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The Hashemite Kingdom of Jordan

Ministry of Water and Irrigation

Water Quality Improvement and Conservation Project

Micro Irrigation Systems Training Modules - Vol.2
Systems Management
System Evaluation

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The following Modules are included in two (2) separate volumes

System Operation
- 1-0 System Overview
- 1-1 Pumping Units
- 1-2 Motors and Engines
- 1-3a Media Filters
- 1-3b Media Filter Backwashing
- 1-4 Screen Filters
- 1-5 Fertilizer Injection System
- 1-6 Emitters
- 1-7 Laterals
- 1-8 Main and Submain Pipelines
- 1-9 Pipeline Protection

System Management
- 2-1 Soil-Water System
- 2-2 Use of Saline Irrigation Water
- 2-3 Crop Water Requirements
- 2-4 Irrigation Scheduling

System Evaluation
- 3-1 Evaluation Overview
- 3-2 Data Collection
- 3-3 Data Analysis
- 3-4 Recommendations
- 3-5 Pumping Plants

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INTRODUCTION

The Action Memo authorizing the commencement of this work was approved by USAID on 27 December 1994 A contract between DAI and the Water and Environment Research and Study Center (WERSC) of the University of Jordan was approved and signed on 6 April 1995

The purpose of this work was two fold develop training material to be used to train farmers, JVA and MOA staffs, and other interested parties and to develop the capability of the WERSC to prepare training material for adult learners To successfully accomplish the purposes of the contract, intense interaction between the WQIC Project and the WERSC was needed Consequently, the work is not solely that of one party but is truly a joint effort

The long time needed to complete the modules is due to many factors The most important were

- The WERSC, who has extensive experience in teaching soils and irrigation courses to students, has had little experience in preparing material for training adults The first materials prepared were too theoretical and unsuited for the intended audience This necessitated a complete rewrite of the first few modules and heavy editing of others
- It was decided early on that the time would be taken to do a good job and not just rush through the process We think the effort has been well spent
- The MWI and JVA has had difficulty appointing personnel to staff a pilot Irrigation Advisory Service These personnel are to be the first trained and in turn to use the material to train farmers and others This deficiency effectively removed the pressure to complete quickly and in turn preparation of the modules was often set aside for more pressing issues

This report, including the training modules, is being issued in English, REPORT 3114-97-3b-10E, and Arabic, REPORT 3114-97-3b-10A

It must be stressed that these modules are not to be viewed as static end products During the use of each component of this work the instructor is requested to take notes of his ideas and comments and suggestions from the trainees These notes should be used to periodically revise the training material The material should efficiently provide the information needed by trainees and as their needs change so should the modules, also, changing needs are sure to require additional modules

OVERVIEW OF THE MODULES

There are 20 modules plus one Training Session Preparation checklist for the instructor and one System Performance Evaluation Effectiveness form to be completed by the farmer a short time after an evaluation The modules are split into three series System Operation, System Management, and System Evaluation Titles for the modules in each series are given in Table 1 The Training Session Preparation checklist (0-1) and System Performance Evaluation Effectiveness (3-0) are included in the annex to this report, the modules are in two (2) separate volumes

System Operation covers the hardware of the micro irrigation system, design, operation, and maintenance topics are covered The procedures presented will not design a state of

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the art system but will design a system that can achieve high irrigation water use efficiency within the constraints of today's farmer in Jordan

System Management covers the factors important in the proper management of a micro irrigation system Surveys of irrigation water use in the Jordan Valley have identified this area as the one most critical to achieving efficient use of water resources An attempt has been made to cover in sufficient detail the four key factors in efficient management soils, use of water with varying levels of salinity, crop water requirements, and irrigation scheduling

System Evaluation discusses the evaluation of the micro irrigation system Both the physical hardware and management are evaluated Evaluations are tools to help farmers identify problem areas in system hardware and management Results of an evaluation allow the farmer to rank the improvements needed based on costs and expected water savings He can then implement those improvements that are financially beneficial to his operation

The System Performance Evaluation Effectiveness form is to be completed by the farmer a short time after an evaluation Results from this form should be tabulated and used to identify areas in the evaluation and reporting process needing improvement

Table 1 Micro irrigation systems training module number codes and titles

System Operation	System Management	System Evaluation
1-0 System Overview	2-1 Soil-Water System	3-1 Evaluation Overview
1-1 Pumping Units	2-2 Use of Saline Irrigation Water	3-2 Data Collection
1-2 Motors and Engines	2-3 Crop Water Requirements	3-3 Data Analysis
1-3A Media Filters	2-4 Irrigation Scheduling	3-4 Recommendations
1-3B Media Filter Backwashing		3-5 Pumping Plants
1-4 Screen Filters		
1-5 Fertilizer Injection System		
1-6 Emitters		
1-7 Laterals		
1-8 Main and Submain Pipelines		
1-9 Pipeline Protection		

STRUCTURE OF EACH MODULE

Each training module consists of four components Instructor's Guide, Lecture Notes, Transparencies, and Supplemental The first three components are presented for use by the instructor, the fourth is a take-home handout for the trainee In addition, the Training Session Preparation checklist for the instructor should be considered an integral part of each module In completing the check-list prior to beginning each module training session, the instructor ensures that training will proceed smoothly with few unplanned interruptions

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Instructor's Guides give in brief outline form the flow of the presentation Questions to be asked participants are presented in **bold** face type Notes giving ideas for presentation of the module are included in some guides after the outline The guide should be read by the instructor during the training session preparation stage

Lecture Notes are to be used by the instructor in presenting module material to the trainees Instructors are expected to have sufficient familiarity with the subject of the module being taught to be able to answer questions, lead discussions, and add supplemental material if requested by the trainees **Bold** type is used to highlight questions to be asked trainees and to indicate points that should be stressed ***Bold Italic*** type is used to highlight material and instructions for the instructor Instructors should record answers to questions, discussion points, and comments on the module and place the notes taken in the file with the original module This material will be very useful to future instructors using the same module and can be used to strengthen the module in later revisions

Transparency Masters are provided for each training module The instructor who first uses the module must copy the master onto transparency film for use in the training session After the training session, the transparency film should be kept in the module file for use in later sessions **(Show Transparency X)** in the Lecture Notes tells the instructor when to show a given transparency, X stands for a sequential number found in the lower right corner of each transparency In the event of a mixing of transparencies from more than one module, each transparency has the module number in the upper right corner Instructors should ***not just show*** the transparencies, but should use them for instruction On design figures or graphs, point out the steps of the design process (how to use the figure or graph), on equations, explain what each variable represents and how its value is obtained

Supplemental contains the material presented in the training program and is to be given to participants Supplemental contains all that is in the lecture notes, excepting additional material brought in by the instructor at participant requests, and is designed to provide the reference information trainees may need after the training program If deemed necessary, instructors may add material to the supplemental as an annex

MODULE PRESENTATION

Instructors are encouraged to read *Promoting water conservation by training Jordan Valley Farmers*, which is included in the annex to this report, prior to conducting a training session This section discusses the principles important in conducting a successful training program for adults

Modules, excepting system evaluation field data collection, are designed to be presented in one working day The modules requiring field collection of data may need two days if there are difficulties getting started and in the data collection process It is essential that the instructor visit the farm to be used for field work in advance of the exercise He should conduct a walk-through and record his observations for use when conducting the exercise An early visit would allow time for correction of major deficiencies, if any are identified in the walk-through, or the selection of another farm in the event deficiencies

MICRO IRRIGATION SYSTEMS

SYSTEM OVERVIEW

[Instructor's Guide]

1 MODULE OBJECTIVES

Upon completion of this module the participant will be able to

- List the advantages and disadvantages of trickle irrigation
- Sketch the layout of a trickle irrigation system and describe the function of each component

2. TRAINING AIDS

2 1 Overhead Transparencies

2 2 Participant Handouts Supplemental, description of trickle irrigation advantages and disadvantages and basic system components

2 3 Equipment Requirements

2 3 1 Overhead projector

2 3 2 White board, markers, eraser

2 3 3 Samples of selected components

3. PRESENTATION PLAN

3 1 Discussion of Module Objectives

3 2 Introduction to trickle irrigation

3 2 1 Ask participants to explain **Why do you use a trickle irrigation system on your farm?** List the advantages they see from using the system, record the comments on the white board

3 2 2 Ask participants to **Describe problems you have with your trickle irrigation system?** List the disadvantages they see from using the system, record the comments on the white board

3 2 3 Compare trickle irrigation to other irrigation systems

3 2 4 Discuss the advantages and disadvantages of a trickle irrigation system, **compare** with the list given by the participants and discuss differences

3 2 5 Discuss how participants can diminish the disadvantages of the trickle system

3 2 6 **Break** [during break instructor should copy reasons, problems, and key discussion comments on paper for later reference]

3 3 Discussion of Head Control Unit

3 3 1 Discuss why the head control unit is important and its functions

3 3 2 Discuss unit components in sequence, begin at the point where water enters the unit (pool or pipe), describe the function of each component

REPORT 3114-97-3b-10E

MICRO IRRIGATION SYSTEMS
Training Modules

SYSTEM OPERATIONS

1-0 System Overview
1-1 Pumping Units
1-2 Motors and Engines
1-3A Media Filters
1-3B Media Filter Backwashing
1-4 Screen Filters
1-5 Fertilizer Injection System
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WATER QUALITY IMPROVEMENT AND CONSERVATION PROJECT
United States Agency for International Development
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MICRO IRRIGATION SYSTEMS

SYSTEM OVERVIEW

[Supplemental]

1. INTRODUCTION

- Trickle or drip irrigation is the irrigation water application system where water is delivered by a pipe network under low pressure and applied at a point or over a very limited fraction of the total surface area of a field, Figure 1

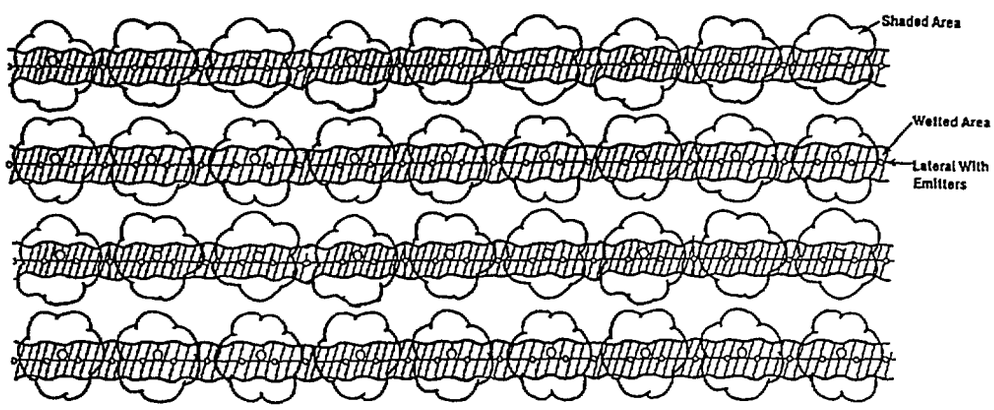

Figure 1 Typical wetting pattern for a trickle irrigation system with 35% soil surface wetting

A trickle system is more than a means of irrigation It can also be utilized to provide the plants with supplementary soluble materials such as fertilizers, fumigants, insecticides, and nematicides Because the chemicals are delivered directly to the crop root zone, less is required In addition, the danger of burning the roots is minimized because the chemicals are greatly diluted

- Trickle irrigation systems apply water directly to the crop root zone, wetting a limited amount of surface area and depth of soil Such systems were originally designed for applications in which there were relatively large distances between plants, such as in an orchard Subsequent to the successful use of trickle systems with widely spaced plants, special tubing was developed that made drip systems equally applicable to row crops

- A major difference between trickle systems and most other water application systems is that water used by crops is resupplied to the soil at short periods of 1 to 3 days An advantage of the short irrigation cycle is that soil moisture is maintained near the optimum, Figure 2, and plants always have easy access to water, Figure 3 Delivery of water on a short application cycle eliminates water stress as a factor limiting the crop yield

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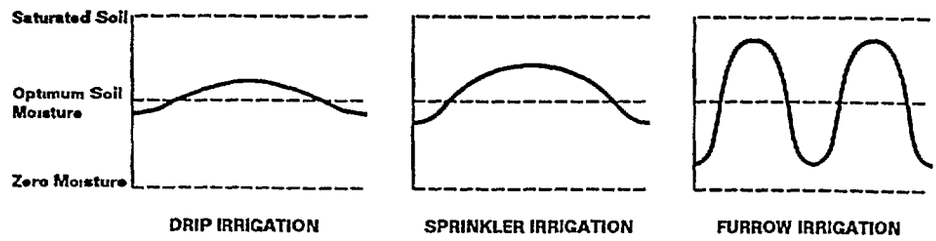

Figure 2 Relative moisture variation by irrigation method

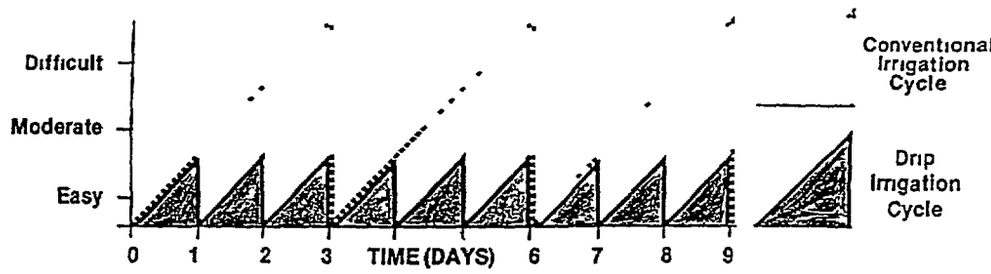

Figure 3 Ability of a plant to obtain water

2 CHARACTERISTICS OF A TRICKLE IRRIGATION SYSTEM

2 1 Soil wetting

- Trickle irrigation systems normally wet only a portion of the horizontal cross sectional area of soil as depicted in Figure 4 A 30% to 50% root zone wetting has been recommended for trickle irrigation, this value is often exceeded in tree crops The percentage of wetted area as compared to the entire cropped area depends on volume and rate of discharge at each emission points, and the type of soil being irrigated
- The area wetted at each emission point is usually quite small at the soil surface and expands somewhat with depth to form a bulb shaped cross section, Figure 4

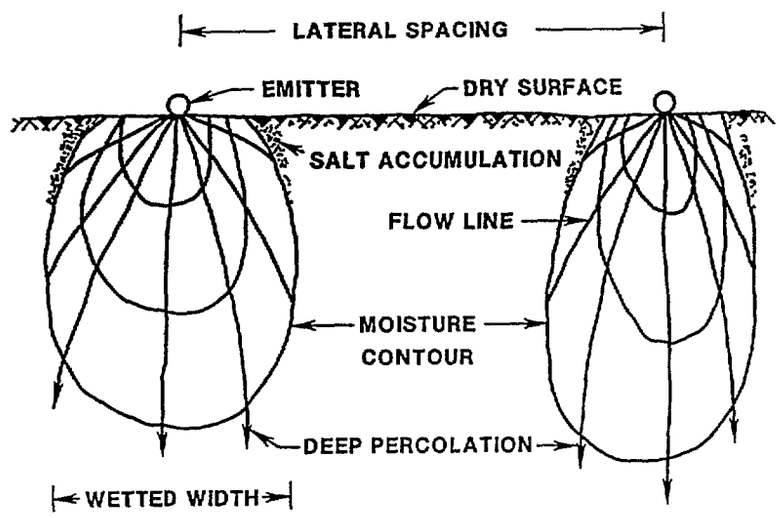

Figure 4 Typical pattern of soil wetting under trickle irrigation

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2 2 Advantages

Trickle irrigation is a convenient and efficient means of supplying water directly to the soil surrounding individual plants

- Water and cost savings Trickle irrigation can *reduce operating costs*, this has been a main cause of interest in this new method In addition, trickle systems can irrigate some kinds of crops with significantly less water than is required by the other irrigation methods For example, young orchards irrigated by trickle system may require only one-half as much water as orchards irrigated by sprinkle or surface irrigation As orchards mature, savings of water from operation of trickle system diminish, but they still may be important to growers who need to irrigate efficiently because of scarcity and high price of water

- Trickle irrigation can reduce the cost of labor Water applied by trickle needs merely to be regulated and not tended Such regulation usually is accomplished by automatic timing devices

- Easier field operation Trickle irrigation hinders weed growth because much of the soil surface is never wetted by irrigation water (Figure 1) This reduces costs of labor and chemical needed to control weeds Also, because a trickle system wets less soil during an irrigation, uninterrupted orchard or field operations are possible With row crops on beds, for example, the furrows in which farm workers walk remain relatively dry and provide firm footing

- Injecting fertilizers into the irrigation water Trickle irrigation can eliminate the labor needed for ground application of fertilizers Several highly soluble and liquid fertilizers are available for injection Greater control over fertilizer placement and timing through trickle irrigation may lead to improved efficiency

- Use of saline water Frequent irrigations maintain most of the soil in a well-aerated condition and at a soil moisture content that does not fluctuate between wet and dry extremes Less drying down between irrigations keeps the salts in the soil more dilute, making it possible to use more saline water than can be used with other irrigation methods

- Use on rocky soils and steep slopes Trickle irrigation systems can be designed to operate efficiently on almost any topography Since the water is applied close to each plant, rocky areas can be irrigated effectively by trickle system even when the spacing between plants is irregular and plant sizes vary Problem soils with intermixed textures and profiles and/or shallow soils, which cannot be graded, can be efficiently irrigated by trickle system

2 3 Disadvantages

The main disadvantages inherent in trickle irrigation systems are several

- Trickle irrigation systems have a comparatively high initial cost but annual operating costs are comparable with other irrigation methods if maintenance costs are not excessive
- They have continuous maintenance requirements Emission device clogging is the most persistent problem encountered with trickle irrigation Pipeline and component damage by equipment, animals, or personnel are other problems
- They have a tendency to build up local soil surface salinity, Figure 4 Light rains can leach the salts downward into the root zone When rains occur after a period of salt accumulation, irrigation should occur on schedule unless about 50 mm of rain has fallen

  Salts also concentrate below the soil surface at the perimeter of the wetted soil volume Too much drying of the soil between irrigations may cause salts to migrate back towards the center of the root zone, which can cause crop damage, Figure 5

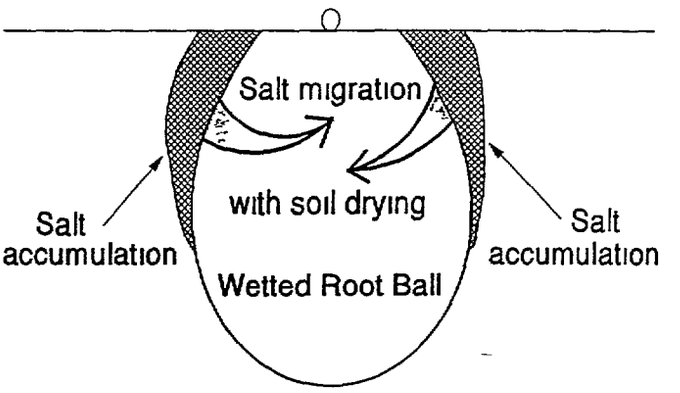

Figure 5 Salt migration routes when soil dries after trickle irrigating

- Where improperly designed, distribution of water can be spotty Sloping lateral lines can cause individual emitters to discharge with a 50% difference from the design volume Emitters at the ends of sloping laterals will drain the laterals at shut off, some plants will receive too much water and others too little
- Clogging Because emitter outlets are very small, they can easily become clogged by particles of mineral or organic matter Clogging reduces emission rates, reducing water distribution uniformity, and thereby causing damage to plants

  Sometimes mineral particles or organic matter present in the irrigation water are not removed before the water enters the pipe network Particles may form in the water as it stands in the lines or evaporates from emitter orifices

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between irrigations, iron oxide, calcium carbonate, algae, and microbial slimes form in some irrigation systems Chemical treatment of waters can prevent or correct most of these causes of clogging

- If an irrigation is missed because of uncontrolled events, crop damage may occur quickly The ability of the roots to obtain water is restricted by the relatively small volume of soil wetted, which should be at least 33% of the total potential root zone
- Should a main line or submain break or the filtration system malfunction, contamination may enter the system The contamination can plug a large number of emitters, which may result in damage to a large number of plants

3 TRICKLE IRRIGATION SYSTEM COMPONENTS

A trickle irrigation system is made up of many different specialized components Figure 6 shows a typical trickle irrigation system layout These components can be clustered into two main categories, the head control unit and the water distribution system

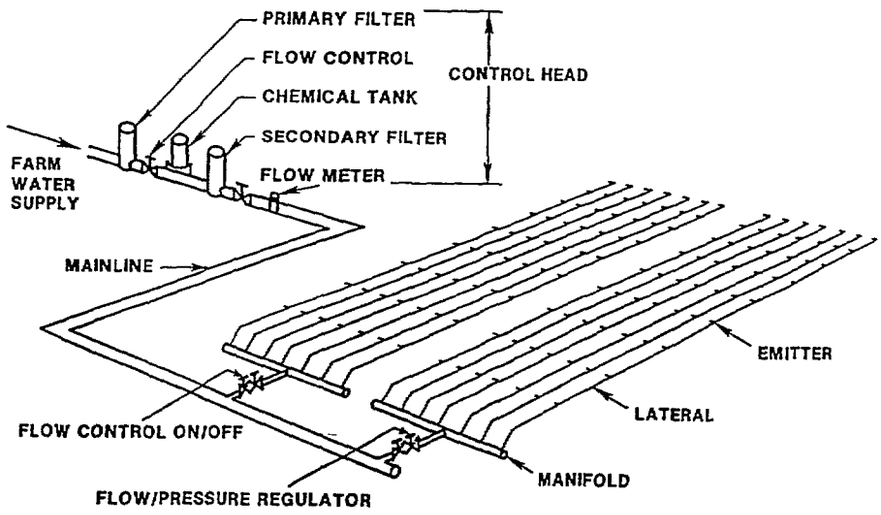

Figure 6 Basic components for water distribution in a trickle irrigation system

3 1 Head Control Unit Components

- Pump (optional) Provides water under pressure to the trickle irrigation system if the water source is at a pressure lower than that required
- Main Control valve Main control valves are used to isolate the trickle irrigation system from the water source This valve is often immediately followed by the back flow prevention valve
- Primary filter, generally a media filter The primary filter is located after the pump or inlet from a pressurized irrigation water delivery pipeline Its purpose is to remove both large and fine particles from the flow A media filter is not easily plugged by algae and can remove relatively large amounts of suspended solids before cleaning is needed

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- Pressure gauges Pressure gauges are used to measure pressure differences across filter units, inlet pressure versus outlet pressure Pressure differences indicate when a filter unit should be cleaned or flushed A high increase in the pressure difference across a filter, more than 14 to 34 kPa, indicates that the filter is becoming clogged, flow is decreasing, and cleaning is needed
- Flow control valve Allows the flow to be restricted or cut off
- Back flow prevention valve This valve is used to prevent water in the trickle system piping from traveling back to the source in the event of an unscheduled shut-down This is particularly important when chemical injection is used and the potential exist for contamination of the water source, aquifer
- Chemical tank Chemical tanks are used to mix fertilizers or other chemicals with water to allow their injection into the irrigation water delivery pipeline
- Injection system Differential pressure and venturi injectors are the two systems commonly used in Jordan The injection system puts chemicals into the irrigation water at the desired concentration If the chemical to be injected can form precipitates, the injection system may be placed before the media filter Generally the injection system follows the media filter to allow removal of particulate matter that may react with the injected chemicals
- Secondary filter, generally a screen filter This filter consists of a screen made of metal, plastic, or synthetic cloth enclosed in a special housing used to limit the maximum particle size that can pass The secondary filter is used downstream of the primary filter to remove any particles that may pass through the primary filter during normal or cleaning/flushing operations This filter removes particulates entering the system from the chemical injector
- Flow control valve Allows the flow to be restricted or cut off This valve is used to establish a pressure differential across the differential pressure injector system
- Flow meter A flow meter is a valuable aid in scheduling irrigations and monitoring system performance Flow measurements can indicate if pressure regulation is malfunctioning, excessive leaks exist, emitters are clogged or emitter opening enlargement is occurring Propeller meters are cheap and should be a part of every trickle irrigation system

3 2 Water Distribution System Components

- Main pipeline The water delivery pipeline that carries water from the control head unit to the submains or manifolds
- Flow control valves at each off take from the main line Control valves allow the operator to easily remove a section of the system from operation without hampering irrigation in the remainder of the system With control valves the number of submains receiving water can be regulated, allowing pipeline pressures to be kept within operating ranges of pressure regulators

- Flow pressure regulators at each submain or manifold Regulators are used to maintain pressures in each submain or manifold within specified tolerances Lateral operating pressures must be within design tolerances or emission devices do not function as designed, emission uniformity suffers, and water is wasted
- Submain or manifold line The water delivery pipeline that supplies water from the main to the laterals
- Flush valves at the end of each main and submain line To assist in keeping sediment buildup at a minimum Flushing is recommended on a regular interval All connections and pipeline fittings shall be large enough in diameter to facilitate flushing Filtration should be effective enough so that flushing of the system is needed no more frequently than once per week
- Lateral lines The water delivery pipeline that supplies water to the emission devices from the submain or manifold
- Emission devices The devices used to control the discharge from the lateral lines at discrete or continuous points Line-source emitters discharge from closely spaced perforations, emitters, or a porous wall along the lateral line Point-source emitters discharge from individual and wide spaced emission points Sprayers apply water by a small spray or fine mist to the soil surface, travel through the air is instrumental in the distribution of water
- Flush valves at the end of each lateral line To assist in keeping sediment buildup at a minimum Flushing is recommended on a regular interval All connections and line fittings shall be large enough in diameter to facilitate flushing

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MICRO IRRIGATION SYSTEMS

PUMPING UNITS

[Supplemental]

1 INTRODUCTION

Pumps are simple mechanical devices or machines that convert mechanical energy into hydraulic energy within the pumped fluid They are commonly used on farms to lift irrigation water from one elevation to a higher level or to add pressure to the water so it may be distributed to different locations on the farm

Several types of pumps are available for use in irrigation deep well turbine, centrifugal, and axial flow propeller pumps For the specific purposes of this module, it is assumed that a conventional centrifugal pump, electric or diesel motor driven, is used for pumping the irrigation water Centrifugal pumps are used to pump water in applications requiring high heads but limited discharges

Impellers are the means of energy transfer from a motor or engine to irrigation water Energy transfer is acquired by either centrifugal force or lifting action Centrifugal forces due to impeller rotation causes water to flow towards it's outer edge creating vacuum at the impeller center, or eye, if the pump is primed, in a radial direction to the shaft The flow rate is a function of the width and rotation rate of the impeller The velocity of the impeller outer edge, a function of impeller diameter and rotation speed, determines the pressure output The larger the diameter, the greater the pressure, the larger the width, the higher the flow rate for a specific rotation rate

The key requirement in pump selection for typical irrigation installations is that there is correspondence between the requirements of the irrigation system and the maximum operating efficiency of the pump The requirements of the irrigation system are the flow rates and pressure output necessary to operate the system as designed A pump is selected using manufacturer's performance curves These curves are graphical presentations of relationships between pump discharge, head output, power requirement, impeller size, and efficiency

2. PUMP SELECTION

The aim of the selection process is to satisfy the capacity and total head requirements of the irrigation system, while obtaining the maximum attainable efficiency at the lowest horsepower and energy requirement The capacity of the pump must satisfy the peak irrigation requirement for the project area under the specified cropping mix, for a specific irrigation regime The total head is the sum of the lift required to bring the irrigation water to the pump inlet and the discharge pressure-head required to operate the irrigation system

Using the capacity and total head, a pump is selected from manufacturers performance curves, see Figure 1 for the components of a performance curve The pump should have high operation efficiency Next, the pump horsepower

requirement is determined from these curves Finally, an appropriate motor or engine is selected

A relatively steep head-discharge (Head-Q) curve implies pumping lift variations as capacity increases, accounting for fluctuating water levels A flat Head-Q curve may indicate the possibility of maintaining constant heads over a varying range of discharge flows, taking care of pressure variations A good combination of both characteristics is desired in the case of trickle laterals operating at constant heads over a variety of flows using water pumped from a pool

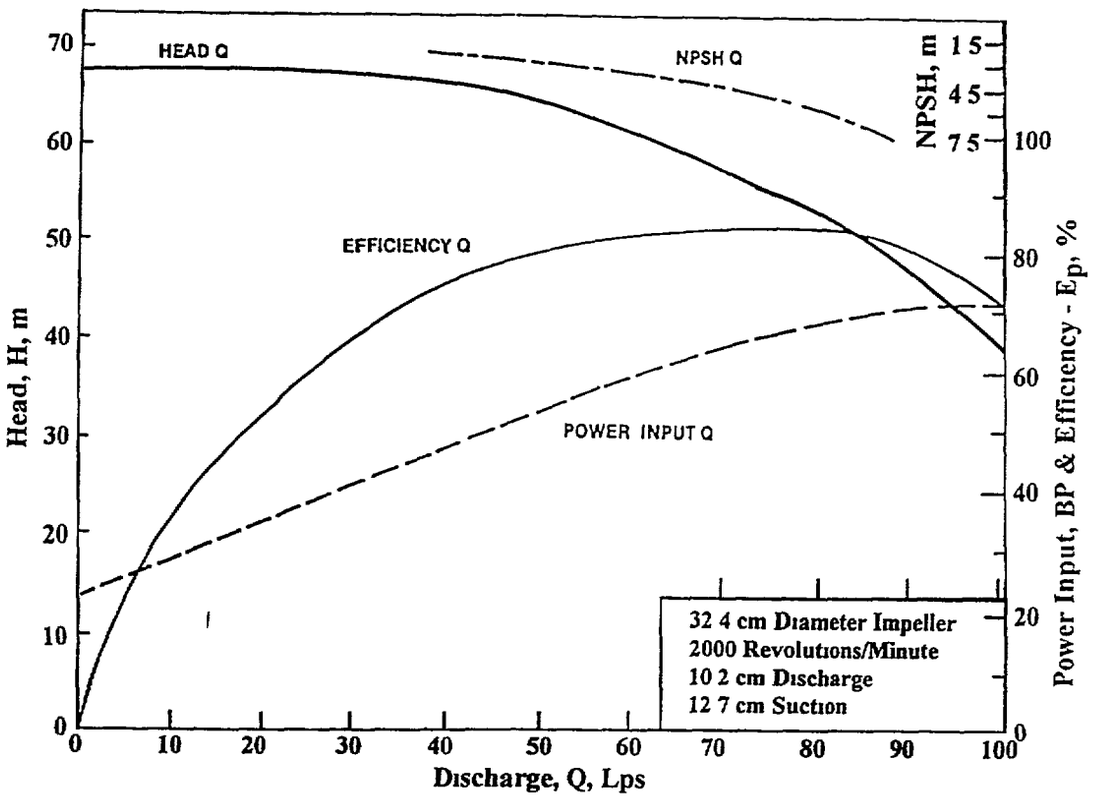

Figure 1 Typical centrifugal pump characteristic curves

2 1 Net Positive Suction Head

The net positive suction head (NPSH) relates the atmospheric pressure on water on the intake side of the pump to the vapor pressure of water By the time the water reaches the intake of the pump, the original head due to atmospheric pressure has been reduced by the height of the pump intake above the water surface, the velocity head developed, and friction losses in the intake pipe If the pressure head remaining is less than the vapor pressure of the water at the operating temperature, the water will vaporize as it is accelerated by the pump impeller A rise of pressure to levels greater than vapor pressure, due to impeller rotation, will cause the vapor bubbles to collapse violently and may seriously damage the metal impeller This effect is called cavitation

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The NPSH available at the pump inlet must be greater than the manufacturer recommended $NPSH_r$ to avoid cavitation, $NPSH_a > NPSH_r$
The NPSH available at the pump is defined as

$$NPSH_a = P_{atmos} - h_{zs} - h_{fs} - P_v$$

where P_{atmos} = atmospheric pressure, m, h_{zs} = static suction lift, m, h_{fs} = friction head loss on the suction side of the pump, m, and P_v = vapor pressure at operating temperature, m Values for P_v and P_{atmos} can be taken from Table 1 for Jordan Valley locations

Table 1 Atmospheric and vapor pressure constants

Temperature, °C	P_v, m	Altitude, m	P_{atmos}, m
10	0 13	0	10 4
20	0 24	-100	10 5
30	0 43	-200	10 6
		-300	10 7
		-400	10 8

The static suction lift is equal to the difference in height between the level of the water surface and the centerline of the pump intake It is defined as positive if the water surface is below the pump intake The friction head loss is computed for the straight length of pipe and any fittings on the suction side of the pump The friction head loss is normally quite small because it is proportional to the fluid velocity squared which is less than 1 m/sec on the suction side of a properly installed pump

A factor of safety of 0 6 m is deducted from the calculated $NPSH_a$ to account for unanticipated conditions on the suction side of the pump

2 2 Head Requirements

Pumps are chosen to match the irrigation system performance characteristics at high efficiency The first step is to develop an irrigation system performance curve which relates the total system head to discharge The head requirements are two fold the fixed part doesn't change with the discharge and the varying part changes with discharge

$$TDH = H_{fix} + H_{var}$$

where

$$H_{fix} = h_{zs} + h_{zd} \text{ and}$$
$$H_{var} = h_{pool} + h_f + h_p + V^2/2g$$

with TDH = total dynamic head requirement, m, H_{fix} = fixed system head, m, H_{var} = variable system head, m, h_{zs} = static head on the suction side of the pump, m, h_{zd} = static head on the discharge side, m, h_{pool} = drop in pool level with pumping (full level minus level at the intake limit), m, h_f = total friction head

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loss in the micro irrigation system, m, h_p = pressure head at the critical nozzle or dripper, m, V = velocity at the critical discharge point, m/sec^2, and g = acceleration of gravity, m/sec^2 Usually $V^2/2g$ is very small and can be neglected

The TDH is substituted for head in the power calculations Figure 2 shows the distribution of the components for TDH Figure 3 shows an example of a system head-discharge curve Figure 4 shows the impact of two different approaches to irrigation system operation on the pump selection process

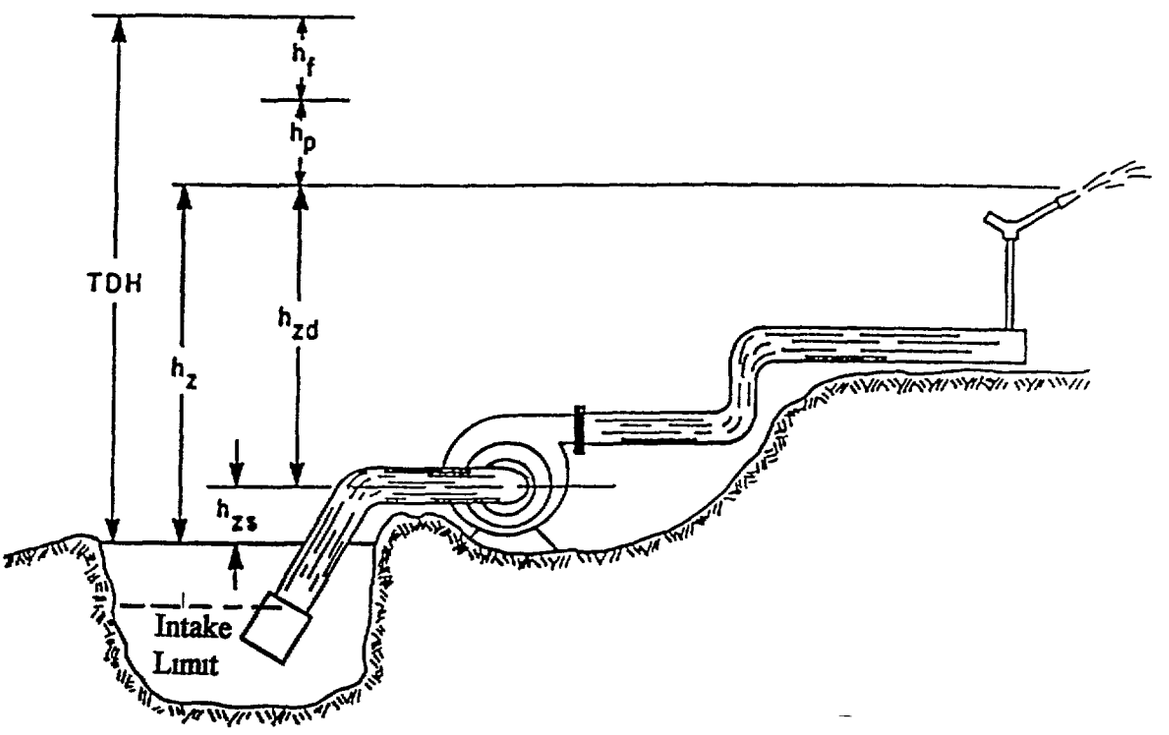

Figure 2 Distribution of elevation, pressure, and friction head in a centrifugal pump installation

2 3 Power Requirements

Power requirements of pumping plants are directly proportional to flow rate and total head and inversely proportional to efficiency The power must be supplied by a motor to the pump drive shaft so the impeller can impart power to the water Formulas for calculation of power requirements are

$$P = QH/(4634E)$$

Where P = metric horse power (mhp), metric hp, Q = pump discharge, l/min, H = discharge pressure head, m, E = pump efficiency, decimal fraction

