Irrigation Manual

Planning, Development, Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation

Module 9

Localized Irrigation Systems

Planning, Design, Operation and Maintenance

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Foreword

The first edition of the Irrigation Manual was published in 1990 in two volumes by the "Smallholder Irrigation" Project (UNDP/FAO/AGRITEX/ZIM/85/004). The authors of this first edition were FAO Staff on the project[1]. This edition of one hundred copies ran out within two years from publishing.

Although the manual was written with Zimbabwe in mind, it soon became popular in several countries of the sub-region. In view of the high demand, it was decided to proceed with a second edition. The experience gained from using the first edition of the manual as the basic reference for the AGRITEX[2] training programme of irrigation practitioners and the University of Zimbabwe, was incorporated in the second edition which was published in 1994, in one volume by the "Technical Assistance to AGRITEX" project (UNDP/FAO/AGRITEX/ZIM/91/005). This second edition was published under the same authors as the first edition, with the assistance of a review committee from AGRITEX[3]. The two hundred copies of this edition also ran out within two years of publishing.

In 1995, the FAO Sub-regional Office for East and Southern Africa (SAFR) was established in Harare, Zimbabwe, in order to provide easy access to technical assistance and know-how for the countries of the sub-region[4]. In view of the high demand for support in the field of smallholder irrigation by the countries of the sub-region, this office was strengthened with four water resources management officers and a number of on-going programmes have been developed to provide this support. One of these programmes is the publishing of a new regional edition of the irrigation manual in support of the on-going national training programmes within several countries in the sub-region and to provide the basic reference for another important programme, which is the sub-regional training on planning and design of smallholder irrigation schemes.

This third edition aspires to further strengthen the engineering, agronomic and economic aspects of the manual and to introduce new modules related to social, health and environmental aspects of irrigation development. The emphasis is directed towards the engineering, agronomic and economic aspects of smallholder irrigation, in view of the limited practical references in this area. This manual, being directed to the irrigation practitioner, does not provide an in-depth analysis of the social, health and environmental aspects in irrigation development. It only attempts to introduce the irrigation practitioner to these areas, providing a bridge between the various disciplines involved in irrigation development.

The initiatives and efforts of the Water Resources Management Team of SAFR in publishing this Manual are considered as a valuable contribution to the dissemination of knowledge and training of irrigation practitioners in the sub-region. The material covered by this manual is expected to support both national and sub-regional training programmes in the planning, design, construction, operation and maintenance and on-farm water management of irrigation schemes. This will support the implementation of FAO's mandate to increase food production through water control, intensification and diversification, which are the basic components of the Special Programme for Food Security (SPFS).

The manual is the result of several years of field work and training irrigation engineers in the sub-region. The approaches have been field tested and withstood the test of time.

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[2] *Agritex: Department of Agricultural Technical and Extension Services, Ministry of Lands and Agriculture, Zimbabwe.*

[3] *Review committee: E. Chidenga, Acting Chief Irrigation Officer; P. Chipadza, Senior Irrigation Specialist; A. Dube, Senior Irrigation Specialist; L. Forichi, Irrigation Specialist; L. Madhiri, Acting Principal Irrigation Officer; S. Madyiwa, Irrigation Specialist; P. Malusalila, Chief Crop Production; R. Mariga, Assistant Secretary, Economic and Markets Branch; D. Tawonezvi, Agricultural Economist.*

[4] *The following 21 countries are part of the FAO-SAFR region: Angola, Botswana, Burundi, Comoros, Eritrea, Ethiopia, Kenya, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Rwanda, Seychelles, South Africa, Swaziland, Tanzania, Uganda, Zambia, Zimbabwe.*

For ease of reference to the various topics covered by this Manual, the material has been divided into 14 modules, covering the following:

Module 1:	Irrigation development: a multifaceted process
Module 2:	Natural resources assessment
Module 3:	Agronomic aspects of irrigated crop production
Module 4:	Crop water requirements and irrigation scheduling
Module 5:	Irrigation pumping plant
Module 6:	Guidelines for the preparation of technical drawings
Module 7:	Surface irrigation systems: planning, design, operation and maintenance
Module 8:	Sprinkler irrigation systems: planning, design, operation and maintenance
Module 9:	Localized irrigation systems: planning, design, operation and maintenance
Module 10:	Irrigation equipment for pressurized systems
Module 11:	Financial and economic appraisal of irrigation projects
Module 12:	Guidelines for the preparation of tender documents
Module 13:	Construction of irrigation schemes
Module 14:	Monitoring the technical and financial performance of an irrigation scheme

To those who have been waiting for so long for a practical irrigation engineering manual: here it is. I am sure that it will have a lot to offer to both new and experienced irrigation engineers.

Victoria Sekitoleko
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Acknowledgements

The preparation of the third edition of the Irrigation Manual is an initiative of FAO's Sub-Regional Office for East and Southern Africa (SAFR).

The whole project was managed and coordinated by Andreas P. Savva and Karen Frenken, Water Resources Development and Management Officers at FAO-SAFR. Andreas Savva is considered as the main author and Karen Frenken as the main technical editor.

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Unit conversion table

Length

1 inch (in)	0.0254 m
1 foot (ft)	0.3048 m
1 yard (yd)	0.9144 m
1 mile	1609.344 m
1 metre (m)	39.37 inches (in)
1 metre (m)	3.28 feet (ft)
1 metre (m)	1.094 yards (yd)
1 kilometre (km)	0.62 miles

Area

1 square inch (in^2)	6.4516×10^{-2} m^2
1 square foot (ft^2)	0.0929 m^2
1 square yard (yd^2)	0.8361 m^2
1 acre	4046.86 m^2
1 acre	0.4046 ha
1 square centimetre (cm^2)	0.155 square inches (in^2)
1 square metre (m^2)	10.76 square feet (ft^2)
1 square metre (m^2)	1.196 square yard (yd^2)
1 square metre (m^2)	0.00024 acres
1 hectare (ha)	2.47 acres

Volume

1 cubic inch (in^3)	1.6387×10^{-5} m^3
1 cubic foot (ft^3)	0.0283 m^3
1 cubic yard (yd^3)	0.7646 m^3
1 cubic centimetre (cm^3)	0.061 cubic inches (in^3)
1 cubic metre (m^3)	35.315 cubic feet (ft^3)
1 cubic metre (m^3)	1.308 cubic yards (yd^3)

Capacity

1. imperial gallon	0.0045 m^3
1. US gallon	0.0037 m^3
1. imperial barrel	0.1639 m^3
1. US. barrel	0.1190 m^3
1 pint	0.5681 l
1 US gallon (dry)	0.0044 m^3
1 litre (l)	0.22 imp. gallon
1 litre (l)	0.264 U.S. gallon
1 litre (l)	0.0061 imperial barrel
1 hectolitre (hl)	100 litres = 0.61 imperial barrel = 0.84 US barrel
1 litre (l)	1.760 pints
1 cubic metre of water (m^3)	1000 l = 227 U.S. gallon (dry)
1 imperial barrel	164 litres

Mass

1 ounce	28.3286 g
1 pound	0.4535 kg
1 long ton	1016.05 kg
1 short ton	907.185 kg
1 gram (g)	0.0353 ounces (oz)
1 kilogram (kg)	1000 g = 2.20462 pounds
1 ton	1000 kg = 0.984 long ton = 1.102 short ton

Pressure

1 pound force/in^2	6894.76 N/m^2
1 pound force/in^2	51.7 mm Hg
1 Pascal (PA)	1 N/m^2 = 0.000145 pound force /in^2
1 atmosphere	760 mm Hg = 14.7 pound force/in^2 (lbf/in^2)
1 atmosphere	1 bar
1 bar	10 metres
1 bar	100 kpa

Energy

1 B.t.u.	1055.966 J
1 foot pound-force	1.3559 J
1 B.t.u.	0.25188 Kcalorie
1 B.t.u.	0.0002930 KWh
1 Joule (J)	0.000947 B.t.u.
1 Joule (J)	0.7375 foot pound-force (ft.lbf)
1 kilocalorie (Kcal)	4185.5 J = 3.97 B.t.u.
1 kilowatte-hour (kWh)	3600000 J = 3412 B.t.u.

Power

1 Joule/sec	0.7376 foot pound/sec
1 foot pound/sec	1.3557 watt
1 cheval-vapor	0.9861 hp
1 Kcal/h	0.001162 kW
1 watt (W)	1 Joule/sec = 0.7376 foot pound/sec (ft lbf/s)
1 horsepower (hp)	745.7 watt 550 ft lbf/s
1 horsepower (hp)	1.014 cheval-vapor (ch)
1 kilowatt (kW)	860 Kcal/h = 1.34 horsepower

Temperature

^{0}C (Celsius or centigrade-degree)	$^0C = 5/9 \times (^0F - 32)$
^{0}F (Fahrenheit degree)	$^0F = 1.8 \times {}^0C + {}^0F$
K (Kelvin)	$K = {}^0C + 273.15$

List of abbreviations

A_w	Area wetted by one emitter
AC	Asbestos Cement
ASAE	American Society of Agricultural Engineers
BHP	Brake power
BOQ	Bill of quantity
C	Roughness coefficient
C_v	Coefficient of variation
D	Diameter
ΔHs	Allowable pressure variation
E_a	Field application efficiency
EC_e	Electrical conductivity of the soil saturation extract
EC_w	Electrical conductivity of the irrigation water
ET_o	Reference crop evapotransipration
ET_{crop}	Crop evapotransipration
$ET_{crop\text{-}loc}$	Crop evapotransipration to be considered under localized irrigation
EU	Coefficient reflecting the uniformity of water apllication
EU	Design emission uniformity
F	Christiansen's reduction factor for various number of outlets
FC	Field Capacity
g	Acceleration due to gravity
GC	Ground cover
IF	Irrigation frequency
IR_g	Gross irrigation requirement
IR_n	Net irrigation requirement
ISO	International Organization for Standardization
H	Emitter operating pressure
HDPE	High density polyethylene
HL	Head loss
K_c	Crop factor
K_r	Ground cover reduction factor
kPa	Kilopascal

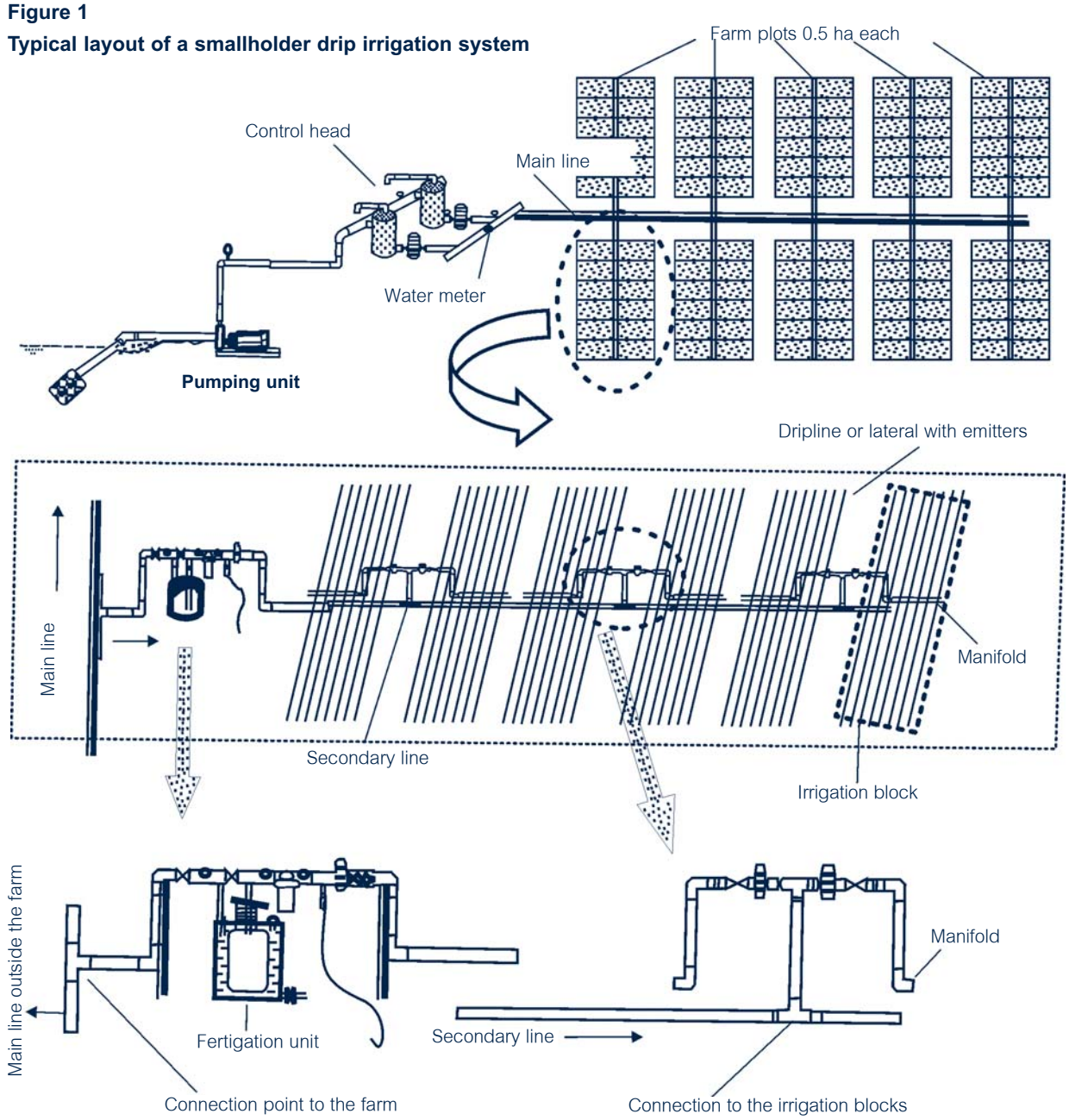
kW	kilowatt
L	Length
LDPE	Low density polyethylene
lph	litres per hour
lps	litres per second
LR	Leaching requirement
LR_t	Leaching requirement ratio under drip irrigation
N_p	Number of emitters per plant
P	Allowable moisture depletion
P_w	Wetted perimeter
PE	Polyethylene
PVC	Polyvinyl chloride
PWP	Permanent Wilting Point
Q	Discharge
q	Emitter discharge
R	Rainfall
RZD	Effective root zone depth
S_e	Emitter spacing
S_e'	Wetted area dimension
S_p	Distance between the plants within a row
S_r	Row spacing
SABS	South African Bureau of Standards
T_a	Duration of irrigation per day
TDH	Total Dynamic Head
TDR	Temperature Discharge Relationship
uPVC	unplasticized polyvinyl chloride
UV	Ultra violet
W	Wetted diameter
Y_r	Relative yield
ZITC	Zimbabwe Irrigation Technology Centre

Chapter 1
Introduction

Localized irrigation is the slow application of water to the soil through mechanical devices called emitters, located at selected points along the water delivery line. The different types of localized irrigation comprise: drip, micro-jet, also known as jet spray, and micro-sprinkler irrigation. All localized irrigation systems consist of a pumping unit, a control head, main and sub-main pipes, laterals and emitters. Figure 1 presents a typical layout of a drip irrigation system for smallholders.

The filtered water, at times mixed with nutrients, moves through the system losing its pressure in the emitter from where it is discharged in small volumes. The movement of water through the soil is mostly by unsaturated flow.

Figure 1
Typical layout of a smallholder drip irrigation system



According to FAO (1984), drip irrigation was first used in glass houses in England in the late 1940s and in open fields in Israel in the 1950s. In the 1960s, the importance of drip irrigation grew with the development of cheap plastic pipes and fittings. It should be mentioned that buried clay pots, which can be considered as a form of localized irrigation, were used in Iran for the irrigation of trees long before the development of modern localized irrigation systems.

The early field work on modern drip irrigation systems was carried out under desert conditions and on sandy soils, where superior performance was demonstrated in relation to surface and sprinkler irrigation under these extreme conditions. After more than 20 years of research, trials and field use world wide, localized irrigation systems have proven to be the most efficient means of water distribution and application and an ideal way of supplying the plants with nutrients.

1.1. Advantages of localized irrigation

Many claims as to the advantages of localized irrigation have been and are still being made. Currently, the following advantages are recognized:

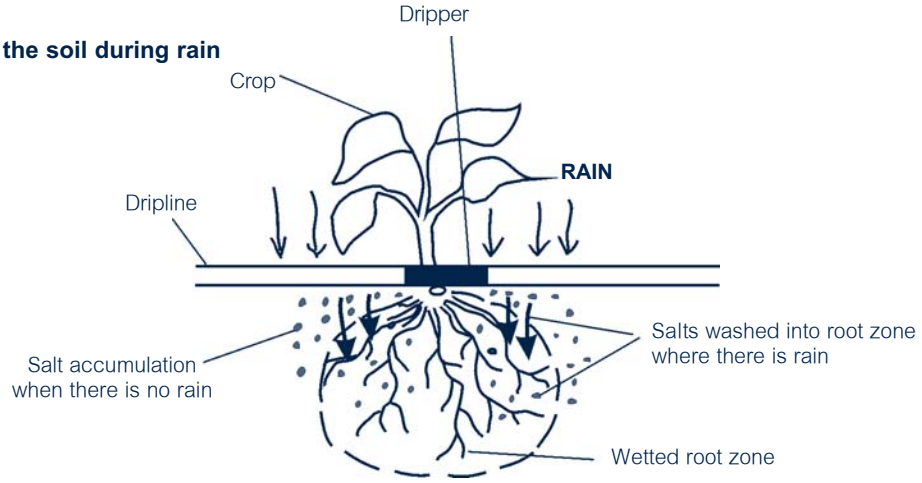
- The evaporative component of evapotranspiration is reduced, as only a limited area of the soil is wetted. This is more prevalent with young trees.
- The limited wetted area results in reduced weed growth.
- The slow rate of water application improves the penetration of water into problematic soils.
- The higher degree of inbuilt management that localized irrigation offers reduces substantially deep percolation and runoff losses, thus attaining higher irrigation efficiencies. Consequently, localized irrigation is considered as a water-saving technology.
- The very frequent irrigation attainable through localized irrigation systems results in more diluted salts in the soil moisture solution and pushes (leaches) these salts to the sides of the wetted volume of the soil. Hence, water of higher salt content can be used with these systems.
- The moisture availability to the plant at low soil tension results in faster growth, higher yields and better quality.
- Since fertilizers can be injected into the system in a controlled manner, fertilizer losses can be substantially reduced under localized irrigation.
- The controlled water and fertilizer application, attainable with localized irrigation, makes these systems more environmentally and health friendly.

1.2. Disadvantages of localized irrigation

The major disadvantages of localized irrigation are:

- Localized systems are prone to clogging because of the very small aperture of the water emitting devices. Hence the need for proper filtration and, at times, chemigation.
- The movement of salts to the fringes of the wetted area of the soil may cause salinity problems through the leaching of salts by rain to the main root volume. This can be avoided if the system is turned on when it rains, especially when the amount of rain is not enough to leach the salts beyond the root zone depth. Figure 2 illustrates the flow of water from the dripper into the soil and the effect of rain on deposited salts.
- Rodents, dogs and other animals in search of water can damage the lateral lines.
- For crops of very high population density, the system may be uneconomic because of the large number of laterals and emitters required.

Figure 2
Salt movement in the soil during rain



Chapter 2
Preliminary design steps

The particular way of water movement in the soil under localized irrigation and the pattern of this movement means that the conventional ways of calculating irrigation and leaching requirements are less fully applicable. Irrigation and leaching requirement pertaining to localized irrigation and the preliminary design steps are discussed in this Chapter.

2.1. Crop water requirements

Estimating the reference crop evapotranspiration (ET_o), using the Penman-Monteith method, and the crop evapotranspiration (ET_{crop}), through the use of the appropriate crop factor K_c, have been covered in Module 4. Evapotranspiration is composed of the evaporation from the soil and the transpiration of the plant. Since under localized irrigation only a portion of the soil is wetted, the evaporation component of evapotranspiration can be reduced accordingly, using the appropriate ground cover reduction factor K_r.

For the design of surface and sprinkler irrigation systems: $ET_{crop} = ET_o \times K_c$

For the design of localized irrigation systems:

$$ET_{crop\text{-}loc} = ET_{crop} \times K_r$$

$$ET_{crop\text{-}loc} = ET_o \times K_c \times K_r$$

FAO (1984) provides the reduction factors suggested by various researchers in order to account for the reduction in evapotranspiration (Table 1).

Table 1

Values of K_r suggested by different authors (Source: FAO, 1984)

Ground cover (GC)(%)	Crop factor K_r according to:		
	Keller & Karmeli	Freeman & Garzoli	Decroix CTG REF
10	0.12	0.10	0.20
20	0.24	0.20	0.30
30	0.35	0.30	0.40
40	0.47	0.40	0.50
50	0.59	0.75	0.60
60	0.70	0.80	0.70
70	0.82	0.85	0.80
80	0.94	0.90	0.90
90	1.00	0.95	1.00
100	1.00	1.00	1.00

For design purposes, the estimated ET_{crop} must be multiplied by the K_r value that corresponds to a ground cover (GC) value of Table 1, usually 70-100% depending on the crop and its expected ground cover, so that the system can meet the crop water requirements when the crop is fully grown. A GC of 80% should be expected for mature trees.

Keller and Bliesner (1990) propose the following equation for estimating the daily $ET_{crop\text{-}loc}$ for localized irrigation systems:

Equation 1

$$T_d = U_d \times [0.1(P_d)^{0.5}]$$

Where:

T_d = estimated ET_{crop} at peak demand for localized irrigation

U_d = conventionally estimated peak ET_{crop}

P_d = percentage ground cover (%).

T_d and U_d are in mm/unit time, normally mm/day, mm/decade, mm/month or mm/season. The time period for T_d and U_d in Equation 1 should be the same.

Example 1

The peak crop water requirements for mature citrus trees are estimated to be 7.1 mm per day, using the modified Penman-Monteith method. The ground cover is estimated at 70%. Referring to Table 1, the suggested values of K_r are 0.82 based on Keller and Karmeli, 0.85 based on Freeman and Garzoli and 0.80 based on Decroix. What are the corresponding values of $ET_{crop\text{-}loc}$ for localized irrigation at peak demand?

Keller and Karmeli : $ET_{crop\text{-}loc} = 7.1 \times 0.82 = 5.8$ mm/day

Freeman and Garzoli : $ET_{crop\text{-}loc} = 7.1 \times 0.85 = 6.0$ mm/day

Decroix CTGREF : $ET_{crop\text{-}loc} = 7.1 \times 0.80 = 5.7$ mm/day

Using Equation 1, the $ET_{crop\text{-}loc}$ for localized irrigation of Example 1 would be:

Keller and Bliesner : T_d or $ET_{crop\text{-}loc} = 7.1 \times [0.1(70)^{0.5}] = 5.9$ mm/day

The above comparison shows that Freeman and Garzoli are the most conservative, followed closely by Keller and Bliesner. However, the differences between the different methods are small.

For the estimates of seasonal water requirements, the same approach should be followed on a month by month basis or a decade by decade (ten-day period) basis. In the case of mature trees, the ground cover remains the same throughout the year. For non-perennial crops, such as vegetables, both ET_{crop} and ground cover change on a decade by decade basis.

2.2. Irrigation requirements

FAO (1984) defines the net irrigation requirements (IR_n) as the depth or volume of water required for normal crop production over the whole cropped area, excluding contribution from other sources. The following equation is used:

Equation 2

$$IR_n = (ET_{crop} \times K_r) - R + LR$$

Where:

IR_n	=	net irrigation requirement
ET_{crop}	=	crop evapotranspiration
K_r	=	ground cover reduction factor
R	=	water received by plant from sources other than irrigation (for example rainfall)
LR	=	amount of water required for the leaching of salts

The next element that should be incorporated in the calculations, in order to derive the gross irrigation requirements, is the irrigation efficiency. The same reference defines the gross irrigation requirement (IR_g) as the depth or volume of irrigation water required over the whole cropped area minus contributions from other sources plus water losses and/or operational wastes. The following equation is used:

Equation 3

$$IR_g = \frac{ET_{crop} \times K_r}{E_a} - R + LR$$

Where:

E_a = field application efficiency

According to Rainbird International (1980), the following efficiencies should be used when the surface area wetted by one emitter does not exceed 60 cm in diameter:

Hot dry climate : $E_a = 0.85$

Moderate climate : $E_a = 0.90$

Humid climate : $E_a = 0.95$

According to FAO (1984), the irrigation efficiency is expressed by the following equation:

Equation 4

$$E_a = K_s \times EU$$

Where:

$$K_s = \frac{\text{Average water stored in root volume}}{\text{Average water applied}}$$

EU = Coefficient reflecting the uniformity of application

The same reference recognizes that the EU varies with the emitter characteristics and recommends that the design EU should not be less than 0.90. The following K_s values, depending on the soil type, are provided by the same reference:

Coarse sand or light topsoil with gravel subsoil : $K_s = 0.87$

Sand : $K_s = 0.91$

Silt : $K_s = 0.95$

Loam and clay : $K_s = 1.00$

Example 2

What would be the peak net and gross irrigation requirements for the citrus of Example 1, grown on silt soil, if applying a K_r of 0.85 (Freeman and Garzoli) and assuming no rainfall and a EU of 0.90?

Using Equation 2:

$IR_n = (7.1 \times 0.85) - 0 + LR = 6.04$ mm/day + LR

Using Equation 4:

$E_a = 0.95 \times 0.90 = 0.86$

Using Equation 3:

$$IRg = \frac{7.1 \times 0.85}{0.86} - 0 + LR = 7.02 \text{ mm/day} + LR$$

If the Rainbird International approach is used, E_a should be 0.85 for hot dry climate, which is very close to the 0.86 obtained in the above example.

2.3. Leaching requirements

Localized irrigation, by providing the means for light and frequent irrigation, keeps the salt concentration in the soil water to a minimum. This, combined with sufficient leaching, can keep the salt concentration in the soil water at almost the same level as the concentration in the irrigation water. This is why yields obtained with drip irrigation systems using poor quality water are considerably higher than those obtained with other irrigation methods.

For salinity management, data on the electrical conductivity of the irrigation water (EC_w) and the electrical conductivity of the soil saturation extract (EC_e) are needed. Keller and Bliesner (1990) extrapolated the basic data and equations of FAO (1985) in order to establish the maximum EC_e. They considered this point as the theoretical level of salinity that would reduce the yield to zero. They maintained the minimum EC_e values from FAO (1985). For drip irrigation, when the EC_w is less than or equal to $minEC_e$, no yield reduction should be expected ($Y_r = 1$) (Table 2.)

The first step is to establish the relative yield. If the EC_w is between the min EC_e and the average of the $maxEC_e$ and $minEC_e$ then:

Equation 5

$$Y_r = \frac{maxEC_e - EC_w}{maxEC_e - minEC_e}$$

Where:

Y_r	=	relative yield, which is expressed as the ratio of estimated reduced yield to the full potential
EC_w	=	electrical conductivity of irrigation water (dS/m or mmhos/cm)
$minEC_e$	=	electrical conductivity of the saturated soil extract that will not decrease the crop yield (dS/m or mmhos/cm)
$maxEC_e$	=	electrical conductivity of the saturated soil extract that will reduce the crop yield to zero (dS/m or mmhos/cm)

Table 2

Minimum and maximum values of EC_e for various crops (Source: Keller and Bliesner, 1990)

Crop	EC_e (dS/m)	
	Min	Max
Field Crops		
Cotton	7.7	27
Sugar beet	7.0	24
Sorghum	6.8	13
Soya bean	5.0	10
Sugarcane	1.7	19
Fruit and nut crops		
Date palm	4.0	32
Fig olive	2.7	14
Pomegranate	2.7	14
Grapefruit	1.8	8
Orange	1.7	8
Lemon	1.7	8
Apple, pear	1.7	8
Walnut	1.7	8
Peach	1.7	6.5
Vegetable Crops		
Zucchini squash	4.7	15
Beets	4.0	15
Broccoli	2.8	13.5
Tomato	2.5	12.5
Cucumber	2.5	10
Cantaloupe	2.2	16
Spinach	2.0	15
Cabbage	1.8	12
Potato	1.7	10

Crop	EC_e (dS/m)	
	Min	Max
Field Crops		
Corn	1.7	10
Flax	1.7	10
Broad bean	1.6	12
Cow pea	1.3	8.5
Bean	1.0	6.5
Fruit and nut crops		
Apricot	1.6	6
Grape	1.5	12
Almond	1.5	7
Plum	1.5	7
Blackberry	1.5	6
Boysenberry	1.5	6
Avocado	1.3	6
Raspberry	1.0	5.5
Strawberry	1.0	4
Vegetable Crops		
Sweet corn	1.7	10
Sweet potato	1.5	10.5
Pepper	1.5	8.5
Lettuce	1.3	9
Radish	1.2	9
Onion	1.2	7.5
Carrot	1.0	8
Turnip	0.9	12

Note: Minimum EC_e does not reduce yield
Maximum EC_e reduces yield to zero

Example 3

Assuming that the citrus (orange) orchard of Example 1 will be irrigated with water of EC_w = 2 dS/m, what would be the relative yield?

Using Equation 5 and the data from Table 2:

$$Y_r = \frac{8 - 2}{8 - 1.7} = 0.95$$

Therefore, the expected yield using this water for the irrigation of orange trees under a drip irrigation system would be 95% of what could be expected if the water had an EC_w value equal or less that the $minEC_e$ value.

In order to maintain the predicted yield from high frequency irrigation, estimated at 95% of the full potential yield, Keller and Bliesner (1990) propose the use of the following equation to estimate the leaching requirement ratio:

Equation 6

$$LR_t = \frac{EC_w}{2 \times [maxEC_e]}$$

Where:

LR_t = leaching requirement ratio under drip irrigation

EC_w = electrical conductivity of irrigation water (ds/m or mmhos/cm)

$maxEC_e$ = electrical conductivity of saturated soil extract that will reduce the crop yield to zero (dS/m or mmhos/cm)

The leaching requirements would then be calculated using Equation 7:

Equation 7

$$LR = LR_t \times (IR_n/E_a)$$

Example 4

What would be the gross irrigation requirement of Example 2, taking into consideration the leaching requirements?

Using Equation 6, the leaching ratio would be:

$$LR_1 = \frac{2}{2 \times [8]} = 0.13$$

Using Equation 7, the leaching requirements are calculated as follows:

LR = 0.13 x (7.1 x 0.85/0.86) = 0.91 mm/day

Therefore, the gross irrigation water requirement estimated earlier would have to be revised to incorporate the leaching requirements as follows:

IR_g = 7.02 + 0.91 = 7.93 mm/day

2.4. Percentage wetted area

The percentage wetted area (P_w) is the average horizontal area wetted within the top 30 cm of the crop root zone depth in relation to the total cropped area. Often the question of how many emitters per plant are required arises. This number will depend on the desirable percentage wetted area (P_w) and the area wetted by one emitter.

What would be the desirable P_w? Most engineers agree on a minimum of 33% and maximum of 67% for widely spaced crops. Keller and Bliesner (1990) present a relationship that may exist between the potential production and P_w. They suggest that P_w often approaches 100% for closely spaced crops with rows and drip laterals spaced less than 1.8 m apart. However, they do not provide recommendations for widely spaced crops, with rows and emitter laterals spaced more than 1.8 m apart.

Taking this, and experience from elsewhere, into consideration, a P_w of 50-60% for low rainfall areas and 40% for high rainfall areas is proposed for widely spaced crops. However, local experiences and data are always preferable in establishing the most economical P_w value.

The area wetted by an emitter (A_w), along a horizontal plane (30 cm below the soil surface), depends on the soil and topography, on the flow rate of the emitter and on the volume of irrigation water. Schwartzmass and Zur (1985) developed empirical equations to estimate the wetted depth and width. However, these equations may be of limited applicability as soils vary greatly. It is therefore advisable to carry out simple field tests in order to establish the A_w. Alternatively, if there is a localized system operating in a nearby field with similar soils, the wetted pattern could be checked there. In the absence of locally available data, Rainbird International (1980) recommends the use of the data presented in Table 3.

Table 3

Area wetted by one emitter depending on soil type (Source: Rainbird International, 1980)

Soil type	Area wetted by one emitter, A_w (m^2)
Sandy soils	0.5-2
Loam soils	2-6
Clay	6-15

Keller and Bliesner (1990) recommend the use of the data presented in Table 4, which are typical for a 4 lph (litres per hour) dripper.

