TECHNICAL ASPECTS AND COST ESTIMATING PROCEDURES OF SURFACE AND SUBSURFACE DRIP IRRIGATION SYSTEMS

Volume 2 of 3

A MANUAL FOR IRRIGATION DESIGNERS

by

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Technical Aspects and Cost Estimating Procedures of Surface and Subsurface Drip Irrigation Systems Volume 2: A Manual for irrigation designers **(WRC Report No. TT 525/12)**
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List of Acronyms and Abbreviations

Agrilasa	The Agri-Laboratory Association of Southern Africa
ARC-IAE	Agricultural Research Council's Institute for Agricultural Engineering
CV	Coefficient of variation
DI	Dirt index
DU	Distribution Uniformity
EU	Emission uniformity
HG	hydraulic gradient
IR	Irrigation Rate
IRRICOST	A computer program to estimate both the annual fixed and variable irrigation costs
KBase	Knowledge Base System
OHS	Open Hydroponic System
PE	Polyethylene
Ppm	Parts per million
PVC	Polyvinylchloride
SABI	South African Irrigation Institute
SANAS	South African National Accreditation System
SAPWAT	South African Plant Water Requirements
SDI	Subsurface drip irrigation
TDS	Total dissolved solids
WHC	Water holding capacity
WRC	Water Research Commission

1 INTRODUCTION

This manual is the product of a technology transfer project (Project No K5/1806//4) funded by the Water Research Commission (WRC), undertaken by the Agricultural Research Council's Institute for Agricultural Engineering (ARC-IAE), and entitled "Technology Transfer of the technical aspects and the cost estimating procedures of surface and subsurface drip irrigation systems". The information compiled herein is a combination of WRC funded research output, data obtained from irrigation companies that are active in the South African market, and international literature on the topic of drip irrigation and filtration.

The following WRC reports were analysed and information extracted:

1. Du Plessis, FJ; Van Averbeke, W; Van der Stoep, I. 2002. *Micro-Irrigation for smallholders, guidelines for funders, planners, designers and support staff in South Africa.* Report No. TT 164/01. Water Research Commission, Pretoria, RSA.
2. Koegelenberg, FH. 2003. "Micro irrigation systems" in: *Irrigation Design Manual.* Revised edition. ARC-IAE, Pretoria. RSA.
3. Koegelenberg, FH; Reinders, FB; Van Niekerk, AS; Van Niekerk, R; Uys, WJ. 2002. *Performance of Surface Drip Irrigation Systems Under Field Conditions*. Report No. 1036/1/02. Water Research Commission, Pretoria, RSA.
4. Marais, A. 2001. *Subsurface Drip Irrigation Systems*. Paper No. 8736. Netafim, White River, RSA.
5. Oosthuizen, LK; Botha, PW; Grovè, B; Meiring, JA; Monkhei, MM; Pretorius, IG. 2005. *Cost estimating procedures for micro-, drip- and furrow irrigation systems as well as economic analysis of the relevant irrigation systems for large- and small scale farmers in the Onderberg/Nkomazi region*. Report 974/1/05. Water Research Commission, Pretoria RSA.
6. Reinders, FB; Smal, HS; Van Niekerk, AS; Bunton, S; Mdaka, B. 2005. *Sub-Surface Drip Irrigation: Factors Affecting the Efficiency and Maintenance*. Report No. 1189/1/05. Water Research Commission, Pretoria, RSA.
7. Van Niekerk, AS; Koegelenberg, FH; Reinders, FB; Ascough, GW. 2006. *Guidelines for the Selection and Use of Various Micro-Irrigation Filters with Regards to Filtering and Backwashing Efficiency*. Report No. 1356/1/06. Water Research Commission, Pretoria, RSA.

The purpose of the manual is to provide a comprehensive reference document for irrigation designers operating in South Africa and other SADC countries. It should be read and used in conjunction with the KBase, (a database developed as part of the WRC project by NB Systems) which contains technical information on drippers and filters, and the IRRICOST spreadsheet model, a cost estimating tool that was adapted specifically for the purposes of the WRC project by the University of the Free State.

1.1 Defining drip irrigation

The term *drip irrigation* refers to pressurised irrigation systems that irrigate a part of the soil surface area of a field in a controlled manner, as distinct from other systems that are designed to apply water to the entire soil surface. The definition limits the choice of equipment to either surface or subsurface drip irrigation. These two types of systems are found in a variety of on-farm applications, and range from ultra-low flow rates to high flow rates, able to supply water to very small proportions of the surface or subsurface area.

1.2 Origins of drip irrigation

The first experimental system of this type was established in 1959 in Israel by Simcha Blass and his son Yeshayahu in the late 1950s. Blass developed and patented the first practical surface drip irrigation emitter. Unlike earlier systems, which released water through tiny holes but which were blocked easily by tiny particles, water was released through larger and longer passageways, using friction to slow the water flow rate inside a plastic emitter.

1.3 Terminology

A drip irrigation system is understood to include a water pump, filtration and fertigation equipment, and in-field water distribution equipment. A schematic representation of a drip irrigation system is presented in Figure 1.

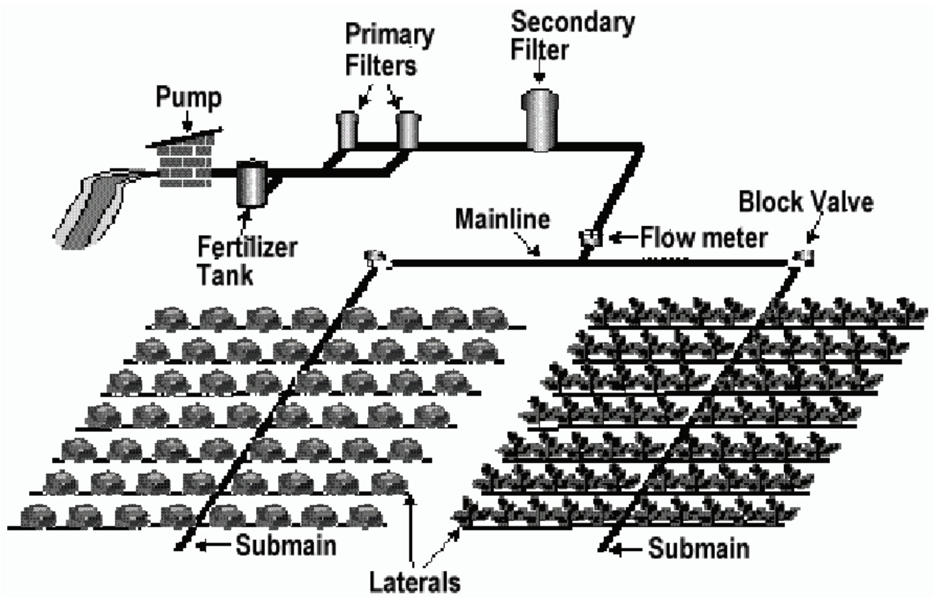

Figure 1: Schematic diagram of a typical drip irrigation system

1.4 Scope of the manual

The manual covers the technical aspects and cost estimating procedures of designing surface and subsurface drip irrigation systems. It does not include the general aspects of irrigation planning and design that are applicable to all types of irrigation systems, such as water resource assessments, topographical surveying, soil surveys, climatic data and crop water requirements, and system automation. The ARC's Irrigation Design Manual can be consulted for more information on these topics.

This manual includes recommendations and guidelines regarding the suitability and management of soil and water for drip irrigation, and the selection, costing, design, operation and maintenance of drip irrigation and filtration equipment. It is aimed specifically at drip irrigation in field and permanent crop applications, and does not apply to greenhouses or specialised fertigation units.

1.5 Organisation of content

Figure 2 shows the structure of the manual. The content is presented under the three broad headings of technical aspects, guidelines, and procedures.

The technical aspects of drippers and filters are covered in Chapters 2 and 3, which provide background information on different types of equipment, and the factors to be taken into consideration when selecting system components.

General and specific guidelines for the planning, design and management of drip irrigation and filtration are covered in Chapters 4 and 5.

Chapters 6 and 7 provide details on the methods and calculations used during the planning and design of drip irrigation systems. Although the chapter on cost estimating procedures (Chapter 7) could appear earlier in the manual, the need to first understand the design process determined the placing of this material towards the end of the manual.

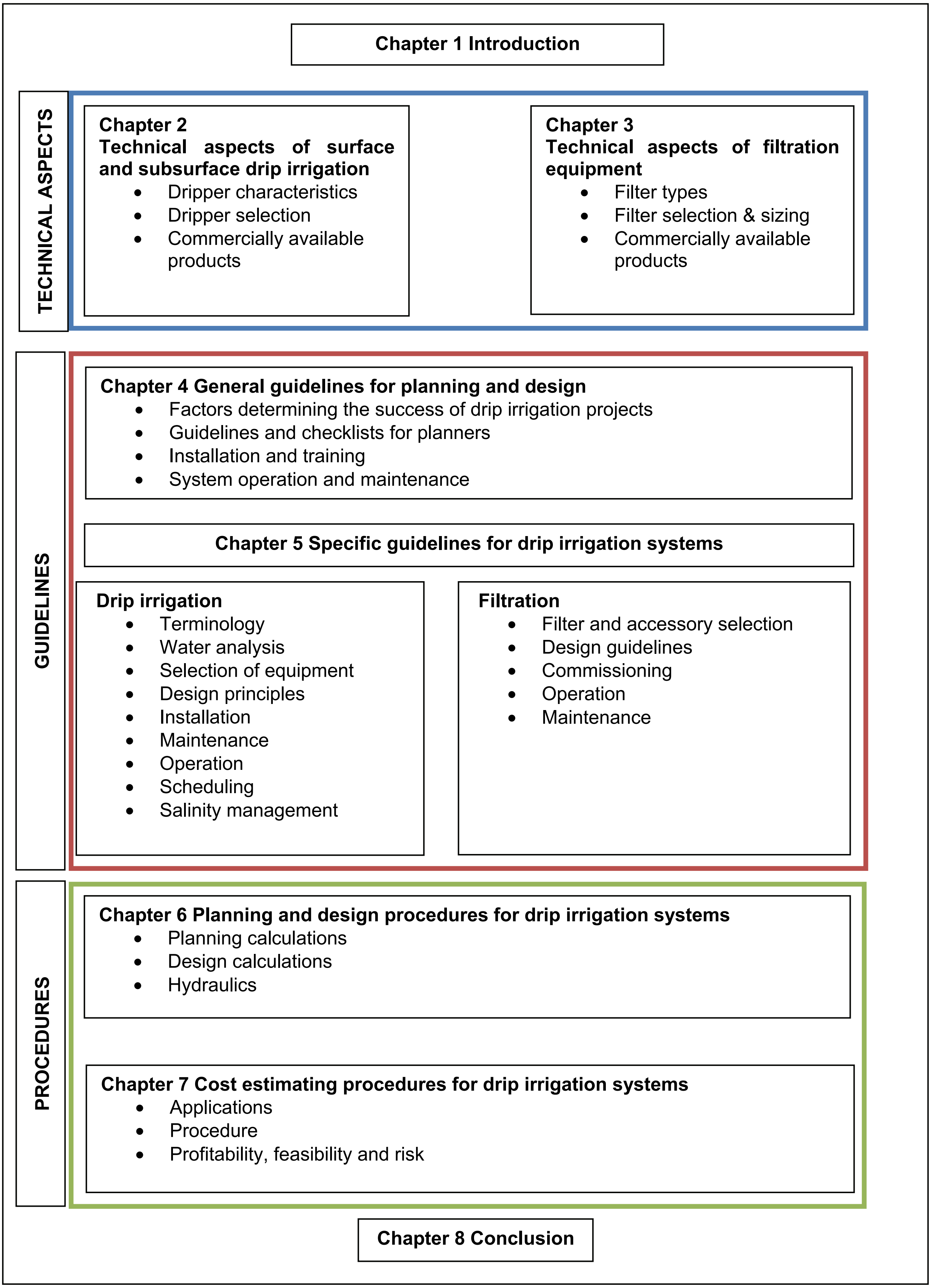

Figure 2: Structure of the manual

2 TECHNICAL ASPECTS OF SURFACE- AND SUBSURFACE DRIP IRRIGATION SYSTEMS

Drip irrigation is considered to be one of the most efficient types of irrigation. However, it is of the utmost importance to correctly plan, design, select, install and maintain all the system components to ensure successful long-term operation.

As shown in Figure 1, the water is pumped via filters and valves through the manifold to the laterals. The mechanisms which let water out from the laterals into the atmosphere are known as drip emitters, drippers, or emitters. Drip emitters are found in a large variety of characteristics and shapes, covering the whole spectrum from small button-shaped drip emitters to inline long flow-path drippers. Some characteristics of drip systems are highlighted in Table 1.

Table 1: Some directives with regard to characteristics of drip systems

Characteristic	Description
Application	Row crops (both permanent and annual crops), also underground on pastures, sugar, cotton, for instance
Method of water application	Point application by means of drip action, lateral distribution by soil
Potential system efficiency	95% +
Mounting of emitter in relation to lateral	On wall inside lateral, or in-line as integral part of tubing, or directly/ indirectly on outer wall of tubing
Emitter interval	Externally mounted: At random intervals. All other: At fixed intervals varying between 0,3 m and 1,25 m
Emitter discharge	0,5 to 25ℓ/h
Operating pressure	5 to 35 m (also pressure compensating)

2.1 Drip emitter characteristics

There is a wide variety of drip emitters commercially available. Distinctions between types can be made on the basis of operating principle (pressure sensitive or pressure compensating), positioning relative to the lateral (internal, external, etc.), and construction (flow path length, etc.).

Regardless of the type of emitter selected for use, it is always important to select good quality, tested components when designing and installing drip irrigation. The use of cheap but inferior materials and novel components which have yet to prove their worth should be avoided. The company membership directory of the South African Irrigation Institute (SABI) provides a useful reference for established and recognised suppliers of irrigation equipment in South Africa.