Also P = QH/(102E) for P = power in KW and Q = pump discharge, lps

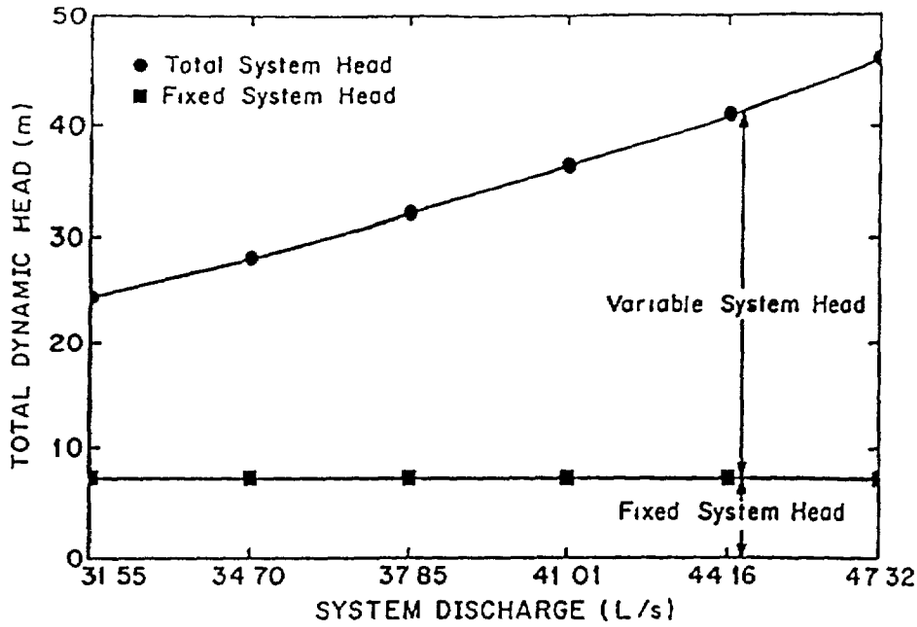

Figure 3 System head-capacity curve shown as a summation of fixed and variable heads

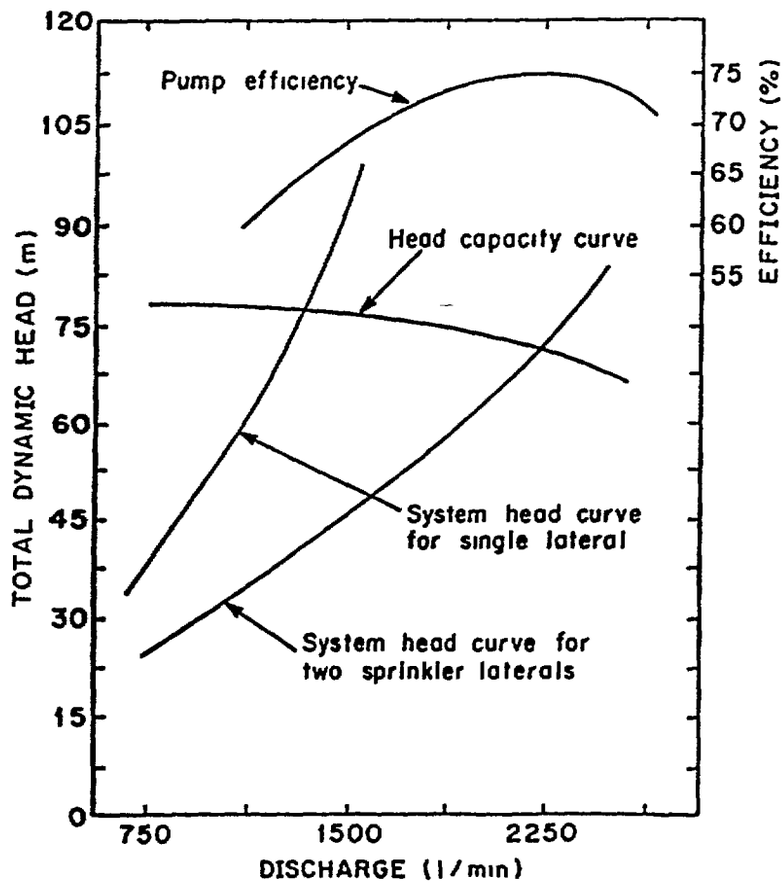

Figure 4 Variation of system head curve with change in system operation and intersection of pump performance curves

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2 4 Pump Selection Example

An irrigation system has a discharge requirement of 37 8 l/sec at a total head of 18 29 m Select the most efficient pump model for this application and from the pump characteristic curves determine the impeller diameter, operation efficiency, NPSH required, and power required

From Figure 5, select pump model 1030A The other information is read from the pump characteristic curve, Figure 6

D = 241 mm
E = 82 percent
$NPSH_r$ = 5 2 m
P = 12 hp

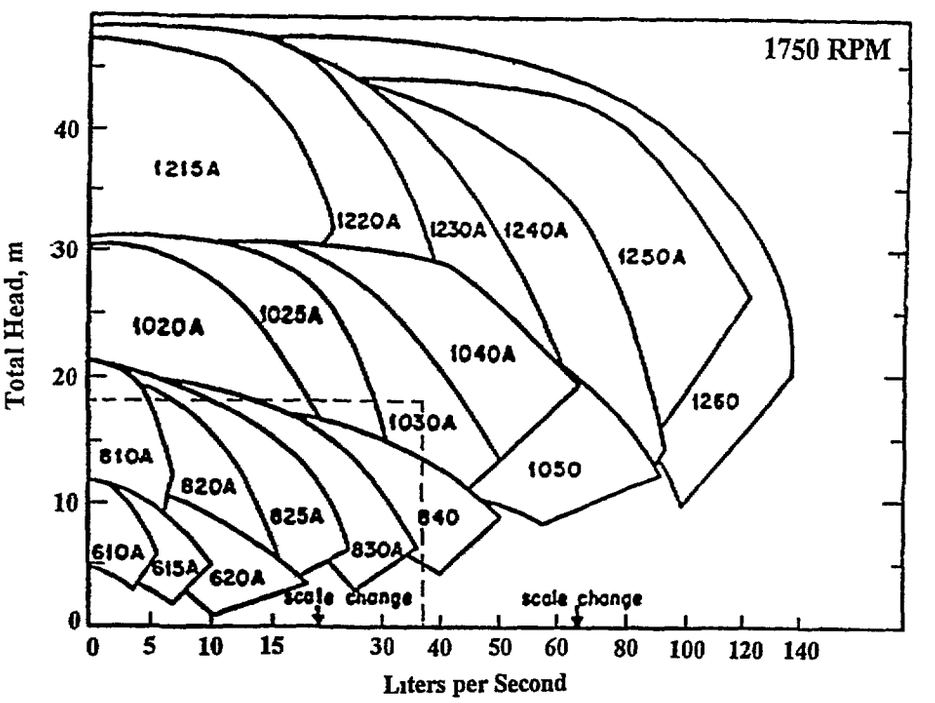

Figure 5 Envelope curves for pump selection based on system operating requirements

3. PUMP INSTALLATION

Proper installation of pumps is required to insure that (a) cavitation does not occur, (b) the pump is operating on that portion of the pump characteristic curve for which it was selected, and (c) friction loss on the discharge side of the pump is minimized

3 1 Intake Line

Certain conditions can promote cavitation and air entrapment in the pump even when $NPSH_a$ requirements are met The entrainment of air can be caused by aeration of the flow before it enters the suction line

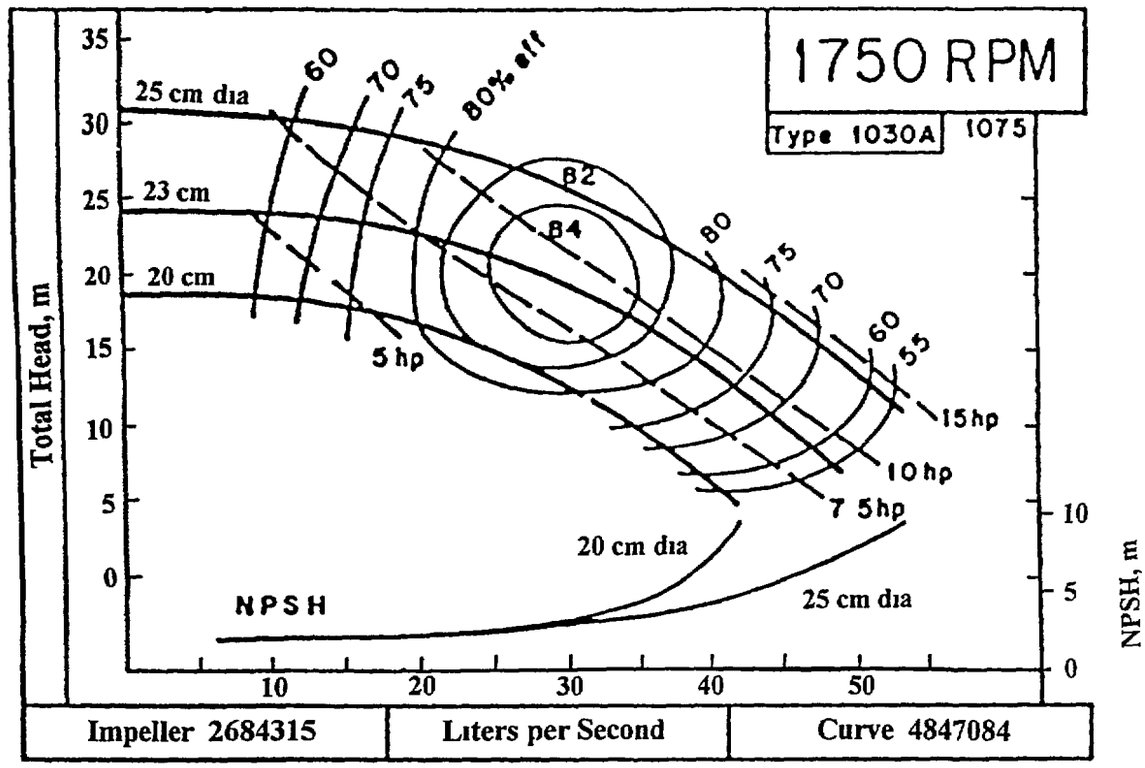

Figure 6 Pump performance curves corresponding to the model shown in Figure 5

- Small bubbles generated by a falling stream of water pass through the suction line of the pump This results in reduced discharge in comparison to that indicated by the pump characteristic curve When the pipe filling a pool discharges close to the suction inlet of the pump, water with entrained air is present near the pump suction line inlet When water is entering the pool at the same time the pump is operating, air bubbles can pass into the inlet line

Methods are available to reduce the potential for air entrainment and cavitation, see Figure 7

- Maintain velocities in the suction line equal to or less than 3 3 m/s
- Submerge the inlet by a depth equal to 4 pipe diameters to discourage vortex formation
- If the flow in the inlet line must change direction by 90 degrees, this is most efficiently done through two 45 degree elbows
- Using **D** for the diameter of the suction line before necking down to the pump intake, the nearest obstruction to flow should be no less than 4**D** from the pump intake

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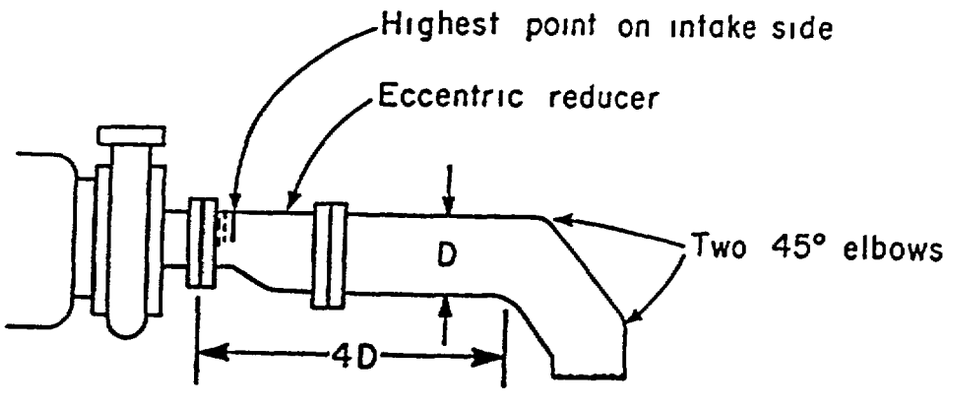

Figure 7 Recommended fittings on the intake side of centrifugal pump installations

- The pump intake should be at the highest position on the intake line so no air is allowed to accumulate and form an air pocket which reduces the flow area It is recommended that an eccentric reducer be used on the pump intake with the straight portion being on the upper part of the intake line, see Figure 7 Eccentric reducers with an interior angle of approximately 28 degrees give an optimum balance between reducer length and minimum friction loss
- Allow at least 2 pipe diameters for clearance between the suction pipe inlet and the walls and floor of concrete sumps Use 3 or more pipe diameters for clearance in earthen sumps
- It is recommended that flanged fittings, which are bolted externally, be used instead of plumbing fittings that are threaded The flanged fittings do not have the friction losses and turbulence associated with the abrupt edges of the threaded fittings
- Air release valves that bleed air out of the fitting or line may also be required Their recommended placement is on top of the pump housing or at the high point in the high velocity discharge Air release valves preclude the formation of an air pocket that may partially block the area

3 2 Discharge Line

Pumps are required to pressurize water at the design discharge Needless headloss, which must be paid for in energy costs but serves no benefit to the system, is to be avoided Excessive headloss results in the system operating on different portions of the pump characteristic curves, at a higher head and lower discharge at a lower efficiency It also results in higher energy costs per volume of water delivered to the soil

There are two major criteria for reducing the friction loss on the discharge side of the pump to the lowest possible amount (a) water does not like to turn corners and (b) fittings should be placed in the low velocity flow stream These recommendations are accomplished by minimizing the number of elbows on the

discharge line and by expanding up to the mainline diameter before installing flow control fittings

- The number of elbows may be minimized by inspecting the pump location and the direction required for the discharge (i e , direction of the mainline) Adjustment of the discharge direction can often be accomplished by unbolting and rotation of the pump discharge housing, which can be performed in the field
- The recommended way of expanding to the mainline diameter is by installation of a concentric expansion, with an interior angle of between 10 and 16 degrees, that goes directly from the pump discharge to the mainline diameter The absolute minimum friction loss is accomplished by a fitting that has a concentric expansion up to about 80 percent of the downstream diameter followed by an abrupt expansion to the full diameter
- Flanged fittings reduce turbulence and friction compared to threaded fittings

Discharge Line Installation Comparison

A pump with an electric motor is to be operated for 2000 hours per year Assume the cost of electricity is JD 0 04/kWh and the electric motor efficiency is 85 percent The discharge is required for flow in a horizontal mainline 20 cm in diameter The required flow rate is 37 83 lps, the pump discharge diameter is 7 5 cm, and the pump efficiency is assumed constant in order to compare the effects of the discharge fittings alone Two installations are to be evaluated

1 Vertical-throw discharge from pump
   - Flow turned horizontal by branch flow through a 7 5 cm tee with threaded fittings and L/D ratio equal to 60
   - 7 5 cm gate valve with L/D ratio equal to 8
   - Abrupt expansion in diameter from 7 5 cm to 20 cm

2 Horizontal-throw discharge from pump
   - Concentric expansion in diameter from 7 5 cm to 20 cm with 12 degree interior angle
   - 20 cm diameter gate valve with L/D ratio equal to 8

The solution is obtained by applying the appropriate resistance coefficients to compute the headloss through each fitting For all fittings other than the abrupt and concentric expansions, the headloss is computed as

$$h_f = \frac{KV^2}{2g}$$

where h_f = friction headloss, m, K = resistance coefficient (Table 2), V = flow velocity, m/s, and g = acceleration of gravity = 9 81 m/s^2

For the abrupt expansion, K is calculated from

$$K = \left[1 - (d_1/d_2)^2\right]^2$$

where d_1 = upstream pipe diameter, cm, and d_2 = downstream diameter, cm For the concentric expansion, K is calculated using

$$K = 2\,6\sin(\theta/2)\left[1 - (d_1/d_2)^2\right]^2$$

where θ = interior angle, degrees

The power required to overcome the headloss to push the water through the fittings is calculated using

$$P = \frac{Q \times H}{102 \times E}$$

where P = power, kW, Q = discharge, lps, H = total friction headloss through the fittings, m, and E = efficiency, decimal fraction In this example E will only refer to the motor efficiency since pumps for both installations are assumed to have the same efficiency In reality, E should be the pumping plant efficiency, which is the product of the motor and pump efficiencies The annual operating cost is computed by

$$C = P \times T \times C_{elec}$$

where C = annual operating costs, JD/yr, T = annual time of operation, h, and C_{elec} = cost of electricity, JD/kWh

Using data from Table 3, the difference in annual operating costs for the two installations is

$$\Delta C = C_1 - C_2$$

$$\Delta C = \text{JD}255\,68/\text{yr} - \text{JD}26\,48/\text{yr} = \text{JD}229\,20/\text{yr}$$

The JD229 2is the additional cost per year to pressurize the water to get it through the high headloss fittings This cost can be completely avoided by selection of the correct installation configuration given by Installation #2

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Table 2 Values of resistance coefficient, K, for standard pipe fittings and valves

Standard fitting or valve	Nominal diameter — mm (in) 75 (3)	100 (4)	125 (5)	150 (6)	175 (7)	200 (8)	250 (10)	300 (12)	350 (14)
Elbows Flanged									
Regular 90^0	0 34	0 31	0 30	0 28	0 27	0 26	0 25	0 24	0 23
Long radius 90^0	0 25	0 22	0 20	0 18	0 17	0 15	0 14	0 13	0 12
Long radius 45^0	0 19	0 18	0 18	0 17	0 17	0 17	0 16	0 15	0 15
Elbows Screwed									
Regular 90^0	0 80	0 70							
Long radius 90^0	0 30	0 23							
Regular 45^0	0 30	0 28							
Bends									
Return flanged	0 33	0 30	0 29	0 28	0 27	0 25	0 24	0 23	0 23
Return screwed	0 80	0 70							
Tees Flanged									
Line flow	0 16	0 14	0 13	0 12	0 11	0 10	0 09	0 08	0 08
Branch flow	0 73	0 68	0 65	0 60	0 58	0 56	0 52	0 49	0 47
Tees Screwed									
Line flow	0 90	0 90							
Branch flow	1 20	1 10							
Valves Flanged									
Globe	7 0	6 3	6 0	5 8	5 7	5 6	5 5	5 4	5 4
Gate	0 21	0 16	0 13	0 11	0 09	0 075	0 06	0 05	0 04
Check	2 0	2 0	2 0	2 0	2 0	2 0	2 0	2 0	2 0
Angle	2 2	2 1	2 0	2 0	2 0	2.0	2 0	2 0	2 0
Valves Screwed									
Globe	6 0	5 7							
Gate	0 14	0 12							
Check	2 1	2 0							
Angle	1 3	1 0							
Foot Valve	0 80	0 80	0 80	0 80	0 80	0 80	0 80	0 80	0 80
Basket Strainer	1 25	1 05	0 95	0 85	0 80	0 75	0 67	0 60	0 53
Inlets or Entrances									
Inward	0 78								
Projecting									
Sharp cornered	0 50	All diameters							
Slightly rounded	0 23	All diameters							
Bell-mouthed	0 04	All diameters							

Sudden enlargements $K = [1-(D_r)^2]^2$ where D_r = ratio of small to large inside diameter

Sudden contraction $K = 0\ 7\ [1 - (D_r)^2]$

Table 3 Comparison of pump installation annual energy costs

Installation # 1				Installation # 2			
Fitting	Inlet dia (cm)	K factor	Headloss (m)	Fitting	Inlet dia (cm)	K factor	Headloss (m)
Tee branch	7 5	1 08	4 04	Concentric exp	7 5	0 20	0 75
Gate valve	7 5	0 14	0 52	Gate valve	20	0 11	0 01
Abrupt exp	7 5	0 74	2 77				
Total (m)			7 33	Total (m)			0 76
Power Req (kW)			3 196	Power Req (kW)			0 331
Annual Cost (JD)			255 68	Annual Cost (JD)			26 48

3 3 Pump Support

Pump support refers to the support of the intake and discharge lines connected to the pump Pump housings are not constructed to support the weight of the intake and discharge lines, especially when they are full of water The pump and motor should be securely anchored in their permanent position The intake and discharge pipes should then be brought to the position of the pump and supported so they can be directly bolted to the pump using flanged fittings Proper intake and discharge line support is shown in Figure 8

It is common to fit the intake and discharge lines with Dresser couplings This type of flexible coupling absorbs elongation and shrinkage of the pipeline that occurs with temperature changes and during pump operation

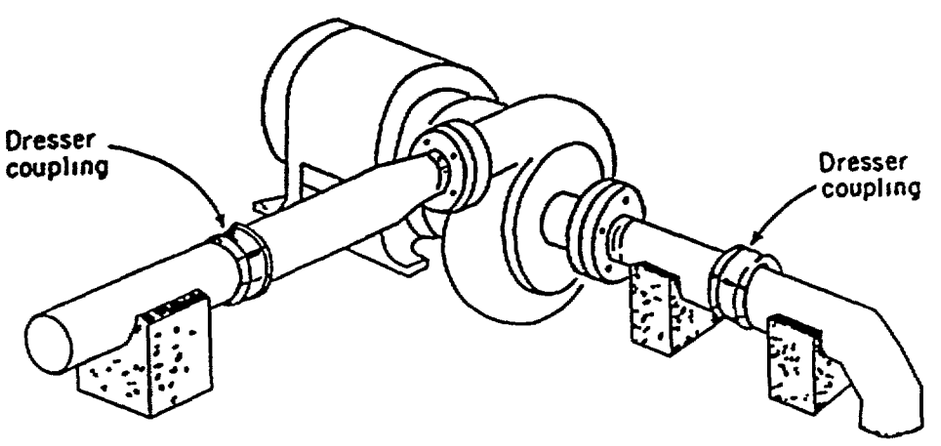

Figure 8 Schematic of installation with correct support of intake and discharge lines to pump

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MICRO IRRIGATION SYSTEMS

MOTORS AND ENGINES

[SUPPLEMENTAL]

1 INTRODUCTION

The goal in selecting a power unit for an irrigation system is to choose one that is reliable and able to drive the pump so it delivers the desired Q_s and TDH and is cost-effective The choice between electric motors or the various types of internal-combustion engines should be based on the expected life-cycle cost of owning and operating the power unit (costs of competitive energy sources electric, diesel, or gasoline)

2 ELECTRIC MOTORS

Electric motors are characterized by long life, low maintenance requirements, and high reliability They keep a constant efficiency and rpm under varying load conditions Larger motors are more efficient in this respect, they exhibit low substantial change in efficiency with age Motors draw power in accordance with actual prevailing loads

Motor performance can be degraded due to excessive heat resulting from overload, poor ventilation, low voltage and voltage imbalance among phases of a 3- phase motor Motor life can be increased by maintaining loads at 100% or less, confining voltage imbalance within 4% and increasing the current power producing factor

When an electric motor is used to drive the pump, the rotation speed of the pump will be fixed. For 50-cycle electricity it is approximately 1465 or 2875 rpm

Electric motors are capable of continuous operation at their rated horsepower provided they are adequately cooled When operated at half or more of their rated output the energy per unit or power output, kW/hp-hr, is nearly constant

Selecting a suitable motor for a direct or indirectly coupled electric-powered pumping plant is relatively easy The motor needs to have a rated power output at least equal to the power required to drive the pump at the necessary or desired speed Table 1 gives the efficiency of electric motors at different loads

3 ENGINES

Internal-combustion engines used in irrigation are generally higher in initial cost and more difficult to maintain than electric motors, but their fuel cost is usually lower Where portability is desired or where providing access to an adequate source of electricity would be prohibitively expensive, internal-combustion engines are the only option

Selecting an engine to drive a pump is considerably more complicated than selecting a motor Engine speed can vary, and as it varies, the power-output capability of the engine, unit fuel consumption and efficiency also vary Information on an engine's output and fuel consumption at varying speeds should be available from the manufacturer A typical performance curve is shown in Figure 1

Table 1 Motor efficiency at various horsepower and loads

Horsepower	Efficiency 100% load	Efficiency 50% load	Horsepower	Efficiency 100% load	Efficiency 50% load
3	84	81	60	90	87
5	85	80	75	90	90
7 5	86	81	100	90	89
10	87	83	125	91	90
15	89	85	150	91	90
20	89	85	200	92	90
30	89	83	250	92	91
40	90	89	300	92	91
50	90	89	350	92	91

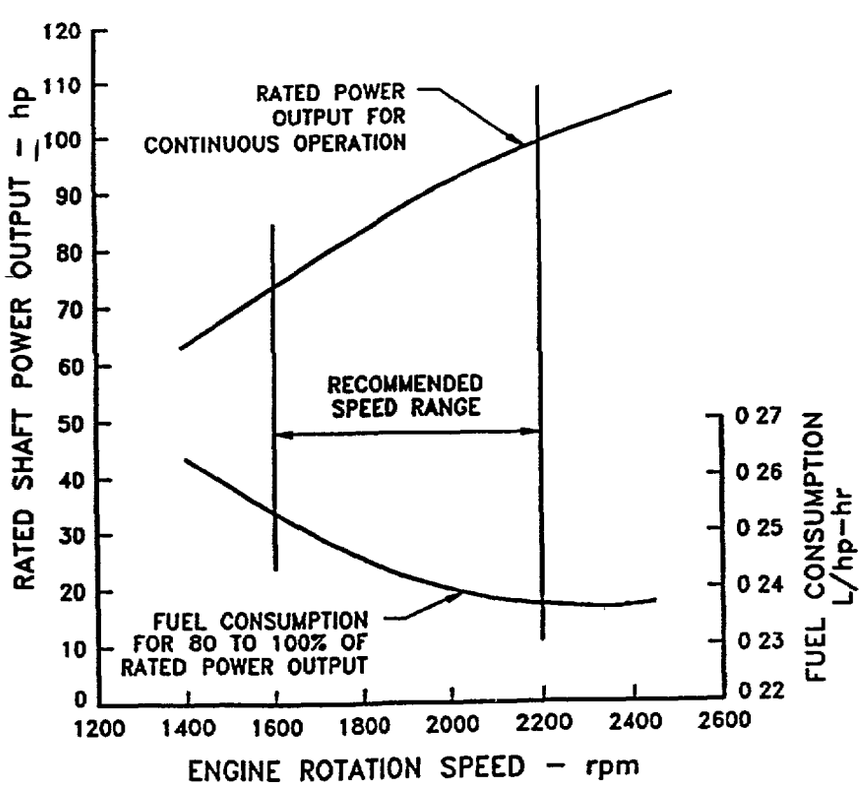

Figure 1 A diesel engine's performance curves for continuous duty (with no accessories) at sea level and 15 °C

Some performance curves are for engines operating intermittently and stripped of all accessories that take output power Such curves need to be *derated* by 15 to 20% to

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allow for continuous operation In addition, 2 to 4% of the output power must be subtracted to allow for an air cleaner, generator, and muffler A cooling fan consumes 5 to 10% of the engine's output power

Performance curves are usually reported for an engine operating at sea level at an ambient temperature of 15 °C The density of the air and thus the quantity of oxygen decreases as either elevation or temperature increases It is necessary to derate engine performance to adjust for the ambient temperature and elevation of the pump installation
General rules for altitude and temperature derating of naturally aspirated engines are

- Reduce continuous load rating by 3% for every 300 m above sea level
- Reduce continuous load rating by 1% for every 5 °C above 15 °C

After derating for altitude and temperature, remember that some power is required for the accessories mentioned above

3 1 Indirectly coupled pump

The procedure to select an engine to drive an indirectly couple pump is relatively simple

- Find an engine that appears to have sufficient power when operating at a suitable speed and within its efficient speed range
- Derate the engine's rated power output, at the selected speed, for altitude and temperature
- Subtract the power required to operate the necessary accessories and auxiliary equipment plus an additional 10% (of the derated power output) from the derated power output at the desired speed The additional 10% is a safety factor
- Check whether the required power to drive the pump is within ±5% of the value determined in the above step If it is, the power unit is well suited to drive the pump at the designated speed

3 2 Directly coupled pump

Both the engine and the pump will run at the same speed when they are directly coupled This adds to the complexity of matching them, because both the power required by the pump and the engine output power depend on the speed of rotation The power output of the engine increases almost directly with the rotation speed while the power required by the pump increases as the cube of the speed

- Find an engine that appears to have sufficient power when operating at a suitable pump speed for the required Q_s and TDH within the engine's efficient speed range
- Derate the engine's rated continuous-power output versus rotation-speed curve for the site elevation and highest anticipated ambient temperature at the air filter inlet

- Subtract the power required to operate the necessary accessories and auxiliary equipment plus an additional 10% (of the derated power output) from the derated curve to obtain the available power curve The additional 10% is a safety factor
- Check the pump's characteristic curves to determine if there is an impeller diameter and speed combination that has a power requirement within ±5% of the available power curve determined in the above step If there is such a combination within the pump's efficient operating range that will give the required Q_s and TDH, the power unit is well suited to drive the pump

MATCHING AN ENGINE AND PUMP

CASE STUDY, DIRECT COUPLED

Given

Engine with the performance curve shown in Figure 2
Power required by the pump = 60 hp
Pump speed = 2000 rpm
Elevation is 1,524 m above sea level

Maximum temperature expected in the pump house ≈ 38 °C
The engine will be air-cooled

Design

From Figure 2 the rated continuous daily duty power output of the engine is 92 horsepower when operating at 2000 rpm, sea level, and 15 °C Derating the power output for elevation and temperature gives

$$92\left[1.0 - 0.03\left(\frac{1524}{300}\right) - 0.01\left(\frac{38-15}{5}\right)\right] = 73.7 \text{ hp}$$

Assuming 3% of the power is required for accessories and 7.5% is required for the cooling fan, the remaining power is

$$73.7\,(1.0 - 0.03 - 0.075) = 66.0 \text{ hp}$$

Allowing a 10% factor for safety, the power remaining to drive the pump is

$$66.0 - (0.1 \times 73.7) = 58.6 \text{ hp}$$

This is within ±5% of the 60 hp required to drive the pump, and 2000 rpm is within the engine's efficient operating range

From the fuel-consumption curve in Figure 2, the rate of diesel consumption will be 0.24 l/hp-hr when the engine is over 80% loaded When producing 60 hp to drive the pump plus the power required by accessories and the cooling fan, the engine's fuel consumption rate will be about

$$0.24\,[60 + 73.7\,(0.03 + 0.075)] = 16.3 \text{ lph}$$

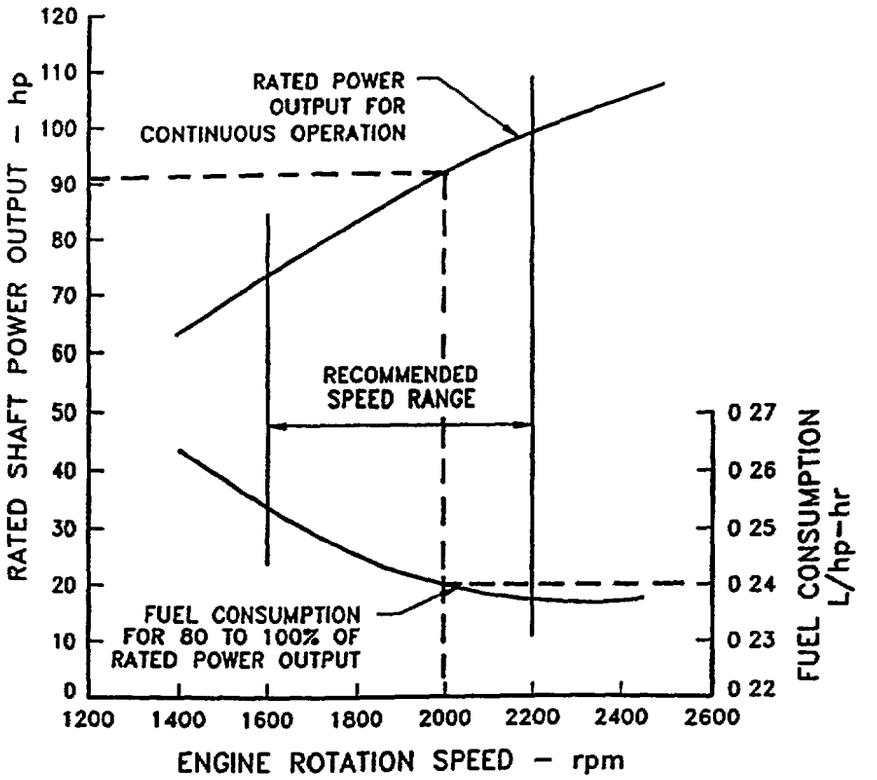

Figure 2 A diesel engine's performance curves for continuous duty (with no accessories) at sea level and 15 °C

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MICRO IRRIGATION SYSTEMS

MEDIA FILTER DESIGN

[Supplemental]

1. INTRODUCTION

Graded-sand media filters consist of fine gravel and sand of selected sizes placed inside a cylindrical tank As water passes through the tank, the gravel and sand perform the filtration

Media filters are primarily used for filtering out heavy loads of very fine sand and organic material Sand media filters are most effective in filtering organic material, because they can collect contaminants through the depth of the sand bed and accumulate large quantities of algae before backwashing is necessary A sand media filter can handle larger loads of contaminants than a screen of comparable fineness It can do it with less frequent backflushing and a smaller pressure drop

Media filters, or sand filters, are generally very reliable and require little maintenance Proper filter media selection and proper set up and adjustment are crucial to satisfactory operation Recommended practice is to use a screen filter downstream from the media filter to catch particles that escape during backwashing

2. DESIGN

It is recommended that media material be fine enough to retain all particles larger than one-tenth the diameter of the orifice or flow passages of the emitter Characteristics of common media used in filters is given in Table 1 The sand particles should have ragged edges with a range of sizes to create a tortuous path Crushing plants are a good source for suitable materials Most river sands have rounded edges and are not suitable as filtration media.