Table 4

Estimated areas wetted by a 4 lph drip emitter operating under various field conditions (Source: Keller and Bliesner, 1990)

Soil or root depth and soil texture[1]	Degree of soil stratification[2] and equivalent wetted soil area[3] (m x m)		
	homogeneous	stratified	layered[4]
	S_e' x W	S_e' x W	S_e' x W
Depth 0.75 m:			
Coarse	0.4 x 0.5	0.6 x 0.8	0.9 x 1.1
Medium	0.7 x 0.9	1.0 x 1.2	1.2 x 1.5
Fine	0.9 x 1.1	1.2 x 1.5	1.5 x 1.8
Depth 1.50 m:			
Coarse	0.6 x 0.8	1.1 x 1.4	1.4 x 1.8
Medium	1.0 x 1.2	1.7 x 2.1	2.2 x 2.7
Fine	1.2 x 1.5	1.6 x 2.0	2.0 x 2.4

1) ***Coarse*** *includes coarse to medium sands;* ***medium*** *includes loamy sand to loam;* ***fine*** *includes sandy clay to loam to clay (if clays are cracked, treat like coarse to medium soils).*

2) *Almost all soils are stratified or layered.* ***Stratified*** *refers to relatively uniform texture but having some particle orientation or some compaction layering, which gives higher vertical than horizontal permeability.* ***Layered*** *refers to changes in texture with depth as well as particle orientation and moderate compaction.*

3) *W, the long area dimension, is equal to the wetted diameter; Se', the wetted area dimension, is equal to 0.8 x W.*

4) *For soils that have extreme layering and compaction that causes extensive stratification, the Se' and W may be as much as twice as large.*

2.5. Number of emitters per plant and emitter spacing

The number of the emitters required per plant is established as follows:

Equation 8

$$\text{Emitters per plant} = \frac{\text{Area per plant} \times P_w}{A_w}$$

Area per plant (m^2)

P_w = Percentage wetted area/100 (%/100)

A_w = Area wetted by one emitter (m^2)

Referring to Table 3, for loam soils the A_w could be 4 m^2 (2-6 m^2). Referring to Table 4, for layered silt soils (fine) the A_w could be between 2.7 m^2 (1.5 x 1.8) and 4.8 m^2 (2.0 x 2.4), if 4 lph emitters are used and the root zone depth is >1 metre.

Example 5

Assuming a tree spacing of 6 m x 6 m, a P_w of 50% and an A_w of 4 m^2 for loamy soils, what would be the number of emitters per plant?

Using Equation 8:

$$\text{Emitters per plant} = \frac{(6 \times 6) \times 0.6}{4} = 5.4$$

which means that 5 emitters per plant are required.

If, however, the citrus trees were in a desert climate, a P_w of 60% would have been advisable. Under those conditions the number of emitters would be:

$$\text{Emitters per plant} = \frac{(6 \times 6) \times 0.5}{4} = 5.4$$

which means that 6 emitters per plant are required.

Should these emitters be placed in one emitter line or two? The answer to this question depends on the spacing of the trees, the required P_w and the wetted diameter from one emitter for the soil under consideration. It should be pointed out that the soil type affects the water movement in the soil. As a rule, A_w is higher in fine textured soils than coarse textured soils. Likewise, soil compaction and stratification encourage higher horizontal water movement in the soil.

If using a single lateral, with emitters spaced along the lateral at equal distances, the emitter spacing (S_e) can be calculated using the following equation:

Equation 9

$$S_e = \frac{S_p}{N_p}$$

Where:

S_e = the distance between the emitters, which is the emitter spacing

S_p = distance between the plants within a row

N_p = number of emitters per plant

In Example 5, $N_p = 5$ and $S_p = 6$. Therefore, using Equation 9, $S_e = 6/5 = 1.2$ m.

Having established N_p, S_p and S_e, the percentage wetted area (P_w) should be checked to see if it is still within the recommended limit. This can be done using Equation 10:

Equation 10

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

Where:

W = wetted width or width of wetted strip along lateral with emitters (m)

S_r = distance between plant rows or row spacing (m)

The diameter of the wetted area can be calculated using Equation 11:

Equation 11

$$A_w = \frac{\pi \times D^2}{4}$$

Where:

A_w = area wetted by one emitter (m^2)

D = diameter of wetted area (m)

Since the area wetted by one emitter (A_w) has been estimated to be 4 m^2, rearranging Equation 11 and substituting the value $A_w = 4\ m^2$ gives a wetted diameter of:

$$D = \sqrt{[(4 \times A_w)/\pi]} = \sqrt{[(4 \times 4)/3.14]} = 2.26\ m$$

This is equivalent to the wetted width W in Equation 10.

By introducing different values in Equation 10, we can verify if $P_w = 50\%$, as originally envisaged:

$$P_w = \frac{100 \times 5 \times 1.2 \times 2.26}{6 \times 6} = 0.38 = 38\%$$

This means that the P_w that can be achieved from one line is not satisfactory. Increasing the number of emitters along the lateral will not change the P_w, as according to Equation 9, ($N_p \times S_e$) remains the same for a fixed S_p and therefore the P_w in Equation 10 also remains the same. Consequently, two emitter lines have to be used. In order to have uniform wetting between the two laterals, their spacing should not exceed 80% of the wetted diameter, which is 0.8 x 2.26 = 1.81 m. The total number of emitters per plant should be about the same as for one line. For uniformity purposes, we should have equal numbers of emitters on each line or lateral. As five emitters have to be used (Equation 8), the next closest total even number per plant will be six emitters or three emitters per line or lateral.

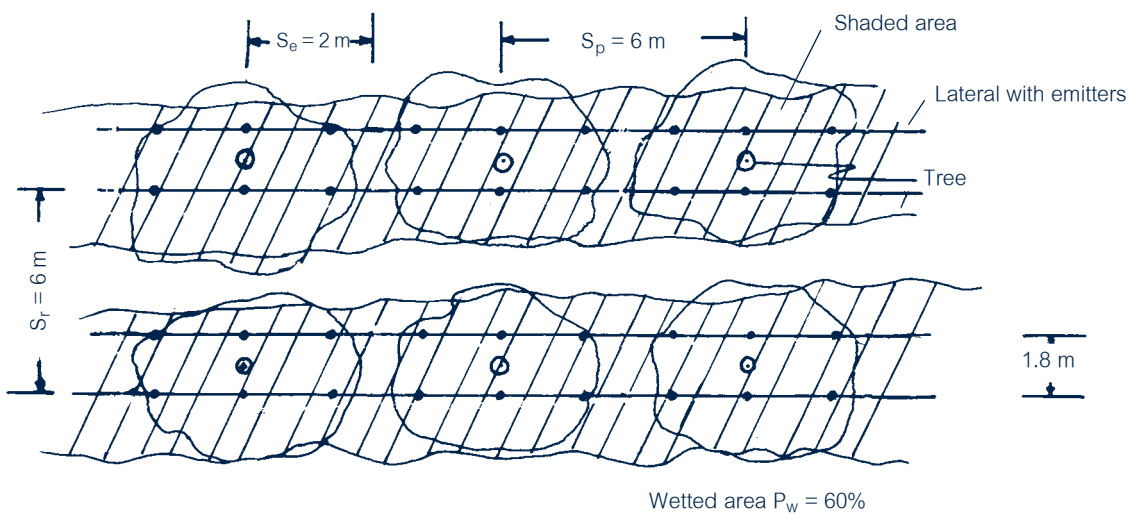
In this case the P_w will be:

$$P_w = \frac{100 \times 6 \times 2 \times 1.81}{6 \times 6} = 60\%$$

While this is more than the desired P_w of 50%, we will have to adopt it instead of the too low 38%.

Figure 3 shows the wetted area of this example, where $N_p = 5$, $S_e = 2.0$ m, $S_p = 6$ m and $S_r = 6$ m.

Figure 3
Plant and emitter distance and spacing



2.6. Irrigation frequency and duration

As a rule, localized systems provide the means for extremely frequent irrigation. This entails the use of very low soil moisture depletion levels. The following example demonstrates the process of calculating the irrigation frequency at peak demand.

Example 6

What is the irrigation frequency at peak demand, using the different data generated in the previous examples, as well as considering the following:

- *Effective rooting depth (RZD) = 1 m*
- *Available soil moisture = 120 mm/m*
- *Moisture depletion for a drip system = 20%*

Net irrigation requirement (IR_n) = 6.04 mm/day
Net irrigation requirement per tree = (6.04/1000) x 6 x 6 = 0.217 m^3 or 217 l/day per tree
Tree spacing = 6 x 6 m
Area of wetted soil = S_p x S_r x P_w = 6 x 6 x 0.6 = 21.6 m^2
Available soil moisture per tree = 120 mm/m = (120/1000) x 21.6 = 2.592 m^3 or 2 592 l/tree
Readily available moisture for drip system to be replenished by irrigation = 2592 x 0.2 = 518 l/tree
Irrigation frequency at peak demand = 518/217 = 2.39 days, say 2 days

Since irrigation will be done every two days, the net amount of water to be applied should be 2 x 217 = 434 litres per tree.

However, the design process can be simplified if we assume one day frequency at peak demand. This implies that the moisture depletion may be further reduced.

In order to maintain reasonable investment costs, drip irrigation systems should be designed to operate as long as possible, but exceeding neither 90% of the time available nor more than 22 hours per day (ASAE, 1990). This allows for a small safety margin for repairs, etc.

By applying the following equation, the duration of irrigation or length of operation time (T_a) at peak demand can be established:

Equation 12

$$T_a = \frac{IR_g}{N_p \times q}$$

Where:

T_a = duration of irrigation per day (hr)
IR_g = gross irrigation requirement (mm/day)
N_p = number of emitters per plant
q = emitter discharge (l/hr or lph)

A limited choice of emitter discharges is available on the market. The most common is the 4 lph. However, 2, 6 and 8 lph emitters are also available.

Example 7

Using, the results of Example 6, what is the irrigation duration per day?

The gross irrigation requirements calculated earlier were IR_g = 7.93 mm/day, which is 7.93 x 6 x 6 = 0.285 m^3 or 285 l/tree per day.

Using Equation 12, the daily hours of operation are calculated for the different emitters:

T_a for 8 lph drippers = 285/(6 x 8) = 5.94 hours
T_a for 6 lph drippers = 285/(6 x 6) = 7.92 hours
T_a for 4 lph drippers = 285/(6 x 4) = 11.88 hours

The above example shows that the 4 lph dripper calls for the operation of the system for 11.88 hours per day. This is well below the optimum. The 6 lph dripper will allow the irrigation of two sub-units per day, for the total of almost 16 hours per day (7.92 x 2 = 15.84). If the area allows for three equal irrigation units, then the 8 lph dripper would result in a more economical system, operating for almost 18 hours per day (5.94 x 3 = 17.82), as long as the higher flow would not result in runoff.

Another option would be to increase the average discharge of the 4 lph dripper by slightly increasing the pressure so that T_a = 11 hours. In this case q = 285/(11 x 6) = 4.32 lph. This option would result in the most economical solution as the system could operate for 22 hours per day by dividing the total area into two equal sub-units. Irrigation would be applied for 11 hours to each sub-unit.

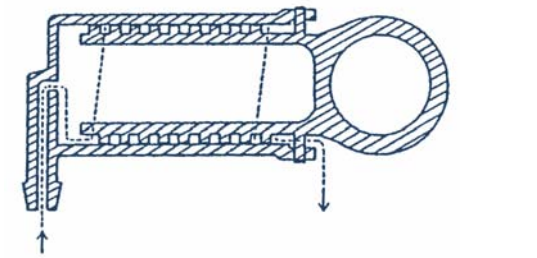
2.7. Emitter selection

The selection process is not a matter of following a checklist, as one decision will change the assumptions used in making other decisions. A combination of objective and subjective judgements are used for the selection process.

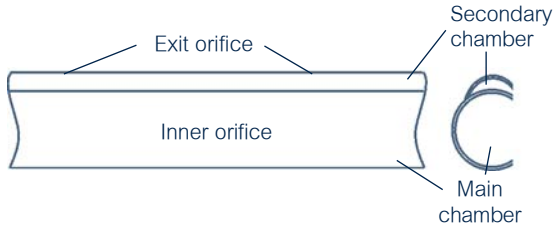
The following are some of the major emitter characteristics that affect the system efficiency and should all be taken into consideration during the emitter selection process:

- Emitter discharge exponent
- Discharge-pressure relationship to design specification
- Stability of discharge-pressure relationship over a long time
- Manufacturer coefficient of variation
- Range of operating pressure

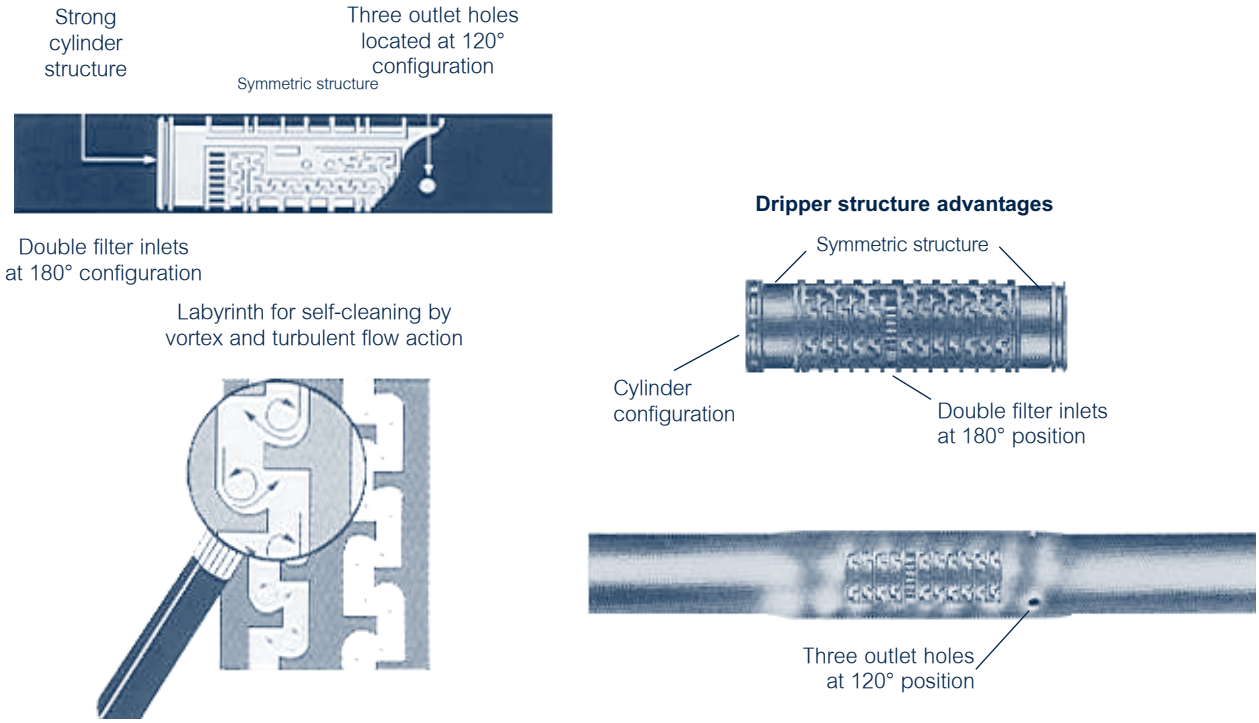
Figure 4
Different types of emitters



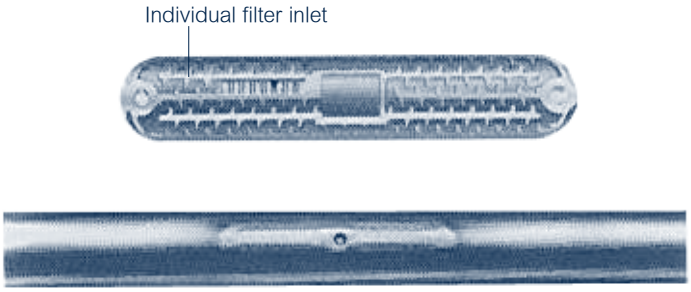
a. Long-path emitter



b. Orifice emitter



c. In-line labyrinth with vortex and filter inlets



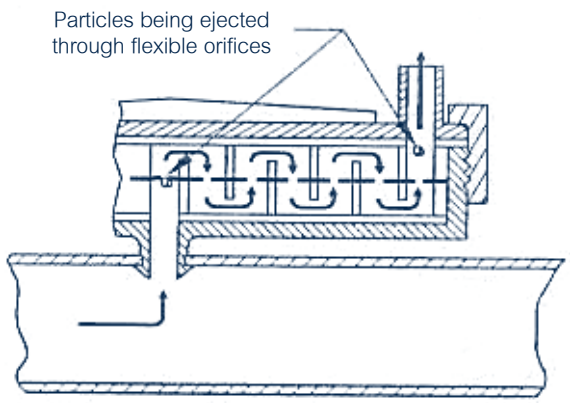
d. Labyrinth type molder emitters

- Susceptibility to clogging
- Type of emitter connection to lateral and head losses

2.7.1. Types of emitters

In terms of the mechanism applied to dissipate the pressure, emitters can be of the long-path type, the tortuous (labyrinth)- and short-path type, the orifice type and the vortex type. Figure 4 shows different types of emitters. Long-path emitters are characterized by laminar flow. Tortuous-path emitters have relatively long flow paths and some of them may look similar to ordinary long-path emitters. However, their path is shorter, the path cross-section is larger and the flow regime is almost fully turbulent. The flow regime in the orifice emitters is fully turbulent.

Figure 5
Cross-section of a continuous flushing emitter



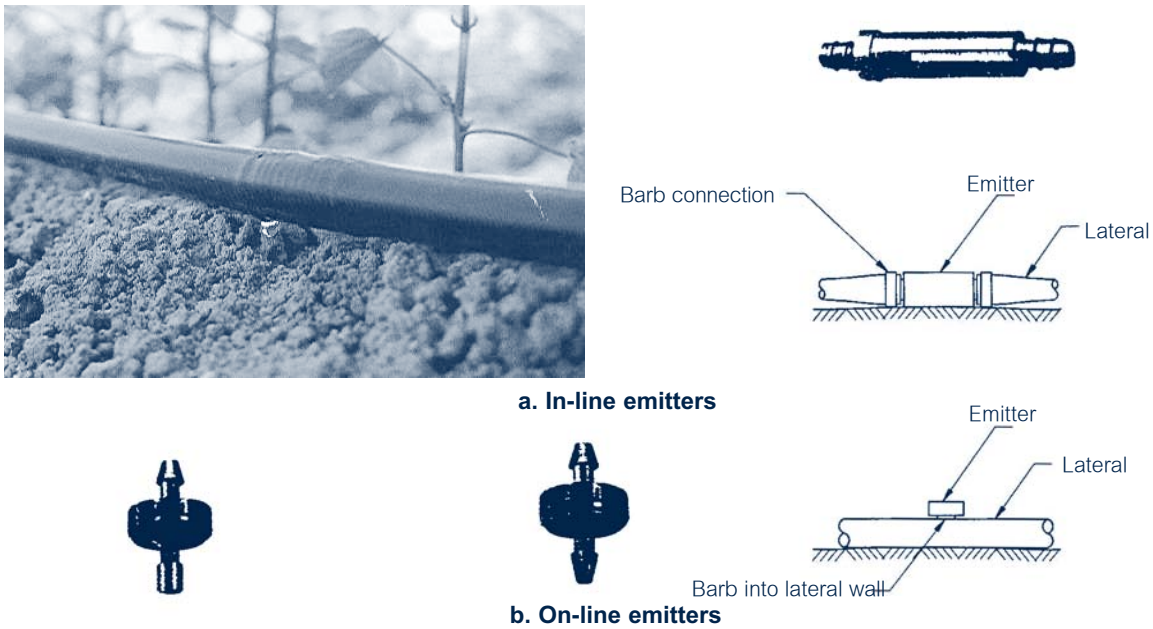
Vortex emitters have a flow path containing a round cell that causes circular flow. The circular motion of the water is achieved because water enters tangentially to the outer wall. This generates a fast rotational motion that creates the vortex in the centre. As a result of the vortex, the head losses are higher than in a simple orifice, permitting the use of larger openings and thereby making them less susceptible to clogging. A combination of vortex and tortuous path is common in some of the modern emitters.

Long-path, short-path and orifice emitters can be pressure-compensating, delivering almost constant flow over a wide range of pressures. This is achieved through the use of silicon membranes or other means that restrict the flow cross-section as the pressure increases. Unfortunately, the flexibility of the membranes becomes distorted over time.

Another characteristic of some emitters is their ability to flush. The two types of self-flushing emitters are on-off flushing and continuous flushing. On-off flushing emitters flush for only a few moments each time the system is started and again when it is turned off. Continuous flushing emitters are constructed so that they can eject large particles during operation. They do this by using relatively large-diameter flexible orifices in series to dissipate pressure (Figure 5).

Emitters are also classified as on-line or in-line depending on their connection to the lateral. Figure 6 shows in-line and on-line emitters.

Figure 6
In-line and on-line emitters



a. In-line emitters

b. On-line emitters

2.7.2. Discharge versus pressure relationship

The discharge versus pressure relationship of an emitter can be expressed by the following equation:

Equation 13

$$q = K_d \times H^x$$

Where:

q = emitter discharge (lph)
K_d = discharge coefficient that characterizes each emitter
H = emitter operating pressure (m)
x = emitter discharge exponent

The emitter discharge exponent (x) is a measure of the slope of the q (y-axis) versus H (x-axis) curve. The lower the value of x, the less the flow will be affected by pressure variations. For fully compensating emitters x = 0, which means that the flow is not affected at all by pressure variations. Fully turbulent emitters, like the orifice, have an x value of 0.5 and the vortex type emitters have an x of about 0.4. The exponent of tortuous-path emitters is between 0.5 and 0.7, while the exponent of long-path emitters is between 0.7 and 0.8.

In order to determine the K_d and x, the values of q and H would have to be determined at two different pressures and discharges. The discharge exponent would then be calculated using Equation 14:

Equation 14

$$x = \frac{\text{Log}\,[q_1 / q_2]}{\text{Log}\,[H_1 / H_2]}$$

Assume, for example, that q_1 = 3 lph at H_1 = 5 m and q_2 = 4 lph at H_2 = 10 m. Substituting these values in Equation 14 would give:

$$x = \frac{\text{Log}\,[3 / 4]}{\text{Log}\,[5 / 10]} = 0.42$$

K_d can be calculated as follows, by rearranging Equation 13 and introducing the value of x:

$$K_d = \frac{q}{H^x} = \frac{4}{10^{0.42}} = 1.52$$

The head and discharge relationship between two emitters with the same characteristics can be expressed with the following relationship:

Equation 15

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

Where:

q_a = average emitter flow rate obtainable under pressure H_a (lph)
q = emitter flow rate obtained under pressure H (lph)
x = emitter exponent

Example 8

From the manufacturer's catalogues, the following was derived for a 4 lph dripper: x = 0.42, q = 4 lph at H = 10 m. The desirable average flow rate for the most economical option, with the 4 lph emitter, is q_a = 4.32 lph (see section 2.6). What is the pressure required to deliver the 4.32 lph?

By substituting these values in Equation 15:

$$H_a = 10\left[\frac{4.32}{4}\right]^{1/0.42} = 10\,[1.08]^{2.28} = 12.0 \text{ m}$$

2.7.3. Manufacturer's coefficient of variation

ASAE (1990) defines the manufacturer's coefficient of variation (Cv) as a measure of the variability of discharge of a random sample of a given make, model and size of emitter, as provided by the manufacturer and before any field operations or aging has taken place. This is determined through a discharge test of a sample of 50 emitters under a set pressure at 20°C. The results obtained are incorporated in Equation 16 to obtain Cv:

Equation 16

$$Cv = \frac{\sqrt{[q_1^2 + q_2^2 \ldots + q_n^2 - nq_a^2] / [n - 1]}}{q_a}$$

or $Cv = sd / q_a$

Where:

Cv = manufacturer's coefficient of variation
$q_1, q_2 \ldots q_n$ = individual emitter discharge (lph)
q_a = average emitter discharge, $(q_1 + q_2 + \ldots q_n) / n$ (lph)
sd = estimated standard deviation of the discharge rates of the emitters (lph)
n = number of emitters in a sample

However, when more than one emitter is used per plant, the variation in the volume of water delivered to each plant is less, as one emitter may have a high and the other a low flow rate, thereby compensating each other. To account for this, an expression of the system coefficient of manufacturing variation was developed as expressed in Equation 17:

Equation 17

$$Cvs = Cv / \sqrt{n}$$

Where:

Cvs	=	system coefficient of manufacturing variation
Cv	=	manufacturer's coefficient of variation
n	=	number of emitters per plant

Table 5 provides the recommended classification of coefficient of manufacturing variation.

Table 5

Recommended classification of manufacturer's coefficient of variation Cv (Source: ASAE, 1990)

Emitter type	Cv Range	Classification
Point-source	< 0.05	excellent
	0.05 to 0.07	average
	0.07 to 0.11	marginal
	0.11 to 0.15	poor
	> 0.15	unacceptable
Line-source	< 0.10	good
	0.10 to 0.2	average
	> 0.2	marginal to unacceptable

Note: While some literature differentiates between 'point-source' and 'line-source', based on the distance between the emitters, in this Module the difference is based on the material used for the dripline or lateral. The thick wall material is considered as being 'point-source', while the tape type of material is considered as being 'line-source'.

2.7.4. Temperature versus discharge relationship

The temperature in a localized irrigation lateral is different from the air temperature. When the laterals are exposed to the sun, the temperature can rise substantially. The increase in temperature reduces the viscosity of water, thereby increasing the discharge of long-path emitters. For a long-path emitter with x = 0.8, the increase in discharge is 1% for every 2°C increase in temperature. For a tortuous-path emitter with x = 0.6 the increase in discharge is about 1% for every 4°C increase in temperature. As a rule, vortex type emitters tend to provide lower discharges with a rise in temperature. Solomon (1977) reports a temperature-discharge ratio TDR of 0.92 for 45°C and 0.88 for 65°C.

The rise in temperature can also cause dimensional changes in the flow passages of some emitters thus affecting the discharge.

In the case of pressure compensating emitters, the higher temperatures cause changes in the characteristics of the materials of which they are made.

2.7.5. Emitter connection loss

Keller and Karmeli (1975) reported that roughness coefficient values (C) ranging from 80-140 in test laterals were determined. The two predominant emitter connections are on-line and in-line (Figure 5). The in-line connection has a loss equivalent to the head loss of 0.22 m of the same lateral. In the case of the standard barb (5 mm x 5 mm) on-line emitter, the loss is equivalent to the head loss of 0.10 m of the same lateral for the 15 mm diameter and 0.17 m for the 12.5 mm diameter (Figure 7).

Figure 7

Emitter connection loss values for different barb sizes and lateral diameters (Source: Keller and Bliesner, 1990)

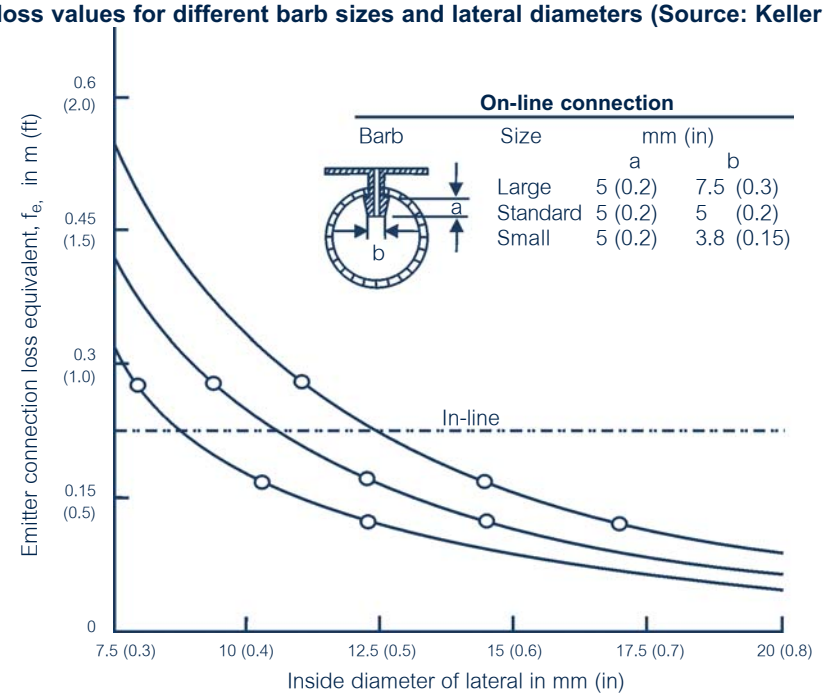


Table 6
Recommended ranges of design emission uniformities (Source: ASAE, 1990)

Emitter type	Spacing (m)	Topography	Slope (%)	EU Range (%)
Point-source on perennial crops	>4	Uniform steep	<2	90-95
		undulating	>2	85-90
Point-source on perennial or semi-permanent crops	<4	Uniform steep	<2	85-90
		undulating	>2	80-90
Line-source on annual or perennial crops	All	Uniform steep	<2	80-90
		undulating	>2	70-85

2.8. Design emission uniformity

ASAE (1990) suggests the following equation to estimate design emission uniformity in terms of Cv and pressure variation at the emitter:

Equation 18

$$EU = 100 \times (1.0 - 1.27Cv / \sqrt{N_p}) \times (q_m / q_a)$$

Where:

EU = the design emission uniformity (%)
N_p = the number of emitters per plant
Cv = the manufacturer's coefficient of variation
q_m = the minimum emitter discharge for minimum pressure in the sub-unit (lph)
q_a = the average or design emitter discharge for the sub-unit (lph)

The sub-unit is a unit of a system where the difference in the emitter operating pressure should not exceed the allowable pressure variation. It is a hydraulic unit.

The basis of this formula is the ratio of the minimum to the average emission rate. This concept was initially developed by Keller and Karmeli (1974). It is based on the principle that, because of the limited wetted area within the system, it is more important to be concerned about under-irrigation than over-irrigation. Table 6 provides the recommended values of EU.

2.9. Allowable pressure variation

According to ASAE (1990), pressure differences throughout the system or block or sub-unit should be maintained within such a range that the design emission uniformity (EU) is obtained.

In order to achieve this, Keller and Bliesner (1990) propose the following equation:

Equation 19

$$\Delta H_s = 2.5 \times [H_a - H_m]$$

Where:

ΔH_s = allowable pressure variation that will give an EU reasonably close to the desired design value (m)
H_a = pressure head that will give the q_a required to satisfy Equation 12 with the EU required in Equation 18
H_m = pressure head that will give the required q_m to satisfy EU in Equation 18

From the manufacturer's performance tables, the q_a is available at a pressure head H_a. However, H_m is also required in order for ΔH_s to be calculated.

By re-arranging Equation 18, the q_m can be determined:

$$q_m = \frac{EU \times q_a}{100 \times [1.0 - 1.27Cv / \sqrt{N_p}]}$$

After q_m is established, the H_m can be calculated from Equation 20, which is similar to Equation 15:

Equation 20

$$H_m = H_a \times \left[\frac{q_m}{q_a}\right]^{1/x}$$

Unfortunately, only serious manufacturers provide data on emitter manufacturers variability and emitter exponents. Engineers are therefore obliged to design without this information. In such cases the allowable pressure variation is estimated to 10% of the emitter operating pressure. Azenkot (1999) suggests that for emitters with exponent $x = 0.5$ the allowable pressure variability should be 20% of the operating pressure, limiting thus the flow variability among emitters to 10%.

Example 9

Assuming that an emitter with the following characteristics, provided by the manufacturer, is considered for use: q = 4 lph, H = 10 m, Cv = 0.07 and x = 0.42. What is the allowable pressure variation?

Through the application of Equation 15, q_a = 4.32 lph at H_a = 12 m is calculated. From Table 6, for citrus grown on fairly level ground, spaced at 6 x 6 m, the range of design EU is 90-95%. We can adopt 90% for our conditions.