2.1.1 Dripper types

The purpose of the drip emitter is to apply water at a specific flow rate (determined during the planning process and called the *design emitter discharge*, q_e) over a specific area of soil in the field. Emitter discharge is determined by the pressure of the water at the emitter; the design discharge is delivered at a specific pressure called the *design operating pressure*. At pressures higher than the design operating pressure, the emitter will discharge more than the design discharge, and at pressures lower than the design operating pressure, the emitter will discharge less than the design discharge. The discharge-pressure relationship is characterised by the equation:

$$q_e = K \times p^x \qquad \text{(Equation 2.1)}$$

where

K	=	discharge coefficient, include qe and units
p	=	operating pressure
x	=	discharge exponent

This relationship is presented graphically in Figure 3:

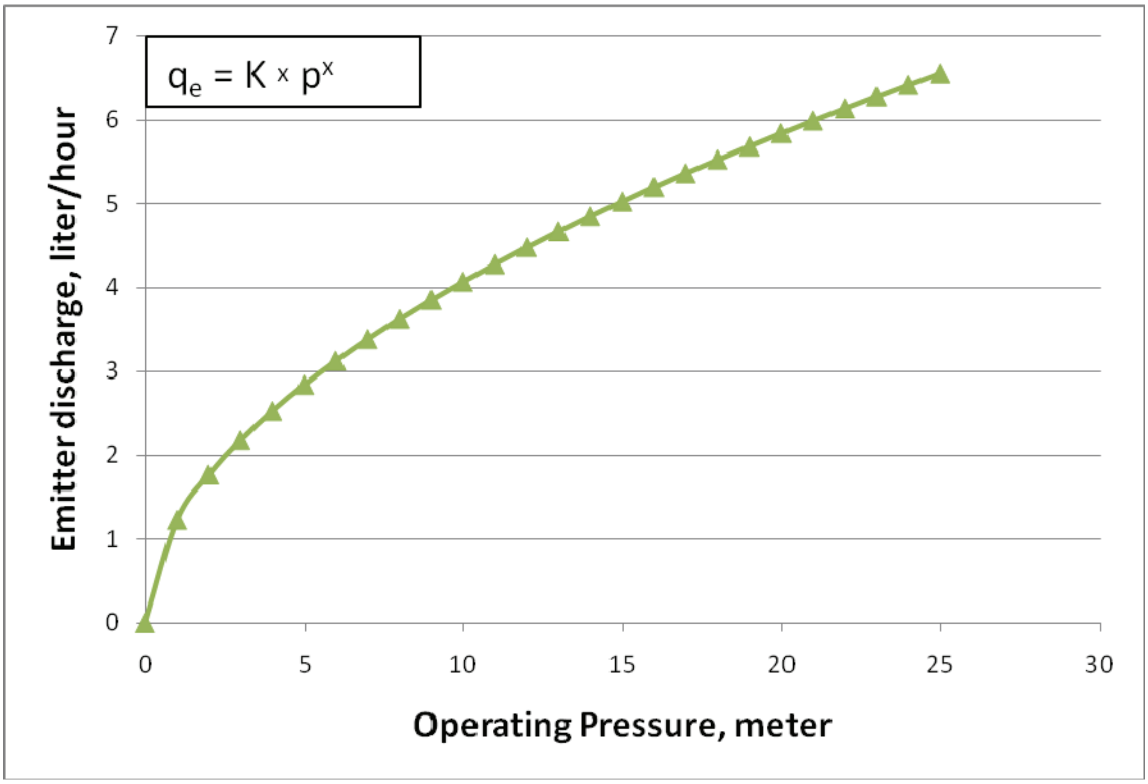

Figure 3: Emitter discharge/ operating pressure relationship of pressure sensitive emitters

2.1.1.1 Pressure sensitive emitters

Pressure sensitive emitters (also known as conventional emitters) operate according to the relationship expressed in Figure 3. The discharge of pressure sensitive emitters is a function of the operating pressure inside the lateral. It is therefore essential to ensure that system pressure inside the sidelines and laterals is kept within the required tolerances during the designing process, in order to maintain uniformity of emitter discharge within the specified ranges.

Advantages of pressure sensitive emitters:

- Relatively low cost compared to pressure compensating drippers
- Simple composition enhances uniform discharge between emitters (low coefficient of variation (CV) values)
- Fewer and uncomplicated components decrease vulnerability to mechanical damage

Disadvantages of pressure sensitive emitters:

- Lateral length and therefore discharge is influenced by topography directly influencing the operating pressure
- Larger pipe diameters are normally used along flatter gradients to limit friction losses
- It is often necessary to maintain downhill flow directions in both laterals and sidelines: costs will escalate in case a more extensive supply system is required
- Relatively complicated design processes, (normally requiring the use of advanced equations, graphic aids, and even computer programmes) are inevitable, and complicate the design process

2.1.1.2 Pressure compensated emitters

In a **pressure compensated** emitter, the regulating mechanism affects the discharge/pressure relationship, with discharge remaining constant over a specified pressure range (as seen in Figure 4). Usually, the only limitation is that a minimum required pressure should be maintained to perform the compensating function. Pressure compensated emitters are available for all types of pressurised systems but are more expensive than non-compensating emitters.

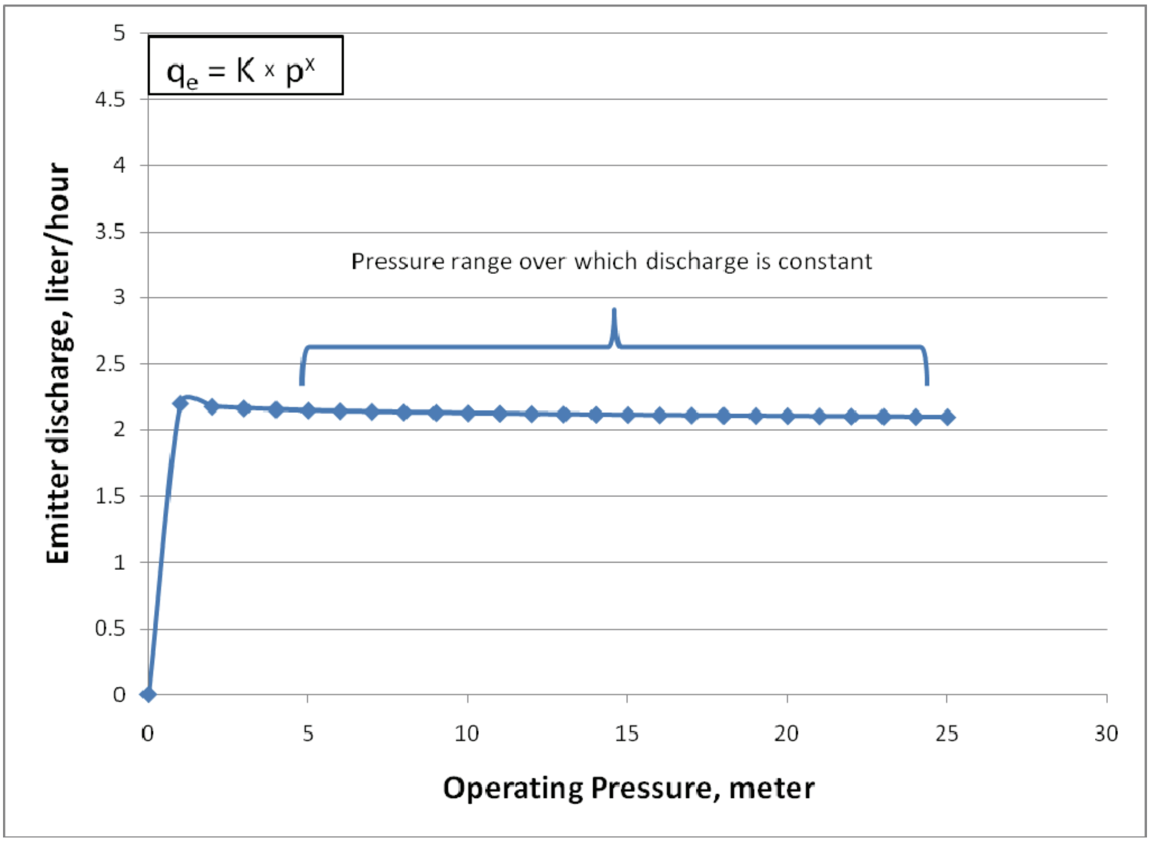

Figure 4: Emitter discharge/pressure relationship of pressure compensated emitters

Advantages of pressure compensating emitters:

- Longer laterals of the same diameter pipe can be used, because emitter discharge remains constant and is not influenced by pressure variations due to friction or topography.

- Similarly, smaller diameter pipes can generally be used in sidelines and laterals, and in some cases even in the distribution network.
- In most cases it is advantageous to maintain a flow direction opposite to that of the soil gradient in the sidelines and emitter lines, thus eliminating supply lines by supplying water to the sideline at the point closest to the source.
- The CV of the emitters constitutes the total discharge variation of a system. Low CV values of well-designed and well-manufactured emitters therefore ensure even distribution of water and plant nutrients, often safely within the normal allowable tolerances.
- Advanced design techniques such as complicated equations and graphic aids, or even computer programmes, are not required for the designing process: Sensible application of basic pipe hydraulics is all that is required for this purpose.

Disadvantages usually associated with pressure compensating emitters:

- Complicated composition involves more components, resulting in increased vulnerability
- The composition of the emitter components makes it difficult to maintain low CV values
- Higher emitter costs

2.1.2 Mounting

Drippers can be mounted onto dripper lines in various ways, as shown in Figure 5. It can be

- Inline
- Internal
- Integral and
- External

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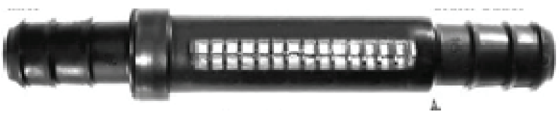
<tr><td></td><td></td></tr>
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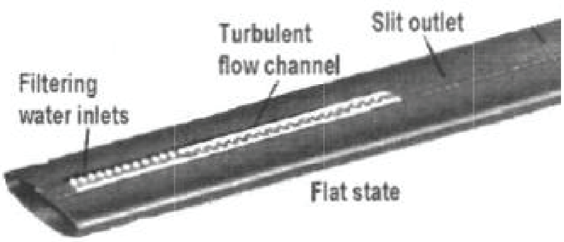
<tr><td>
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<tr><th colspan="2">External</th></tr>
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Figure 5: Ways of mounting drippers to the dripper line

2.1.2.1 ***In-line*** *with dripper line*

In this case, the dripper is cylindrical with a barbed adaptor at each end. They are fitted to the dripper line (after the pipe has been manufactured) so that the hollow cylindrical core forms part of the dripper line. The pipe is usually cut into pre-determined lengths and the ends of the pipe are mechanically pressed over the barbed ends of the dripper. One limitation is that only specially fabricated dripper pipes can be used. These pipes are available only in specified diameters which fit tightly over the ends of the barbed ends of the dripper.

2.1.2.2 ***Internal*** *to the dripper line*

The dripper is fixed to the inner wall of the unique dripper pipe by thermal fusing (also known as bond on), during the manufacturing process. Standard polyethylene (PE) pipes are therefore out of the question in this case. Two kinds of drippers are mainly used:

- **Cylindrical drippers**, inserted into the pipe where the wall of the pipe forms the casing of the dripper.
- **Elongated drippers**, (so small that they cause little friction) fixed to the inner wall of the pipe during the pipe manufacturing process.

2.1.2.3 ***Integral with the wall*** *of the dripper line*

In this case the unique thin-walled dripper line is manufactured so that the dripper components (pressure sensitive or pressure compensating) are formed inside the pipe wall by thermal extrusion.

2.1.2.4 ***External*** *mounting on the wall of the pipe*

These drippers are fitted with a barbed connection which is pressed either into a pre-punched hole in the dripper line, or into the end of the extension tubing. The diameter of the pipe is irrelevant when using this approach, and standard, low density PE pipes with small diameters can be used. Dripper spacing can be random, according to requirements. The only limitation on the size of the emitter is the manufacturing cost. A measure of robustness is required because of vulnerability to factors such as the movement of people and implements, especially in rare cases where the dripper is linked to the dripper line by means of extension tubing.

2.1.3 Composition and components

There are too many types and compositions of drippers to consider individually: drippers vary to such an extent that it is even difficult to identify common components: Representative examples of drippers that are commonly found in everyday use are illustrated in Figure 5. An initial distinction can however be made between the short and long flow path types.

Short flow path type drippers usually are physically small and discharge is regulated by means of a built-in mechanism.

Long flow path type. All the drippers shown in Figure 5 are of the long flow path type, except the small button type which is mounted to the outside of the pipe. Long flow path type drippers mainly use friction and turbulence in the flow path to decrease the lateral pressure until the design discharge is reached. The cross section area of the flow path is usually about 1 mm^2. Depending on the design approach, the flow path can vary considerably in length, up to 1 m and more. Although flow velocities are relatively low, the flow is regarded as turbulent because of the continuous changes in direction experienced along the labyrinth. Common components include the following, among others:

2.1.3.1 The inlet

The water flows into the emitter from the lateral via a barbed coupling of the type mounted on the outside of the lateral. All the other types have openings between the outside of the body and the pressure reducing mechanism, which often is part of the body. This opening generally has some kind of grid or screen to prevent dirt from entering the mechanism and blocking the flow path.

2.1.3.2 The body

The emitter body houses the pressure reducing mechanism (except in the integral type, where the core is situated inside the wall).

2.1.3.3 The casing

The casing encloses the body or the active pressure reducing mechanism, and is available in various shapes:

- It can be a shell which fits onto the core, e.g. the larger button type outside the dripper line
- The body and casing can form a homogeneous unit, e.g. the small button type
- It can be a cylindrical casing which encloses the core, e.g. the in-line type
- The dripper line itself can form the casing, e.g. drippers mounted inside, as well as the type formed inside the wall of the dripper line

2.1.3.4 Outlets

All drippers have one or more outlets exposed to the atmosphere. The discharge holes of internal drippers are punched into the wall of the dripper line during the manufacturing process.

2.1.4 Pressure compensating mechanisms

These mechanisms are optionally available as components to most tried and tested pressure compensating emitters, except for the in-line type drippers.