Table 1 Characteristics of filter media

Media Type	Media size mm	Filtration capacity 0 06 lpm/cm^2	0 102 lpm/cm^2
No 8 Crushed granite	1 9	0 11	0 15
No 11 Crushed granite	1	0 08	0 11
No 16 Crushed silica	0 825	0 08	0 10
No 20 Crushed silica	0 55	0 06	0 08

Uniformity cannot be overlooked in the media selection criteria Extremely fine media particles in an otherwise larger grade of media may pass through the filter and on to the irrigation system, potentially clogging the system **All filtration media should have a uniformity coefficient (UC) of 1 5 or less** The UC is defined as the 40-percent retained size of the media divided by the 90-percent retained size Retained size refers to the

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particle sizes of the media that are retained in a sieve analysis A value of UC = 1 0 indicates that all particles are of the same size

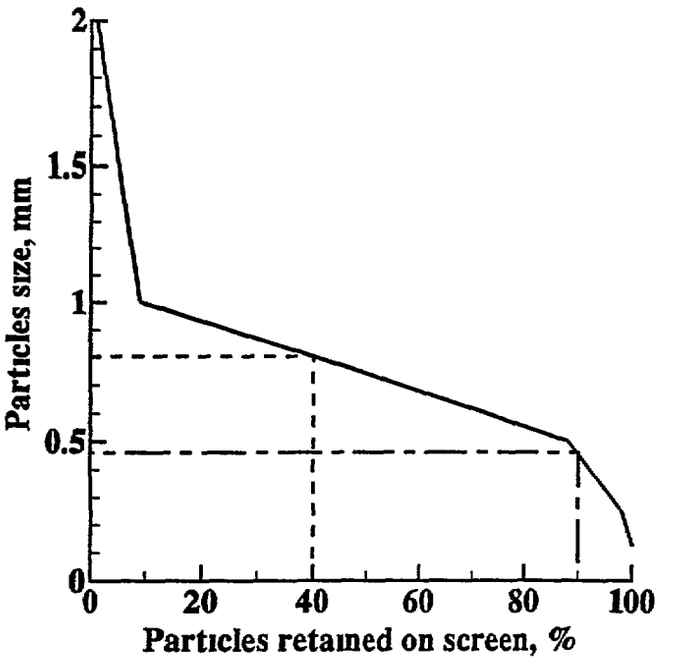

Figure 1 Filter media particle size analysis

For the sample shown in Figure 1

$$UC = \frac{0\,8}{0\,46} = 1\,74$$

A UC = 1 74 indicates that the sample material is not suitable for use as filter media unless the very small particles are removed

The media should be from parent material that does not dissolve in the irrigation water, the chemicals found in the water must be considered

At a flow velocity of 0 102 lpm/cm^2 of filter surface, the numbers 8 and 11 crushed granite remove most particles larger than one-twelfth of the mean granule size or approximately 0 16 and 0 08 mm, respectively The silica sand media, numbers 16 and 20, remove particles approximately one-fifteenth the mean granule size or approximately 0 06 and 0 04 mm, respectively The size of particle passing through the media increases as the rate of flow increases

The total number (and/or size) of tanks required is determined by dividing the system flow rate by the rated capacity of each tank **At least two tanks are required per system to provide backwash capability.** Typically, three or more tanks in a system provide better performance during backflush, because 2/3 or more of the filtered flow capacity, instead of 1/2, is available to backflush each tank

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Flow rates through each filter should be greater than 0 06 lpm/cm^2 of filter surface area. If the filter is sized for flow rates below 0 06 lpm/cm^2 of filter surface area, it is commonly experienced that channeling will take place within the media. As a result a pressure drop may not be sensed, which may lead to not backwashing filters that are in fact dirty This can lead to the movement of contaminants through the filter media and into the irrigation system Media filter tanks should be backwashed each day, regardless of the pressure readings across the filter

Flow rates through each filter should be less than 0 102 lpm/cm^2 of filter surface area. At higher flow rates turbulence within the filter will cause coning and disruption of the media bed, creating distortions and aberrations of filter performance

A gravel pack of washed, crushed rock 1 3 cm - 1 9 cm in size is used to provide coverage of 5 1 cm - 7 6 cm above the highest point of the filter underdrain The filter media should be packed to an appropriate depth (about 36 cm or to one half the diameter of horizontal filters) with silica sand or equivalent crushed material Filter design must allow for a 60% expansion of the bed upon backwashing, otherwise some sand would be lost with the backwash water It is recommended that the depth not exceed 46 cm to 90 cm or the bed may not lift properly when the filter is backwashed and channels of coarser aggregate may develop, which will reduce the effectiveness of the filter

Tables 2 and 3 give typical backwash flow requirements and tank size and number recommendations for vertical media tanks Similar tables can be derived for horizontal media tanks

Table 2 Typical backwash flow requirements for vertical media tanks

Tank diameter (cm)	Media bed area (cm^2)	Backwash flow rate (lpm)
50	1,963	130
60	2,827	187
70	3,848	254
80	5,027	332
90	6,362	420
100	7,854	518
110	9,503	627
120	11,310	746

Table 3 Recommended media tank sizes, vertical orientation

Irrigation System Flow Rate (LPS)	Number and Size (CM) of Tanks
3 15	2-46
6 31	3-46
8	3-60
9 46	3-61
12	3-70
12 62	3-76
15 77	3-76
18 92	4-76
22 08	4-76
25 23	4-76
28 39	4-91
31 54	4-91
34 69	4-91
37 85	3-122
41 00	3-122
44 16	3-122
47 31	3-122
50 46	4-122

In horizontal filters, the depth of media material significantly effects the surface area of the media bed

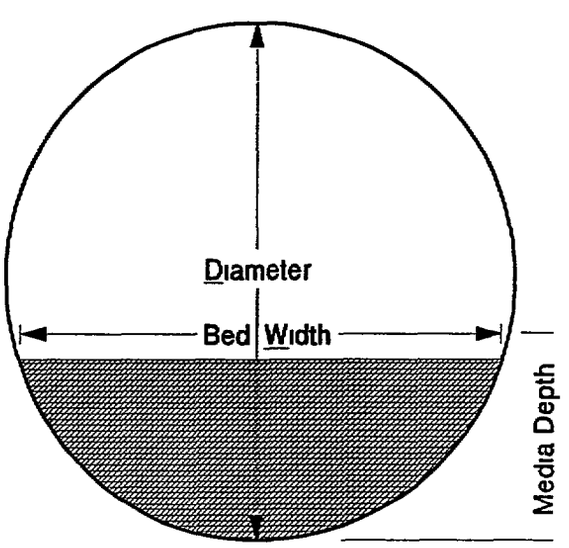

Figure 1 Definition of filter and media terms

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Given the diameter of the media filter tank (D), the media bed width (W), and the media bed depth (M), then the equations relating the variables are

$$W = [\, D^2 - (D - 2M)^2 \,]^{1/2}$$

or

$$M = 0.5\, [\, D - (D^2 - W^2)^{1/2} \,]$$

Figure 2 can be used to find the width of the media bed if the depth of media in the filter tank is known It can also be used to find the depth of media needed to satisfy a given bed width requirement Figure 3 shows the range of flow-rate filter-bed area values that are acceptable

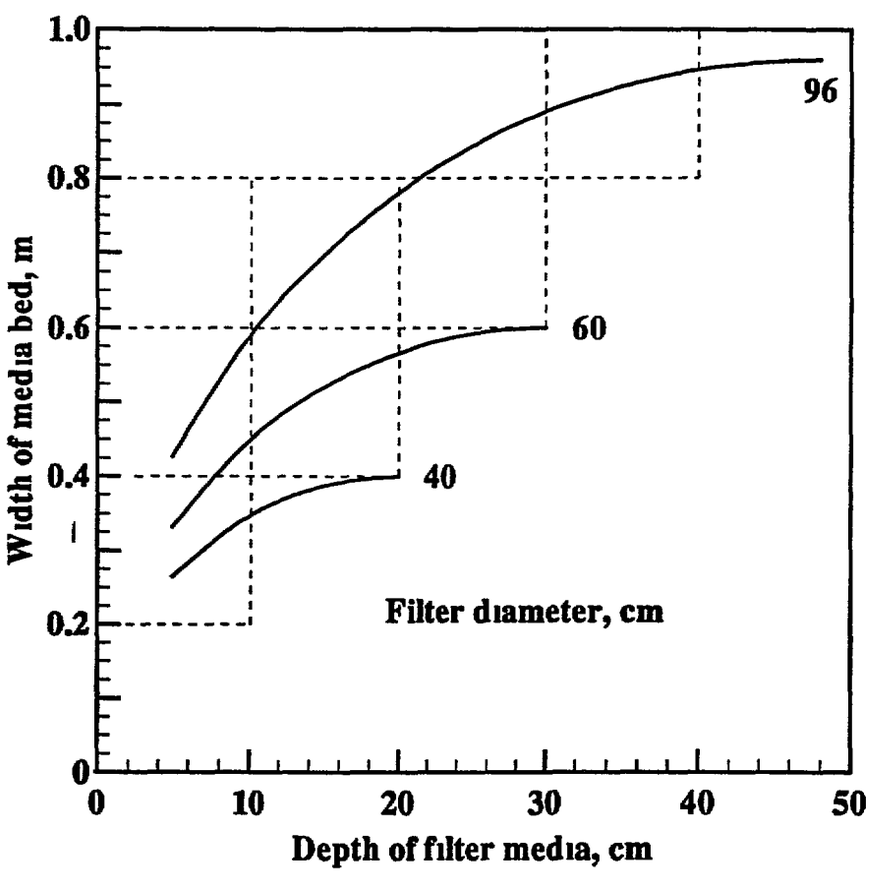

Figure 2 Media depth surface-width relationships for common horizontal filter diameters

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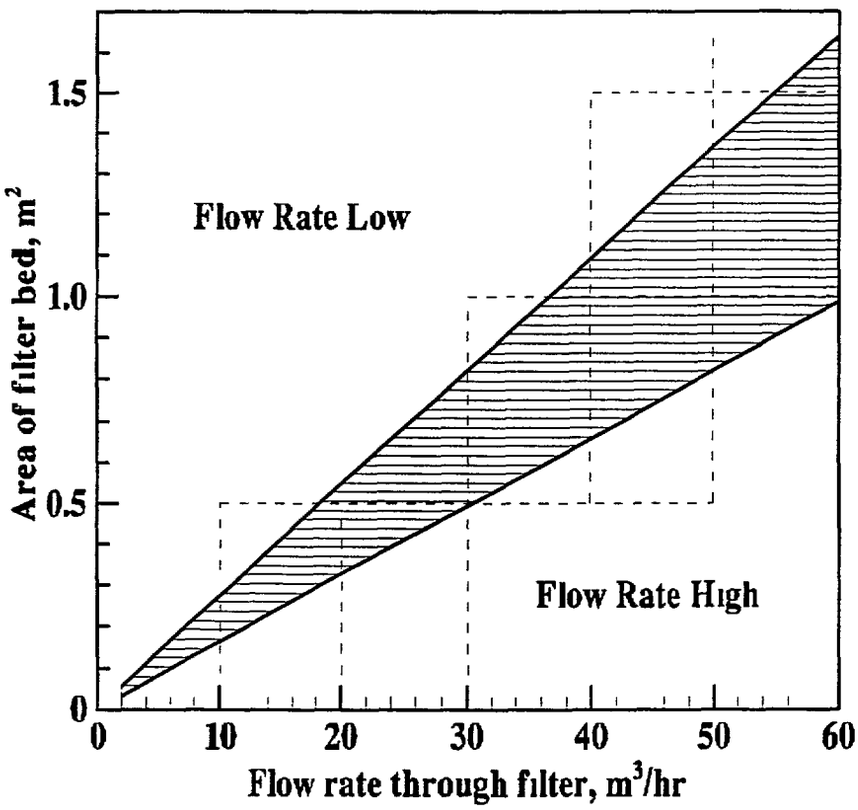

Figure 3 Range of acceptable design values for flow-rate and media surface area

MEDIA FILTER DESIGN
CASE STUDY I

1 DESIGN DATA

Normal flow rate into the system = 12 lps = 720 lpm
Assume dirty to extra dirty water
Smallest emitter passage = 1 mm
A pump supplies water from a pool, **flow rate can be increased for backwashing**

2. DESIGN STEPS

- Mean filtration capacity needed 1 mm/10 = 0 1 mm diameter
- Proper media to use Table 1 shows that number 11 Crushed granite has a mean filtration capability of about

  0 08 mm @ 0 06 lpm/cm^2, and
  0 11 mm @ 0 102 lpm/cm^2

  This media is suitable for the flow rate and water conditions
- Media filter bed area For extra dirty water the flow rate through the media bed should be low, use 0 07 lpm/cm^2

  720 lpm / 0 07 lpm/cm^2 = 10,286 cm^2
- Tank size for irrigation flow rates Table 2 shows

  7,696 cm^2 with 2 - 70 cm tanks or
  11,544 cm^2 with 3 - 70 cm tanks

  The temptation is to increase the flow rate through the media bed and use the 2 - 70 cm tanks This would be a mistake because it ignores the hydraulics of the system during backwash.
- Tank size for irrigation and backwashing flow rates, two tanks

  Flow rate per square cm = 720 lpm / 7696 cm^2 = 0 094 lpm/cm^2

  During the backwash cycle, the total required flow rate would be

  Total flow rate = normal flow + backwash flow (Table 2)
  974 lpm = 720 lpm + 254 lpm

  With a two tank installation, the flow rate per unit area through the one tank not being backwashed would be

  974 lpm / 3,848 cm^2 = 0 253 lpm/cm^2

  This flow rate is more than double the maximum allowable and therefore unacceptable At high flow rates the quantity of media material lost during each backwash cycle will be great
- Tank size for irrigation and backwashing flow rates, three tanks

  Flow rate per square cm = 720 lpm / 11,544 cm^2 = 0 062 lpm/cm^2

During the backwash cycle, the total required flow rate would be

Total flow rate = normal flow + backwash flow (Table 2)
974 lpm = 720 lpm + 254 lpm

With a three tank installation, the flow rate per unit area through the two tanks not being backwashed would be

$$974 \text{ lpm} / 7{,}696 \text{ cm}^2 = 0\ 127 \text{ lpm/cm}^2$$

This flow rate is slightly higher than the maximum allowed during filtration mode but is acceptable for the short backwashing cycle

The recommended configuration would be 3 - 70 cm vertical filter tanks filled with number 11 crushed granite media

In most situations the minimum number of tanks should be three With three tanks about half of the inflow would always be available for irrigation and backwashing velocities will not be excessive With two tanks, no flow would be available for irrigation during the backwash cycle and in many cases the backwashing velocities are excessive

Table 1 Characteristics of filter media

Media Type	Media size mm	Filtration capacity 0 06 lpm/cm²	0 102 lpm/cm²
No 8 Crushed granite	1 9	0 11	0 15
No 11 Crushed granite	1	0 08	0 11
No 16 Crushed silica	0 825	0 08	0 10
No 20 Crushed silica	0 55	0 06	0 08

Table 2 Typical backwash flow requirements for vertical media tanks

Tank diameter (cm)	Media bed area (cm²)	Backwash flow rate (lpm)
50	1,963	130
60	2,827	187
70	3,848	254
80	5,027	332
90	6,362	420
100	7,854	518
110	9,503	627
120	11,310	746

MEDIA FILTER DESIGN
CASE STUDY II

1 DESIGN DATA

Normal flow rate into the system = 8 lps = 480 lpm
Assume dirty to extra dirty water
Smallest emitter passage (GR emitter) = 1 mm
A pump supplies water from a pool, **flow rate can be increased for backwashing**

2 DESIGN STEPS

- Mean filtration capacity needed 1 mm/10 = 0 1 mm diameter
- Proper media to use Table 1 shows that number 11 Crushed granite has a mean filtration capability of about

  0 08 mm @ 0 06 lpm/cm^2, and
  0 11 mm @ 0 102 lpm/cm^2

  This media is suitable for the flow rate and water conditions
- Media filter bed area For extra dirty water the flow rate through the media bed should be low, use 0 06 lpm/cm^2

  480 lpm / 0 07 lpm/cm^2 = 6,857 cm^2
- Tank size for irrigation flow rates Table 2 shows

  7,696 cm^2 with 2 - 70 cm tanks or
  8,481 cm^2 with 3 - 60 cm tanks

  The temptation is to increase the flow rate through the media bed during the backwashing cycle and use the 2 - 70 cm tanks This would be a mistake because it ignores the hydraulics of the system during backwashing
- Tank size for irrigation and backwashing flow rates, two tanks

  Flow rate per square cm = 480 lpm / 7696 cm^2 = 0 062 lpm/cm^2

  During the backwash cycle, the total required flow rate would be

  Total flow rate = normal flow + backwash flow (Table 2)
  734 lpm = 480 lpm + 254 lpm

  With a two tank installation, the flow rate per unit area through the one tank not being backwashed would be

  734 lpm / 3,848 cm^2 = 0 191 lpm/cm^2

  This flow rate for backwashing is greater than the maximum allowable and should not be used At high flow rates the quantity of media material lost during each backwash cycle will be great
- Tank size for irrigation and backwashing flow rates, three tanks

  Flow rate per square cm = 480 lpm / 8,481 cm^2 = 0 057 lpm/cm^2

During the backwash cycle, the total required flow rate would be

Total flow rate = normal flow + backwash flow (Table 2)
667 lpm = 480 lpm + 187 lpm

With a three tank installation, the flow rate per unit area through the two tanks not being backwashed would be

$$667 \text{ lpm} / 5{,}654 \text{ cm}^2 = 0\ 118 \text{ lpm/cm}^2$$

This flow rate is slightly higher than the maximum allowed during filtration mode but is acceptable for the short backwashing cycle

The recommended configuration would be 3 - 60 cm vertical filter tanks filled with number 11 crushed granite media

In most situations, particularly where the filtration tanks are directly connected to the JVA pressure pipeline, the minimum number of tanks should be three With three tanks about half of the inflow would always be available for irrigation and backwashing velocities will not be excessive With two tanks, no flow would be available for irrigation during the backwash cycle and in many cases the backwashing velocities are excessive

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MICRO IRRIGATION SYSTEMS
MEDIA FILTER BACKWASHING

[Supplemental]

1. INTRODUCTION

Backwashing of the media filter is an essential part of the filtering process If it is not done at the proper time flow is restricted and if it is not done correctly debris flushed from the filter may enter the water delivery system and ultimately plug emitters

2. BACKWASHING

2 1 Initial set-up

Setting the backwash flow rate is perhaps the most important adjustment for media filters Figures 1a and 1b show the positions of the sand media during filtration and backwashing Excessive backwash flow rates will expand the media to the point that the media itself is expelled from the tank Insufficient backwash flow will not expand the media enough to purge all the entrapped sediment The backwash flow rate must be properly adjusted to achieve maximum filter performance

Backwash flow rates vary with the type of media The exact flow rate should be determined experimentally in the field The following procedure should be followed to adjust the backwash flow control in a newly installed system

- Turn on the system and operate until the design pressure and flow rate are attained

- Open the backwash restrictor valve a small amount, Figure 2 Item E
  NOTE· ***Never start the adjustment with a high flow rate, because the high flow rate can destroy the integrity of the media/gravel layers in the tank.***

- Release all entrapped air from each tank by partially opening and closing each tank valve

- Close the valve on one tank. This changes that tank from filtering mode to backwash mode Run backwash water waste through a 100 mesh screen, nylon stocking, or other sampling device to monitor contamination types and quantities

- Gradually open the backwash restrictor valve until a small amount of media from the backwash water appears in the sampling device

- When media begins to show in the backwash water, close the backwash restrictor valve until the water is essentially clear of media A trace of media is acceptable since it is desirable that the lighter granules (fines) in the bed be allowed to wash out

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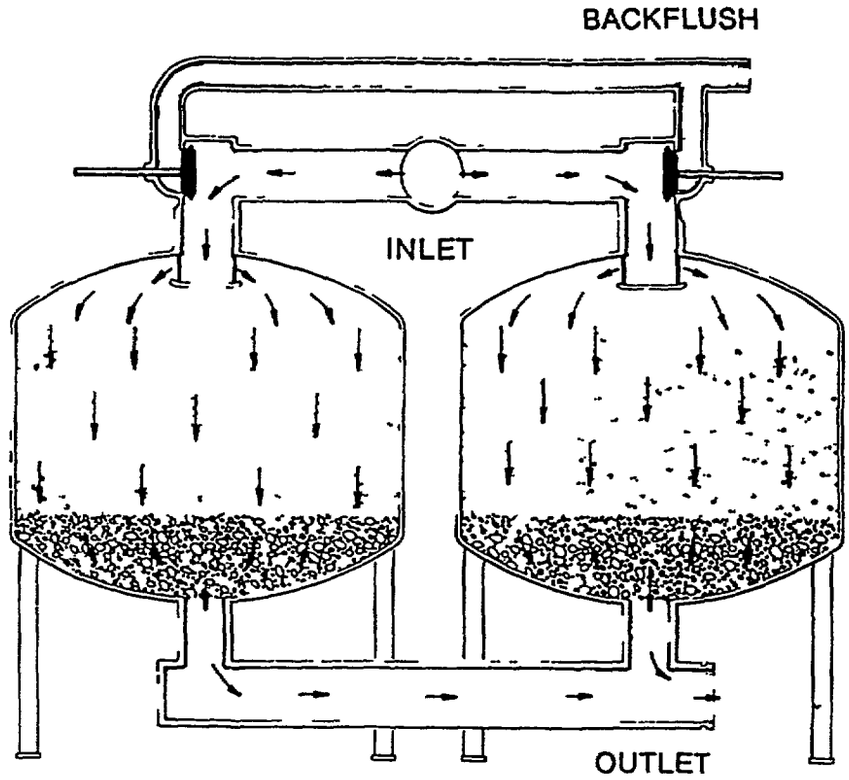
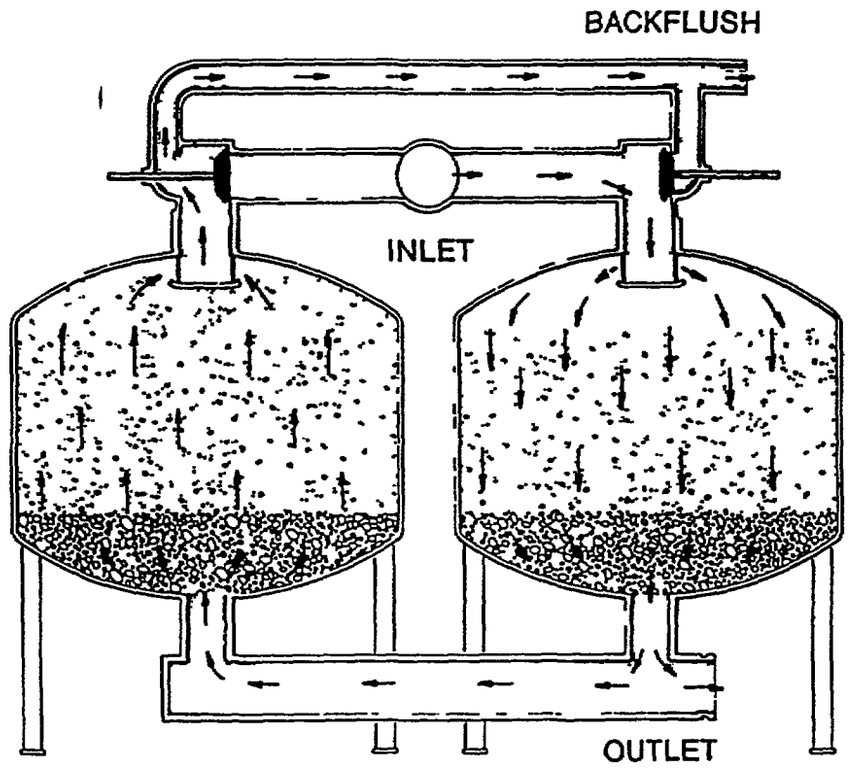


A. The filtration process



B The backwashing process

Figure 1 Modes of media filter operation

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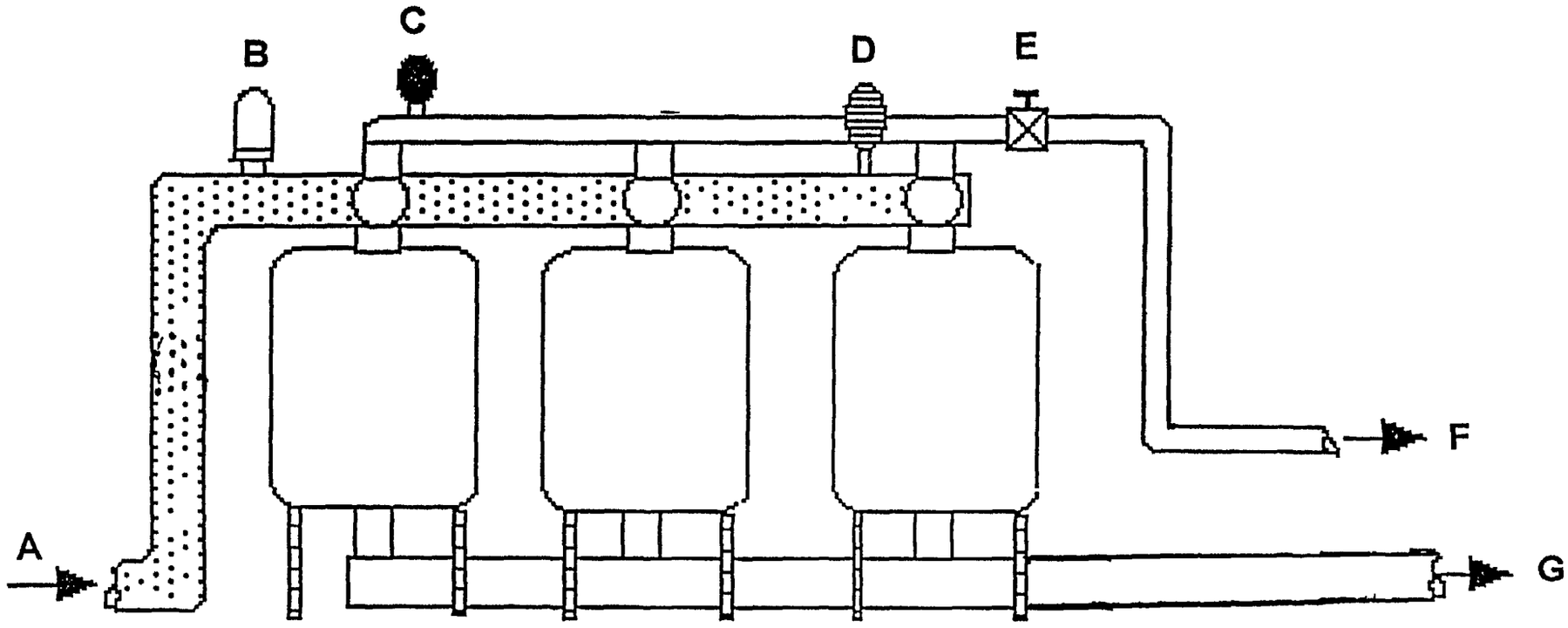

A - irrigation water source
B - Pressure relief valve
C - vacuum relief valve
D - air vent
E - backwash restrictor valve
F - backwash water waste
G - clean water into irrigation system

Figure 2 Media filter tank plumbing and fittings

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- After completing the above adjustments, all tanks should be backwashed extensively to remove contaminants and fine material usually found in newly installed media

- **It is good practice to remove the handle of the backwash restrictor valve after it has been set** This prevents it from being moved accidentally during routine maintenance backflushing cycles

Air can become entrapped in the top of the filter causing poor filtration and excessive headloss This is normally released during each flushing cycle but it is preferable to provide a continuous type air relief valve at the head of the filter manifold to prevent this occurrence

2 2 Operation

Filters should be cleaned, backwashed, and inspected regularly **No more than a 55 kPa (8 psi) increase in operating pressure, over the clean condition, across the filter should be allowed before cleaning.** Table 1 gives values for the initial/clean condition pressure drop across the filter Backwashing should be frequent enough to keep the pressure drop within the prescribed design limits Filters should be flushed at least once daily to prevent migration of sediment through the filter bed or consolidation of the sediment in a layer above the bed

Table 1 Pressure drop across clean filter media

Initial Pressure Drop kPa (bar)	Media Size mm	Media Type
14 - 21 (0 14-0 21)	1 9	No 8 Crushed granite
14 - 21 (0 14-0 21)	1	No 11 Crushed granite
34 (0 34	0 825	No 16 Crushed silica
34 (0 34	0 55	No 20 Crushed silica

Backwashing flow rates vary with the size of the media and the construction of the filter tank Typical recommended backwashing flow rates vary from 0 042 to 0 06 l/s/cm^2 of filter bed for number 20 media and between 0 084 and 0 102 l/s/cm^2 of filter bed for numbers 16 and 11 media To determine the correct flow rate for a given filter, follow the initial set-up procedure described previously Table 2 gives typical backwash flow requirements for vertical media tanks

The filters are backwashed one tank at a time, to remove the filtered contaminants To backwash, **a portion (or all) of the filtered water from one or more tanks is directed into the outlet of the tank to be cleaned** This expands the media sand and flushes contaminants from the bed, discharging them out through a backwash line for disposal The backwash operation should take from 5 to 15 minutes Observing the backwash water is a simple method for checking the efficiency of the cleaning operation Initial backwash water is extremely turbid, followed by a gradual clearing

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Table 2 Typical backwash flow requirements for vertical media tanks

Tank diameter (cm)	Media bed area (cm^2)	Backwash flow rate (lps)
50	1,963	3
60	2,827	4 5
70	3,848	6
80	5,026	8
100	7,854	12
120	11,310	18

The first increment of water entering the lines immediately after backwashing may be of similar quality as the untreated water when raw water is used for backwashing A by-pass or dump valve arrangement should be provided to get rid of this contaminated new water When the new water flows clean it can be introduced into the system mains

Automatic flushing should be used where the water is high in silt and clay

Periodic inspection of the filter bed right after backwashing should be made to see whether the sand particles are loosely packed as in the original condition Additional sand may be required if some is washed away A complete change may be needed when backwashing cannot remove the organic or other material adhering to the sand grains

3 TROUBLE SHOOTING MEDIA FILTERS

Problem Poor Filtration

Probable Cause	Solution
1 Excessive flow through filters, causing coning of media and/or forcing contaminants through filter to outlet	1 Reduce flow rate or add filter unit(s)
2 Air in filter(s) causing disruption of media bed	2 Install auto or manual air bleed device
3 Incorrect media in filtration system	3 Replace with proper media
4 Excessively high pressure forcing contaminants through filters	4 Readjust backwash control valve to proper setting
5 Insufficient depth of media, which allows contaminants to pass through the system	5 Add media to achieve proper depth (Typically 31 - 33 cm)

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Problem. Consistently High Pressure Differential

Probable Cause	Solution
1 Filter sealed over with contaminants restricting backwash flow	1 Open tanks and skim away excess or caked contaminants from the media sand bed's surface Return tanks to normal service Backwash each tank until backwash flow runs clean
2 Insufficient backwash flow	2 Readjust backwash flow or partially close field valve
3 Filter media low causing inadequate backwash	3 Add media to correct level
4 Caking or cementation of the media bed resulting in clogging of the pores	4 Replace media and readjust backwashing flow rates Backwash at the end of each irrigation cycle, more often if needed

Problem. Media Material Appears Downstream

Probable Cause	Solution
1 Incorrect media material (i e too fine)	1 Replace with properly sized media material
2 Broken, damaged, or missing PVC lateral pipe(s)	2 Repair or replace
3 Excessive flow through filters	3 Reduce flow rate or add filter unit(s)

Problem. Increasing Frequency of Backwash Cycle

Probable Cause	Solution
1 Backwash flow or duration is not adequate to flush filter tanks of all contaminants	1 Readjust backwash flow and/or increase duration of backwash cycle
2 Insufficient media depth	2 Add media to achieve proper depth
3 Increased concentration of contaminants in water supply (Note may only be a seasonal problem)	3 Add extra filter tank(s) to system or reduce flow rate

Problem Backwash Valve(s) Leak

Probable Cause	Solution
1 Obstruction in valve seat	1 Remove obstruction
2 Rubber seating disc is worn or damages	2 Replace seat disc
3 Diaphragm damaged (leaking from port of diaphragm chamber at rear of valve)	3 Replace diaphragm
4 Pinched or worn o-ring	4 Replace o-ring and lubricate shaft

Problem Water Hammer

Probable Cause	Solution
1 Air in tanks	1 Bleed off trapped air See start-up instructions Check also for leaks in pump suction line An air bleed at filter inlet may also help
2 Long backwash line causing vacuum	2 Install vacuum breaker on backwash line

Problem Automatic Backwash Fails to Cycle

Probable Cause	Solution
1 Controller power off, blown fuse or circuit breaker tripped	1 Turn power on Be sure wiring is connected Reset circuit breaker or install a new fuse
2 Improper setting on differential pressure switch	2 Inspect seal for signs of tampering
3 Solenoid(s) malfunctioning	3 Check connections Clean ports Check filter screen on water pickup assembly for damaged screen and clean or replace if necessary
4 Loss of sufficient system pressure to actuate valve(s)	4 Check system for pressure leaks Also, inspect filter screen on water pickup assembly for damaged screen Clean or replace if needed

MICRO IRRIGATION SYSTEMS

SCREEN FILTERS

[Supplemental]

1 INTRODUCTION

Where they are suitable, tubular screen filters provide a simple and efficient means for filtering water They are useful in very clean water if they are maintained frequently Their two-dimensional surfaces have little debris storage capacity, so they are primarily used as *backup devices* after the primary filter has removed the dirt load Screen filters efficiently remove very fine sand or small amounts of algae Even moderate amounts of algae can block single screens

2 DESIGN SPECIFICATIONS

Hole size and the total amount of open area determine the efficiency and operational limits of screen filters The wire or nylon mesh obstructs much of the open area For example, a standard 200-mesh stainless steel screen has only 33 6% open area, Table 1 gives data for stainless steel screen mesh material [1] An equivalent nylon mesh with the same-sized openings has significantly less open area Therefore, it is important to consider the percentage of open area when sizing a filter for a given system discharge

Table 1 Stainless steel screen mesh specifications

Mesh	Opening Microns	Wire diameter (inches)	Wire diameter (millimeters)	Open area (%)
16	1003	0 023	0 5842	39 9
30	516	0 013	0 3302	37 1
40	381	0 010	0 2540	36 0
50	279	0 009	0 2286	30 3
60	234	0 0075	0 1905	30 5
80	178	0 0055	0 1397	31 4
100	140	0 0045	0 1143	30 3
120	117	0 0037	0 09398	30 7
150	104	0 0026	0 06604	37 4
200	74	0 0021	0 05334	33 6

The maximum recommended flow rate through a mesh screen filter should be less than 135 l/s/m^2 (0 0135 l/s/cm^2) of screen open area

A screen filter with a high discharge in relation to the screen area may require frequent cleaning and have a short life The factors that should be considered when selecting screen filters are water quality, system discharge, filtration area, and percent of open area per filter, desired cleaning cycle, and allowable pressure drop

[1] Standard market grade stainless steel material

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Screen designs should allow for the easy removal of the screen element for cleaning and inspection The design should be such that contaminants will not fall from the screen into the outlet port of the screen housing Vertical screen tanks have been notoriously poor in this regard

The head loss through a screen filter unit will normally range between 35 to 70 kPa (5 to 10 psi) The loss depends on the valving, filter size, percentage of open area in the screen (sum of the holes), and discharge The anticipated head loss between the inlet and outlet of the system just before cleaning should be used when computing the required system inlet pressure

Table 2 gives specifications for a series of double element screen filters that are available from a Jordanian manufacturer Note that the flow rate through the filter is over ten times the recommended maximum flow rate for a screen filter Users should expect frequent cleaning of the filter and a shortened life for the screen

Table 2 Manufacturer specifications for double element screen filters, 100 mesh screens [1]

Manufacturer rated flow rate gpm (lps)	Holes in the elements Element 1 No	Element 1 Area cm²	Element 2 No	Element 2 Area cm²	Flow rate through holes[2] (lps/cm²)	Flow rate through filter[3] (lps/cm²)
75 (4 73)	77	118 53	70	107 76	0 0439	0 1449
150 (9 46)	189	290 94	140	215 51	0 0439	0 1449
225 (14 19)	315	484 90	160	246 30	0 0575	0 1901

1 Standard market grade stainless steel mesh material, specifications in Table 1
2 Considering only the open area of the holes in the smallest element, element 2
3 Considering the open area of the element holes reduced by the screen mesh wires

3. CLEANING

The *duration of operation* of the filter is the period between cleanings The need for cleaning is determined by drop of pressure across the filter It is customary to clean screen filters whenever the pressure drop has increased by 20 to 35 kPa (3 to 5 psi) or at predetermined intervals

As the screen material becomes covered by debris during operation, the pressure differential across the screen increases This has two results

- If the pressure differential becomes sufficiently great, the screen will burst
- The mesh fabric expands and allows larger sized particles to be "extruded" through the fabric

Simple manual cleaning is satisfactory when cleaning is required only once or twice a week If cleaning is required more frequently, a manually actuated or automatic cleaning system should be considered

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Regardless of the cleaning system used, extreme care should be taken to prevent contaminants from bypassing the filter during cleaning Backflushing with filtered water is recommended Also, downstream safety devices, such as Y-filters at manifold off takes or small filters or hose washer screens at each lateral connection, provide additional protection Extreme caution in keeping large particles out of the system is necessary This is especially important in view of the potential for accidents, such as breaks in the main line or manifold A few handsful of sand can ruin a system

Vertical screen filter units, which open at the top and the filtered water exits at the bottom, are commonly used in Jordan These units, which require removal of the screen for manual cleaning, offer ample opportunity for contaminants to move downstream during cleaning To prevent contamination of the system, many trickle irrigation equipment manufacturers are marketing horizontal or inverted screen filter units

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TROUBLE SHOOTING SCREEN FILTERS

Problem Poor Filtration

Probable Cause	Solution
1 High pressure after flushing due to wedged contaminants in cartridge element	1 Manually clean cartridge and readjust flush water volume
2 Contaminants down stream of filtration system	2 Torn or punctured mesh, worn or damaged end seals, o-rings or broken cartridge Replace with new parts Excessively coarse filter mesh-replace with finer mesh material
3 Heavy organic contaminants in mesh causing continual high pressure differential and particulate migration down-stream	3 Frequent manual cleaning or installation of media filters up-stream
4 Pressure differential builds rapidly	4 Excessive flow rates or change in water quality Reduce volume or add filter units

Problem Automatic Backwash Fails to Cycle

Probable Cause	Solution
1 Controller power off, blown fuse or circuit breaker tripped	1 Turn power on Be sure wiring is connected Reset circuit breaker or install a new fuse
2 Solenoid(s) malfunctioning	2 Check connections Clean ports Check filter screen on water pickup assembly for damaged screen and clean or replace if necessary

SCREEN FILTER DESIGN

CASE STUDY I

1 DESIGN DATA

Normal flow rate into the system = 8 lps
Irrigation system uses micro sprayers, smallest passage = 1 5 mm
Design for a minimum of 2 units
Maximum flow rate through the screen mesh = 0 0135 lps/cm²

2. DESIGN STEPS

- Mean filtration capacity needed 1 5 mm/10 = 0 15 mm diameter
- Proper screen to use Table 1 shows that a 100 mesh screen has a mesh opening of 0 14 mm, which is slightly less than the required 0 15 mm
- Calculate the minimum open area (at maximum allowed flow rate) needed in the screen

$$\frac{[8\ \text{lps}]_{\text{Flow Desired}}}{[0\ 0135\ \text{lps}/\text{cm}^2]_{\text{max Flow Allowed}}} = [593\ \text{cm}^2]_{\text{Screen Open Area}}$$

- Calculate the area of screen that must be available for flow, area of open holes in the smallest element(s) of the filter unit(s) From Table 1, the open area for a 100 mesh stainless steel screen is 30 3%

$$\frac{[593\ \text{cm}^2]_{\text{Hole Area Needed}}}{[0\ 303]_{\%\ \text{Open Area}}} = [1957\ \text{cm}^2]_{\text{Screen Exposed Area}}$$

- Find the number of filter units needed, use the largest units (225 gpm) listed for a Jordanian manufacturer of screen filters, Table 2 If both screen elements are used, the area of open holes for the smallest screen must be used First, assume both screen elements are to be used

$$\frac{[1957\ \text{cm}^2]_{\text{Hole Area}}}{[246\ 3\ \text{cm}^2]_{\text{Filter Hole Area}}} = 8\ \text{units}$$

For the specified flow rate of 8 lps, the manufacturer would recommend one 150 gpm filter unit To keep the flow rate through the smallest screen element mesh below the recommended maximum of 0 0135 lps/cm², eight 225 gpm units should be used

If the screen filter follows a properly installed and operated media filter, only one screen element would be needed If only the largest screen element is used, four 225 gpm units would be needed to meet the flow rate requirements

$$\frac{[1957\ \text{cm}^2]_{\text{Hole Area}}}{[484\ 9\ \text{cm}^2]_{\text{Filter Hole Area}}} = 4\ \text{units}$$

SCREEN FILTER DESIGN

CASE STUDY II

1. DESIGN DATA

Normal flow rate into the system = 12 lps
Irrigation system uses micro sprayers, smallest passage = 1 5 mm
Design for a minimum of 2 units
Maximum flow rate through the screen mesh = 0 0135 lps/cm²

2. DESIGN STEPS

- Mean filtration capacity needed 1 5 mm/10 = 0 15 mm diameter
- Proper screen to use Table 1 shows that a 100 mesh screen has a mesh opening of 0 14 mm, which is slightly less than the required 0 15 mm
- Calculate the minimum open area (at maximum allowed flow rate) needed in the screen

$$\frac{[12\ \text{lps}]_{\text{Flow Desired}}}{[0\ 0135\ \text{lps}/\text{cm}^2]_{\text{max Flow Allowed}}} = [888\ 9\ \text{cm}^2]_{\text{Screen Open Area}}$$

- Calculate the area of screen that must be available for flow, area of open holes in the smallest element(s) of the filter unit(s) From Table 1, the open area for a 100 mesh stainless steel screen is 30 3%

$$\frac{[888\ 9\ \text{cm}^2]_{\text{Hole Area Needed}}}{[0\ 303]_{\%\ \text{Open Area}}} = [2933\ 7\ \text{cm}^2]_{\text{Screen Exposed Area}}$$

- Find the number of filter units needed, use the largest units (225 gpm) listed for a Jordanian manufacturer of screen filters, Table 2 If both screen elements are used, the area of open holes for the smallest screen must be used First, assume both screen elements are to be used

$$\frac{[2933\ 7\ \text{cm}^2]_{\text{Hole Area}}}{[246\ 3\ \text{cm}^2]_{\text{Filter Hole Area}}} = 12\ \text{units}$$

For the specified flow rate of 12 lps, the manufacturer would recommend one 225 gpm filter unit To keep the flow rate through the screen mesh below the recommended maximum of 0 0135 lps/cm², twelve 225 gpm units should be used

If the screen filter follows a properly installed and operated media filter, only one screen element would be needed If only the largest screen element is used, six 225 gpm units would be needed to meet the flow rate requirements

$$\frac{[2933\ 7\ \text{cm}^2]_{\text{Hole Area}}}{[484\ 9\ \text{cm}^2]_{\text{Filter Hole Area}}} = 6\ \text{units}$$