As we have calculated earlier, the number of emitters per tree N_p = 6. The next step is to calculate the H_a and H_m corresponding respectively to the q_a and q_m that would provide the EU = 90%.

$$q_m = \frac{90 \times 4.32}{100\,[1.0 - 1.27 \times 0.07 / \sqrt{6}]} = 4.03 \text{ lph}$$

Using Equation 20:

$$H_m = 12\left[\frac{4.03}{4.32}\right]^{1/0.42} = 10.2 \text{ m}$$

The allowable pressure variation (ΔH_s) would then be:

$$\Delta H_s = 2.5\,[12 - 10.2\,] = 4.5 \text{ m}$$

This means that in the design process provisions should be made so that the head losses and elevation difference within each hydraulic unit do not exceed the 4.5 m.

If it was opted to aim for a higher EU value (95%), then the ΔH_s would be small:

$$q_m = \frac{95 \times 4.32}{100\,[1.0 - 1.27 \times 0.07 / \sqrt{6}]} = 4.26 \text{ lph}$$

$$H_m = 12\left[\frac{4.26}{4.32}\right]^{1/0.42} = 11.6 \text{ m}$$

and therefore:

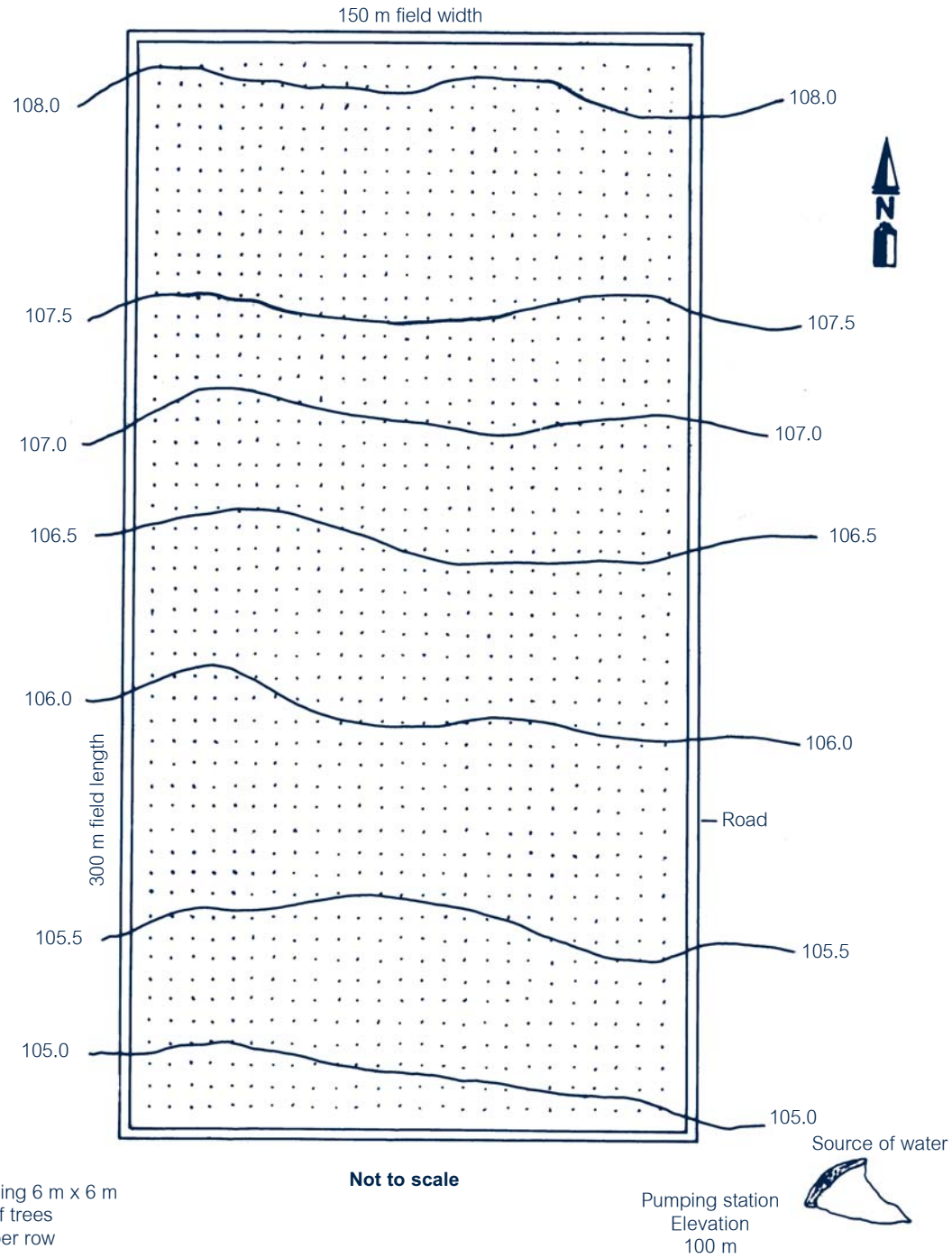
$$\Delta H_s = 2.5\,[12 - 11.6\,] = 1.0 \text{ m}$$

Chapter 3

Final design steps for a point-source drip irrigation system for an individual commercial farm

This chapter covers the final design steps for a citrus orchard under drip irrigation for an individual commercial farm. Figure 8 presents a contour map of the proposed area for irrigation dimensioned at 300 m x 150 m.

Figure 8
Layout of a citrus orchard for an individual farmer



Assuming that the 4 lph dripper (operating at H_a = 12 m to deliver q_a = 4.32 lph) is used, and taking into consideration the daily irrigation frequency, the total area should be irrigated in two shifts per day. Hence a layout using the map of Figure 8 (4.5 ha) should be prepared, keeping in mind that each shift requires its individual control.

There are several options for the layout. One option is to provide a line running from south to north along the eastern boundary of the plot so that it feeds manifolds parallel to it. The manifolds in turn would supply the laterals or driplines running west along the whole width of the field. This option utilizes long laterals. Another option is to provide a line running from south to north along the middle of the field and supplying manifolds parallel to it. In this case shorter laterals would be used. The manifolds will operate independent of each other at a time (one per shift). Two driplines will be provided for each line of trees. Each citrus tree will be provided with 6 drippers, 3 per lateral.

Looking at the layout of Figure 8, let us try the option where laterals run the full width of the field going westwards. Along the length of the field, measuring 300 m, we can fit 50 rows of trees and along the width of the field, measuring 150 m, we can fit 25 trees. Each row will start at half of the tree spacing (3 m) away from the edge of the field. The laterals or driplines will run along the length of the width of the field and along the direction of the contours.

3.1. Pipe size determination

In order to achieve the high degree of uniformity (90%), the allowable pressure variation within a hydraulic unit should not exceed ΔH_s = 4.5 m (see Example 9). A hydraulic unit is a sub-unit with an inlet pressure regulator beyond which no other pressure regulator is required. In our example, the dripper operating pressure H_a, which will satisfy the EU conditions, is 12 m or 120 kPa.

3.1.1. Laterals

The most commonly used dripline sizes are 12 mm and 16 mm inside diameter polyethylene. However, 20, 25, 32 and 40 mm inside diameter sizes are also available. Figure 9 can be used to calculate the friction losses in the various sizes of polyethylene pipe. This figure presents the head losses for class 4 (rated at 4 kg/cm^2) and class 6 (rated at 6 kg/cm^2) polyethylene pipe.

There are two driplines per tree. Based on the assumptions made earlier (Figure 3), each dripline will provide water to one side of the 25-tree row, through three 4 lph drippers per tree, discharging q_a = 4.32 lph each at H_a = 12 m. The flow in the drip hose would then be:

$$Q = 25 \times 4.32 \times 3 = 324 \text{ lph or } 0.324 \text{ m}^3/\text{h}$$

The pressure in the hose is not expected to exceed 40 m, since the drippers in this example will operate at 12 m and the ΔH_s = 4.5 m. Therefore, referring to the friction loss chart of Figure 9, the polyethylene pipe rated at 4 kg/cm^2 or 40 m can be used. If a 12 mm hose is used, the head loss for 0.324 m^3/hr is equal to 28%. Thus, the friction losses for the 148 (25 x 6 - 2) m length of lateral would be:

$$HL = 0.28 \times 148 = 41.44 \text{ m}$$

However, a drip hose is a multi-exit system, with the flow reducing along the way. Hence a reduction coefficient F should be used. Table 7 shows the values of coefficient F for different numbers of openings along the pipe.

Table 7

Reduction coefficient F for multiple outlet lines (Source: Keller and Karmeli, 1975)

Number of outlets	F value	Number of outlets	F value
1	1.000	14	0.387
2	0.639	16	0.382
3	0.535	18	0.379
4	0.486	20	0.376
5	0.457	25	0.371
6	0.435	30	0.368
8	0.415	40	0.364
10	0.402	50	0.361
12	0.394	100	0.356

In our example, each drip hose will carry 75 drippers (25 x 3). Using the F for 75 emitter points (0.358), the friction losses for the 12 mm hose would be:

$$HL = 0.28 \times 148 \times 0.358 = 14.84 \text{ m}$$

The friction loss is far beyond the 4.5 m allowable for a sub-unit, bearing in mind that this limit should also include friction losses in other pipes within the sub-unit and elevation differences. If the 16 mm hose is used, its friction loss would be:

$$HL = 0.049 \times 148 \times 0.358 = 2.60 \text{ m}$$

This is below the limit. However, as the friction losses charts are based on a friction coefficient C of 150, because of their smooth internal wall surface and since the introduction of the dripper increases the roughness, an increase in the friction losses should be introduced as mentioned earlier. For in-line emitters, this is equivalent to

Figure 9
Head losses in soft polyethylene pipes

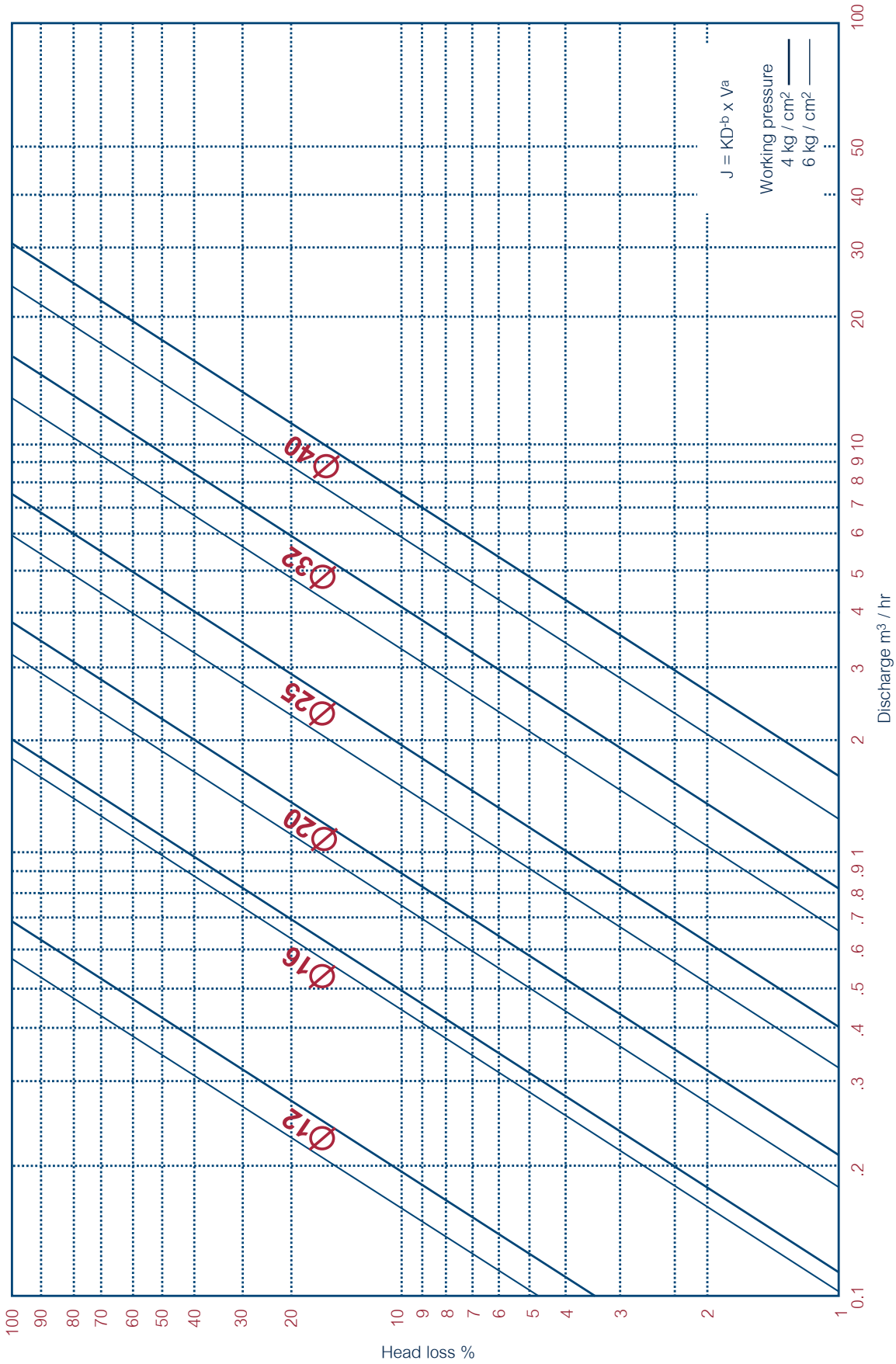
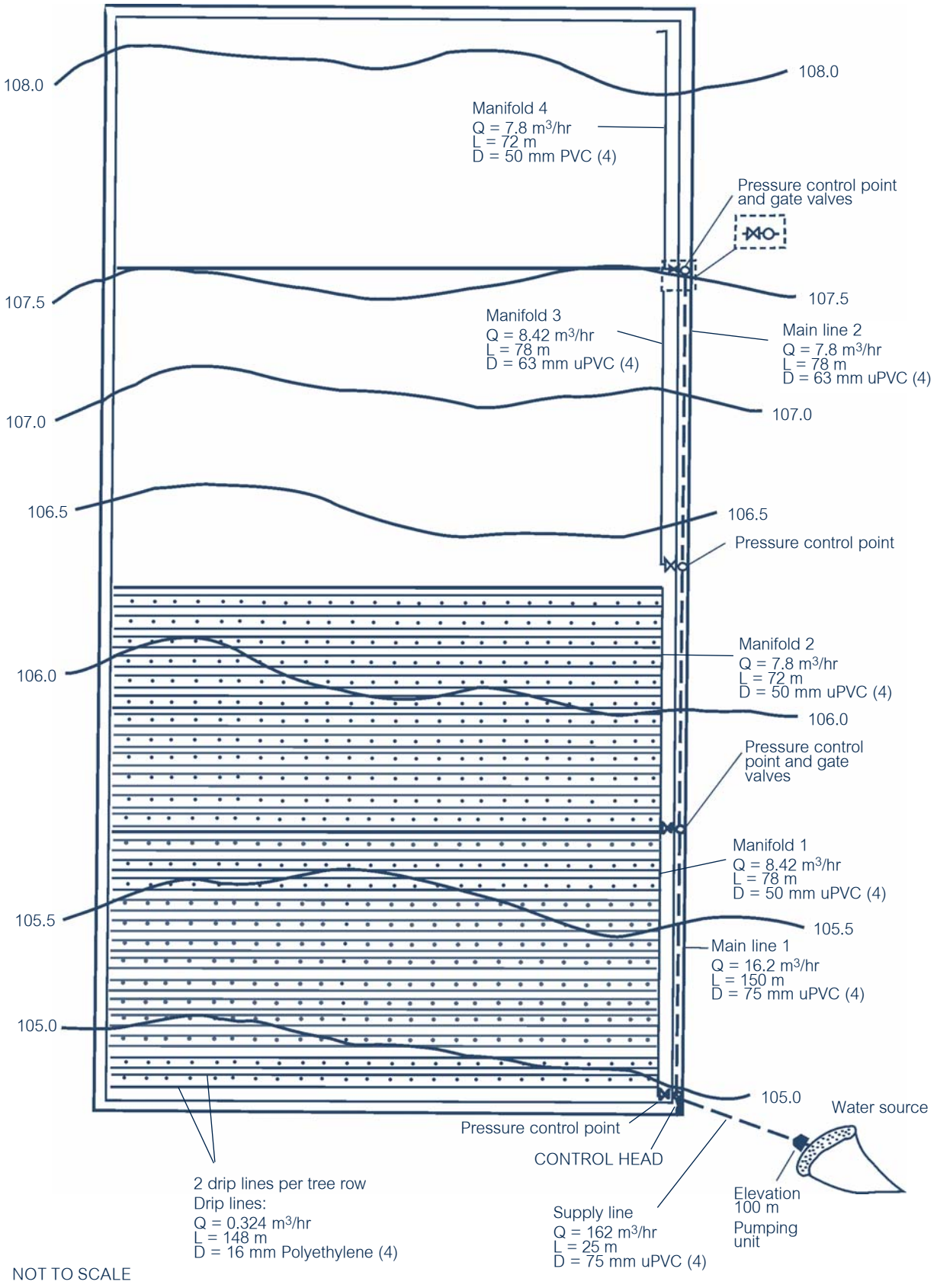


Figure 10

Layout of a drip system and pipe sizing for a citrus orchard for an individual farmer



0.22 m pipe length of 16 mm polyethylene pipe. For the standard barb (5 mm x 5 mm) on-line emitter, this is the equivalent of 0.1 m pipe length. Thus, for the 16 mm hose the friction losses would be:

HL = 2.60 + (0.049 x 0.22)
= 2.61 m for in-line emitters

and

HL = 2.60 + (0.049 x 0.1)
= 2.60 m for on-line emitters

Both cases are below the 4.5 m allowable pressure variation calculated earlier. The 16 mm pipe being chosen, then 4.5 - 2.61 = 1.89 m are left to cover the friction losses of the manifold and the difference in elevation from the pressure control point of the sub-unit.

3.1.2. Manifolds

A manifold is the portion of the pipe network between the mainline and the laterals (Figure 1). Referring to Figure 8, and taking into consideration that half of the area should be irrigated at a time in order to have the envisaged 22 hours daily operation, at least two manifolds would be required. However, the difference in elevation between the inlet of each manifold and the highest point in its command area is about 1.5 m, which is very close to the balance of 1.89 m calculated earlier. Such an arrangement would not accommodate the head losses in the manifold, unless it is oversized and therefore more expensive. Under these circumstances four manifolds are proposed, of which two will operate at a time, so that the total area is irrigated in 22 hours (Figure 10).

The first manifold will supply 13 rows of trees (26 laterals), the second manifold 12 rows of trees (24 laterals), the third 13 and the fourth 12 rows of trees. The first two manifolds will operate together (shift 1) and the last two will operate together (shift 2).

The head losses for the first and third manifolds, including 10% for the manifold-to-lateral connection (grommet take-offs) losses, would be calculated as follows:

Q = 0.324 x 26 = 8.42 m^3/hr
L = 13 x 6 = 78 m
D = 50 mm uPVC class 4 (Figure 11)
F = 0.370
HL = 0.037 x 78 x 0.370 x 1.1 = 1.18 m

The head losses for the second and fourth manifold would be:

Q = 0.324 x 24 = 7.8 m^3/hr
L = 12 x 6 = 72 m
D = 50 mm uPVC class 4
F = 0.372
HL = 0.032 x 72 x 0.372 x 1.1 = 0.94 m

Since the balance of allowable pressure variation is 1.89 m, the difference in elevation plus the head losses within the command area of each manifold should be checked for compliance to this limit.

	1st Manifold	2nd Manifold	3rd Manifold	4th Manifold
HL (m)	1.18	0.94	1.18	0.94
Difference in elevation (m)	0.70	0.70	1.20	0.70
Total HL (m)	1.88	1.64	2.38	1.64

While the total of HL and difference in elevation for the 1st and 2nd and the 4th manifolds is less than 1.89 m, the total for the 3rd manifold exceeds this limit, obliging an increase in the pipe size:

Q = 8.42 m^3/hr
L = 78 m
D = 63 mm uPVC class 4 (Figure 11)
F = 0.370
HL = 0.013 x 78 x 0.370 x 1.1 = 0.41 m

This will bring the total to 0.41 + 1.20 = 1.61 m, which is within the limit. Thus, the selected options are having the following losses:

	1st Manifold	2nd Manifold	3rd Manifold	4th Manifold
HL (m)	1.18	0.94	0.41	0.94
Difference in elevation (m)	0.70	0.70	1.20	0.70
Total HL (m)	1.88	1.64	1.61	1.64

3.1.3. Mainline

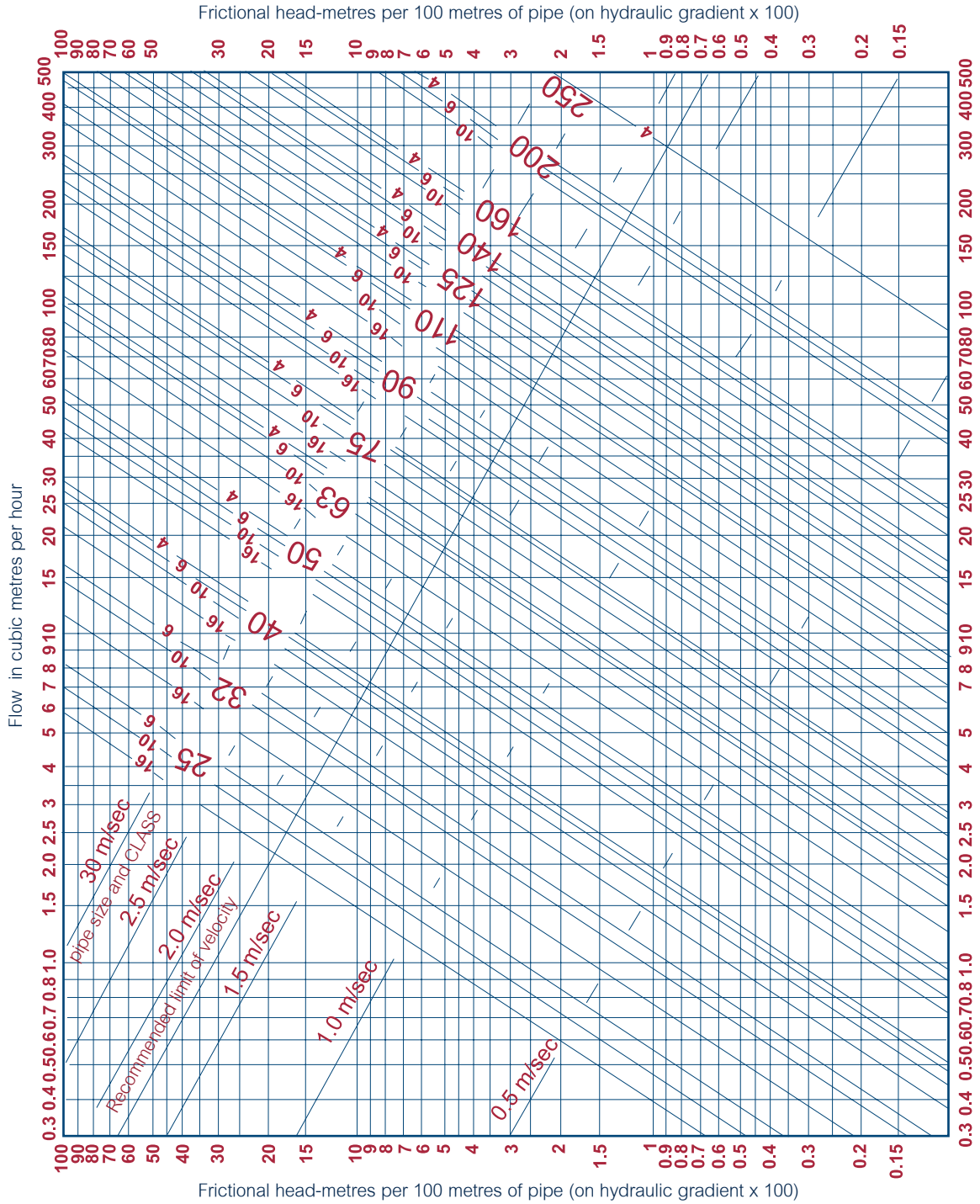
The mainline should be sized in such a way to allow for the separate use of the first two manifolds from the last two manifolds. Two cases will therefore be considered:

Last 2 manifolds in operation

Q1 = 8.42 + 7.78 = 16.20 m^3/hr
L1 = 25 x 6 = 150 m (distance between 1st and 3rd manifold)
D1 = 75 mm uPVC class 4
HL1 = 0.016 x 150 = 2.40 m
Q2 = 7.78 m^3/hr
L2 = 13 x 6 = 78 m (distance between 3rd and 4th manifold)
D2 = 63 mm uPVC class 4
HL2 = 0.012 x 78 = 0.94 m
HL total = 0.94 + 2.4 = 3.34 m

Figure 11

Friction loss chart for rigid PVC pressure pipes (Source: South African Bureau of Standards, 1976)



First two manifolds in operation

Since the first manifold offtake is at the beginning of the mainline, the flow in the mainline will be the flow required for the second manifold.

Q = 7.78 m^3/hr
L = 13 x 6 = 78 m (distance between 1st and 2nd manifold)
D = 75 mm uPVC class 4
HL = 0.005 x 78 = 0.39 m

Since the worst case is when the last two manifolds are in operation, the sizing of the mainline is based on this worst case.

3.1.4. Supply Line

The supply line connects the mainline to the pumping unit:

Q = 16.20 m^3/hr
L = 25 m
D = 75 m uPVC
HL = 0.016 x 25 = 0.40 m

3.2. Total head requirement

The total head requirements of the irrigation system are composed of:

- the suction lift
- friction losses in the supply line
- friction losses in the control head
- friction losses in the mainline
- friction losses in the manifold
- friction losses in the laterals or driplines
- the dripper's operating pressure
- the difference in elevation between the water level and the highest point on the land
- 10% for friction losses in fittings

Assuming that the suction lift is 2 m and the difference in elevation between the water level and the highest point in the field (Figure 10) is 8.2 m (108.2 - 100), the head losses in the control head must be calculated before the total head requirements can be compiled.

3.2.1. The irrigation control head

In summary, the control head is composed of the filtering system, the chemigation unit and the water meter. The head losses vary with the filtration requirements, which may use gravel and screen filters or only screen filters. Therefore, the head losses should be based on the equipment actually used. For our example, 7 m is considered sufficient to cover the filtration and chemigation needs.

3.2.2. Total dynamic head

The total head requirements are as follows:

Suction lift	2.00 m
Supply line	0.40 m
Control head	7.00 m
Mainline	3.34 m
Manifold	0.94 m
Laterals	2.61 m
Operating pressure	12.00 m
Subtotal	28.29 m
Fittings 10%	2.83 m
Difference in elevation	8.20 m
Total	**39.32 m**

This was based on the highest dynamic head. Considering the fact that the worst case for the manifolds is when the last two are in operation (see Section 3.1.3) and that of these last two manifolds the 4th one has the highest HL (0.94 m), then this is the one to be taken into consideration in the calculation of the total head requirements above.

3.3. Power requirements

The following equations can be applied to calculate the power requirements of the pump in kW and BHP respectively (see Module 5).

Equation 21a

$$\text{Power requirements in kW} = \frac{Q \times H}{360 \times e}$$

Equation 21b

$$\text{Power requirements in BHP} = \frac{Q \times H}{273 \times e}$$

In this example the pump efficiency is assumed to be 55%:

$$\text{Power requirements} = \frac{16.2 \times 39.32}{360 \times 0.55} = 3.2 \text{ kW}$$

or

$$\text{Power requirements} = \frac{16.2 \times 39.32}{273 \times 0.55} = 4.2 \text{ BHP}$$

Assuming a derating of 20%, as explained in Module 5, the power requirement would be:

Power requirements = 3.2 x 1.2 = 3.8 kW
Power requirements = 4.2 x 1.2 = 5.0 BHP

3.4. Bill of Quantities

After the detailed designs have been completed, relevant drawings should be prepared based on which the Bill of Quantities can be prepared. For details the reader is referred to Chapter 8.

Chapter 4
Design of a point-source drip irrigation system for smallholder farmers

In order to design a drip irrigation system for smallholder farmers, there is a need to ensure that each plot holder has a degree of individual responsibility for the use and maintenance of the irrigation equipment. This can be provided for by designing a system in which each farmer is responsible for their equipment at plot level, as in the case of the smallholder sprinkler example in Module 8. This scenario will promote a sense of ownership and responsibility. The rest of the system can be shared.

In this example, we shall design a drip irrigation system for 8 smallholder farmers on the same area as the one designed for an individual commercial farm in the previous chapter (Figure 8). Taking into consideration drains and roads of 4 m between the plots, each plot holder will have approximately 0.52 ha (72 m x 72 m) of the total of 4.5 ha. To maximize production and ensure quick returns from the drip irrigation system, we should consider irrigating high value crops such as horticultural crops. As a rule, crop rotation becomes critically important when horticultural crops are grown. Consequently, the designed system should be able to accommodate the spacing requirements of different crops. Very closely spaced crops such as onions, rape, carrots and others would require closely spaced laterals, especially at the initial stages of growth. Considering that about 40% of the cost of the system lies with the laterals, such an investment may prove uneconomic. This becomes more critical when soils are very light, limiting the lateral movement of the water. Therefore, while the design of this system will follow the same procedure as discussed earlier and will be based on the requirements of tomatoes, it will also provide for the needs of other crops, especially at their initial growth stages.

4.1. Crop water and irrigation requirements

For design purposes, a crop with the highest crop water requirements should be considered. Let us assume that tomatoes have the highest peak crop water requirements of 4.3 mm/day for the same area on which the individual commercial drip design was made and that they have a ground cover of 90% during the period of peak water demand.

Using a Freeman and Garzoli's K_r value of 0.95 (Table 1), the $ET_{crop\text{-}loc}$ of tomato for localized irrigation would be:

$$ET_{crop\text{-}loc} = 4.3 \times 0.95 = 4.09 \text{ mm/day}$$

The K_s for silt was determined to be 0.95 and the EU 0.9 (see Section 2.2). Using Equation 4, this gives an irrigation efficiency of:

$$E_a = 0.95 \times 0.9 = 0.86$$

4.2. Leaching requirements

It was stated earlier that the EC_w of the irrigation water is 2 dS/m (Example 3). The $minEC_e$ which would cause no yield reduction in tomatoes, is 2.5 dS/m (Table 2). Therefore, the irrigation water would not reduce the expected yield. However, in order to maintain the predicted yield from high frequency irrigation, estimated at 100% of the full yield potential, and to avoid long term accumulation of salts in the soil, the leaching requirement ratio and the leaching requirement should be calculated using Equation 6 and 7 respectively:

$$LR_1 = \frac{2}{2 \times [12.5]} = 0.08 \text{ mm/day}$$

and

$$LR = 0.08 \times (4.09 / 0.86) = 0.38 \text{ mm/day}$$

The gross irrigation requirements IR_g can be obtained using Equation 3 as follows:

$$IR_g = (4.09 / 0.86) + 0.38 = 5.14 \text{ mm/day}$$

4.3. Percentage wetted area

The recommended spacing of tomatoes is 0.9 m between rows and 0.3 m within rows. Earlier on it was mentioned that P_w approaches 100% for closely spaced crops with rows and driplines spaced less than 1.8 m (see Section 2.4).

4.4. Number of emitters per plant

Assuming that we use a lateral for every two rows of tomatoes and one emitter supplying two plants, what would be the P_w? Looking at Table 4 for shallow root zone depth and fine layered soils, W = 1.8 m. Through the application of Equation 10, P_w is derived as follows:

$$P_w = \frac{100 \times 0.5 \times 0.3 \times 1.8}{0.3 \times 0.9} = 100\%$$

Thus, if one lateral with emitters spaced at 0.3 m is used to serve two tomato lines the P_w would be 100%. Where tomatoes are grown in beds, the same P_w of 100% is achievable, if the spacing of the laterals is maintained at 1.8 m or less.

4.5. Irrigation frequency and duration

Using the same approach adopted in Example 6, the irrigation frequency at peak demand is calculated as follows:

Net irrigation requirement (IR_n)
= 4.09 mm/day or 4.09 x 0.9 x 0.3
= 1.10 l/day per plant

Crop spacing
= 0.9 m x 0.3 m

Effective rooting depth (RZD)
= 0.5 m

Area of wetted soil
= S_p x S_r x P_w
= 0.9 x 0.3 x 1
= 0.27 m^2

Available soil moisture
= 120mm/m or 120/1000 x 0.5 x 0.27 x 1000
= 16.2 l/plant

Moisture depletion for drip irrigation system
= 20%

Readily available moisture to be replenished by irrigation
= 16.2 x 0.2
= 3.24 litres per plant

Irrigation frequency at peak demand
= 3.24/1.10
= 2.95 days, say 3 days

Under drip irrigation, water is applied when the moisture tension in the soil reaches 15-20 cb for vegetables, which means that irrigation is practiced just below field capacity. Hence, daily irrigation will be adopted for the designs.