In pressure compensating dripper types, the pressure reducing characteristics of the labyrinth are usually combined with a free-moving diaphragm, of which the active part is situated over and on the downstream side of the labyrinth. This diaphragm is manufactured of a high quality synthetic elastic material which is chemically stable in respect of all known chemicals. The water inside the lateral exercises the necessary pressure which causes the diaphragm to distort, thereby reducing the flow opening and keeping the discharge constant. A flushing action usually takes place during the stage that the dripper line is filled with water and before enough pressure is built up to activate the diaphragm.

Typical examples pressure compensating drippers are illustrated in Figure 6.

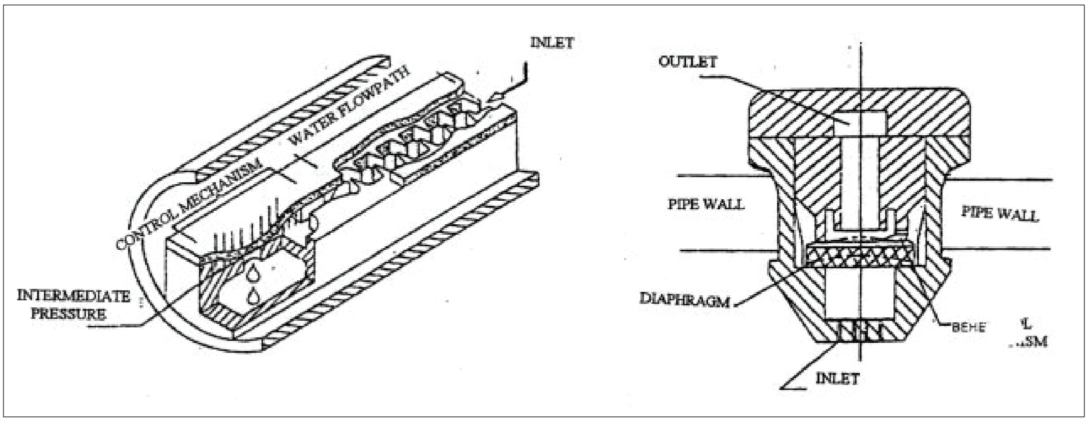


Figure 6: A diagram of typical pressure compensating drippers

2.2 Selection of a dripper type

The choice between one emitter and another, or even between the concepts of pressure sensitive and pressure compensating emitters is often subjective, or made according to preconceived guidelines, or even based on historical or circumstantial reasons. Choices can be made more scientifically, according to the following guidelines:

2.2.1 Drip application

- Drip irrigation has a high system efficiency.
- Most drippers are mounted inside the laterals, and under some conditions whole systems can be suspended above ground level.
- Drip systems have limitations because they feature point application. The lateral water spreading capacity of the soil can therefore be a determining factor in the decision-making process.

The shape and size of the wetted profile in the soil are therefore very important for obvious reasons. It should be able to store at least enough water in an area accessible to the feeding roots (or an acceptable part thereof) of the crop. The method of placing irrigation water on top of the soil, as well as the distribution of water in the soil (especially lateral distribution), should correlate well with the nature, shape and extent of the root system, and any limitations affecting these. These aspects are particularly important in cases where no clear-cut decision about drip irrigation can be made.

Since crop characteristics are usually common knowledge, and limitations from a soil science point of view would have become evident during the soil survey, the main remaining unknown factor is the ability of the soil to distribute irrigation water laterally. Three basic, interactive factors are responsible for this very important characteristic. They are -

- the clay percentage in the soil; and/or
- the percentage fine fraction in the sand; and/or
- the presence of organic material in the soil.

The distribution of the water in the soil occurs along the hydraulic gradient between the wet and the dry soil: laterally by means of capillary action, and vertically due to gravitation. With point application, this wetting and distribution pattern more or less takes the shape of an onion, as shown in Figure 7.

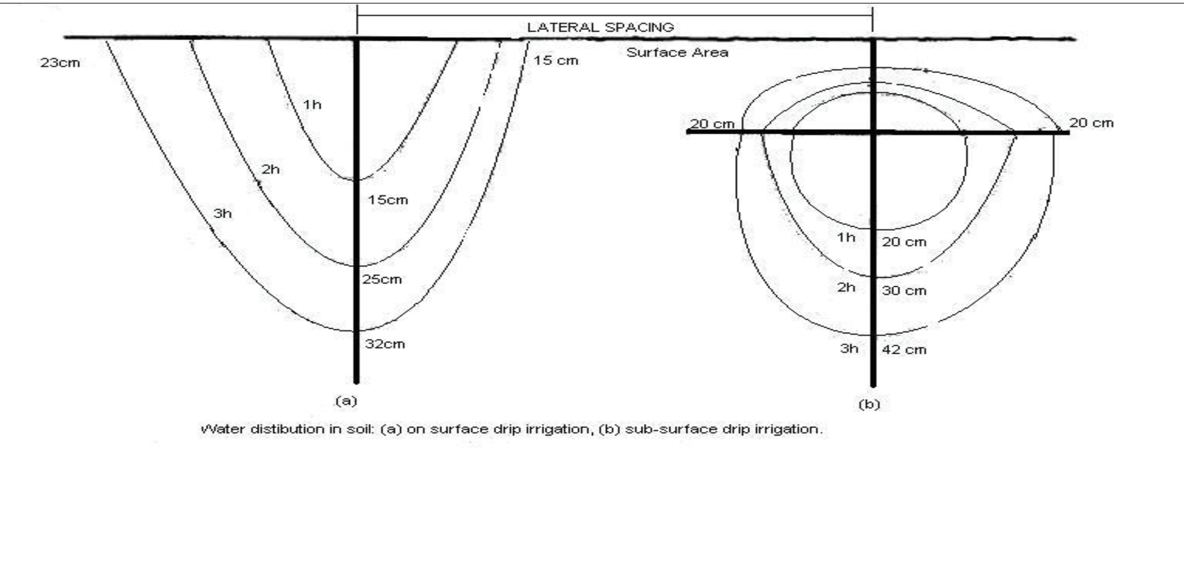


Figure 7: Typical water distribution patterns in soil; (a) surface and (b) subsurface application

Although these factors are individually quantifiable, their combined effect on the lateral water distribution capacity of the soil cannot be calculated theoretically. Further, it is generally assumed that soil with a high clay content gives better horizontal distribution than soils with a high sand fraction (Figure 8).

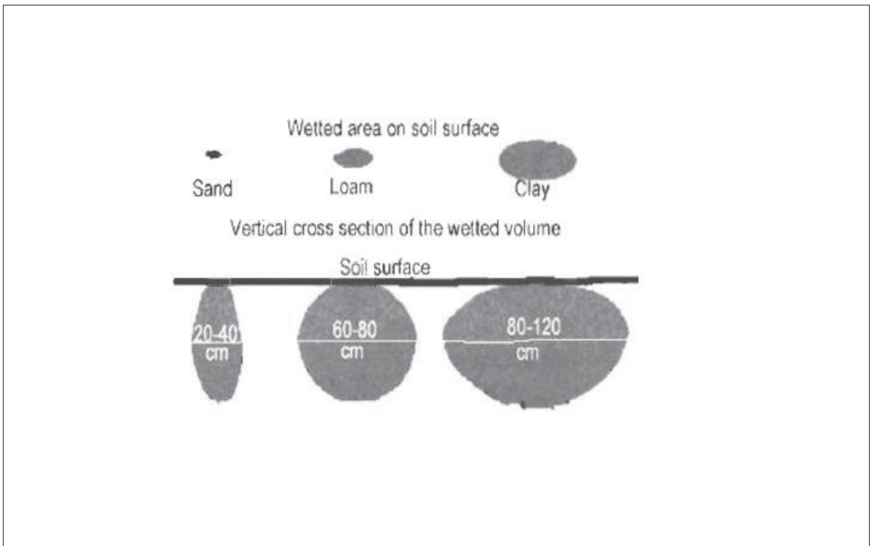


Figure 8: Typical assumed water distribution patterns under drip irrigation depending on soil type

These characteristics can be reliably established through experimental observation and calculation, according to the following guidelines:

- Lay-out dripper lines (preferably 20 m to 30 m long), on the soil that is to be irrigated, with different inter-dripper spacing.
- Connect the lines to a water source which will provide a continuous and stable supply.
- Switch on the system at the required operating pressure, and irrigate for about 12 hours on heavier clay soils, and for about six hours on lighter sandy soils.
- Allow the water to penetrate the soil for a further 24 and 12 hours respectively, without any interference, in order to allow the wet zone to reach its maximum dimensions.
- Dig longitudinal and cross profile furrows, and make the necessary observations and measurements to establish whether the proposed system will satisfy all requirements according to established norms.

Due to the lower emitter discharge of drippers, the standing time is usually longer and the farmer's operating system should be able to accommodate the choice.

Cost aspects play a key role in decision making, and require a careful and objective approach:

- **Crop type:** A drip system on citrus, equipped with double dripper lines, can be more expensive than a micro system. Conversely, a drip system on a vineyard can be cheaper than a micro system.
- **Emitter type:** Pressure compensating emitters are generally more expensive than pressure sensitive emitters, but cost savings on the distribution system may completely reverse the picture.
- **Filtration:** The role of filtration cannot be ignored. Cleaner or dirtier water can overturn the cost implications completely in favour of a different type of system.
- **Operating pressure:** Operating pressure also plays an important role from the operational cost point of view, and should be considered in the total cost structure.

2.2.2 Pressure sensitive or pressure compensating

Besides the cost aspects, specific technical aspects may necessitate the use of pressure compensating emitters under certain conditions:

- The use of pressure sensitive emitters on very steep inclines may require an impractical number of branch lines to maintain specified discharge limits. Pressure compensating emitters may possibly provide the only practical solution.
- Long emitter lines (especially dripper lines with limited diameters), with little or no topographical slope, may have excessive friction losses, and will therefore also not conform to the specified limited discharge tolerances. Additional distribution and/or branch lines, or pressure compensating emitters, are the only alternatives.
- Uneven terrain, where topographic features are the only cause for unacceptable emitter discharge deviations, will naturally require pressure compensating emitters.
- Even systems which can easily and economically make use of pressure sensitive emitters may have sections which will unavoidably endure excess pressure. Pressure compensating emitters will effectively and economically solve this problem.

2.2.3 Different drip system concepts

In general there are two drip system concepts in use: The conventional concept, and the open hydroponic system (OHS) approach. These approaches differ vastly, with the latter not yet having been implemented on either a large scale or over the long term in South Africa.

2.2.3.1 Conventional concept

All systems that make use of the strip wetting principle, both pressure sensitive and pressure compensating modes, fall under the "conventional" category. Although laterals are traditionally placed above ground, in some cases it is more beneficial to place them underground.

The aim of the general conventional approach is to create a continuous wet zone in the soil, within which sufficient feeding roots of row crops will develop and function satisfactorily. It is therefore important to make maximum use of the lateral water distribution capacity of the soil by means of adequate emitter overlapping.

Emitter spacing should therefore be selected sensibly and practically, as shown later in Section 5.6. A pre-assembled dripper line is normally manufactured according to standard manufacturing processes with a wide range of dripper spacing options, ranging from about 0,3 to 1,25 m. This allows the designer to satisfy the minimum system requirements indicated by the results of the experimental tests carried out to determine the potential lateral water distribution capacity of the specific soil.

When underground application of this concept is considered, some features, guidelines and limitations should be considered. Circumstances under which the underground application can be implemented beneficially include:

- Where regular burning occurs, e.g. sugar cane fields
- If the crop and soil combination requires short cycle irrigation
- Where harvesting practices can be simplified, e.g. mechanical harvesting of tomatoes or cotton
- To prevent pathogens from reaching the soil surface, e.g. using sewage

Crops which are typically successfully irrigated with this method include strawberries, sugar cane, chillies, broccoli, lettuce, onions, tomatoes, cotton and water-melon.

The equipment necessary for applying chemicals for plant nutrition, insect control and preventing dripper blockages should be installed at a suitable place in the system.

Root penetration is a potentially serious problem. Plants such as lettuce, asparagus and sweet potato may be more likely to create problems with root penetration, as can shallow (5 to 7 cm) positioning of dripper lines. Special preventive practices may be required:

- Decreasing the pH of the water regularly can be beneficial, but the soil should be monitored periodically to prevent toxicity in the root zone.
- Drippers that close automatically under low pressure conditions are more resistant to root penetration.

- Shock dosages of chlorine can be applied after harvesting for a period just long enough to fill all the dripper lines.
- Scheduling should be effected to ensure that plants never experience any water stress.
- Application of Trefluralin combinations at relatively regular four to six months intervals prevents root penetration.

Potential soil penetration of the drippers due to vacuum conditions is a common problem, especially when the system is switched off. The design should therefore make provision for the following preventative measures:

- Anti-vacuum valves should be installed downstream of all shut-off valves
- Likewise, anti-vacuum valves should be installed at all high points

The installation depth (usually between 0,1 m to 0,3 m) depends on the plant root system and the lateral water distribution capacity of the soil. Water distribution can be improved by implementing the following practices:

- Use drippers with a low discharge (<2 ℓ/h).
- Use plant nutrients containing calcium and nitrates instead of sodium and ammonia to improve water distribution.
- Apply pulse irrigation.

In the USA it has been found that the discharge of pressure sensitive drippers decreases with 10% to 20%. Sufficient provision should be made for this in the design of system capacity.