Table 1 Stainless steel screen mesh specifications

Mesh	Mesh opening (millimeters)	Wire diameter (inches)	Wire diameter (millimeters)	Open area (%)
16	1 003	0 023	0 5842	39 9
30	0 516	0 013	0 3302	37 1
40	0 381	0 010	0 2540	36 0
50	0 279	0 009	0 2286	30 3
60	0 234	0 0075	0 1905	30 5
80	0 178	0 0055	0 1397	31 4
100	0 140	0 0045	0 1143	30 3
120	0 117	0 0037	0 09398	30 7
150	0 104	0 0026	0 06604	37 4
200	0 074	0 0021	0 05334	33 6

Table 2 Jordanian manufacturer specifications for double element screen filters, 100 mesh stainless steel screens [1]

Manufacturer rated flow rate gpm (lps)	Holes in the elements Element 1		Element 2		Flow rate through holes[3] (lps/cm²)	Flow rate through filter[4] (lps/cm²)
	No	Area[2] cm²	No	Area[2] cm²		
75 (4 73)	77	118 53	70	107 76	0 0439	0 1449
150 (9 46)	189	290 94	140	215 51	0 0439	0 1449
225 (14 19)	315	484 90	160	246 30	0 0579	0 1911

1 Standard market grade stainless steel mesh material, specifications in Table 1
2 Each hole in the element is 14 mm in diameter or 1 539 cm²
3 Considering only the open area of the holes in the smallest element, element 2
4 Considering the open area of the element holes reduced by the screen mesh wires

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SCREEN FILTER DESIGN

CASE STUDY III

1 DESIGN DATA

Normal flow rate into the system = 8 lps
Irrigation system uses GR emitters, smallest passage = 1 mm
Design for a minimum of 2 units
Maximum flow rate through the screen mesh = 0 0135 lps/cm²

2. DESIGN STEPS

- Mean filtration capacity needed 1 0 mm/10 = 0 10 mm diameter
- Proper screen to use Table 1 shows that a 200 mesh screen has a mesh opening of 0 074 mm, which is less than the required 0 1 mm
- Calculate the minimum open area (at maximum allowed flow rate) needed in the screen

$$\frac{[8\ \text{lps}]_{\text{Flow Desired}}}{[0\ 0135\ \text{lps}/\text{cm}^2]_{\text{max Flow Allowed}}} = [593\ \text{cm}^2]_{\text{Screen Open Area}}$$

- Calculate the area of screen that must be available for flow, area of open holes in the smallest element(s) of the filter unit(s) From Table 1, the open area for a 200 mesh stainless steel screen is 33 6%

$$\frac{[593\ \text{cm}^2]_{\text{Hole Area Needed}}}{[0\ 336]_{\%\ \text{Open Area}}} = [1764\ 9\ \text{cm}^2]_{\text{Screen Exposed Area}}$$

- Find the number of filter units needed, use the largest units (225 gpm) listed by a Jordanian manufacturer of screen filters, Table 2, assume that a 200 mesh can be used in place of the standard 100 mesh If both screen elements are used, the area of open holes for the smallest screen must be used First, assume both screen elements are to be used

$$\frac{[1764\ 9\ \text{cm}^2]_{\text{Hole Area}}}{[246\ 3\ \text{cm}^2]_{\text{Element Hole Area}}} = 7\ \text{units}$$

To keep the flow rate through the screen mesh below the recommended maximum of 0 0135 lps/cm², seven 225 gpm units fitted with 200 mesh stainless steel screens should be used

If the screen filter follows a properly installed and operated media filter, only one screen element would be needed If only the largest screen element is used, four 225 gpm units would be needed to meet the flow rate requirements

$$\frac{[1764\ 9\ \text{cm}^2]_{\text{Hole Area}}}{[484\ 9\ \text{cm}^2]_{\text{Filter Hole Area}}} = 3\ 6\ \text{or}\ 4\ \text{units}$$

MICRO IRRIGATION SYSTEMS
FERTILIZER INJECTION

[Supplemental]

1 INTRODUCTION

Trickle irrigation systems are particularly adaptable to applying fertilizers directly to plant root systems The fertilizer solution is injected into the irrigation water distribution system and carried directly to the emitter close to the plant Advantages of this fertilizer application method, called fertigation, in comparison to conventional application methods are several

- Less equipment is required to apply fertilizer
- Less energy is expended in applying the fertilizer
- Usually less labor is needed
- The supply of nutrients can be more carefully regulated and monitored
- The nutrients can be distributed more evenly throughout the entire root zone
- Nutrients can be applied to the soil when crop or soil conditions would otherwise prohibit entry into the field by conventional means

The uniformity of fertilizer application is approximately equal to the uniformity of water applications Thus, an acceptable emitter discharge uniformity is a prerequisite to fertilizer injection The total irrigation time, including start-up, injection, and system flushing, should not apply more water than the available water holding capacity in the soil Otherwise, the fertilizer may be moved below the root zone

Care must be taken to see that the fertilizers and concentrations used are not corrosive to distribution system parts Table 1 indicates the potential degree of corrosion problems on different types of metal from various fertilizers

Due to the addition of nutrient to the water supply, algae growth, and bacterial slime, problems may also occur, which can cause clogging of emitters and filters Complete flushing of both the fertilizer injection and irrigation water delivery systems after completion of fertilizer application can reduce these problems

Table 1 Severity of corrosion damage to common metals caused by fertilizers

Type of metal	Calcium Nitrate	Ammonium Nitrate	Ammonium Sulfate	Urea	Phosphoric Acid	Diammonium Phosphate	Complete Fertilizer[1]
Galvanized Iron	M	SV	C	N	SV	N	M[2]
Sheet Aluminum	N	SL	SL	N	M	M	SL
Stainless Steel	N	N	N	N	SL	N	N
Yellow Brass	SL	C	M	N	M	SV	SV
Solution pH	5 6	5 6	5 0	7 6	0 4	8 0	7 3

1 17% Nitrogen — 17% Phosphorus — 10% Potassium
2 N = None, SL = Slight, M = Moderate, C = Considerable, SV = Severe

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2 MIXING FERTILIZERS

- Dry fertilizer conditioners Most dry solid fertilizers are manufactured by coating them with a special conditioner to keep moisture from being absorbed by the fertilizer pellets To avoid having the conditioners create problems of plugging screens and emitters it is best to mix the solid fertilizer with water and allow it to stand for a few hours The conditioner will rapidly settle to the bottom of the mixing tank Then the clear liquid can be siphoned off the top portion without disturbing the bottom sediment

- Cold solutions upon mixing Most dry nitrogen fertilizers will absorb heat from the water when they are mixed This will result in a very cold liquid which may cause the formation of frost on the outside of the mixing tank even in warm weather This cold temperature should pose no problem for injecting into the water or for plants since the cold fertilizer will be mixed with a much larger volume of water at a warmer temperature

  The real problem from cooling of water upon fertilizer mixing is that the total solubility of the fertilizer is usually low when the solution is cold Consequently, it mav be difficult to dissolve as much fertilizer as was expected to go into solution If this is the case, it will be necessary to allow the mixture to stand for several hours to warm up Then more fertilizer can be mixed into the fertilizer solution However, again the temperature will drop

- Mixing fertilizers and/or other chemicals for fertigation To avoid problems it is always best to check for compatibility when you are mixing two or more fertilizers or other chemicals with irrigation water The compatibility test is easy to do Take a glass jug of about 4 liter capacity and fill with irrigation water and the same mix ratio of fertilizers or chemicals to be used for field application Shake the mixture and observe it during an hour or so If the water remains clear and no sediment collects at the bottom of the container, clogging of lines and emitters will probably not occur

Nitrogen

When anhydrous ammonia or aqua ammonia fertilizers are injected into irrigation water, the ammonium is quite water soluble However, the pH of the water is raised to about pH 10 5 to 12 When the pH of water or soil is 9 2 then 50% of the nitrogen from the ammonia application is in the form of ammonia gas (NH_3) This ammonia gas can volatilize into the atmosphere and escape from the water or soil The extent of volatilization is pH dependent as indicated below

pH	% N volatilized
7 2	1
8 2	10
9 2	50
10 2	90
11 2	99

This strong pH dependence shows why a significant potion of the applied ammonia nitrogen fertilizer is lost if it is injected into irrigation water with a pH of 8 or higher Also, the reaction of the ammonia with the water drives the pH even higher Injecting aqua ammonia into normal irrigation water will push the pH beyond pH 9 4 where losses of ammonia can be from 30 to 50% of the applied nitrogen

This pH relationship holds for all ammonia fertilizers and for any ammonium (NH_4^+) fertilizers added to high pH waters The loss of ammonia gas will be more rapid from nitrogen treated water when the air is windy and especially when the air is very dry

It is best to fertigate with ammonia or ammonium fertilizers on cool, humid days with little wind It is best to acidify the irrigation water ***before*** injecting the fertilizer This will reduce the pH of the water and keep more of the nitrogen in the non-volatile ammonium form (NH_4^+)

- High pH of the irrigation water will cause calcium and magnesium ions in the water to form a precipitate of calcium and magnesium hydroxide and carbonate This precipitate is lime in a very finely divided form The harder the water is the more lime precipitate that forms when ammonia is injected into the water This precipitate can clog emitters and filters
- Ammonium thiosulfate should not be mixed with acidic materials because it will decompose into yellow elemental sulfur and ammonium sulfate at pH values below pH 6
- Do not inject calcium ammonium nitrate along with any sulfate or phosphate compounds Trying to acidify irrigation water with sulfuric acid or urea sulfuric acid and injecting calcium ammonium nitrate results in producing a white creamy gypsum mixture Trying to inject calcium ammonium nitrate along with potassium sulfate will have the same effect Attempting to mix calcium ammonium nitrate with any phosphate fertilizer will convert to insoluble calcium phosphate materials

Phosphorus

Most phosphorus fertilizers can ***not*** be injected into irrigation water because they have too low solubility Special precautions must be followed when injecting phosphate fertilizers The water must be acidified to avoid the formation of insoluble calcium and magnesium phosphate compounds that can clog filters or emitters, and which may cause uneven application of phosphate over the field

The crop needs most of the phosphorus very early in the growth cycle It is best to apply most phosphate fertilizers as preplant or at planting by conventional fertilizer application methods

- Phosphorus and calcium when in solution together, form tricalcium phosphate which is an insoluble phosphate This can clog irrigation lines

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and emitters Calcium can come from either the irrigation water or other fertilizers

- Phosphorus and magnesium when in solution together can form magnesium phosphates which are insoluble and can clog lines and emitters Magnesium can come from either the irrigation water or other fertilizers
- Phosphorus and iron when in solution together can form iron phosphates which are insoluble However, most waters contain only low levels of iron and this is rarely a problem
- For ammonium polyphosphate materials (10-34-0, 10-37-0, and 7-21-7) and monoammonium phosphates (11-55-0) the quality of the irrigation water must be known before attempting to inject these fertilizers These phosphorus materials react in hard water (with calcium and magnesium above 50 ppm, or with bi-carbonates above 150 ppm) to form precipitates which cause plugging
- Urea phosphate materials (Urea + phosphoric acid, 17-45-0) have a low enough pH to sequester calcium and magnesium and prevent precipitates from forming Also, phosphorus in these materials is more mobile in the soil (especially calcareous soils) than are most other phosphorus sources Urea offers a nitrogen source and can help free up fixed phosphorus in highly calcareous soils
- Injecting phosphoric acid into irrigation water will be effective only as long as the pH of the fertigated water remains very low (below pH 4) As the pH rises due to dilution with the irrigation water, the phosphate precipitates with the calcium and magnesium in the water This precipitate can clog filters and emitters, and cause a very non-uniform application of phosphorus

Calcium

- Fertilizers containing calcium should be flushed from all tanks, filters, and tubing before injecting any phosphorus fertilizer Calcium reacts with phosphorus to form calcium phosphate which is insoluble
- Calcium should not be injected with potassium sulfate It combines to form insoluble gypsum

Table 2 presents some common fertilizers and their approximate solubility in irrigation water Table 3 presents nutrient concentration recommendations for some common horticultural crops grown in the region

Table 2 Approximate solubility of fertilizers in irrigation water [1]

Fertilizer	Form	Grade	Density[2] kg/L	Solubility kg/L
Nitrogen Fertilizers				
Ammonium nitrate	NH_4NO_3	34-0-0	1 261	0 183
Ammonium Polysulfide	NH_4S_x	20-0-0	1 105	High
Ammonium Sulfate	$(NH_4)SO_4$	21-0-0		0 706
Ammonium Thiosulfate	$(NH_4)_2S_2O_3$	12-0-0		Very high
Anhydrous Ammonia[3]	NH_3	82-0-0	0 617	0 38
Aqua Ammonia[3]	NH_3-H_2O	20-0-0	0 913	High
Calcium Nitrate	$Ca(NO_3)_2$	15 5-0-0		1 212
Urea	$CO(NH_2)_2$	46-0-0		1 0
Urea Sulfate	$CO(NH_2)_2$-H_2SO_4	28-0-0		High
Urea Ammonium Nitrate	$CO(NH_2)_2$-NH_4NO_3	32-0-0	1 328	High
Phosphate Fertilizers				
Ammonium Phosphate[3]	$NH_4H_2PO_4$	8-24-0	1 261	Moderate
Ammonium Polyphosphate[3]	$(NH_4)_3P_2O_7$	9-30-0	1 357	High
	$(NH_4)_5P_3O_{10}$	10-34-0	1 369	High
	$(NH_4)_7P_5O_{16}$	11-37-0	1 405	High
Concentrated superphosphate[3]	$Ca(H_2PO_4)_2$	0-45-0		0 018
Diammonium Phosphate	$(NH_4)_2HPO_4$	18-46-0		0 575
Monoammonium Phosphate	$NH_4H_2PO_4$	11-48-0		0 227
Phosphoric Acid	H_3PO_4	0-54-0		0 457
Potash Fertilizers				
Potassium Chloride	KCL	0-0-60		0 347
Potassium Nitrate	KNO_3	13-0-44		0 133
Potassium Sulfate[3]	K_2SO_4	0-0-50		0 12
Micro nutrients				
Iron Sulfate	$FeSO_4$-$7H_2O$			0 1565
Magnesium Sulfate[3]	$MgSO_4$-$7H_2O$			0 71
Manganese Sulfate	$MnSO_4$-$4H_2O$			1 053
Ammonium Molybdate	$(NH_4)_6MO_7O_{24}$-$4H_2O$			0 43
Zinc Sulfate	$ZnSO_4$-$7H_20$			0 965
Lime Sulfur	CaS_5+Ca_2SO_3-$5H_2O$		1 273	High
Sulfuric Acid	H2SO4		1 837	Very high

1 Solubility is highly dependent upon water temperature and water hardness Hard water has high dissolved concentrations of calcium and/or magnesium

2 Density of the fertilizer when supplied in liquid form

3 Should not be applied through trickle irrigation systems because the material is hard to dissolve or sensitive to water hardness

Table 3 Recommended concentrations of nutrients in irrigation water, **g/m³**

Crop	Nitrogen	Phosphorus	Potassium
Cucumber	150 - 200	30 - 50	150 - 200
Eggplant	130 - 170	50 - 60	150 - 200
Bell pepper	130 - 170	30 - 50	150 - 200
Tomato	150 - 180	30 - 50	200 - 250
Potato	130 - 150	30 - 50	120 - 180
French beans	80 - 120	30 - 50	150 - 200
Strawberries	80 - 100	30 - 50	150 - 200
Lettuce	100	30 - 50	150
Iceberg lettuce	100	18	120
Shamouti orange	35	3 - 5	8 - 10
Banana	15	—	45
Sunflower	40 - 60	20 - 30	100

Note These recommendations are based on research work done in Cyprus and Israel and are presented as a guide only Soil tests or plant leaf analyses should be done by each farmer to determine the optimum application of nutrients for a given soil, water, and crop combination

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3 CALCULATION OF FERTILIZER INJECTION RATE

Step 1 Determine the amount of nutrient to apply during this fertigation

This amount is often based upon the total nutrient need of the crop divided by the total number of fertigation applications The amount may be based upon an estimation of the maximum rate of nutrient uptake by the crop at that specific stage of growth

Assume the desired nutrient to apply is 20 Kg of nitrogen per hectare

Step 2 Choose the type of fertilizer

Assume the fertilizer is Urea 46-0-0 as a solid or
Urea Ammonium Nitrate 32-0-0 (UAN 32) as a liquid

Step 3 Determine the kilograms of fertilizer to use

For solid fertilizers

Determine the kilograms of solid fertilizer that must be dissolved in water for injection and the total number of liters of resulting fertilizer solution Note, that a solid, mixed nutrient fertilizer may not dissolve at first Each component has a different dissolution rate Thus, it is very important that all of the solid fertilizer be in solution before attempting to inject the fertilizer into the irrigation line

$$\frac{\text{Kg of nutrient}}{\text{Hectare}} \times \frac{\text{1 unit fertilizer}}{\text{___ nutrient portion}} = \frac{\text{Kg fertilizer}}{\text{Hectare}} \qquad (1)$$

$$\frac{\text{20 Kg of N}}{\text{Hectare}} \times \frac{\text{1 unit Urea}}{\underline{\text{0 46}}\text{ N}} = \frac{\text{43 48 Kg Urea}}{\text{Hectare}}$$

When dissolving a solid fertilizer it is important to check the solubility table to obtain an idea of approximately how many liters of water should be used to dissolve this amount of fertilizer Table 2 indicates that about 1 kg of Urea will dissolve in 1 liter of water Estimate the amount of water needed

$$\frac{\text{Kg of fertilizer}}{\text{Hectare}} \times \frac{\text{1 Liter of water}}{\text{___ Kg dissolved}} = \frac{\text{Liters of water}}{\text{Hectare}} \qquad (2)$$

Using our example of Urea with a solubility of 1 kg of Urea per 1 liter

$$\frac{\text{43 48 Kg of Urea}}{\text{Hectare}} \times \frac{\text{1 Liter of water}}{\underline{\text{1}}\text{ Kg Urea}} = \frac{\text{43 5 Liters of water}}{\text{Hectare}}$$

The estimate shows that if we try to dissolve all of the Urea in 40 liters of water it probably will not dissolve It would be better to use a 75 liter container Add 50 liters of water first and then slowly mix in the solid Urea fertilizer with additional mixing until all of it has dissolved If the fertilizer has a conditioner, allow this to settle to the bottom Then siphon off the clear liquid to use for injection into the irrigation water

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For liquid fertilizers

Use equation 3 followed by the conversion of mass to volume (density) with equation 4 to determine the volume of liquid to be injected Note that the fertilizer density value goes at the bottom of the second term to give the result in liters

Using our example of Urea Ammonium Nitrate 32-0-0 with a density of 1 328 kg/l and an application of 20 kg of N/ha gives

$$\frac{20 \text{ Kg of N}}{\text{Hectare}} \times \frac{1 \text{ unit UAN 32}}{0\ 32 \text{ N}} = \frac{62\ 5 \text{ Kg UAN 32}}{\text{Hectare}}$$

$$\frac{62\ 5 \text{ Kg of UAN 32}}{\text{Hectare}} \times \frac{1 \text{ Liter of water}}{1\ 328 \text{ Kg UAN 32}} = \frac{47\ 1 \text{ Liters of water}}{\text{Hectare}}$$

Step 4. Calculate the total area to be fertigated

Normally this would be the area covered by one irrigation set

Assume the irrigation set is for 20 dunums or 2 hectare

Step 5 Multiply the liters of fertilizer per hectare by the total number of hectares to be fertigated

For the example with solid Urea dissolved in 50 liters of water this would be 100 liters of solution per irrigation

For the example with the liquid Urea Ammonium Nitrate this would be 94 2 liters of solution per irrigation

Step 6 Determine the total time for injection

Usually this time will equal the total time for irrigation, less time allowed for the system to fill with water and stabilize, and less time allowed for the system to flush after injection is completed

Assume the irrigation set is to last 6 hours and the Urea is to be injected in 4 hours

Step 7. Calculate the rate of fertilizer injection into the irrigation system

$$\frac{100 \text{ liters Urea}}{4 \text{ hours}} = \frac{25 \text{ liters Urea}}{\text{hour}}$$

The above value is applicable for Venturi injection systems but is not valid for pressure differential type systems, see Case Study I

Step 8 Check for system capacity

At this point it is important to double check that the rate of fertilizer injection just calculated can be delivered by the type of injection system you use, see case studies that follow In this example the injection system must be able to handle 25 liters of fertilizer solution injected per hour

4 INJECTION EQUIPMENT

Similar equipment may be used for injecting all liquid solutions, such as fertilizers and chemicals to control bacteria and pH, into the irrigation water delivery lines Gases, such as chlorine, are normally bled into the line from pressurized tanks

The auxiliary positive displacement pump, which feeds the fertilizer solution into the distribution line, is probably the most common type of injection system used in the world Use of this method requires an energy source and is more costly to operate than the two methods discussed below However, the positive displacement pump can provide very accurate volumes of injected solution

4 1 Pressure differential fertilizer injection

The pressure differential type of fertilizer injection is the system commonly used in Jordan A schematic of this type of fertilizer injector is shown in Figure 1

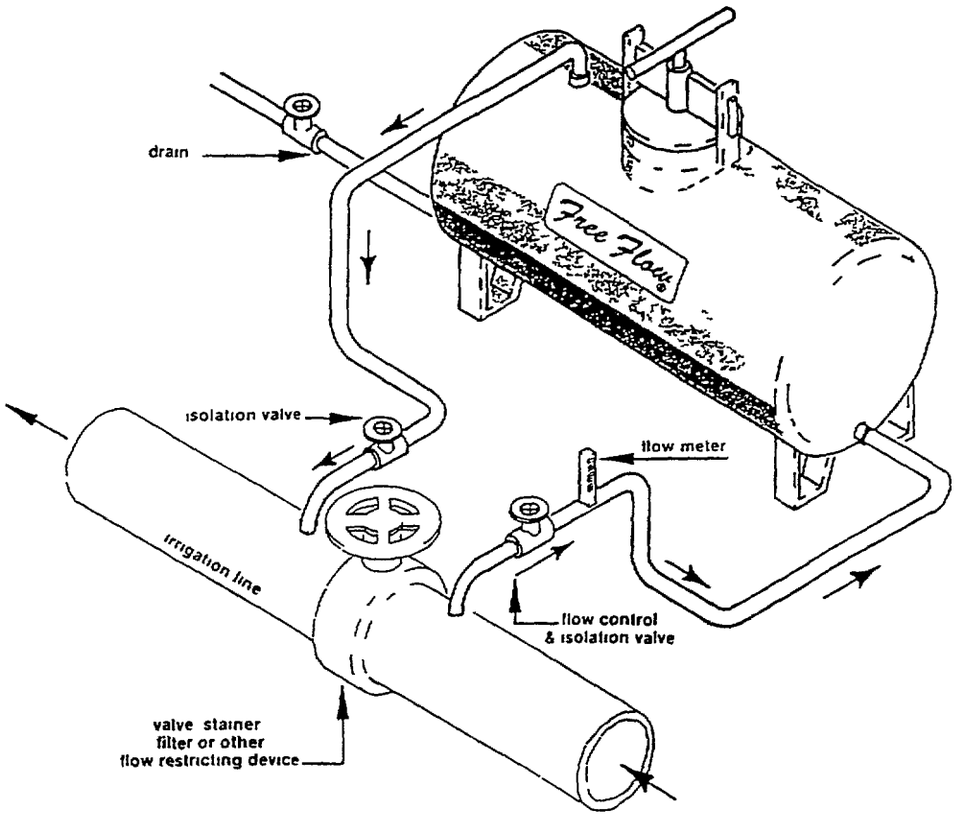

Figure 1 Pressure differential fertilizer injection system

- The flow rate through the pressurized fertilizer holding tank is controlled by valves on either side of the tank A pressure reducing obstruction or device in the line causes a difference in pressure to move fluid through the tank The advantage of this type of system is that there are no moving parts A disadvantage is that the nutrient concentration is not constant but continuously changing with time Figure 2 compares the nutrient concentration in the tank for the pressure differential and Venturi injection methods

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- The function for the concentration of material remaining in the tank as a ratio of the original concentration is given as

$$N_c = 100 \exp\left[-\frac{q_{\%} \times T}{100}\right] \tag{3}$$

$$q_{\%} = \frac{Q_t}{V_t} \times 100$$

where N_c = concentration of material remaining in the tank, %, $q_{\%}$ = flow rate through the tank as a percentage of tank volume, %, T = time fertilizer has been flowing from the tank, same time unit as used for Q_t, Q_t = flow rate through the tank, lpm or lph, and V_t = volume of fertilizer tank, liters

Another useful form of equation 3 finds the flow rate required to reach a certain nutrient concentration at the end of a specified time

$$Q_t = -\frac{V_t}{T} \times \ln\left(\frac{N_c}{100}\right) \tag{3a}$$

Another finds the time needed to reach a given nutrient concentration at a given flow rate

$$T = -\frac{V_t}{Q_t} \times \ln\left(\frac{N_c}{100}\right) \tag{3b}$$

- Flow rates through the tank can be controlled by valves and meters Disk orifices installed in the tank discharge line can also control flow The governing equation for the orifice diameter is given by

$$D = \sqrt{\frac{15\ 13 \times Q_t}{Co\sqrt{\Delta P}}} \tag{4}$$

where D = orifice diameter, mm, Q_t = flow rate through the tank lpm, C_o = orifice coefficient, and ΔP = pressure differential across the orifice, kPa

- The standard value for C_o is 0 62 Applications of equations 3 and 4 are demonstrated in Case I The nomograph given in Figure 4 can also be used to find the required size of orifice

- The concentration of nutrient in the irrigation water can be calculated

$$C_f = \frac{100 \times F_r}{w} \tag{5}$$

where C_f = concentration of nutrient in the irrigation water, mg/l, F_r = the nutrient application rate, kg/ha, and w = the net amount of irrigation water applied during the fertilizer injection period, mm

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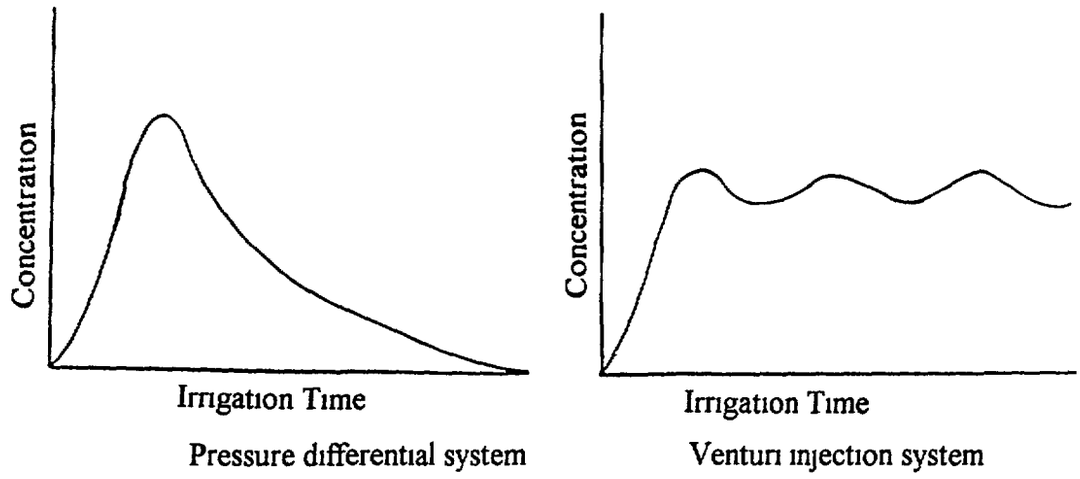


Figure 2 Nutrient concentration in the tank as a function of irrigation time

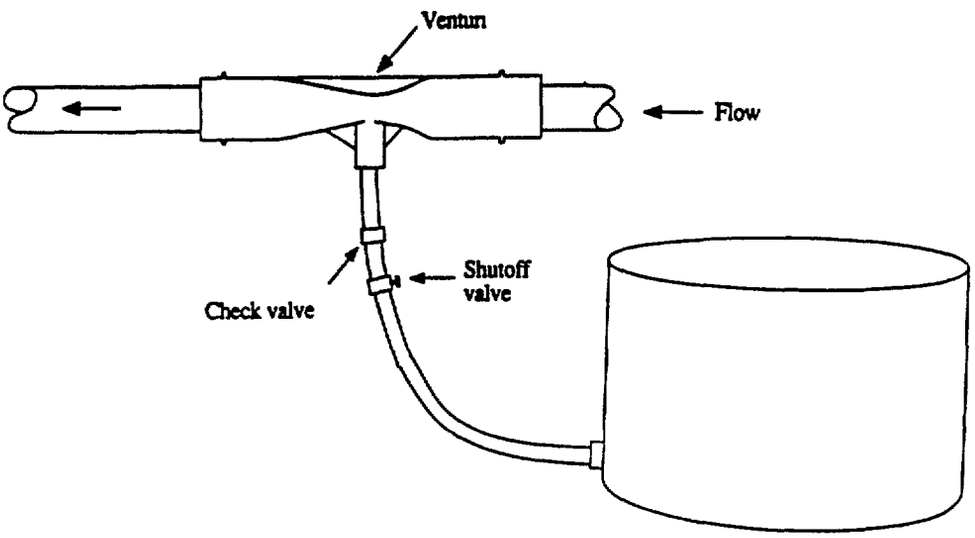
4 2 Venturi injection

The Venturi injection system operates on the principle that a pressure drop accompanies a change in velocity of water as it passes through a constriction The reduced pressure in the constriction forces the chemical into the line See Figure 3 for installation schematics Table 3 gives performance data for typical Venturi injector sizes

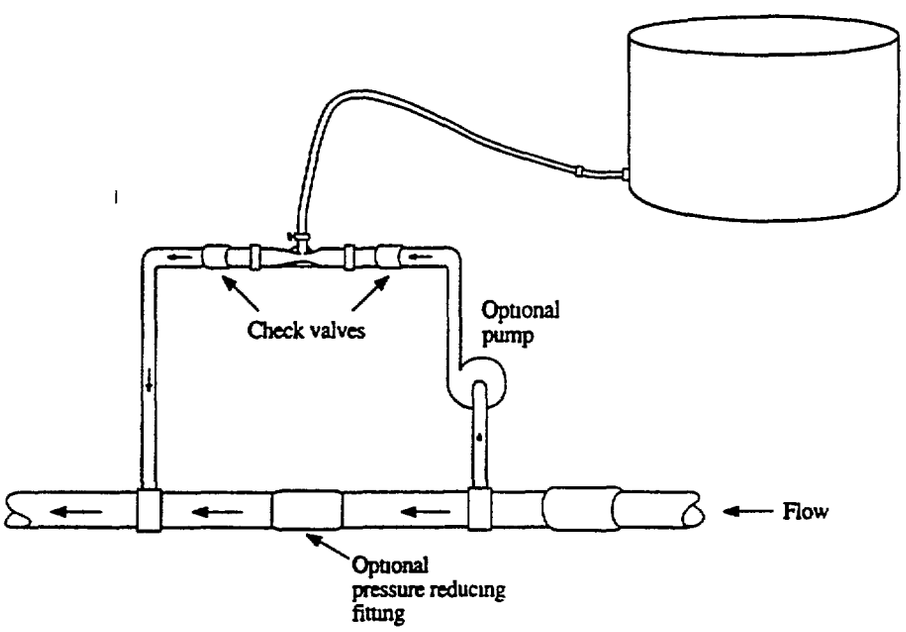
- An advantage of the Venturi injection system is that the nutrient concentration is constant with time, Figure 4 This derives from the injected liquid being sucked into the irrigation line by the pressure differential in the Venturi The injected solution is not diluted in the tank by the irrigation water during delivery
- Reducing system pressure to operate a Venturi can adversely affect the performance of the irrigation system When this is a problem a small auxiliary pump (usually centrifugal) can be installed in series with the Venturi device to create a differential pressure across the Venturi For injectors an outlet pressure of at least 20% less than the inlet pressure is required to start suction Full suction capacity is reached when the pressure difference is approximately 50%

4 3 Operating procedures

- Material should not be injected into the system until all lines are filled and emitters are discharging This ensures that the material injected is properly diluted and toxic doses will not be delivered to some plants For large systems, allow at least one hour of water delivery before beginning injection For small systems, one-half hour may be sufficient time for the system to stabilize
- Material should be removed from all lines to avoid potential corrosion problems and excessive bacterial growth Do not allow material to set in the lines when the system is not operating For large systems, allow at least one hour of water delivery after completing injection For small systems, one-half hour may be sufficient time for the system to flush



Venturi inserted directly in the main water line



Venturi with a bypass system and optional booster pump

Figure 3 Two methods for connecting a Venturi injection system

Table 4 Typical Venturi injector performance data

Operating Pressure		Suction Capacity of Injectors in lph			
Injector inlet kPa (PSI)	Injector outlet kPa (PSI)	Size[1] (12 5mm)	Size (25mm)	Size (37 5mm)	Size (50mm)
140 (20)	35 (5)	68	238	644	1930
	70 (10)	42	170	454	1893
	80 (12)	30	144	360	1249
	105 (15)	8	38	170	606
210 (30)	35 (5)	68	227	681	1912
	70 (10)	68	227	651	1912
	105 (15)	49	197	511	1741
	140 (20)	26	114	322	1136
275 (40)	105 (15)	68	227	681	1912
	140 (20)	61	227	606	1912
	170 (25)	42	170	397	1533
	210 (30)	11	76	170	908
345 (50)	140 (20)	64	227	681	1912
	170 (25)	64	227	662	1912
	210 (30)	57	208	530	1552
	240 (35)	30	132	341	1155
	275 (40)	4	45	57	208
415 (60)	210 (30)	64	227	681	1912
	240 (35)	61	227	613	1666
	275 (40)	45	197	473	1552
	310 (45)	19	102	246	757
485 (70)	240 (35)	64	227	681	1912
	275 (40)	64	227	625	1912
	310 (45)	57	216	511	1817
	345 (50)	34	170	322	1401
	380 (55)	8	83	76	454
550 (80)	310 (45)	64	227	662	1912
	345 (50)	64	227	568	1912
	380 (55)	45	189	476	1741
	415 (60)	34	114	246	1211
	450 (65)	0	34	57	416
690 (100)	415 (60)	64	227	681	1912
	450 (65)	64	227	625	1912
	485 (70)	49	216	511	1779
	520 (75)	30	170	341	1287
	550 (80)	4	91	132	681

1 Size refers to the nominal pipe size of the inflow/outflow connecting pipes Size *does not* indicate the diameter of the Venturi throat

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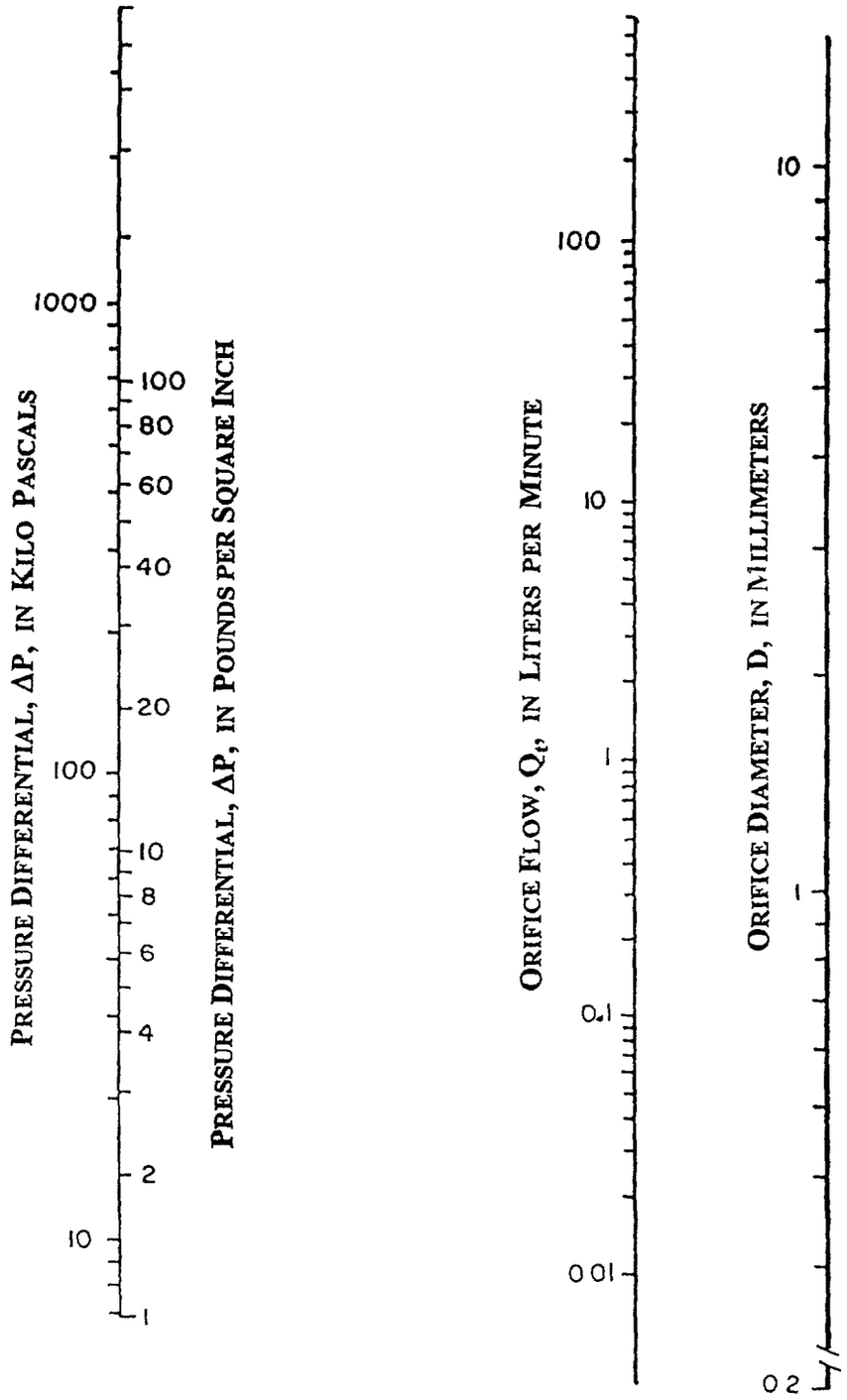

Figure 4 Nomograph for determining orifice size for desired flow rates and differential pressures, orifice discharge coefficient equals 0 62

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FERTILIZER INJECTION
PRESSURE DIFFERENTIAL INJECTION SYSTEM
CASE STUDY I

1 DESIGN DATA

Given.

