ 30m and wetting diameter of 33m	No.	20		

No.	Description of items	Unit	Quantity	Unit Cost	Total cost(birr)
	Sub Total 2				
3	**Fittings and Accessories**				
3.1	Riser pipes for sprinklers (3/4")Type and height???	m	20		
3.2	lateral quick coupler (1½")	No.	20		
3.3	Riser quick coupler (1½"x3/4")	No.	20		
3.4	Connector/ takeoff (∅75x40)	No.	180		
3.5	Plastic End Cap 40mmcompression	No.	15		
3.6	Plastic End Cap 75mmPVC	No.	7		
3.7	Straight(75mmx75mm) PVC	No.	284		
3.8	Straight connector(90mmx90mm)PVC	No.	40		
3.9	Straight connector(110mmx110mm)PVC	No.	38		
3.10	Compression male adaptor (90mmx110mm)	No.	1		
3.11	Compression adaptor (90mmx140mm)	No.	1		
3.12	S.W. Tee (90x90x75) PVC	No.	3		
3.13	S.W. Tee (110x110x75) PVC	No.	1		
3.14	Solvent weld PVC 90^{o}elbow (90mmx75mm)	No.	2		
	Sub Total 3				
4	**Control heads**				
4.1	Gate valve, 1 ½″ (F/M)	No.	1		
4.2	Air Release Valve 3/4″	No.	1		
4.3	Non-Return Valve	No.	1		
4.5	Pressure Regulator (1 ½″) female threaded	No.	1		
4.6	Plastic Screen Filter 3/4″(120-mesh) threaded	No.	1		
	Sub Total 4				
5	**Pumps and generator**				
	Submersible pump with 59hp	No.	1		
	Standby generator	No.	1		
	Sub Total 5				
6	**Earthwork and Installation cost**				
	Excavation cost	ha	30		
	System installation cost	ha	30		
	Sub Total 5				
	Total cost (birr)				
	Administration Cost, and Contingency (10%)				
	Grand total (birr)				

In the case of 'local tenders' for the purchase of relatively limited quantities, the tender document that must be available and given to prospective bidders on request should include only the general conditions of the tender and the technical specifications of goods. It is important that all required conditions be clearly stated in detail in the tender document, including the time and method of delivery, method of payment, i.e. letter of credit, cash against documents, payment on delivery, etc.; and other related information.

In the case of 'international bids', the contract documents must include, in detail, the following:

- invitation for bids;
- instructions to bidders (source of funds, eligible bidders, goods and services, cost, content of bidding documents, preparation and submission of bids, opening and evaluation, award of contract, etc.);

- general conditions of contract (definitions, country of origin and standards, performance, security, inspection and tests, insurance, transportation, warranty, payment, amendments, delays, force majeure, etc.);
- special conditions; technical specifications (general, materials and workmanship, schedules of requirements/bill of quantities, and particular technical requirements/ specifications);
- bid form and price schedules;
- contract form, bid security and performance security.

4 INSTALLATION AND TESTING OF SPRINKELR SYSTEM

4.1 RECEIVING AND HANDLING OF PIPES AND FITTINGS

4.1.1 Receiving, unloading and handling guide

Pipes and fittings are delivered to a project site in rolls or pieces depending on the type of product. When a load of pipes and fittings arrives at the site, it is the responsibility of the engineer to check it thoroughly. If possible, it is required to inspect each piece for damage. It is quite necessary to check quantities against the delivering list. Note missing or damaged items on bill of loading; set aside any damaged items and notify the supplier.

In order to avoid any damage to pipes and fittings, the person in charge of the site must adhere to the following recommendations.

- The storage surface must be flat, stable, and free of stones and debris.
- Unload the truck, being careful to avoid any movement, which could cause injury to the personnel or damage to the product and make note if any missing products in the delivery lot.
- Unload layer by layer, ensuring they do not fall to the ground.
- Do not discard damaged materials; rather identify them carefully for later inspection and notify to the supplier on time.
- Do not return damaged product before the authorization of the supplier.

4.1.2 Storage of received materials

Pipes and fittings delivered in rolls or pieces must be stored appropriately as described below.

- Deposit the products on a clear, flat surface, and far away from any source of fire hazard.
- Specially fittings must be stored inside shelter and take care not to be lost.
- The maximum pipe storage height is preferable not to exceed 1.5m.
- Use chocks to prevent the pile of pipes from falling down which could result in damage to the pipes, or worse still, cause injury to a person.
- If the pipes are stockpiled along the trench, they should be as close as possible to the trench, on the opposite side from the backfill, to minimize loading, unloading and transportation.

4.2 INSTALLATION OF PIPE LINES AND FITTINGS

4.2.1 Installation of mains and submain pipes

Mains and submain pipes in sprinkler system are buried. For installation of main and submain pipes, first make sure that the pipes, fittings and valves are free from any defects impairing strength and durability and be of the best commercial quality for the purposes specified. Further, all dust, dirt and foreign matter must be removed from the pipe. All pipes, valves and pipe fittings shall conform to the relevant standards. As the pipes are usually buried, to protect them from farming operations and traffic hazards, the following guide may be used in their installation.

4.2.1.1 Trench excavation

Proper layout, demarcation and pegging that guides the excavation line has to be carried out before commencing excavation works. According to the volume of earth work, labor availability and accessibility the excavation works can be carried out by labor or excavator. During the excavation works, the excavated material should not block sidewalks, utility outlets and back falling of excavated material to the trench. The excavation of trenches for pipelines shall at any one time be limited to lengths approved by the design engineer.

The width of the trench varies based on pipe size, soil type and other site specific conditions. The minimum clear width of the trench measured at the center line of the pipe is generally specified at least 300mm greater than the outside diameter of the pipe to enable backfill material to be installed in the pocket area. For pipes with outside diameter of 200mm up to 400mm commonly 500mm width is recommended to allow free movement of human being shoulder during excavation and installation.

The pipes should be buried at depth of 350mm-400mm below the deepest recorded penetration of plough depth. Therefore, the commonly used depth of excavation is 500mm plus the pipe outside diameter.

Adequate dewatering system to lower the existing ground water table below the level of the trench bottom and to keep the trench dry until pipes are assembled and back filled. If during the progress of the work the trench in part or in whole becomes flooded, the contractor shall immediately stop all relevant work until the trench is dry.

4.2.1.2 Installation

After excavation of the trench, installation follows. Installation of pipelines includes construction of beddings and foundation, laying and jointing of pipes and fittings, manholes and other structures in the line, testing, and backfilling of trenches, surface restoration and commissioning.

i) Pipe laying, jointing and cutting

After the planning is done and trenches are excavated, layout of pipes follows. The easiest way to install the pipe is to start at the water source and work out to the valves, and then continue to the end of each lateral. For laying the pipes, first granular bedding of sand for pipes shall be placed by spreading and compacting granular bedding material over the complete width of the pipe trench. Where pipes are jointed, bell holes of ample dimensions shall be formed in the bedding to ensure that each pipe is uniformly supported throughout the length of its barrel and to enable the joint to be made and inspected during testing. After pipe laying, additional material shall be placed and compacted by hand rammer in 150mm layers equally on each side of the pipe as side support for the pipe.

Where pipes are laid on granular beds in ground with high groundwater level, puddled clay stanks shall be constructed at 25m intervals at the mid-point of an individual pipe. The stanks shall be 0.5m long and shall be recessed 300mm into the sides and base of the trench, and shall extend by a minimum of 150mm above the top level of the granular material.

Hydrants must be installed out of the way and must be painted with a bright-coloured paint to prevent them from being run over. All mainlines and submains must be flushed after installation to get rid of dirt that may have entered the pipes during installation. Pressure measuring points must be installed after each control valve at a block or hydrant so that the design operating pressure of the system can be set at those points.

While laying pipes, all joints shall be flexible joints and comply with the relevant provisions of the appropriate standards and shall be made to the manufacturer's recommendations.

Flanged joints shall be properly aligned before any bolts are tightened. Gaskets for flanged joints shall be of the inside-bolt-circle type. Gaskets may be secured temporarily to one flange face by a minimum quantity of clear rubber solution. Unless specified otherwise joints having exposed mild steel components shall be cleaned and all loose rust shall be removed. The internal lining in a gap which has been left for the joint to be made shall be completed in accordance with the recommendations issued by the manufacturer unless specified otherwise. The external protection shall comprise bitumen applied to a thickness of not less than one millimeter onto the external surface of the joint, followed where appropriate by a spiral wrap of heavy duty glass fiber tape bonded with hot bitumen.

For closing lengths, it may be necessary to cut pipes of various materials. Pipes shall be cut by a method which provides a clean square profile without splitting or fracturing the pipe wall, and which causes minimum damage to any protective coating. Where necessary, the cut ends of pipes shall be formed to the tapers and chamfers suitable for the type of joint to be used and any protective coatings shall be made good.

In general during pipe laying and joining works the following guides shall be adopted:

- When pipes are supplied in rolls properly transport the roll to installation trench, unroll and stretch straight off side of the trench length.
- Immediately before being laid and jointed, each pipe and fitting shall be carefully examined for flaws, cracks, or any other damage and all dust, dirt and foreign matter must be removed from the pipe. Therefore, sufficient care shall be taken to ensure that each pipe and fitting remains clean during the laying.
- If the Engineer deems the defective pipe as being suitable for use, the defective pipe shall be cut back at least 150mm beyond any visible flaw and prepared for jointing.
- All pipe lining and jointing shall be carried out by experienced pipe layers, well skilled in their work, to the grades, levels and lines shown on the drawing
- Joint the HDPE pipes using welding machines or compression fittings off side of the trench.
- Before pipe laying to the trench clean all stone, soil and other debris that might have fallen to the trench.
- Drag the pipes carefully section by section to the trench and laid on a natural bed over the trench formation when there is no rocky or stony ground exists.
- HDPE pipes with small diameter pipes may be laid to curves, not exceeding 1.3 times the minimum diameter.
- For the installation of valves and other fittings where required, pipes shall be cut and prepared using proper tools.
- Additional care should be taken during the laying of pipes by using suitable caps or plugs to cover open ends in the event of a prolonged interruption on completion of the work.

ii). Installation of fittings

As presented in section 1.6, there are several types of PVC and PE fittings. The most common fittings used in PVC pipes are Solvent Weldand threaded fittings. There are, however, different options of connecting HDPE pipe with fittings and the most commonly used are described below.

a) Flanged fittings

Flanged fittings are used mostly in large sizes exceeding 90mm size and when there is a need to use flanged fittings and pipes. All flanged connections are face to face dimension by using backing rings, bolts, nuts and gaskets.

b) Butt weld fittings

All pipes are going to be joined face to face by welding or by using weldable fittings such as reducer, tee, elbow and etc. Also there is an option of using electro fusion fittings mostly during maintenance work and some special cases like welding that to be carried above ground level on roof and other raised areas. All weldable fittings are carried by using standard welding machines.

c) Compression fittings (Sleeve connection)

These types of fitting connections represents for joining of PE pipes and all of the compression fittings and shall be consist the following parts:

- Body and lock nut- with great rigidity and low moisture absorbency
- Grip/splits ring- strong, hard, highly crystalline and is known as plastic engineering.
- Thrust ring/Bushing – with a characteristic of chemical resistance to solvents, acids and alkaline, toughness and flexibility.
- 'O' rings – made of rubber.

During installation of these types of fittings the following guide points shall be adopted:

- Level the end of the pipe to be inserted in to the fitting.
- Disconnect the lock nut from the body by rotating anti clock wise and remove the grip ring.
- During installation clean the pipe surface that to be inserted in to the fitting and the internal surface of the compression fitting.
- Insert the nut and the grip to the pipe which is ready for connection.
- Insert and push the pipe end to the bushing ring.
- After ensuring proper insertion of the pipe to the bushing ring push back the grip until it connects to the bushing ring and then locks the nut to the body by rotating clock wise.

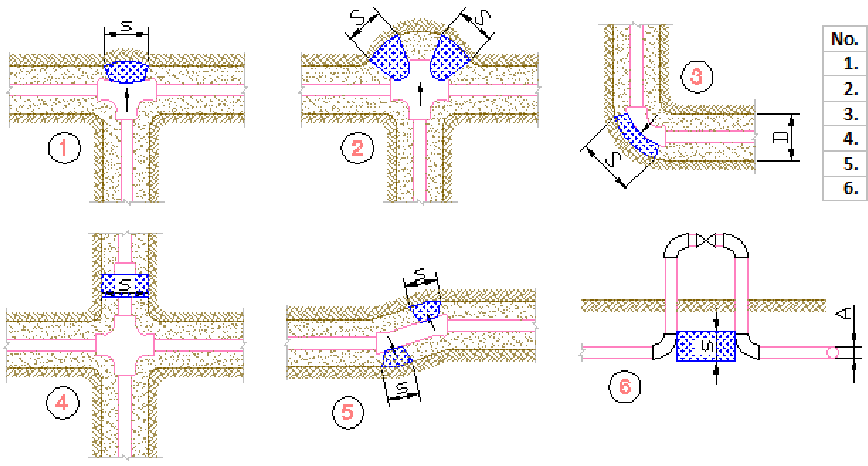
d) Threaded fittings

This can be referring to any types threaded fittings.

- Use adequate teflon on external threaded part of the fitting during connection thread to thread.
- Connect at right position of the fitting thread to ensure tight connection.
- Be care full not to damage the peach of the thread.