2.2.3.2 The Open Hydroponic System approach

This concept, which is radically different from conventional drip irrigation practices, was developed in the 1990s in Spain for the irrigation of citrus orchards. The basic approach was derived from the philosophy that ideal conditions for the absorption of water and plant nutrients on a daily cycle need to be provided to a volume of as little as 120 ℓ to the feeding roots of the tree. This means that the full crop water requirement is applied during the active transpiration period every day. Remarkable success has been achieved thus far, especially regarding marketable quality. The concept has been implemented in a number of countries. Research is currently under way locally, and it is therefore appropriate to take note of design factors which are unique to this concept:

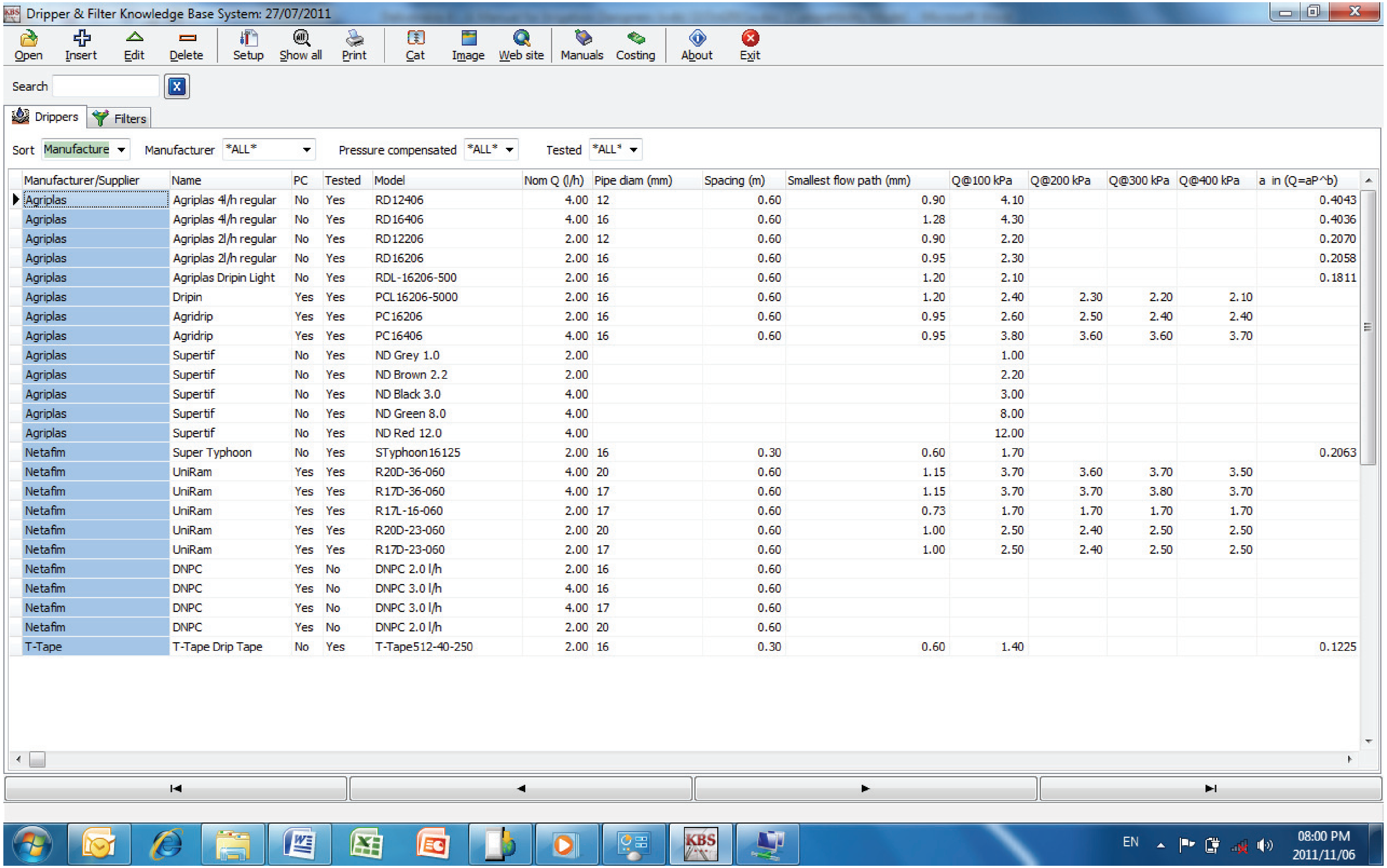
- Trees are planted with initially only one emitter each. As demand increases with growth, the original emitter is either replaced with a larger one, or a second one is added. Dripper positions relative to the tree are also adjusted during the early developmental stages. This means that the hydraulic design, especially for soils with steep slopes, cannot be finalised from the outset with pressure sensitive emitters because of tolerance limitations. Pressure compensating drippers are therefore strongly recommended.
- Due to the above-mentioned conditions, it is also basically impossible to make use of a system with emitters that are integral with the laterals, and the use of on-line mounted drippers is also almost unavoidable.

- If the use of in-line or internally mounted drippers is considered at all, the absolutely plant-bound spacing should be taken into account. The manufacturing specifications should make thorough provision for this, especially regarding the thermal characteristics of the specific dripper line material. The installation of this type of system can be very complicated as far as layout is concerned, where one or two emitters have to be provided (and maybe moved) and maintained for each tree.
- Although the cost of the emitter itself is relatively high in systems with on-line drippers compared to other types, it is partially compensated by the use of standard PE pipes instead of special dripper lines.
- This approach also requires the daily provision of plant nutrients with the water. Installing suitable equipment at both the control centre and individual blocks is therefore a prerequisite.
- Automation of the operating and management system will be virtually unavoidable.

2.3 Commercially available equipment

A huge variety of drippers are available on the South African market. Data on drippers from the most prominent suppliers have been captured in a Knowledge Base System (KBase) as part of the WRC project and is shown in Figure 9 and is included as a CD in the back cover of Volume 1, the Main Report. Further, the individual suppliers can also be contacted for information and specifications.

Only drippers from reputable irrigation companies where good quality control and testing are in place must be used.



Manufacturer/Supplier	Name	PC	Tested	Model	Nom Q (l/h)	Pipe diam (mm)	Spacing (m)	Smallest flow path (mm)	Q@100 kPa	Q@200 kPa	Q@300 kPa	Q@400 kPa	a in (Q=aP^b)
Agriplas	Agriplas 4l/h regular	No	Yes	RD12406	4.00	12	0.60	0.90	4.10				0.4043
Agriplas	Agriplas 4l/h regular	No	Yes	RD16406	4.00	16	0.60	1.28	4.30				0.4036
Agriplas	Agriplas 2l/h regular	No	Yes	RD12206	2.00	12	0.60	0.90	2.20				0.2070
Agriplas	Agriplas 2l/h regular	No	Yes	RD16206	2.00	16	0.60	0.95	2.30				0.2058
Agriplas	Agriplas Dripin Light	No	Yes	RDL-16206-500	2.00	16	0.60	1.20	2.10				0.1811
Agriplas	Dripin	Yes	Yes	PCL16206-5000	2.00	16	0.60	1.20	2.40	2.30	2.20	2.10	
Agriplas	Agridrip	Yes	Yes	PC16206	2.00	16	0.60	0.95	2.60	2.50	2.40	2.40	
Agriplas	Agridrip	Yes	Yes	PC16406	4.00	16	0.60	0.95	3.80	3.60	3.60	3.70	
Agriplas	Supertif	No	Yes	ND Grey 1.0	2.00				1.00				
Agriplas	Supertif	No	Yes	ND Brown 2.2	2.00				2.20				
Agriplas	Supertif	No	Yes	ND Black 3.0	4.00				3.00				
Agriplas	Supertif	No	Yes	ND Green 8.0	4.00				8.00				
Agriplas	Supertif	No	Yes	ND Red 12.0	4.00				12.00				
Netafim	Super Typhoon	No	Yes	STyphoon16125	2.00	16	0.30	0.60	1.70				0.2063
Netafim	UniRam	Yes	Yes	R20D-36-060	4.00	20	0.60	1.15	3.70	3.60	3.70	3.50	
Netafim	UniRam	Yes	Yes	R17D-36-060	4.00	17	0.60	1.15	3.70	3.70	3.80	3.70	
Netafim	UniRam	Yes	Yes	R17L-16-060	2.00	17	0.60	0.73	1.70	1.70	1.70	1.70	
Netafim	UniRam	Yes	Yes	R20D-23-060	2.00	20	0.60	1.00	2.50	2.40	2.50	2.50	
Netafim	UniRam	Yes	Yes	R17D-23-060	2.00	17	0.60	1.00	2.50	2.40	2.50	2.50	
Netafim	DNPC	Yes	No	DNPC 2.0 l/h	2.00	16	0.60						
Netafim	DNPC	Yes	No	DNPC 3.0 l/h	4.00	16	0.60						
Netafim	DNPC	Yes	No	DNPC 3.0 l/h	4.00	17	0.60						
Netafim	DNPC	Yes	No	DNPC 2.0 l/h	2.00	20	0.60						
T-Tape	T-Tape Drip Tape	No	Yes	T-Tape512-40-250	2.00	16	0.30	0.60	1.40				0.1225

Figure 9: List of the drippers and selected data captured in the KBase

3 TECHNICAL ASPECTS OF FILTRATION EQUIPMENT

3.1 Background

The filter is the heart of any drip system. In general, water filters are designed to remove specific types of contaminants for industrial, irrigation or municipal purposes. Filtration and/or treatment of irrigation water for application through drip systems is essential to prevent harmful physical, chemical or organic substances from blocking the emitters.

It is necessary to have a thorough understanding of water quality aspects and a comprehensive knowledge of the variety of drippers for design purposes, because the type of filter to be used and the level of filtration required are closely related to the type of the irrigation system and the effect of impurities in the water on the drippers. Appropriate maintenance schedules, and the correct selection and management of the filtration system, is therefore of particular importance for optimum performance of the irrigation system:

3.2 Filter types

The need to filter irrigation water originated with the development of the micro-irrigation concept in Israel. Initially, mesh filters were used, but the need to filter very dirty water led to the development of more efficient filters which could also handle much higher flow rates. Mesh, disc and sand filters are currently used in South Africa.

3.2.1 Mesh filters

Mesh filters consist of a permeable membrane which is usually located inside a supporting, cylindrical core. The mesh is usually manufactured of stainless steel or a nylon compound. The filtering qualities are determined by the size of the mesh openings, the total mesh area, and the facility for cleaning the mesh during regular maintenance operations. Two typical constructions are illustrated in Figure 10. Mesh filters are suitable for filtering good quality water in which sand and silt occurs. Algae can however block the openings of a mesh filter.

Standard filter ratings						
Micron	300	250	200	130	100	80
mm	0,3	0,25	0,2	0,13	0,1	0,08
Mesh	50	60	75	120	155	200

Figure 10: Mesh filters and fineness ratings (Photo: Arkal)

3.2.2 Disc filters

Disc filters offer a three-dimensional filter action, and therefore have a much higher capacity compared to mesh filters of the same basic dimensions. The filter consists of a number of grooved circular plastic discs which are tightly stacked cylindrically. Water flows from the outside of the cylinder through the discs to the inside. All foreign matter larger than the permeable openings of the specific grooves is retained by the discs.

Dirt is removed from the discs by flushing with filtered water in the opposite direction through the discs (backwashing). In some filters, the discs can also be loosened from one another and even rotated during backwashing, results in cleaner discs. Figure 11 illustrates the flow pattern of a typical disc filter during the filtration and backwashing actions.

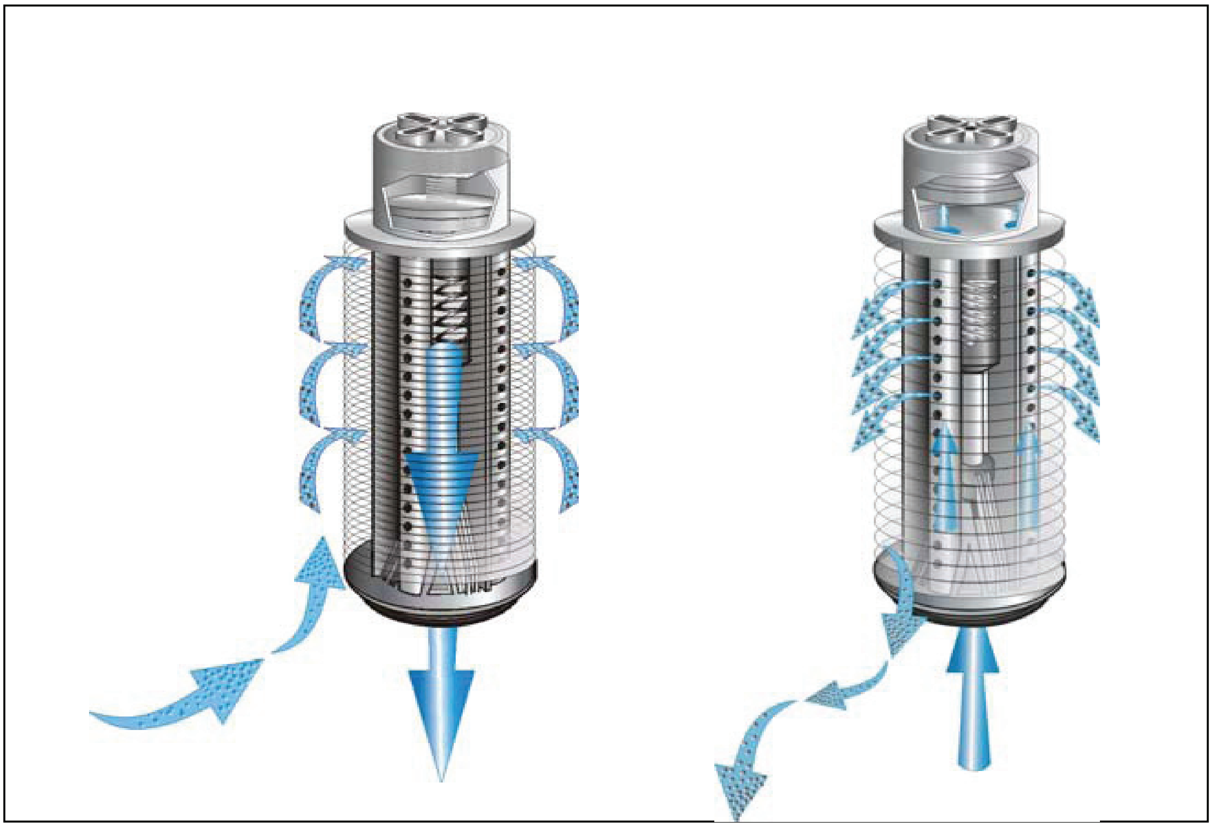


Figure 11: Filtration and backwash action in disc filters (Photos: Arkal)

Disc and mesh filters are selected so that the allowable pressure difference over the clean filters is ≤ 10 kPa. Table 2 shows the allowable pressure difference over disc/mesh filter banks.