Irrigation set time	6 hr
Irrigation application, w	12 mm
Area	20 du
Amount of nutrient, F_r	20 kg/ha
Tank Capacity, V_t	100 liters
Pressure differential, ΔP	20 kPa

Find

- Flow rate through the tank to have an N_c less than 5% after 4 hours
- Diameter of the required orifice
- Average nutrient concentration in the irrigation water
- Time required for the concentration of nutrient in the tank to be 50 % of the original concentration

2 DESIGN STEPS

- Flow rate through the tank to have an N_c less than 5% after 4 hours

  Equation 3a is used to find Q_t

$$Q_t = -\frac{V_t}{T} \times \ln\left(\frac{N_c}{100}\right) = -\frac{100}{4} \times \ln\left(\frac{5}{100}\right) = 75 \text{ lph}$$

- Diameter of the required orifice

  From the nomograph of Figure 4 with $\Delta P = 20$ kPa and an injection flow = 75 lph = 1 25 lpm read an orifice diameter of about 2 5 mm

  The exact orifice size can be calculated by using equation 4

$$D = \left[\frac{1513 \times Q_t}{C_o\sqrt{\Delta P}}\right]^{05} = \left[\frac{1513 \times 125}{062\sqrt{20}}\right]^{05} = 261 \text{ mm}$$

- Average nutrient concentration in the irrigation water, use equation 5

  w = 4/6 × 12 = 8 mm of water applied in 4 hours

$$C_f = \frac{100 \times F_r}{w} = \frac{100 \times 20}{8} = 250 \text{ mg / liter}$$

- Time required for the concentration of nutrient in the tank to be 50 % of the original concentration

  Solve for the time in hours to reach 50 percent concentration using equation 3b

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$$T = -\frac{V_t}{Q_t} \times \ln\left(\frac{N_c}{100}\right) = -\frac{100}{75} \times \ln\left(\frac{50}{100}\right) = 0\,9 \text{ hr}$$

For the conditions given, the fertilizer concentration should equal 50 percent of the original concentration after about 0 9 hours of operation

3. Discussion

If the nutrient concentration in the tank is less than the maximum this must be considered in evaluating the results from the calculations For example, equation 3b finds the time required for the tank concentration to reach 50% of its initial value, not necessarily the time for the nutrient in the tank to reach 50% Any dilution will result in conservative calculations, i e , the actual concentration of nutrient in the tank will be less that that calculated

FERTILIZER INJECTION
VENTURI INJECTION SYSTEM
CASE STUDY II

1. DESIGN DATA

Given·

Area	10 du
Irrigation set time	6 hr
Irrigation application, w	12 mm
Amount of nutrient	20 Kg
Fertilizer	Urea
Tank Capacity	100 liters
Inlet pressure, P_i	210 kPa

Find.

- Injection rate of fertilizer into the system
- Average nutrient concentration in the irrigation water, C_f
- Size of the required Venturi

2 DESIGN STEPS

- Injection rate of fertilizer into the system, Q_f

  First determine the amount of fertilizer to use, equation 1

$$\frac{20 \text{ Kg of N}}{\text{Hectare}} \times \frac{1 \text{ unit Urea}}{0.46 \text{ N}} = \frac{43.48 \text{ Kg Urea}}{\text{Hectare}}$$

  Estimate the amount of water needed for dissolving the Urea, equation 2

$$\frac{43.48 \text{ Kg of Urea}}{\text{Hectare}} \times \frac{1 \text{ Liter of water}}{1 \text{ Kg Urea}} = \frac{43.5 \text{ Liters of water}}{\text{Hectare}}$$

  At 50 liters per hectare, the 100 liter tank capacity is sufficient for this application to 2 hectares

  Assume an injection time of 4 hours, which leaves 1 hour for start-up and one hour for system flushing

$$Q_f = \frac{2 \text{ ha} \times 50 \text{ l/ha}}{4 \text{ hr injection}} = 25 \text{ lph}$$

- Average nutrient concentration in the irrigation water, use equation 5

  w = 4/6 × 12 = 8 mm of water applied in 4 hours

$$C_f = \frac{100 \times F_r}{w} = \frac{100 \times 20}{8} = 250 \text{ mg/l}$$

- Size of Venturi required

First find the outlet pressure, P_o, that satisfies the constraint for a minimum percent pressure differential of 20%

$$\%\Delta P = \frac{P_I - P_O}{P_I} \times 100$$

$$P_O = P_I - \frac{\%\Delta P \times P_I}{100} = 210 - \frac{20 \times 210}{100} = 168 \text{ kPa}$$

Enter Table 4 with an inlet pressure of 210 kPa and look for a Venturi that has a suction capacity of 25 lph Check that the outlet pressure is equal or less than 168 kPa

From Table 4 read that a 12 5mm nominal diameter Venturi operating with an outlet pressure of 140 kPa has a suction capacity of 26 lph

P_o = 140 kPa < 168 kPa, the 20% pressure differential constraint is satisfied

MICRO IRRIGATION SYSTEMS

EMITTERS

[Supplemental]

1 INTRODUCTION

An emitter is a device which applies water to the soil from the distribution system The two major categories of emitters are point-source and line-source Both categories have been successfully used in various cropping situations There are numerous attributes sought in an emitter, such as

- It should be available in small increments of discharge
- The flow should be controlled within narrow limits, as a function of operating pressure, to properly apply water used by the crop
- A large flow passageway is more resistant to clogging by particles that pass through the screen and filtration system
- The emitter should resist degradation due to temperature fluctuations and solar radiation
- The manufacturer should specify a useful life for the emitter, during which it will operate according to design specifications

2. EMITTER TYPES

2 1 Orifice The class of "Orifice emitters" includes many drip and spray emitters and also single chamber line-source tubing In a nozzle or orifice emitter, water flows through a small diameter opening or series of opening where most of the pressure head is lost The flow regime is *fully turbulent* and the discharge of the emitter, q, is given as

$$q = 3\ 6 \times A \times K_q \sqrt{2gH}$$

where q = emitter discharge, lph, A = flow cross section area, mm^2, K_q = outlet discharge coefficient that depends on the characteristic of the orifice or nozzle and ranges from 0 6 to 1 0, g = acceleration of gravity = 9 8 m/s^2, and H = working pressure head, m The previous equation enables computation of the orifice cross section area necessary to provide the desired discharge Orifice emitters are used as point-source emitters

2 2 Long-path Most loss of head in a common long-path emitter (Figure 1) occurs in the long-path where the flow is *laminar* and the discharge of the emitter, q, is given as

$$q = \frac{H \times g \times D^4 \times \pi}{K \times l_c \times \nu}$$

Where D = cross-sectional diameter of the flow, mm, K = conversion coefficient = $3\ 56 \times 10^7$, l_c = length of the flow path in the emitter, m, and ν = kinematic viscosity of water, 1×10^{-6} m^2/s at 20 °C Long-path emitters are the type found in most line-source tubing used for vegetable crops

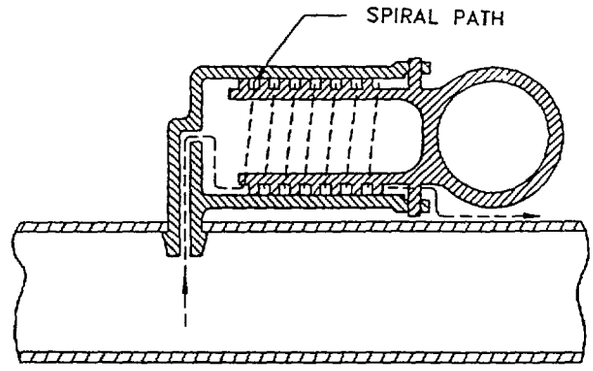

Figure 1 Typical long-spiral-path emitter

2 3 Compensating Compensating emitters are constructed to yield a nearly constant discharge over a wide range of pressure Long-path, short-path and orifice type compensating emitters are available The constant discharge is achieved by using a *resilient* material in the flow path This is acted on by the line pressure so that the flow cross-section decreases as the pressure increases A peculiar problem of compensating emitters is that the resilient material may distort over a period of time and gradually squeeze off the flow even though pressure remains constant Compensating emitters are used in point-source applications

2 4 Flushing On-Off and continuous flushing are the two types of self-flushing emitters The *on-off* emitters flush for only a few moments each time the system starts operating and shuts off, they flush twice during each irrigation cycle They are typically of the compensating type Continuous flushing emitters are constructed so that they can eject relatively large particles during operation They do this by using relatively large diameter flexible orifices in series to dissipate pressure As shown in Figure 2, particles larger than the diameter of the orifice are ejected by a local increase of pressure as the particle reaches each successive flexible orifice Flushing emitters are used in point-source applications

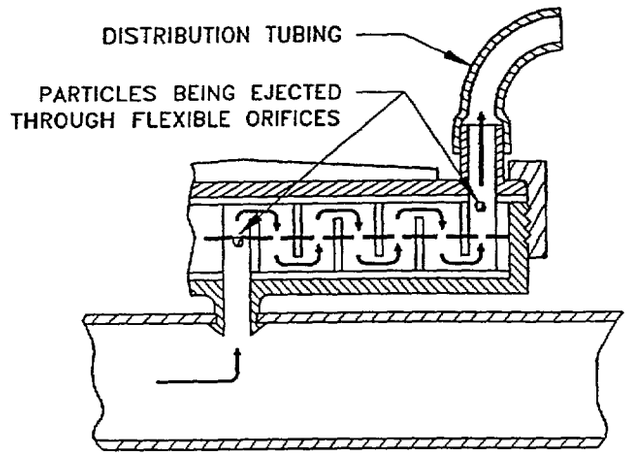

Figure 2 A typical continuous flushing emitter

Point-source emitters are typically used on *widely spaced crops*, such as orchards and vineyards and *line-source systems* are used on *closely spaced* row crops, such as vegetables Also, *Point and line source* emitters may be used in a *mixture of cropping situations* The key design principle is to apply water with *high uniformity* to the root zone

3 EMITTER CLOGGING

To achieve the low rates of discharge required in trickle irrigation, the cross sections of the flow channel must be within the range of 0 25 mm to 2 5 mm Necessity for such small channels makes all emitters susceptible to clogging Therefore, careful filtration of all irrigation water is required The usual recommendation is to remove all particles larger than one-tenth the diameter of the emitter passageway Even this level of filtration is not sufficient for long-path emitters because of sediment deposits along the passageway, which can cause slow clogging over a period

Sensitivity to clogging is a very important consideration when selecting an emitter Two critical parameters related to clogging susceptibility are the size of the flow passage and the velocity of water through the passage The relation between a passage's susceptibility to clogging and the passage cross-section is

- *Very sensitive* — less than 0 7 mm,
- *Sensitive* — 0 7 to 1 5 mm, and
- *Relative insensitive* — larger than 1 5 mm or continuously flushing emitters

The velocity of water through the passage is as important as the passage dimensions Velocities ranging from 4 to 6 m/s have resulted in reduced clogging

With line-source tubing, the tendency to clog can be reduced significantly by regular lateral flushing

4 MANUFACTURING COEFFICIENT OF VARIATION

It is impossible to manufacture any two items exactly alike The small differences between what appear to be identical emitters cause significant variations in discharge This is because the critical dimensions of the emitter flow passage are small and therefore difficult to manufacture precisely Small variations in passage size, shape and surface finish result in a relatively large percentage of variation from the nominal emitter dimensions Also, some emitters use an elastomer to provide pressure compensating or flushing ability, all such materials are inherently difficult to manufacture with uniform dimensions and characteristics The amount of difference to be expected between components varies depending on the emitter's design, the materials used in its construction and the precision with which it is manufactured

4 1 Coefficient of emitter manufacturing variation, v

The coefficient of emitter manufacturing variation is used as a measure of the variations anticipated in discharge in a sample of new emitters The value of v

should be available from the manufacturer, but it can be determined from the discharge of a sample set of at least 50 emitters operated at a reference pressure head and calculated by

$$v = \frac{\sqrt{q_1^2 + q_2^2 + \quad q_n^2 - n(q_a^2)/(n-1)}}{q_a}$$

where **v** = coefficient of manufacturing variation of the emitter, q_1, q_2, q_n = the individual emitter discharge rate values, lph, n = number of emitters in the sample, and q_a = average discharge rate of the sample, lph Table 1 can be used to assess the quality of the emitters tested

Table 1 Classification of emitter coefficient of variation, **v**

Quality of emitter	Drip & spray emitter	Line-source tubing
Excellent	**v** < 0 05	**v** < 0 1
Average	0 05 < **v** < 0 07	0 1 < **v** < 0 2
Marginal	0 07 < **v** < 0 11	
Poor	0 11 < **v** < 0 15	0 2 < **v** < 0 3
Unacceptable	0 15 < **v**	0 3 < **v**

The physical significance of **v** is derived from the classic bell-shaped normal distribution curves in which

- All of the observed discharge rates fall within $(1 \pm 3v)q_a$,
- Approximately 95% of the discharge rates fall within $(1 \pm 2v)q_a$,
- The average of the low one-fourth of the discharge rates is approximately equal to $(1 - 1\ 27v)q_a$, and
- Approximately 68% of the discharge rates fall within $(1 + v)q_a$
- **Example** an emitter has **v** = 0 06 and q_a = 4 lph
  95% of the discharge can be expected to fall within the range of 3 52 and 4 48 lph, and the average discharge of the *low one-quarter* will be approximately 3 7 lph

4 2 System coefficient of emitter variation, $\mathbf{v_s}$

Since more than one emitter or emission point may be used per plant, the variations in flow rate for all emitters around the plant generally compensate for one another One emitter might have a high flow rate and another would probably have a lower flow rate, on the average, the variations in the total volume of water delivered to each plant is less than might be expected from considering **v** alone The $\mathbf{v_s}$ may be characterized by

$$\mathbf{v_s} = \frac{\mathbf{v}}{\sqrt{\mathbf{N_p}}}$$

where $\mathbf{v_s}$ = system coefficient of variation and Np = number of emitters watering each plant

It should be emphasized that *v is a property of the emitter alone and v_s is a property of the trickle irrigation system as a whole*

5 RELATION OF PRESSURE TO DISCHARGE

The relation between change in pressure head and discharge is the most important characteristic of an emitter Figure 3 shows this relationship for various types of emitters The emitter discharge exponent, x, measure the flatness of the discharge-pressure curve, and clearly demonstrates the desirability of a compensating emitter that has a flat discharge-pressure relationship Compensating emitters usually have a high v and their long-term performance is effected by temperature and material fatigue The performance of compensating emitters over the planned period of use requires careful consideration

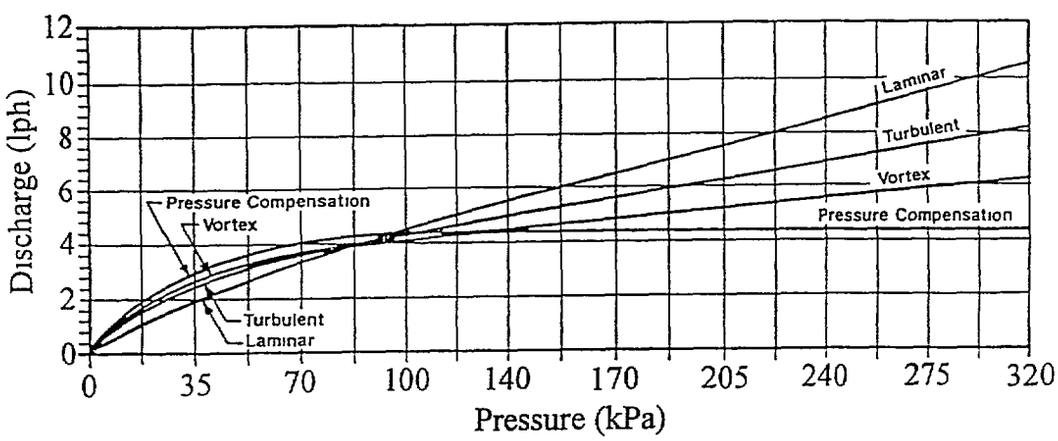

Figure 3 Discharge versus pressure relationships for different types of emitter flow paths

5 2 Allowable head variation

- Figure 4 is a schematic of the distribution of pressure head in a simple subunit H_m and H_n are the maximum and minimum operating heads, respectively

- Figure 5 shows an example of the combined effects of pressure head and manufacturing variations on individual emitter discharges ΔH_s = variation in subunit operating head, m, H_a = average operating head, m, q_a = average emitter discharge, lph, q_x = maximum emitter discharge, lph, q_n = minimum emitter discharge, lph, and sd = standard deviation, a statistical measure of the variations

  The particular example depicted in Figures 4 and 5 is for a subunit on a level field with constant diameter manifolds and laterals in which variation in subunit head, ΔH_s, equals 3 0 meters when the average pressure head, H_a, equals 12 2 meters This gives a subunit head loss ratio of 0 25

- In Figure 5 the region of emitter discharge is bounded on the sides by the minimum and maximum pressure in the subunit The bottom and top of the

region are bounded by the minimum and maximum discharge expected from a test sample of emitters at each possible operating pressure

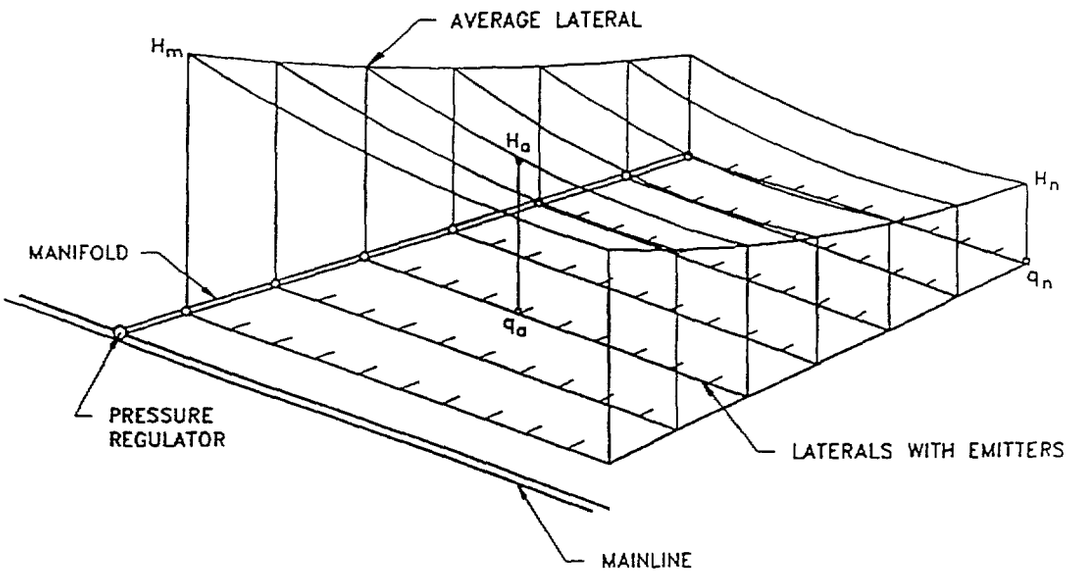

Figure 4 Distribution of pressure head in a subunit

ΔH_s on a level field is caused by friction loss in the lateral tubing H_a and q_a are not midway between the extremes of pressure This is because discharge and loss of pressure are greatest in the first part of constant diameter manifolds and laterals

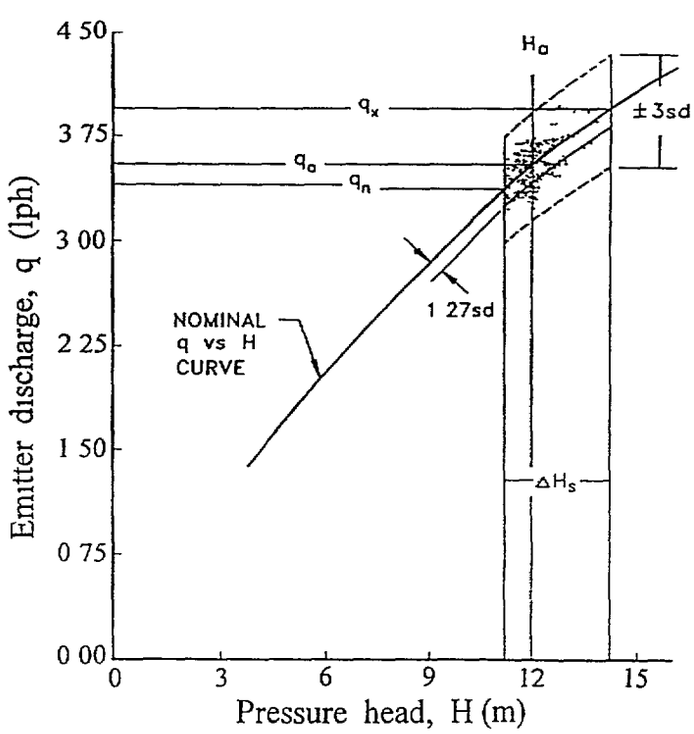

Figure 5 Combined effect of pressure head and manufacturing variations on the discharge from individual emitters

6 SELECTING EMITTERS

The long-term application efficiency of a trickle irrigation system is directly effected by the emitters selected for use Emitter selection is influenced by

- Quality of the water supply,
- Adequacy of filtration,
- Power available on site,
- Degree of automation,
- Reliability of the management,
- Available labor,
- Emitter design, quality, and clogging potential,
- Allowable variation of pressure,
- Soil type and stratification, and
- The percentage area wetted, P_w

The two most important of these items are the *percentage area wetted* and the *reliability of the emitter against clogging* and malfunctioning

Table 2 gives estimates of the areas wetted, A_w, by a standard 4 lph emitter for different soil conditions and depths The area of surface soil wetted by a drip emitter usually is less than half as large as A_w measured at a depth of 15 to 30 cm unless the application causes surface ponding The standard 4 lph emitter approximates the most common average discharge rate, q_a The long dimension, w, is equal to the maximum expected diameter of the soil bulb S'_e is the optimum emitter spacing and is 0 8 times the maximum expected wetted diameter This is the emitter spacing that would give a reasonably uniform and continuous wetted strip The P_w is the average horizontal area wetted in the top 15 to 30 cm of the crop root zone as a percentage of the total crop area

Table 2 Estimated areas wetted by a 4 lph emitter operating under various field conditions

Root depth and Soil texture	Degree of soil stratification[1]		
	Homogeneous	Stratified	Layered
	$S'_e \times w$	$S'_e \times w$	$S'_e \times w$
Root depth 0 75 m	(m × m)	(m × m)	(m × m)
Coarse	0 4 × 0 5	0 6 × 0 8	0 9 × 1 1
Medium	0 7 × 0 9	1 0 × 1 2	1 2 × 1 5
Fine	0 9 × 1 1	1 2 × 1 5	1 5 × 1 8
Root depth 1 5 m			
Coarse	0 6 × 0 8	1 1 × 1 4	1 4 × 1 8
Medium	1 0 × 1 2	1 7 × 2 1	2 2 × 2 7
Fine	1 2 × 1 5	1 6 × 2 0	2 0 × 2 4

1 Almost all soils are stratified or layered Stratified refers to relatively uniform texture, but having some particle orientation or some compaction layering that gives a higher horizontal than vertical permeability Layered refers to changes of texture with depth, as well as particle orientation and moderate compaction

6 1 Straight single-lateral systems with $S_e \leq S'_e$

$$P_w = \frac{N_p \times S_e \times w}{S_p \times S_r} \times 100$$

Where P_w = percentage of soil area wetted along a horizontal plane 30 cm below the soil surface, %, N_p = number of emission points per plant, S_e = emitter or emission point spacing, m, w = width of a strip wetted by a row of emitters spaced at S'_e or closer along a single line, m, S_p = plant spacing in the row, m and S_r = row spacing, m

If $S_e > S'_e$ then S_e must be replaced by S'_e

6 2 Double-lateral systems

The two laterals should be spaced S'_e apart This is done to maximize wetted area without leaving extensive dry areas between the lines

$$P_w = \frac{N_p \times S'_e (S'_e + w)}{2 \times (S_p \times S_r)} \times 100$$

If the layout is not designed for optimum wetting and $S_e < S'_e$, then S'_e should be replaced by the actual S_e values used

6 3 Spray emitter systems

The soil surface wetted, A_s, must first be determined Estimate the sprayer wetted diameter by observing a few sprayers operating at the design pressure and flow rate

$$P_w = \frac{N_p [A_s + (S'_e \times PS)/2]}{S_p \times S_r} \times 100$$

Where A_s = soil surface area directly wetted by the sprayer = $\pi \times D^2/4$, m^2, and PS = perimeter of the area directly wetted by the sprayers = $\pi \times D$, m

6 4 Duration of irrigation water application

After selection of a trial emitter, check the duration of irrigation water application for the periods of peak use by

$$T_a = \frac{G}{N_p \times q_a}$$

where T_a = irrigation application time required during the peak use period, hrs/day, G = gross volume of water required per plant (or unit length of row) during the peak use period, l/day, Np = number of emitters per plant, and q_a = average emitter discharge, lph If T_a cannot be satisfied by the system operation times, another emitter must be selected

7 EMITTER PLACEMENT

Field slope must be considered when selecting the placement of emitters near a plant On sloping fields the wetted pattern may be distorted in the downslope direction On steep slopes this distortion can be extreme, as much as 90% of the pattern may be on the downslope side Emitters should be placed with this distortion in mind, Figure 6

Soil texture influences the shape of the wetted soil volume On sandy soils water tends to move downward a greater distance than its movement horizontally On heavy soils, such as clays, or soils overlaying a shallow barrier water's horizontal movement tends to exceed its downward movement The effect of soil texture on water movement is reflected in the estimated areas wetted by an emitter given in Table 2 Figure 7 shows the placement of inline emitters on a sandy or light soil to water a tree crop Figure 8 shows an alternate placement using four online emitters to water each tree, Figure 9 shows the resulting wetted soil volume

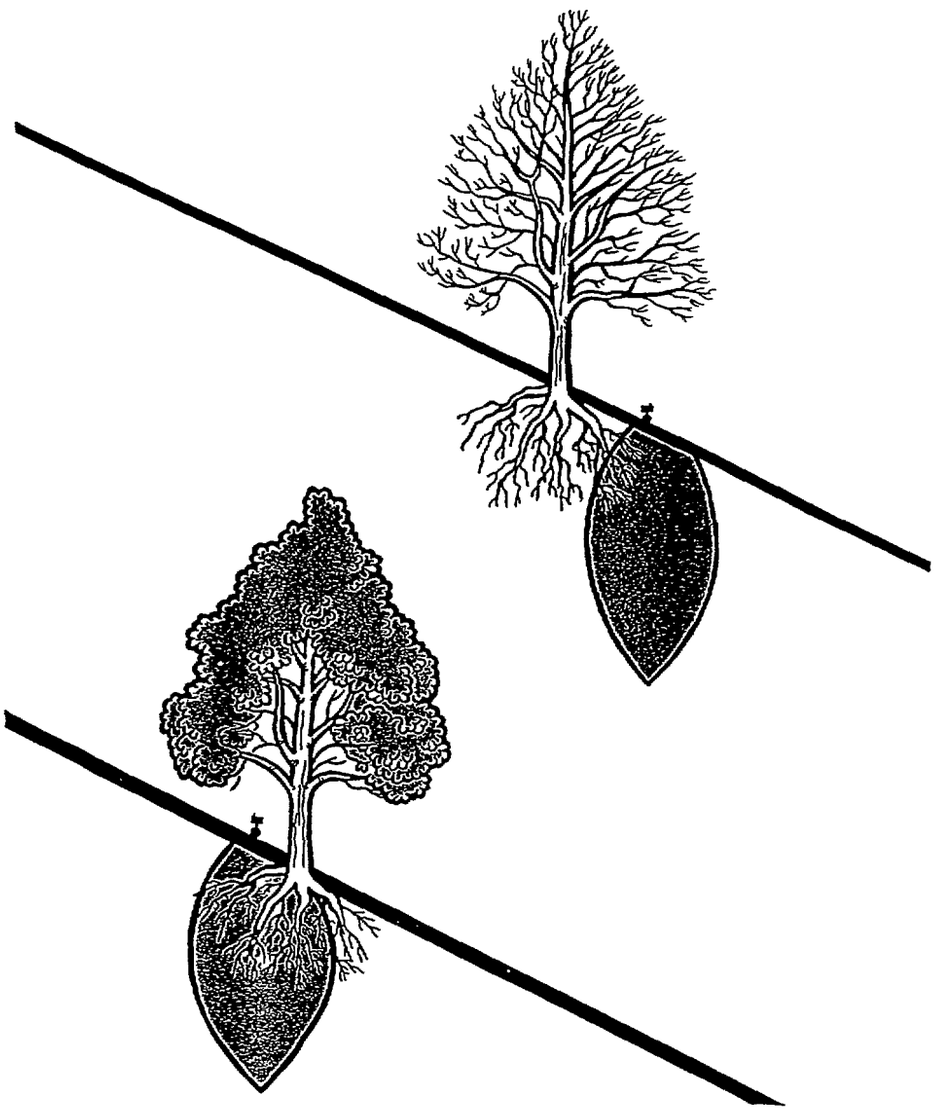

Figure 6 Emitter wetting pattern on a sloping field

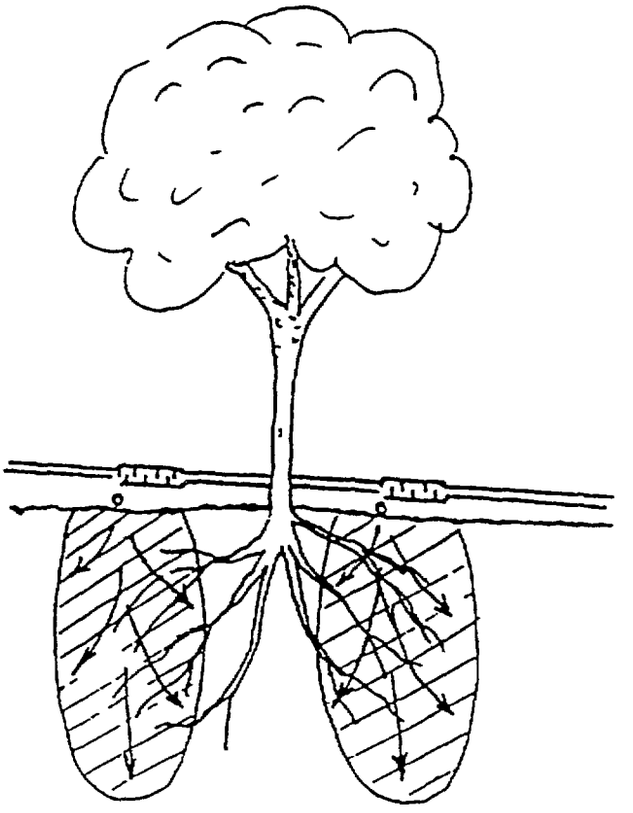

Figure 7 Wetting pattern for an inline emitter on a sandy soil

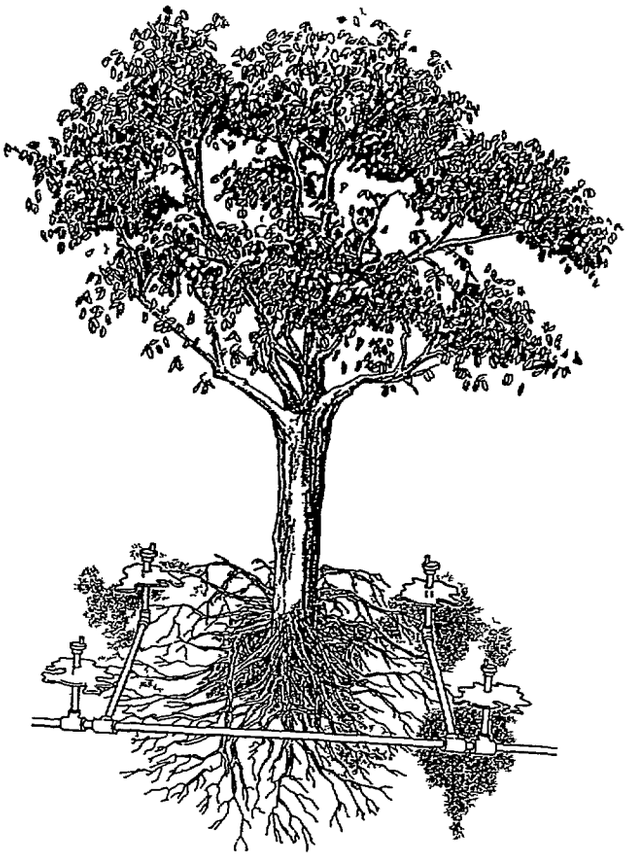

Figure 8 Placement of four emitters to water a tree crop

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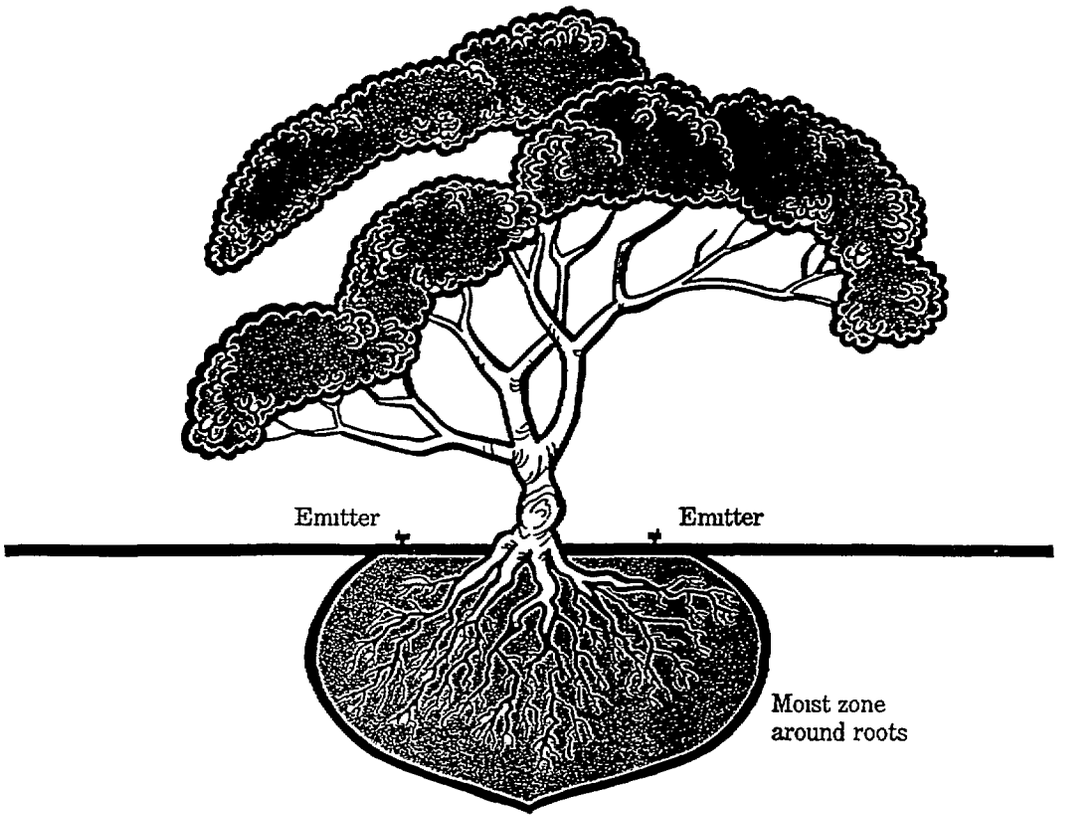

Figure 9 Wetted soil volume resulting from the proper placement of emitters near a tree crop

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COEFFICIENT OF EMITTER MANUFACTURING VARIATION

CASE STUDY I

DATA COLLECTED

Table 1 Data collected for an emitter discharge test

Emitter No	Observed Discharge (Lph)	q^2	Emitter No	Observed Discharge (Lph)	q^2
1	3 0	9 00	2	3 0	9 00
3	3 1	9 61	4	3 1	9 61
5	3 2	10 24	6	3 2	10 24
7	3 3	10 89	8	3 3	10 89
9	3 4	11 56	10	3 5	12 25
11	3 5	12 25	12	3 6	12 96
13	3 7	13 69	14	3 7	13 69
15	3 7	13 69	16	3 7	13 69
17	3 7	13 69	18	3 8	14 44
19	3 8	14 44	20	3 8	14 44
21	3 9	15 21	22	3 9	15 21
23	3 9	15 21	24	4 0	16 00
25	4 0	16 00	26	4 0	16 00
27	4 0	16 00	28	4 1	16 81
29	4 1	16 81	30	4 1	16 81
31	4 1	16 81	32	4 2	17 64
33	4 2	17 64	34	4 2	17 64
35	4 2	17 64	36	4 3	18 49
37	4 3	18 49	38	4 3	18 49
39	4 3	18 49	40	4 4	19 36
41	4 44	19 71	42	4 4	19 36
43	4 44	19 71	44	4 5	20 25
45	4 5	20 25	46	4 5	20 25
47	4 6	21 16	48	4 7	22 09
49	4 8	23 04	50	4 9	24 01
	$\Sigma q_i^2 = 790\ 15$			$q_a = 3\ 946$	

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COEFFICIENT DETERMINATION

The coefficient of emitter manufacturing variation is calculated using the equation

$$v = \frac{\sqrt{q_1^2 + q_2^2 + \quad q_n^2 - n(q_a^2)/(n-1)}}{q_a}$$

$$v = \frac{\sqrt{(79015 - 50 \times 3946^2)/(50-1)}}{3946} = 012$$

- All of the observed discharge rates fall within $(1 \pm 3v) \times q_a = 2\ 53$ to $5\ 37$
- Approximately 95% of the discharge rates fall within $(1 \pm 2v) \times q_a = 3\ 00$ to $4\ 89$
- The average of the low one-fourth of the discharge rates is approximately equal to $(1 - 1\ 27v) \times q_a = 3\ 35$, and
- Approximately 68% of the discharge rates fall within $(1 + v) \times q_a = 4\ 42$

The *System coefficient of emitter variation*, v_s, is a function of the number of emitters used per plant in the field system layout

$$v_s = \frac{v}{\sqrt{N_p}}$$

As alternatives for the number of emitters per plant use 1, 2, and 3

- One emitter per plant $v_s = \frac{012}{\sqrt{1}} = 0\ 12$,
- Two emitters per plant $v_s = \frac{012}{\sqrt{2}} = 0\ 08$, and
- Three emitters per plant $v_s = \frac{012}{\sqrt{3}} = 0\ 07$