For vegetables, where the very frequent irrigation requires frequent opening and closing of valves, it is advisable that the system operates during daytime only. Alternatively, automation can be adopted. However, this is not advisable for smallholders in view of its sophistication.

The gross irrigation requirements during the peak demand period are 5.14 mm or 5.14 x 0.9 x 0.3 = 1.39 l/day per plant. One emitter supplies two plants. Using Equation 12, the length of operation time is calculated as follows:

T_a = 1.39/(8x0.5) = 0.35 hours for the 8 lph emitter
T_a = 1.39/(6x0.5) = 0.46 hours for the 6 lph emitter
T_a = 1.39/(4x0.5) = 0.70 hours for the 4 lph emitter
T_a = 1.39/(2x0.5) = 1.40 hours for the 2 lph emitter

4.6. Emitter selection

Over the last 10 years, vegetables under drip irrigation have been grown on beds of 1.2 m width with 0.3 m wide paths between beds. This arrangement facilitates better movement in carrying out different cultural practices, especially harvesting. Also, the soil fertility is built up where the crop is grown and soil compaction reduced substantially. This design will therefore be based on this approach. For crop rotation purposes each farmer's plot has been divided into four sub-units, allowing the farmer to irrigate up to four different crops per season. Assuming an operation of 12 hours per day and the irrigation of one sub-unit per farmer at a time, the different emitter flow rates will be tested to find the best fit to this case.

In addition to this option, a number of other alternatives will be considered as presented in Table 8 and Figure 12, based on a spacing of 1.5 m between driplines and 0.3 m between the emitters along the lateral:

- Alternatives 1, 2 and 3: The farmer's plot of 72 m x 72 m is divided into four sub-units. The width of each sub-unit is (72/4) = 18 m and the length 72 m. Each sub-unit has (18/1.5) = 12 driplines or laterals. Each lateral has (72/0.3) = 240 emitters.
- Alternatives 4, 5 and 6: The farmer's plot of 72 m x 72 m is divided into three sub-units. The width of each sub-unit is (72/3) = 24 m and the length 72 m. Each sub-unit has (24/1.5) = 16 driplines or laterals. Each lateral has (72/0.3) = 240 emitters.
- Alternatives 7, 8 and 9: The farmer's plot of 72 m x 72 m is divided into six sub-units. The width of each sub-unit is (72/6) = 12 m and the length 72 m. Each sub-unit has (12/1.5) = 8 driplines or laterals. Each lateral has (72/0.3) = 240 emitters.

Three of the nine alternatives considered are close to the 12 hour per day operation of the system at peak demand (Table 8). These are:

Alternative 2:
four farmers irrigating at the same time with 2 lph emitters

Alternative 3:
two farmers irrigating at the same time with 4 lph emitters

Alternative 9:
two farmers irrigating at the same time with 6 lph emitters

For all three alternatives, the daily operation is 11.2 hours and the system capacity 23 m^3/hr. Regarding ease of operation it is preferable to have half the farmers irrigating simultaneously and not one quarter. This favours Alternative 2 with the 2 lph emitters. Also looking at the

Figure 12

Alternative subdivisions of the smallholder plots (four, three and six sub-units per plot)

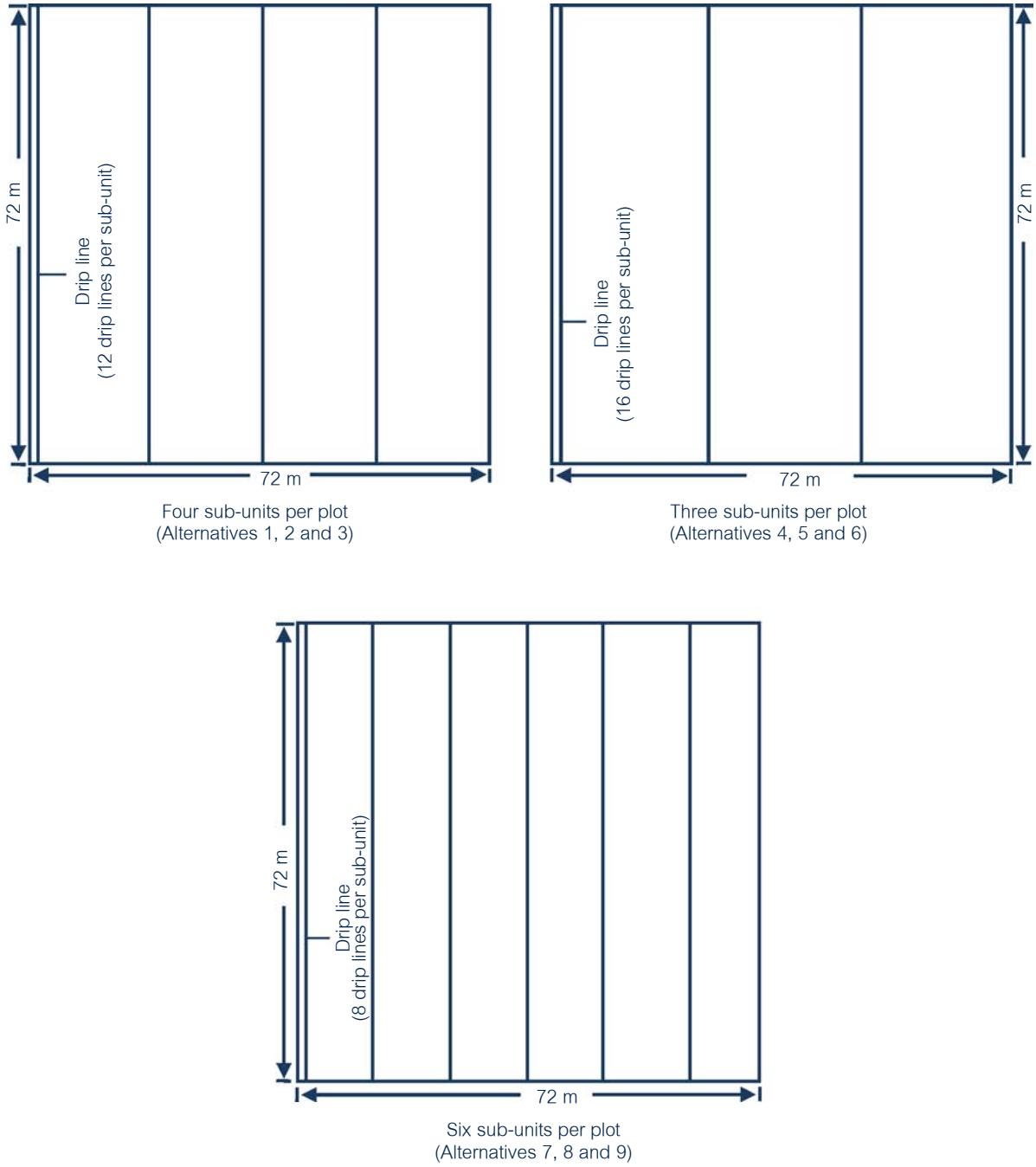


Table 8

Alternative options for the emitter selection for the point-source drip irrigation system

Alternative	No. of sub-units per farmer's plot (1)	Width of one sub-unit (m) (2)=72/(1)	No. of laterals per sub-unit (3)=(2)/1.5	No. of emitters per lateral (4)=72/0.3	No. of emitters per sub-unit (5)=(3)x(4)	Emitter flow (lph) (6)	No. of rotation shifts (7)	Duration of each shift T_a (hrs) (8)	Daily at operation peak (hrs) (9)=(1)x(7)x(8)	No. of sub-units operating at the same time (10)*	System capacity (m^3/hr) (11)=(5)x(6)x(10)
1. • Four sub-units per farmer	4	18	12	240	2 880	8	1	0.35	1.40	8	184
• All farmers irrigate at the	4	18	12	240	2 880	6	1	0.46	1.84	8	138
same time	4	18	12	240	2 880	4	1	0.70	2.80	8	92
• Each farmer irrigates one	4	18	12	240	2 880	2	1	1.40	5.60	8	46
sub-unit at a time											
2. • Four sub-units per farmer	4	18	12	240	2 880	8	2	0.35	2.80	4	92
• Four farmers irrigate at the	4	18	12	240	2 880	6	2	0.46	3.68	4	69
same time	4	18	12	240	2 880	4	2	0.70	5.60	4	46
• Each farmer irrigates one	4	18	12	240	2 880	2	2	1.40	11.2	4	23
sub-unit at a time											
3. • Four sub-units per farmer	4	18	12	240	2 880	8	4	0.35	5.60	2	46
• Two farmers irrigate at the	4	18	12	240	2 880	6	4	0.46	7.36	2	35
same time	4	18	12	240	2 880	4	4	0.70	11.2	2	23
• Each farmer irrigates one	4	18	12	240	2 880	2	4	1.40	22.4	2	12
sub-unit at a time											
4. • Three sub-units per farmer	3	24	16	240	3 840	8	1	0.35	1.05	8	246
• All farmers irrigate at the	3	24	16	240	3 840	6	1	0.46	1.38	8	184
same time	3	24	16	240	3 840	4	1	0.70	2.10	8	123
• Each farmer irrigates one	3	24	16	240	3 840	2	1	1.40	4.60	8	61
sub-unit at a time											
5. • Three sub-units per farmer	3	24	16	240	3 840	8	2	0.35	2.10	4	123
• Four farmers irrigate at the	3	24	16	240	3 840	6	2	0.46	2.76	4	92
same time	3	24	16	240	3 840	4	2	0.70	4.20	4	61
• Each farmer irrigates one	3	24	16	240	3 840	2	2	1.40	8.40	4	31
sub-unit at a time											

6. • Three sub-units per farmer	3	24	16	240	3 840	8	4	0.35	4.20	2	61
• Two farmers irrigate at the	3	24	16	240	3 840	6	4	0.46	5.52	2	46
same time	3	24	16	240	3 840	4	4	0.70	8.40	2	31
• Each farmer irrigates one	3	24	16	240	3 840	2	4	1.40	16.8	2	15
sub-unit at a time											
7. • Six sub-units per farmer	6	12	8	240	1 920	8	1	0.35	2.10	8	123
• All farmers irrigate at the	6	12	8	240	1 920	6	1	0.46	2.76	8	92
same time	6	12	8	240	1 920	4	1	0.70	4.20	8	61
• Each farmer irrigates one	6	12	8	240	1 920	2	1	1.40	8.40	8	31
sub-unit at a time											
8. • Six sub-units per farmer	6	12	8	240	1 920	8	2	0.35	4.20	4	61
• Four farmers irrigate at the	6	12	8	240	1 920	6	2	0.46	5.52	4	46
same time	6	12	8	240	1 920	4	2	0.70	8.40	4	31
• Each farmer irrigates one	6	12	8	240	1 920	2	2	1.40	16.8	4	15
sub-unit at a time											
9. • Six sub-units per farmer	6	12	8	240	1 920	8	4	0.35	8.40	2	31
• Two farmers irrigate at the	6	12	8	240	1 920	6	4	0.46	11.2	2	23
same time	6	12	8	240	1 920	4	4	0.70	16.8	2	15
• Each farmer irrigates one	6	12	8	240	1 920	2	4	1.40	33.6	2	8
sub-unit at a time											

* *(10) = number of farmers irrigating at the same time*

potential flow in the lateral, the same option is in an advantageous position when it comes to lateral pipe size and head losses since it has the lowest discharge:

Alternative 2: 240 x 2 = 480 lph = 0.48 m^3/hr
Alternative 3: 240 x 4 = 960 lph = 0.96 m^3/hr
Alternative 9: 240 x 6 = 1 440 lph = 1.44 m^3/hr

Furthermore, most of the modern driplines with built-in emitters come with around 2 lph emission points. Ideally, it would be preferable for all farmers to irrigate at the same time. It would make the operation easier. This would favour alternative 7 with the 2 lph dripper. However, the degree of system utilization would be reduced to 8.4 hours of operation per day and the system capacity would be increased to 31 m^3/hr, increasing the overall capital cost.

Another consideration is the additional number of offtake points required to control the flow in each of the six plots, which further increases the cost of the system. The choice between Alternative 2 and Alternative 7 will therefore be based on the required degree of flexibility and the capital availability. Irrespective of the selected alternative, the desirable emitter will have the following characteristics:

q_a = 2 lph, H_a = 10m, Cv = 0.03 and x = 0.5

Based on Table 4, a Cv of less than 0.05 is considered as excellent. This is the reason for selecting an emitter with Cv = 0.03. With respect to the emitter discharge exponent x, turbulent flow is always preferable, hence adoption of x = 0.5.

4.7. Allowable pressure variation

Referring to Equation 19, H_a and H_m should be known before the allowable pressure variation is calculated. While H_a is provided by the manufacturer, together with the corresponding q_a, the q_m to satisfy the chosen EU and the corresponding H_m should be calculated.

From Table 6, the recommended EU for a point-source emitter, where the emitter is spaced less than 4 m on uniform topography with slopes of <2%, is 85-90%. In our example, let us adopt an EU of 90%. Using the rearranged Equation 18, the minimum allowable discharge q_m can be calculated as follows:

$$q_m = \frac{90 \times 2}{100 \times [1.0 - 1.27(0.03 / \sqrt{0.5})]} = \frac{180}{94.6} = 1.90 \text{ lph}$$

Using Equation 20:

$$H_m = 10 \left[\frac{1.90}{2} \right]^{1/0.5} = 9.03 \text{ m}$$

Therefore, using Equation 19:

$$\Delta H_s = 2.5(10 - 9.03) = 2.43 \text{ m}$$

Thus, the allowable pressure variation within a hydraulic unit should not exceed 2.43 m.

4.8. Layout of a drip system for the eight smallholder farmers

Assuming that Alternative 2 was adopted, a layout should be prepared as shown in Figure 13, taking into account the fact that there are two rotational irrigation shifts per day (Table 8). It is advisable to provide a road running along the middle of the field, in order to improve access to the individual farmers' plots. If a 4 m wide road is provided with two drains of 1 m each, then each plot could be 72 m (= (150 - 2)/2) wide.

The major disadvantage of this layout is that the single lateral per bed cannot provide sufficient lateral water movement required for closely spaced crops such as onion and rape. To accommodate their needs during the first month of their growth, each lateral should be moved from the centre to one side of the bed and then moved across to the other side of the bed. However, after the first month of growth for most soils the roots would have grown substantially, and one lateral per bed operating from the middle can satisfy the crop requirement.

4.9. Pipe size determination

Alternative 2 provides for four sub-units per plot, each sub-unit operating independently of each other. It would therefore be necessary to provide a manifold for each sub-unit as shown in Figure 13.

4.9.1. Laterals

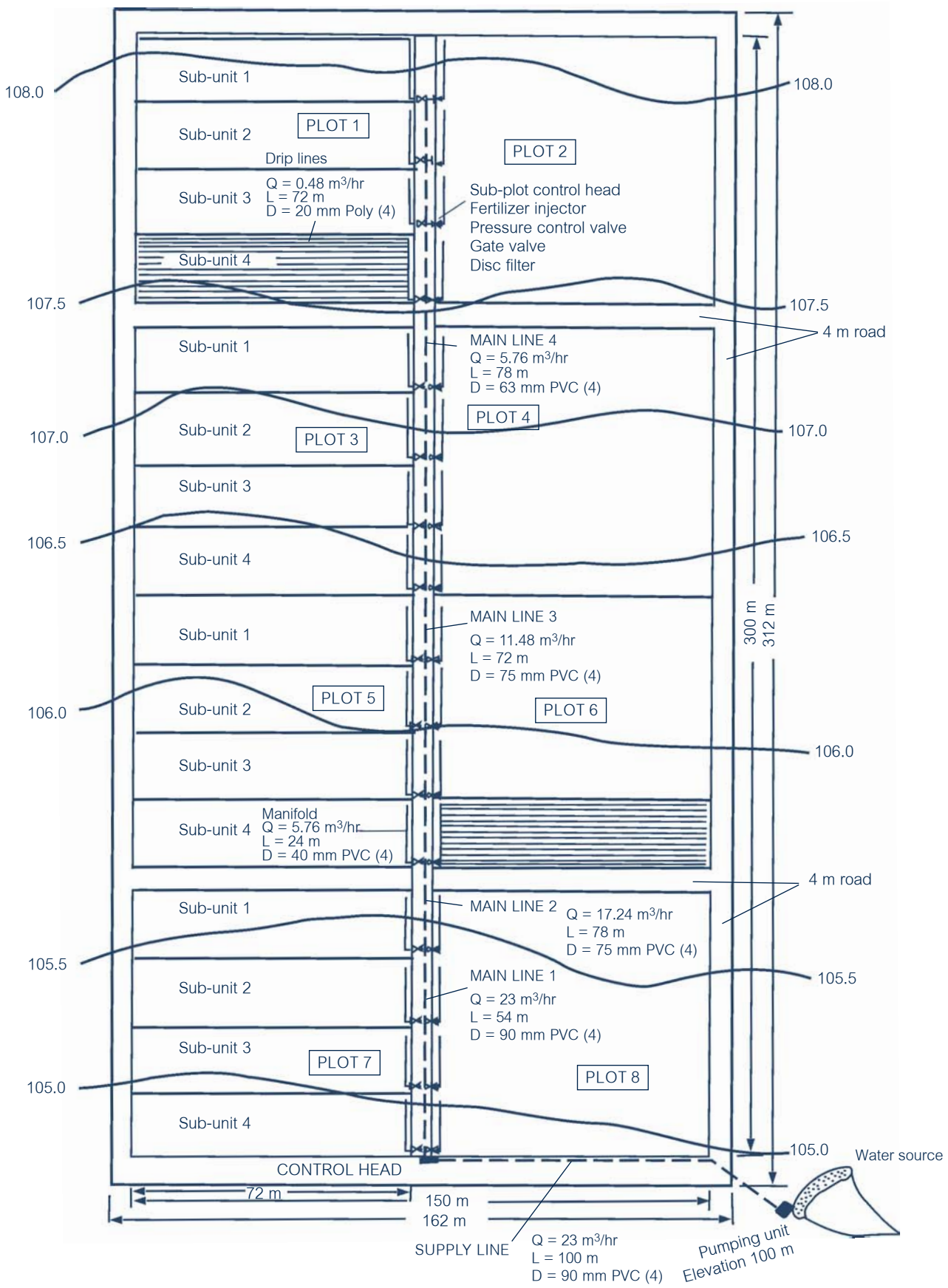
Wherever possible, laterals should be laid in the direction of the contours in order to improve the uniformity of water application. The spacing that was adopted earlier is 0.3 m between the emitters and 1.5 m between laterals (1.2 m bed width plus 0.3 m between the beds). The number of emitters per lateral would be 72/0.3 = 240. Since the average flow per emitter is 2 lph, the flow in the drip hose would be:

Q = 240 x 2 = 480 lph or 0.48 m^3/h

If the 12 mm diameter class 4 hose is selected, the friction losses for the 72 m long hose would be (Figure 9):

HL = 0.60 x 72 = 43.2 m

Figure 13
Point-source drip system layout and pipe sizing for eight smallholders



Using an F value of 0.356 (Table 7) for 240 emission points and increasing the friction losses for in-line emitters and on-line emitters to cater for pressure losses due to connections (Figure 7), the friction losses would be:

HL = (0.60 x 72 x 0.356) + (0.60 x 0.22)
= 15.51 m for in-line drippers

HL = (0.60 x 72 x 0.356) + (0.60 x 0.17)
= 15.48 m for on-line drippers

Both cases are well above the 2.43 m allowable pressure variation.

Following the same procedure, the 16 mm hose head losses are checked as follows:

HL = (0.095 x 72 x 0.356) + (0.095 x 0.22)
= 2.45 m for in-line emitters

HL = (0.095 x 72 x 0.356) + (0.095 x 0.1)
= 2.45 m for on-line emitters

This is still above the 2.43 allowable pressure variation.

If the 20 mm class 4 hose is used then:

HL = (0.034 x 72 x 0.356) + (0.034 x 0.2)
= 0.88 for in-line emitters

HL = (0.034 x 72 x 0.356) + (0.034 x 0.07)
= 0.87 for on-line emitters

This is below the allowable pressure variation by 1.55 m and 1.56 m respectively for in-line and on-line emitters. This balance can be used for the head losses in the manifold and the difference in elevation within the hydraulic unit, which is the area controlled by a manifold.

4.9.2. Manifolds

Each manifold will supply a sub-unit of 72 m x 18 m, providing water to (18/1.5) = 12 driplines. The head losses in the manifold, including 10% for the manifold-to-lateral connection losses, are as follows:

Q = 0.48 x 12 = 5.76 m^3/hr
L = 18 m
D = 40 mm uPVC Class 4
F = 0.394 (12 outlets)
HL = 0.06 x 18 x 0.394 x 1.1 = 0.47 m

Additionally, the friction losses in the manifold part crossing the road should be calculated:

HL = 0.06 x 6 = 0.36 m

Therefore, the total HL for the manifold would be 0.47 m + 0.36 m = 0.83 m, giving a balance of 1.55 - 0.83 = 0.72 m for the in-line emitter case, which can be used for the difference in elevation within the sub-unit (or hydraulic unit).

Looking at the contours, plots 3 and 4 have higher slopes. We will therefore use the steeper sub-unit of plot 3 (sub-unit 1) to verify the compliance within the allowable pressure variation.

In this case, the difference in elevation between the inlet of the manifold and the highest point in the sub-unit is 0.40 m. This brings the total to 0.88 + 0.83 + 0.40 = 2.11 m, which is within the limit of 2.43m. If the slope was uneven, then checking the compliance to allowable pressure variation should be done for each of the sub-units.

4.9.3. Mainline

In this example, the mainline runs from the middle of the southern border of the field to the last manifold off take in plots 1 and 2 (Figure 13). It runs close to the eastern side of the road.

In establishing the operation of the scheme (Table 8), it was concluded that the best option would be when half of the farmers operate one sub-unit at a time. From the hydraulics point of view, it is advantageous to irrigate the sub-units of the four western plots and then the sub-units of the four eastern plots. This will allow the use of a smaller size mainline, since water will be diverted along the total length of the main as it moves from south to the north.

Referring to Figure 13, the worst hydraulic case would be when all number 1 sub-units of plots 1, 3, 5 and 7 are irrigated simultaneously. The same holds true for all number 1 sub-units of plots 2, 4, 6 and 8 when irrigated at the same time.

The first 54 m of the mainline will carry the total capacity of the system established earlier (Table 8), which is 23 m^3/hr. From the friction losses chart for uPVC pipes of 90mm class 4 (Figure 11), the head losses are calculated as follows:

Q = 23 m^3/hr
L = 3 x 18 = 54 m
D = 90 mm uPVC class 4
HL = 0.013 x 54 = 0.70 m

Between the inlet of the manifold of sub-unit 1 of plot 7 and sub-unit 1 of plot 5 the head losses will be:

Q = 23 - 5.76 = 17.24 m^3/hr
L = 4 x 18 + 6 (road) = 78 m
D = 75 mm uPVC class 4
HL = 0.02 x 78 = 1.56 m

Between the inlet of the manifold of sub-unit 1 of plot 5 and sub-unit 1 of plot 3 the head losses will be:

Q = 17.24 - 5.76 = 11.48 m^3/hr
L = 4 x 18 = 72 m
D = 75 mm uPVC class 4
HL = 0.009 x 72 = 0.65 m

Between the inlet of the manifold of sub-unit 1 of plot 3 and sub-unit 1 of plot 1 the head losses will be:

Q = 5.76 m^3/hr
L = 4 x 18 + 6 = 78 m
D = 63 mm uPVC class 4
HL = 0.0068 x 78 = 0.53 m

Therefore, the total head losses in the mainline will be:

Total HL = 0.7 + 1.56 + 0.65 + 0.53 = 3.44 m

4.9.4. Supply Line

This is the pipe connecting the mainline to the pumping unit. The length is estimated to be 100m.

Q = 23 m^3/hr
L = 100 m
D = 90 mm uPVC class 4
HL = 0.013 x 100 = 1.3 m

4.10. Total head requirement

The total head requirement is composed of the head losses in all pipes calculated earlier and added to the sum total of the following: the suction lift, the difference in elevation between the level of the water and the highest position in the field, the head losses in fitting, the head requirement of the control head, the dripper operating pressure. The control head, which is composed of the filtering system and the water meter, is considered as identical to that used in the previous chapter, which was 7 m. The same head losses are assumed to cover the requirements of the fertigation units provided to each farmer.

Suction lift	2.00 m
HL supply line	1.30 m
HL control head	7.00 m
HL mainline	3.44 m
HL manifold	0.83 m
HL laterals	0.88 m
Emitter operating pressure	10.00 m
Subtotal	25.45 m
10% fittings	2.55 m
Difference in elevation	8.20 m
Total	**36.20 m**

4.11. Power requirement

Assuming a 60% pump efficiency and using Equations 20a and 20b, the power requirements are as follows:

$$\text{Power requirements in kW} = \frac{23 \times 36.20}{360 \times 0.6}$$

= 3.9 kW, increased to 4.6 kW assuming 20% derating

or

$$\text{Power requirements in BHP} = \frac{23 \times 36.20}{273 \times 0.6}$$

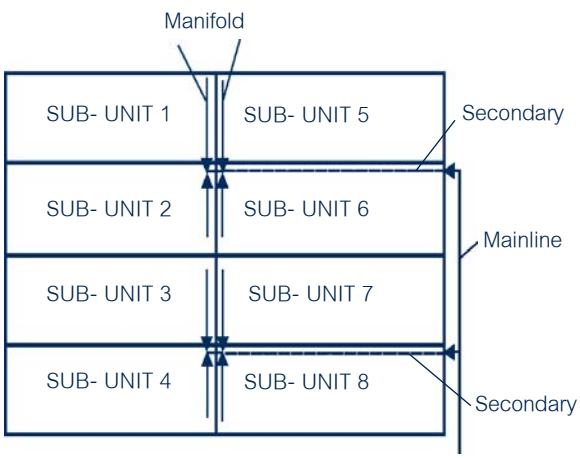
= 5.08 BHP, increased to 6.1 BHP assuming 20% derating

4.12. Alternative layout

Another promising layout, shown in Figure 14, would be the division of each sub-unit of every plot in two. This would increase the number of sub-units to 8 per plot. Each sub-unit would then be operated independently.

Figure 14

Alternative subdivision of the smallholder plots (eight sub-units per plot)



The advantages of such a layout would be:

- All farmers can operate their system at the same time, with one sub-unit per farmer operating at a time. This provides more flexibility.
- The size of dripline will be reduced from 20 mm to 16 mm.
- A bigger variety of crops can be grown at the same time.
- The driplines from one sub-unit can be shifted to the one opposite, allowing the irrigation of very closely spaced crops such as carrots, etc.

However, there are some disadvantages:

- Either the number of mainlines would be increased by two, or secondary lines would be required to supply the manifolds.
- Since the number of manifolds will be doubled, the fittings (valves, elbows, tees, etc.) required for the manifolds would also also doubled.

Chapter 5
Design of a line-source drip irrigation system for smallholder farmers

While some literature differentiates between 'point-source' and 'line-source' according to the distance between the emitters, in this Module the difference is based on the material used for the dripline or lateral. The tape type of material is considered as being 'line-source', while the thick wall material, used in Chapter 3 and 4, is considered as being 'point-source'.

Line-source laterals come in the form of tapes or thin walled flat hoses with built-in emission devices. Following are the design steps for a line-source drip irrigation system for the same smallholders for whom the point-source drip irrigation design was made in Chapter 4. Tomatoes are again used for this example.

5.1. Crop water, irrigation and leaching requirements

The net irrigation requirements were calculated in Chapter 4 to be 4.09 mm/day and the gross irrigation requirements (including leaching) 5.14 mm/day, taking into consideration an application efficiency (E_a) of 86% and leaching requirements of 0.38 mm/day.

5.2. Percentage wetted area and number of emitters required per plant

In Section 2.4, it was mentioned that P_w should approach 100% for closely spaced crops with rows and emitter lines spaced less than 1.8 m. The P_w for tomatoes was also calculated to be 100% for an emitter spacing of 0.3 m along the lateral and one emission point per two plants (Chapter 4). The tomatoes are grown at 0.9 m row spacing on raised beds of 1.2 m width with 0.3 m paths between them.

5.3. Irrigation frequency and duration

Using the data generated earlier, the irrigation frequency at peak demand was calculated as follows:

Net Irrigation Requirement (IR_n)
= 4.09 mm/day or 4.09 x 0.9 x 0.3
= 1.10 l/day per plant

Crop spacing
= 0.9 m x 0.3 m

Effective rooting depth (RZD)
= 0.5 m

Area of wetted soil
= S_p x S_r x P_w
= 0.9 x 0.3 x 1
= 0.27 m^2

Available soil moisture
= 120 mm/m or 120/1000 x 0.5 x 0.27 x 1000
= 16.2 l/plant

Moisture depletion for drip irrigation system
= 20%

Readily available moisture
= 16.2 x 0.2
= 3.24 l/plant

Irrigation frequency at peak demand
= 3.24/1.10
= 2.95 days, say 3 days

For reasons given in Section 4.4, we assume a one day frequency at peak demand. The gross irrigation requirements are 5.14 mm/day or 5.14 x 0.9 x 0.3 = 1.39 l/day per plant.

Assuming 0.3 m emission spacing along the tape and using three different flow rates for the same tape, the length of operation time was calculated using Equation 12 as follows:

T_a = 1.39/(1.20 x 0.5) = 2.32 hours
T_a = 1.39/(1.75 x 0.5) = 1.59 hours
T_a = 1.39/(2.75 x 0.5) = 1.01 hours

5.4. Emitter selection

As a rule, the flow of tapes provided by the manufacturers is given in lph per 100 m length of tape or lph per emission point. The catalogues also provide the emitter spacing, the desired EU, the inlet pressure to the emitter line and the length of run of the tape under different slopes. The same catalogues from reputable manufacturers also provide the Cv and the emitter exponent.

Referring to Figure 12, the same nine alternatives will be considered but now using the following three flow rates per emission point: 1.2, 1.75 and 2.75 lph. From the analysis presented in Table 9, it appears that there are five promising alternatives to consider when the daily operation at peak demand is in the range of 9-13 hours.