Table 2: Guidelines for maximum allowable pressure drop over disc/mesh filter banks

Clean disc/mesh filter bank (kPa)	Allowable pressure build up over filter bank (kPa)	Allowable pressure drop over filter bank before backwashing (kPa)
≤ 30	≤ 40	≤ 70

3.2.3 Sand filters

Like disc filters, sand filters also offer a three-dimensional filtering action. They offer a particularly large medium area, thus the total capacity of a sand filter is much higher than that of other filter types. It also has a finer filter action, making it a very popular choice. Most manufacturers specify a sand filter with a wide spectrum of granular sizes capable of removing particles down to 80 microns from the water.

The medium area is the determining factor for calculating the filter capacity. The theoretical maximum filter capacity of a "0,8" mm sand is 50 m^3/h per square metre sand surface. However, there are two major reasons why it is not advisable to use sand filters maximally:

- The lower the flow rate during filtration, the better the result
- At the same time, backwashing intervals increase in inverse proportion to the decline in utilisation

Although sand filters require little maintenance, it is important that the filters are backwashed regularly to prevent excessive accumulation of dirt which could screen off the sand surface, and consequently be forced through the sand due to the increased pressure difference resulting in a process known as funnelling. It has been determined in practice that the best backwashing rates of sand filters should be identical to or slightly lower than the maximum filtration rate. It is also recommended that the sand is replaced on a regular basis, at least once a year.

Sand filters are always operated in conjunction with secondary disc or mesh filters. There are two reasons for this:

- Under normal circumstances, the secondary filter serves as a check on the performance of the sand filter. During incidental funnelling, the material will move through the sand and will be intercepted by the secondary filter. This condition warns the operator that the sand filter needs to be serviced.
- If the sand filter is damaged internally, the filter sand is intercepted by the secondary filter, preventing it from entering the emitters.

The shape and function of typical sand filters are illustrated in Figure 12.

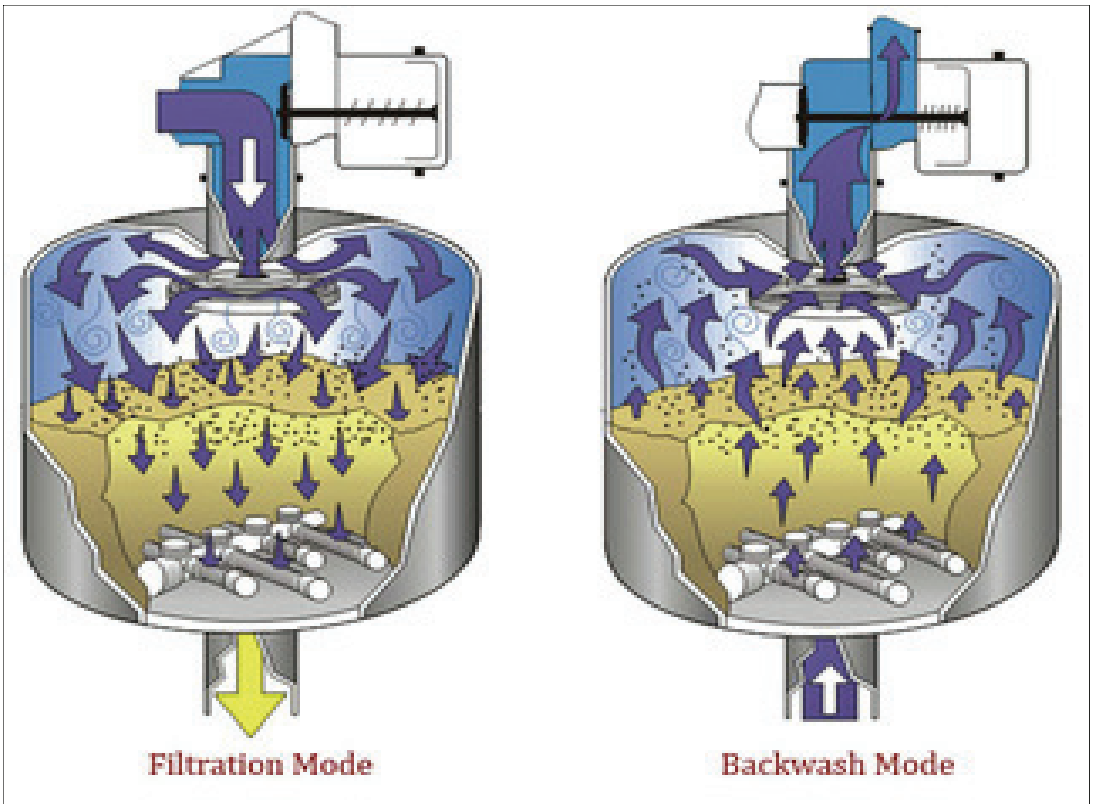


Figure 12: Operation of sand filters

Sand filters are selected so that the allowable pressure difference over the clean filters is ≤ 10 kPa and the flow rate limitation of ≤ 50 m^3/h per m^2 sand surface. Table 3 shows the allowable pressure difference over sand filter banks.

Table 3: Guidelines for maximum allowable pressure drop over sand filter banks

Clean sand filter bank (kPa)	Allowable pressure build up over filter bank (kPa)	Allowable pressure drop over filter bank before backwashing (kPa)
≤ 40	≤ 20	≤ 60

3.3 Selection of filter type

The type of filter to be used, and the level of filtration which is to be handled by the filter medium, are closely related to both the type of system which is to be served and the amount of dirt in the water. Because dripper blockages are difficult to see, and can only be repaired by replacement, drip irrigation in general requires a high degree of filtration.

Sand filters fitted with secondary filters are recommended for drip irrigation with 'normal' stored or running water. Because mesh filters are basically not back-washable, disc filters are recommended for this purpose.

Disc filters are usually adequate in cases where clean water (e.g. most borehole water) is used for irrigation. The filtration level will be fine enough, and the only limitation will be the length of the backwash cycle.

3.4 Selection of filter size or filter capacity

The size and/or the number of filters required for a system depends on:

- The total flow in the system and the maximum recommended flow through each filter
- The amount of dirt present in the water
- The minimum back-wash or cleaning cycle

3.4.1 Maximum flow rate

The higher the flow rate through a filter, the higher the pressure loss over the filter. An example of pressure loss information provided by a manufacturer is shown in Figure 13.The colour codes for the filter grade refer to the fineness of the filter – the finer the grade of filtration (smaller grade number), the higher the pressure loss through the filter at the same flow rate.

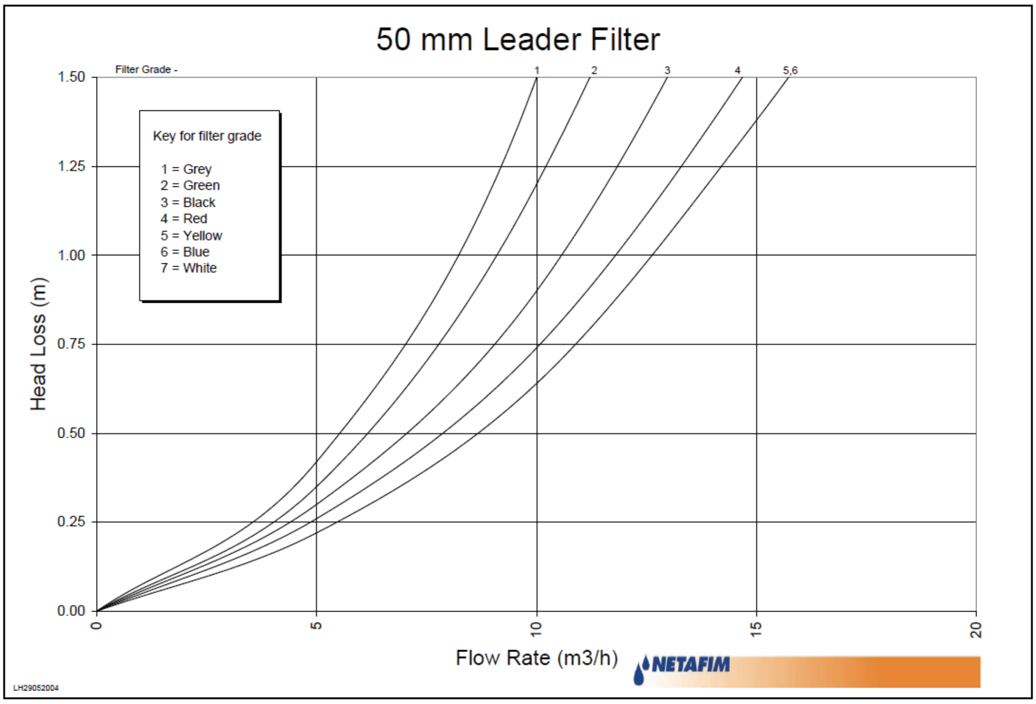


Figure 13: Example of pressure loss graphs (Source: Netafim)

Pressure losses should be limited for both physical and economical reasons. The total pressure loss over a clean filter at the maximum allowable flow rate should not exceed 10 kPa. This guideline, however, is not rigid, but can be adapted according to relevant system factors. Excessive pressure losses may adversely affect the filtration efficiency and may even damage the medium.

3.4.2 Dirtiness of the water

An adaptation in the recommended flow rate of filter is necessary if the silt load of the irrigation water is abnormally high. For example, the recommended maximum flow rate of sand filters of < 50 m^3/h per m^2 sand surface can be reduced for the Orange River with its heavy silt load to 30-35 m^3/h per m^2 sand surface.

For filtration purposes, the dirtiness of irrigation water is measured with a special but simple apparatus called the dirt index meter. The dirt index (DI) is expressed as a percentage. The interpretation of DI is explained in Table 4.

Table 4: Classification of the dirt index figures for irrigation water

Dirt index (DI) [%]	Classification
< 1	**Clean**
> 1	**Dirty**
Approximately 5	Fairly dirty: blockage of most filters within a few days
Approximately 30	Very dirty: blockage of most filters within a few hours
Approximately 60	Extremely dirty: blockage of most filters within a few minutes

The ARC-Institute for Agricultural Engineering in Weavind Park, Pretoria may be contacted for more information on the relevant apparatus.

3.4.3 Cleaning cycle

During the filtration process there is an increase in the total pressure loss over the filter due to blockage. The pressure loss over a typical filter is illustrated in Figure 14.

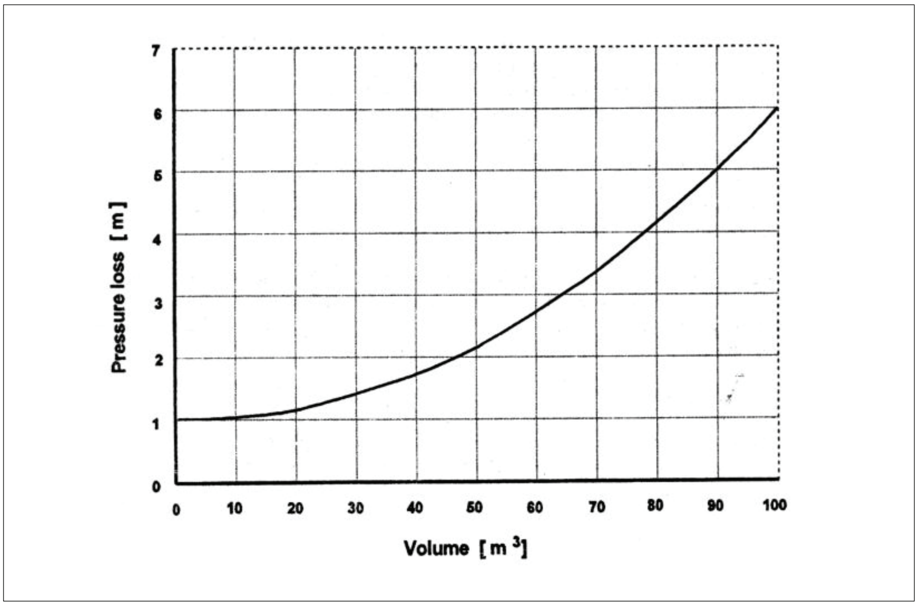


Figure 14: Typical blockage graph of filter

Figure 14 shows that an increase in the allowable pressure loss over a filter will result in an increase in the capacity:

- An increase of about 1,5 to 2,0 m in sand filters may cause funnelling, with resulting penetration of dirt.
- With disc and mesh filters, excessive pressure losses may cause the dirt to be forced through the medium, decreasing efficiency in that way.
- In some filters, especially mesh filters which filter from the outside to the inside of the core, the entire element may collapse if the pressure loss is excessive. In this case a large concentration of dirt (which has accumulated on the element) may be released into the system, causing serious blockages in the emitters.
- Elements, and even sand, which lose their function due to excessive pressure losses, are more difficult to clean, while the efficiency of backwash actions will also decrease.