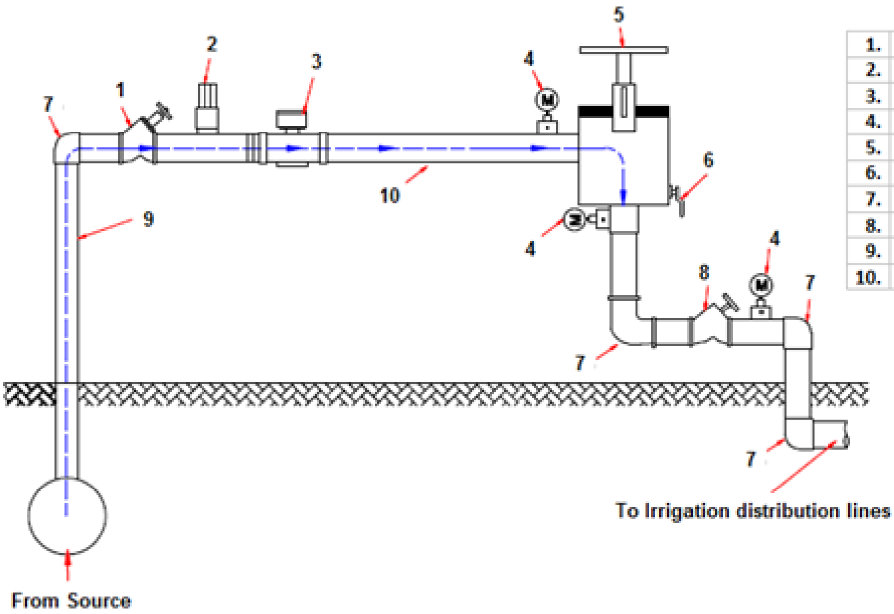
iii) Curves and bends

The pipes shall be laid in straight lines where possible. Curves of long radius shall be obtained by deflection at the joints. The deflection of the joints for this purpose shall not be more than 50% of the maximum deflection as specified by the pipe manufacturer for the relevant type of joint. Concrete thrust blocks shall be provided where ordered by the engineer. Concrete for thrust blocks shall be placed carefully against undisturbed earth or rock and shall in no case give less than 150mm of cover to the pipe. Concrete shall be grade C25. When casting thrust blocks, no couplings or joints shall be covered, and where timber shuttering has been used such timber shall be removed before backfilling.



No.	Description	Min. size of 'S'
1.	Tee line connection	8A
2.	Cross line connection	6A
3.	Elbow line connection	12A
4.	Reducer line connection	5A
5.	Direction change	6A
6.	Main valve anchor	6A

Figure 4-1: Thrust blocking for PVC pipes



1.	Main valve (Gate valve)
2.	Vacuum breaker/Air release valve
3.	Water meter
4.	Pressure gauge
5.	Filter
6.	Ball valve (flushing valve)
7.	Elbow (90°)
8.	Pressure regulating valve
9.	Riser pipe
10.	Connecting pipe/supply line

Figure 4-2: Example of control head installation

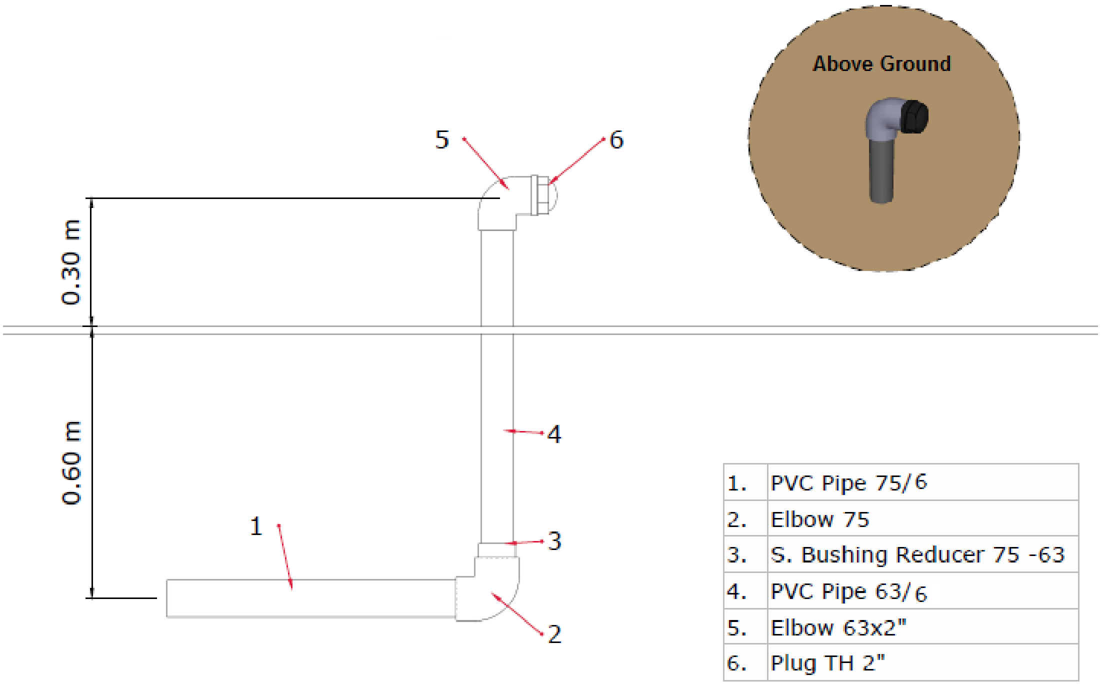


Figure 4-3: Example of end line of sub main pipe installation

iv) Testing of main and submain pipes and fittings

As soon as pipes have been placed on their bedding and before backfilling they shall be tested for leakage. Before any testing, the contractor shall ensure that the pipeline is anchored adequately and that thrusts from bends, branch outlets or from the pipeline ends are transmitted to solid ground or to a suitable temporary anchorage. Open ends shall be stopped with plugs, caps or blank flanges properly jointed.

The Contractor shall not cover up any pipe except uPVC pipe until it has been inspected, tested and approved. uPVC may be covered to a depth of 150mm to reduce thermal movement if immediate inspection and testing is not practicable.

Before testing, valves shall be checked and sealed, the sections of main filled with water and the air released. After having been filled, pipelines shall be left under operating pressure for the period of not less than three (3) hours, so as to achieve conditions as stable as possible for testing.

The pressure shall then be raised until the test pressure being 125 % times the maximum working pressure is reached in the lowest part of the tested section, and the pressure shall be maintained at this level, by pumping if necessary, for a period of one hour. The pump shall then be disconnected, and no further water shall be permitted to enter the pipeline for a further period of one hour. At the end of this period the original pressure shall be restored by pumping and the loss measured by drawing off water from the pipeline until the pressure at the end of test is reached again.

v) Filling and protection

After testing, the pipe must be surrounded by fill for proper protection. Back filling can be done by using selected soil from the excavated native material in the trench provided, which is free from large stones, and free of debris or other organic materials up to 500mm height over the crown of the pipe in which it is up to the maximum depth of the plough. The purpose of the backfill is to protect the pipe from damage and floating over during water filling condition. It is not necessary to compact the backfill directly over the top of the pipe for the sake of the pipe's structural strength. However, it may be necessary for the sake of roadway integrity.

The pipe shall be protected with concrete encasement from live traffic loads at road crossings. Filling and protection to pipes shall extend fully to the sides of the excavation. The Contractor shall provide and maintain an adequate support system for upholding the ground actually encountered, and the safety of adjacent structures or utilities shall not be affected.

All support systems shall be properly maintained until the permanent work is sufficiently advanced to permit it to be removed. No gaps or voids are permitted as a result of the removal of the support system. Gaps and voids that may be created upon removal of the support system shall be properly filled with an approved granular material or Sand or other approved means.

The trench above the so finished pipe surround shall be filled with fill and shall be compacted flush with ground level.

4.2.2 Installation of laterals, sprinklers and other fittings

After installation of main and submain pipes, the lateral pipes are installed as per the design and arrangement of shifts of laterals. The laterals are HDPE/aluminum pipes which should be carefully connected to the submain pipes at riser points. The inlet end of the laterals are connected to the submain with appropriate connectors but the other end of the laterals shall be closed by end plugs.

The lateral pipes are connected to each other to meet the field length by quick couplers. It is important to make sure that the laterals are aligned and the couplers are properly fixed to avoid unnecessary stress on the pipes and leakage. At the couplings, risers are connected on the other end of which sprinkler heads are fixed. If the risers are longer than 60cm, they may need tripod to keep them vertical, which otherwise tilted due to the force of water coming out through sprinkler nozzles.

4.3 FIELD EVALUATION OF SPRINKLERS

The purpose of a sprinkler system is to distribute water over the surface of the soil uniformly. Right after installation and successful testing of pipes and fittings, the uniformity of the sprinklers shall be tested. The degree of uniformity of sprinklers application rate for given set of conditions in the field can be computed from field observations of the depths of water collected in open cans placed at regular intervals within a sprinkled area. Typical catch-can spacings are 2 or 3 m on a square gridand with sprinklers (usually four sprinklers) mounted on a lateral placed in the center. The operating time used for testing should last at least 2hours. Then, the test results are analyzed with Christiansen uniformity coefficient which is expressed as:

$$Cu = 100\left(1 - \frac{\sum x}{mn}\right) \qquad \text{---- (4.1)}$$

Where,

- Cu = coefficient of uniformity
- m= average value of all observations, mm
- n = total number of observation points (sprinklers)
- x = numerical deviation of individual observations from the average observation, mm

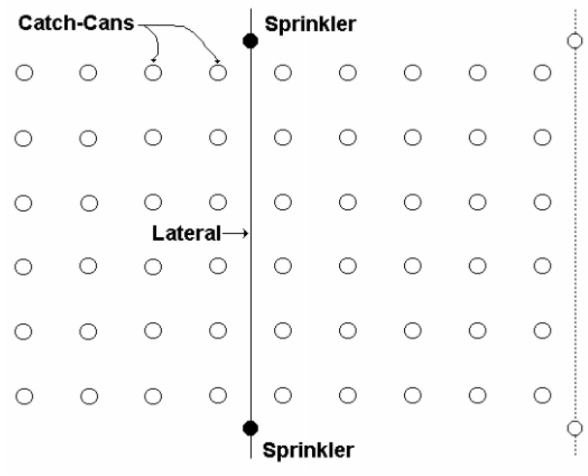


Figure 4-4: Field evaluation of sprinklers

Satisfactory Cu value has to be of 85% or more. A value below 85% is non-satisfactory and may render waste of water and need to check any faults in the installation.

Worked example 15. In a sprinkler uniformity test, the depths of water, in cm, caught in 25 open cans placed at regular intervals of 3meters with a sprinkled area of 12mx12m are given below. Compute the uniformity coefficient.

			North			
	0.58	0.55	0.51	0.62	0.61	
	0.40	0.45	0.62	0.43	0.38	
West	0.36	0.52	0.60	0.42	0.43	East
	0.42	0.46	0.47	0.42	0.44	
	0.54	0.42	0.52	0.47	0.52	
			South			

Solution:

- The number of catch cans, n = 25
- The sum of all depths caught by the cans = 12.16cm
- The mean depth of water caught by the cans, m = 0.49cm
- The sum of absolute deviations of individual depth from the mean, x = 1.79cm

Now, the uniformity coefficient, Cu is:

$$Cu = 100\left(1 - \frac{\sum x}{mn}\right) = 100 \times \left(1 - \frac{1.79}{0.49 \times 25}\right) = 85.4\%$$

It may be noted from the above analysis that the Cu value is above 85% and is satisfactory.

5 OPERATION AND MAINTAINANCE

Appropriate operation and maintenance is not less important than proper design. It is rather the key factor for good irrigation management and to assure the ongoing integrityof the facilities embodied in the sprinkler irrigation system. Because the success or failure of any properly designed and installed system are determined by the way both the irrigation system as a whole and its component parts are operated and maintained.

Technical guidelines and manual on the requirements of operation and maintenance (O&M) of equipment and the system will be provided by the manufacturers and/or suppliers. But further as the efficient operation of an irrigation system depends mainly on the ability of the farmer to make the best use of it, the following is the general instruction for the farmers, and system operators with regard to the O&M of a sprinkler irrigation system.

5.1 OPERATION

Operation of sprinkler system according to schedule facilitates optimal utilization of the system, efficient water use and energy saving.

5.1.1 When and how long to irrigate

The application of the exact amount of water required by the crops at the right time is the main achievement of the irrigation installation. Farmers shall strictly follow the main elements of irrigation programming, such as water discharge and rate, operating hours and irrigation frequency for equity of water allocation as well as to achieve high water use efficiency. They shall also operate the system at the required pressure.

5.1.2 Starting and stopping the system

Starting and shutting down the system needs to be done very carefully in order to prevent surges and water hammer and to avoid air pockets in the pipelines. The opening and closing of the valves at the head of the system, the main and sub-main pipelines, should always be done slowly.

Farmers shall strictly follow the pumping operation schedules. The starting and stopping times for each pump unit shall be scheduled to match to the desired irrigation hours. There may be a need to readjust the pumping period when there would be adverse weather condition in terms of rain fall amount, distribution and intensity of solar radiation. The readjustment should be done either based on actual records or predictions of weather condition (rainfall or solar radiation) in the command areas and the surrounding environment. The farmers have to be informed and trained about the readjustment process in the irrigation system. If the measured rainfall is, for example, more than half of the daily deficit, farmers needs to be instructed to stop the pumping operation. Otherwise, in the absence of recorded rainfall data, personal judgment will govern to operate or not to operate the pump. However, to operate the pump at the delivery point, the supplier’s instructions should be followed.

5.2 MAINTENANCE

The performance of sprinkler system has to be monitored inreal-time. In addition to the daily monitoring of its performance, periodic inspection of individual components should be performed.

An indication of the comprehensive performance of the system can be obtained by the measurement of the flow rate by a water meter in the control head and comparing the measured value with the scheduled flow rate. Lower measurement results may indicate clogging of nozzles, while a higher measured flow rate may indicate breakage or leakage of water in the system or wear and expansion of the sprinkler nozzles.

The efficiency of the pumping system has significant effect on pumping energy costs. It is recommended to test the pump efficiency at least once every two years.

The integrity of the pipline system is a crucial factor in water use efficiency. Plastic pipes are damaged easily by rodents, woodpeckers, human beings, mechanical tools and in some cases by extreme climate conditions; overheating and freezing of water in the system.

Another deterimental phenomenon in pipelines and accssories is the precipitation of non-soluble salts from the irrigation water that reduce the cross-section of pipelines, thus increases friction head losses and may obstruct sprinklers. Preciptation affects small-diameter laterals more severely.

Mechanical tools can damage aluminium pipes. The most sensitive component is the rubber seal in the coupler. These seals are prone to degradation and wear by hot and dry weather and the friction in the course of coupling and uncoupling.

uPVC pipes are damaged by sunlight if they are not buried in the soil. HDPE pipes are prone to damage by animals and machines. Small plugs can fix small holes but in the case of bigger holes, the pipe has to be cut and joined by a special coupler.

Wear and tear in valves occurs initially to the flexible seals and the diaphrams in the hydraulic valves. In hydraulic valves, the control tubes have to be checked for integrity and leakage.

In filtering systems (if provided), the filtering elements have to be checked for integrity. In automatic back-flushed system, the control elements have to be tested for accuracy.