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EMITTER SELECTION

CASE STUDY II

1 DESIGN DATA

Citrus orchard tree spacing (S_p x S_r)	3 m x 4 m
Gross water required per tree per day, Q_a	120 liters/day
The percentage wetted area required for full cover (shaded area of 80% of cropped area)	30 - 50%
Equivalent wetted soil area (S'_e x w) for a homogeneous medium soil texture with a soil or root zone depth of 1 5 m	1 0 m x 1 2 m

Available emitters

a) Straight single-lateral system, on-line emitters, q_a = 4 lph

b) Line-source tubing, emission point spacings = 30 cm, q_a = 4 lph

c) Sprayers, q_a = 60 lph, surface soil D_{wetted} = 1 0 m, and N_p = 4 per tree

2 DESIGN STEPS

Calculate the percentage area wetted, P_w, and required irrigation time for each water application option

a) Straight single-lateral system with one on-line emitter per tree

$S_e > S'_e$ therefore S_e must be replaced by S'_e

$$P_w = \frac{N_p \times S_e \times w}{S_p \times S_r} \times 100 = \frac{1 \times 10 \times 1.2}{3 \times 4} \times 100 = 10\,\%$$

Thus, a minimum of 4 emitters will be required to obtain a percentage area wetted of 40% When four emitters are used for each tree, they should be installed in a zigzag pattern to give the optimal emitter spacing in all directions, Figure 10

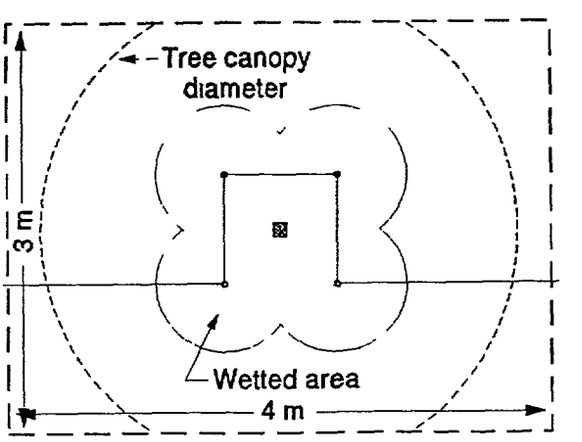

Figure 10 Zigzag pattern layout for each tree

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The time required for a complete irrigation in one day using four emitters is

$$T_a = \frac{Q_a}{N_p \times q_a} = \frac{120}{4 \times 4} = 7\ 5 \text{ hours}$$

However, the *recommended* operation time for the trickle irrigation system is *90%* of the 24 hours per day for a one station farm Thus, irrigation can be completed in *22 5 hours every three days*

- Sizes of the trickle irrigation pipes (mains, sub-mains, manifolds, laterals, pump, etc) will be *small* and the cost will be *low*
- The *wetted area* represents a *circle* with a diameter of 2 5 m (about 40% of the area allocated for a tree) in the vicinity of the root zone

b) Line-source tubing with emission point spacings of 30 cm

$$N_p = \frac{S_p}{S_e} = \frac{300 \text{ cm}}{30 \text{ cm}} = 10$$

$$P_w = \frac{N_p \times S_e \times w}{S_p \times S_r} \times 100 = \frac{10 \times 0\ 3 \times 1\ 2}{3 \times 4} \times 100 = 30\ \%$$

Time required for a complete irrigation in one day

$$T_a = \frac{Q_a}{N_p \times q_a} = \frac{120}{10 \times 4} = 3 \text{ hours}$$

Irrigation can be completed in *9 hours every three days*

- Sizes of trickle irrigation pipes (mains, sub-mains, manifolds, laterals, pump, etc) will be *moderate* and the cost will be *moderate*
- The *wetted area* represents a *strip* with a width of about *1 2 m*, Figure 11 This will force the roots to follow the wetted area Thus, root distribution will be in a strip (rectangular), which is *not recommended* for tree crops The root distribution should be circular in accordance with the tree canopy

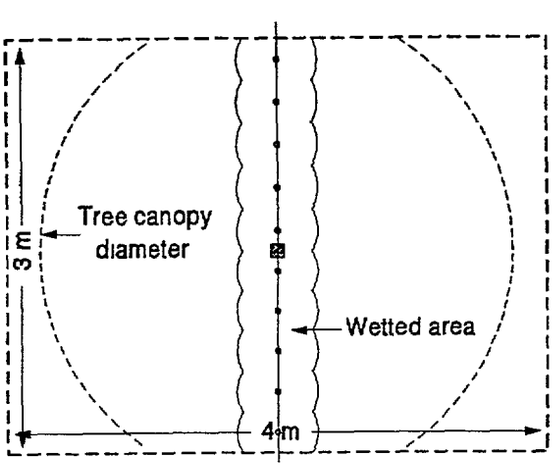

Figure 11 Line-source emitter wetting pattern

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c) Sprayers

Assume sprayer placement is optimal

$$A_s = (\pi D^2)/4 = (3\ 14 \times 1\ 0^2)/4 = 0\ 785$$

$$PS = \pi D = 3\ 14 \times 1\ 0 = 3\ 14$$

$$P_w = \frac{N_p[A_s + (S'_e \times PS)/2]}{S_p \times S_r} \times 100 = \frac{4[0\ 785 + (10 \times 314)/2]}{3 \times 4} \times 100 = 78\ 5\ \%$$

Time required for a complete irrigation in one day is

$$T_a = \frac{Q_a}{N_p \times q_a} = \frac{120}{4 \times 60} = 0.5 \text{ hours}$$

Most of the time the system is *not* operating (higher cost)

- Sizes of trickle irrigation pipes (mains, sub-mains, manifolds, laterals, pump, etc) will be *large* and the cost will be *high*
- With a very short time for water application, runoff is likely
- Figure 12 shows the wetted area at a depth of 15 to 30 cm, which is greater than the surface wetted area

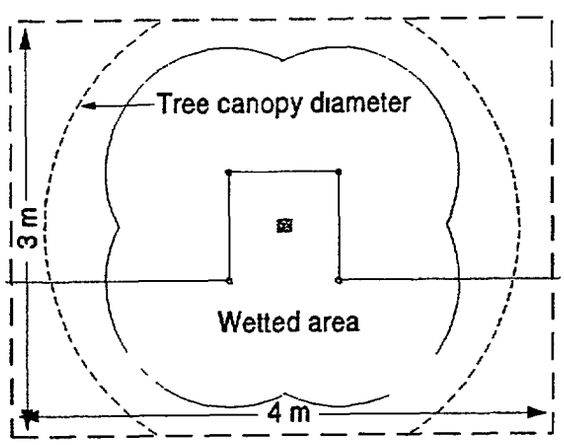

Figure 12 Effective wetted soil area for four sprayers

3. CONCLUSIONS

- *Never* replace the four on-line emitters by one or two sprayers with wetted diameters equal to 1 0 meter This will *reduce* the area wetted, may result in surface run-off, and some irrigation water could be *lost* as deep percolation
- You *can* replace the four on-line emitters by one or two sprayers with larger wetted diameters, if they have a flow rate less than the maximum intake rate of the soil Sprayers have larger flow passages and, therefore, are less susceptible to plugging Using low flow rate sprayers will lower costs of the delivery system

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- The required percentage wetted area varies according to the size of the tree canopy (shaded area) and plant spacing The size of the tree canopy varies according to tree age and variety The percentage wetted area can be satisfied using

  One emitter ($P_w = 10\%$) for the year of planting
  Two emitters ($P_w = 20\%$) for the second year
  Three emitters ($P_w = 30\%$) for the third year
  Four emitters ($P_w = 40\%$) for the fourth year (expected year of full shading)

EMITTER SELECTION

CASE STUDY III

1 DESIGN DATA

Design a trickle irrigation system for a tomato field in the Jordan Valley

Line-source GR tubing delivers water

Emission point flow rate	4 lph
Plant spacing (S_p x S_r)	0 5 x 1 8m
Rooting depth	0 75 m
Soil type	Medium homogeneous
$S'_e \times w$	$0\ 7 \times 0\ 9$

2 DESIGN STEPS

- With an optimal emission point spacing of 70 cm, 0 714 emitters contribute to each plant

$$P_w = \frac{N_p \times S_e \times w}{S_p \times S_r} \times 100 = \frac{0\ 714 \times 0\ 7 \times 0\ 9}{0.5 \times 1\ 8} \times 100 = 50\ \%$$

Each plant receives 4 × 0 714 = 2 856 lph

- With an emitter spacing of 50 cm, which is less than the optimal emitter spacing of 70 cm, 1 emitter contributes to each plant

$$P_w = \frac{N_p \times S_e \times w}{S_p \times S_r} \times 100 = \frac{1 \times 0.5 \times 0\ 9}{0.5 \times 1\ 8} \times 100 = 50\ \%$$

Each plant receives 4 lph

- Using an emitter spacing of 30 cm, which is even less than the previous emitter spacing of 50 cm, results in 1 67 emitters contributing to each plant

$$P_w = \frac{N_p \times S_e \times w}{S_p \times S_r} \times 100 = \frac{1\ 67 \times 0\ 3 \times 0\ 9}{0.5 \times 1\ 8} \times 100 = 501\ \%$$

Each plant receives 4 × 1 67 = 6 680 lph

3 CONCLUSIONS

- GR tubing with emission point spacings of 70 cm should be used
- Notice that when an emission point spacing closer than the optimum is used, there is little, if any, increase in the wetted area (from 50 % to 50 1 %)
- The additional water applied (1 144 lph and 3 824 lph at emission point spacings of 50 cm and 30 cm, respectively) is lost as deep percolation

MICRO IRRIGATION SYSTEMS

LATERALS

[Supplemental]

1 INTRODUCTION

Lateral tubing branches from submains Laterals distribute water to emitters, which deliver water directly to the soil surface over the root zone In most installations field dimensions, field slopes crops, and cultural practices are deciding factors for determining lateral line lengths and diameters

2 GENERAL DESIGN FACTORS

2 1 Lateral length

- Lateral lengths must be kept reasonably short to avoid excessive differences in pressure along the lateral
- Factors that affect the maximum recommended length are

  Discharge per emitter or unit length of porous tubing,
  Desired emission uniformity,
  Flow characteristics of the emitter selected,
  Lateral layout pattern,
  Terrain slope, and
  Lateral diameter

2 2 Allowable pressure variation

- Laminar flow emitters

  The relationship between discharge and operation pressure is nearly linear, doubling the pressure doubles the discharge Therefore, the variations in operation pressure head within the system are often held to within ± 5% of the desired average

- Turbulent flow emitters

  The change in discharge varies with the square root of the pressure head, the emitter discharge exponent **x** equals 0 5 Consequently, the pressure must be increased four times to double the flow Variations in operation pressure heads within the system are often allowed to ± 10% of the desired average

- Flow-compensating emitters

  When the emitter discharge exponent **x** ranges between 0 3 and 0 4, considerable regulation is achieved (i e , a 50% head differential would cause only a variation of 13% to 18% in discharge), and there is still some capability to adjust the discharge rate

  Compensating emitters are valuable on hilly sites where it is impractical to design for uniform pressure along the laterals and submains

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2 3 Connection losses

- The three main types of lateral connections are in-line, on-line, and on-line riser Figure 1 shows that the in-line connection has the simplest configuration On-line-risers are used in subsurface applications However, the subsurface application method is cost effective only when the emitter spacing is wide, or where it provides agronomic advantages

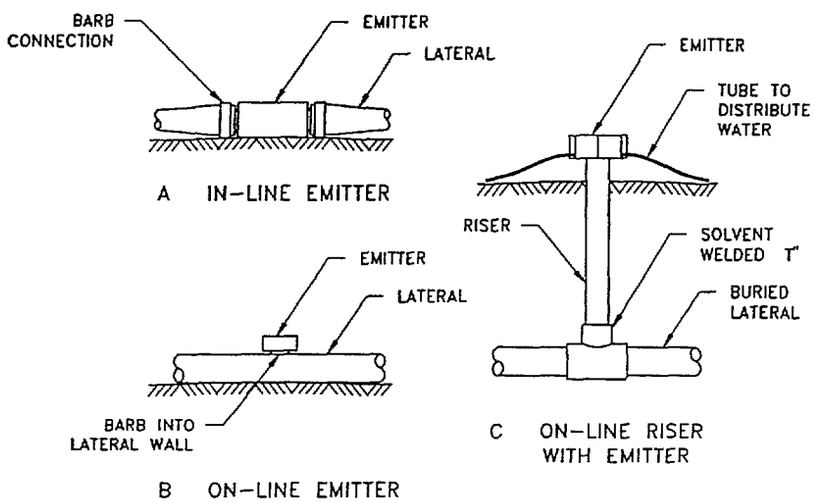

Figure 1 Typical connections of emitters to laterals

- Stress due to on-line emitter barbs stretching the lateral wall can create a problem Excess stress causes premature aging and cracking at the joint This results in leakage and in extreme cases the emitter connections may rupture To prevent this potential hazard, on-line emitters should be connected to the lateral with barbs in properly sized, smooth-edged, punched-out holes In-line emitters (non-GR) should be provided with compression barbs or compression ring fittings

- The emitter connection friction loss is expressed as an equivalent length of lateral, f_e, when estimating loss due to friction in laterals The f_e depends on the size and type of barb and on the inside diameter of the lateral Figure 2 gives estimated f_e values for in-line emitters and three different sizes of on-line barbs as a function of the inside diameter of the lateral

2 4 Field parameters

- Average field slope

  On fields where the average slope in the direction of the laterals is **less** than 3%, it is most economical to supply laterals on both sides of each submain The submain should be positioned so that starting from a common submain connection the minimum pressures in the pair of laterals (one to either side of the submain) is equal

  On fields where the average slope in the direction of the laterals is **steeper** than 3%, it is recommended that the supply laterals be on only one side of the submain

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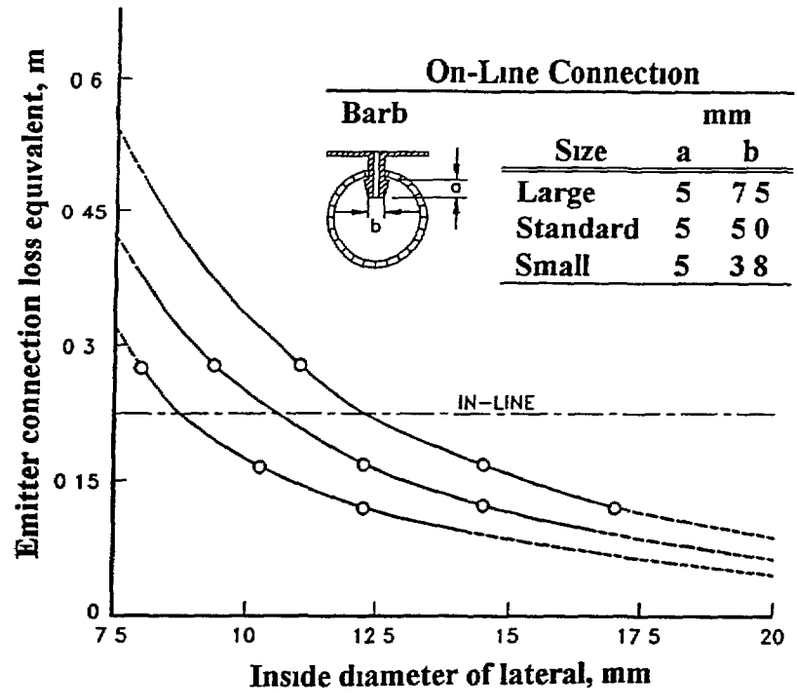

Figure 2 Emitter connection loss, f_e, values for different barb sizes and lateral diameters

- Field Geometry

  It is most convenient for field irrigation management, irrigation scheduling, irrigation system operation, etc to have the same submain spacing and lateral length for all crops on the farm If this cannot be done, at a minimum try to use the same submain spacings and lateral lengths for a given field and crop

  If the hydraulic design indicates that the best lateral length is 60 m, but the field geometry is 200 m x 200 m Then, it is more convenient to have a lateral length of 50 m rather than 60 m

3 Numerical Lateral Design

3 1 Lateral flow rate

- When two laterals extend in opposite directions from a common inlet point on a submain, they are referred to as a pair of laterals When the field slope is the same on both sides of the submain, the length of a pair of laterals, L_p, is equal to the submain spacing, S_m When considering the length of a single lateral, which extends in one direction from a submain, the length is designated by L

- Flow rate of a lateral can be computed by

$$Q_L = \frac{L \times q_a}{S_e} = n_e \times q_a$$

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where Q_L = lateral flow rate, lph, L = lateral length, m, S_e = spacing of emitters on the lateral, m, n_e = number of emitters along the lateral, and q_a = required average emitter discharge, lph

$$q_a = \frac{q_t \times I}{T_a \times EU \times N_p}$$

Where q_t = volume of water needed per plant per day, lpd, I = irrigation interval, days, T_a = irrigation time required during the peak use period, hr, EU = design emission uniformity, decimal, and N_p = number of emitters per plant

3 2 Pressure Heads

About three-fourths of the head loss occurs between the location of the average emitter and the lateral inlet, where the flow is greatest As flow in the lateral decreases, because of water being discharged through the emitters, the head loss curve flattens, see Figure 3, so that only about one-forth of the total pressure loss takes place between the average emitter and the end of the lateral The general location of the average emitter is between 0 38L and 0 4L, measured from the submain, for constant diameter laterals on a uniform slope

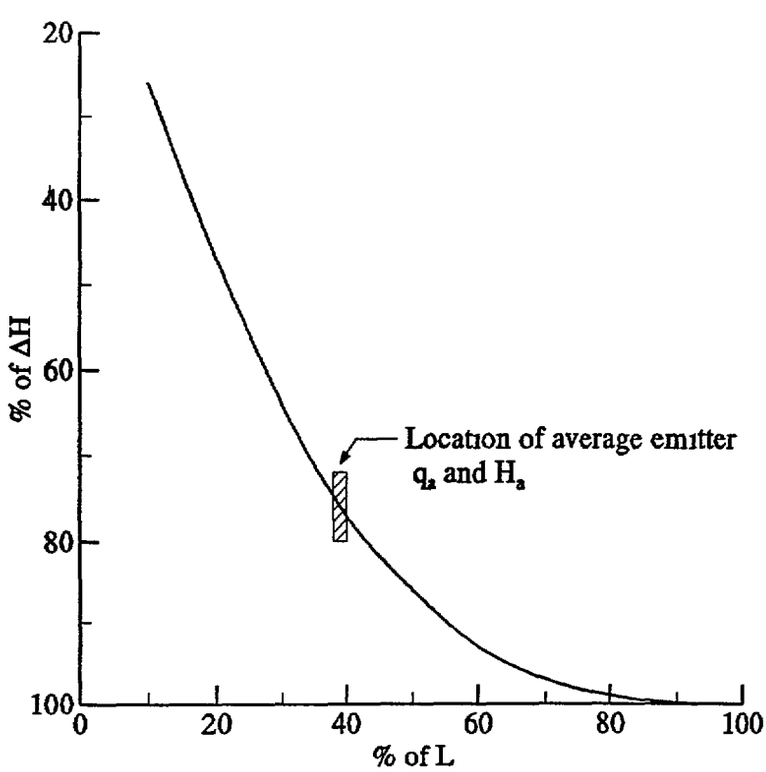

Figure 3 A typical headloss curve for a constant diameter lateral on a uniform slope

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- Design emission uniformity (EU)

  The EU specifies the relation between the gross irrigation quantity and the net addition to the average plant root zone For a new system, the design EU should be within the range given in Table 1

Table 1 Recommended ranges of design emission uniformities

Emitter type	Emitters per plant	Topography	EU range %
Point-source	≥ 3	Uniform[1]	90 – 95
Point-source	< 3	Uniform	85 – 90
Point-source	≥ 3	Undulant[2]	85 – 90
Point-source	< 3	Undulant	80 – 90
Spray	All	Uniform	90 – 95
Spray	All	Undulant	85 – 90
Line-source	All	Uniform	80 – 90
Line-source	All	Undulant	70 – 85

1 Uniform with slopes ≤ 2 %
2 Undulant with slopes > 2 %

- The working pressure required by the average emitter in the system, H_a, is computed as the head that will give q_a

$$H_a = H\left[\frac{q_a}{q}\right]^{1/x}$$

Where H = rated working pressure head of the emitter, m, q_a = average emitter discharge, lph, q = rated emitter discharge, lph, and x = emitter discharge coefficient

- The minimum permissible design discharge, q_n, is found using the design EU, q_a, N_p, and v

$$q_n = \frac{q_a \times EU}{100\left(1 - 1.27 \times v / \sqrt{N_p}\right)}$$

Where v = manufacturers coefficient of emitter variation

- The working pressure required for the minimum design discharge in the system, H_n, is computed as the head that will give q_n

$$H_n = H_a\left[\frac{q_n}{q_a}\right]^{1/x}$$

Where H_a = working pressure required by the average emitter in the system, m, q_a = average emitter discharge, lph, q_n = minimum permissible design discharge, lph, and x = emitter discharge coefficient

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- Allowable Subunit Pressure Head Variation, ΔH_s

  The allowable subunit (submain plus attached laterals make up a subunit) pressure head variation is

$$\Delta H_s = 2\ 5\ (H_a - H_n)$$

- Allowable Lateral Pressure Head Variation, ΔH

  ΔH is the maximum allowable lateral pressure head variation that will satisfy the design emission uniformity Limit the lateral pressure head differences to one-half of the allowable subunit pressure head variation

$$\Delta H = 0\ 5\Delta H_s$$

- With the calculated and known information it is possible to calculate the inside diameter of lateral tubing needed

$$D = \left[\frac{F \times L\left(7\ 89 \times 10^5\right) Q_L^{\ 1\ 75}\left(S_e + f_e\right)}{\Delta H \times S_e}\right]^{0.211}$$

  Where D = **inside** diameter of lateral line required, mm, F = multiple outlet reduction factor, which equals 0 36 for trickle irrigation laterals having more than 20 outlets, see Table 2 for lesser outlet numbers, Q_L = lateral discharge, lps, and f_e = emitter connection loss equivalent, m

  Manufacturers use different outside and inside diameters for their tubing To select the correct size lateral line, check the inside diameter of the nominal tubing supplied

Table 2 Reduction coefficient, F, for multiple outlet pipes

Number of emitters	F End[1]	F Mid[2]	Number of emitters	F End	F Mid
1	1 00	1 00	8	0 42	0 38
2	0 64	0 52	9	0 41	0 37
3	0 54	0 44	10 - 11	0 40	0 37
4	0 49	0 41	12 - 15	0 39	0 37
5	0 46	0 40	16 - 20	0 38	0 36
6	0 44	0 39	21 - 30	0 37	0 36
7	0 43	0 38	≥ 31	0 36	0 36

1 The first emitter is a full space from the lateral inlet
2 The first emitter is one-half space from the lateral inlet

- In some cases the farmer may wish to reuse lateral lines in another location with a different discharge The equation can be manipulated to calculate the maximum lateral length that should be used under the new conditions

$$L = \frac{S_e \times \Delta H \times D^{4\ 75}}{F \times 7\ 89 \times 10^5 \times Q^{1\ 75}\left(S_e + f_e\right)}$$

4 GRAPHICAL LATERAL DESIGN

Emitter flow variation caused by lateral pressure variation is a function of the emitter x value As shown on Figure 4, when the x value is 0 5, which is true for most orifice type emitters, a pressure variation of 20% is equivalent to a 10% emitter flow variation On the design charts for uniform down, Figure 5, and up slopes, Figure 6, there will be a 20% pressure variation if zone A is used and a 40% pressure variation if zone B is used When used with the nomograph shown in Figure 7, the correct lateral size can be determined The figures also can be used to check the design when a lateral size is given

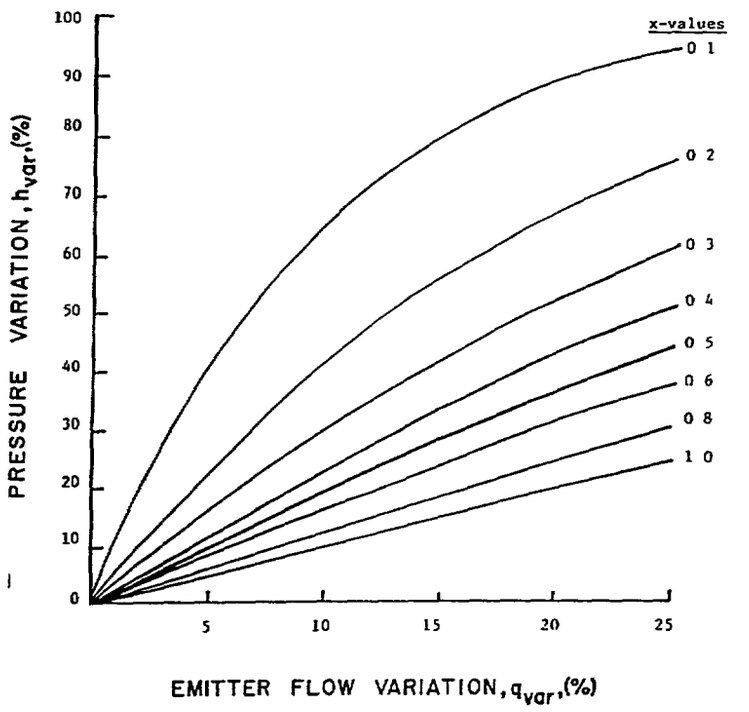

Figure 4 Relationship between emitter flow variation and pressure variation for different emitter x-values

4 1 Selecting the correct lateral line size

- Establish a trial L/H in Quadrant IV
- Using Figure 5 or 6 move horizontally from L/H to the % slope of the lateral line in Quadrant III From the intersection point draw a vertical line into Quadrant I
- Establish a point along this line in Quadrant I at the upper boundary of 'desirable' zone A or 'acceptable' zone B The design criteria will determine whether zone A or zone B is used From this point draw a horizontal line into Quadrant II
- Draw a vertical line into Quadrant II from the L/H value in Quadrant IV so that it intersects the horizontal line from Quadrant I (above step)
- At the intersection point, determine the ΔH/L value in Quadrant III

- From the nomograph, Figure 7, using the total discharge Q_L and $\Delta H/L$, the minimum lateral line inside diameter is read

4 2 Checking acceptability of a given lateral line

- Use Figure 7, the total discharge, and lateral line inside diameter to determine $\Delta H/L$
- Use the desired L and H values to establish L/H in Quadrant IV of Figure 5 or 6, draw a vertical line into Quadrant II to the $\Delta H/L$ value, then move horizontally into Quadrant I
- Move horizontally from L/H in Quadrant IV to the % slope of the lateral line in Quadrant III From the intersection point draw a vertical line into Quadrant I
- At the intersection point in Quadrant I, determine the acceptability of the design

  Zone A – desirable
  Zone B – acceptable
  Zone C – not acceptable

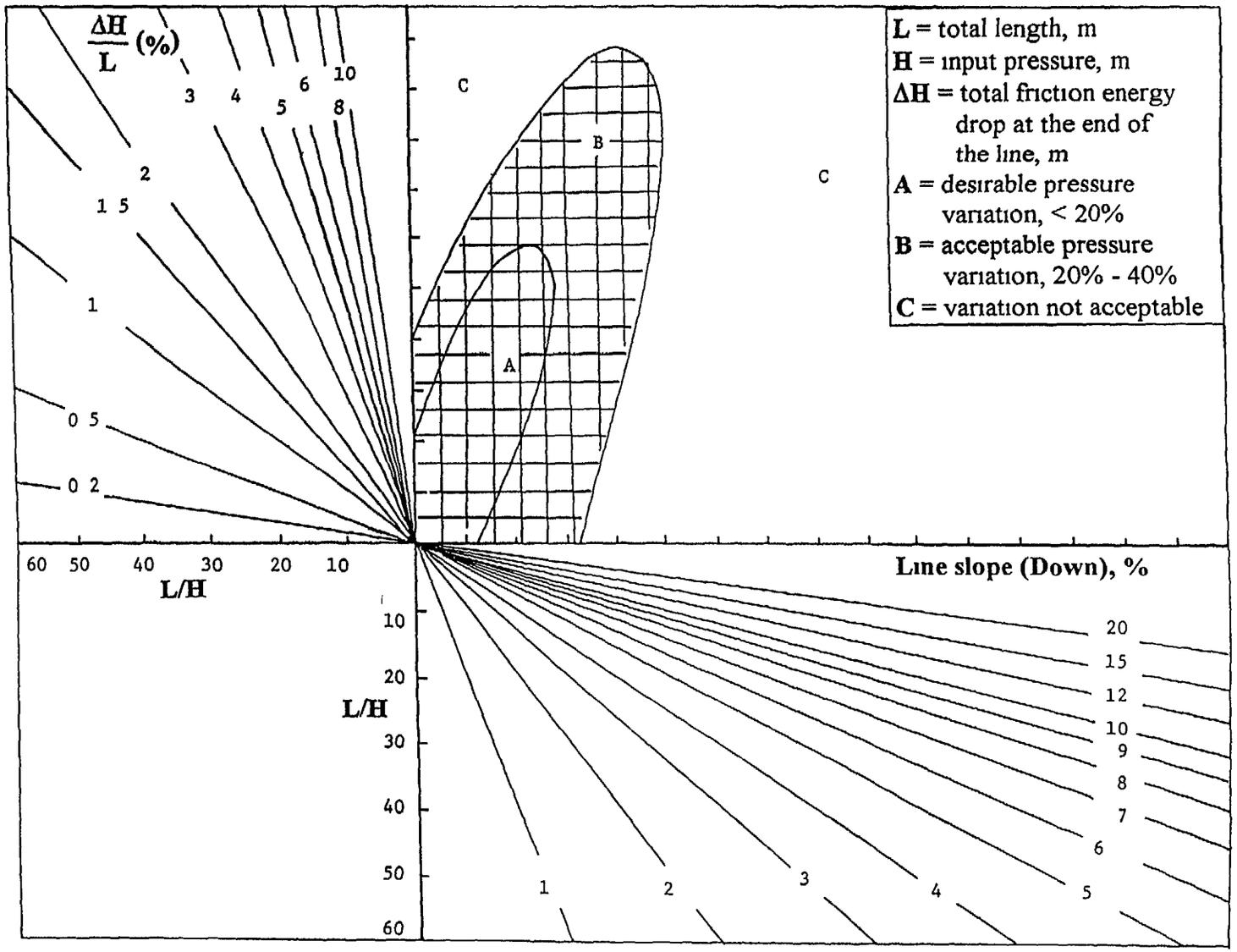

Figure 5 Lateral design chart, down slope

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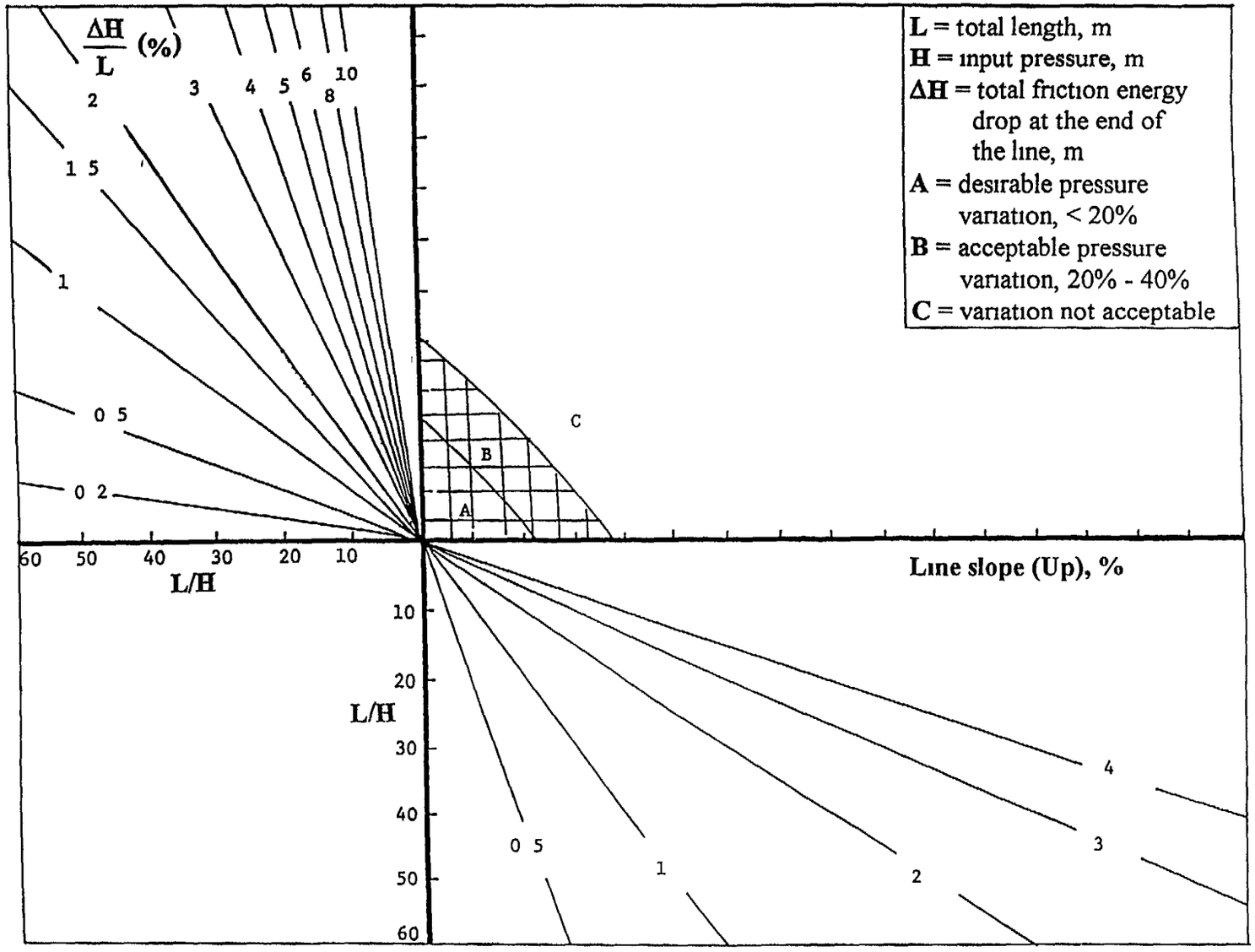

Figure 6 Lateral design chart, up slope

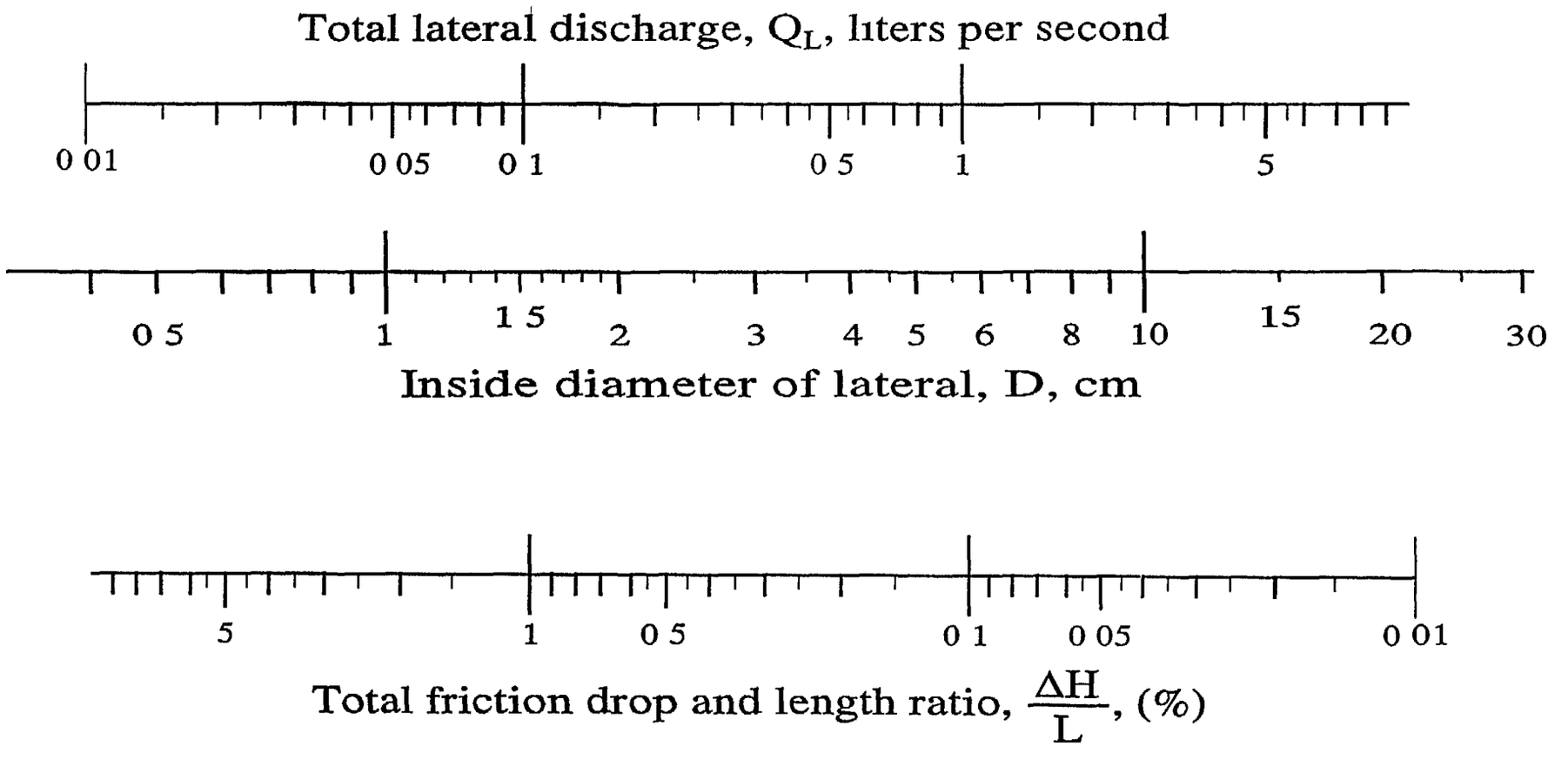

Figure 7 Nomograph for trickle irrigation lateral design

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LATERAL DESIGN

CASE STUDY I, NUMERICAL

1 DESIGN DATA

Emitter and lateral characteristics

$q = 4$ Lph	$H = 10$ m	$x = 0\ 42$
$EU = 80\%$	$v = 0\ 033$	$N_p = 4$
$S_e = 0\ 5$ m	$L = 50$ m	$q_t = 16$ lpd
$I = 3$ days	$T_a = 4$ hours	