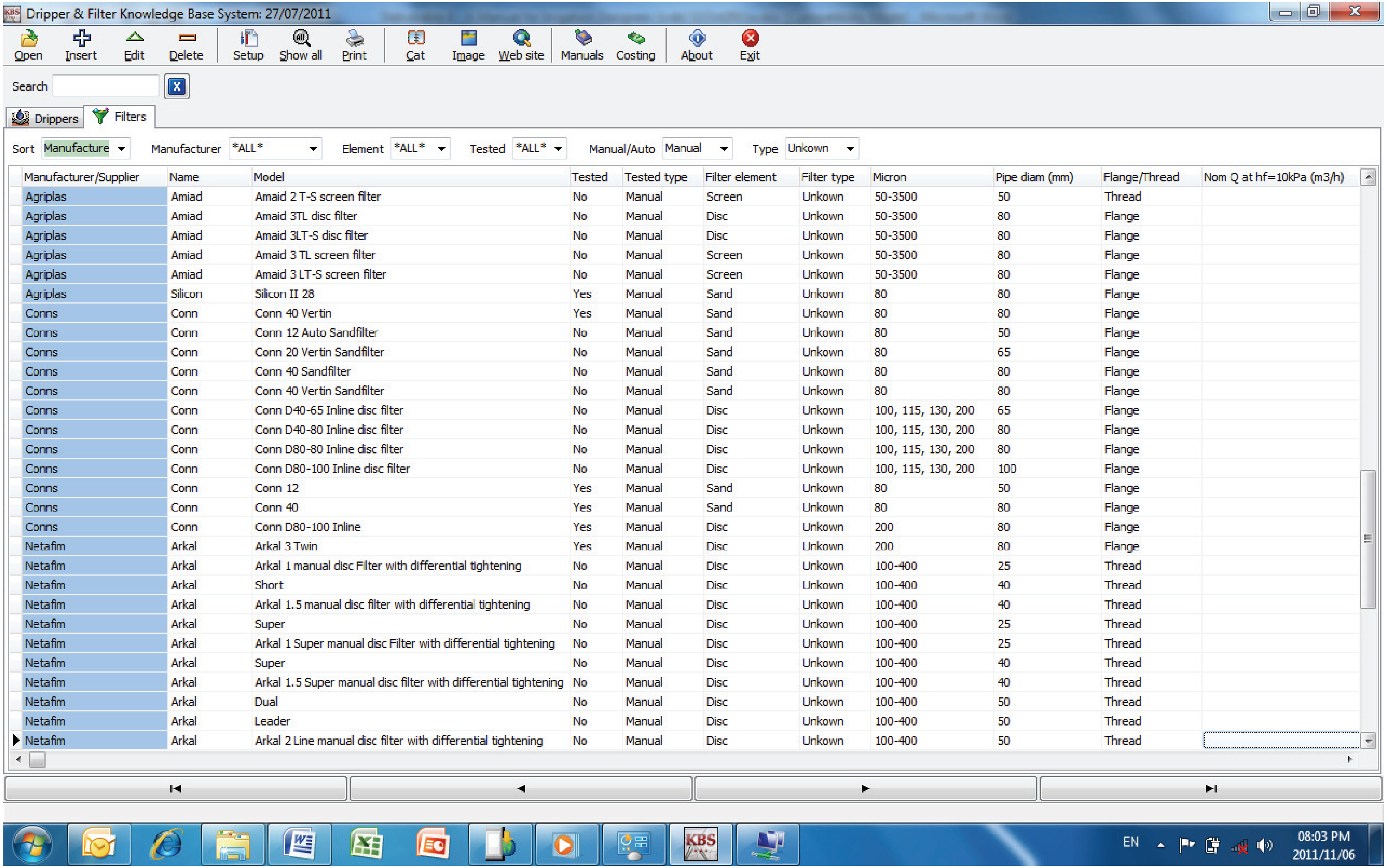
The backwash cycle depends exclusively on the quality of the water. Dirtier water requires shorter backwash cycles, and more and/or larger filters.

3.5 Commercially available products

A huge variety of filtration equipment is available on the South African market. The main suppliers are Agriplas, Conns and Netafim. Data pertaining to these manufacturers' filtration equipment has been captured in a Knowledge Base System (KBase), a sample of which is shown in Figure 15. The KBase is included as a CD in the back cover of Volume 1, the Main Report.

Suppliers of these products can also be contacted directly for information on the selection and design of filters.

Only filters from reputable irrigation companies where good quality control and testing are in place must be used.



Manufacturer/Supplier	Name	Model	Tested	Tested type	Filter element	Filter type	Micron	Pipe diam (mm)	Flange/Thread	Nom Q at hf=10kPa (m3/h)
Agriplas	Amiad	Amaid 2 T-S screen filter	No	Manual	Screen	Unkown	50-3500	50	Thread	
Agriplas	Amiad	Amaid 3TL disc filter	No	Manual	Disc	Unkown	50-3500	80	Flange	
Agriplas	Amiad	Amaid 3LT-S disc filter	No	Manual	Disc	Unkown	50-3500	80	Flange	
Agriplas	Amiad	Amaid 3 TL screen filter	No	Manual	Screen	Unkown	50-3500	80	Flange	
Agriplas	Amiad	Amaid 3 LT-S screen filter	No	Manual	Screen	Unkown	50-3500	80	Flange	
Agriplas	Silicon	Silicon II 28	Yes	Manual	Sand	Unkown	80	80	Flange	
Conns	Conn	Conn 40 Vertin	Yes	Manual	Sand	Unkown	80	80	Flange	
Conns	Conn	Conn 12 Auto Sandfilter	No	Manual	Sand	Unkown	80	50	Flange	
Conns	Conn	Conn 20 Vertin Sandfilter	No	Manual	Sand	Unkown	80	65	Flange	
Conns	Conn	Conn 40 Sandfilter	No	Manual	Sand	Unkown	80	80	Flange	
Conns	Conn	Conn 40 Vertin Sandfilter	No	Manual	Sand	Unkown	80	80	Flange	
Conns	Conn	Conn D40-65 Inline disc filter	No	Manual	Disc	Unkown	100, 115, 130, 200	65	Flange	
Conns	Conn	Conn D40-80 Inline disc filter	No	Manual	Disc	Unkown	100, 115, 130, 200	80	Flange	
Conns	Conn	Conn D80-80 Inline disc filter	No	Manual	Disc	Unkown	100, 115, 130, 200	80	Flange	
Conns	Conn	Conn D80-100 Inline disc filter	No	Manual	Disc	Unkown	100, 115, 130, 200	100	Flange	
Conns	Conn	Conn 12	Yes	Manual	Sand	Unkown	80	50	Flange	
Conns	Conn	Conn 40	Yes	Manual	Sand	Unkown	80	80	Flange	
Conns	Conn	Conn D80-100 Inline	Yes	Manual	Disc	Unkown	200	80	Flange	
Netafim	Arkal	Arkal 3 Twin	Yes	Manual	Disc	Unkown	200	80	Flange	
Netafim	Arkal	Arkal 1 manual disc Filter with differential tightening	No	Manual	Disc	Unkown	100-400	25	Thread	
Netafim	Arkal	Short	No	Manual	Disc	Unkown	100-400	40	Thread	
Netafim	Arkal	Arkal 1.5 manual disc filter with differential tightening	No	Manual	Disc	Unkown	100-400	40	Thread	
Netafim	Arkal	Super	No	Manual	Disc	Unkown	100-400	25	Thread	
Netafim	Arkal	Arkal 1 Super manual disc Filter with differential tightening	No	Manual	Disc	Unkown	100-400	25	Thread	
Netafim	Arkal	Super	No	Manual	Disc	Unkown	100-400	40	Thread	
Netafim	Arkal	Arkal 1.5 Super manual disc filter with differential tightening	No	Manual	Disc	Unkown	100-400	40	Thread	
Netafim	Arkal	Dual	No	Manual	Disc	Unkown	100-400	50	Thread	
Netafim	Arkal	Leader	No	Manual	Disc	Unkown	100-400	50	Thread	
Netafim	Arkal	Arkal 2 Line manual disc filter with differential tightening	No	Manual	Disc	Unkown	100-400	50	Thread	

Figure 15: Sample of filter data captured in the KBase

4 GENERAL GUIDELINES FOR PLANNING AND DESIGN

4.1 Introduction

Planning is the most important part of the drip irrigation system design process, as every decision made at this early stage will affect the cost and efficiency of the system. The WRC report *Micro-irrigation for smallholders: Guidelines for funders, designers and support staff in South Africa* by Du Plessis FJ et al., 2002 forms the basis for the following guidelines.

4.2 Factors determining success and failure in drip irrigation

Various factors determine the success and failure of drip irrigation. Table 5 summarises the six categories regarded as critical factors.

Table 5: Categories of critical factors in drip irrigation

Category	Critical factors
The farmer's circumstances	Level of education Irrigation farming experience Irrigation farming training Attitude of farmer towards drip irrigation Geographic location of the farm Suitability of climate Production potential of the soil Size of operation Land ownership Degree of dependency on farm income
Water Supply	Amount of irrigation water available Reliability of the water supply system Quality of the irrigation water Frequency of the supply of water Management of supply
Irrigation system	Pump and on-farm water distribution system Suitability of the in-field system Filtration Fertiliser application System installation Performance relative to other systems used or know by the farmer Innovation and adaptation in problem solving
General management	Utilisation of system Maintenance of system Irrigation scheduling practices Crop management Labour requirement Time management Record-keeping

Organisational arrangements	Physical service providers available to the farmer Extension services Infrastructural, institutional, social and extension factors
Economic and financial factors	Cost of the system Cost of water supply Scale of the production unit Access to and use of finance and credit Cash-flow on and off farm Marketing

4.2.1 Factors related to the farmer's conditions and circumstances

A farmer's personal traits and attitudes may influence the success and failure in drip irrigation. The farmer's level of education of determines how effectively they will use written information, and influences their ability to maintain essential records. Hands-on experience of drip irrigation, or exposure to formal or informal training in irrigation increases the likelihood of farmers adopting drip irrigation successfully. Adoption is also influenced by the initial attitude of farmers towards drip irrigation.

4.2.2 Factors related to water supply and water quality

The supply of water to the farm or field edge is a critical factor in drip irrigation. Overall, an abundant and reliable supply of water enhanced the likelihood of success, as it compensates for the teething problems that farmers may experience when using drip irrigation for the first time. Conversely, projects can fail in situations where the supply of water was limited or unreliable.

4.2.3 Factors related to drip irrigation equipment

Drip irrigation equipment includes the water pump, the filtration and fertigation equipment, and the in-field water distribution equipment. The operation and maintenance of all of these can influence effectiveness and efficiency.

4.2.4 Factors related to general farm management

Managerial problems are in many cases the root cause of drip irrigation ineffectiveness. In most cases, the underlying causes of managerial problems are an attitude of risk avoidance or a lack of understanding of the new system.

Farmers fail in most cases to give adequate attention to maintenance of the components of their drip irrigation system.

4.2.5 Geographical, institutional and organisational factors

Remoteness of a project has a distinct disadvantage, because it limits access to input and produce markets, services and communication.

4.2.6 Economic and financial factors

One of the important concerns of irrigation economics is the transformation of water into consumer goods. This transformation is achieved by removing the environmental limitation of water deficits in the production of crops used for fibre or food. Relative to many other irrigation systems, the capital outlay per unit area needed to install a drip irrigation system is known to be high, presenting an obstacle to the selection of drip irrigation. Moreover, the capital cost per unit area for drip irrigation increases as the area covered by the system is reduced, which deters small-scale farmers from adopting drip irrigation.

The cost of water is an essential concern in irrigation economics. In South Africa, the real cost of water is increasingly being realised, because of water scarcity and increasing demand for water by non-agricultural users.

4.3 Guidelines for planning, design and management of drip irrigation projects

The guidelines have been structured into the following five main categories:

- System planning;
- System design;
- System installation and training;
- System operation and maintenance, and
- Financial aspects.

4.3.1 System planning

4.3.1.1 General issues

The selected project approach will have a considerable influence on the development and potential for success of the project. Table 6 gives a summary of the general issues.

Table 6: Summary of general issues and guidelines for system planning

Issue	Guideline
Background information	• Collect standard information required for planning the drip irrigation; assess the data for accuracy and reliability; resolve conflicting facts; compile and communicate findings. • Collect information on current and historical development initiatives; verify the information for accuracy; resolve conflicting facts; compile and communicate findings. • Share the information obtained among local stakeholders and among farmers intended to benefit from the irrigation project. • Incorporate findings where possible into the planning of the irrigation project. • Build flexibility into the plan to allow for existing diversity, and future change.
Introduction and implementation of drip irrigation	• Apply a phased approach to planning and implementation of drip irrigation: Too much too soon is likely to undermine farmer confidence. • Present farmers with a realistic portrait of what can be expected from drip irrigation during the first and subsequent years. • Provide an explanation of the advantages and disadvantages of drip irrigation. • Ensure that farmers understand the proposed project, and allow for their inputs. • In consultation with farmers, develop principles and procedures that will be adhered to by all during implementation of the project.

Engagement of farmer support services	• Identify the local farmer support or extension agencies mandated to serve the farmer's needs. • Encourage the formation of a small project support team, committed to assist farmers during implementation and operation of the irrigation project. • Acknowledge the importance of the project support team, by informing them of all developments in the project, and involving them in all the stages of planning and implementation, including physical presence during lay-out and installation of the equipment. • Assign a central role to the dedicated staff in the project support team. • Plan and programme for continuity of the provision of support in the form of an after-care service.

An inventory of existing information should be compiled at project initiation. In addition to standard information of specific importance to irrigation planning, the inventory should also contain information on current and historical development initiatives in the area. Sharing the content of the inventory with the farmer creates awareness, and helps to remove or avoid confusion on who is doing what in the area of operation.

4.3.1.2 Planning with farmers: the central role of the end-users of technology

There is a close relationship between a farmer's success in drip irrigation and the life experiences of the farmer with irrigated agriculture. Familiarity with irrigation and crop management provide farmers with confidence about their ability to grow crops successfully. When confronted with a new technology, such as drip irrigation, it will be possible to focus most of their attention on the challenges imposed by the innovation, without being overly concerned about other aspects of their crop production enterprise. Table 7 summarises the issues concerned with planning with farmers.

Table 7: Summary of issues and guidelines for system planning with farmers

Issue	Guideline
Farmer experience	• Determine the life experience of the intended end-users, with special reference to the skills required to conduct a drip irrigation enterprise successfully. Give specific attention to agricultural and irrigation experience, technological experience, and experience in basic record-keeping and marketing of agricultural products. • Plan implementation of production based on these findings, allowing for a phasing-in of drip irrigation on a smaller area in cases where farmer experience is lacking. • Plan for rapid progress in cases where a phased-in approach is taken, by ensuring intensive monitoring and advisory support during the initial phases.
Technical experience	• Plan, design and operation and maintenance of the drip irrigation system in accordance with the level of technical and mechanical knowledge and skills of farmers. • Limit the responsibilities of farmers in terms of system operation and maintenance as much as possible. Prepare and implement a hands-on training program to provide farmers with the ability and confidence to execute the technical and mechanical tasks allocated to them by the overall plan.

Financial dependency	• Determine the degree to which farmers are dependent on the income derived from irrigated cropping, especially in cases where drip irrigation is to replace an existing irrigation system. When the level of dependency is high, plan for phased-in conversion of the irrigation system. This will enable farmers to maintain income from the irrigation practices they are familiar with, whilst they develop confidence in the use of drip irrigation on a smaller area.
Communication skills	• Develop an appropriate way of communicating knowledge and information to the farmers.