Sprinkler heads are prone to wear and malfunction. Hence, periodical and more frequent checks have to be done. The most wear-sensitive components of the sprinkler heads are the flexible seals, the nozzles, the springs and the hammer. In water carrying sand, there will be acclerated wear of metallic nozzles while plastic nozzles are more resistant. Enalrgment of the nozzle cross-section may cause upward deviation in the flow rate of the sprinkler and decrease in the distribution uniformity. Sprinkler nozzles need to be cleaned if found plugged and need to be replaced if found defective and worn.

The following may be taken as a guide as maintenance schedules for sprinkler systems.

Table 5-1: Maintenance schedule for sprinkler irrigation system (manual control)*

Monitor	With each cycle of irrigation	Annually
Inspect the system for leakage	X	
Check system pressure and system flow	X	
Service air valves, hydrants and other fittings		X
Check sprinklers for wear and replace springs, washers and nozzles where necessary		X
Flush mainlines		X
Replace rubbers at quick coupling pipes where necessary		X

REFERENCES

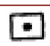
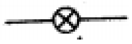
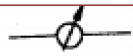
- Abdella Abdu. 2011. Sustainable Groundwater Development and Management for Irrigation in Raya and Kobo Valleys, Northern Ethiopia. Unpublished MSc. Thesis. Addis Ababa University.
- Awulachew, S.B., T. Erkossa and R.E. Namara. 2010. Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. IWMI.
- Azenkot A. 2001. Irrigation Systems. Irrigation and Soil Field Service. Mashav and Cinadco. Israel. MASHAV and CINADCO. Israel.
- FAO. 2001. Planning, Design, Operation and Maintainance. Planning, Development, Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation. Volume V, Module 10-14. Harare.
- FAO. 2001. Sprinkler Irrigation: Planning, Design, Operation and Maintainance. Planning, Development, Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation. Volume III, Module 8. Harare
- Girma, M.M., S.B. Awulachew. 2007. Irrigation Practices in Ethiopia: Characterstics of Selected Irrigation Schemes. International Water Management Insititute. Working Paper 24.
- Moshe, S. 2011. Sprinkler Irrigation - Technology and Application.
- Nathan, R. 2002. Fertilization Combined with Irrigation (Fertigation). Department of Soil and Irrigation. MASHAV and CINADCO. Israel.
- Phocaides, T. 2000. Technical Handbook on Pressurized Irrigation Techniques. FAO, Rome.
- Sapir, E. and M. Sne. 2001. Sprinkler Irrigation. Irrigation and Soil Field Service. MASHAV and CINADCO. Israel.
- WWDSE. 2008. Raya Valley Pressurized Irrigation Project – Final Detail Engineering Design Document.

APPENDICES

APPENDIX I: Unit conversion

Length:	
1m	100cm
1cm	10mm
1km	1000m
Area:	
1ha	10000m^2
1km^2	100ha
Volume:	
1m^3	1000 lit
1gallon	3.78 lit
Pressure:	
1 atm	1 bar
1atm	1kg/cm^2
1atm	10m head

APPENDIX II: Common symbols used in pressurized system

Well	
Pump	
Head control	
Water meter	
Filter	
Valve	
Hydraulic valve	
Hydraulic valve with a pilot	
Air release valve	
Flow rate(m^3/s)	
Head loss(m)	
Pressure (m)	

APPENDIX III: Sprinkler irrigation system design data collection form

Sprinkler Irrigation System Design Data Collection Form

1. General:

Place : _______________
Location : _______________
Size of Field, ha : _______________
Average land holding size, ha: _______________
No. of benefecieries: _______________

2. Soil Data:

Type : _______________
Infiltration rate: _______________
Field capacity, w/w : _______________
Permanent Wilting point, w/w: _______________
Dry bulk density: _____________________
Salinity, ds/m: ___________________

3. Crop Data:

Type : _______________
Effective depth of root zone: _______________
Maximum Allowable deficit: _______________
Max. Daily Consumption, mm/day: __________________

4. Water:

Source : _______________
Discharge, m^3/h: _______________
Quality, ds/m: _______________

APPENDIX IV: Sprinkler irrigation system uniformity of application test form

Sprinkler Irrigation System

Uniformity of Application Test

Place: ________________ **Date:** _____________ **Test No.:** __________

1. Sprinkler size: _____________
2. Pressure, bar: _____________
3. Flow Rate: _____________
4. Riser Height: _____________
5. Wind Speed, km/hr: _____________
6. Can Spacing: _____________
7. Start Time: _____________
8. End Time: _____________

APPENDIX V: HDPE pipes inner diameter and wall thickness

OD (mm)	Class									
	2.5		4		6		8		10	
	ID (mm)	Wall thickness	ID (mm)	Wall thickness	ID (mm)	Wall thickness	ID (mm)	Wall thickness	ID (mm)	Wall thickness
16									12.8	1.6
20							16.8	1.6	16.2	1.9
25					21.8	1.6	21.1	2.0	20.4	2.3
32			28.8	1.6	28.2	1.9	27.2	2.4	26.2	2.9
40			36.8	1.6	35.2	2.4	34.0	3.0	32.6	3.7
50	46.8	1.6	46.0	2.0	44.0	3.0	42.6	3.7	40.8	4.6
63	59.8	1.6	58.2	2.4	55.4	3.8	53.6	4.7	51.4	5.8
75	71.2	1.9	69.2	2.9	66.0	4.5	64.0	5.5	61.4	6.8
90	85.6	2.2	83.0	3.5	79.2	5.4	76.8	6.6	73.6	8.2
110	104.6	2.7	101.6	4.2	96.8	6.6	93.8	8.1	90.0	10.0
125	118.8	3.1	115.4	4.8	110.2	7.4	106.6	9.2	102.2	11.4
140	133.0	3.5	129.2	5.4	123.4	8.3	119.4	10.3	114.6	12.7
160	152.0	4.0	147.6	6.2	141.0	9.5	136.4	11.8	130.8	14.6
180	171.2	4.4	166.2	6.9	158.6	10.7	153.4	13.3	147.2	16.4

Source: Moshe, 2011

APPENDIX VI: PVC pipes inner diameter and wall thickness

OD (mm)	Class							
	4		6		8		10	
	ID (mm)	Wall thickness	ID (mm)	Wall thickness	ID (mm)	Wall thickness	ID (mm)	Wall thickness
63	59.4	1.8	59.0	2.0	58.2	2.4	57.0	3.0
75	71.4	1.8	70.4	2.3	69.2	2.9	67.8	3.6
90	86.4	1.8	84.4	2.8	83.0	3.5	81.4	4.3
110	105.6	2.2	103.2	3.4	101.6	4.2	99.4	5.3
140	134.4	2.8	131.4	4.3	129.2	5.4	126.6	6.7
160	153.6	3.2	150.2	4.9	147.6	6.2	144.6	7.7
225	216.2	4.4	211.2	6.9	207.8	8.6	203.4	10.8
280	269.0	5.5	262.8	8.6	258.6	10.7	253.2	13.4
315	302.6	6.2	295.6	9.7	290.8	12.1	285.0	15.0

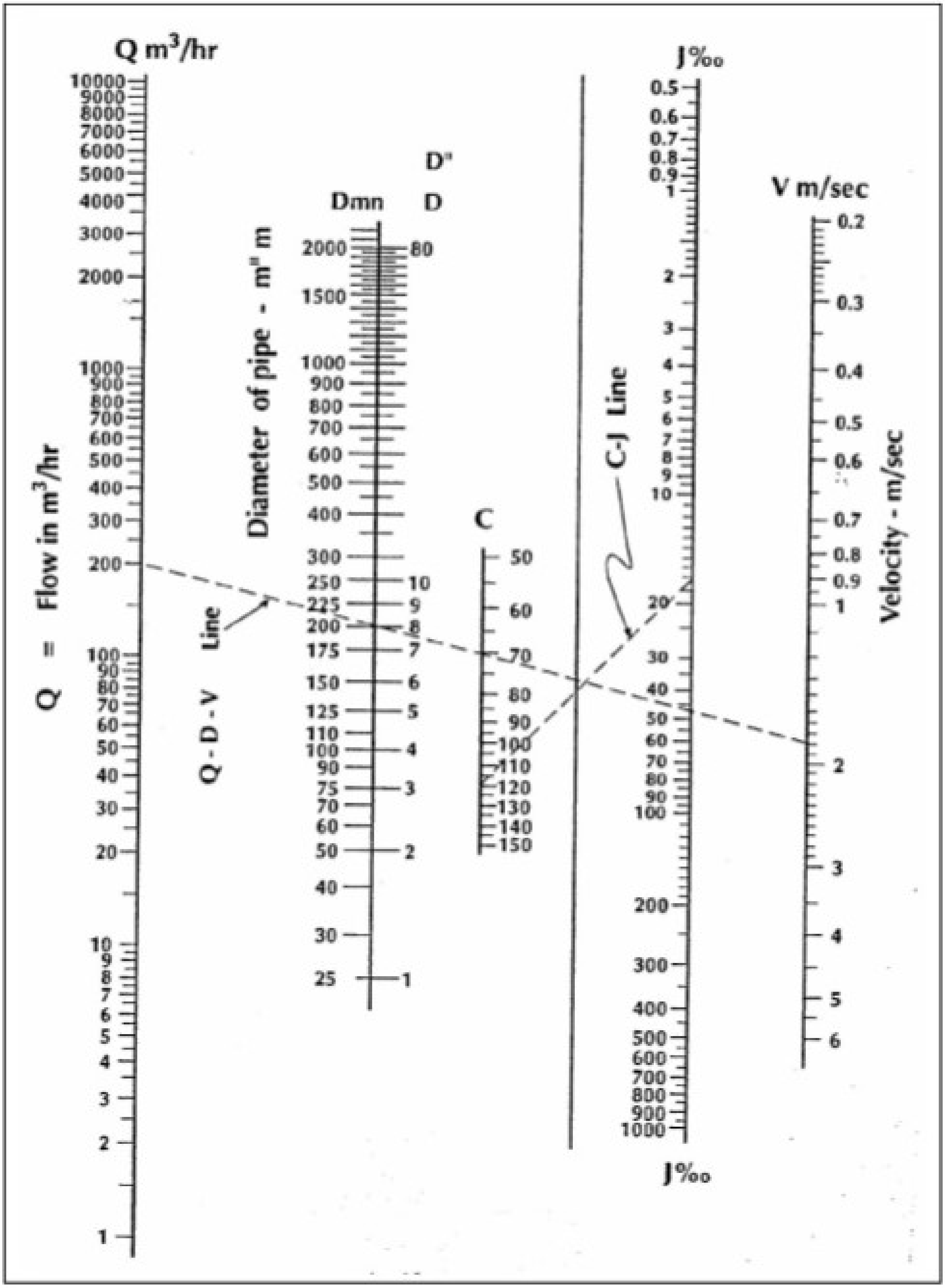
Source: Moshe, 2011

APPENDIX VII: Minor head loss coefficients

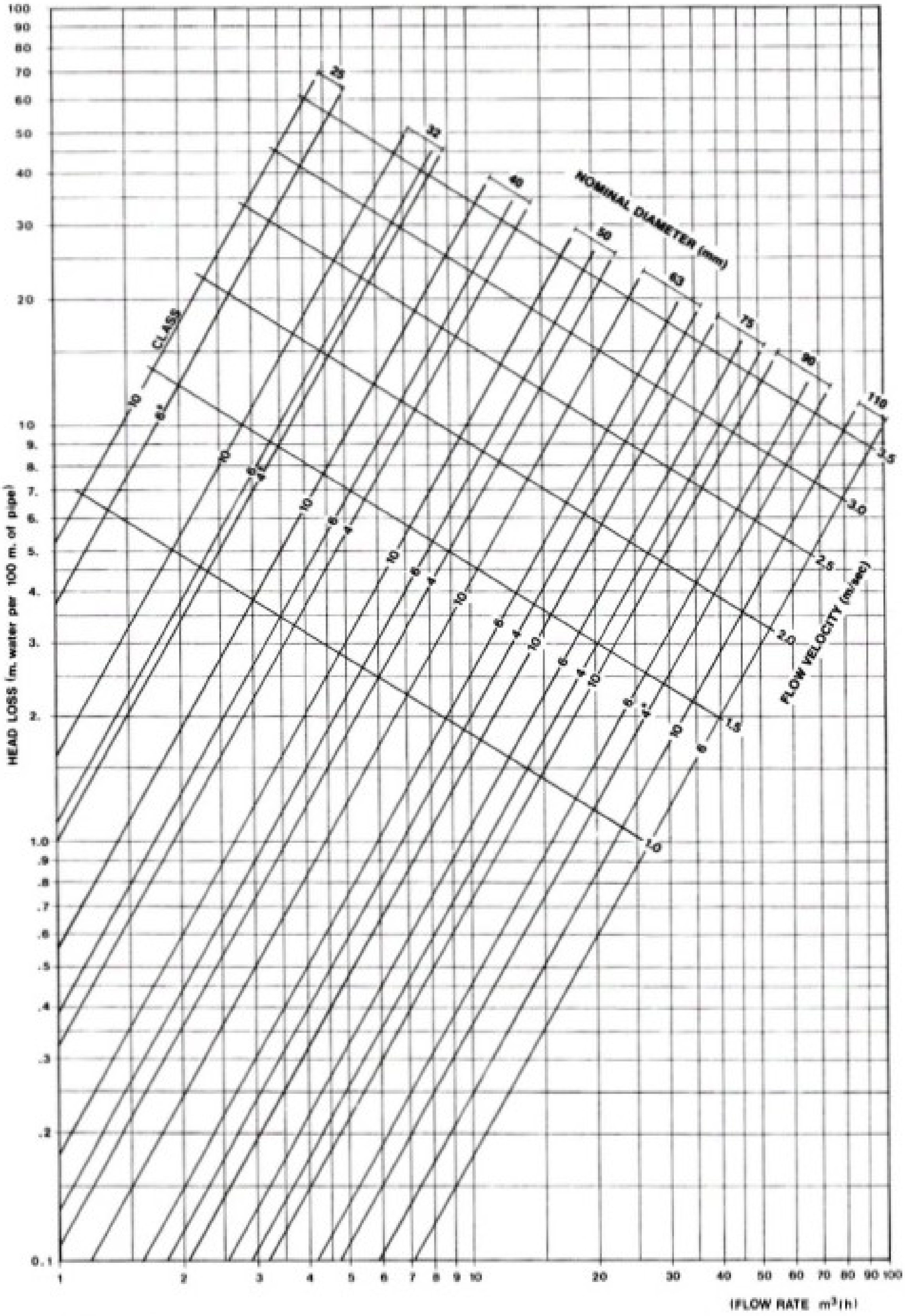
Fitting, valve	Loss coefficient, K	Fitting, Valve	Loss Coefficient, K
45^o standard elbow	0.35	Gate valve	0.20
90^o standard elbow	0.75	Three-fourths open	0.90
Coupling or union	0.04	On-half open	4.50
Tee, along run	0.40	One-fourth open	24.00
Branching flow	1.00	Globe valve, open	6.40
Ball check valve, open	70.00	Globe valve, half open	9.50