Laterals are GR type with in-line emitters

2. DESIGN STEPS

- The average emitter discharge required (q_a)

$$q_a = \frac{q_t \times I}{T_a \times EU \times N_p} = \frac{16 \times 3}{4 \times 0\ 80 \times 4} = 3\ 75 \text{ lph}$$

- The minimum discharge (q_n)

$$q_n = \frac{q_a \times EU}{1 - \frac{1\ 27v}{\sqrt{N_p}}} = \frac{3\ 75 \times 0\ 8}{1 - \frac{1\ 27 \times 0\ 033}{\sqrt{4}}} = 3\ 06 \text{ lph}$$

- The average pressure head (H_a)

$$H_a = H\left[\frac{q_a}{q}\right]^{1/x} = 10\left[\frac{3\ 75}{4}\right]^{1/0\ 42} = 8\ 58 \text{ m}$$

- The minimum pressure head (H_n) that will give the minimum discharge

$$H_n = H_a\left[\frac{q_n}{q_a}\right]^{(1/x)} = 8\ 58 \times \left[\frac{3\ 06}{3\ 75}\right]^{(1/0\ 42)} = 5\ 29 \text{ m}$$

- The allowable subunit pressure head variation (ΔH_s)

$$\Delta H_s = 2\ 5(H_a - H_n) = 2\ 5(8\ 58 - 5\ 29) = 8\ 23 \text{ m}$$

- Limit the lateral pressure head variation (ΔH) to one-half of the allowable subunit pressure head variation

$$\Delta H = 0\ 5\ (8\ 23) = 4\ 11 \text{ m}$$

- Discharge for 50 m lateral (Q_L)

$$Q_L = \frac{L \times q_a}{S_e} = n_e \times q_a = \frac{50 \times 3\,75}{0\,5} = 375 \text{ lph} = 0\,10 \text{ lps}$$

- Lateral diameter

$$D = \left[\frac{F \times L\left(7\,89 \times 10^5\right) Q_L^{\,1\,75}\left(S_e + f_e\right)}{\Delta H \times S_e}\right]^{0\,211}$$

$$D = \left[\frac{0\,36 \times 50\left(7\,89 \times 10^5\right) 0\,10^{1\,75}\left(0\,5 + 0\,225\right)}{4\,11 \times 0\,5}\right]^{0\,211} = 11\,08 \text{ mm}$$

For field installation the next available lateral line with inside diameter larger than 11 mm would be used

Note The graphical procedure covered in Section 4 can be used for this design problem

L/H = 5
Field slope = 0%
$\Delta H/L$ = 4%
Q_L = 0 123 lps
Lateral diameter = 12 mm for Zone A, 90% EU
Lateral diameter = 11 mm for Zone B, 80% EU

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LATERAL DESIGN

CASE STUDY II, GRAPHICAL

1 DESIGN DATA

q_a = 4 Lph H = 10 m
S_e = 0 3 m L = 100 m
Field slope = 1% down
Lateral lines are GR type with in-line emitters

2 DESIGN STEPS

- Number of emitters = 100/0 3 = 333
- Total lateral discharge Q_L = 333 × 4 = 1332 lph = 0 37 lps
- Determine L/H = 100/10 = 10
- Using Figure 8 move horizontally from L/H = 10 to the 1% down slope line in Quadrant III From the intersection point draw a vertical line into Quadrant I
- Establish a point along this line in Quadrant I at the upper boundary of 'desirable' region A From this point draw a horizontal line into Quadrant II
- Draw a vertical line into Quadrant II from L/H = 10 so that it intersects the horizontal line from Quadrant I
- At the intersection point, determine ΔH/L = 3 5% in Quadrant III
- From the nomograph, Figure 9, using the total discharge Q_L = 0 37 lps and Δ H/L = 3 5%, the minimum lateral line inside diameter is read as 1 9 cm or 19 mm For field installation the next available lateral line with inside diameter larger than 19 mm would be used

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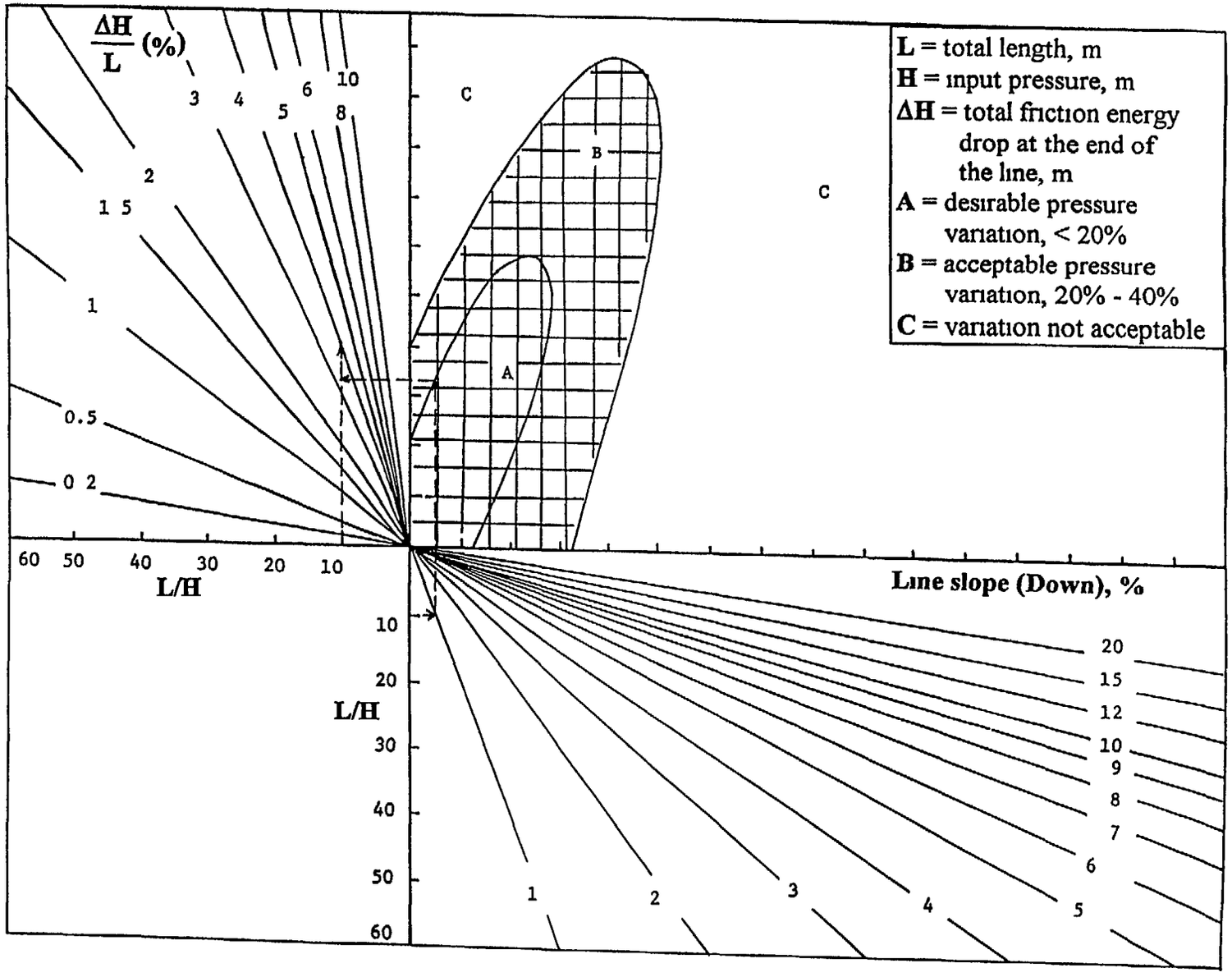

Figure 8 Lateral design chart, down slope

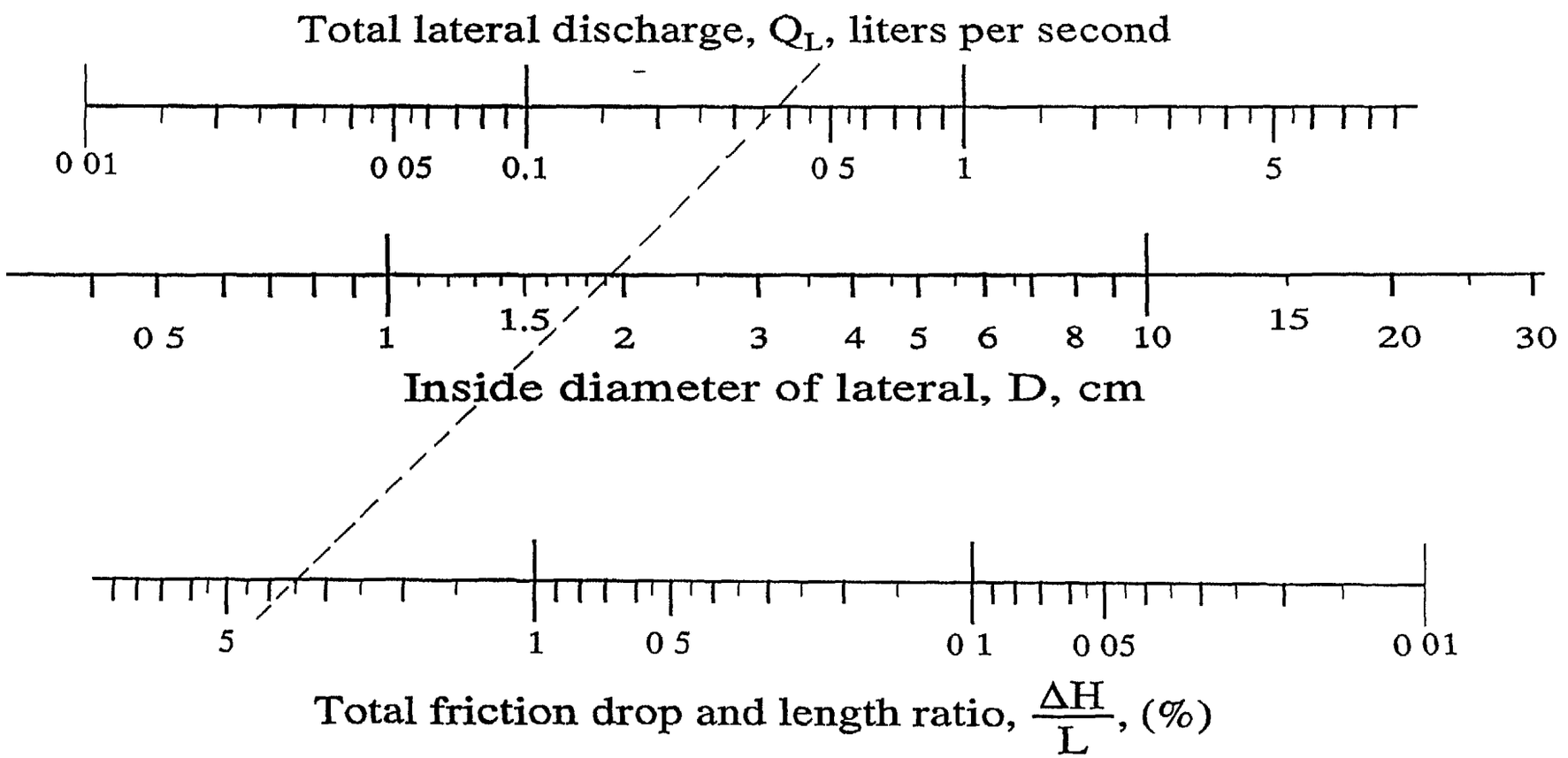

Figure 9 Nomograph for trickle irrigation lateral design

MICRO IRRIGATION SYSTEMS
MAIN AND SUBMAIN PIPELINES

[Supplemental]

1 INTRODUCTION

- Common thermoplastic pipe materials are PolyVinyl Chloride (PVC) and PolyEthylene (PE) These materials are used in a wide variety of applications in trickle irrigation systems Because they are easy to fabricate, locally produced PVC and PE pipes are employed in many irrigation systems in Jordan
- Surge pressures, commonly referred to as water hammer, occur in unsteady flow regimes and are associated with rapid changes in flow velocity and resulting rapid changes in pressure Rapid changes in the flow velocity cause the kinetic energy associated with velocity to be converted to pressure The more rapid the change in flow velocity, the greater will be the magnitude of resulting pressure surge

  Pressure surges occur when valves are opened or closed, when pumps are started or stopped or by sudden releases of entrapped air
- Thermoplastic pipes are divided into low and high pressure categories The pressure categories are based on the pipe material diameter, and design operating pressure including any surge pressure

  Low pressure
  Nominal diameter 114 mm to 630 mm
  Internal pressure less than 545 kPa (5 4 atm or 79 psi)

  High pressure
  Nominal diameter 21 mm to 710 mm
  Internal pressure 550 to 2170 kPa (5 4 to 21 4 atm or 80 to 315 psi)

2. WATER DISTRIBUTION SYSTEM PIPE LINES

2 1 Mainlines

- The principle function of the mainline is to convey the required quantities of water from the source to all parts of the service area at the pressure required to operate all laterals under maximum flow conditions The principal design problem is the selection of pipe sizes that will accomplish this function economically Here the line running from the water source to the design area, usually called the supply line, will be treated as part of the mainline
- The design of mainlines requires an analysis of the entire system to determine maximum requirements for capacity and pressure The classical procedure is to assume, within a reasonable range, several values of allowable head loss due to friction in main lines and to compute the pipe size or sizes for each assumed value The pipe sizes thus obtained are then checked for energy economy, and the most economical sizes are selected Tables 1 to 3 give head losses due to friction for a range of pipe sizes and flow rates

- The velocity of flow in main lines should be restricted to eliminate excessive water hammer This is particularly important in plastic pipes In plastic pipe the mainline velocities should be limited to 1 5 m/s Surge pressures are approximately equal to 85 kPa for each 0 3 m/s velocity change
- Mainlines are usually laid out so the flow is split or divided as close to the supply end as possible (when more than one mainline is needed), their direction is parallel or at right angles to the rows, they are not looped, and their length is as short as practical
- Flushing valves should be installed at the ends of all mainlines Filtration does not remove all suspended material and eventually sediments accumulate in the tubing These sediments must be flushed out of the lines The frequency of flushing (whether daily, weekly, or monthly) depends upon the severity of sediment accumulation Checking the flush water for suspension is one way to determine sediment buildup

2 2 Submains

- Submains connect the mainline to laterals, which branch from the submain on one or both sides The submain may be on the surface Submain lengths should not exceed 200 m and in some cases 100 m to maintain distribution uniformity and still provide a convenient subunit size
- It is most convenient to have the same submain spacing throughout the field in all crops
- Submains usually start with a pressure regulator and gate valve The area served by one submain is called a subunit Where the average slope along the submain is less than 3%, it is usually most economical to have submains extending in both directions from the water entry point
- Submain diameters (sizes) are selected so that pressure head variation in laterals and the submain did not exceed the allowable pressure head variation in the subunit Allowable variation in the subunit pressure head is that which will give an emission uniformity reasonable close to the desired design value In order to maintain the design emission uniformity, the pressure head must stay between the minimum pressure and the minimum pressure plus allowable head variation while including all effects of pipe friction and elevation Tables 1 to 3 give head losses due to friction for a range of pipe sizes and flow rates
- For the same reason given for mainlines, flushing valves should be installed at the ends of all submains

2 3 Headers

The main purpose of header lines is to reduce pressure head variations on steep topography Each header serves two to five laterals and is connected to and runs parallel with the submain If a header starts with a gate valve or pressure regulator, the subunit is defined as the area served by the header instead of the area served by the submain Often polyethylene tubes can be used for headers, two sizes readily available in Jordan are given in Table 1

Table 1 Friction loss gradient in m per 100 m for different flow rates in polyethylene tubes used for trickle irrigation laterals and headers

Flow Rate lpm	16 (14 7)	20 (17 8)	Flow Rate lpm	16 (14 7)	20 (17 8)
0 5	0 05	0 02	15	19 74	7 96
0 75	0 10	0 04	15 5	20 91	8 43
1	0 17	0 07	16	22 10	8 91
1 25	0 26	0 10	16 5	23 33	9 4
1 5	0 35	0 14	17	24 58	9 90
1 75	0 46	0 19	17 5	25 86	10 42
2	0 58	0 23	18	27 16	10 95
2 25	0 71	0 29	18 5	28 50	11 48
2 5	0 86	0 35	19	29 86	12 03
3	1 18	0 48	19 5	31 25	12 59
3 5	1 55	0 62	20	32 66	13 16
4	1 95	0 79	20 5	34 11	13 74
4 5	2 40	0 97	21	35 58	14 34
5	2 89	1 16	21 5	37 07	14 94
5 5	3 41	1 37	22	38 59	15 55
6	3 97	1 60	22 5	40 14	16 18
6 5	4 57	1 84	23	41 71	16 81
7	5 20	2 10	23 5	43 31	17 45
7 5	5 87	2 37	24	44 94	18 11
8	6 57	2 65	24 5	46 59	18 77
8 5	7 31	2 94	25	48 27	19 45
9	8 08	3 25	25 5		20 14
9 5	8 88	3 58	26		20 83
10	9 71	3 91	26 5		21 54
10 5	10 58	4 26	27		22 25
11	11 47	4 62	27 5		22 98
11 5	12 40	5 00	28		23 72
12	13 36	5 38	28 5		24 46
12 5	14 35	5 78	29		25 22
13	15 37	6 19	29 5		25 98
13 5	16 42	6 62	30		26 76
14	17 50	7 05	30 5		27 55
14 5	18 61	7 50	31		28 34

Table 2 Friction loss gradient in m per 100 m for different flow rates in *IPS-PVC* thermoplastic pipe [1]

Flow rate lps	Nominal pipe size (inside diameter), mm 32 (38 9)	38 (44 6)	50 (55 4)	64 (67 4)	75 (83 4)
0 50	0 66	0 34	0 12		
0 75	1 34	0 70	0 25	0 10	
1 00	2 21	1 16	0 41	0 16	0 06
1 25	3 27	1 71	0 61	0 24	0 09
1 50	4 5	2 35	0 84	0 33	0 12
1 75	**5 90**[2]	3 08	1 10	0 43	0 16
2 00	7 44	3 89	1 39	0 55	0 20
2 25	9 14	**4 76**	1 71	0 67	0 24
2 50		5 74	2 05	0 81	0 29
3 00		7 90	2 82	1 11	0 40
3 50			**3 69**	1 46	0 53
4 00			4 67	1 84	0 67
4 50			5 73	2 26	0 82
5 00				**2 72**	0 99
5 50				3 21	1 17
6 00				3 74	1 36
6 50				4 30	1 56
7 00				4 90	1 78
7 50				5 52	2 01
8 00					**2 25**
8 50					2 50
9 00					2 76
9 50					3 04
10 00					3 32
11 00					3 93

1 32 to 64 mm pipe is SDR 26 (Class 10 9 atm or 160 psi), 75 mm is SDR 32 5 (Class 8 5 atm or 125 psi)

2 For flow rates followithe bolded value, the velocity exceeds 1 5 m/s

Table 3 Friction loss gradient in m per 100 m for different flow rates in SDR 41–*IPS-PVC* (class 6 8 atm or 100 psi) thermoplastic pipe

Flow rate lps	Nominal pipe size (inside diameter), mm 100 (108 7)	150 (160 0)	200 (208 4)	250 (259 7)	300 (308 1)
5 0	0 28				
7 5	0 57				
10 0	0 94				
12 5	**1 40***				
15 0	1 92	0 37			
17 5	2 51	0 49			
20 0		0 61			
22 5		0 76			
25 0		0 91	0 26		
27 5		1 07	0 31		
30 0		**1 25**	0 36		
32 5		1 44	0 41		
35 0		1 64	0 47		
37 5		1 85	0 53		
40 0			0 59		
42 5			0 66		
45 0			0 72	0 25	
47 5			0 80	0 28	
50 0			**0 87**	0 31	
52 5			0 95	0 33	
55			1 03	0 36	
60			1 20	0 42	
65			1 38	0 48	
70				0 55	
75				**0 62**	0 28
80				0 70	0 31
85				0 77	0 34
90				0 86	0 38
95				0 94	0 42
100				1 03	0 46
105				1 12	0 50
110				1 22	**0 54**
115				1 31	0 58
120					0 63
125					0 68
130					0 72
135					0 77
140					0 82
145					0 88

* For flow rates following the bolded value, the velocity exceeds 1 5 m/s

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3 LAYOUT CONSIDERATIONS

The two primary concerns in positioning mainlines, submains, headers, and laterals in a field are to minimize costs and maintain a uniform pressure distribution along the laterals Mainline pipes are the largest in the system and cost substantially more than the laterals, the mainline length should be minimized

Pressure regulators can be used to maintain uniform pressures at the entrance to each submain or header Where possible, use topographic effects to maintain a uniform pressure distribution along the lateral

3 1 Moderate, uniform sloping field

- When fields are large, mainlines are normally placed at the center of the field running in the direction of maximum slope, Figure 1 For small fields, mainlines are placed along one edge to minimize impact on field operations
- Laterals are run at right angles to the submain in the direction of minimum slope, to insure the highest pressure and distribution uniformity for the site Where the topography of the field allows, long laterals may be run slightly down slope to use the pressure gain to offset some of the pressure lost to friction

3 2 On moderately sloping terrain

- It may be possible to place the mainline along the upper edge of the field, Figure 2
- Laterals are run down slope at right angles to the mainline This placement partially balances the friction head loss along the lateral with the gain in pressure due to elevation differences Resulting pressures and discharges are more uniform along the lateral

3 3 Irregular terrain

- Mainlines are placed along the ridges
- Where slopes are not too steep, laterals are run down slope to maintain pressure and discharge uniformity

4 REQUIRED SYSTEM FLOW RATE

4 1 Submain discharge rate

The required trickle irrigation system flow rate must be determined before selecting pipe sizes and pump specifications The designer starts at the lateral and works to the water source

The capacity for any trickle lateral line is given by

$$Q_L = \frac{n_e \times q_a}{3600}$$

where Q_L = required flow rate into the lateral, lps, n_e = the number of emission points on the lateral, and q_a = average individual emission point discharge, lph

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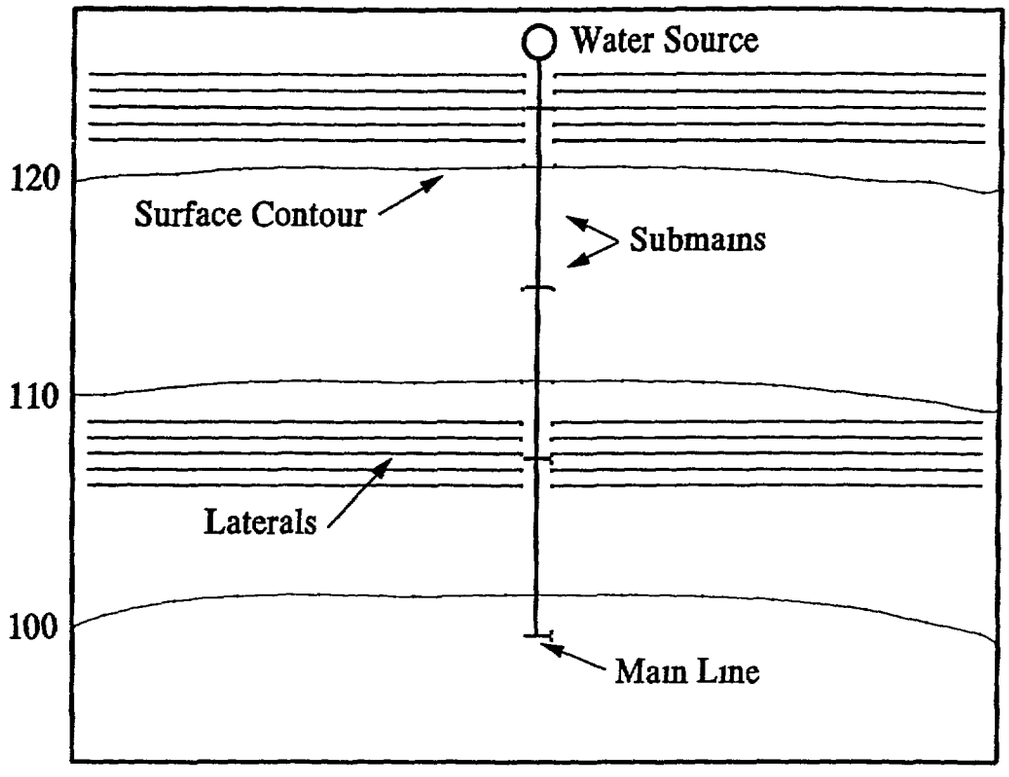

Figure 1 Main and submain placement on a field with moderate, uniform slopes and the water supply at one edge

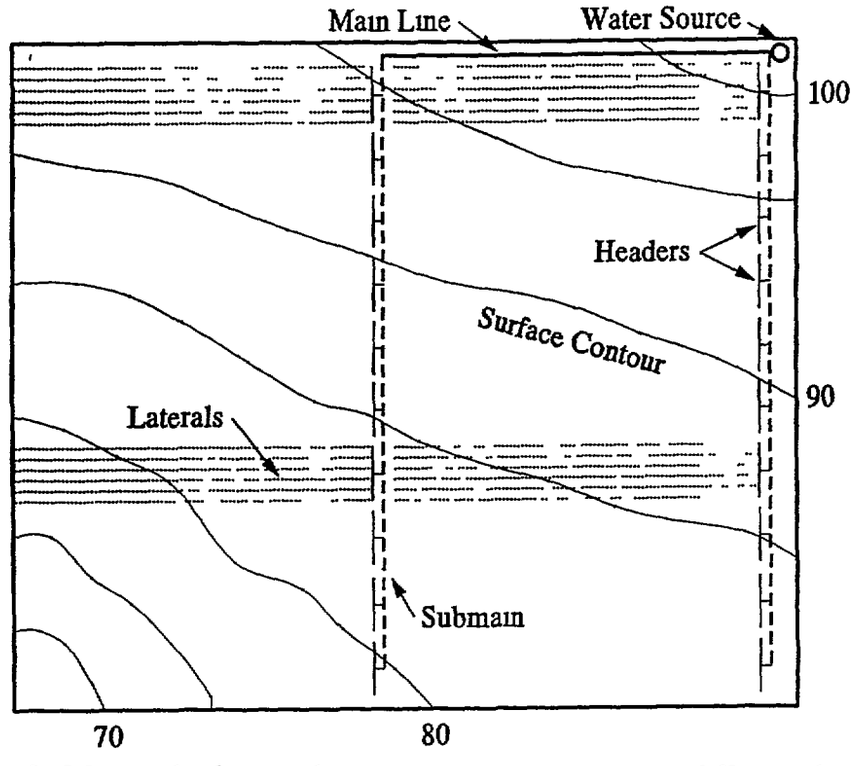

Figure 2 Main and submain placement to minimize pressure differentials in the submains and laterals

See module 1-7, Laterals, for more information on the sizing of lateral lines Individual discharges of all laterals on a submain or header are added to determine the required discharge of the submain or header

$$Q_S = \frac{\sum_{i=1}^{n_L} Q_{L_i}}{E_S}$$

where Q_S = required flow rate into the submain, lps, n_L = the number of laterals on the submain, i = index, and E_S = submain efficiency, decimal fraction

4 2 Mainline discharge rate

Generally all submains on a mainline do not operate at the same time The submains are grouped into sets, all submains in a set operate at the same time Discharges of all submains in a set are added The set having the largest discharge requirement determines the design discharge of the mainline, Q_M

$$Q_M = \frac{Q_{S\,mx}}{E_M}$$

where Q_M = design flow rate of the mainline, lps, $Q_{S\,mx}$ = flow rate of the submain set requiring the largest flow rate, lps, and E_M = mainline efficiency, decimal fraction

4 3 System discharge rate

System capacity must meet peak crop evapotranspiration requirements This is particularly essential where irrigation provides the major or only source of water to the crop System capacity is a function of the number of main lines served at the same time, and the time each submain is operating The operating time per season must be known for economic analysis

5. SUBMAIN AND MAIN LINE DESIGN

5 1 Submain Design

The submain acts as the water delivery control system, pressure regulators are often installed at each submain inlet Design of submains is based on both capacity and uniformity Capacity means the submain size should be large enough to deliver the required amount of water to irrigate the field Uniformity means the submain should be designed to maintain an allowable pressure variation so the flow into all laterals is within the design criteria

The submain is hydraulically the same as a lateral line having steady spatially-varied out flows For single size submains on a uniform slope the design charts presented in Module 1-7, Laterals, may be used For submain design, total discharge is the summation of all lateral line discharges

Since the length of a submain is relatively short, 25m to 75m, simplified design charts can be prepared Figure 3 is designed for submain slopes equal to or larger than 0 5%

Figure 4 is used for slopes less than 0 5% and an allowable pressure variation of 10%

5 1 1 Submain Design Steps, Rectangular Fields

- Determine the total discharge, Q_S, for the submain
- Determine the length and pressure head ratio L/H
- Determine the submain slope If the slope is less than 0 5%, use Figure 4 to design the submain size
- If the submain slope is equal to or larger than 0 5%, use Figure 3 to design the submain

5 1 2 Submain Design Steps, Irregular Fields

The submain design charts are for use on rectangular shaped fields where lateral line lengths are all the same For irregular shaped fields, which can be considered as a triangle or trapezoid, a shape coefficient, C_S, can be applied to determine an adjusted total discharge in order that the design charts can still be used

Consider irregular shaped fields as trapezoids that can be classified in the two groups show in Figures 5 and 6 In group 1 the flow direction in the submain is from the long laterals (A) to the short laterals (B) In group 2 the flow direction in the submain is in the reverse direction When B is zero the field will be triangular The B/A ratio shows the degree of irregular shape

- Determine the total discharge, Q_S, for the submain
- From the field shape and the flow direction in the submain, identify the shape group and determine the values of A and B
- Calculate B/A and determine C_S from either Figure 5 or 6
- Determine the adjusted total discharge, $Q_{adj} = C_S \times Q_S$
- Determine the length and pressure head ratio L/H
- Determine the submain slope
- Determine the submain slope If the slope is less than 0 5%, use Figure 4 and the adjusted discharge, Q_{adj}, to design the submain size
- If the submain slope is equal to or larger than 0 5%, use Figure 3 and the adjusted discharge, Q_{adj}, to design the submain

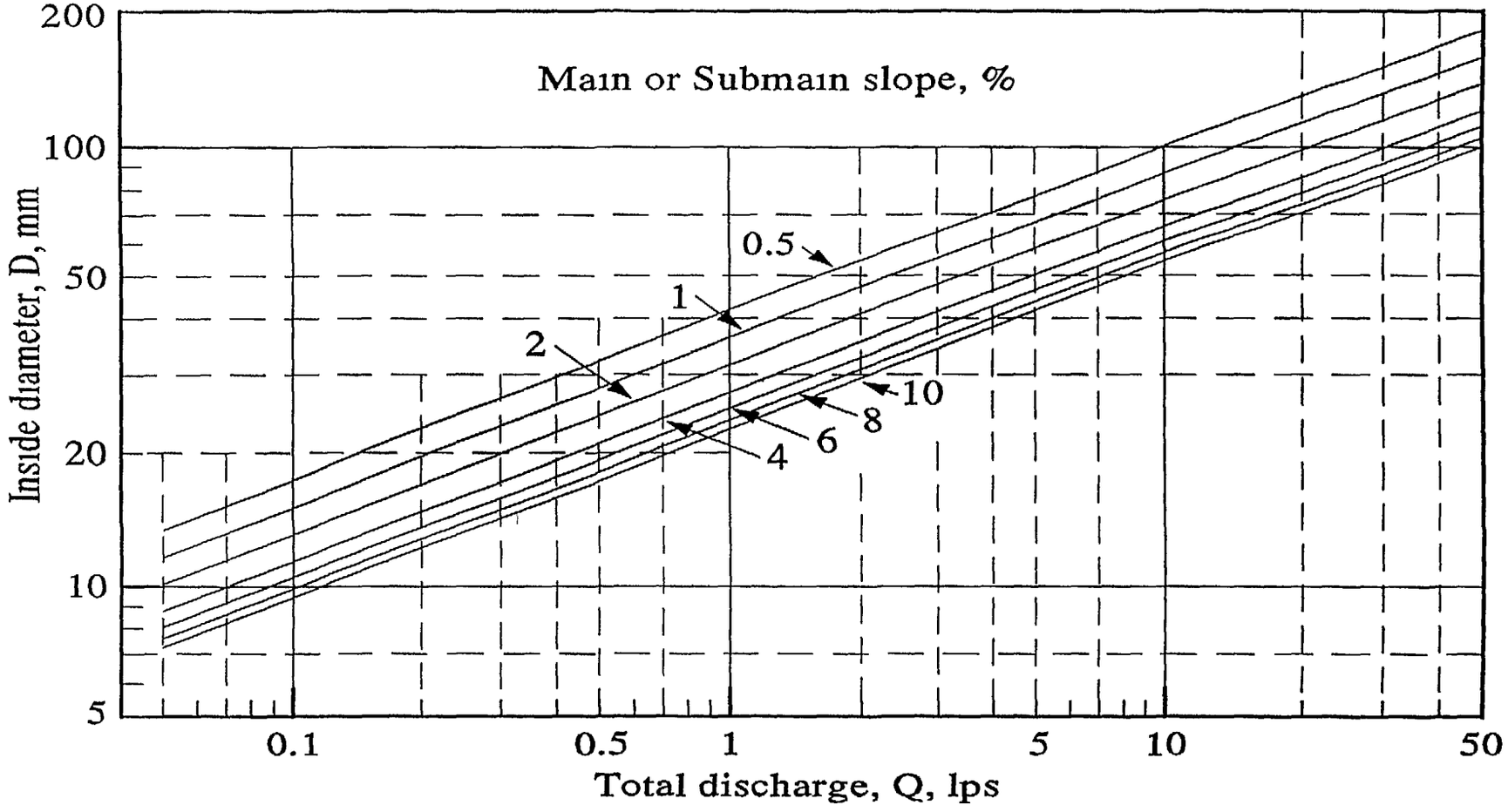

Figure 3 Simplified submain design chart, slope equal to or larger than 0 5%

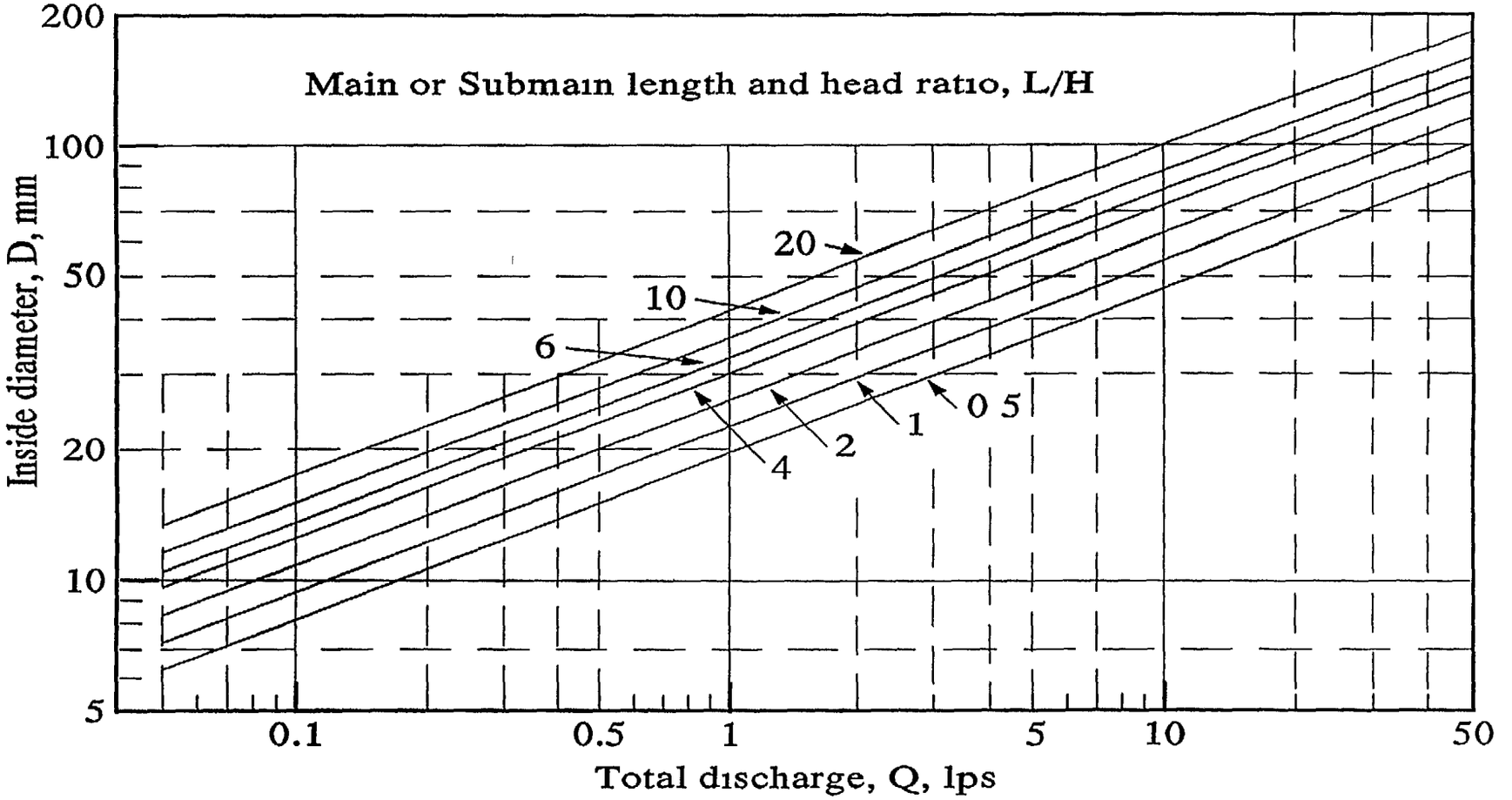

Figure 4 Simplified submain design chart, slope less than 0 5%

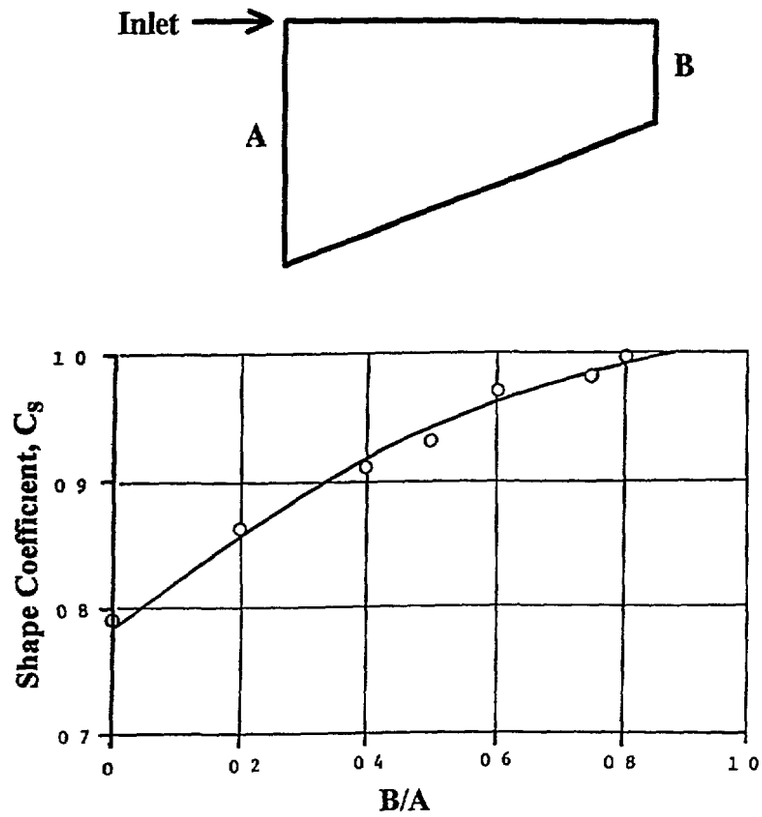

Figure 5 Group 1 field shape and curve for the shape coefficient

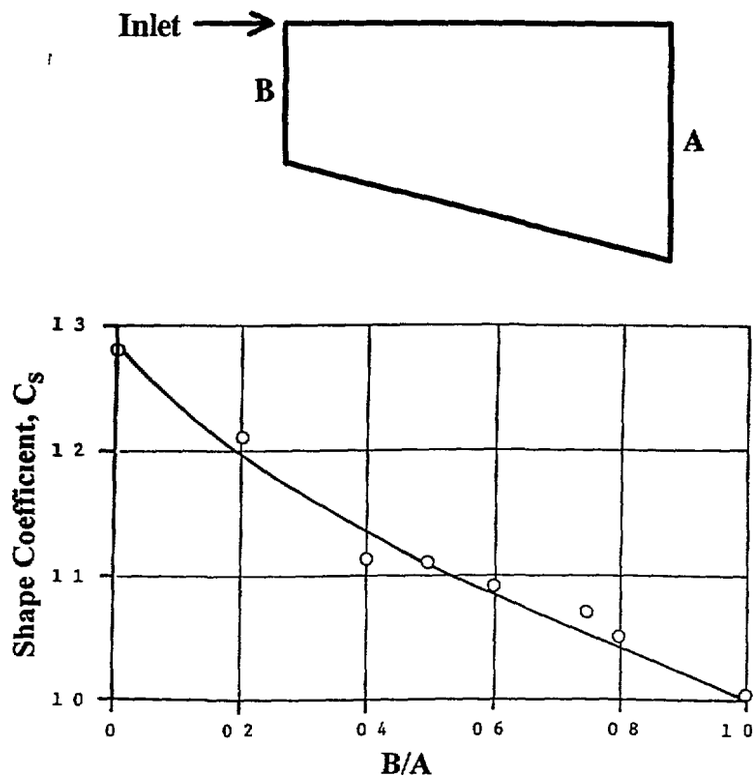

Figure 6 Group 2 field shape and curve for the shape coefficient

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5 2 Mainline Design

The main line serves as a conveyance system for delivering the required amounts of water for irrigation Design of a main line is based on the hydraulics of pipe flow Since the total discharge in the main line is decreasing with respect to length, the main line is usually designed as a series of pipes with decreasing diameters Main lines should be designed such that the total energy at any outlet along the line is equal to or higher than the energy required at that point