4.3.1.3 Water and soil quality, farm size and water supply system

It is possible to produce high yields and products of high quality under conditions using drip irrigation, where conventional ways or irrigating a crop would not yield good results. Examples of such conditions include areas with poor-quality soils, or situations where the availability of water is low. However, farming under such conditions is very demanding and poses a high risk to the inexperienced irrigator. Table 8 gives a summary of the associated issues.

Table 8: Summary of issues and guidelines for system planning; water, soil and farm size

Issue	Guideline
Soil and water quality	• Assess the quality of water and soil according to standard guidelines and procedures. This evaluation should influence design parameter decisions
Project scale	• Determine the supply of water, considering uses other than irrigation from the identified source. • Determine the legalities of water use. • Use expected minimum supply, as determined by seasonal or other variations, as a design parameter. • Allow for a safety margin of at least 30% less than the minimum amount of water available at all times when determining the maximum area to be irrigated from the available source of water. • Use this safety margin to determine the size of the project for implementation at the initial stage. However, allow for expansion by designing for the full area that can be irrigated from the available supply.
Water supply	• Assess the reliability of the water supply. Determine the cause where unreliable. • Take the reliability of the water supply into account especially in climates characterised by high evaporative demand, or when soils have a low water holding capacity. • Avoid using drip irrigation when the reliability of the water supply is not ensured, when dealing with soils with low water holding capacity, or in areas where evaporative demand is high. • Base the choice of system on the total volume of water required during the various stages of growth of the crops to be grown, the flow rate and the pressure available. • Subdivide irrigation blocks into smaller sub-units when pressure or flow rates are subject to considerable variations. • Small units will allow acceptable irrigation practice in each of the sub-units separately, even when pressure or flow rate is inadequate for the entire irrigation block. • Design safety measures into the system when the water supply is unreliable. This can include the building of a small water storage facility.

Water supply management	• Pursue the option of having the water supply managed by a capable and experienced operator. • Ensure a well-functioning support system when a capable and experienced operator to manage the supply system is not available.
Energy for pumping	• Use electricity driven motors where possible. • Ensure adequate hands-on training for operators of pump systems to perform routine maintenance and simple repairs.
Security considerations	• Discourage theft by using components made of materials that have no inherent resale value wherever possible. • Design for the locking away of expensive system components. • Plan for sub-surface installation of immobile system components whilst avoiding measures which compromise system flexibility.
Learning phase	• Plan for the planting of crops which are relatively insensitive to sub-optimal water supply during the initial phases of implementation, allowing farmers to develop confidence to later try high-value crops which are more sensitive to water stress. • Take the financial risk to farmers into account should the first planting fail, and evaluate the effect of such an event on the survival of the enterprise as a whole. When this risk is unacceptably high, introduce intermediate steps (small introduction plots) or when this is not feasible, reconsider the desirability of drip irrigation.

4.3.1.4 Crop production

The success of drip irrigation is highly dependent on the skills and the management ability of farmers. As indicated earlier, it is possible to use drip irrigation to produce high yields of high quality products under conditions where conventional ways of crop irrigation would not yield good results. This applies particularly to conditions of poor quality soils, poor quality water, and limited availability of water.

However, such conditions represent risk, which needs to be avoided especially when planning for farmers who may lack these attributes. When conditions are sub-optimal, a degree of risk can be removed by selecting an appropriate crop. Depending on the prevailing limitation, crops can be selected for their salt tolerance or their resistance to occasional water stress.

Farmers must be provided with appropriate guidelines on the spacing of crops when using drip irrigation, which may differ substantially from their former practices using conventional irrigation. Sub-optimal spacing of plants may have a detrimental effect on yield and economic returns, preventing expected benefits from being realised. Table 9 summary issues and guidelines for crop production.

Table 9: Summary of issues and guidelines for system planning; crop production

Issue	Guideline
Choice of crops	• Allow the selection of crops to be guided by the availability and reliability of the water supply, the quality of water and soils, the experience of the farmers, the reliance of the farmers on income from irrigated cropping, and the existing marketing opportunities. • Encourage farmers to grow crops with which they are familiar, especially during the first few years after implementation. This recommendation should be ignored only when excellent and reliable advisory support is available and committed to guiding farmers during the first few years of production of a new crop.

Choice of in-field system	• Select the type of dripper by considering the quality of water and soils, and the selection of crops to be grown.
Spacing of crops	• Advise farmers of the optimum crop spacing under drip irrigation. The spacing of the plants should preferably be adapted to the spacing of the emitters. This is especially important in the case of seedlings.

4.3.2 System design

4.3.2.1 General issues

Small-scale drip irrigation differs from its large-scale equivalent in several ways, some of which influence the approach to system design. These include the scale of the project; the cash flow, and access to finance by farmers.

The cost of laterals and emitters largely determine the cost of the in-field system. Farmers agreeing to a system that requires laterals to be moved around the field, or between rows, can reduce the cost of their in-field system. This option needs to be discussed carefully with the farmer. Time available to the farmer, and his or her willingness to accept the workload associated with moving laterals need to feature prominently in the discussions. Table 10 provides a summary general issues and associated guidelines.

Table 10: Summary of general issues and guidelines for system design

Issue	Guideline
Approach to system design	• Explore the opportunity of adopting a modular approach, allowing for the area under irrigation to grow incrementally. If a modular approach is desirable, the equipment and pipe sizes should be selected accordingly. • Optimise the design with regards to capital- and operational costs.
In-field system cost	• Explore the desirability of a design that requires the movement of laterals between crop rows (two to three rows per lateral), to reduce capital cost. The decision depends on the farmer's time to move laterals, and willingness to accept the workload of this practice. • Ensure that the sub-main design accommodates one lateral per row, even in cases where a design requiring the moving of laterals is adopted.
Options for system extension	• Incorporate the option to extend the system where other factors allow for this. In practice, this requires incorporating the option of adding one or two additional laterals on the sub-main. • Ensure that this option falls within the tolerance limits of the system.
In-field design tolerances	• Apply standard ARC-IAE norms for in-field design. • Investigate the possibility of reducing capital cost by lowering the emission uniformity (EU) values. Until current knowledge is improved, a minimum EU value of 85% should be maintained.
Water requirements	• Apply the standard procedures recommended in the Irrigation Design Manual (ARC-IAE, 2003), to determine water requirements and system capacity. The SAPWAT procedure produces good results. • Optimise irrigation scheduling taking into account the time available to the farmer, and future extensions to the system.

4.3.2.2 In-field system

The type and spacing of the emitters influence success in drip irrigation. The maintenance requirements of emitters differ, depending mainly on whether they are pressure-compensated or not. Selection of emitter type and spacing should be done with the aim of reducing the risk of failure. Consequently, farmer experience and farming conditions need to be considered carefully when making these decisions. Table 11 summarises the issues and guidelines associated with designing the in-field system.

Table 11: Summary of issues and guidelines for system design; in-field system

Issue	Guideline
Type and spacing of emitters	• Select drippers according to performance. Close spacings are more expensive • Choose between pressure-compensated and non-pressure-compensated.
System management	• Elect for the use of compensation if at all affordable. • Use procedures that apply to design with non-compensating emitters when installing compensated emitters on laterals shorter than 100 meters.

4.3.2.3 Filtration and control components

Unless irrigation water is purified before off-take, all farm drip irrigation systems require filtration of the water. There is, however, a tendency for operators to postpone or even neglect this task.

It is important that farmers are trained to a level where they are confident to inspect the condition of the filter, and to execute maintenance procedures such as the identification and repair of basic faults. Table 12 provides a summary of the issues and guidelines associated with filtration.

Table 12: Summary of issues and guidelines for system design; filtration

Issue	Guideline
Filtration	• Incorporate a filter in the system, unless a supply of filtered water is assured. • Use filters according to water quality. • Select a filter with a capacity that exceeds system needs by about 30% to reduce cleaning requirements and allow expansion of the system in future. • Install a pressure gauge upstream and downstream of the filter to enable the farmer to monitor the condition of the filter and identify when the filter is clogged. • Train the farmer in the operation and maintenance of the filter.
Maintenance design pressure	• Include a schraeder valve to monitor pressure downstream of the control valve of the block. • Include a secondary valve for pressure control when the supply pressure is subject to considerable variation. An inexpensive ball valve can be used as the primary valve, and a gate valve can act as the secondary valve.

4.4 System installation and training

The important role of training as a factor determining the success in drip irrigation cannot be over emphasised. Many farmers lack the knowledge and experience to install and operate a micro-irrigation system without training, even when supplied with comprehensive documentation on both processes.

This means that the person leading and supervising the installation must accept the role of trainer also. At the time of installation and training, a comprehensive set of relevant documentation must be made available to the farmer. This documentation must be referred to as the process installation evolves. Training of the farmer and support team must be incorporated into the installation of a drip irrigation system.

During installation, the farmer must receive hands-on training in the connection of the various components, and the role of each component in the system. This helps to demystify the operation of the system and allows farmers (and extension agents) to acquire knowledge that will reduce their dependency on external agencies for routine repairs and maintenance.

It is extremely important that installation is performed by or under the supervision of a qualified and experienced person. The involvement of this person is required during the entire installation process, from source to last emitter. Table 13 gives a summary of the issues and guidelines associated with installation, commissioning, and training.

Table 13: Summary of issues and guidelines; installation, commissioning, and training

Issue	Guideline
Installation	• Specify excellence in workmanship in the installation contract. • Use the installation process to train the farmer in a hands-on way. • Ensure that the entire installation is conducted under the supervision of a qualified and experienced person.
Commissioning	• Demonstrate to the farmer how to operate the system in accordance with design specifications. • Ensure that the farmer understand that extensions and alterations to the system (for which the system was not designed) should be avoided totally.
Information and documentation	• At the start of the installation process, supply the farmer with a file that contains a list of the components of the irrigation system, including sketches/diagrams, exact specifications and the cost of these components. • Include a comprehensive list with the contact details of all the suppliers of components that were incorporated into the irrigation system. • Include a list of useful suppliers of other services, including repairs, agricultural chemicals, fertilisers, and marketing.
Training (understanding the system)	• Plan the installation well in advance, and ensure that the farmer/operator and extension agent are committed to be present for the duration.
Training (Executing repairs)	• Train the farmer/operator to execute basic repairs, covering at least the following aspects: ▪ Fixing of laterals (normally PE pipes) ▪ Fixing of sub-mains (normally PE pipes) ▪ Fixing of main pipes (normally PVC pipes) ▪ Replacing emitters ▪ Rejoining a lateral to a sub-main • Prepare a list of spare parts that should be kept in stock, to enable the farmer/operator to execute basic repairs immediately. • Ensure that spares have been purchased at installation of the system.

	The spares should include at least the following items: ▪ Couplings for all sizes of pipes in laterals (2), sub-mains (1) and main pipes (1) ▪ An additional 100 m dripper line • Supply the farmer/operator with a troubleshooting checklist, designed to respond to “what if” questions and providing detailed advice on how to solve the most common problems. • This list should include a number of emergency actions and temporary solutions to problems, which allow the system to be used whilst more permanent solutions are pursued.
Drip Irrigation	• Explain and demonstrate the concept of drip irrigation early in the project. This should cover at least the aspects of discharge in a drip system, and the distribution of water below the dripper. Discharge is best explained by placing a container below a dripper, relating the release of water to the expiry of time. • The distribution of water in the soil below the dripper can be demonstrated by digging narrow trenches along the dripper line and across the line at the position of a dripper. • Make the farmer aware of the distribution of plant roots when demonstrating the water distribution in the soil below a dripper. Link the concentrated distribution of the roots to the reduction in rainfall effectiveness experienced when using a drip system.
Prevention of clogging	• Explain to farmer and extension agent the detrimental effect of dirt entering the drip irrigation system. • Demonstrate to farmer and extension agent how to prevent dirt from entering the irrigation system. A demonstration of how to move the system in a way that prevents the entry of dirt and subsequent clogging is very important.

4.5 System operation and maintenance

4.5.1 General issues

Drip irrigation is expected to reduce the amount of labour and time a farmer has to spend irrigating their crops compared to conventional irrigation. These benefits may not necessarily become evident immediately after converting from conventional to drip irrigation. Savings in time and labour will become apparent over time, when the farmer has become used to operating the system. Farmers should be encouraged to invest these savings in additional profitable activities.

All industry standard practices for system maintenance should be applied to the drip irrigation system. Among others, these practices include the flushing of mains, sub-mains, and laterals, and correcting the position of laterals. Refer to other suitable publications for comprehensive guidelines on standard maintenance practices in drip irrigation systems. Users are also reminded to carefully consider the system-specific maintenance practices and procedures recommended by manufacturers. See Table 14 for a summary of operation and maintenance issues and guidelines.

Table 14: Summary of issues and guidelines; general operations and maintenance

Issue	Guideline
Standard maintenance practices	• Apply the standard practices for system maintenance as recommended. • Encourage farmers to practice chemical weed control, reducing the hazard of system damage caused by mechanical cultivation. • Explain and demonstrate the damage likely to be caused when practicing mechanical cultivation, and demonstrate how such damage should be repaired.
Time and labour savings	• Explain to farmers how the drip irrigation system should be used to save time and labour. • Explore with farmers the potential for additional profitable activities, which can be undertaken using the spare time and labour that has become available.
Record keeping	• Provide farmers with simple forms on which to enter records. • Encourage farmers to keep records, and explain the potential benefits that can be derived from keeping accurate records. • Arrange a review event, during which the records are analysed in the presence of the farmer, and ensure that this leads to conclusions and recommendations for improved management.

4.5.2 Water supply system and in-field irrigation system

Regular flushing of main pipes, sub-mains, and laterals is necessary to ensure long-term functioning of a drip irrigation system. It is therefore important that farmers develop confidence in the execution of these procedures. The positive effect of flushing needs to be explained during installation. As installation progresses and the different components are positioned in the system, the farmer can be shown what flushing does to the various components, and what happens to the components when this necessary practice is ignored. Commissioning is the best time to train the farmer or the operator in the correct flushing procedures. Clear guidelines on these procedures should form part of the files supplied to the farmer and extension agent.