APPENDIX VIII: Slide rule for calculation of head losses by Hazen-Williams

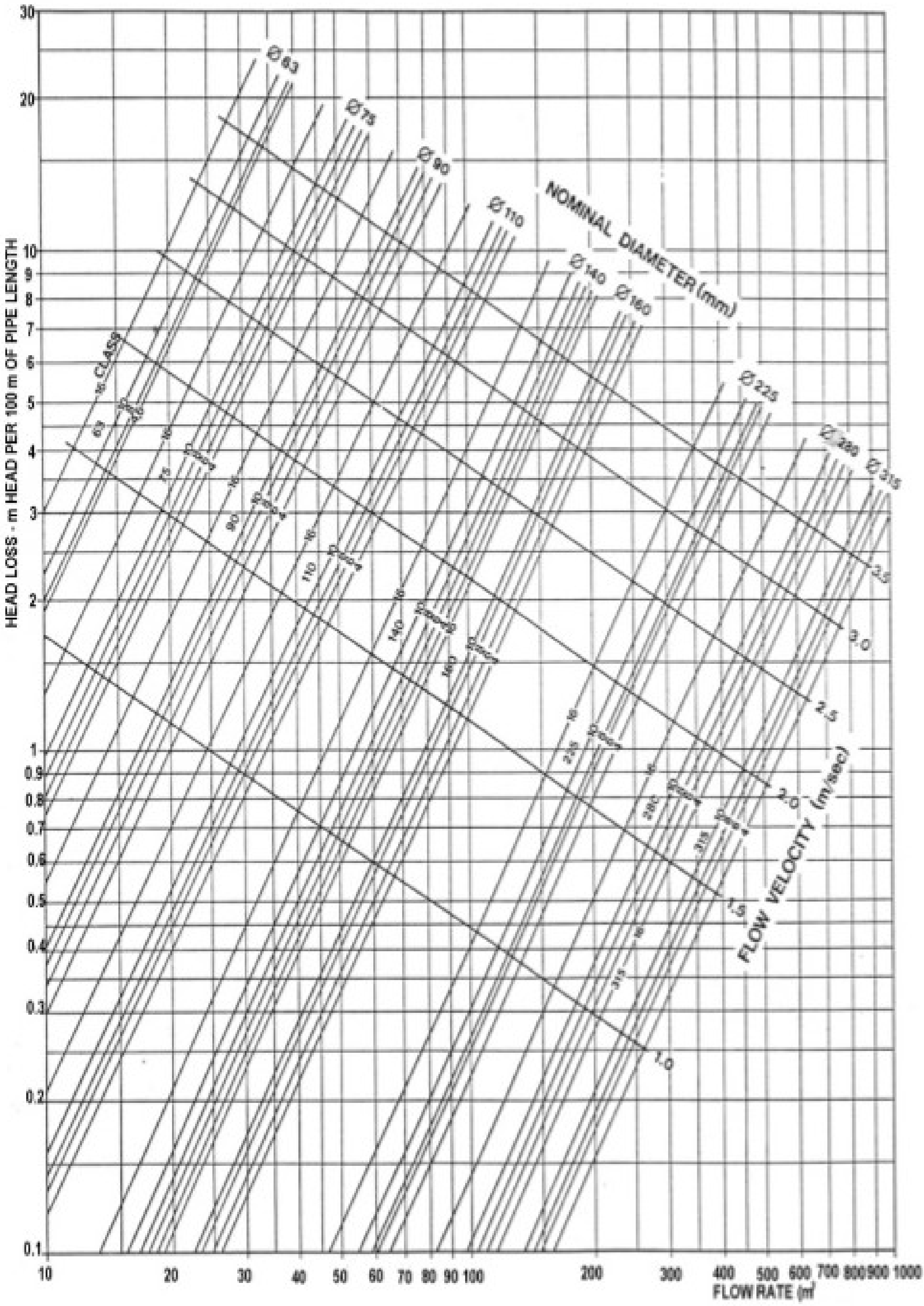
Formula



APPENDIX IX: Nomograph for calculation of head losses in HDPE pipes of different classes



APPENDIX X: Nomograph for calculation of head losses in PVC pipes of different classes



APPENDIX XI: Head loss chart for aluminum pipes, m.

Loss of Head, J in 100m Length					
Discharge (m^3/hr)	Nominal Diameter				
	2"	3"	4"	6"	8"
2	0.32	0.02			
3	0.71	0.09	0.01		
4	1.24	0.16	0.03		
6	1.89	0.23	0.05		
8	3.54	0.44	0.09		
10	5.69	0.72	0.17		
15	13.32	1.66	0.39	0.03	
20	20.95	2.62	0.63	0.07	0.01
30	49.50	6.07	1.40	0.19	0.04
35	63.00	7.82	1.82	0.23	0.05
40		9.70	2.28	0.30	0.06
45		11.71	2.78	0.37	0.08
50		14.39	3.36	0.44	0.10
55		17.02	3.94	0.51	0.12
60		21.18	4.90	0.60	0.15
80		34.50	8.05	1.06	0.26
90		44.60	10.42	1.36	0.33
100			12.90	1.68	0.40
120			19.31	2.58	0.58
150			29.90	3.89	0.92
180				5.02	1.20
200				6.23	1.50
250				9.18	2.19
300				14.60	3.48
350				18.90	4.51
400					5.11
425					6.14
450					6.85

APPENDIX XII: Head loss charts for PVC pipes

Friction Loss Charts for PVC Pipes Using Darcy-Weisbach Equation

Loss of Head, J in 100m Length (Class-4)

	63mm (ID=59.4)		75mm (ID=71.4)		90mm (ID=86.4)		110mm (ID=105.6)		140mm (ID=134.4)		160mm (ID=153.6)		225mm (ID=216.2)		280mm (ID=269)		315mm (ID=302.6)		
Discharge (m3/hr)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	Discharge (m3/hr)
1	0.100	0.031	0.069	0.013	0.047	0.005	0.032	0.002	0.020	0.000	0.015	0.000							1
2	0.201	0.106	0.139	0.044	0.095	0.018	0.063	0.007	0.039	0.002	0.030	0.001							2
3	0.301	0.215	0.208	0.090	0.142	0.036	0.095	0.014	0.059	0.004	0.045	0.002	0.023	0.000					3
4	0.401	0.356	0.278	0.149	0.190	0.060	0.127	0.023	0.078	0.006	0.060	0.003	0.030	0.001					4
5	0.501	0.526	0.347	0.219	0.237	0.089	0.159	0.034	0.098	0.009	0.075	0.005	0.038	0.001					5
6	0.602	0.724	0.416	0.302	0.284	0.122	0.190	0.047	0.118	0.013	0.090	0.007	0.045	0.001	0.029	0.000			6
7	0.702	0.948	0.486	0.395	0.332	0.160	0.222	0.062	0.137	0.017	0.105	0.009	0.053	0.002	0.034	0.001			7
8	0.802	1.197	0.555	0.500	0.379	0.202	0.254	0.078	0.157	0.022	0.120	0.011	0.061	0.002	0.039	0.001	0.031	0.000	8
9	0.903	1.471	0.625	0.614	0.427	0.248	0.286	0.096	0.176	0.027	0.135	0.014	0.068	0.003	0.044	0.001	0.035	0.001	9
10	1.003	1.769	0.694	0.738	0.474	0.298	0.317	0.115	0.196	0.033	0.150	0.017	0.076	0.003	0.049	0.001	0.039	0.001	10
12	1.203	2.434	0.833	1.016	0.569	0.411	0.381	0.158	0.235	0.046	0.180	0.024	0.091	0.005	0.059	0.002	0.046	0.001	12
14	1.404	3.188	0.972	1.330	0.664	0.538	0.444	0.207	0.274	0.060	0.210	0.032	0.106	0.006	0.068	0.002	0.054	0.001	14
16	1.605	4.027	1.111	1.680	0.758	0.679	0.508	0.262	0.313	0.077	0.240	0.040	0.121	0.008	0.078	0.003	0.062	0.002	16
18	1.805	4.949	1.249	2.065	0.853	0.835	0.571	0.322	0.353	0.096	0.270	0.050	0.136	0.010	0.088	0.003	0.070	0.002	18
20	2.006	5.951	1.388	2.483	0.948	1.004	0.635	0.387	0.392	0.116	0.300	0.061	0.151	0.012	0.098	0.004	0.077	0.002	20
22	2.206	7.031	1.527	2.934	1.043	1.186	0.698	0.457	0.431	0.138	0.330	0.072	0.167	0.014	0.108	0.005	0.085	0.003	22
24	2.407	8.187	1.666	3.416	1.138	1.381	0.762	0.532	0.470	0.162	0.360	0.085	0.182	0.016	0.117	0.006	0.093	0.003	24
26	2.608	9.418	1.805	3.930	1.232	1.589	0.825	0.612	0.509	0.187	0.390	0.098	0.197	0.019	0.127	0.007	0.100	0.004	26
28	2.808	10.722	1.944	4.474	1.327	1.809	0.889	0.697	0.549	0.215	0.420	0.113	0.212	0.022	0.137	0.008	0.108	0.004	28
30	3.009	12.098	2.082	5.048	1.422	2.041	0.952	0.787	0.588	0.243	0.450	0.128	0.227	0.024	0.147	0.009	0.116	0.005	30
35			2.429	6.611	1.659	2.673	1.111	1.030	0.686	0.323	0.525	0.169	0.265	0.032	0.171	0.011	0.135	0.006	35
40			2.776	8.352	1.896	3.376	1.269	1.302	0.784	0.412	0.600	0.216	0.303	0.041	0.196	0.014	0.155	0.008	40
45					2.133	4.149	1.428	1.599	0.882	0.511	0.675	0.268	0.341	0.051	0.220	0.018	0.174	0.010	45
50					2.370	4.989	1.587	1.923	0.979	0.620	0.750	0.325	0.379	0.062	0.245	0.022	0.193	0.012	50
55					2.607	5.894	1.745	2.272	1.077	0.738	0.825	0.387	0.416	0.074	0.269	0.026	0.213	0.015	55
60					2.844	6.864	1.904	2.646	1.175	0.865	0.900	0.454	0.454	0.087	0.293	0.030	0.232	0.017	60
65					3.081	7.896	2.063	3.044	1.273	1.002	0.975	0.526	0.492	0.101	0.318	0.035	0.251	0.020	65
70							2.221	3.465	1.371	1.147	1.050	0.602	0.530	0.115	0.342	0.040	0.271	0.023	70
75							2.380	3.910	1.469	1.302	1.125	0.683	0.568	0.131	0.367	0.046	0.290	0.026	75
80							2.539	4.378	1.567	1.465	1.200	0.769	0.606	0.147	0.391	0.051	0.309	0.029	80
85							2.697	4.868	1.665	1.637	1.275	0.859	0.643	0.165	0.416	0.057	0.328	0.032	85
90							2.856	5.380	1.763	1.817	1.350	0.953	0.681	0.183	0.440	0.064	0.348	0.036	90
95							3.015	5.914	1.861	2.006	1.425	1.053	0.719	0.202	0.465	0.070	0.367	0.040	95
100									1.959	2.204	1.500	1.156	0.757	0.222	0.489	0.077	0.386	0.044	100
105									2.057	2.409	1.575	1.264	0.795	0.243	0.513	0.084	0.406	0.048	105
110									2.155	2.624	1.650	1.377	0.833	0.264	0.538	0.092	0.425	0.052	110
120									2.351	3.076	1.800	1.614	0.908	0.310	0.587	0.108	0.464	0.061	120
125									2.449	3.040	1.875	1.739	0.946	0.334	0.611	0.116	0.483	0.066	125
135									2.645	3.479	2.025	2.002	1.022	0.384	0.660	0.134	0.522	0.076	135
145									2.841	3.942	2.175	2.282	1.098	0.438	0.709	0.152	0.560	0.086	145
150									2.938	4.183	2.250	2.428	1.136	0.466	0.734	0.162	0.580	0.092	150
160											2.400	2.733	1.211	0.524	0.782	0.182	0.618	0.103	160
170											2.550	3.053	1.287	0.586	0.831	0.204	0.657	0.115	170
180											2.700	3.052	1.363	0.650	0.880	0.226	0.696	0.128	180
190											2.850	3.355	1.438	0.718	0.929	0.250	0.734	0.142	190
200											3.000	3.670	1.514	0.789	0.978	0.274	0.773	0.155	200
225													1.703	0.978	1.100	0.340	0.870	0.193	225
250													1.893	1.186	1.223	0.413	0.966	0.234	250
275													2.082	1.412	1.345	0.492	1.063	0.278	275
300													2.271	1.656	1.467	0.576	1.159	0.326	300
325													2.460	1.917	1.589	0.667	1.256	0.378	325
350													2.650	2.196	1.712	0.764	1.353	0.433	350
375													2.839	2.491	1.834	0.867	1.449	0.491	375
400													3.028	2.804	1.956	0.976	1.546	0.553	400
450															2.201	1.211	1.739	0.686	450

Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velcoities of water are generally less than 3 m/s

Recommended velocity range is 1.5 to 2.5m/s (yellow shaded)

Friction Loss Charts for PVC Pipes Using Darcy-Weisbach Equation

Loss of Head, J in 100m Length (Class-6)