Alternative 1, with an emission of 1.2 lph and a system capacity of 27.6 m^3/hr, would require 9.28 hours of daily operation. This is a fairly flexible option, allowing all

Table 9

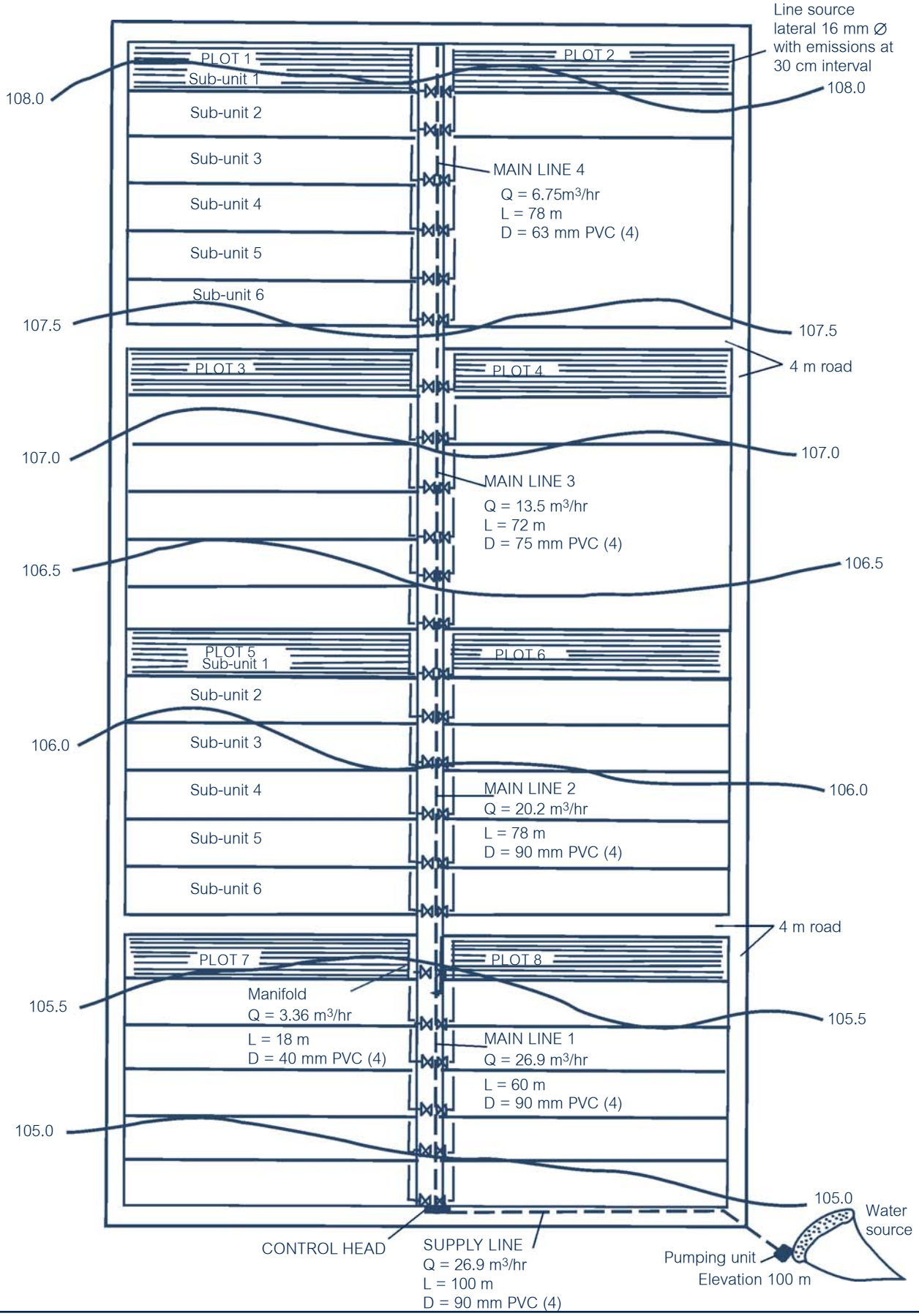
Alternative options for the emitter selection for the line-source drip irrigation system

Alternative	No. of sub-units per farmer's plot (1)	Width of one sub-unit (m) (2)=72/(1)	No. of laterals per sub-unit (3)=(2)/1.5	No. of emitters per lateral (4)=72/0.3	No. of emitters per sub-unit (5)=(3)x(4)	Emitter flow (lph) (6)	No. of rotation shifts (7)	Duration of each shift T_a (hrs) (8)	Daily at operation peak (hrs) (9)=(1)x(7)x(8)	No. of sub-units operating at the same time (10)*	System capacity (m^3/hr) (11)=(5)x(6)x(10)
1. • Four sub-units per farmer											
• All farmers irrigate at the	4	18	12	240	2 880	1.20	1	2.32	9.28	8	27.6
same time	4	18	12	240	2 880	1.75	1	1.59	6.32	8	40.3
• Each farmer irrigates one sub-unit at a time	4	18	12	240	2 880	2.75	1	1.01	4.04	8	63.4
2. • Four sub-units per farmer											
• Four farmers irrigate at the	4	18	12	240	2 880	1.20	2	2.32	18.56	4	13.8
same time	4	18	12	240	2 880	1.75	2	1.59	12.75	4	20.2
• Each farmer irrigates one sub-unit at a time	4	18	12	240	2 880	2.75	2	1.01	8.08	4	31.7
3. • Four sub-units per farmer											
• Two farmers irrigate at the	4	18	12	240	2 880	1.20	4	2.32	37.12	2	6.9
same time	4	18	12	240	2 880	1.75	4	1.59	25.44	2	10.1
• Each farmer irrigates one sub-unit at a time	4	18	12	240	2 880	2.75	4	1.01	16.16	2	15.8
4. • Three sub-units per farmer											
• All farmers irrigate at the	3	24	16	240	3 840	1.20	1	2.32	6.96	8	36.9
same time	3	24	16	240	3 840	1.75	1	1.59	4.77	8	53.8
• Each farmer irrigates one sub-unit at a time	3	24	16	240	3 840	2.75	1	1.01	3.03	8	84.5
5. • Three sub-units per farmer											
• Four farmers irrigate at the	3	24	16	240	3 840	1.20	2	2.32	13.72	4	18.4
same time	3	24	16	240	3 840	1.75	2	1.59	10.50	4	26.9
• Each farmer irrigates one sub-unit at a time	3	24	16	240	3 840	2.75	2	1.01	16.50	4	42.2

6. • Three sub-units per farmer	3	24	16	240	3 840	1.20	4	2.32	27.84	2	9.2
• Two farmers irrigate at the same time	3	24	16	240	3 840	1.75	4	1.59	19.08	2	13.4
• Each farmer irrigates one sub-unit at a time	3	24	16	240	3 840	2.75	4	1.01	12.12	2	21.1
7. • Six sub-units per farmer											
• All farmers irrigate at the same time	6	12	8	240	1 920	1.20	1	2.32	13.92	8	18.4
	6	12	8	240	1 920	1.75	1	1.59	9.54	8	26.9
• Each farmer irrigates one sub-unit at a time	6	12	8	240	1 920	2.75	1	1.01	6.06	8	42.2
8. • Six sub-units per farmer											
• Four farmers irrigate at the same time	6	12	8	240	1 920	1.20	2	2.32	27.84	4	9.2
	6	12	8	240	1 920	1.75	2	1.59	19.08	4	13.4
• Each farmer irrigates one sub-unit at a time	6	12	8	240	1 920	2.75	2	1.01	12.12	4	21.1
9. • Six sub-units per farmer											
• Two farmers irrigate at the same time	6	12	8	240	1 920	1.20	4	2.32	55.68	2	4.6
	6	12	8	240	1 920	1.75	4	1.59	38.16	2	6.7
• Each farmer irrigates one sub-unit at a time	6	12	8	240	1 920	2.75	4	1.01	24.24	2	10.6

* *(10) = number of farmers irrigating at the same time*

Figure 15
Line-source drip system and pipe sizing for smallholders



farmers to irrigate at the same time and completing irrigation within daylight. However, the system capacity is higher than the capacity required by the other promising options. Being a very low emission, 1.2 lph is also more prone to clogging.

Alternative 2, with an emission of 1.75 lph and a system capacity of 20.2 m^3/hr, would require 12.75 hours of daily operation at peak demand. It is a less flexible option, as only half of the farmers can irrigate at a time and part of the operation would be in the very early hours of the day. However, the advantage of Alternative 2 is that the size of the main line can be smaller because of the lower system capacity.

Alternative 6, with an emission of 2.75 lph and a system capacity of 21.1 m^3/hr, would require 12.1 hours of daily operation. However, only two of the eight farmers can irrigate at the same time. This makes the operation of the system more complicated, since problems may arise in scheduling each farmers' irrigation slot.

Alternative 7, with an emission of 1.75 lph and a system capacity of 26.9 m^3/hr, would require 9.5 hours of daily operation during the peak demand period. It combines the advantage of more sub-units per farmer (which means more choices of crops to be grown) and the fact that irrigation can be practiced simultaneously by all farmers. Countering this flexibility, the system capacity is higher as is the cost of system installation because more offtakes would be required to accommodate the six sub-units per farmer plot.

Alternative 8 is also attractive. It allows six crop choices for each farmer, while maintaining the daily operation to 12.1 hours with a system capacity of 21.1 m^3/hr under 2.75 lph emission. The only drawback of this option is that only half of the farmers could irrigate at the same time.

In addition to the above five alternatives, Alternative 5 with an emission of 1.75 lph and Alternative 6 with an emission of 2.75 lph also fall within the range of 9-13 hours of daily operation. However, the reduced number of sub-units per plot, being only 3, limits the farmers' choices of crops to be grown.

Assuming that Alternative 7 is the farmers' preferred option, the layout of the system would be as shown in Figure 15. The emission flow would be 1.75 lph and the system capacity 26.9 m^3/hr, allowing a daily operation of 9.5 hours during peak demand.

5.5. Allowable pressure variation

From the manufacturer's catalogue Cv = 0.03, x = 0.48 for the q_a of 1.75 lph at an H_a of 10 m. The EU is considered to be 90%. Using the rearranged Equation 18, the minimum allowable discharge (q_m) can be calculated as follows:

$$q_m = \frac{90 \times 1.75}{100 \times [1.0 - 1.27(0.03 / \sqrt{0.5})]} = 1.66 \text{ lph}$$

Using Equation 20:

$$H_m = 10 \left[\frac{1.66}{1.75} \right]^{1/0.48} = 8.96 \text{ m}$$

Therefore:

$$\Delta H_s = 2.5 (10-8.96) = 2.6 \text{ m}$$

The allowable pressure variation within the hydraulic unit (plot sub-unit) should be 2.6 m or less. The sub-unit for each plot is considered as the hydraulic unit. Each sub-unit will be provided with a manifold supplying eight laterals each of 72 m in length.

5.6. Pipe size determination

5.6.1. Laterals

The nominal diameter of tape is 16 mm. From the head losses chart (Figure 16) provided by the manufacturer, the HL = 1.2 m for a length of 72 m and a dripper spacing of 0.3 m. This leaves a balance of (2.6 - 1.2) = 1.4 m. The discharge in a lateral would be:

$$Q = 240 \times 1.75 = 420 \text{ lph or } 0.42 \text{ m}^3\text{/hr}$$

5.6.2. Manifolds

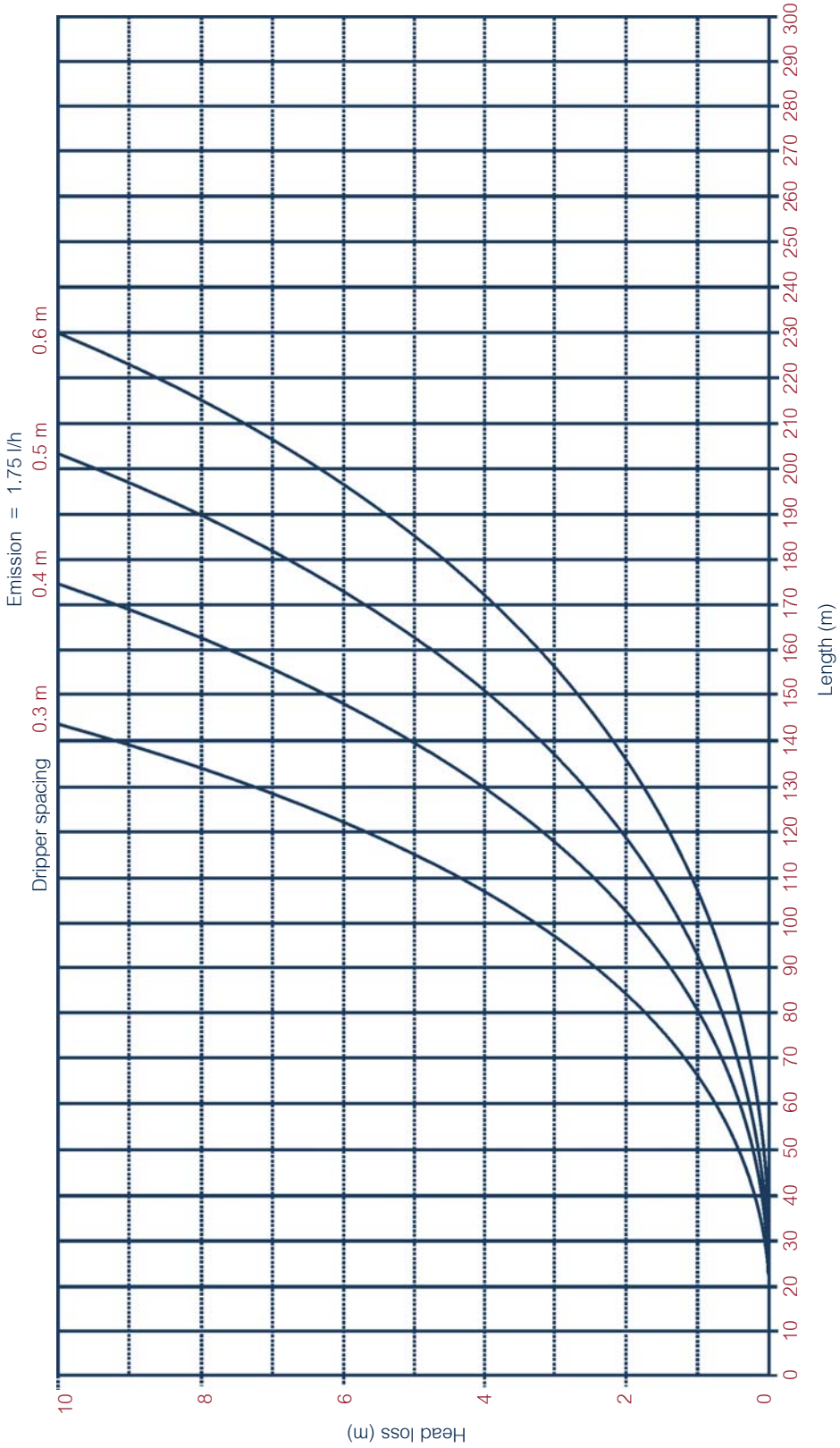
Manifolds will run across the contours as shown in Figure 15, supplying eight laterals each. The head losses, including 10% for the manifold-to-lateral connection (grommet take-offs) losses, are calculated as follows:

$$Q = 0.42 \times 8 = 3.36 \text{ m}^3\text{/hr}$$
$$L = (72/6) = 12 \text{ m}$$
$$D = 40 \text{ mm uPVC Class 4}$$
$$F = 0.415 \text{ (8 outlets)}$$
$$HL = 0.019 \times 12 \times 0.415 \times 1.1 = 0.1 \text{ m}$$

Additionally, there is a short length of manifold crossing the 6 m wide main road.

$$HL = 0.019 \times 6 = 0.01$$

Figure 16
Head loss chart for drip tapes



This gives a total HL of 0.11 m. While a smaller diameter pipe could be used, in practice it is difficult to connect the laterals to the manifolds through grommets when the manifold is less than 40 mm in diameter. Looking at the sub-unit with the steepest slope (sub-unit 1 of plot 3), the difference in elevation is about 0.4 m. Therefore, the total losses within the hydraulic unit are (1.20 + 0.11 + 0.40) = 1.71 m, which is within the ΔHs of 2.6 m.

5.6.3. Mainline

The mainline runs along the middle of the scheme and next to the road from where manifolds are supplied. The worst hydraulic case will be when all sub-units number 1 in all eight plots are in operation. The head losses will be as follows:

Q_1 = 26.9 m^3/hr
L_1 = 5 x 12 = 60 m
D_1 = 90 mm uPVC class 4
HL_1 = 0.017 x 60 = 1.02 m

Q_2 = 26.9 - (3.36 x 2) = 20.2 m^3/hr
L_2 = 6 x 12 + 6 (road) = 78 m
D_2 = 90 mm uPVC class 4
HL_2 = 0.01 x 78 = 0.78 m

Q_3 = 20.2 -(3.36 x 2) = 13.5 m^3/hr
L_3 = 6 x 12 = 72 m
D_3 = 75 mm uPVC class 4
HL_3 = 0.012 x 72 = 0.86 m

Q_4 = 13.5 -(3.26 x 2) = 6.75 m^3/hr
L_4 = 6 x 12 + 6 = 78 m
D_4 = 63 mm uPVC class 4
HL_4 = 0.0085 x 78 = 0.66 m

HL main = (1.02 + 0.78 + 0.86 + 0.66) = 3.32 m

5.6.4. Supply line

This is the pipe connecting the mainline to the pumping unit. The length is estimated to be 100 m.

Q = 26.9 m^3/hr
L = 100 m
D = 90 mm uPVC class 4
HL = 0.017 x 100 = 1.7 m

5.7. Total head requirement

The total head requirement is composed of the head losses in all pipes calculated earlier plus the sum total of the following: the suction lift, the difference in elevation between the level of the water and the highest position in the field, the head losses in fitting, the head requirement of the control head, the dripper operating pressure. The control head, which is composed of the filtering system and the water meter, is considered as identical to that used in the previous chapter, which was 7 m. The same head losses are assumed to cover the requirements of the fertigation units provided to each farmer.

Suction lift	2.00
HL supply line	1.70
HL control head	7.00
HL main line	3.32
HL manifold	0.11
HL lateral	1.20
Emitter operating pressure	10.00
Subtotal	25.33
10% for fitting	2.53
Difference in elevation	8.20
Total	**36.06**

The total head requirement (total dynamic head) of 36.06 m is within the pressure rating of class 4 uPVC pipe used in this design.

5.8. Power requirement

Using Equations 21a and 21b and a pump efficiency of 55% , the power requirements will be:

$$\text{Power requirements in kW} = \frac{26.9 \times 36.06}{360 \times 0.55}$$

= 4.9 kW, increased to 5.9 kW assuming 20% derating

or

$$\text{Power requirements in BHP} = \frac{26.9 \times 36.06}{273 \times 0.55}$$

= 6.5 BHP, increased to 7.8 BHP assuming 20% derating

Chapter 6
Drip irrigation system powered by a treadle pump

Over the past 5-10 years, manual pumps have gained popularity among smallholders in Sub-Saharan Africa to irrigate small vegetable gardens from shallow water sources (see Module 5). These pumps are used to supply water to short furrows and basins through a polyethylene 50 mm hose attached to the outlet of the pump.

In order to enhance the efficiency of these systems and in view of the limited water resources available, the use of drip irrigation has been considered for this purpose. Two options seemed to be feasible. The first option would require an overhead reservoir, 3 m high, supplying a drip irrigation system operating at low pressure. A treadle pump would be used to pump water into the overhead tank. Figure 17 presents the drip irrigation system supplied by the tank. These systems are commercially available at a cost of US$5000 per hectare, including the treadle pump, the hose, the overhead tank and the drip irrigation system.

Figure 17
Family drip system

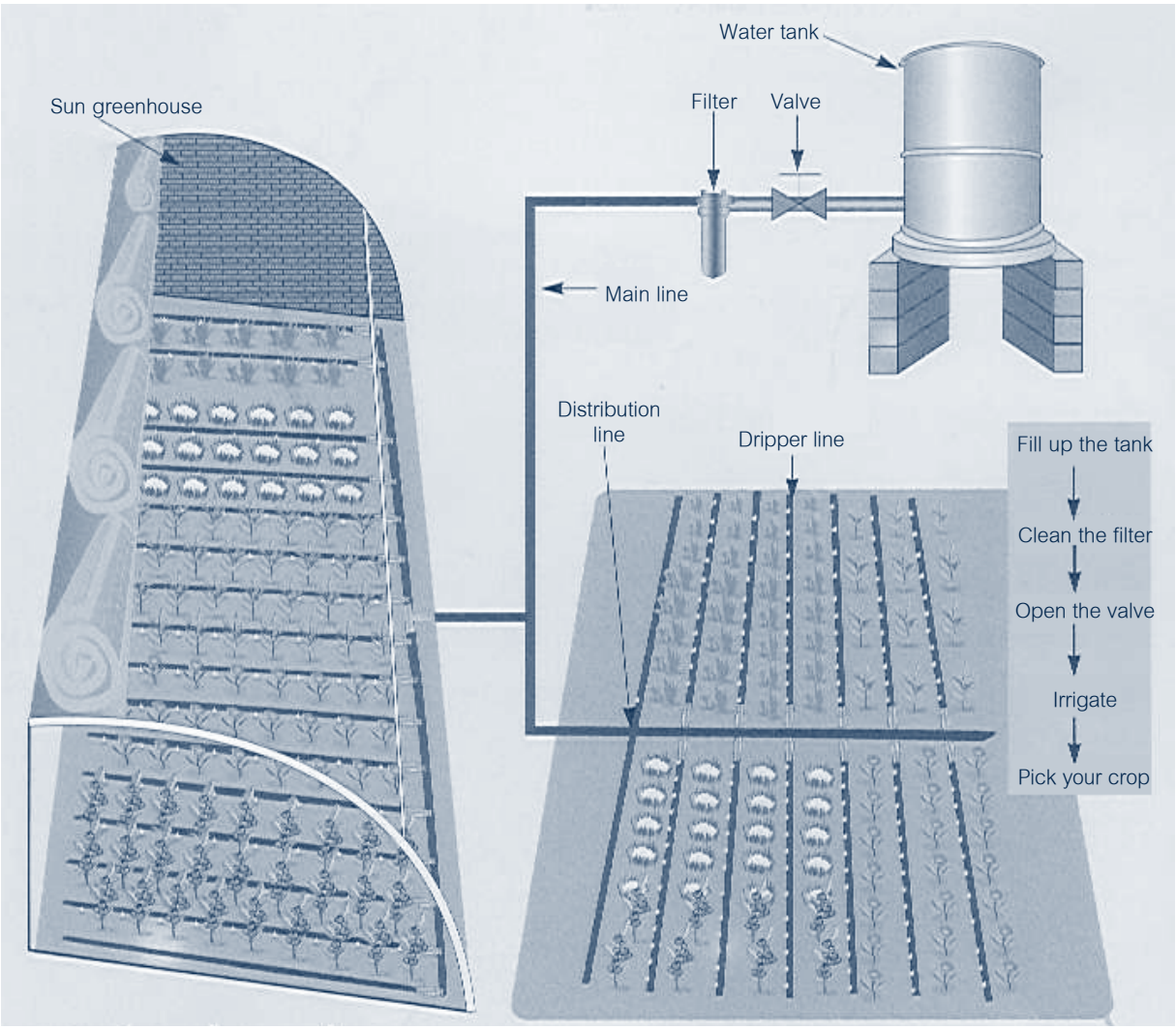
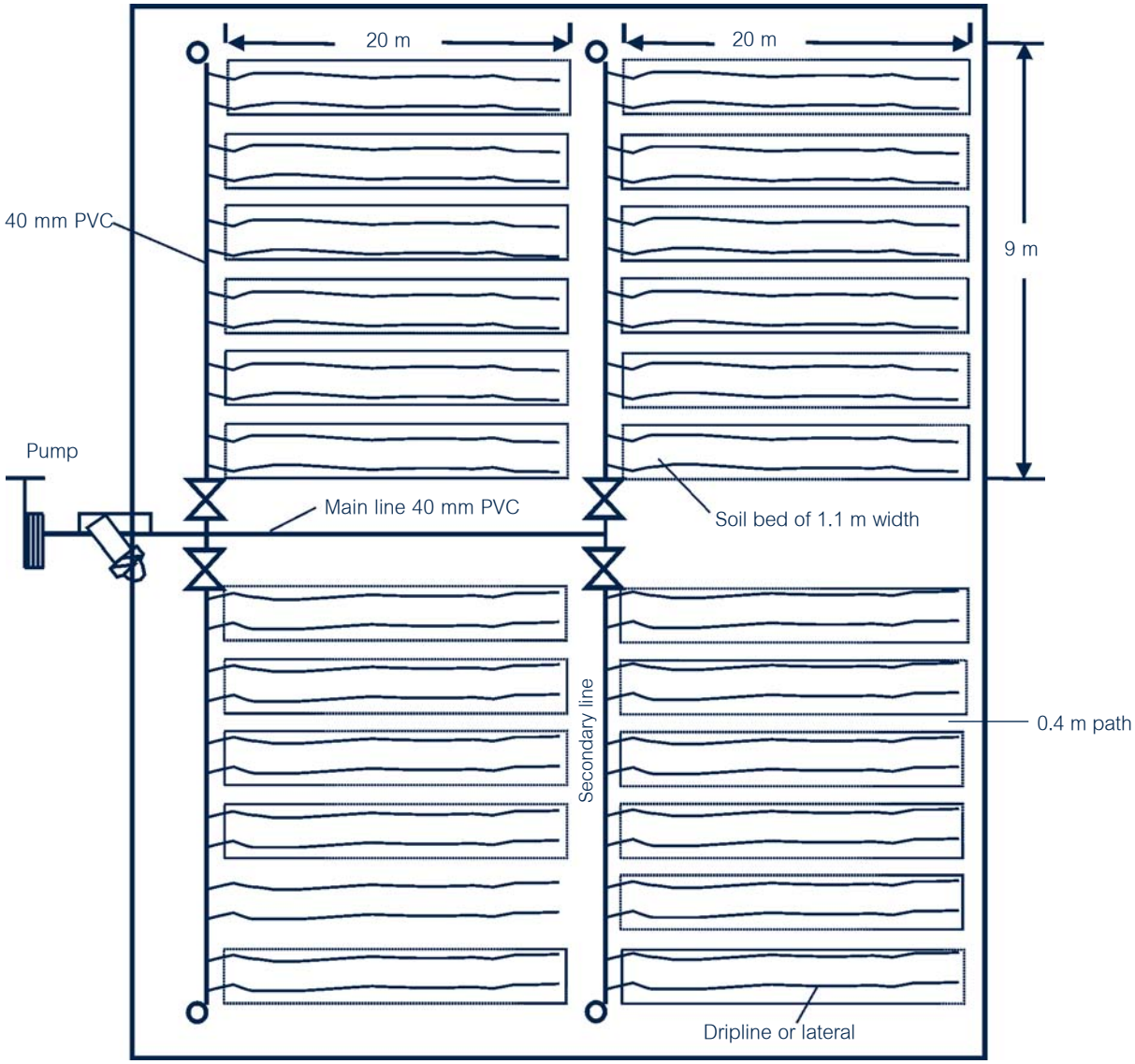


Figure 18
Typical drip irrigation plot, using a treadle pump

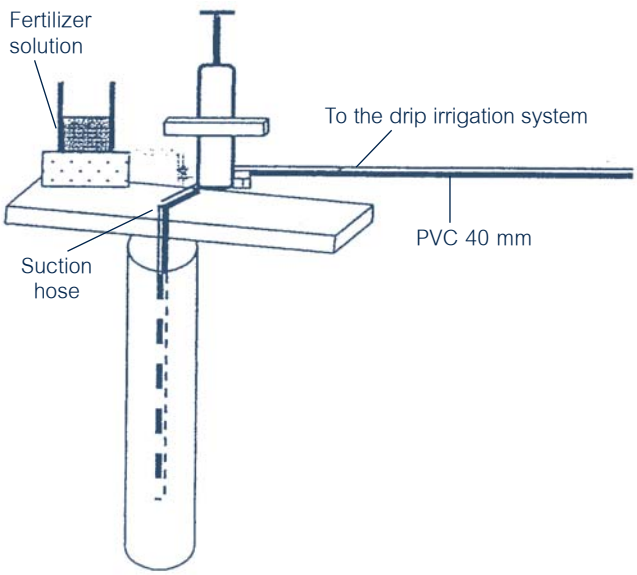


The second option would be the direct connection of the treadle pump to the low-pressure drip irrigation system. The Zimbabwe Irrigation Technology Centre (ZITC) tested the technical feasibility of such a system on behalf of FAO in 2001. The layout of this system is presented in Figure 18.

Figure 19 shows the special arrangements made for injecting the fertilizer solution through the suction of the pump.

Figure 19

Special arrangements made for injecting the fertilizer solution through the suction of the pump



uPVC pipes were used to supply the tape type of line-source drip system. Each bed of 1.1 m width was provided with two drip laterals. Tests have demonstrated the technical feasibility of this option. The per hectare cost was US$3500 for the complete system including the treadle pump

Chapter 7

Final design steps for a micro spray irrigation system for an individual commercial farm

A micro spray irrigation system, also known as micro-jet or spray emitter irrigation system, is very similar to a drip irrigation system except that each emitter (sprayer) can wet larger areas than the emitters of drip irrigation systems. Spray emitters are normally used on coarse-textured soils, where wetting sufficiently large areas would require large numbers of drippers. This is because coarse-textured soils have inherently more vertical wetting than do fine textured soils (see Module 1). Also, they are used for trees where one to two sprayers per tree can cover the wetted area requirements.

In order to facilitate the design of the spray emitter system, one needs to be supplied with the manufacturer's data on the characteristics of that particular sprayer. This refers particularly to the relationship between the pressure and the wetted diameter of the sprayer, as well as the emitter exponent and the coefficient of discharge.

The same field of citrus as used in Chapter 3 will also be the basis for design. The preliminary steps that were undertaken in Chapter 2 for the design of the drip emitter system are also common to the spray emitter system.

7.1. Crop water, irrigation and leaching requirements

The crop water requirements of citrus tree, their irrigation and leaching requirements were calculated in Chapter 2. The gross irrigation requirements, including the leaching require-ments, were estimated to be 7.93 mm/day (Example 4).

7.2. Percentage wetted area

As discussed in Section 2.4, the desirable percentage wetted area (P_w) for our example would be 50%. It is therefore necessary to identify a sprayer which can cover 50% of the surface area commanded by one tree, which is 18 m^2 (36 x 0.5). Another consideration is the soil infiltration rate. In order to avoid runoff the application rate of the sprayer should not exceed the soil infiltration rate. The area directly wetted by the sprayer (A_w), can be calculated using the Equation 22:

Equation 22

$$A_w = \frac{\pi \times d^2}{4} \times \frac{(\omega)}{360}$$

Where:

d = is the diameter of a circle approximated by the wetting pattern

ω = is the approximate angle of the pie-wedged shape cut out of the circle

Assuming that the soil infiltration rate is 6 mm/hr, a sprayer from a manufacturer catalogue should be selected and the wetted area calculated using Equation 22.

Referring to Table 10, obtainable from a manufacturer, the performance characteristics of a sprayer are provided for different pressures and nozzle sizes. This table is for 360° water distribution.

Assuming that a blue nozzle is selected operating at 14 m head, the wetted diameter is 6.0 m. The wetted area is calculated using Equation 22:

$$A_w = \frac{3.14 \times 6^2}{4} \times \frac{360}{360} = 28.3\ m^2$$

Since this is far above the minimum required area of 18 m^2 (P_w = 50%), another option could be considered. Looking at the wetted diameter of a sky blue nozzle operating at 14 m head, which is 5.0 m, the same calculation can be made:

$$A_w = \frac{3.14 \times 5^2}{4} \times \frac{360}{360} = 19.6\ m^2,$$

which is close to 18 m^2

The application rate from this emitter, also provided by the manufacturer, is presented in Figure 20. The highest application rate occurring near the emitter is 3.5 mm/hr, which is well within the 6 mm/hr soil infiltration rate. If the blue nozzle operating at 14 m head is chosen, the application rate near the emitter would be 4.5 mm/hr, which is also below the soil infiltration rate.

7.3. Irrigation frequency and duration

As explained earlier, very frequent irrigation is practiced under localized irrigation. This entails the use of low soil moisture depletion levels. The following example will clarify this concept.