- From the topographic map of the field, plot the profile of the mainline
- Plot the required pressure head along the main line profile
- Determine the energy slope, %, along the main line

$$\text{Energy Slope} = \frac{\text{Total Energy at Inlet} - \text{Total Energy at End}}{\text{Main Line Length}} \times 100$$

- Design the main line size for each section using Figure 7 with the total flow rate in each section and the main line energy slope A section is the distance between submain off takes

Caution: For all sections of the main line the energy gradient must be higher than the pressure head required for the laterals Figure 8 shows acceptable (line A – B) and unacceptable (line B – C) energy gradient lines

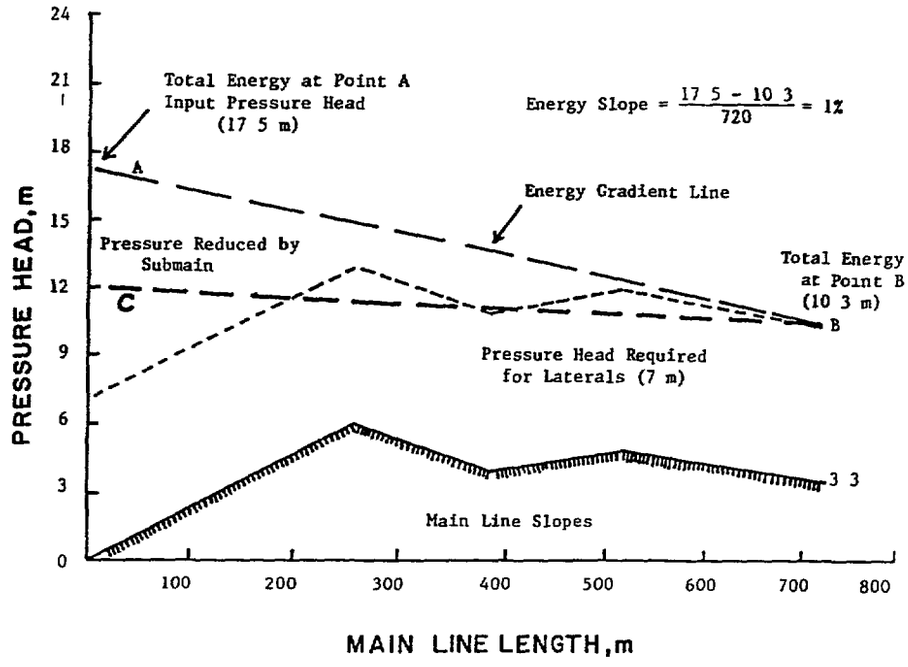

Figure 8 Main line energy gradient lines

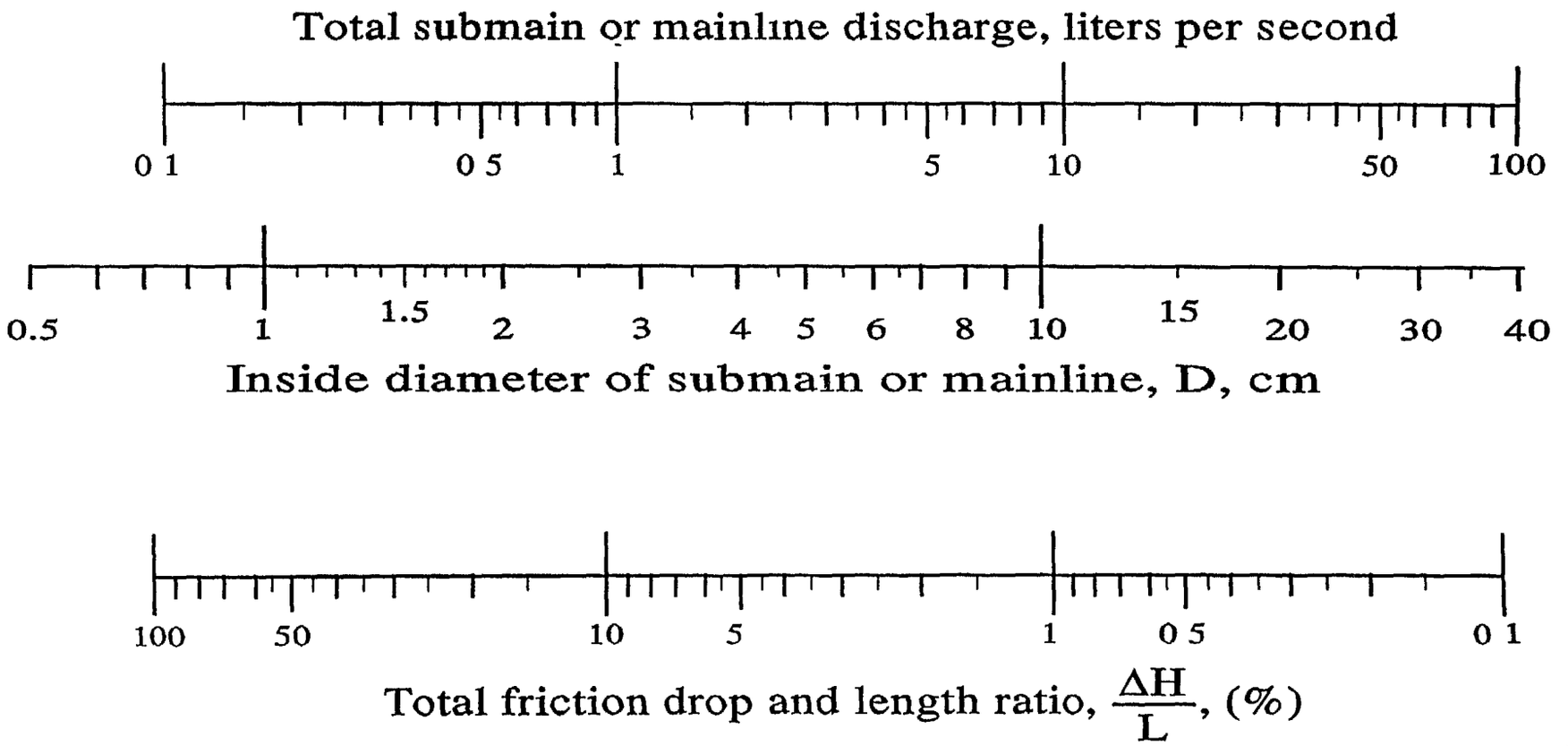

Figure 7 Nomograph for sizing submain and main lines for trickle irrigation system design

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SUBMAIN AND MAIN PIPELINE SIZING

CASE STUDY

1 Design Data

11 laterals per submain
- $Q_L = 0\ 2$ lps
- Lateral spacing = 2 m
- First lateral is placed 1 m from the submain inlet
- Pressure required at submain inlet = 10 m
- Submain slope = 3%

8 submains on the main line
- Submains are paired
- Submain spacing = 50 m
- Distance from source to first submain pair = 10 m
- Pressure head at the source = 15 m
- Main line slope = 1%

Submain and mainline efficiencies, $E_S = E_M = 95\%$

2 Design Calculations

2 1 Design flow rates

- Flow rate per submain (Q_S)

$$Q_S = \frac{\sum_{i=1}^{n_L} Q_{Li}}{E_S} = \frac{Q_L \times n_L}{E_S} = \frac{0\ 2 \times 11}{0\ 95} = 2\ 32 \text{ lps}$$

- Flow rate required at head of mainline to irrigate 8 submains (Q_M)

$$Q_M = \frac{\sum_{i=1}^{n_S} Q_{Si}}{E_M} = \frac{Q_S \times n_S}{E_M} = \frac{2\ 32 \times 8}{0\ 95} = 19.54 \text{ lps}$$

2 2 Submain Design

- Submain length = 2 × 10 + 1 = 21 m
- Slope = 3%
- From Figure 9 the inside diameter of the submain is about 40 mm The next **larger** available size of pipe should be used for field installation

2 3 Main Line Design

- Mainline length = 3 × 50 + 10 = 160 m
- Determine the energy slope, %, along the main line

$$\text{Energy Slope} = \frac{\text{Total Energy at Inlet} - \text{Total Energy at End}}{\text{Main Line Length}} \times 100$$

$$\text{Energy Slope} = \frac{15 - 10}{160} \times 100 = 3\ \%$$

- From Figure 10 the design main line inside diameter is about 110 mm The next **larger** available size of pipe should be used for field installation

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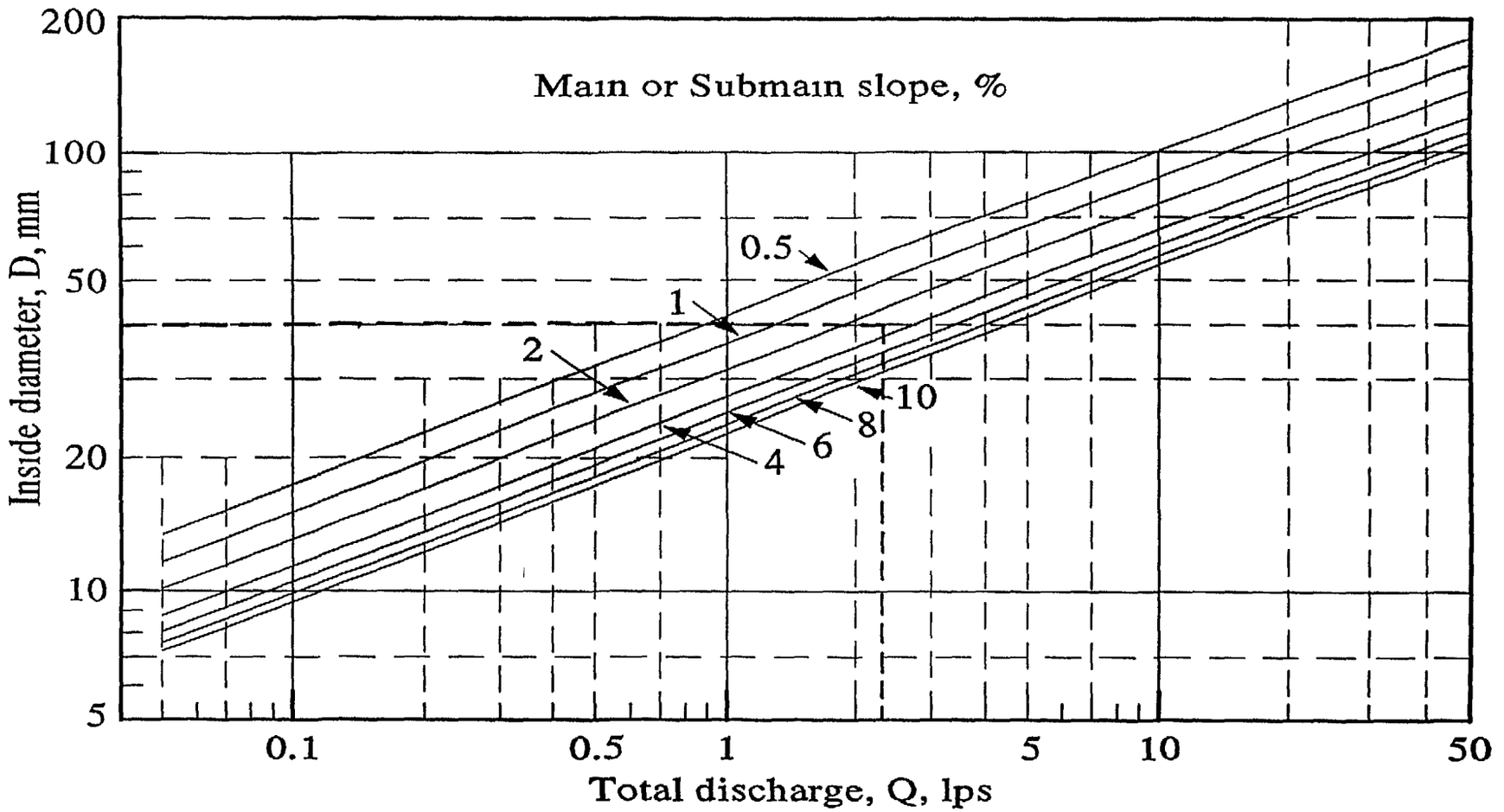

Figure 9 Simplified submain design chart, slope equal to or larger than 0 5%

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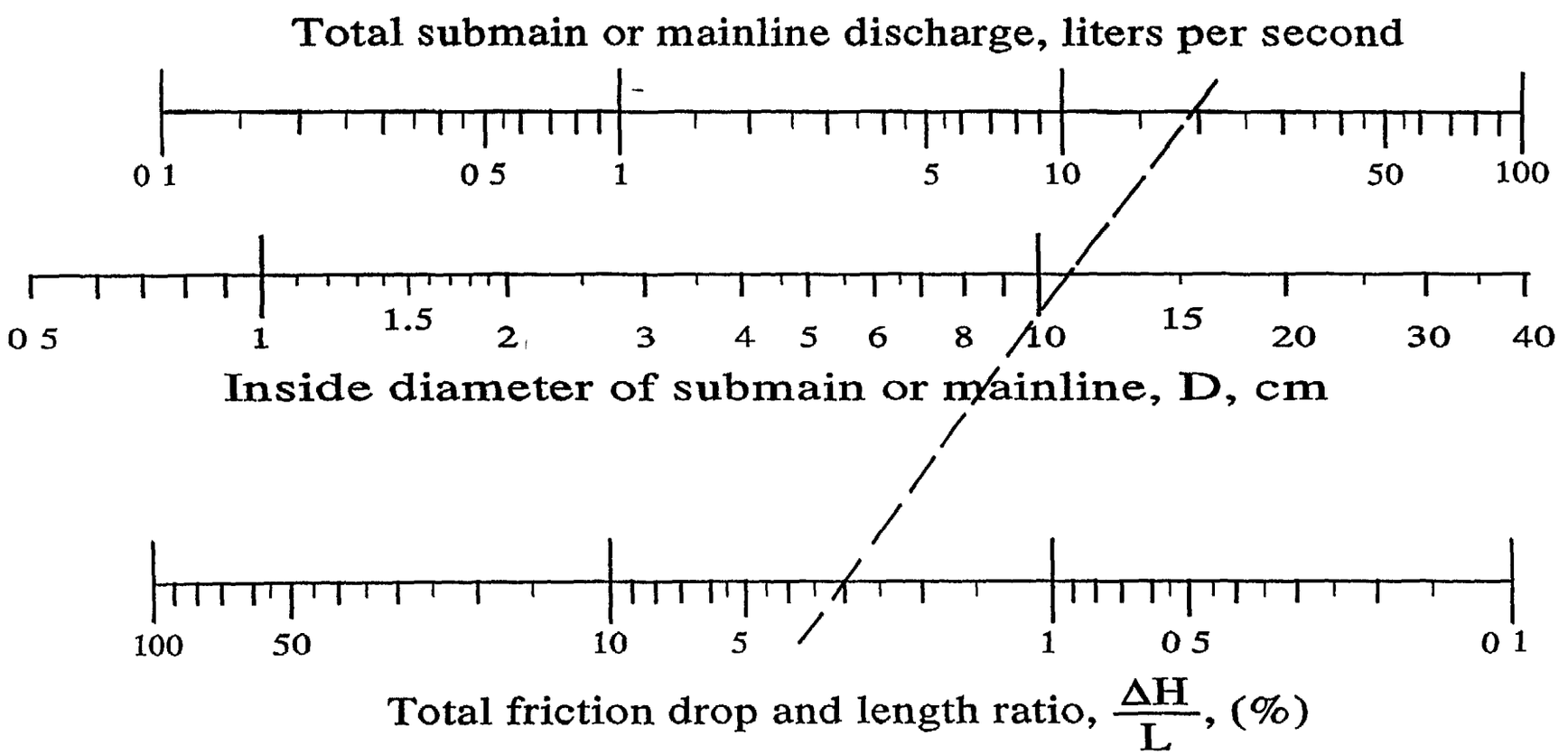

Figure 10 Nomograph for sizing submain and main lines for trickle irrigation system design

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MICRO IRRIGATION SYSTEMS

PIPELINE PROTECTION

[Supplemental]

1 INTRODUCTION

Air release and air & vacuum valves (generally one combination valve does both actions) are required to remove entrapped air when filling and operating the pipeline, to allow the entry of air when the pipeline is being drained after operations are completed There are three reasons why air in pipelines is undesirable

- Flow restriction Air bubbles tend to collect at high points This air accumulation forms a restriction in the pipe similar to a partially closed valve The increased friction reduces the flow rate "High" points do not need to be very high Gradual undulations on gently rolling land are often the biggest culprits because they tend to have many small high points and are easily neglected
- Surging Large air bubbles moving in pipelines will compress at low points (high pressure) and expand at high points (low pressure locations), causing a surging action
- Sudden surging and dislodging Air bubbles which accumulate near high points may increase in size until the tangential force of the moving water causes them to suddenly move downstream This results in large pressure surges

Pressure relief valves need to be installed in a pipeline to prevent pipe damage caused by pressure surges Pressure relief and air valves insure safe and efficient operation of the system Without these devices, the pipeline may not only operate inefficiently, raising operation costs, it is subject to failure

2 PIPELINE PROTECTION DEVICES

2 1 Air release, air & vacuum, and combination valves

Air release valves (ARV) are used to remove small pockets of air that collect at high points in the pipeline This air can be picked up with water at a pump intake or mix with the water at a gravity inlet structure (such as Tel Al-Thahab Weir) If air is not removed from the pipeline, it reduces the carrying capacity of the pipeline by restricting the diameter of the flow path available for water passage Restricting the flow path requires the pump to operate at higher heads to supply the required flow, increasing energy costs Air pockets in a pipeline can also increase the damaging effects of water hammer and pressure surges

Air & vacuum valves (AVV) are used to efficiently remove the large volume of air in a pipeline when it is initially filled They also admit the large volume of air needed to prevent collapse of the line when it is emptied of water Air & vacuum valves are not suitable for removing the small pockets of air that accumulate during pipeline operation

Combination air valves (CAV) allow the efficient entry and exit of large air volumes to the pipe These valves also have a small orifice to release air accumulated in small pockets during operation

2 1 1 Valve operation

- Air release valves are installed on high points in the system During system operation, small particles of air will separate from the water and enter the valve Each particle of air will displace an equal amount of the water within the valve and lower the liquid level relative to the float When the water level lowers to a point where the float is no longer buoyant, the float will drop This action opens the valve orifice and allows the air that has accumulated in the upper portion of the valve to be released to the atmosphere As air is released, the water level within the valve once again rises, lifting the float and closing the valve orifice This cycle repeats itself as often as air accumulates in the valve ARV are not recommended for vacuum protection nor to vent large volumes of air when filling large diameter pipelines because they have small orifices, usually less than 12 mm Figure 1 shows the design of such a valve

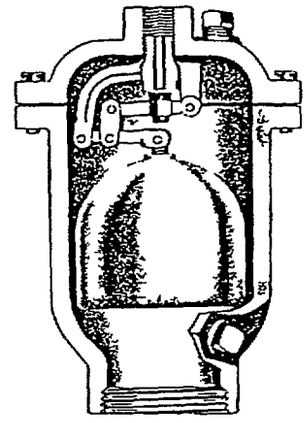

Figure 1 A compound lever air release valve

- Air & vacuum valves are installed on each high point in the system or changes in grade Typical AVV have a large discharge orifice equal in size to the valve's inlet As the pipeline fills air is exhausted to the atmosphere As air leaves the pipeline, water will enter the valve and lift the float to close the valve orifice The rate air is exhausted is a function of pressure differential, which develops as water fills the pipeline, compresses the air giving it an escape velocity equal to that of the incoming water Any time during operation, should internal pressure of the pipeline approach a negative value, due to column separation, draining of the pipeline, power outage or pipeline break, the float will immediately drop away from the orifice and allow air to re-enter the pipeline Air re-entry during water column separation will prevent a vacuum protecting the pipeline against collapse

  During system operation and while under pressure, small amounts of air will enter the AVV from the pipeline and displace water Eventually, the entire valve may fill with air, but it will not open

because the system pressure will continue to hold the float closed against the valve orifice *The AVV is intended to exhaust air during pipeline filling and to admit air during pipeline drainage It will not open and vent air as it accumulates during pipeline operation* Figure 2 shows the construction of a typical AVV

- Combination air valves have operating features of both ARV and AVV These valves are installed on all high points of a system where it has been determined both ARV and AVV are needed to vent and protect the system Generally a CAV is used instead of an AVV A CAV is depicted in Figure 3 The separate parts of the CAV operate as described for the ARV and AVV

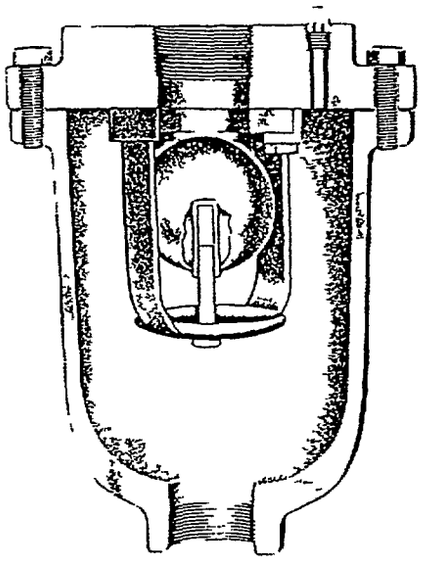

Figure 2 A typical air & vacuum valve

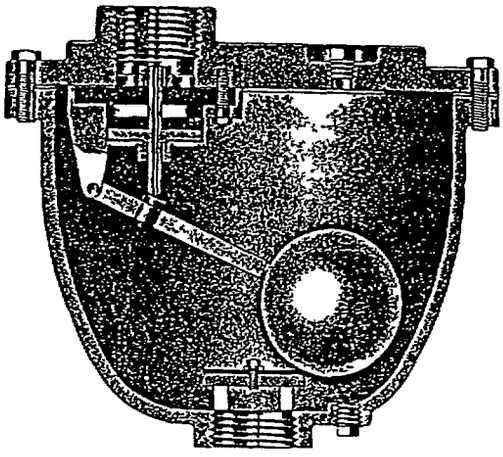

Figure 3 Typical single body combination air release and air & vacuum valve

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2 1 2 Valve placement

- AVV or CAV should be installed at high points in the physical layout of the pipeline and at high points along the hydraulic gradient Together with ARV, or more commonly CAV, they should also be installed at the ends and intermediate points along the length of pipeline which is parallel to the hydraulic grade line It is recommended that CAV be placed every 0 5 to 1 0 km along descending pipeline sections, especially at points where the decreasing pipeline grade is steep

- Air may be released from solution if there is adequate drop in pressure Such conditions may occur along mainline which rises in elevation or where velocity is increased through a flow restriction such as a partially closed valve This air should be bled off by appropriately placed ARV to avoid blockage of the pipeline ARV are therefore required along all ascending lengths of pipeline, particularly at points where there is a decrease in the upward gradient

- Other reasonable points of ARV placement are on the discharge side of pumps, at high points on large flow control valves, and upstream of orifice plates and reducing tapers if they are located in relatively high velocity flow stream

2 1 3 Valve sizing

- Air release valve orifices are sized based on the venting capacity required and the system operating pressure The minimum venting capacity is taken as 2% of the pipeline flow capacity and can be calculated from

$$\text{ARV capacity} = \frac{\text{Flow Capacity}}{50}$$

where ARV capacity is lps and flow capacity is also in lps

Example A pipeline actual flow capacity is 12 l/s at 4 bar The amount of air to be vented from the pipeline is

$$\text{ARV capacity} = \frac{12}{50} = 0\ 24 \text{ lps}$$

The size of the ARV orifice required, 0 79 mm, is read from the graph in Figure 4 The selected ARV orifice is slightly oversized

- Air & vacuum valves use a slightly different approach to sizing For pipelines being filled by a pump use the flow capacity from the pump as the required capacity needed for the AVV If the line is being filled or drained by gravity use

$$\text{AVV capacity} = 0\ 014321 \times \sqrt{SD^5}$$

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where S = slope, m/m, D = pipe diameter, cm, and AVV capacity = m^3/min Use the highest required flow capacity for the valve, either filling or draining Use 34 5 kPa as the maximum pressure allowed **during draining** and 13 8 kPa as the maximum pressure allowed **during filling** Enter the graph given in Figure 5 to find the required orifice size

- The combination valves are sized by using the orifice values found for the ARV and AVV valves

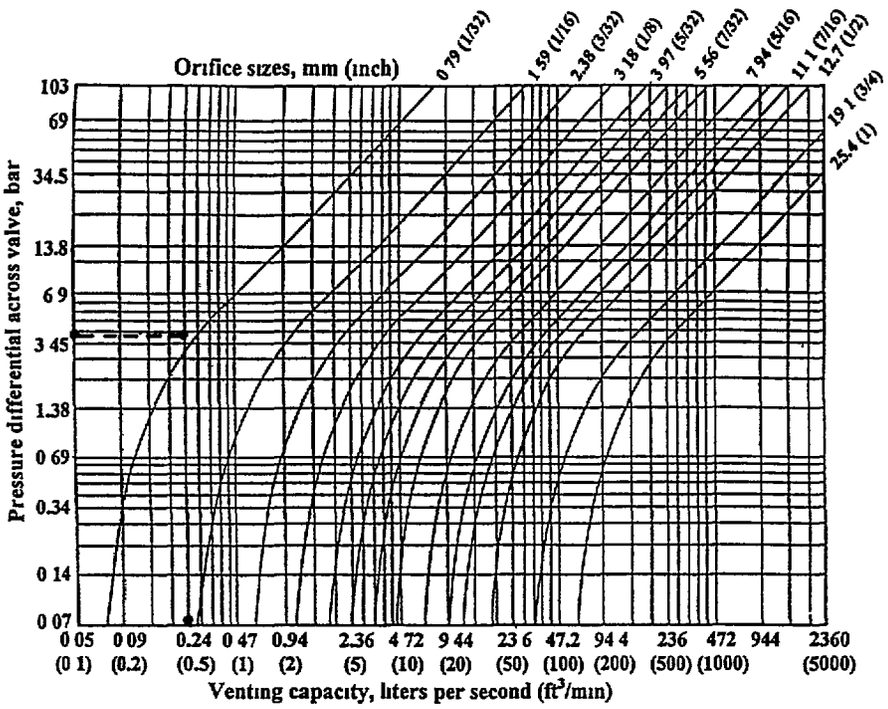

Figure 4 Venting capacity graph for air release valves

- Another approach to sizing AVV is by the diameter of the pipeline The ratio of AVV vent diameter to pipeline diameter for high pressure systems should be 0 1 or greater that is, valve diameter should be ≥ 10 percent of the pipeline diameter Table 1 indicates minimum recommended valve sizing for high and low pressure systems

Table 1 Minimum diameter of the vent or port for AVV for high and low pressure pipelines

Pipe diameter (mm)	Outlet diameter (mm)	Pipe diameter (mm)	Outlet diameter (mm)
High Pressure Lines[1]		**Low Pressure Lines**[2]	
102	13	152 or less	51
127 → 203	25	178 → 254	76
254 → 500	51	305 or larger	102

1 Internal pressures of 550 to 2170 kPa
2 Internal pressures of 545 kPa or less

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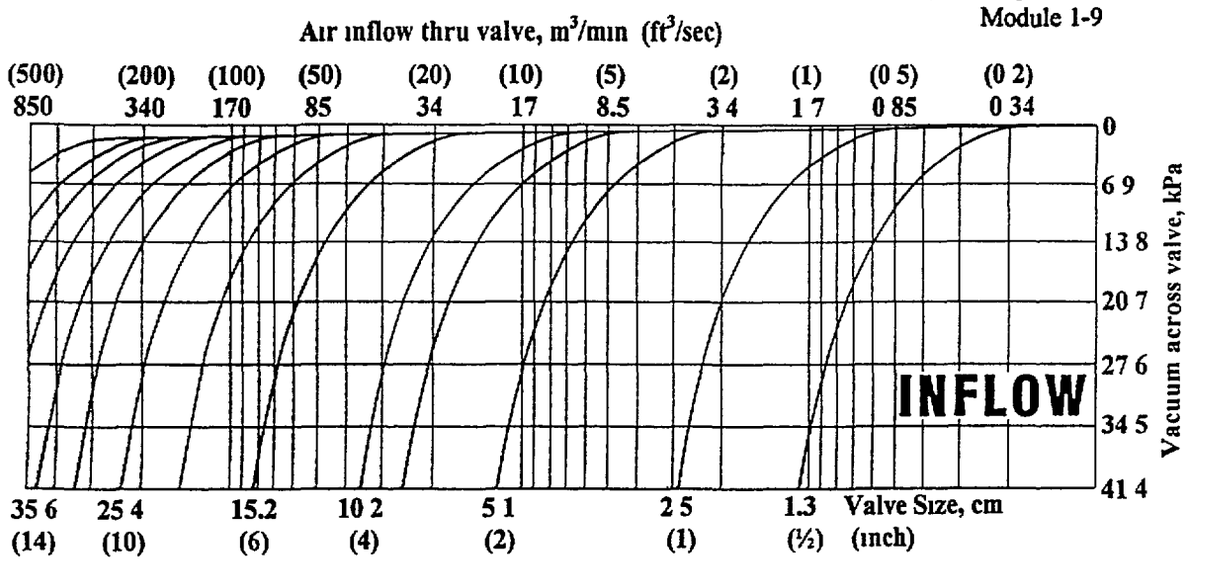

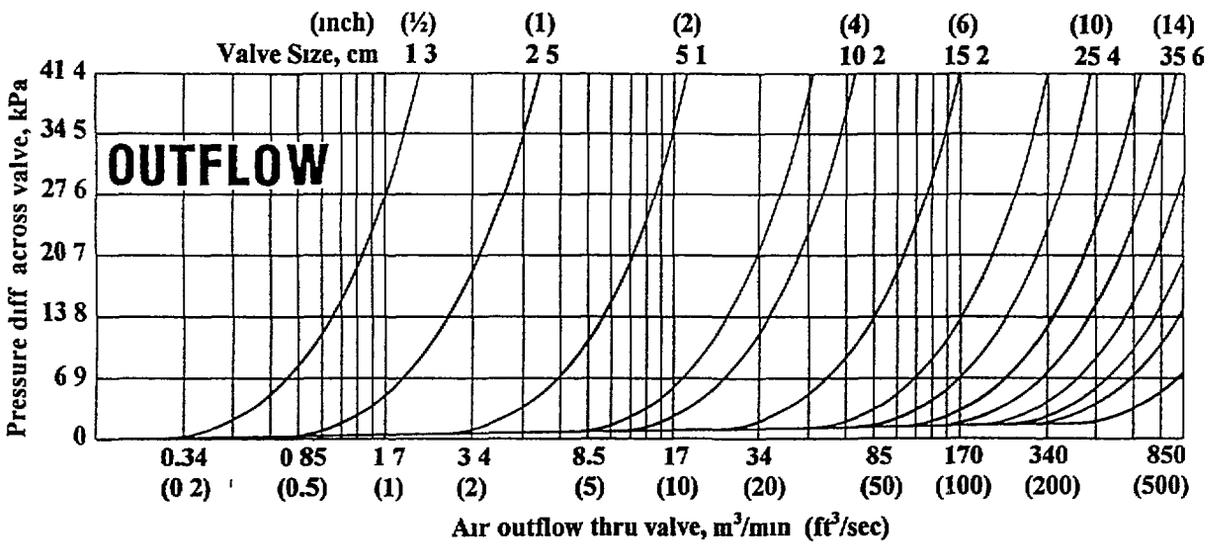

The curves are actual flow capacities at one bar atmospheric pressure and 21 °C temperature base on the actual test These curves are not merely flow capacities across the orifice, but flow capacities across the entire valve

Figure 5 Performance graph for air & vacuum valves

2 2 Pressure surge protection

- The need to protect pipelines from surge pressures that develop during sudden valve closure has been described in the section on water hammer An inverse condition exists if a pump is suddenly shut off In this case the flow stops and the sudden deceleration of the water column causes a pressure drop at the point of pump discharge This negative pressure surge moves along the pipeline The sudden pressure drop may cause vaporization, pipeline collapse, or induction of air at atmospheric pressure into the pipeline through an AVV or CAV
- High pressure surges can be controlled through installation of pressure relief valves at those points in a pipeline where it is anticipated pressure waves will be generated or reflected Typical installation points are between the pump and the first valve on the discharge line and at the end of

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the pipeline Relatively simple valves of this type suitable for distribution systems on-farm operate using a spring-loaded discharge valve, Figure 6

Under normal operating pressures the valve remains in the closed position If water hammer causes a pressure surge in the line, the excess pressure depresses the spring thereby opening the valve and causing water to be discharged from the line The result is that the magnitude of the pressure surge is considerably reduced and the reflected shock wave does not damage the pipeline The level of pressure at which the valve will be activated can be preset by the manufacturer or set in the field to correspond to the operating pressure of a particular system

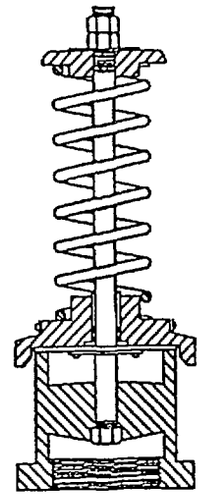

Figure 6 A typical spring loaded pressure relief valve

2 2 1 Low Pressure Pipelines

Pressure relief valves shall be large enough to pass the full pump discharge with a pipeline pressure no greater than 50% above the permissible working head of the pipe

2 2 2 High Pressure Pipelines

The ratio of nominal size pressure relief valve to pipeline diameter shall be no less than 0 25 Pressure relief valves shall be set to open at a pressure no greater than 34 5 kPa above the pressure rating of the pipe or the lowest pressure rated component in the system

- The opposite problem is encountered when sudden down surges in pressure are caused by pumps stopping The objective of pipeline protection in this case is to reduce the magnitude of the down surge so that the reflected high pressure wave is also reduced The most common method of limiting down surge is to feed water into the pipeline as soon as the pressure drops Different methods of accomplishing this objective are applicable depending on the operating pressure of the system and anticipated magnitude of the pressure surge

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