Discharge (m3/hr)	63mm (ID=59)		75mm (ID=70.4)		90mm (ID=84.4)		110mm (ID=103.2)		140mm (ID=131.4)		160mm (ID=150.2)		225mm (ID=211.2)		280mm (ID=262.8)		315mm (ID=295.6)		Discharge (m3/hr)
	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	
1	0.102	0.032	0.071	0.014	0.050	0.006	0.033	0.002	0.020	0.001	0.016	0.000							1
2	0.203	0.109	0.143	0.047	0.099	0.020	0.066	0.008	0.041	0.002	0.031	0.001							2
3	0.305	0.222	0.214	0.096	0.149	0.041	0.100	0.016	0.061	0.004	0.047	0.002	0.024	0.000					3
4	0.407	0.368	0.286	0.159	0.199	0.067	0.133	0.026	0.082	0.007	0.063	0.004	0.032	0.001					4
5	0.508	0.543	0.357	0.235	0.248	0.099	0.166	0.038	0.102	0.010	0.078	0.005	0.040	0.001	0.026	0.000			5
6	0.610	0.747	0.428	0.323	0.298	0.136	0.199	0.052	0.123	0.014	0.094	0.007	0.048	0.001	0.031	0.001			6
7	0.712	0.979	0.500	0.423	0.348	0.179	0.233	0.069	0.143	0.019	0.110	0.010	0.056	0.002	0.036	0.001			7
8	0.813	1.236	0.571	0.534	0.397	0.226	0.266	0.087	0.164	0.024	0.125	0.013	0.063	0.002	0.041	0.001	0.032	0.000	8
9	0.915	1.519	0.643	0.656	0.447	0.277	0.299	0.107	0.184	0.030	0.141	0.016	0.071	0.003	0.046	0.001	0.036	0.001	9
10	1.017	1.827	0.714	0.789	0.497	0.334	0.332	0.128	0.205	0.036	0.157	0.019	0.079	0.004	0.051	0.001	0.040	0.001	10
12	1.220	2.513	0.857	1.086	0.596	0.459	0.399	0.177	0.246	0.051	0.188	0.027	0.095	0.005	0.061	0.002	0.049	0.001	12
14	1.423	3.292	1.000	1.422	0.695	0.601	0.465	0.231	0.287	0.067	0.220	0.035	0.111	0.007	0.072	0.002	0.057	0.001	14
16	1.626	4.158	1.142	1.797	0.795	0.759	0.532	0.292	0.328	0.086	0.251	0.045	0.127	0.009	0.082	0.003	0.065	0.002	16
18	1.830	5.110	1.285	2.208	0.894	0.933	0.598	0.359	0.369	0.107	0.282	0.056	0.143	0.011	0.092	0.004	0.073	0.002	18
20	2.033	6.145	1.428	2.655	0.994	1.122	0.665	0.432	0.410	0.129	0.314	0.068	0.159	0.013	0.102	0.005	0.081	0.003	20
22	2.236	7.260	1.571	3.137	1.093	1.325	0.731	0.510	0.451	0.154	0.345	0.081	0.175	0.016	0.113	0.005	0.089	0.003	22
24	2.440	8.454	1.714	3.653	1.192	1.543	0.797	0.594	0.492	0.180	0.376	0.095	0.190	0.018	0.123	0.006	0.097	0.004	24
26	2.643	9.725	1.856	4.202	1.292	1.776	0.864	0.683	0.533	0.209	0.408	0.109	0.206	0.021	0.133	0.007	0.105	0.004	26
28	2.846	11.072	1.999	4.784	1.391	2.021	0.930	0.778	0.574	0.239	0.439	0.125	0.222	0.024	0.143	0.008	0.113	0.005	28
30	3.050	12.493	2.142	5.398	1.490	2.281	0.997	0.877	0.615	0.271	0.471	0.142	0.238	0.027	0.154	0.010	0.121	0.005	30
35			2.499	7.070	1.739	2.987	1.163	1.149	0.717	0.360	0.549	0.189	0.278	0.036	0.179	0.013	0.142	0.007	35
40			2.856	8.931	1.987	3.773	1.329	1.452	0.820	0.459	0.627	0.241	0.317	0.046	0.205	0.016	0.162	0.009	40
45					2.235	4.637	1.495	1.784	0.922	0.570	0.706	0.299	0.357	0.058	0.231	0.020	0.182	0.011	45
50					2.484	5.576	1.661	2.145	1.025	0.691	0.784	0.362	0.397	0.070	0.256	0.024	0.202	0.014	50
55					2.732	6.588	1.827	2.535	1.127	0.823	0.863	0.431	0.436	0.083	0.282	0.029	0.223	0.016	55
60					2.981	7.672	1.994	2.951	1.230	0.965	0.941	0.506	0.476	0.098	0.307	0.034	0.243	0.019	60
65							2.160	3.395	1.332	1.117	1.020	0.586	0.516	0.113	0.333	0.039	0.263	0.022	65
70							2.326	3.865	1.435	1.279	1.098	0.671	0.555	0.129	0.359	0.045	0.283	0.025	70
75							2.492	4.361	1.537	1.452	1.176	0.761	0.595	0.147	0.384	0.051	0.304	0.029	75
80							2.658	4.883	1.640	1.634	1.255	0.856	0.635	0.165	0.410	0.057	0.324	0.033	80
85							2.824	5.429	1.742	1.825	1.333	0.957	0.674	0.184	0.436	0.064	0.344	0.036	85
90							2.990	6.001	1.845	2.027	1.412	1.062	0.714	0.205	0.461	0.071	0.364	0.040	90
95									1.947	2.237	1.490	1.173	0.754	0.226	0.487	0.079	0.385	0.045	95
100									2.049	2.458	1.569	1.288	0.793	0.248	0.512	0.086	0.405	0.049	100
105									2.152	2.687	1.647	1.409	0.833	0.272	0.538	0.094	0.425	0.054	105
110									2.254	2.926	1.725	1.534	0.873	0.296	0.564	0.103	0.445	0.058	110
120									2.459	3.431	1.882	1.798	0.952	0.347	0.615	0.121	0.486	0.068	120
125									2.562	3.697	1.961	1.938	0.992	0.374	0.640	0.130	0.506	0.074	125
135									2.767	4.256	2.117	2.231	1.071	0.430	0.692	0.150	0.547	0.085	135
145									2.972	4.851	2.274	2.543	1.150	0.490	0.743	0.171	0.587	0.097	145
150									3.074	5.161	2.353	2.705	1.190	0.522	0.769	0.181	0.607	0.103	150
160											2.510	3.045	1.269	0.587	0.820	0.204	0.648	0.116	160
170											2.666	3.402	1.349	0.656	0.871	0.228	0.688	0.129	170
180											2.823	3.777	1.428	0.728	0.922	0.253	0.729	0.144	180
190											2.980	4.170	1.507	0.804	0.973	0.280	0.769	0.158	190
200													1.587	0.883	1.025	0.307	0.810	0.174	200
225													1.785	1.095	1.153	0.381	0.911	0.216	225
250													1.983	1.328	1.281	0.462	1.012	0.262	250
275													2.182	1.581	1.409	0.550	1.114	0.312	275
300													2.380	1.854	1.537	0.645	1.215	0.366	300
325													2.578	2.147	1.665	0.747	1.316	0.423	325
350													2.777	2.459	1.793	0.855	1.417	0.485	350
375													2.975	2.789	1.921	0.971	1.519	0.550	375
400															2.049	1.092	1.620	0.619	400
450															2.306	1.355	1.822	0.768	450

Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velcoities of water are generally less than 3 m/s

Recommended velocity range is 1.5 to 2.5m/s (yellow shaded)

Friction Loss Charts for PVC Pipes Using Darcy-Weisbach Equation

Loss of Head, J in 100m Length (Class-8)

Discharge (m3/hr)	63mm (ID=58.2)		75mm (ID=69.2)		90mm (ID=83.0)		110mm (ID=101.6)		140mm (ID=129.2)		160mm (ID=147.6)		225mm (ID=207.8)		280mm (ID=258.6)		315mm (ID=290.8)		Discharge (m3/hr)
	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	
1	0.104	0.035	0.074	0.015	0.051	0.006	0.034	0.002	0.021	0.001	0.016	0.000							1
2	0.209	0.117	0.148	0.051	0.103	0.022	0.069	0.008	0.042	0.003	0.032	0.001	0.016	0.000					2
3	0.313	0.237	0.222	0.104	0.154	0.044	0.103	0.017	0.064	0.005	0.049	0.003	0.025	0.001					3
4	0.418	0.392	0.296	0.172	0.205	0.073	0.137	0.028	0.085	0.009	0.065	0.005	0.033	0.001					4
5	0.522	0.580	0.369	0.255	0.257	0.107	0.171	0.041	0.106	0.013	0.081	0.007	0.041	0.001	0.026	0.000			5
6	0.627	0.797	0.443	0.350	0.308	0.148	0.206	0.057	0.127	0.018	0.097	0.010	0.049	0.002	0.032	0.001	0.025	0.000	6
7	0.731	1.044	0.517	0.459	0.360	0.193	0.240	0.074	0.148	0.024	0.114	0.013	0.057	0.002	0.037	0.001	0.029	0.001	7
8	0.836	1.319	0.591	0.580	0.411	0.244	0.274	0.094	0.170	0.030	0.130	0.016	0.066	0.003	0.042	0.001	0.033	0.001	8
9	0.940	1.621	0.665	0.712	0.462	0.300	0.309	0.115	0.191	0.037	0.146	0.019	0.074	0.004	0.048	0.001	0.038	0.001	9
10	1.045	1.949	0.739	0.857	0.514	0.361	0.343	0.138	0.212	0.044	0.162	0.023	0.082	0.005	0.053	0.002	0.042	0.001	10
12	1.254	2.682	0.887	1.178	0.616	0.497	0.411	0.190	0.254	0.061	0.195	0.032	0.098	0.006	0.063	0.002	0.050	0.001	12
14	1.463	3.512	1.035	1.543	0.719	0.651	0.480	0.249	0.297	0.080	0.227	0.042	0.115	0.008	0.074	0.003	0.059	0.002	14
16	1.671	4.437	1.182	1.950	0.822	0.822	0.548	0.315	0.339	0.100	0.260	0.053	0.131	0.011	0.085	0.004	0.067	0.002	16
18	1.880	5.452	1.330	2.396	0.925	1.010	0.617	0.387	0.382	0.123	0.292	0.066	0.148	0.013	0.095	0.005	0.075	0.003	18
20	2.089	6.556	1.478	2.881	1.027	1.215	0.686	0.465	0.424	0.148	0.325	0.079	0.164	0.016	0.106	0.005	0.084	0.003	20
22	2.298	7.746	1.626	3.404	1.130	1.435	0.754	0.549	0.466	0.175	0.357	0.093	0.180	0.018	0.116	0.006	0.092	0.004	22
24	2.507	9.020	1.773	3.964	1.233	1.671	0.823	0.640	0.509	0.204	0.390	0.109	0.197	0.021	0.127	0.008	0.100	0.004	24
26	2.716	10.377	1.921	4.560	1.336	1.922	0.891	0.736	0.551	0.235	0.422	0.125	0.213	0.025	0.138	0.009	0.109	0.005	26
28	2.925	11.814	2.069	5.191	1.438	2.189	0.960	0.838	0.594	0.267	0.455	0.142	0.229	0.028	0.148	0.010	0.117	0.006	28
30			2.217	5.857	1.541	2.469	1.028	0.945	0.636	0.302	0.487	0.160	0.246	0.032	0.159	0.011	0.126	0.006	30
35			2.586	7.671	1.798	3.234	1.200	1.238	0.742	0.395	0.568	0.210	0.287	0.041	0.185	0.015	0.146	0.008	35
40			2.956	9.690	2.055	4.085	1.371	1.564	0.848	0.499	0.650	0.265	0.328	0.052	0.212	0.018	0.167	0.011	40
45					2.311	5.020	1.543	1.921	0.954	0.614	0.731	0.326	0.369	0.064	0.238	0.023	0.188	0.013	45
50					2.568	6.037	1.714	2.310	1.060	0.738	0.812	0.392	0.410	0.077	0.265	0.027	0.209	0.016	50
55					2.825	7.133	1.885	2.730	1.166	0.872	0.893	0.463	0.451	0.091	0.291	0.032	0.230	0.018	55
60					3.082	8.306	2.057	3.179	1.272	1.015	0.975	0.539	0.492	0.106	0.317	0.038	0.251	0.022	60
65							2.228	3.657	1.378	1.168	1.056	0.620	0.533	0.122	0.344	0.043	0.272	0.025	65
70							2.400	4.163	1.484	1.329	1.137	0.706	0.574	0.139	0.370	0.049	0.293	0.028	70
75							2.571	4.697	1.590	1.500	1.218	0.797	0.615	0.157	0.397	0.056	0.314	0.032	75
80							2.742	5.259	1.696	1.679	1.299	0.892	0.656	0.176	0.423	0.062	0.335	0.036	80
85							2.914	5.848	1.802	1.867	1.381	0.992	0.697	0.195	0.450	0.069	0.356	0.040	85
90							3.085	7.019	1.908	2.064	1.462	1.096	0.738	0.216	0.476	0.076	0.377	0.044	90
95									2.014	2.269	1.543	1.205	0.779	0.237	0.503	0.084	0.398	0.048	95
100									2.120	2.482	1.624	1.319	0.819	0.260	0.529	0.092	0.418	0.053	100
105									2.226	2.703	1.705	1.436	0.860	0.283	0.556	0.100	0.439	0.057	105
110									2.332	2.932	1.787	1.558	0.901	0.307	0.582	0.109	0.460	0.062	110
120									2.544	3.414	1.949	1.814	0.983	0.357	0.635	0.126	0.502	0.072	120
125									2.650	3.667	2.030	1.948	1.024	0.384	0.661	0.136	0.523	0.078	125
135									2.862	4.196	2.193	2.229	1.106	0.439	0.714	0.155	0.565	0.089	135
145									3.074	4.755	2.355	2.526	1.188	0.498	0.767	0.176	0.607	0.101	145
150											2.436	2.681	1.229	0.528	0.794	0.187	0.628	0.107	150
160											2.599	3.001	1.311	0.591	0.847	0.209	0.670	0.120	160
170											2.761	3.337	1.393	0.657	0.900	0.233	0.711	0.133	170
180											2.924	3.688	1.475	0.726	0.952	0.257	0.753	0.147	180
190											3.086	4.054	1.557	0.798	1.005	0.283	0.795	0.162	190
200													1.639	0.873	1.058	0.309	0.837	0.177	200
225													1.844	1.073	1.191	0.380	0.942	0.218	225
250													2.049	1.291	1.323	0.457	1.046	0.262	250
275													2.254	1.525	1.455	0.540	1.151	0.309	275
300													2.458	1.776	1.587	0.628	1.255	0.360	300
325													2.663	2.043	1.720	0.723	1.360	0.414	325
350													2.868	2.326	1.852	0.823	1.465	0.471	350
375													3.073	2.624	1.984	0.929	1.569	0.532	375
400															2.117	1.040	1.674	0.595	400
450															2.381	1.278	1.883	0.732	450