Table 10

Performance table of sprayers, being 20 cm above the ground level, for 360° water distribution

Model	Colour code	Pressure (m)	Flow rate (lph)	Wetted diameter (m)	Constant K	Exponent X
0.25	Sky Blue	14	19	5.0	5.15	0.5
		20	23	5.5		
		25	26	6.0		
		30	28	6.0		
040	Blue	14	33	6.0	9	0.5
		20	40	7.0		
		25	45	7.0		
		30	49	7.0		
050	Green	14	39	6.5	10.5	0.5
		20	47	6.5		
		25	53	6.5		
		30	58	6.5		
060	Grey	14	49	6.5	13	0.5
		20	58	7.0		
		25	65	7.0		
		30	71	7.0		
070	Black	14	56	7.5	15	0.5
		20	67	8.0		
		25	75	8.0		
		30	82	8.0		
090	Orange	14	74	7.5	19.7	0.5
		20	88	8.0		
		25	99	8.0		
		30	108	8.0		
120	Red	14	100	7.5	26.6	0.5
		20	119	8.0		
		25	113	9.0		
		30	146	9.0		
160	Brown	14	130	8.5	34.7	0.5
		20	155	8.5		
		25	173	8.5		
		30	190	9.0		
200	Yellow	14	167	8.5	44.75	0.5
		20	200	9.0		
		25	224	9.0		
		30	245	9.0		

Example 10

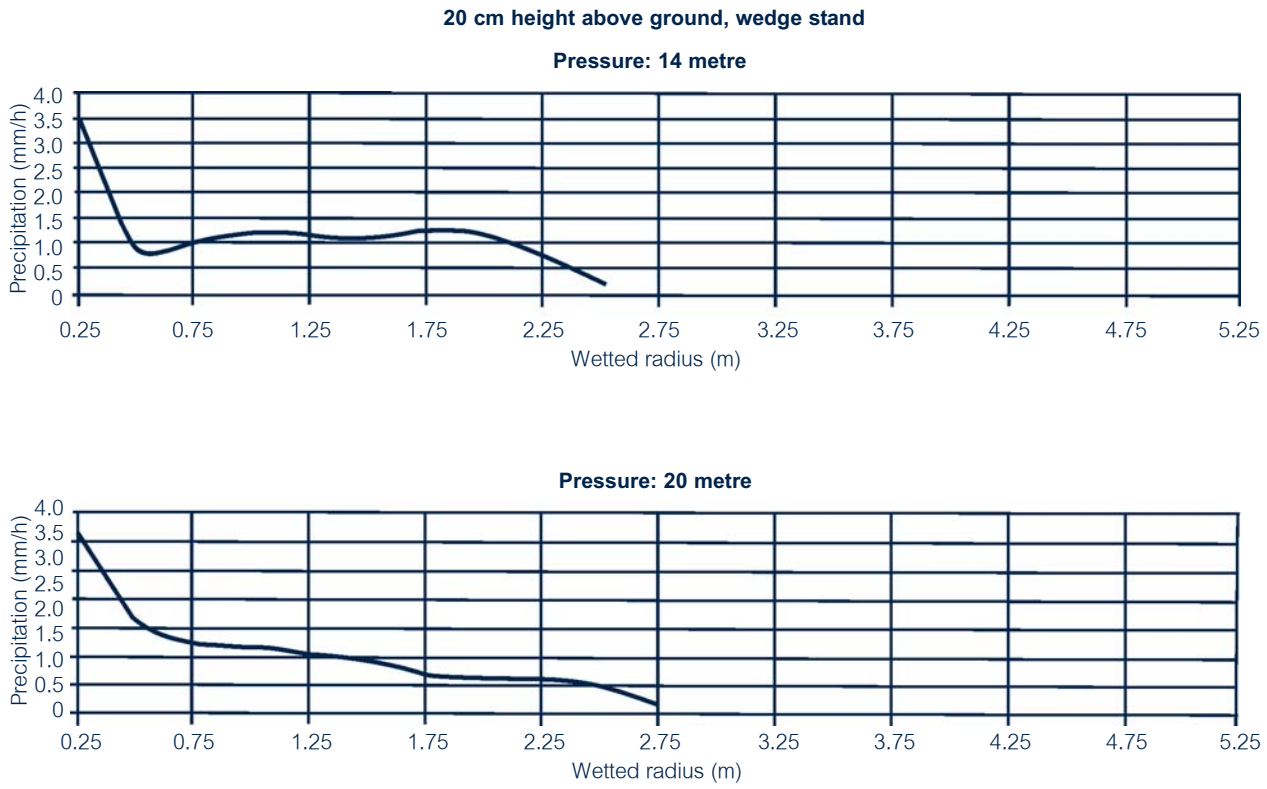
Using the data generated earlier, the irrigation frequency at peak demand is calculated as follows:

IR_n = 6.04 mm/day or (6.04 x 6 x 6 x 0.5) = 217 l/day per tree
Tree spacing = 6 m x 6 m
Effective root zone depth (RZD) = 1 m
Desirable soil wetted area = S_p x S_r x P_w = 6 x 6 x 0.5 = 18 m^2
Available moisture = 120 mm/m
Moisture depletion = 20%

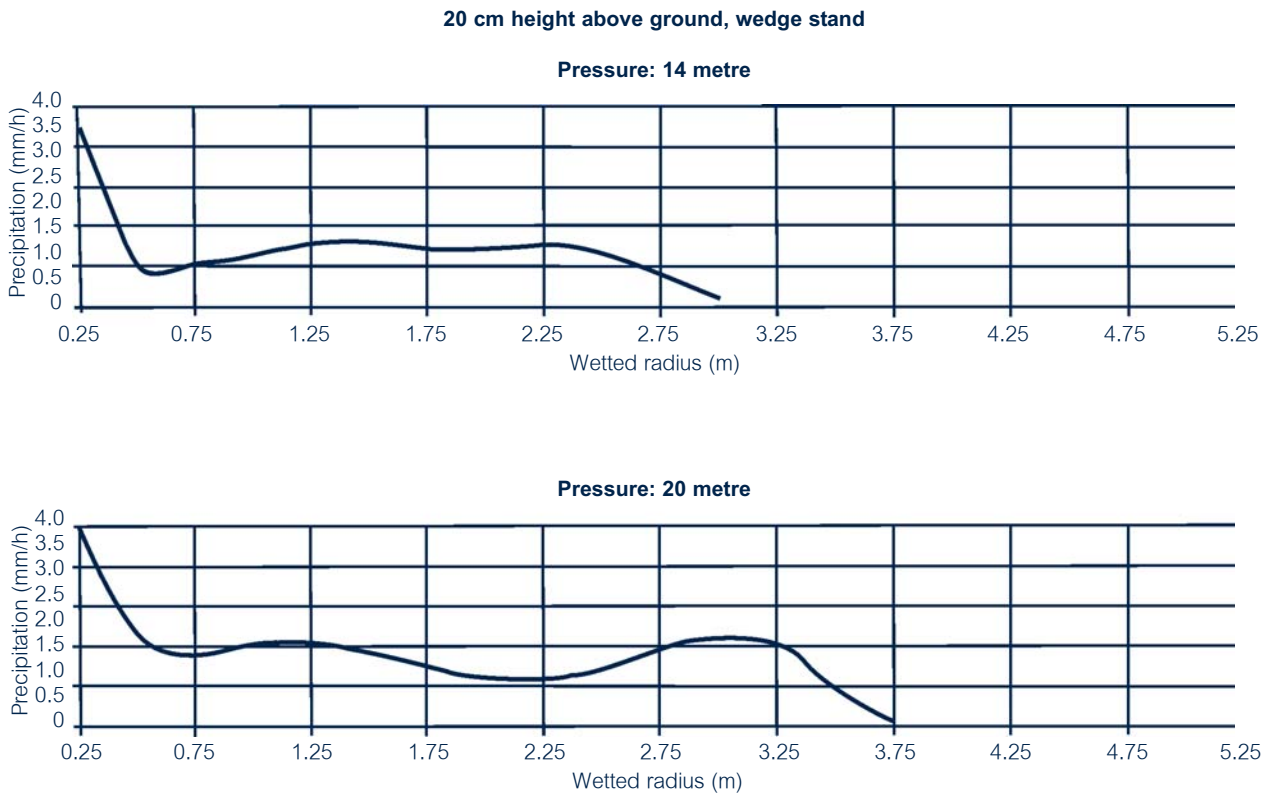
	Sky blue nozzle	**Blue nozzle**
Wetted area A_w	19.6 m^2	28.3 m^2
Percentage wetted area P_w	100 x (19.6/(6 x 6)) = 54%	100 x (28.3/(6 x 6)) = 79%
Available soil moisture per tree	(120/1000) x 19.6 x 1000 = 2352 l/tree	(120/1000) x 28.3 x 1000 = 3396 l/tree
Readily available moisture	2352 x 0.2 = 470 l/tree	3396 x 0.2 = 679 l/tree
Irrigation frequency at peak	470/217 = 2.2 days, say 2 days	679/217 = 3.1 days, say 3 days
IR_n to be applied per irrigation	217 x 2 = 434 l/tree	217 x 3 = 651 l/tree

Figure 20

Precipitation from different types of sprayer for different pressures



a. Sky blue nozzle



b. Blue nozzle

For design purposes, we assume a daily irrigation providing IR_g of 7.93 mm/day or 285 l/day per tree (Example 4).

The duration of irrigation per set, or the length of operation time (T_a) at peak demand, is established using Equation 12:

$$\text{For the sky blue nozzle: } T_a = \frac{285}{1 \times 19} = 15 \text{ hours}$$

$$\text{For the blue nozzle: } T_a = \frac{285}{1 \times 33} = 8.7 \text{ hours}$$

If the sky blue nozzle is adopted the system can start at 06.00 hours and be switched off at 21.00 hours, allowing one shift per day. If the blue nozzle is used two shifts per day can be accommodated (06.00-15.00 hours and 15.00-24.00 hours). However, this may be considered inconvenient from the operational point of view.

A third option to be considered is the use of the sky blue nozzle operating at a pressure of 25 m. This will provide a T_a of 11 hours (285/26), which makes it very convenient for two shifts per day (0.600-17.00 hours and 18.00-05.00 hours), in addition to providing a better degree of system utilization. However, the operating costs of this option would be higher.

Assuming that the farmer opted for the convenience of 15 hours operation per day (first option) and the relatively lower operating cost, the sky blue nozzle operating at 14 m pressure will be adopted for this design.

7.4. Allowable pressure variation

According to the manufacturers table (Table 10), for the sky blue nozzle $H_a = 14$ m to provide a $q_a = 19$ lph. Then, the H_m to provide the q_m that satisfies the uniformity of Equation 19 is required.

Earlier on, a design emission uniformity of 90% was adopted. Assuming a Cv of 0.05 (from Table 5), the allowable minimum discharge q_m for the minimum pressure H_m in the sub-unit is calculated from the rearranged Equation 18:

$$q_m = \frac{90 \times 19}{100 \times [1.0 - (1.27 \times 0.05 / \sqrt{1})]} = 18.3 \text{ lph}$$

Using Equation 15, with $x = 0.5$, H_m is calculated as follows:

$$H_m = 14 \times \left[\frac{18.3}{19}\right]^{1/0.5} = 13 \text{ m}$$

Therefore, the minimum discharge of 18.3 lph is obtained under a H_m of 13.0 m. The average emitter discharge of 19 lph is obtained with a pressure of 14.0 m. The allowable pressure variation would then be (Equation 19):

$$\Delta H_s = 2.5[14 - 13] = 2.5 \text{ m}$$

7.5. Layout of the micro spray system and pipe size determination

Referring to the example of an individual commercial farm (Chapter 3), by adopting the 19 lph spray emitter and taking into consideration the daily irrigation frequency, the total area should be irrigated in one shift per day. Hence a layout using the map of Figure 8 should be prepared. One option is to provide a supply line to the south eastern corner of the plot, feeding the mainline running along the road and parallel to the eastern boundary. From the mainline four manifolds, of which the first two will supply 13 rows of trees and the last 2 will each supply 12 rows of trees, will be used (Figure 21).

7.5.1. Laterals

As in the previous examples, class 4 polyethylene pipes will be used. In this example, each spray line will provide water to 25 emitters (150/6). One spray emitter irrigates one tree and discharges $q_a = 19$ lph at a H_a of 14 m. The flow in the polyethylene pipe would then be:

$$Q = 25 \times 19 = 475 \text{ lph or } 0.475 \text{ m}^3\text{/hr}$$

If the 25 mm diameter polyethylene pipe is used, then the friction losses for the 147 m length, allowing for half the spacing from the mainline to the first emitter, would be:

$$Q = 0.475 \text{ m}^3\text{/hr}$$
$$L = 150 - 3 = 147 \text{ m}$$
$$D = 25 \text{ mm PE}$$
$$F = 0.371 \text{ (25 outlets)}$$
$$HL = 0.014 \times 147 \times 0.371 = 0.76 \text{ m}$$

Assuming 10% additional losses for the connection of the micro tube to the lateral, then the HL of the lateral will be (0.76/0.90) = 0.84 m.

Additionally, the head losses in the 0.6 m micro tube of 8 m inside diameter should be calculated using the Hazen - Williams formula (Equation 23):

Equation 23

$$H_f(100) = k \frac{(Q / C)^{1.852}}{D^{4.87}}$$

Where:

$H_f(100)$ = friction losses in metres per 100 metres of tube (m)

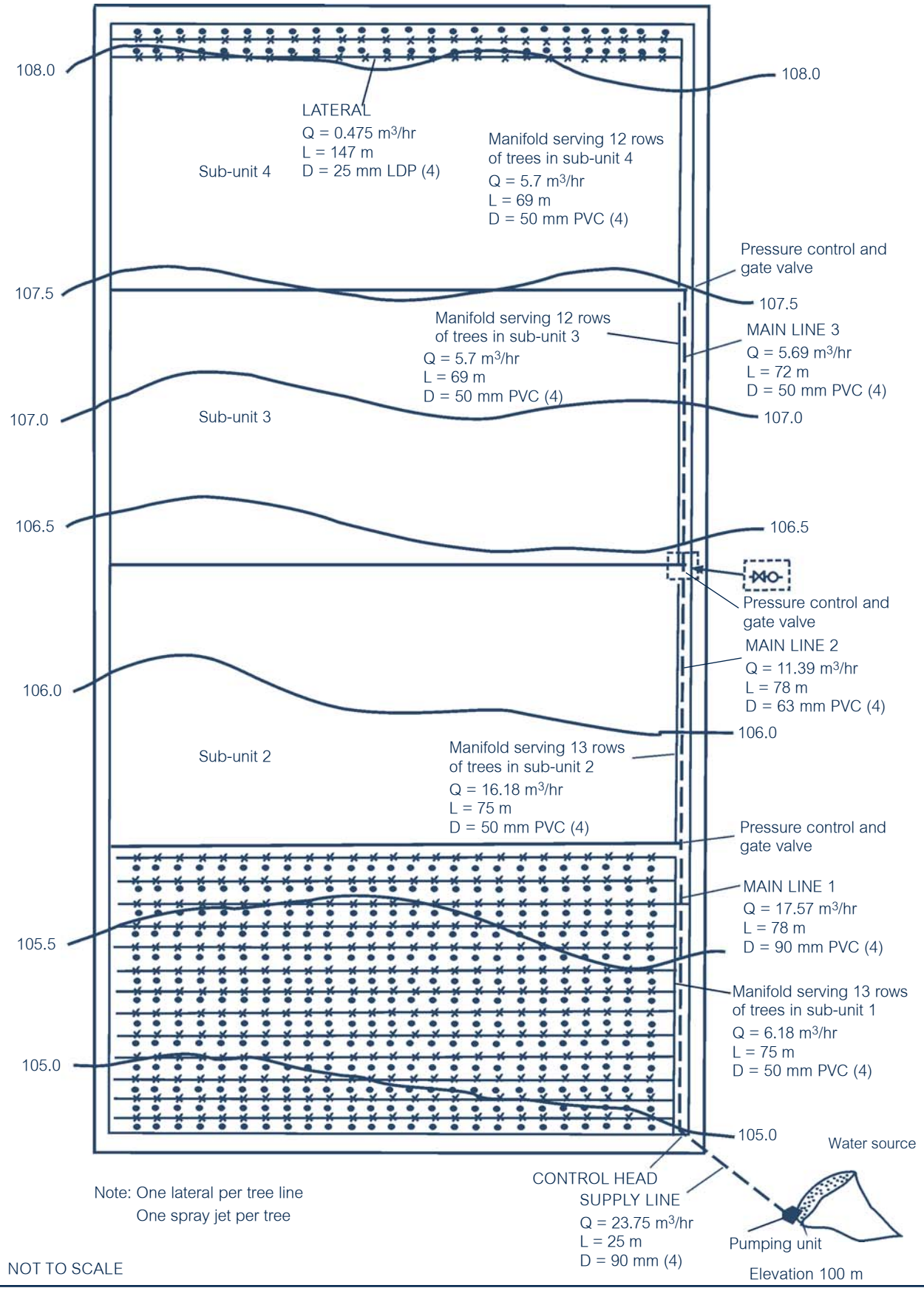
K = constant = 1.22×10^{12}

Q = flow (lps)

D = inside diameter (mm)

C = coefficient of retardation depending on pipe material (C = 140 for plastic)

Figure 21
Micro spray layout and pipe sizing for an individual farmer's citrus orchard



For our example the head losses in the 0.6 m micro tube of 8 mm diameter will be:

$$H_f(100) = 1.22 \times 10^{12} \times \frac{((18.3/(60 \times 60))/140)^{1.852}}{8^{4.87}}$$

$$= 0.292 \text{ m per 100 m}$$

The HL in the 0.6 m long micro tube = 0.00292 x 0.6 = 0.002 m, which is negligible.

7.5.2. Manifolds

The first and second manifolds will have a flow of 0.475 x 13 = 6.18 m^3/hr each. The third and fourth manifolds will have a flow of 0.475 x 12 = 5.7 m^3/hr each.

The next step is to establish whether the head losses are within the allowable pressure variation. Looking at the steepest sub-unit (3), the difference in elevation between the inlet of the manifold and the furthest sprayer is about 1 m. Therefore, the balance of 0.66 m (2.5 - 0.84 - 1) can be used for the head losses in this manifold. Following the same procedure, the balance of ΔHs for each manifold is calculated as follows:

Sub-unit 1 ΔH_s balance = 0.91 m (2.5 - 0.84 -0.75)
Sub-unit 2 ΔH_s balance = 0.86 m (2.5 - 0.84 - 0.81)
Sub-unit 3 ΔH_s balance = 0.66 m (2.5 - 0.84 - 1)
Sub-unit 4 ΔH_s balance = 0.96 m (2.5 - 0.84 - 0.7)

The pipe sizing of each manifold is calculated in such a way so that the corresponding ΔH_s balance is not exceeded. The head losses, including 10% for the manifold-to-lateral connection (grommet take-off) losses, would be calculated as follows:

Sub-unit 1 and 2

Q = 6.18m^3/hr
L = 75 m
D = 50 mm uPVC class 4
F = 0.390 (13 outlets)
HL = 0.022 x 75 x 0.390 x 1.1 = 0.71 m

Sub-unit 3 and 4

Q = 5.7 m^3/hr
L = 69 m
D = 50 mm uPVC class 4
F = 0.394 (12 outlets)
HL = 0.017 x 69 x 0.394 x 1.1 = 0.51 m

Therefore the HL of all manifolds plus the difference in elevation plus the HL of the lateral is within the ΔH_s.

7.5.3. Mainline

The mainline will supply all manifolds operating at the same time.

The total Q provided to the mainline by the supply line is (2 x 13 + 2 x 12) x 25 x 19 = 23 750 lph or 23.75 m^3/hr. However, at the beginning of the mainline the flow is reduced by 6.18 m^3/hr, which is the flow provided to the first manifold. Therefore:

Q_1 = 23.75 - 6.18 = 17.57 m^3/hr
L_1 = 13 x 6 = 78 m
D_1 = 90 mm uPVC class 4
HL_1 = 0.008 x 78 = 0.62 m

Q_2 = 17.57 - 6.18 = 11.39 m^3/hr
L_2 = 13 x 6 = 78 m
D_2 = 63 mm uPVC class 4
HL_2 = 0.02 x 78 = 1.56 m

Q_3 = 11.39 - 5.7 = 5.69 m^3/hr
L_3 = 12 x 6 = 72 m
D_3 = 50 mm uPVC class 4
HL_3 = 0.017 x 72 = 1.22 m

Total HL = 0.62 + 1.56 + 1.22 = 3.40 m

7.6.4. Supply line

The supply line starts from the water source to the southeastern corner of the plot, where it joins the mainline. Its discharge is 23.75 m^3/hr. The friction losses for 25 m long, 90 mm diameter uPVC class 4 pipeline would be:

HL = 0.0125 x 25 = 0.31 m

7.6. Total head requirement

The total head requirement is composed of the head losses in all pipes calculated earlier in addition to the sum of the following: the suction lift, the difference in elevation between the level of the water and the highest position in the field, the head losses in fitting plus the head requirement of the control head, the sprayer operating pressure. The control head, which is composed of the filtering system, the chemigation unit and the water meter, is considered as identical to that used in the previous chapter, which was 7 m.

Suction lift	2.00
Control head	7.00
HL supply line	0.31
HL mainline	3.40
HL manifold	0.71
HL lateral	0.84
Sprayer operating pressure	14.00

Subtotal	28.26
Fittings 10%	2.83
Emitter height above ground	0.20
Difference in elevation	8.20
Total	39.49

This is within the pressure rating of the class 4 uPVC pipes used in this design.

7.7. Power requirement

In this example, where Q = 23.75 m^3/hr and H = 39.48 m, the power requirements would be calculated using Equation 21a and 21b as follows, if a pump efficiency of 60% is assumed:

$$\text{Power requirements} = \frac{23.75 \times 39.48}{360 \times 0.6} = 4.3 \text{ kW}$$

or

$$\text{Power requirements} = \frac{23.75 \times 39.48}{273 \times 0.6} = 5.7 \text{ BHP}$$

Assuming 20% derating the power requirement will be:

Power requirements = 4.3 x 1.2 = 5.2 kW

Power requirements = 5.7 x 1.2 = 6.8 BHP

Chapter 8
Bill of Quantities for localized irrigation systems

A localized irrigation system is composed of the pumping unit, the supply line, the control head, the mainline and eventually secondary lines, the manifolds and the laterals or driplines with emitters (Figure 1).

Upon the completion of the design, drawings showing the various components of the system are prepared. These drawings refer to the connections of fittings, pipes, valves and other accessories required for the construction of the system. From these drawings and the layout map, a list of the items required for the construction of the system, called Bill of Quantities, can be compiled.

8.1. Pipes and fittings

As a rule, uPVC pipes are used for the underground part and polyethylene (PE) pipes for the above ground part of localized irrigation systems. Lay flat hoses and PE pipes are also used for the manifolds of localized irrigation system when they are above ground.

8.1.1. uPVC pipes and fittings

uPVC pipes come in 6 m lengths. The most commonly available uPVC pipes fall in four classes. Table 11 presents the working pressure of each class. As a rule, all uPVC fittings are rated at class 16 level. The most commonly used sizes are 25 mm to 250 mm diameter. All uPVC pipes and fittings should be buried, even if they are treated against the ultraviolet (UV) light range. Prolonged exposure to UV rays causes these pipes to become brittle. A change in colour of the uPVC pipe indicates prolonged unshaded storage, hence the requirement for the covered storage of uPVC pipes.

Table 11
uPVC pipe classes and corresponding working pressure rating (Source: SABS, 1976)

Class	Working Pressure (kPa)
4	400
6	600
10	1 000
16	1 600

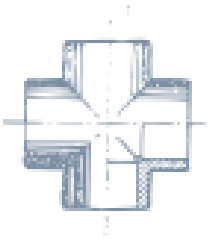
The most common uPVC fittings used with uPVC pipes are shown in Figure 22. While adapter types with rubber rings are used in some countries, the most common fitting in others are the solvent welding fittings, combined with threaded fitting where connection with valves and steel fittings are required. Bends 90° (SIV) (Figure 22a) or 45° are used when deviation from the straight line is required. Tees (TIV) (Figure 22b) have the same diameter on all three branches. Crosses (XIV) (Figure 22c) can be very useful where two secondaries branch from the main line or two laterals from a secondary. Reducing bushings (DIV)

Figure 22 (a-b)
uPVC fittings

a. SIV - 90º BEND for solvent welding

b. TIV - 90º TEE for solvent welding

Figure 22(c-j)
uPVC fittings

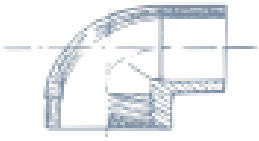


c. XIV - CROSS for solvent welding

d. DIV - REDUCING BUSHING for solvent welding

e. CIV - END CAP for solvent welding

f. TIFV - 90º TEE with two plain sockets and the third one with parallel thread (female)



g. GIFV - 90º ELBOW one end plain, the other with parallel thread

h. NIFV - BARREL NIPPLE one end plain for solvent welding, the other end parallel threaded

i. TBRP - PVC FLANGE with holes for bolts: TCP - tapered core

j. VTP - 90º TEE with two plain sockets and the third one with parallel male thread

(Figure 22d) are used when change in size is required. End caps (CIV) (Figure 22e) are used when the end of a pipe must be permanently closed. Tees with two plain sides for solvent welding and a middle outlet with female thread (TIFV) (Figure 22f) are used where threaded steel fittings are required. These, as well as the GIFV (Figure 22g), are used where threaded fittings, e.g. gate valves, ball valves, and disc fittings are required. Barrel nipples (NIFV) with one side plain for solvent welding and the other side with male thread (Figure 22h) can be used to connect a brass gate valve to a tee. In some countries, fabricated tees (VTP) (Figure 22j) are used for this purpose. Another set of useful fittings is the flange (TBRP) (Figure 22i) which, combined with the tapered core (TCP), can allow the connection of flanged items such as cast iron valves or water meters to the system.

8.1.2. PE pipes and fittings

Polyethylene comes in low density (LDPE) or high density (HDPE), depending on the density of the polymers used in the manufacture. For localized irrigation systems the laterals are made of LDPE.

Table 12
LDPE as per DIN 8072 'Type 32'

Outside diameter (mm)	Pressure rating					
	4 Bar		6 Bar		10 Bar	
	Wall thickness (mm)	Inside diameter (mm)	Wall thickness (mm)	Inside diameter (mm)	Wall thickness (mm	Inside diameter (mm)
12	1.3	9.4	1.6	8.8	2.0	8.0
16	1.8	12.4	2.0	12.0	2.7	10.6
20	2.0	16.4	2.2	15.6	3.4	13.2
25	2.2	20.6	2.7	19.6	4.2	16.6
32	2.4	27.2	3.4	25.2	5.4	21.2
40	3.0	34.0	4.3	31.4	6.7	26.6
50	3.7	43.6	5.4	39.2	8.3	33.4
63	4.7	53.6	6.7	49.6	10.5	42.0
75	5.6	63.8	8.1	58.8	12.5	50.0
90	-	-	-	-	15.0	60.0

Table 13
HDPE as per ISO 161/1 and DIN 'Type 50'

Outside diameter (mm)	Pressure rating			
	4 Bar	6 Bar	10 Bar	16 Bar
	Wall thickness (mm)			
16	-	-	2.0	2.9
20	-	-	2.0	2.9
25	-	2.0	2.3	3.6
32	-	2.0	3.0	4.5
40	2.0	2.3	3.7	5.7
50	2.0	2.9	4.6	7.1
63	2.5	3.6	5.8	8.9
75	2.9	4.3	6.9	10.6
90	3.5	5.1	8.2	12.7
110	4.3	6.3	10.0	15.5
125	4.9	7.1	11.4	17.6
140	5.4	8.0	12.8	19.7
160	6.2	9.1	14.6	22.5
200	7.7	11.4	18.2	27.6
250	9.7	14.2	22.8	34.5

Tables 12 and 13 provide the dimensions and the pressure ratings of LDPE as per DIN 8072 'Type 32' and HDPE as per ISO 161/1 and DIN 8074 'Type 50' respectively. As a rule, the 4 bar rated LDPE is used for the laterals. This pipe comes in coils of various lengths, depending on the diameter. The LDPE is connected to the uPVC manifolds through grommet take-offs, as shown in Figure 23, which also shows the different line connectors that are used when lateral repairs are needed. The same connectors are also used to connect LDPE to the tape type lateral after a short length of LDPE is connected to the manifold through a grommet take-off.

The end of each lateral is closed either by folding the lateral and inserting a sleeve of PVC pipe or by using end plugs.

8.2. Specialized equipment for localized irrigation systems

8.2.1. Control head

The control head is composed of the filtering system, the water metering system and the pressure measurement points. The filtering system can be a combination of sand filters and screen or disk filters or only disc or screen filters,

Figure 23
Various polyethylene connections

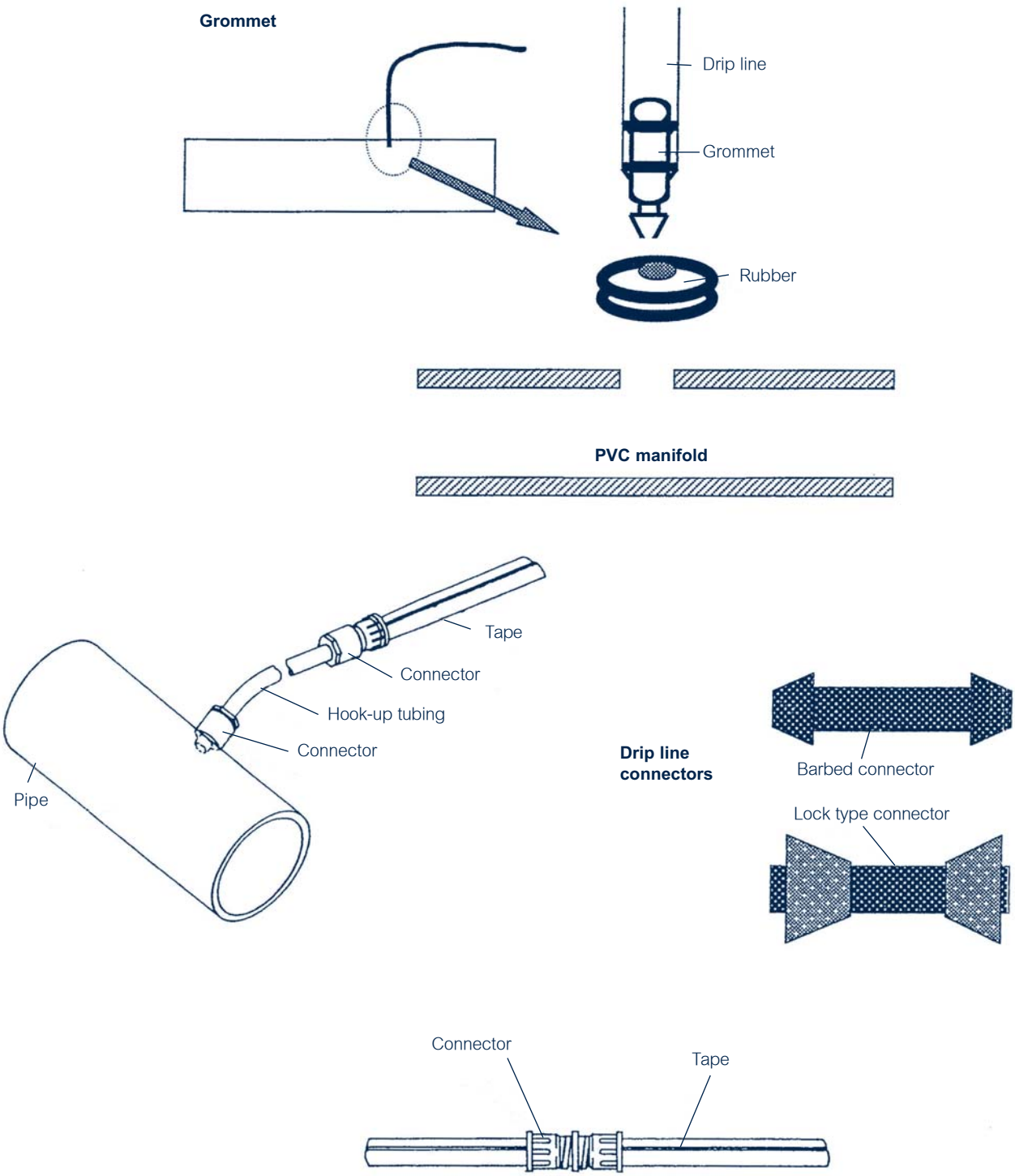
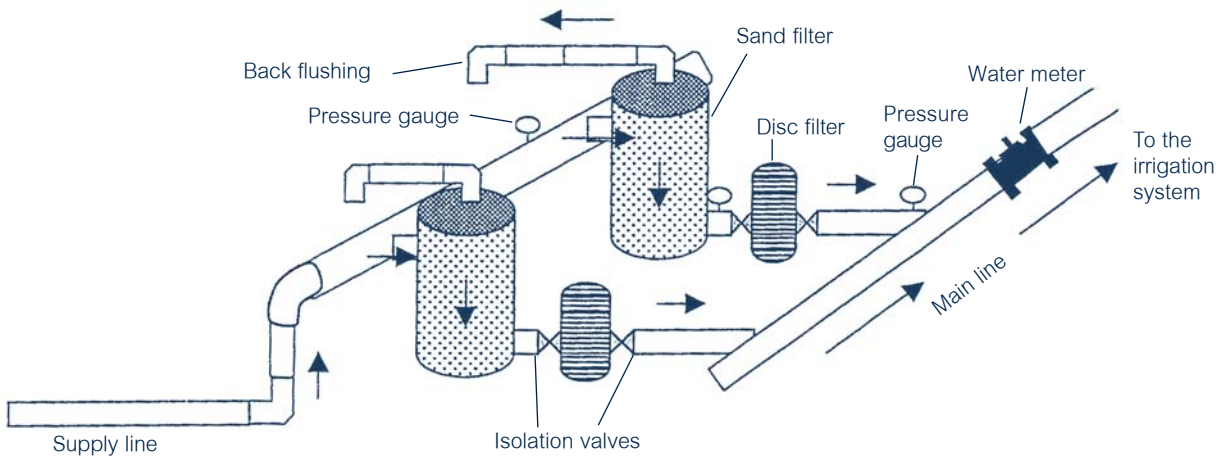


Figure 24
Components of the control head (Source: Savvides, 2001)



depending on the sediment content of the water. In our example where surface water is used, the combination option is relevant. Figure 24 shows how these filters are joined together. The same figure also shows the pressure points and the water meter.