Notes: Head loss values are subjected to the following conditions:

- Pipes are flowing full.
- Pipes are carrying clear water at approximately 15.6°C
- Velcoities of water are generally less than 3 m/s
- Recommended velocity range is 1.5 to 2.5m/s (yellow shaded)

Friction Loss Charts for PVC Pipes Using Hazen-Williams Equation (C=150)

Loss of Head, J in 100m Length (Class-4)

	63mm (ID=59.4)		75mm (ID=71.4)		90mm (ID=86.4)		110mm (ID=105.6)		140mm (ID=134.4)		160mm (ID=153.6)		225mm (ID=216.2)		280mm (ID=269)		315mm (ID=302.6)		
Discharge (m3/hr)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	Discharge (m3/hr)
1	0.100	0.024	0.069	0.010	0.047	0.004	0.032	0.001	0.020	0.000	0.015	0.000							1
2	0.201	0.088	0.139	0.036	0.095	0.014	0.063	0.005	0.039	0.002	0.030	0.001							2
3	0.301	0.186	0.208	0.076	0.142	0.030	0.095	0.011	0.059	0.003	0.045	0.002	0.023	0.000					3
4	0.401	0.316	0.278	0.129	0.190	0.051	0.127	0.019	0.078	0.006	0.060	0.003	0.030	0.001					4
5	0.501	0.478	0.347	0.195	0.237	0.077	0.159	0.029	0.098	0.009	0.075	0.005	0.038	0.001					5
6	0.602	0.670	0.416	0.274	0.284	0.108	0.190	0.041	0.118	0.013	0.090	0.007	0.045	0.001	0.029	0.000			6
7	0.702	0.892	0.486	0.364	0.332	0.144	0.222	0.054	0.137	0.017	0.105	0.009	0.053	0.002	0.034	0.001			7
8	0.802	1.142	0.555	0.466	0.379	0.184	0.254	0.069	0.157	0.021	0.120	0.011	0.061	0.002	0.039	0.001	0.031	0.000	8
9	0.903	1.420	0.625	0.580	0.427	0.229	0.286	0.086	0.176	0.027	0.135	0.014	0.068	0.003	0.044	0.001	0.035	0.001	9
10	1.003	1.726	0.694	0.704	0.474	0.278	0.317	0.105	0.196	0.032	0.150	0.017	0.076	0.003	0.049	0.001	0.039	0.001	10
12	1.203	2.419	0.833	0.987	0.569	0.390	0.381	0.147	0.235	0.045	0.180	0.024	0.091	0.004	0.059	0.002	0.046	0.001	12
14	1.404	3.218	0.972	1.314	0.664	0.519	0.444	0.195	0.274	0.060	0.210	0.031	0.106	0.006	0.068	0.002	0.054	0.001	14
16	1.605	4.121	1.111	1.682	0.758	0.665	0.508	0.250	0.313	0.077	0.240	0.040	0.121	0.008	0.078	0.003	0.062	0.001	16
18	1.805	5.126	1.249	2.092	0.853	0.827	0.571	0.311	0.353	0.096	0.270	0.050	0.136	0.009	0.088	0.003	0.070	0.002	18
20	2.006	6.230	1.388	2.543	0.948	1.005	0.635	0.378	0.392	0.117	0.300	0.061	0.151	0.012	0.098	0.004	0.077	0.002	20
22	2.206	7.433	1.527	3.034	1.043	1.199	0.698	0.451	0.431	0.139	0.330	0.073	0.167	0.014	0.108	0.005	0.085	0.003	22
24	2.407	8.733	1.666	3.564	1.138	1.408	0.762	0.530	0.470	0.164	0.360	0.085	0.182	0.016	0.117	0.006	0.093	0.003	24
26	2.608	10.128	1.805	4.134	1.232	1.633	0.825	0.615	0.509	0.190	0.390	0.099	0.197	0.019	0.127	0.006	0.100	0.004	26
28	2.808	11.618	1.944	4.742	1.327	1.874	0.889	0.705	0.549	0.218	0.420	0.114	0.212	0.022	0.137	0.007	0.108	0.004	28
30	3.009	13.202	2.082	5.388	1.422	2.129	0.952	0.801	0.588	0.248	0.450	0.129	0.227	0.024	0.147	0.008	0.116	0.005	30
35			2.429	7.169	1.659	2.832	1.111	1.066	0.686	0.329	0.525	0.172	0.265	0.033	0.171	0.011	0.135	0.006	35
40			2.776	9.180	1.896	3.627	1.269	1.365	0.784	0.422	0.600	0.220	0.303	0.042	0.196	0.014	0.155	0.008	40
45					2.133	4.511	1.428	1.698	0.882	0.525	0.675	0.274	0.341	0.052	0.220	0.018	0.174	0.010	45
50					2.370	5.483	1.587	2.063	0.979	0.638	0.750	0.333	0.379	0.063	0.245	0.022	0.193	0.012	50
55					2.607	6.541	1.745	2.462	1.077	0.761	0.825	0.397	0.416	0.075	0.269	0.026	0.213	0.015	55
60					2.844	7.685	1.904	2.892	1.175	0.894	0.900	0.466	0.454	0.088	0.293	0.030	0.232	0.017	60
65					3.081	8.913	2.063	3.354	1.273	1.036	0.975	0.541	0.492	0.102	0.318	0.035	0.251	0.020	65
70							2.221	3.848	1.371	1.189	1.050	0.620	0.530	0.117	0.342	0.041	0.271	0.023	70
75							2.380	4.372	1.469	1.351	1.125	0.705	0.568	0.133	0.367	0.046	0.290	0.026	75
80							2.539	4.927	1.567	1.523	1.200	0.795	0.606	0.150	0.391	0.052	0.309	0.029	80
85							2.697	5.513	1.665	1.703	1.275	0.889	0.643	0.168	0.416	0.058	0.328	0.033	85
90							2.856	6.129	1.763	1.894	1.350	0.988	0.681	0.187	0.440	0.065	0.348	0.036	90
95							3.015	6.774	1.861	2.093	1.425	1.092	0.719	0.207	0.465	0.071	0.367	0.040	95
100									1.959	2.302	1.500	1.201	0.757	0.227	0.489	0.078	0.386	0.044	100
105									2.057	2.519	1.575	1.315	0.795	0.249	0.513	0.086	0.406	0.048	105
110									2.155	2.746	1.650	1.433	0.833	0.271	0.538	0.094	0.425	0.053	110
120									2.351	3.226	1.800	1.684	0.908	0.319	0.587	0.110	0.464	0.062	120
125									2.449	3.479	1.875	1.816	0.946	0.344	0.611	0.119	0.483	0.067	125
135									2.645	4.013	2.025	2.094	1.022	0.396	0.660	0.137	0.522	0.077	135
145									2.841	4.580	2.175	2.390	1.098	0.452	0.709	0.156	0.560	0.088	145
150									2.938	4.877	2.250	2.545	1.136	0.482	0.734	0.166	0.580	0.094	150
160											2.400	2.868	1.211	0.543	0.782	0.187	0.618	0.106	160
170											2.550	3.209	1.287	0.607	0.831	0.210	0.657	0.118	170
180											2.700	3.568	1.363	0.675	0.880	0.233	0.696	0.131	180
190											2.850	3.943	1.438	0.746	0.929	0.257	0.734	0.145	190
200											3.000	4.336	1.514	0.821	0.978	0.283	0.773	0.160	200
225													1.703	1.021	1.100	0.352	0.870	0.198	225
250													1.893	1.240	1.223	0.428	0.966	0.241	250
275													2.082	1.480	1.345	0.511	1.063	0.288	275
300													2.271	1.739	1.467	0.600	1.159	0.338	300
325													2.460	2.017	1.589	0.696	1.256	0.392	325
350													2.650	2.313	1.712	0.798	1.353	0.450	350
375													2.839	2.628	1.834	0.907	1.449	0.511	375
400													3.028	2.962	1.956	1.022	1.546	0.576	400
450															2.201	1.271	1.739	0.717	450

Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velcoities of water are generally less than 3 m/s

Recommended velocity range is 1.5 to 2.5m/s (yellow shaded)

Friction Loss Charts for PVC Pipes Using Hazen-Williams Equation (C=150)

Loss of Head, J in 100m Length (Class-6)

Discharge (m3/hr)	63mm (ID=59)		75mm (ID=70.4)		90mm (ID=84.4)		110mm (ID=103.2)		140mm (ID=131.4)		160mm (ID=150.2)		225mm (ID=211.2)		280mm (ID=262.8)		315mm (ID=295.6)		Discharge (m3/hr)
	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	
1	0.102	0.025	0.071	0.011	0.050	0.004	0.033	0.002	0.020	0.001	0.016	0.000							1
2	0.203	0.091	0.143	0.038	0.099	0.016	0.066	0.006	0.041	0.002	0.031	0.001							2
3	0.305	0.192	0.214	0.081	0.149	0.034	0.100	0.013	0.061	0.004	0.047	0.002	0.024	0.000					3
4	0.407	0.327	0.286	0.138	0.199	0.057	0.133	0.021	0.082	0.007	0.063	0.003	0.032	0.001					4
5	0.508	0.494	0.357	0.209	0.248	0.086	0.166	0.032	0.102	0.010	0.078	0.005	0.040	0.001					5
6	0.610	0.693	0.428	0.293	0.298	0.121	0.199	0.045	0.123	0.014	0.094	0.007	0.048	0.001	0.031	0.000			6
7	0.712	0.921	0.500	0.390	0.348	0.161	0.233	0.061	0.143	0.019	0.110	0.010	0.056	0.002	0.036	0.001			7
8	0.813	1.180	0.571	0.499	0.397	0.206	0.266	0.077	0.164	0.024	0.125	0.012	0.063	0.002	0.041	0.001	0.032	0.000	8
9	0.915	1.467	0.643	0.621	0.447	0.257	0.299	0.096	0.184	0.030	0.141	0.015	0.071	0.003	0.046	0.001	0.036	0.001	9
10	1.017	1.784	0.714	0.755	0.497	0.312	0.332	0.117	0.205	0.036	0.157	0.019	0.079	0.004	0.051	0.001	0.040	0.001	10
12	1.220	2.500	0.857	1.058	0.596	0.437	0.399	0.164	0.246	0.051	0.188	0.026	0.095	0.005	0.061	0.002	0.049	0.001	12
14	1.423	3.326	1.000	1.407	0.695	0.582	0.465	0.218	0.287	0.067	0.220	0.035	0.111	0.007	0.072	0.002	0.057	0.001	14
16	1.626	4.259	1.142	1.802	0.795	0.745	0.532	0.280	0.328	0.086	0.251	0.045	0.127	0.009	0.082	0.003	0.065	0.002	16
18	1.830	5.297	1.285	2.241	0.894	0.926	0.598	0.348	0.369	0.107	0.282	0.056	0.143	0.011	0.092	0.004	0.073	0.002	18
20	2.033	6.439	1.428	2.724	0.994	1.126	0.665	0.423	0.410	0.130	0.314	0.068	0.159	0.013	0.102	0.004	0.081	0.003	20
22	2.236	7.682	1.571	3.250	1.093	1.343	0.731	0.505	0.451	0.156	0.345	0.081	0.175	0.015	0.113	0.005	0.089	0.003	22
24	2.440	9.025	1.714	3.818	1.192	1.578	0.797	0.593	0.492	0.183	0.376	0.095	0.190	0.018	0.123	0.006	0.097	0.004	24
26	2.643	10.467	1.856	4.428	1.292	1.831	0.864	0.687	0.533	0.212	0.408	0.111	0.206	0.021	0.133	0.007	0.105	0.004	26
28	2.846	12.007	1.999	5.079	1.391	2.100	0.930	0.789	0.574	0.243	0.439	0.127	0.222	0.024	0.143	0.008	0.113	0.005	28
30	3.050	13.643	2.142	5.772	1.490	2.386	0.997	0.896	0.615	0.276	0.471	0.144	0.238	0.027	0.154	0.009	0.121	0.005	30
35			2.499	7.679	1.739	3.174	1.163	1.192	0.717	0.368	0.549	0.192	0.278	0.036	0.179	0.013	0.142	0.007	35
40			2.856	9.833	1.987	4.065	1.329	1.527	0.820	0.471	0.627	0.245	0.317	0.047	0.205	0.016	0.162	0.009	40
45					2.235	5.056	1.495	1.899	0.922	0.586	0.706	0.305	0.357	0.058	0.231	0.020	0.182	0.011	45
50					2.484	6.145	1.661	2.308	1.025	0.712	0.784	0.371	0.397	0.071	0.256	0.024	0.202	0.014	50
55					2.732	7.332	1.827	2.753	1.127	0.849	0.863	0.443	0.436	0.084	0.282	0.029	0.223	0.016	55
60					2.981	8.614	1.994	3.235	1.230	0.998	0.941	0.520	0.476	0.099	0.307	0.034	0.243	0.019	60
65							2.160	3.752	1.332	1.157	1.020	0.603	0.516	0.115	0.333	0.040	0.263	0.022	65
70							2.326	4.304	1.435	1.327	1.098	0.692	0.555	0.132	0.359	0.045	0.283	0.026	70
75							2.492	4.890	1.537	1.508	1.176	0.786	0.595	0.150	0.384	0.052	0.304	0.029	75
80							2.658	5.511	1.640	1.699	1.255	0.886	0.635	0.169	0.410	0.058	0.324	0.033	80
85							2.824	6.166	1.742	1.901	1.333	0.991	0.674	0.189	0.436	0.065	0.344	0.037	85
90							2.990	6.855	1.845	2.114	1.412	1.102	0.714	0.210	0.461	0.072	0.364	0.041	90
95									1.947	2.336	1.490	1.218	0.754	0.232	0.487	0.080	0.385	0.045	95
100									2.049	2.569	1.569	1.340	0.793	0.255	0.512	0.088	0.405	0.050	100
105									2.152	2.812	1.647	1.466	0.833	0.279	0.538	0.096	0.425	0.054	105
110									2.254	3.065	1.725	1.598	0.873	0.304	0.564	0.105	0.445	0.059	110
120									2.459	3.601	1.882	1.878	0.952	0.357	0.615	0.123	0.486	0.069	120
125									2.562	3.884	1.961	2.025	0.992	0.385	0.640	0.133	0.506	0.075	125
135									2.767	4.479	2.117	2.335	1.071	0.444	0.692	0.153	0.547	0.086	135
145									2.972	5.113	2.274	2.666	1.150	0.507	0.743	0.175	0.587	0.099	145
150									3.074	5.444	2.353	2.838	1.190	0.540	0.769	0.186	0.607	0.105	150
160											2.510	3.199	1.269	0.608	0.820	0.210	0.648	0.118	160
170											2.666	3.579	1.349	0.681	0.871	0.235	0.688	0.132	170
180											2.823	3.979	1.428	0.757	0.922	0.261	0.729	0.147	180
190											2.980	4.398	1.507	0.836	0.973	0.288	0.769	0.163	190
200													1.587	0.920	1.025	0.317	0.810	0.179	200
225													1.785	1.144	1.153	0.394	0.911	0.222	225
250													1.983	1.390	1.281	0.479	1.012	0.270	250
275													2.182	1.659	1.409	0.572	1.114	0.323	275
300													2.380	1.949	1.537	0.672	1.215	0.379	300
325													2.578	2.260	1.665	0.779	1.316	0.440	325
350													2.777	2.592	1.793	0.894	1.417	0.504	350
375													2.975	2.946	1.921	1.016	1.519	0.573	375
400															2.049	1.145	1.620	0.646	400
450															2.306	1.424	1.822	0.803	450

Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velcoities of water are generally less than 3 m/s

Recommended velocity range is 1.5 to 2.5m/s (yellow shaded)

Friction Loss Charts for PVC Pipes Using Hazen-Williams Equation (C=150)

Loss of Head, J in 100m Length (Class-8)

	63mm (ID=58.2)		75mm (ID=69.2)		90mm (ID=83.0)		110mm (ID=101.6)		140mm (ID=129.2)		160mm (ID=147.6)		225mm (ID=207.8)		280mm (ID=258.6)		315mm (ID=290.8)		
Discharge (m3/hr)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	Discharge (m3/hr)
1	0.104	0.027	0.074	0.012	0.051	0.005	0.034	0.002	0.021	0.001	0.016	0.000							1
2	0.209	0.097	0.148	0.042	0.103	0.017	0.069	0.006	0.042	0.002	0.032	0.001							2
3	0.313	0.205	0.222	0.088	0.154	0.036	0.103	0.014	0.064	0.004	0.049	0.002	0.025	0.000					3
4	0.418	0.349	0.296	0.150	0.205	0.062	0.137	0.023	0.085	0.007	0.065	0.004	0.033	0.001					4
5	0.522	0.528	0.369	0.227	0.257	0.094	0.171	0.035	0.106	0.011	0.081	0.006	0.041	0.001	0.026	0.000			5
6	0.627	0.740	0.443	0.319	0.308	0.131	0.206	0.049	0.127	0.015	0.097	0.008	0.049	0.002	0.032	0.001			6
7	0.731	0.985	0.517	0.424	0.360	0.175	0.240	0.065	0.148	0.020	0.114	0.011	0.057	0.002	0.037	0.001			7
8	0.836	1.261	0.591	0.543	0.411	0.224	0.274	0.084	0.170	0.026	0.130	0.014	0.066	0.003	0.042	0.001	0.033	0.000	8
9	0.940	1.568	0.665	0.675	0.462	0.278	0.309	0.104	0.191	0.032	0.146	0.017	0.074	0.003	0.048	0.001	0.038	0.001	9
10	1.045	1.906	0.739	0.820	0.514	0.338	0.343	0.126	0.212	0.039	0.162	0.021	0.082	0.004	0.053	0.001	0.042	0.001	10
12	1.254	2.672	0.887	1.150	0.616	0.474	0.411	0.177	0.254	0.055	0.195	0.029	0.098	0.005	0.063	0.002	0.050	0.001	12
14	1.463	3.555	1.035	1.530	0.719	0.631	0.480	0.236	0.297	0.073	0.227	0.038	0.115	0.007	0.074	0.002	0.059	0.001	14
16	1.671	4.552	1.182	1.959	0.822	0.808	0.548	0.302	0.339	0.094	0.260	0.049	0.131	0.009	0.085	0.003	0.067	0.002	16
18	1.880	5.661	1.330	2.437	0.925	1.005	0.617	0.375	0.382	0.116	0.292	0.061	0.148	0.012	0.095	0.004	0.075	0.002	18
20	2.089	6.881	1.478	2.962	1.027	1.222	0.686	0.456	0.424	0.142	0.325	0.074	0.164	0.014	0.106	0.005	0.084	0.003	20
22	2.298	8.210	1.626	3.533	1.130	1.457	0.754	0.544	0.466	0.169	0.357	0.088	0.180	0.017	0.116	0.006	0.092	0.003	22
24	2.507	9.645	1.773	4.151	1.233	1.712	0.823	0.640	0.509	0.198	0.390	0.104	0.197	0.020	0.127	0.007	0.100	0.004	24
26	2.716	11.187	1.921	4.815	1.336	1.986	0.891	0.742	0.551	0.230	0.422	0.120	0.213	0.023	0.138	0.008	0.109	0.004	26
28	2.925	12.832	2.069	5.523	1.438	2.278	0.960	0.851	0.594	0.264	0.455	0.138	0.229	0.026	0.148	0.009	0.117	0.005	28
30			2.217	6.276	1.541	2.589	1.028	0.967	0.636	0.300	0.487	0.157	0.246	0.030	0.159	0.010	0.126	0.006	30
35			2.586	8.349	1.798	3.444	1.200	1.286	0.742	0.399	0.568	0.209	0.287	0.039	0.185	0.014	0.146	0.008	35
40			2.956	10.692	2.055	4.410	1.371	1.647	0.848	0.511	0.650	0.267	0.328	0.051	0.212	0.017	0.167	0.010	40
45					2.311	5.485	1.543	2.049	0.954	0.636	0.731	0.332	0.369	0.063	0.238	0.022	0.188	0.012	45
50					2.568	6.667	1.714	2.490	1.060	0.773	0.812	0.404	0.410	0.076	0.265	0.026	0.209	0.015	50
55					2.825	7.954	1.885	2.971	1.166	0.922	0.893	0.482	0.451	0.091	0.291	0.031	0.230	0.018	55
60					3.082	9.345	2.057	3.491	1.272	1.083	0.975	0.566	0.492	0.107	0.317	0.037	0.251	0.021	60
65							2.228	4.048	1.378	1.256	1.056	0.657	0.533	0.124	0.344	0.043	0.272	0.024	65
70							2.400	4.644	1.484	1.441	1.137	0.753	0.574	0.142	0.370	0.049	0.293	0.028	70
75							2.571	5.277	1.590	1.637	1.218	0.856	0.615	0.162	0.397	0.056	0.314	0.031	75
80							2.742	5.947	1.696	1.845	1.299	0.965	0.656	0.182	0.423	0.063	0.335	0.035	80
85							2.914	6.654	1.802	2.064	1.381	1.079	0.697	0.204	0.450	0.070	0.356	0.040	85
90							3.085	7.397	1.908	2.295	1.462	1.200	0.738	0.227	0.476	0.078	0.377	0.044	90
95									2.014	2.537	1.543	1.326	0.779	0.251	0.503	0.086	0.398	0.049	95
100									2.120	2.789	1.624	1.458	0.819	0.276	0.529	0.095	0.418	0.054	100
105									2.226	3.053	1.705	1.596	0.860	0.302	0.556	0.104	0.439	0.059	105
110									2.332	3.328	1.787	1.740	0.901	0.329	0.582	0.113	0.460	0.064	110
120									2.544	3.910	1.949	2.044	0.983	0.386	0.635	0.133	0.502	0.075	120
125									2.650	4.217	2.030	2.205	1.024	0.417	0.661	0.144	0.523	0.081	125
135									2.862	4.863	2.193	2.543	1.106	0.481	0.714	0.166	0.565	0.094	135
145									3.074	5.551	2.355	2.902	1.188	0.549	0.767	0.189	0.607	0.107	145
150											2.436	3.090	1.229	0.584	0.794	0.201	0.628	0.114	150
160											2.599	3.483	1.311	0.658	0.847	0.227	0.670	0.128	160
170											2.761	3.897	1.393	0.737	0.900	0.254	0.711	0.143	170
180											2.924	4.332	1.475	0.819	0.952	0.282	0.753	0.159	180
190											3.086	4.788	1.557	0.905	1.005	0.312	0.795	0.176	190
200													1.639	0.995	1.058	0.343	0.837	0.194	200
225													1.844	1.238	1.191	0.427	0.942	0.241	225
250													2.049	1.505	1.323	0.519	1.046	0.293	250
275													2.254	1.795	1.455	0.619	1.151	0.349	275
300													2.458	2.109	1.587	0.727	1.255	0.410	300
325													2.663	2.446	1.720	0.843	1.360	0.476	325
350													2.868	2.806	1.852	0.967	1.465	0.546	350
375													3.073	3.188	1.984	1.099	1.569	0.621	375
400															2.117	1.238	1.674	0.699	400
450															2.381	1.540	1.883	0.870	450

Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velcoities of water are generally less than 3 m/s

Recommended velocity range is 1.5 to 2.5m/s (yellow shaded)

APPENDIX XIII: Head loss charts for PE pipes

Friction Loss Charts for Polyethylened (PE) Pipes Using Darcy-Weisbach Equation

Loss of Head, J in 100m Length (Class-4)

Discharge (m3/hr)	16mm (ID=12.8)		20mm (ID=16.6)		25mm (ID=20.8)		32mm (ID=28.8)		40mm (ID=36.6)		50mm (ID=45.6)		63mm (ID=57.6)		75mm (ID=68.6)		Discharge (m3/hr)
	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	
1	2.160	46.131	1.284	13.419	0.818	4.597	0.427	0.980	0.264	0.314	0.170	0.110	0.107	0.036	0.075	0.016	1
2			2.568	45.137	1.636	15.461	0.853	3.296	0.528	1.056	0.340	0.372	0.213	0.122	0.150	0.053	2
3					2.454	31.434	1.280	6.700	0.792	2.146	0.511	0.755	0.320	0.249	0.226	0.109	3
4							1.706	11.085	1.057	3.551	0.681	1.250	0.427	0.412	0.301	0.180	4
5							2.133	16.381	1.321	5.247	0.851	1.847	0.533	0.609	0.376	0.265	5
6							2.560	22.537	1.585	7.219	1.021	2.541	0.640	0.838	0.451	0.365	6
7							2.986	29.516	1.849	9.454	1.191	3.327	0.747	1.097	0.526	0.478	7
8									2.113	11.943	1.361	4.203	0.853	1.386	0.602	0.604	8
9									2.377	14.677	1.532	5.165	0.960	1.703	0.677	0.742	9
10									2.642	17.649	1.702	6.211	1.067	2.048	0.752	0.893	10
12											2.042	8.545	1.280	2.817	0.902	1.228	12
14											2.382	11.191	1.493	3.689	1.053	1.609	14
16											2.723	14.137	1.706	4.661	1.203	2.032	16
18											3.063	17.374	1.920	5.727	1.353	2.497	18
20													2.133	6.887	1.504	3.003	20
22													2.346	8.137	1.654	3.548	22
24													2.560	9.476	1.805	4.131	24
26													2.773	10.900	1.955	4.752	26
28													2.986	12.410	2.105	5.410	28
30															2.256	6.105	30
35															2.632	7.995	35
40															3.008	10.100	40

Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velcoities of water are generally less than 3 m/s

Friction Loss Charts for Polyethylened (PE) Pipes Using Darcy-Weisbach Equation

Loss of Head, J in 100m Length (Class-6)

Discharge (m3/hr)	32mm (ID=27.9)		40mm (ID=34.8)		50mm (ID=43.6)		63mm (ID=55)		75mm (ID=65.4)		90mm (ID=79.8)		Discharge (m3/hr)
	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	
1	0.455	1.139	0.292	0.399	0.186	0.137	0.117	0.045	0.083	0.020	0.056	0.008	1
2	0.909	3.104	0.584	1.067	0.372	0.359	0.234	0.117	0.165	0.051	0.111	0.019	2
3	1.364	6.518	0.877	2.242	0.558	0.754	0.351	0.246	0.248	0.106	0.167	0.041	3
4	1.818	11.034	1.169	3.795	0.745	1.277	0.468	0.416	0.331	0.180	0.222	0.069	4
5	2.273	16.599	1.461	5.709	0.931	1.921	0.585	0.626	0.414	0.271	0.278	0.104	5
6	2.728	23.174	1.753	7.970	1.117	2.683	0.702	0.874	0.496	0.378	0.333	0.145	6
7			2.045	10.567	1.303	3.557	0.819	1.158	0.579	0.502	0.389	0.192	7
8			2.338	13.492	1.489	4.541	0.936	1.479	0.662	0.641	0.445	0.245	8
9			2.630	16.737	1.675	5.634	1.053	1.835	0.745	0.795	0.500	0.304	9
10			2.922	20.296	1.861	6.832	1.170	2.225	0.827	0.964	0.556	0.369	10
12					2.234	9.537	1.404	3.106	0.993	1.346	0.667	0.515	12
14					2.606	12.646	1.638	4.118	1.158	1.784	0.778	0.682	14
16					2.978	16.146	1.872	5.258	1.324	2.278	0.889	0.871	16
18							2.106	6.523	1.489	2.826	1.000	1.081	18
20							2.340	7.910	1.655	3.427	1.111	1.311	20
22							2.574	9.417	1.820	4.080	1.222	1.560	22
24							2.807	11.043	1.986	4.784	1.334	1.830	24
26							3.041	12.785	2.151	5.539	1.445	2.118	26
28									2.316	6.343	1.556	2.426	28
30									2.482	7.197	1.667	2.752	30
35									2.896	9.542	1.945	3.649	35
40											2.223	4.660	40
45											2.501	5.780	45
50											2.778	7.009	50
55											3.056	8.597	55

Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velocities of water are generally less than 3 m/s