8.2.2. Fertigation system at the control head or at the inlet of individual plots

For single user systems provision is also made for the injection of water-soluble fertilizers (fertigation) at the control head, specifically before the filters in order to capture any impurities before entering the system. For smallholders localized irrigation systems fertigation is practiced at the inlet of the individual plots. To avoid any impurities from entering the system, a small line filter is used after the injection point. Figure 25 shows the arrangement of fertigation using the bladder tank.

8.3. Bill of Quantities

Based on the drawings and layout maps for the four designs of localized systems, prepared in Chapters 3, 4, 5 and 7, the Bill of Quantities can be compiled.

8.3.1. List of equipment: Point-source drip irrigation system for an individual user (Chapter 3)

Pumping Plant

- 1 pumping unit capable of delivering 16.20 m^3/hr at a head of 39.32 m with the highest possible efficiency. Pump to be directly coupled to the electrical motor. The pumping unit should be complete, with suction and delivery pipes, valves, strainer, pressure gauge non-return valve and air release valve. Floating suction arrangements are required.

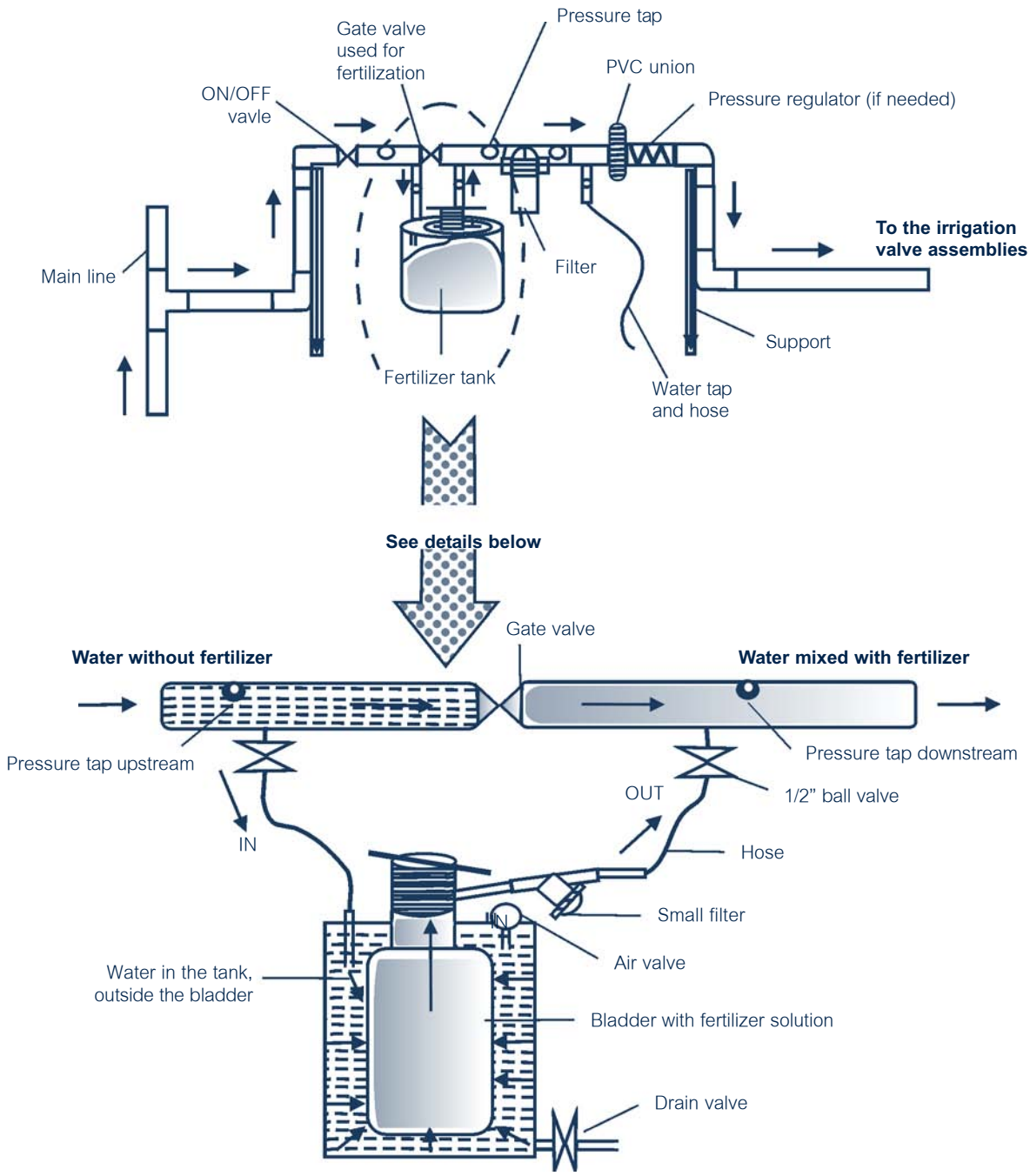
Control head

- One twin barrel sand filter unit equipped with valves for individual back-flushing. Each vessel should be equipped with a disc filter at its outlet followed by a small valve for short hose connection, to be used for washing the disc filters individually. Isolation valves before and after each disc filter are required, to allow for the disconnection of the disc filters from the system (Figure 24).

  Provision should be made for pressure measuring points upstream and downstream of the fertigation unit, and of each vessel and each disc filter and their connection to two pressure gauges through small diameter polyethylene tubes and three way valves. Provision should also be made for the connection of the fertigation unit before the sand filters. The choice of fertigation unit and the size of the filter should be such so that the total head losses in the head of the system do not exceed 7 m just before cleaning is required. The water meter is to be installed after the filtering system and should be of the helix type and flanged.

Figure 25

Smallholder fertigation system at plot level (Source: Savvides, 2001)



Pipes and fittings (See Table 14)

Table 14
Bill of Quantities for pipes and fittings for the point-source drip irrigation system for an individual user

Item	Quantity	Unit	Unit cost	Total cost
Supply and mainline				
- uPVC pipe 75 mm class 4	180	m		
- uPVC pipe 63 mm class 4	78	m		
- reducing bush uPVC 75 mm x 63 mm	1	each		
- elbow 45° uPVC 75 mm	1	each		
- elbow 45° uPVC 63 mm	1	each		
- barrel nipple uPVC 63 mm x 2 inch	1	each		
- end cap uPVC 2 inch	1	each		
- reducing uPVC tee 75 mm x 50 mm x 75 mm	3	each		
- reducing uPVC tee 75 mm x 63 mm x 75 mm	1	each		
- barrel nipple 50 mm x 2 inch	12	each		
- union 50 mm	3	each		
- pressure regulator 2 inch	4	each		
- barrel nipple 63 mm x 2 inch	4	each		
- gate valve 2 inch	1	each		
- union 63 mm	1	each		
- saddle outlet 50 mm x 1 inch	3	each		
- saddle outlet 63 mm x 1 inch	1	each		
- rizer uPVC 25 mm class 16, 1.5 m long	4	each		
- uPVC end cap 25 mm	4	each		
- pressure tap	4	each		
Manifolds				
- uPVC pipe 50 mm class 4	222	m		
- elbow 90° uPVC 50 mm	3	each		
- uPVC pipe 63 mm class 4	78	m		
- elbow 90° uPVC 63 mm	1	each		
- elbow 45° uPVC 50 mm	3	each		
- elbow 45° uPVC 63 mm	1	each		
- barrel nipple 50 mm x 2 inch	3	each		
- end cap 2 inch	3	each		
- barrel nipple 63 mm x 2 inch	1	each		
- end cap 2 inch	1	each		
- grommet take-off 20 mm	100	each		
Laterals				
- LDPE pipe 20 mm class 4	15 000	m		
- drippers 4 lph at H = 10 m with a Cv = 0.07 or better and x = 0.42 or better	7 500	each		
- end sleeves, 2 cm long, 40 mm	100	each		

8.3.2. List of equipment: Point-source drip irrigation system for smallholder farmers (Chapter 4)

Pumping plant

- 1 pumping unit capable of delivering 23.0 m^3/hr at a head of 36.2 m with the highest possible efficiency. Pump to be directly coupled to the electric motor. The pumping unit should be complete, with suction and delivery pipes, valves, strainer, pressure gauge and non-return valve and air release valve at the outlet. Floating suction arrangements are required.

Control head

- One twin barrel sand filter unit equipped with valves for individual back-flushing. Each vessel should be equipped with a disc filter at its outlet followed by a small valve for

short hose connection, to be used for washing the disc filters individually. Isolation valves before and after each disc filter are required, to allow for the disconnection of the disc filters from the system.

Provision should be made for pressure measuring points upstream and downstream of each vessel, and each disc filter and their connection to two pressure gauges through small diameter polyethylene tubes and three-way valves. The total head losses in the control head should not exceed 7 m just before cleaning is required. The water meter is to be installed after the fitting system and should be of the helix type and flanged.

Pipes and fittings (See Table 15)

Table 15

Bill of Quantities for pipes and fittings for the point-source drip irrigation system for smallholder farmers

Item	Quantity	Unit	Unit cost	Total cost
Supply and mainline				
- uPVC pipe 90 mm class 4	162	m		
- reducing bush uPVC 90 mm x 75 mm	1	each		
- elbow 90° uPVC 90 mm	1	each		
- elbow 45° uPVC 90 mm	1	each		
- uPVC pipe 75 mm class 4	78	m		
- reducing bush uPVC 75 mm x 63 mm	1	each		
- uPVC pipe 63 mm class 4	78	m		
- elbow 45° uPVC 63 mm	1	each		
- barrel nipple uPVC 63 mm	1	each		
- end cap female threaded uPVC 63 mm	1	each		
- tee uPVC 90 mm	8	each		
- reducing bush uPVC 90 mm x 40 mm	8	each		
- tee uPVC 75 mm	16	each		
- reducing bush uPVC 75 mm x 40 mm	16	each		
- tee uPVC 63 mm	8	each		
- reducing bush uPVC 63 mm x 40 mm	8	each		
Manifolds				
- uPVC pipe 40 mm class 4	576	m		
- uPVC pipe 40 mm class 16	162	m		
- elbow 90° uPVC 40 mm	128	each		
- brass ball valve 40 mm (1½inch)	64	each		
- barrel nipple uPVC 40 mm	128	each		
- union uPVC 40 mm	32	each		
- pressure regulator 40 mm	32	each		
- socket, female threaded, uPVC 40 mm	64	each		
- disc filter 1 inch	32	each		
- pressure tap	96	each		
- VTP tee uPVC 40 mm x ½inch x 40 mm	64	each		
- brass ball valve ½inch	64	each		
- GI nipple ½inch	64	each		
- reinforced pressure hose ½inch	128	m		
- bladder tank fertigation units complete with accessories	8	each		
- hose clips for ½inch hose	128	each		
- elbow 45° uPVC 40 mm	32	each		
- barrel nipple uPVC 40 mm	32	each		
- end cap, female threaded, uPVC 40 mm	32	each		
Laterals				
- grommet take-off 20 mm	384	each		
- LDPE hose 20 mm class 4	27 648	m		
- in-line drippers 2 lph at H = 10 m with a Cv = 0.03 or better and x = 0.5 or better	92 160	each		
- end sleeves, 2 cm long, 40 mm	384	each		

8.3.3. List of equipment: Line-source drip irrigation system for smallholder farmers (Chapter 5)

Pumping plant

- 1 pumping unit capable of delivering 26.9 m^3/hr at a head of 36.06 m with the highest possible efficiency. Pump to be directly coupled to the electrical motor. The pumping unit should be complete, with suction and delivery pipes, valves, strainer, pressure gauge and non-return valve and air release valve at the outlet. Floating suction arrangements are required.

Control head

- One twin barrel sand filter unit equipped with valves for individual back-flushing. Each vessel should be equipped with a disc filter at its outlet followed by a small valve for short hose connection, to be used for washing the disc filters individually. Isolation valves before and after each disc filter are required, to allow for the disconnection of the disc filters from the system.

Provision should be made for pressure measuring points upstream and downstream of each vessel, and each disc filter and their connection to two pressure gauges through small diameter polyethylene tubes and three-way valves. The total head losses in the control head should not exceed 7 m just before cleaning is required. The water meter is to be installed after the filtering system and should be of the helix type and flanged.

Pipes and fittings (See Table 16)

Table 16

Bill of Quantities for pipes and fittings for the line-source drip irrigation system for smallholder farmers

Item	Quantity	Unit	Unit cost	Total cost
Supply and mainline				
- uPVC pipe 90 mm class 4	246	m		
- reducing bush uPVC 90 mm x 75 mm	1	each		
- elbow 90° uPVC 90 mm	1	each		
- elbow 45° uPVC 90 mm	1	each		
- uPVC pipe 75 mm class 4	78	m		
- reducing bush uPVC 75 mm x 63 mm	1	each		
- elbow 45° uPVC 63 mm	1	each		
- barrel nipple uPVC 63 mm	1	each		
- end cap female threaded uPVC 63 mm	1	each		
- tee uPVC 90 mm	26	each		
- reducing bush uPVC 90 mm x 40 mm	26	each		
- tee uPVC 75 mm	10	each		
- reducing bush uPVC 75 mm x 40 mm	10	each		
- tee uPVC 63 mm	12	each		
- reducing bush uPVC 63 mm x 40 mm	12	each		
Manifolds				
- uPVC pipe 40 mm class 4	576	m		
- uPVC pipe 40 mm class 16	240	m		
- elbow uPVC 40 mm	48	each		
- brass ball valve 40 mm (1½nch)	96	each		
- barrel nipple uPVC 40 mm	48	each		
- end cap female threaded 40 mm	48	each		
- elbow uPVC 40 mm	192	each		
- barrel nipple uPVC 40 mm	192	each		
- union uPVC 40 mm	48	each		
- pressure regulator 40 mm	48	each		
- socket, female threaded, uPVC 40 mm	96	each		
- disc filter 1 inch	48	each		
- pressure tap	144	each		
- VTP tee 90° uPVC 40 mm x ½nch x 40 mm	96	each		
- brass ball valve ½nch	96	each		
- GI nipple ½nch	96	each		
- reinforced pressure hose ½nch	192	m		
- bladder tank fertigation units complete with accessories	8	each		
- hose clips for ½nch hose	192	each		
Laterals				
- grommet take-off 20 mm	384	each		
- LDPE pipe 16 mm	384	m		
- line-source hose with drippers at 30 cm intervals, each dripper providing a discharge of 1.75 lph at H = 10 m with a Cv = 0.03 or better and x = 0.48 or better	3 456	each		
- connector 16 mm	384	each		
- end sleeves, 2 cm long, 40 mm	384	each		

8.3.4. List of equipment: Micro spray irrigation system for an individual user (Chapter 7)

Pumping plant

- 1 pumping unit capable of delivering 23.75 m^3/hr at a head of 39.48 m with the highest possible efficiency. Pump to be directly coupled to the electric motor. The pumping unit should be complete, with suction and delivery pipes, valves, strainer, pressure gauge and non-return valve and air release valve at the outlet. Floating suction arrangements are required.

Control head

- One twin barrel sand filter unit equipped with valves for individual back-flushing. Each vessel should be equipped with a disc filter at its outlet followed by a small valve for short hose connection, to be used for washing the disc filters individually. Isolation valves before and after each disc filter are required, to allow for the disconnection of the disc filters from the system (Figure 21).

Provision should be made for pressure measuring points upstream and downstream of the fertigation unit head, and of each vessel and each disc filter and their connection to two pressure gauges through small diameter polyethylene tubes and three-way valves. Provision should be made also for the connection of a fertigation unit before the sand filters. The choice of fertigation unit and the size of the filter should be such so that the total head losses in the head of the system do not exceed 7 m just before cleaning is required. The water meter is to be installed after the filtering system and should be of the helix type and flanged.

Pipes and fittings (See Table 17)

Table 17

Bill of Quantities for pipes and fittings for the micro spray irrigation system for an individual user

Item	Quantity	Unit	Unit cost	Total cost
Supply and mainline				
- uPVC pipe 90 mm class 4	108	m		
- reducing bush uPVC 90 mm x 63 mm	1	each		
- uPVC pipe 63 mm class 4	78	m		
- reducing bush uPVC 63 mm x 50 mm	1	each		
- uPVC pipe 50 mm class 4	72	m		
- VTP tee 90 mm x 2 inch x 90 mm	2	each		
- VTP tee 63 mm x 2 inch x 63 mm	1	each		
- VTP tee 50 mm x 2 inch x 50 mm	1	each		
Manifolds				
- brass gate valve 2 inch	8	each		
- GI nipple 2 inch	4	each		
- barrel nipple uPVC 50 mm	8	each		
- elbow 90° uPVC 50 mm	4	each		
- uPVC pipe 50 mm class 4	300	m		
- elbow 45° uPVC 50 mm	4	each		
- end cap female threaded uPVC 50 mm	4	each		
Laterals				
- grommet take-off 25 mm	50	each		
- LDPE pipe 25 mm	7 500	m		
- micro-spray with Q = 19 lph at H = 14 m with a Cv = 0.05 or better and x = 0.5 or better	3 456	each		
- LDPE hose 8 mm	750	m		
- stakes for spray jets	1 250	each		
- end sleeves, 2 cm long, 40 mm	50	each		

8.4. Labour and other material

In addition to the above material, labour is required for the following tasks:

- Trenching and back-filling
- Setting out
- Pipe laying

Labour, material and machinery are also required for the construction of the following:

- Access roads and drains
- Fencing
- Toilets, storage structures, etc.

Examples of BOQs for these tasks are given in Module 8 (on sprinkler irrigation) and Module 13 (on the construction of irrigation schemes).

Chapter 9
Emitter clogging and water treatment

The narrowness of water passages of the emitters makes localized irrigation systems prone to clogging. It is therefore necessary that measures are taken and appropriate means are designed to remove the clogging agents. As these measures will depend on the type and amount of impurities present in the water, an analysis of the water is a must before a designer can decide on the appropriate water treatment.

9.1. Causes of clogging

Emitter clogging can be attributed to physical, chemical and biological causes. The first category includes sand, silt, plastic chips and metallic flakes. Chemical precipitation of iron and salts, such as calcium carbonate, and precipitation of fertilizers in the laterals and the emitters belong to the second category. Growth of algae in the water source and, at times, in the dripper, and/or growth of bacterial slime in the system and bacterial precipitation of sulfur or iron fall within the biological causes of clogging.

Very often, the combination of at least two causes is experienced when surface water sources are used, or when pumped water is stored in open reservoirs before it is used. It is therefore necessary to have a complete picture of the water quality so that adequate measures are incorporated in the system. This can be done through a water analysis that includes:

- Total suspended solids
- Complete cation-anion analysis
- Hardness and pH
- Total dissolved solids
- Iron (both ferrous and ferric) and hydrogen sulfide
- Bacteria populations and possibly iron bacteria

The results of the analysis would then be interpreted using Table 18 to establish the degree of restriction of localized irrigation use. The outcome of the water analysis assessment would also determine the type of water treatment required.

9.2. Water treatment for localized irrigation systems

Depending on the nature of the impurities in the water, simple measures or a combination of measures are needed in order to remove the impurities. As a rule, groundwater would require simple filtration systems, such as screen filters or disc filters, to remove the sand. However, as at times precipitation of chemicals can occur because of pH and temperature changes, the treatment of groundwater with chemicals may be necessary. For open sources of water, pretreatment with settling basins or vortex separators followed by sand media filters and screen filters combined with chemical treatment may be required.

As a rule, the filtration and chemigation plant is located at the pumping station. Additional protection should also be provided, through small screens or disc filters at the header

Table 18

Influence of water quality on the potential for clogging problems in drip irrigation systems (Source: FAO, 1985)

Potential problem	Units	Degree of restriction on use		
		None	Slight to moderate	Severe
Physical:				
Suspended solids	mg/l	< 50	50 - 100	> 100
Chemical:				
pH		< 7.0	7.0 - 8.0	> 8.0
Dissolved solids	mg/l	< 500	500 - 2 000	> 2 000
Manganese	mg/l	< 0.1	0.1 - 1.5	> 1.5
Iron	mg/l	< 0.1	0.1 - 1.5	> 1.5
Hydrogen sulphide	mg/l	< 0.5	0.5 - 2.0	> 2.0
Biological:				
Bacterial population	maximum number/ml	< 10 000	10 000 - 50 000	> 50 000

of the laterals or the manifolds, depending on costs. These filters will provide protection when pipe breakages cause the debris to enter the system. For multi-user systems, small screen or disc filters will be required after the fertigation unit of each user.

9.2.1. Filtration

Particle size

Most manufacturers recommend the removal of particles larger than 0.075 mm or larger than 0.15 mm, depending on the emitter path and its aperture. As a rule, it is recommended to remove particles that are larger than one tenth of the diameter of the emitter flow passage. This is because several small particles may group together and cause clogging.

Another aspect that deserves serious consideration is that it is very likely for fine and very fine sands to settle out and deposit in areas where the flow is slow, such as the end of the laterals or at low points, after the system is turned off. Fine particles can also settle along the walls of laminar flow emitters. Therefore, it may be necessary to use 200 mesh screens, even when the emitter passage has a cross-section close to 1 mm.

The standard classification of soil particle sizes as related to screen mesh numbers is provided in Table 19.

The most commonly used fine screen for drip irrigation systems is the 200 mesh screen. The hole/aperture of this screen is 0.074 mm. It is therefore apparent, looking at Table 19, that a good portion of very fine sand and all the silt and clay pass through the filter in the system.

Types of filtration

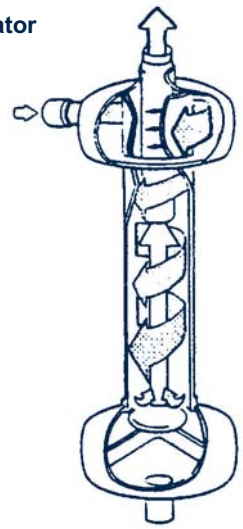
Settling basin

This is an easy way of removing suspended solids from the water. According to Keller and Bliesner (1990), they should be constructed in such a way so that it takes 15 minutes for the entering water to reach the pump intake. During this time, most inorganic particles larger than 0.08 mm will settle. This is equivalent to 200 mesh filtration. As a rule, settling basins are used together with other types of water treatment.

Vortex sand separator

The vortex sand separators are particularly suitable and very effective for treating waters containing appreciable amounts of sand. Modern ones can remove up to 98% of the sand particles that would be contained in a 200 mesh filter. Figure 26 shows a sand separator.

Figure 26
Sand separator



Screen mesh filter

This is the simplest of all filters. It uses either stainless steel or strong plastic mesh, through which the water is filtered. Most screen filters are designed to take water in one direction only. As such, the screen filter can not be back-washed. However, a number of manufacturers produce screen filters that can be back-washed when used in pairs.

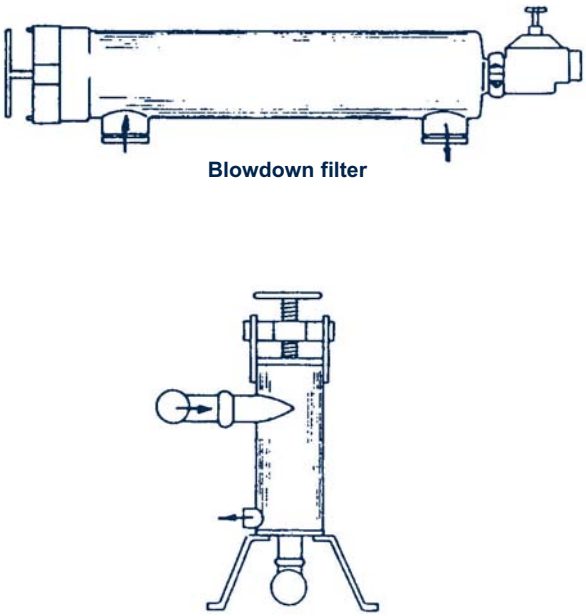
Table 19
Soil particle classification and corresponding screen mesh numbers (Source: Keller and Bliesner, 1990)

Soil classification	Particle size (mm)	Microns	Screen mesh number*
Very coarse sand	1.00 - 2.00	1000 - 2000	18 - 10
Course sand	0.50 - 1.00	500 - 1000	35 - 18
Medium sand	0.25 - 0.50	250 - 500	60 - 35
Fine sand	0.10 - 0.25	100 - 250	160 - 60
Very fine sand	0.05 - 0.10	50 - 100	270 - 160
Silt	0.002 - 0.05	2 - 50	400 - 270
Clay	<0.002	<2	-

* *Screen mesh number refers to the number of openings per linear inch*

As a rule filtering elements are not very strong. Consequently, when the filter becomes blocked the screen or mesh can tear and solids can enter the system. They are not recommended for the removal of algae or sticky organic material. Such material coats the filter screen and is difficult to remove. Most mesh filters are cleaned manually by removing the element from the case and using unfiltered water. Others (blowdown) use the high velocity of flowing water through the middle of the filter, thus dislodging and blowing down the accumulated load of sand. Figure 27 shows two types of screen mesh filters.

Figure 27
Screen mesh filters



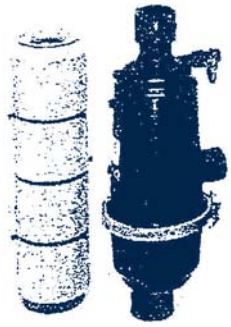
It is customary to clean the screen filters when the pressure drop across the filter increases by 35 kPa. The head loss through a mesh filter ranges from 35 to 70 kPa.

The maximum recommended flow rate through a fine screen should be less than 135 lps per m^2 of screen open area. It should be noted that a standard 200 mesh stainless steel screen has 58% open area, while a nylon mesh of equivalent size has 24% open area.

Disc filter

The element of this type of filter is composed of many plastic discs with grooves that are very tightly spaced (Figure 28). Water is filtered through the grooves.

Figure 28
Disc filter



As water can pass through the discs in both directions, these filters can be back-washed. They have gained popularity during the last 10 to 15 years and are used in place of screen mesh filters, being competitive in cost and having the added advantage of allowing back-washing. When used in combination with sand filters, provision should be made for a hose with clean water when cleaning of the discs.

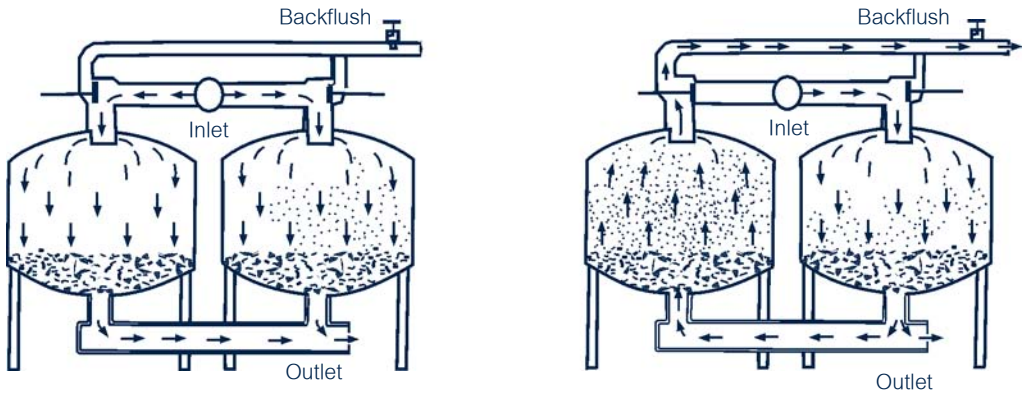
Sand media filter

This type of filter was developed to arrest particles that other types of filters can not remove. They are effective in filtering out particles in the range of 25-200 microns. They are therefore suitable for removing heavy loads of very fine sand and they are especially suitable for removing organic impurities such as algae. During the filtration process, water percolates through layers of sand and particles adhere to the sand to form larger particles. Because of their high cost, they are generally used when a screen or disc filter requires very frequent cleaning or to remove particles that the 200 mesh can not remove. They are recommended for filtering out algae.

The filters are cleaned through back-flushing. For this process a minimum of two filters is required (Figure 29). The clean water from one filter is diverted to the lower end of the other filter. Clean water is pushed through the media, lifting it up to allow the dirty water to flow outside the filter. It is not possible to clean a sand filter if the filtering system has only one sand filter, as there will be no clean water from one filter to back-wash the other.

The maximum recommended pressure drop across sand filters is 70 kPa. It is therefore advisable that back-washing is frequent enough to maintain the pressure drop within the prescribed limits. For this reason, all filters should be equipped with a pressure gauge at the inlet and a pressure gauge at the outlet. The recommended back-washing rates are 7 to 10 lps per m^2 of filter bed for number 30 and 20 media and 14 and 17 lps per m^2 for number 16 and 11 media (Table 20) (Keller and Bliesner 1990).

Figure 29
Sand media filters (Source: James, 1998)



Filtration process **Back-washing process**

Table 20
Type and size of media used in sand filters

Number	Material	Mean granule size (microns)	Particle size removed (microns)
8	Crushed granite	1840	>160
11	Crushed granite	952	>80
16	Silica	806	>60
20	Silica	524	>40
30	Silica	335	>20

While each of the sand filters has a screen at the discharge side, so that no sand goes in the system, it is both a standard practice and advisable that sand media filters are followed by either a screen filter or a disc filter to avoid sand entering the system during the cleaning process.

There are five different sizes and two different types of sand used as media in these filters. Table 20 provides the details. Beach sand should not be used as filter media as it contains calcium carbonate (from ASAE, 1990).

The efficiency of these filters depends on the material used, the depth of the filter bed and the flow rate per unit area. As a rule, for the same water quality and sand media, the higher the flow rate the larger the size of particles that go through. Therefore, the lower the flow rate per unit area of filter the more effective the filtration will be. According to ASAE (1990), in general the water flow rates through filters should be between 10 and 19 lps per m^2 of bed.

On the depth of the bed, FAO (1984) recommends that it should not exceed 45 to 90 cm. When the depth of the filtration exceeds 90 cm, channels may develop in the sand bed during the back-washing process.

9.2.2. Treatment of chemical precipitation

Precipitation of minerals occurs when, due to changes in the pH and/or temperature, soluble minerals start to solidify and slowly cause the clogging of the emitters. There is a difference between the precipitates and the deposits of minerals resulting from evaporation. As the latter form on the outside of the emitter, they cause problems at the outlet of the emitter only.

Calcium precipitates are a potential problem in the case of much well water. According to Keller and Bliesner (1990), a bicarbonate concentration of 2 meq/l or more, combined with a pH > 7.5, is likely to produce calcium precipitates. This can be treated with the injection of acid (usually hydrochloric or sulphuric acid) at such concentrations to maintain a pH between 5.5 and 7. An acid titration in the laboratory, combined with pH measurements, can establish the correct amount of acid required. Typically, the acid is injected at 0.02 to 0.2% of the system capacity.

A simpler and more effective way, especially when the concentration of bicarbonate is very high, is to aerate the water and keep it in a reservoir until the equilibrium is reached and the precipitates settle out in the reservoir.

Iron may cause clogging problems, even at concentrations as low as 0.3 ppm. Iron present in water in its ferrous form (soluble) will precipitate in the presence of oxygen and will be oxidized to the ferric form. This will cause reddish-brown precipitates.

Aeration ponds can also solve the problem of iron precipitates, especially when the concentration is high. For the cases of very high concentration (10 ppm), the combination of a mechanical aerator and a settling tank is advisable. For relatively low concentrations,

chlorination is recommended. A chlorinator, preferably using sodium hypochloride, can be adjusted to provide enough chlorine to allow for a residual level of 1 ppm in the system. Through this process, the iron is oxidized and filtered out by the media filter. The use of calcium hypochloride is not recommended when the water is somewhat hard, as it tends to precipitate calcium.