Friction Loss Charts for Polyethylened (PE) Pipes Using Hazen-Williams Equation

Loss of Head, J in 100m Length (Class-4)

Discharge (m3/hr)	16mm (ID=12.8) velocity (m/s)	J (0/00)	20mm (ID=16.6) velocity (m/s)	J (0/00)	25mm (ID=20.8) velocity (m/s)	J (0/00)	32mm (ID=28.8) velocity (m/s)	J (0/00)	40mm (ID=36.6) velocity (m/s)	J (0/00)	50mm (ID=45.6) velocity (m/s)	J (0/00)	63mm (ID=57.6) velocity (m/s)	J (0/00)	75mm (ID=68.6) velocity (m/s)	J (0/00)	Discharge (m3/hr)
1	2.160	42.779	1.284	12.062	0.818	4.021	0.427	0.824	0.264	0.257	0.170	0.088	0.107	0.028	0.075	0.012	1
2			2.568	43.543	1.636	14.517	0.853	2.976	0.528	0.926	0.340	0.317	0.213	0.102	0.150	0.043	2
3					2.454	30.761	1.280	6.306	0.792	1.963	0.511	0.673	0.320	0.216	0.226	0.092	3
4							1.706	10.743	1.057	3.344	0.681	1.146	0.427	0.367	0.301	0.157	4
5							2.133	16.240	1.321	5.055	0.851	1.733	0.533	0.555	0.376	0.237	5
6							2.560	22.763	1.585	7.085	1.021	2.428	0.640	0.778	0.451	0.332	6
7							2.986	30.285	1.849	9.426	1.191	3.231	0.747	1.036	0.526	0.442	7
8									2.113	12.070	1.361	4.137	0.853	1.326	0.602	0.566	8
9									2.377	15.012	1.532	5.146	0.960	1.649	0.677	0.704	9
10									2.642	18.247	1.702	6.254	1.067	2.005	0.752	0.856	10
12											2.042	8.767	1.280	2.810	0.902	1.200	12
14											2.382	11.663	1.493	3.739	1.053	1.596	14
16											2.723	14.935	1.706	4.788	1.203	2.044	16
18											3.063	18.576	1.920	5.955	1.353	2.542	18
20													2.133	7.238	1.504	3.090	20
22													2.346	8.635	1.654	3.686	22
24													2.560	10.145	1.805	4.331	24
26													2.773	11.766	1.955	5.023	26
28													2.986	13.496	2.105	5.762	28
30															2.256	6.547	30
35															2.632	8.711	35
40															3.008	11.155	40

Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velcoities of water are generally less than 3 m/s

Friction Loss Charts for Polyethylened (PE) Pipes Using Hazen-Williams Equation

Loss of Head, J in 100m Length (Class-6)

	32mm (ID=27.9)		40mm (ID=34.8)		50mm (ID=43.6)		63mm (ID=55)		75mm (ID=65.4)		90mm (ID=79.8)		
Discharge (m3/hr)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	velocity (m/s)	J (0/00)	Discharge (m3/hr)
1	0.455	0.962	0.292	0.328	0.186	0.109	0.117	0.035	0.083	0.015	0.056	0.006	1
2	0.909	3.473	0.584	1.184	0.372	0.395	0.234	0.127	0.165	0.055	0.111	0.021	2
3	1.364	7.360	0.877	2.509	0.558	0.837	0.351	0.270	0.248	0.116	0.167	0.044	3
4	1.818	12.539	1.169	4.274	0.745	1.426	0.468	0.460	0.331	0.198	0.222	0.075	4
5	2.273	18.956	1.461	6.462	0.931	2.155	0.585	0.695	0.414	0.299	0.278	0.114	5
6	2.728	26.570	1.753	9.057	1.117	3.021	0.702	0.975	0.496	0.419	0.333	0.159	6
7			2.045	12.050	1.303	4.019	0.819	1.297	0.579	0.558	0.389	0.212	7
8			2.338	15.430	1.489	5.147	0.936	1.661	0.662	0.714	0.445	0.271	8
9			2.630	19.191	1.675	6.402	1.053	2.066	0.745	0.889	0.500	0.337	9
10			2.922	23.327	1.861	7.781	1.170	2.511	0.827	1.080	0.556	0.410	10
12					2.234	10.907	1.404	3.519	0.993	1.514	0.667	0.574	12
14					2.606	14.510	1.638	4.682	1.158	2.014	0.778	0.764	14
16					2.978	18.581	1.872	5.995	1.324	2.579	0.889	0.979	16
18							2.106	7.457	1.489	3.208	1.000	1.217	18
20							2.340	9.063	1.655	3.899	1.111	1.479	20
22							2.574	10.813	1.820	4.652	1.222	1.765	22
24							2.807	12.704	1.986	5.465	1.334	2.074	24
26							3.041	14.734	2.151	6.339	1.445	2.405	26
28									2.316	7.271	1.556	2.759	28
30									2.482	8.262	1.667	3.135	30
35									2.896	10.992	1.945	4.171	35
40											2.223	5.341	40
45											2.501	6.643	45
50											2.778	8.074	50
55											3.056	9.633	55

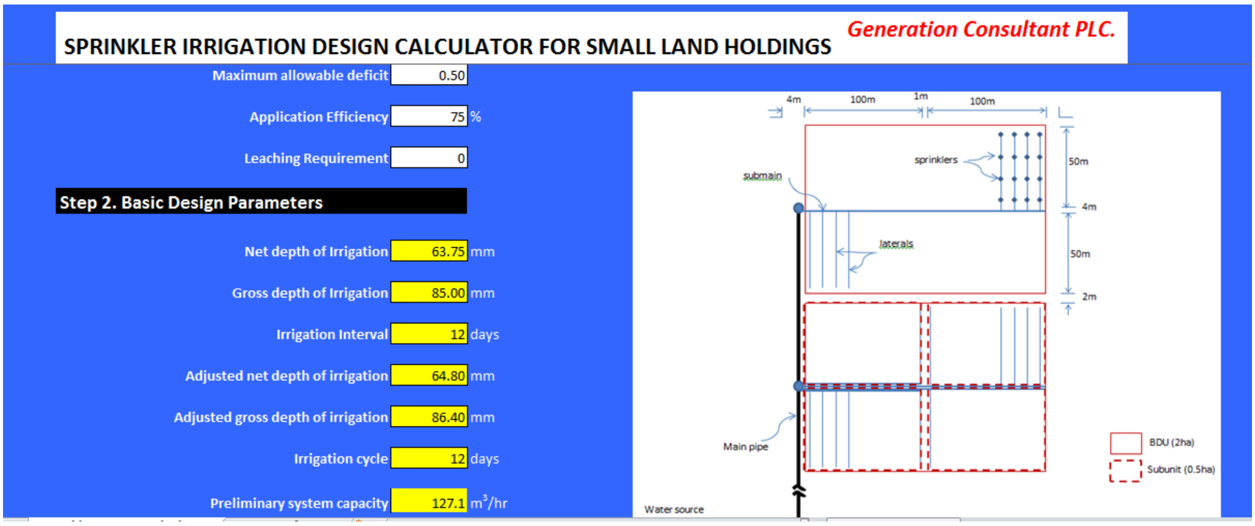
Notes: Head loss values are subjected to the following conditions:

Pipes are flowing full.

Pipes are carrying clear water at approximately 15.6°C

Velcoities of water are generally less than 3 m/s

APPENDIX XIV: Excel template for design of sprinkler irrigation system (Interface)



INDEXES OF KEY WORDS

- **Application efficiency –** it refers to the depth of water stored in the root zone per unit depth water applied usually expressed in percentage.
- **Accessories –** they refer to the minor components of the sprinkler system such as risers, couplers, valves, water meter, pressure guage, bends, plugs, fittings, etc.
- **Application rate –** the depth of irrigation water applied per unit time usually expressed by mm/hr.
- **Basic Design Unit –** it refers to a small block of command area, which can get water from submain.
- **Consumptive use –** it refers to the evapotranspiration need of the crop, which depends on the crop type and climate of the project area.
- **Control head –** it refers to the system regulation point which consists of majorly valves, water meter, pressure gauges, fertilizer connections and water filter.
- **Correction factor –** it refers to a ratio of the frictional head loss in multi-outlet pipe to that in blind pipe.
- **Couplers –** they refer to devices used to provide connection between two pipes and between pipes and fittings.
- **Design of sprinkler system –** refers to determination of the proper sizes of the pipe networks and pump capacity to obtain a system that provides satisfactorily uniform application of water with a minimum annual operation and maintainance cost.
- **Discharge (flow rate) –** it refers to the amount of water that flows through a certain cross-section of pipe per unit time usually expresssed in m^3/hr or lit/hr.
- **Field capacity –** it refers to the amount of water a well-drained soil contains after gravitational water movement has materially ceased.
- **Filters –** they refer to devices which are used to reduce or remove impurities in water before entering to the pipe network.
- **Filtration –** it refers to the process of reducing or removing impurities in water by using filters.
- **Fittings –** they refer to devices which are used to facilitate proper connections of pipes. Fittings include flanges, adapter and nipples.
- **Friction head loss –** it refers to the loss of the pressure head due to the friction of the water with the pipe walls or due to the turbulence of flow by other components of the system.
- **Gross depth of irrigation, d –** it refers to the actual depth of irrigation to apply onto the field which is obtained by considering the efficency of water application and the leaching requirement.
- **Head loss gradient, J (0/00) –** it refers to the frictional head loss per 100m length of pipe.
- **HDPE pipe –** it refers to a flexible pipe which is made of high density polyethylene material.
- **Irrigated area –** it refers to the size of arable land which is commanded by the irrigation system.
- **Inner diameter –** it refers to the internal diameter of a pipe which is expressed in inches for aluminum and steel pipe and in mm for plastic pipes.
- **Intake rate –** it refers to the rate at which water infiltrate into the soil usually expressed in mm/hr.
- **Irrigation cycle, f –** it refers to the period in days required to complete irrigating the design command area.
- **Irrigation interval, F –** it refers to the time period in days between two successive irrigation applications.
- **Lateral pipes –** it refers to the smallest size pipes in a sprinkler system onto which sprinkler heads are connected at regular spacing through a riser pipe.

- **Lateral spacing –** it refers to the regular spacing between two consecutive laterals which are connected on a main pipe.
- **Leaching requirement, LR –** it refers to the water applied onto the soil in excess of the required depth of irrigation to flush out salts from the root zone of the plant.
- **Main line –** it refers to a single largest size pipe line in the sprinkler pipe network.
- **Maximum allowable deficit, MAD –** it refers to the fraction of the soil moisture that is easily absorbed by the plants without any stress that results in yield reduction.
- **Net depth of Irrigation, dn –** it refers to the depth of water to be applied to the soil thatis readily available for the crop to absorb.
- **Nozzle size –** it refers to the dimension of the small openings on a sprinkler head through which water is sprayed onto the field.
- ***Nominal pipe diameter* –** it refers to the diameter of steel pipes up to 10inch, which is expressed as the internal diameter, measured in inches. Wider diameters, as well as the diameter of aluminium,and plastic pipes are expressed as the external diameter, measured in inches in aluminium pipes and in mm in plastic pipes.
- **Outer diameter –** it refers to the external diameter of a pipe.
- **Periodic move system –** it refers to a sprinkler system in which the water source and the pumping plants are fixed and the mains and submains are usually buried with valve outlets at various spacing for the portable laterals. The laterals are periodically shifted from place to place.
- **Permanent wilting point –** it refers to the soil moisture content at which crops can no longer obtain enough water to satisfy their evapotranspiration needs.
- **Pipe network –** it refers to the three major pipes in the sprinkler system, namely main, submain and laterals.
- **Pressure –** it refers to a force required to push water in a given size of pipe, expressed in units of kg/cm^2, bar or atmosphere.
- **Pressure head –** it refers to the pressure of water which is expressed in depth of water column. The common unit of pressure head is meter. A head of 10m is equivalent to 1 atm.or 1 bar.
- **Pressurized system –** It refers to the type of irrigation system which uses pipe networks as means of water conveyance and the water flows in the pipes under pressure.
- **Pump –** it refers to a device which is used to provide sufficient head for the water to move in the sprinkler pipe networks under presssure.
- **PVC pipe –** it refers to a pipe which is made of polyvinyl chloride material
- **Riser pipe –** it refers to short vertical pipe which is placed on lateral on top of which sprinklers are connected.
- **Sprinkler head –** it refers to a device with a nozzle mounted on a short riser pipe to spray water onto the field.
- **Sprinkler nozzle –** it refers to small opening on sprinkler head through which water is applied or sprayed onto the field.
- **Sprinkler spacing –** it refers to the regular spacing between the sprinklers along the sprinkler laterals.
- **Sprinkler system –** it refers to one of the broad classes of pressurized irrigation methods; in which water is applied to crops above the ground in the form of sprays somewhat resembling rainfall.
- **Static head –** it refers to the head from the pump center line to the level of water surface at the source.
- **Submain line –** it refers to the second largest pipe in a sprinkler system onto which lateral pipes are connected at regular spacing.
- **Subunit –** the smallest irrigation operation unit or the manageable size of pressurized irrigation system by each farmer.

- **Supply line –** it refers to a short pipe directly connected to the source or pump, and delivers water to the system via. main pipe.
- **System capacity –** it refers to the flow rate or the volume of water flow per unit time required by the system usually expressed in m^3/hr or liter per hr.
- **System layout –** it refers to the arrangement of the field and the pipe lines on the map depending upon the topography and the location of water source with the consideration of non-irrigable features such as villages and other existing facilities.
- **System shift –** it refers to the periodical movement of a fixed number of laterals from one place to another in a system.
- **Total Available Water, TAW –** it refers to the amount of soil water which is considered as available to plants. It is the water content between field capacity and permanent wilting point.
- **Uniformity Coefficient, Cu –** it refers to an index used to measure the degree of uniformity of sprinklers application rate for given set of conditions in the field.
- **uPVC pipe –** it refers to pipe which is a rigid, chemically resistant form of PVC and is made of unplasticized poly vinyl chloride material.
- **Valves –** they refer to devices which are used to control the flow of the water in irrgiation systems.
- **Wetting diameter –** it refers to the diameter of the soil surface wetted by a certain sprinkler, which is twice the wetting radius of the sprinkler expressed in meter.
- **Wind velocity –** it refers to the rate at which wind blows in a given direction expressed in meter per second or kilometer per hour.

SSIGL 17

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