9.2.3. Organic growth and deposits

Severe clogging is caused by algae and the slime created by bacteria. Algae are common in most surface water resources. The presence of light and nutrients present in the water are, when combined with warm weather, factors promoting the growth of algae in surface water resources. While small amounts of algae can be removed by screen filters, sand media filters are more effective. However, small particles of algae can also pass through the sand filters. Nevertheless, because of the black colour of the laterals and the emitters, these particles can not grow in the system as there is no light. However, in darkness bacteria tend to break down these algae particles. The residual algae can then leave the system through the emitter water passages.

Another measure effective in reducing the algae problem is the use of floating suction when surface water is used. Through this arrangement, the pumped water can be taken from a depth of reduced algae growth because of reduced light.

The most dangerous of all types of clogging is that attributed to the proliferation of the growth of slime-producing bacteria in the system. This slime will act as a glue on which silt and clay particles, as well as algae particles, are joined together to clog the system. These bacteria need no sunlight to grow. The most common ones are airborne. Systems that use open water sources are therefore prone to bacterial slime growth.

Another type of bacteria, ones rather specialized in producing a reddish-brown slime from feeding on metallic iron dissolved in the water as well as on metal parts of the system, are the iron bacteria. Even with concentrations of iron as low as 0.3 ppm, when the pH is between 4.0 and 8.5, they can produce enough slime to clog the emitters (Keller and Bliesner 1990).

9.2.4. Chlorination

Both algae and slime can be effectively controlled through chlorination. They can be eliminated by maintaining a continuous concentration of 1 ppm residual chlorine at the end of the laterals.

Keller and Bliesner (1990) provide the following standard recommendations of chlorination against different micro-organisms and precipitation problems:

Algae	:	Use 0.5 to 1.0 ppm of chlorine continuously or 20 ppm during the last 20 minutes of each irrigation.
Slimes	:	Maintain 1 ppm free residual chlorine at the end of the lateral.
Iron bacteria	:	Use 1 ppm over the number of ppm of iron present in the water (this can vary depending on the number of bacteria present)
Hydrogen sulphide	:	Use 3.6 to 8.4 times the hydrogen sulphide content.
Iron precipitation	:	Use 0.64 times the Fe^{2+} content to maintain 1 ppm residual chlorine at the end of the lateral.
Manganese precipitation	:	Use 1.3 times the Mn content.

9.2.5. Chemical injection systems

Different ways are employed to inject chemicals in the irrigation systems. The most versatile method is the use of pumps. Positive displacement piston or paddle pumps draw the chemical from an open tank and inject it into the irrigation system. Pressure differential is the oldest way to inject chemicals into the irrigation water (see Section 10.2.5). Subsequent developments include a collapsible sack inside the tank, where the solution is placed. The water from the irrigation pipe is then between the sack and the wall of the tank, allowing constant solution injection. Another development is the use of by-pass lines and Venturie-type injectors with metering valves, allowing the drawing of the solution from an open tank to permit constant solution injection.

Whatever the adopted method, the connection of the injecting unit should occur between the pumping unit of the irrigation system and the filtering system, in order to avoid impurities contaminating the system. Provision should also be made to avoid the return of the chemical solution to the water source or of water from the irrigation pipe to the injection tank. In the case of smallholders with individual plots, chemigation should be done at the plot level and a small filter is required after the chemigation unit.

9.3. Conclusion

The need for a well-maintained and fully-functioning water treatment system is great indeed. Back-flushing based on the recommendation of the manufacturer (either automatic or manual), combined with flow and pressure measurement record keeping and analysis, are the most commonly used means for this purpose.

Measurements of the residual levels of chlorine at the furthest laterals and compliance with the recommended levels, combined with periodic flushing of the laterals and manifolds, help to keep the system clean.

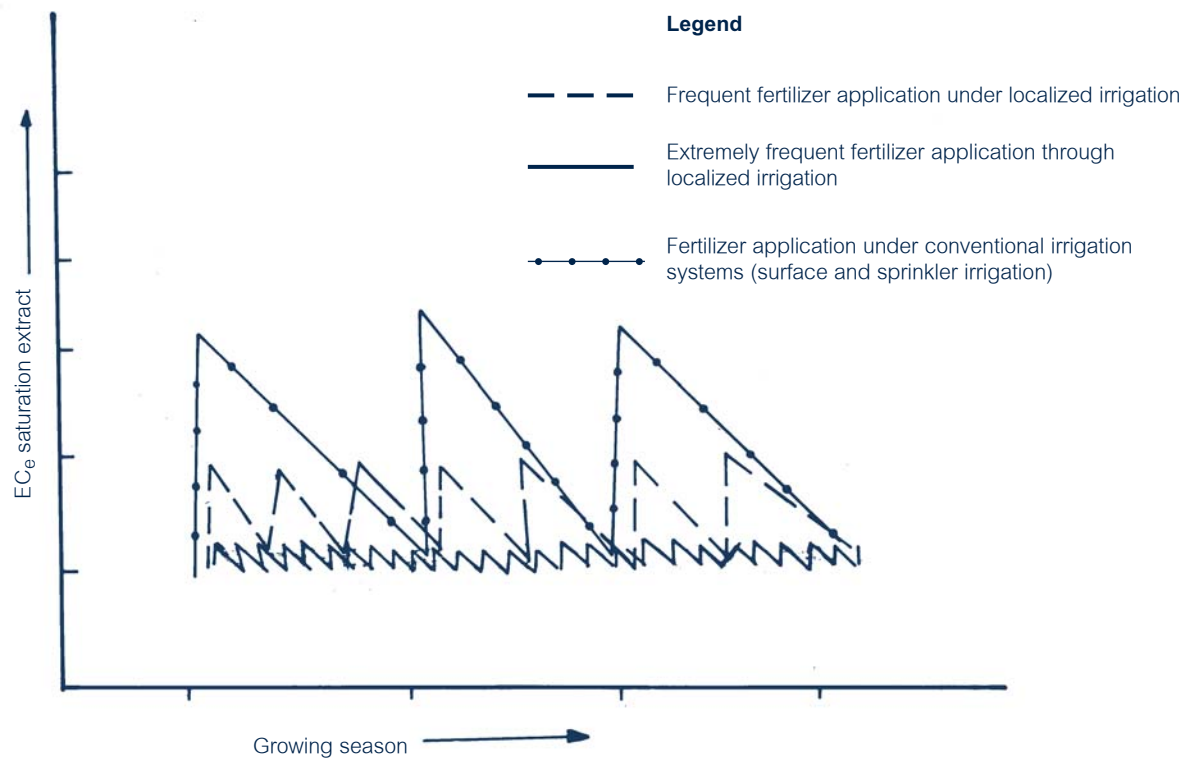
Chapter 10
Fertigation for localized irrigation

Soil fertility is of the greatest importance to the productivity of a farming system. While a number of factors affect the productivity of the soils, the availability of nutrients to the crops is of paramount importance. All other factors being equal, the availability of soil nutrients and the availability of water would determine the level of crop yield. It has therefore become common practice to supplement the available soil nutrients with organic and chemical fertilizers in an effort to increase yields. This is especially true of irrigated conditions, as the second element, water, is also available. Water provides the means for dissolving the nutrients in the soil, enabling their absorption by the plants and the means to meet the evapotranspiring demands of the crop for growth and productivity.

With surface irrigation systems, and to a lesser degree with sprinkler irrigation systems, basic fertilizers are introduced in the soil at planting time, followed by a number (usually two to three depending on crop) of nitrogenous fertilizer top dressings. After every application of fertilizers the salinity of the soil increases substantially, even though this effect is temporary. It is therefore believed that the standard ways of fertilization do not provide the level of nutrients that permit the crops to develop to their full production potential.

Since the introduction of drip and other localized irrigation systems, the use of water-soluble fertilizers (mainly nitrogenous) through the irrigation water has been practiced and with very good results. However, the fertilizer application was rather periodic, even though the number of applications was increased substantially (at times doubled) in relation to the then practiced frequency under the conventional irrigation systems. Figure 30 provides a schematic presentation of fertilizers under different irrigation systems in relation to soil salinity.

Figure 30
Fertilizer application frequency and soil salinity



The injection of other chemicals through the irrigation water, such as fungicides, herbicides, chlorine, acids fumigants etc., was gradually introduced and the expression of drip farming was used to differentiate this practice from the more conventional farming systems.

Subsequent research work carried out in many countries, notably Cyprus, Israel and USA, has led to combined fertigation and irrigation, whereby the water-soluble fertilizers are provided as regularly as the irrigation water.

10.1. Fertilizer distribution in the soil

While the movement of water in the soil affects the distribution of the different nutrients, their movement is also affected by their solubility and their interaction with the ion exchange sites in the soil. Different fertilizers have different chemical characteristics. As such, they behave differently when it comes to their distribution in the soil when applied through drip irrigation (Goldberg et al, 1976; Papadopoulos, 1985).

Nitrates tend to move with the movement of soil moisture, as they stay in the soil solution. Therefore, irregular applications of nitrates increases the electrical conductivity in the soil. This may result in over-fertilization stress of the crop during the day of fertigation (Figure 27) and deficiency stress, due to leaching, after the following irrigation without fertigation (Papadopoulos, 1994). It is therefore recommended that nitrogen is applied with every irrigation. Ammonium nitrogen may, however, temporarily be fixed on the exchange sites of the soil. Thus its movement would be temporarily restricted and so its leaching.

Potassium is not as mobile as nitrogen as it is exchanged on the soil complex. As such, it is not readily leachable. It is distributed uniformly within the wetted volume of the soil.

Phosphorus is often fixed in the soil. However, under drip irrigation the application of relatively large amounts to a small area saturates the absorption and precipitation sites in the soil, spread away from the point of application.

10.2. Types of fertilizer used

Not all types of fertilizers available on the market can be used for fertigation through localized irrigation. The fertilizers to be used should meet the following requirements (Motitis, 1989):

- Fertilizers should be fully water-soluble
- The form of nutrients in the fertilizer should be usable by the plant and stay in that form in the soil for as long as possible
- The nutrient concentration in the fertilizer should be as high as possible
- The cost per unit of nutrient should be low

Based on the above criteria, Motitis (1989) recommends ammonium nitrate (34.5-0-0)[5], monammonium phosphate (12-61-0)[6] or (14-61-0)[7] and potassium nitrate (13-0-46)[8] for use through fertigation.

However, as commercial phosphorus fertilizers may precipitate in a drip irrigation system through reaction with calcium or magnesium ions in the irrigation water, the use of phosphoric acid is recommended by Papadopoulos (1994). It has the added advantage of reducing the pH of the irrigation water. Nevertheless, in the presence of appreciable amounts of calcium and magnesium in the water, any form of inorganic phosphorus will precipitate as dicalcium phosphate. In such a case, glycerophosphoric acid (organic compound) can be safely used according to Keller and Bliesner (1990). It should be pointed out, however, that the cost of organic phosphate compounds is relatively high compared to the inorganic.

10.3. Fertigation recommendation

10.3.1. Concentration of nutrients in irrigation water

Based on research work carried out in Cyprus by Papadopoulos (1987), supplemented by research from other countries, recipes were developed for the concentration of nutrients in the irrigation water to be used through localized irrigation (Motitis, 1989; Papadopoulos, 1994). Table 21 summarizes these recipes for different crops.

[5] *Ammonium nitrate:* *34.5% N - 0% P_2O_5 - 0% K_2O*

[6] *Monammonium phosphate:* *12% N - 61% P_2O_5 - 0% K_2O*

[7] *Monammonium phosphate:* *14% N - 61% P_2O_5 - 0% K_2O*

[8] *Potassium nitrate:* *13% N - 0% P_2O_5 - 46% K_2O*

Table 21

Indicative concentrations of nutrients in irrigation water (g/m³)

Crop	N	P	K
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 bean	80 - 120	30 - 50	150 - 200
Strawberry	80 - 100	30 - 50	150 - 200
Lettuce	100	30 - 50	150
Cotton	40 - 60	20 - 30	100
Water melon	120 - 130	50 - 60	100

A simplified approach to the fertigation procedures for localized irrigation calls for the incorporation of 100% of P, 30-40% of N and K in the soil before planting. The balance of N and K can be provided at regular intervals, starting two weeks after planting. The weekly dose is progressively increased as the crop grows.

10.3.2. Solubility of various fertilizers

Before connecting the fertigation unit to the system, the fertilizers should be dissolved in water. Even though water-soluble fertilizers are used, each fertilizer has a different degree of solubility. Table 22 provides the solubility of common fertilizers used under drip irrigation.

Table 22

Solubility of fertilizers

Type of Fertilizer	Solubility (grams/litre of water)
Liquid fertilizers	Fully soluble
Ammonium nitrate (34.5 - 0 - 0)	1 190
Urea (46 - 0 - 0)	1 100
Ammonium sulphate (21 - 0 - 0)	710
Potassium nitrate (13 - 0 - 46)	320
Mono-ammonium phosphate (14 - 61 -0)	230

Example 11

Assume that one intends to use the combined fertigation with irrigation through a drip system for a cucumber crop, using ammonium nitrate (34.5-0-0), potassium nitrate (13-0-46) and phosphoric acid (61-0-0). What should be the total amount of fertilizers to be injected in the fertigation unit?

The potassium nitrate contains about 38% pure K (*). In order to provide the 200 g/m³ of irrigation water (Table 21), 526 grams of potassium nitrate would be required (100 x 200/38).

The 526 grams of potassium nitrate also contains 13% N, which is 68 grams (526 x 13/100).

The remaining nitrogen requirement of 132 grams (200-68) would have to be provided through the use of ammonium nitrate. This would amount to 383 g/m³ of ammonium nitrate (100 x 132/34.5).

The phosphoric acid contains 61% phosphorus. In order to satisfy the needs of 50 grams of phosphorus per m³, the application of 82 g/m³ would be required (50 x 100/61).

Therefore, for every m³ of irrigation water the following amounts of fertilizers will be injected:

Ammonium nitrate (34. 5-0-0) : 383 g
Potassium nitrate (13-0-46) : 526 g
Phosphoric acid (0-61-0) : 82 g

Assuming that the discharge of the drip system is 20 m³/hr and the irrigation at the specific stage of crop growth requires the system to be operated for 2 hours every time irrigation is practiced, then the total volume of water to be applied is 40 m³. What would be the amount of fertilizers to be injected during this irrigation?

The total amount of fertilizers to be injected would be:

Ammonium nitrate : 40 x 383 = 15 320 g or 15.32 kg
Potassium nitrate : 40 x 562 = 22 480 g or 22.48 kg
Phosphoric acid : 40 x 82 = 3 280 g or 3.28 kg

These quantities should be mixed well with water in a container before they are transferred to the fertigation unit.

(*) Note: From the periodic table the atomic weight of K = 39.1 and of O = 16. Hence, the atomic weight of K2O = 39.1 x 2 + 16 = 94.2. The potassium nitrate contains 46% K2O and therefore contains 38.2% K (0.46 x (39.1 x 2)/94.2)

Example 12

From Example 11, the following amounts of fertilizers were calculated for application during one irrigation, assumed to be 2 hours long and using 40 m³ of water: 15.32 kg of ammonium nitrate, 22.48 kg of potassium nitrate and 3.28 kg of phosphoric acid. How much water is required to dissolve the fertilizers?

No need for concern about the phosphoric acid, since it is fully water-soluble. However, the acid should be added to the water in order to avoid violent reaction.

According to Table 22, in order to dissolve 22.48 kg of potassium nitrate 70.25 litres of water (22.48/0.32) is required. The ammonium nitrate would require 12.9 litres of water (15.32/1.19)

Therefore, a container of about 110-120 litres, which includes the volume of the water and the volume of the fertilizers, would be required to accommodate the solution of all fertilizers. From this container the fertilizers will be injected into the system, using the appropriate fertigation unit, so that the fertigation is completed during the 2 hours (or less) of irrigation.

10.4. Advantages of combined irrigation and fertigation

A number of benefits of combined irrigation and fertigation to both the farmer and the environment have been stressed:

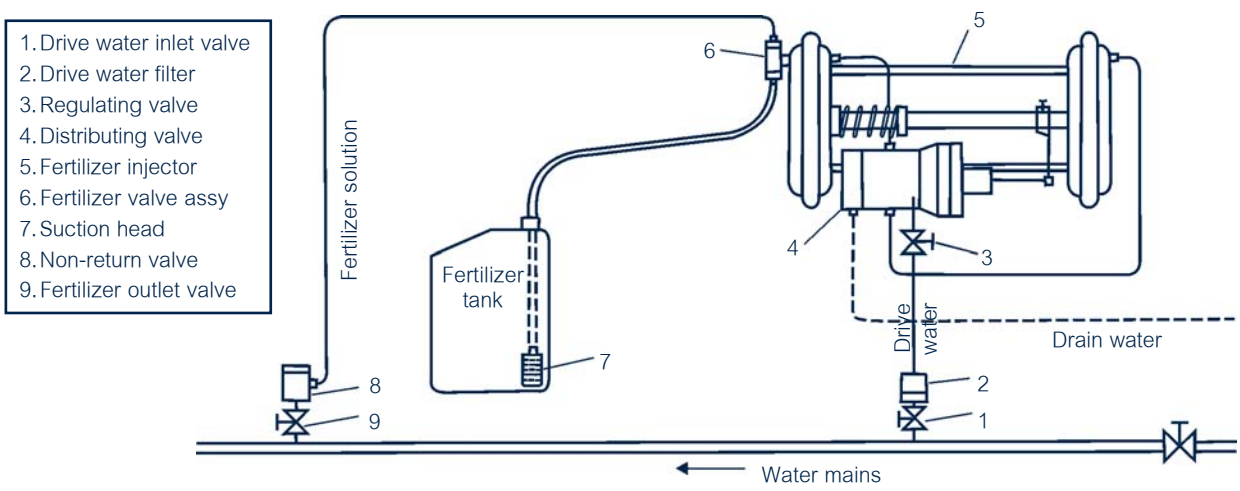
- Through this practice the nutrients are provided in readily available form and in a balanced manner, thus avoiding the high concentrations which may have negative effects on growth and production
- Substantial increase in yield, which for some crops may amount to 100%; yields of open field tomatoes reached 180 tons/ha, potatoes 70 tons/ha, open field watermelon 15 tons/ha (Papadopoulos, 1994)
- Savings in fertilizers and water per kg of produce
- More effective utilization of brackish waters
- Better control of fertilizer application reduces the risk of polluting the water aquifers
- Easier application of fertilizers

10.5. Fertigation systems

The prime prerequisite for the successful implementation of the combined fertigation-irrigation is a well designed and properly constructed localized irrigation system, which provides high uniformity of water and fertilizer application.

Different ways are used to inject fertilizers into an irrigation system. The most versatile method is the use of pumps. Positive displacement piston or paddle pumps draw the chemical solution from an open tank and inject it into the irrigation system. These pumps may use external sources of power such as a small electric motor or engine. The most common injector pumps use the pressurized water from the irrigation line, by means of pistons or diaphragms. The small amount of water that drives the pump (2-3 times the injected volume of solution) is expelled. Figure 31 is a schematic presentation of the connection of a water driven injector.

Figure 31
Water driven injector pump



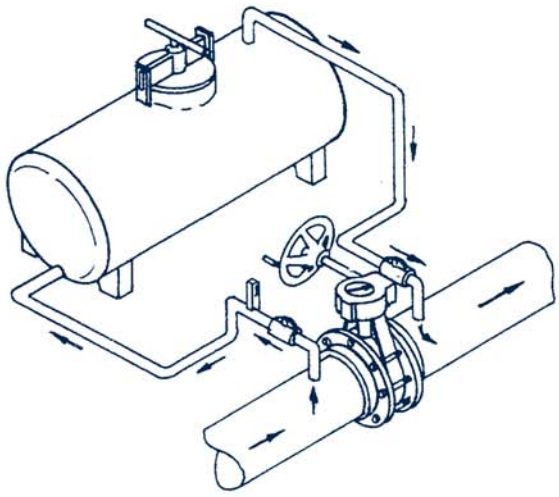
Although more expensive, these injectors provide a constant and adjustable nutrient solution to the irrigation system. Automatic shutoff valves are available for water driven pumps. For electrically driven pumps automatic time controllers are available.

Pressure differential is the oldest way of injecting chemicals into irrigation systems. In a typical differential pressure system, the tank containing the fertilizer is under the same pressure as the irrigation pipe line. In the initial years of localized irrigation, a gate valve on the pipe line, with the inlet and outlet of the tank connected to each side of the valve, was used to adjust the pressure differential and inject the fertilizer. Venturi tubes were also used to develop the pressure differential between the two points. In both cases the solution injected into the system was gradually diluted.

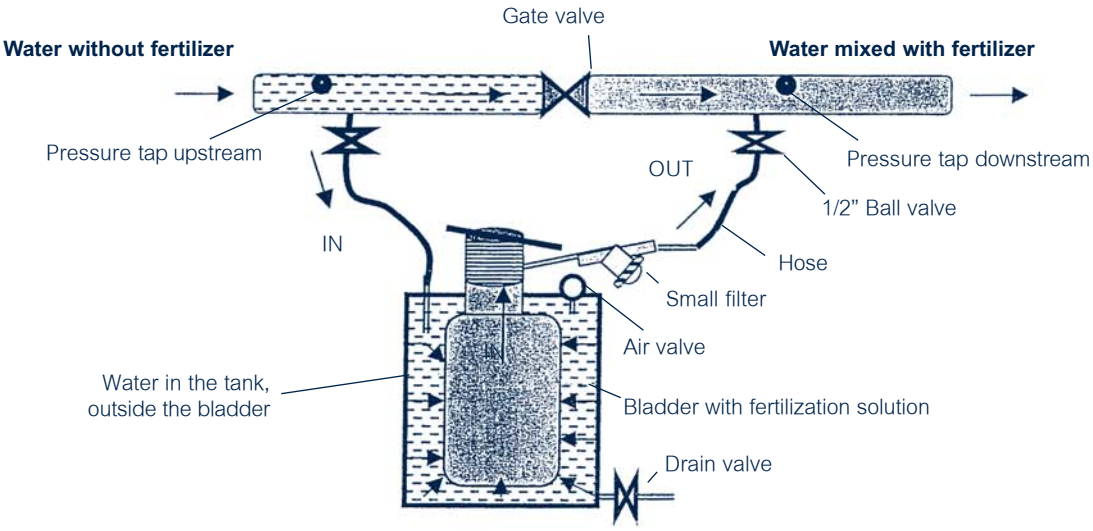
Further developments include a collapsible sack (bladder) inside the tank where the fertilizer solution is placed. The water from the irrigation pipe would then flow between the sack and the wall of the tank allowing constant solution injection. Figure 32 presents different types of fertigation/chemigation systems.

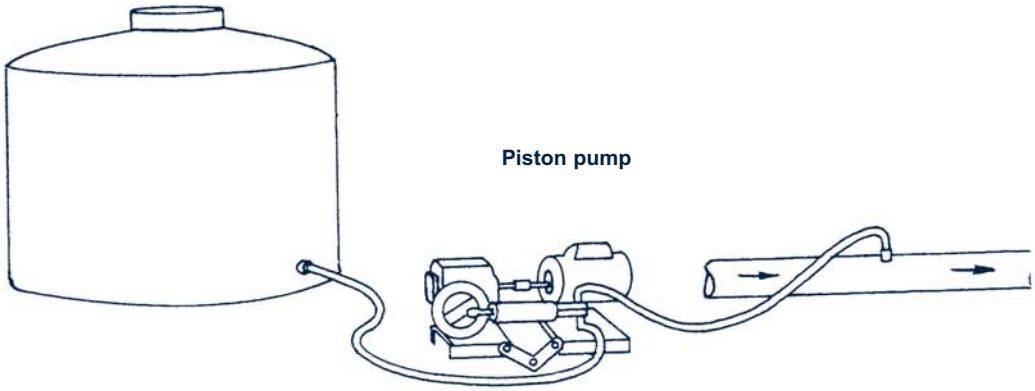
Whatever the adopted option, the connection of the injecting unit should occur between the pumping unit and the filtering system to protect any impurities contaminating the system. Measures should be taken to avoid return of fertilizer to the water source or water from the irrigation pipe to the injection open tank. In the case of smallholders operating within an scheme with a single control head, the injection of fertilizers is done at the plot level. Thus, each plot must be equipped with a small disc filter.

Figure 32
Fertigation systems



Pressure differential tank





Piston pump

Chapter 11
Operation and maintenance of localized irrigation systems

While the importance of designing for high water and nutrient application uniformity and of selecting appropriate water treatment systems and emitters must be stressed, equally important is the correct operation and timely maintenance of a localized irrigation system. Lack of attention to operation and maintenance procedures can result in the malfunctioning of one or another component of the system and thus to serious water stress. Therefore, the success of a localized irrigation system is based on proper operation and a regular maintenance programme. This involves the following:

- Regular checking of all components (pumps, filters, emitters, laterals and fertigation injection)
- Regular back-washing of main filters and cleaning of line filters
- Regular checking of pressure and flow at critical points of the system
- Regular flushing of manifolds and emitter laterals
- Chlorination
- Occasional acid treatment
- Protection against insects and rodents
- Protection against plant roots

11.1. Checking of system components

Details of pump maintenance are provided in Module 5. With respect to filters, pipes and other components, regular inspection, identification and sealing of leaks is necessary in order to maintain the designed pressures and water delivery to the crop.

Periodic opening of the end of the lateral to check for impurities on the inside wall can identify the presence of bacteria slime and measures can then be taken to avoid the clogging of the emitters.

11.2. Back-washing of main filters and cleaning of line filters

Using the pressure gauge, the pressure differential between the inlet and outlet is recorded daily. As the filters remove water impurities, the pressure differential increases. If left unchecked, the load inside the filter will consume unreasonable levels of pressure, resulting in the substantial reduction of the pressure available for the operation of the system. In extreme cases, this results in water stress to the crop. The maximum pressure drop across a sand media filter should not exceed 7 m and it is preferable to range from 3-5 m. For screen and disc filters, the pressure drop should not exceed 2-3 m.

When the level of pressure drop reaches the above limits, the filters should be cleaned. In the case of screen and disc filters, they are opened and, using a hose from the outlet of the sand media filter, cleaned manually. Sand media filters are designed to be cleaned through the back-wash process, whereby clean water from the outlet of one unit is diverted to the lower part of the second unit, lifting up the sand media and flushing out the impurities as was shown in Figure 26.

11.3. Checking pressure and flow

Pressure checks at the filtering system help to decide on the frequency of cleaning the filters. Additionally, pressure checks at critical points of the system (inlet of block and end of lateral) help to identify possible leaks or pipe breakages or blockage in the system.

A water meter or a flow meter, located after the filters, can assist in checking the proper operation of the system. If the flow rate is higher than the designed flow, it is an indication of pipe breakage or the end of a number of laterals being open. On the other hand, if the flow is lower than envisaged, it is a sign of clogging in the system, reduced performance of the pump, or overloaded filters.

11.4. Flushing of manifolds and emitter laterals

Not all impurities are removed from the filtered water. Most of the silt and clay particles pass through the filtering system. Some is deposited in low areas of the distribution system, at the end of the manifold and in the lateral pipe. It is therefore advisable to have flushing points at the end of each manifold that can be opened periodically (N.B. one at a time) to flush out the impurities. The same process should be applied to the laterals by opening the end of each lateral (one at a time) and flushing out the impurities. It should be pointed out that flushing should be more

frequent during warm weather, which promotes the growth of bacteria and algae and the precipitation of carbonates.

Fertigation should be practiced in such a way that all nutrients are out of the system before irrigation is completed. To ensure this process, fertigation should be completed 20-30 minutes before the system is turned off.

11.5. Chlorination

Earlier on, the concentrations of chlorine needed to combat biological and chemical clogging were provided. There are three chlorination methods used:

Intermittent : 15-20 ppm of chlorine on a monthly basis; in the summer it can be more frequent, for example weekly or every fortnight.

Continuous : 3-5 ppm with residual of 1-2 ppm of chlorine.

Slug dose : 200-500 ppm of chlorine applied between crops; this is the least used method.

Of the three sources of chlorine (solid, liquid, gaseous) the solid (calcium hypochlorite) and the liquid (sodium hypochlorite) are the easiest to use. Gaseous chlorine application requires sophisticated equipment. Of the solid and liquid form the latter is preferable, in view of the possible precipitation of calcium. It should be noted that chlorine is more active at pH of 6.5 and lower.

11.6. Acid treatment

Acid is used to clean pipes and emitters of deposits accumulated over time. It is most commonly used against iron oxides, calcium carbonates, magnesium carbonates and bacterial slime. The most commonly used acids include hydrochloric acid 33-35%, sulphuric acid 90% and phosphoric acid (food grade) 85%. It should be noted that acid should always be added to the water and never water to the acid. If water is added to the acid, the acid boils, fumes and splashes, causing serious bodily injuries to the user.

Safety gloves, protective clothing and breathing masks should be used when handling acids. For effective acid treatment, the amount of acid to be used should be such that the pH of the water is reduced to 2-3. Therefore, the amount of acid to be used will depend on the pH of a particular water. While it is preferable to use acid treatment when there is no crop in the ground, at times acid treatment may be necessary while the crop is in the ground. In this case the following procedure, recommended by Tape International (1996), will substantially reduce damage to the roots:

- Fill the soil profile with normal irrigation water
- Calculate accurately the required injection time
- Shut the system down, leaving the acid solution in the pipes for 1-5 hours
- Flush the manifold and laterals thoroughly
- Continue irrigation for 1-2 hours to further dilute acid in the soil

11.7. Protection against insects and rodents

As a rule, the thinner the wall of a lateral the more prone it is to insect and rodent damage. The use of beetle bait pellets and rodent bait pellets is recommended. Standard crop hygiene practices can also help to reduce the problem.

11.8. Protection against plant roots

Plant roots tend to grow into the direction of water and nutrients. Where laterals are buried or covered with mulching material, there is a possibility for the root to enter and block the emitters. A number of measures are used to rectify this problem, including:

- Avoiding moisture stress
- Maintaining good pressure in the laterals (7-10 m)
- Using emitters with appropriately designed outlets
- Using biodegradable chemicals through the system

11.9. Troubleshooting

The following table provides answers to the most common problems encountered with the operation of localized irrigation systems.

Table 23

Problems and suggested solutions in the operation of localized irrigation systems (adapted from: Savvides, 2001)

Potential problem	Suggested solution
Too low pressure at the pump outlet	• Check the suction screen and clean from dirt. • Check the volute and impeller of the pump and clean from dirt. Module 5 provides additional information. • Check for pipe breakage especially the main line. • Check and ensure that the number of blocks under irrigation does not exceed the number specified in the designs.
Too low pressure at the main filter outlet	• If the pressure at the filter inlet is as specified in the designs and the pressure at the outlet is low, then cleaning of filters is required.
Too low pressure at the block inlet	• Check for pipe breakage in the system and rectify. • Check for open laterals at the block level and close them. • Check for number of blocks in operation and do not exceed design number.
Too low pressure in the laterals	• Check block filter and clean. • Check for open laterals and close. • Check block inlet pressure; if low follow earlier recommendations.
Too high pressure at the filter outlet	• Check number of blocks under irrigation. It could be that less blocks than the recommended number are in operation. • Check filter for ruptures and rectify.
Too high pressure at the block inlet	• Check the number of blocks in operation and rectify.
Lack of knowledge on the time required for the fertilizer to exit the system	• Using an electrical conductivity (EC) bridge, measure the EC of the water. Proceed with injection of fertilizer solution at a specified pressure differential. Measure the EC at the outlet of the furthest emitter of a block. The EC will increase and then decrease to the level measured before connecting the injector. The time taken for the injected solution to reach the EC of the water is recorded and used in the future with the same pressure differential.
Clogged emitters	• Flush the manifold and laterals one at a time until clean water comes out. • Chlorinate. • Use acids.
Flow rate after the main filters has been declining over the past few months.	• Gradual clogging of emitters. Use chlorine and/or acids. • Regularly flush manifold and laterals.
Leaking laterals	• Cut the leaking portion and connect the two ends with a connector.
Leaking grommet	• Excavate soil around the manifold. Identify leaking grommet and replace the rabble ring and the grommet, if needed.

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