Visible evidence of clogging or blockages is less obvious in drip systems, because the emission of water from a dripper is slow by design. Usually, problems are only detected when emission from the dripper comes to a total halt. This causes water stress in the plant irrigated by the dripper, a condition that is quite easy to detect. However, by this stage, yield and quality of the crop have been negatively affected. It is therefore important that the farmer executes a monitoring program to ensure optimum functioning of the drippers. Placing containers under drippers and measuring the water released per unit time using a stopwatch and a measuring cylinder are recommended. Regular testing of a drip system is a recommended procedure, because drippers tend to routinely get clogged over time. Table 15 summarises the issues and guidelines for system operations and maintenance.

Table 15: Summary of issues and guidelines; supply and irrigation system O&M

Issue	Guideline
Flushing the irrigation system	• Advise farmers on standard procedures to maintain good functioning of the drip irrigation system in line with the scale of the project. • Provide the farmer with clear guidelines on these procedures. • Train the farmer in the conduct of the procedures.
Blockages in drip systems	• Explain to farmers that drippers can clog routinely over time, necessitating a monitoring program aimed at detecting reductions in the emission of water. • Mark three or more drippers distributed over the length of a lateral, with white paint, and determine the flow rate at each of the drippers. Repeat this procedure for at least three laterals in each block. Develop the details of a monitoring program, and explain what to do when a reduction in the flow rate is detected.
Cleaning emitters	• Demonstrate to the farmer how to unblock a dripper, i.e. by knocking the drippers or by applying external pressure on them.

4.5.3 Application of fertilisers

Fertiliser application through a drip irrigation system must be done with great care, and according to the guidelines of the fertiliser supplier. Table 16 summarises the issues and guidelines associated with applying fertilisers.

Table 16: Summary of issues and guidelines; application of fertilisers

Issue	Guideline
Application of fertilisers	• In all cases, farmers must be supplied with clear guidelines and recommendations on the type of fertilisers to use, the application rate, and the time of application. • Several options are available for fertiliser application. These form part of the range of options considered standard in drip irrigation, e.g. the use of a Venturi apparatus, a fertiliser tank, hydraulic injectors, electrical injectors, and the mixing of fertilisers in a storage tank at the water source or a purpose made fertiliser injection.

4.5.4 Irrigation scheduling and monitoring of water supply to crops

Guidelines for the scheduling of irrigation need to be formulated that apply to the specific conditions found on the farm where drip irrigation is being implemented. Factors that need to be considered include climatic conditions, the crops that will be grown, the relationship between stage of growth and water requirement of these crops, and the cultivation practices. Table 17 summarises the issues and guidelines pertaining to irrigation scheduling and monitoring of water supply.

Table 17: Summary of issues and guidelines; irrigation scheduling and monitoring of water supply

Issue	Guideline
After-care service	• Try to sustain the involvement of a scheduling agency over a period of at least two years. • Ensure that the cost of such a service is incorporated in the total cost of the project.

Early success	• Ensure a concerted effort from all support services to ensure that farmers make a success of the first few seasons. This usually provides farmers with the necessary confidence to proceed without extraordinary support. Since success among farmers also determines success among other stakeholders, the importance of first-stage support cannot be over-emphasised.
Communication	• Obtain a contact (telephone or cell) number where the farmer can be contacted as soon as possible after the project idea has been accepted. Where possible, obtain one or more alternative contact numbers. • Provide the farmer with the contact details, including telephone or cell numbers, of the appropriate team members to contact when an emergency occurs. • Arrange for farmers to network with other users of drip irrigation in their area, to facilitate discussion and sharing of experiences. • Prepare a checklist of issues to raise on every scheduled visit. • Include an inspection of the stock of spare parts on the agenda of the scheduled visits. • Enquire about the usefulness of the troubleshooting checklist, and make notes on issues that should be included in subsequent versions of the checklist.

4.5.5 Financial Issues

4.5.5.1 Capital costs

Consider the financial implications of converting from conventional to drip irrigation. The same constraints also apply to farmers who are new to irrigation.

Drip irrigation systems are expensive in terms of capital outlay per unit area. It is recommended that tried and tested drip irrigation systems are used when planning and designing is done and novel technology is avoided until its reliability has been proven.

The high capital cost of micro-irrigation per unit area demands that utilisation of the system is optimised, implying that the time the water supply and in-field systems are left idle is minimised. The capital cost of drip irrigation per unit area can be reduced IF this principal is taken into account during planning and design, and is implemented effectively on-farm. Use the cost estimating procedure as described in Chapter 7 of this manual. See Table 18 for a summary of capital cost issues and guidelines.

Table 18: Summary of issues and guidelines; capital costs

Issue	Guideline
Conversion from conventional to drip irrigation	• Make a concerted effort to address financial and technology issues in an appropriate way.
Finance	• Assist farmers with negotiations on finance where possible.
High cost of drip irrigation	• Use good quality tested components in the design and installation of drip irrigation. • Avoid cheap but inferior materials and novel components which have yet to prove their worth. • Minimise water supply idle time and in-field systems by considering the possibility of moving laterals to reduce the unit capital cost of drip irrigation considerably.

4.5.5.2 Crops

Given the capital investment required to install a drip irrigation system, it is likely that all or part of the crops grown by the farmer will be marketed. Advise the farmer on the selection of appropriate crops.

The selection of crops, especially those that will be marketed, is very important for the economic viability of the project. See Table 19 for associated issues and guidelines.

Table 19: Summary of guidelines; crops

<table>
<tr><th>Issue</th><th>Guideline</th></tr>
<tr><td>Crops and crop selection</td><td>Carefully discuss the choice of crops to be planted with the farmer.
Pay special attention to the crops selected for marketing (cash crops).
Evaluate the potential and size of local (niche) markets, matching production to demand, including the possibility of staggered planting.
Evaluate the availability of marketing agents and their requirements, and consider the option of contract farming which leaves the farmer to deal with production issues only.
Evaluate the potential of cash crops for distant markets using the following list of decreasing suitability:
Crops that can be stored over a fairly long period, and to which the farmer can add value, e.g. paprika, which can be dried before marketing.
Crops yielding a high-value low-bulk product, which can be stored on-farm. These are well suited for planting on remote smallholdings because they allow marketing to be done when an opportunity arises.
Crops that allow for storage for a few months before being marketed when an opportunity arises, e.g. pumpkins and melons.
Perishable crops, which can be stored for short periods, e.g. cabbage, green peppers and potatoes.
Perishable crops requiring immediate marketing, e.g. green beans and tomatoes.
Develop a plan of action in consultation with the farmer. For each crop, elaborate on the preparations that are needed before planting. Include issues such as soil preparation, and ordering of planting material, fertilisers, and chemicals for weed, disease and pest control.</td></tr>
<tr><td>Permanent crops</td><td>Consider seriously the establishment of permanent or perennial crops on part or all of the farm.
Evaluate carefully the farmer’s cash flow and consultatively develop a suitable way of managing cash flow for sustainability, taking into account the full range of sources of income available to the farmer.</td></tr>
</table>

4.5.5.3 Water

Raise the farmer’s awareness of the need to conserve water and to use this resource as efficiently as possible. Encourage water measurement as a means to optimally schedule the water according to real time climatic conditions and crop needs.

4.5.5.4 Operating costs

Farmers are often more concerned about the capital cost of the system than the operating cost over time, even though in most cases this is much more than the initial capital outlay. This aspect is often neglected due to the complexity of calculating the operational costs.

The University of the Free State's IRRICOST model was adapted as part of the WRC project to estimate the cost of drip irrigation under various scenarios. This provides a useful decision support tool for the planner, designer or farmer. The adapted model is described in more detail in Chapter 7 of this manual.

5 SPECIFIC GUIDELINES FOR DRIP IRRIGATION SYSTEMS

5.1 Background

This chapter covers the specific guidelines for both drip irrigation and filtration systems. The guidelines provided here are valid for both surface- and sub-surface drip irrigation systems.

5.2 Terminology

The terminology applied to drip irrigation has different interpretations compared with that of conventional sprinkler irrigation.

5.2.1 Application rate

In full surface area wetting such as sprinkler or flood irrigation, the application rate is the volume of water applied over a unit area during a specific time unit. The application rate is expressed in units of (litre/m^2)/hour, (m^3/ha/)/hour, or mm/hour. The last unit indicates the depth of the applied water volume equally spread on the irrigated area, i.e. 1 mm water depth over 1 m^2 area is 1 litre/m^2.

In localised drip irrigation, the water does not spread equally on the soil surface. The term Irrigation Rate (IR) designates a virtual value. The applied water quantity per hour over the irrigated area is addressed as if coverage were uniform.

The virtual irrigation rate per single emitter will be its flow rate over the spacing between the emitters.

Example:

Emitter flow rate: 2 ℓ/h

Spacing: 3 × 0.5 m

Irrigation rate = 2/(3 × 0.5) = 1.333 (ℓ/m^2)/h =1.333 mm/h = 13.33 (m^3/ha)/h

5.2.2 Emission uniformity

In an irrigation system where plant nutrients and other chemicals are applied with the irrigation water, it is of the utmost importance that the uniformity of water applied by those emitters that function simultaneously should be maintained within relatively low tolerance levels. This concept is known as emission uniformity of the system, indicated by the internationally accepted symbol, EU.

5.2.2.1 Factors which influence emission uniformity

It is essential to take note of the whole spectrum of the factors which have a combined effect on the EU, even though only some can be measured and therefore formulated. Many of these factors can be eliminated by expert design during the planning process and by applying preventative as well as corrective practices:

- Manufacturing and design characteristics of emitters determines how they react to variables. In practice, emitters cannot be absolutely identical. Manufacturing tolerances will therefore have an effect on the discharge. These differences are measurable and are represented in the EU equations by the manufacturer's CV.

- Varying pressures in the system due to friction, as determined by the hydraulic gradient (HG), will affect the emitter discharge. These conditions can, however, be determined and should therefore be taken into account in the design procedure.
- Varying topographical tendencies have the same effect, and should therefore also be taken into account.
- Partially or completely blocked emitters can affect the total system flow, creating irregularities in the pressure, which influences the system hydraulics, in turn distorting the whole distribution pattern beyond acceptable limits. Good filtration is therefore a primary requirement.
- Systematic blockages of emitters despite good filtration are in some instances unavoidable due to the nature of the contamination. Although it is almost impossible to bring this into account during the designing stage, it can be noticed through vigilant monitoring, after which the necessary corrective steps can be taken.
- Water temperature influences the viscosity, which in some cases is a physical design characteristic of the emitter (long flow path, laminar conditions). Temperature changes can also affect the dimensions of the emitter. These factors and characteristics can almost never be accommodated in the design process.
- Age factors including:
  - Partial blockage which can increase systematically with age despite preventative measures.
  - The physical characteristics of materials (e.g. unstable or poor raw materials) which can change with age. It is good practice to take the known stability of emitters as well as the raw material characteristics into account during the selection process.

5.2.2.2 Important emission uniformity aspects

It is important to compare the lowest emitter discharge with the average emitter discharge. All lower than average emitter discharges are more important than those which are higher than average. The lowest emitter discharges should indeed be viewed as even more important as those that are marginally lower than the average. Higher than average discharges that can have a negative influence due to technical aspects should also be taken into account.

Take the manufacturing factor of the emitter into account when designing a system.

All other factors which are measurable and can have an influence should be taken into account with the formulation of an equation for establishing the EU.

5.2.3 Design equations

The following two equations are used during the design process to determine the allowable emitter discharge variation in an irrigation block, based on an acceptable EU (according to a design norm such as those provided by SABI), an acceptable CV, a required average emitter discharge and a calculated number of emitters per plant, for pressure sensitive emitters:

5.2.3.1 Design emission uniformity (EU) [%]

EU is a statistical parameter by means of which the expected uniformity of the emitter discharge within an irrigation block can be established, and where only the lowest and average emitter discharges are taken into account. This equation is used most often during design.

$$EU = 100\left(1{,}0 - \frac{1{,}27}{\sqrt{e}} CV\right)\frac{q_{e\,min}}{q_e} \qquad (5.1)$$

Where:

EU	=	design emission uniformity [%]
e	=	number of emitters per plant ($\geq$1,0)
CV	=	manufacturer's coefficient of variation [fraction]
$q_{e\,min}$	=	minimum emitter discharge [ℓ/h]
q_e	=	design (average) emitter discharge [ℓ/h]

5.2.3.2 Absolute design emission uniformity (EUa) [%]

This concept is identical to EU, except that this calculation also considers the maximum emitter discharge.

$$EU_a = 100\left(1{,}0 - \frac{1{,}27}{\sqrt{e}} \nu\right)\frac{1}{2}\left(\frac{q_{e\,min}}{q_{e\,av}} + \frac{q_{e\,av}}{q_{e\,max}}\right) \qquad (5.2)$$

Where:

EU	=	design emission uniformity [%]
EU_a	=	absolute design emission uniformity [%]
e	=	number of emitters per plant (>1,0)
CV	=	manufacturer's coefficient of variation [fraction]
$q_{e\,min}$	=	minimum emitter discharge [ℓ/h]
q_e	=	average emitter discharge [ℓ/h]
$q_{e\,max}$	=	maximum emitter discharge [ℓ/h]

The use of these equations is discussed in more detail in Chapter 6.

5.2.3.3 Water distribution

Due to the large number of closely spaced emitters in a drip irrigation system, it is necessary to consider Distribution Uniformity (DU) differently than is the case with sprinkler (overhead) and flood irrigation. The DU of a system is a performance indicator that is calculated for an already installed system, following an irrigation system evaluation. It is calculated by using emitter discharges measured from a representative sample (at least 25 emitters randomly selected in different sections of the irrigated plot) which is then sorted from big to small. The following equation is then used to calculate the Distribution Uniformity of the lower quarter, DU_{lq}:

$$DU_{lq} = 100 \times \frac{Q_{25\%}}{Q_n} \qquad (5.3)$$

Where:

$Q_{25\%}$ is the average flow rate of the 25% of the emitters with the lowest flow rate, and

Q_n is the average flow rate of all the sampled emitters.

The importance of calculation the DU_{lq} value can be seen when the sorted values are presented graphically as a water destination diagram. In the theoretical example shown in Figure 16, the system applied on average 3 mm to the whole field area, which was also the target required. The highest discharging emitter delivered 4 mm while the lowest discharging emitter delivered 2 mm. Half the field was therefore over-irrigated and the other half under-irrigated.

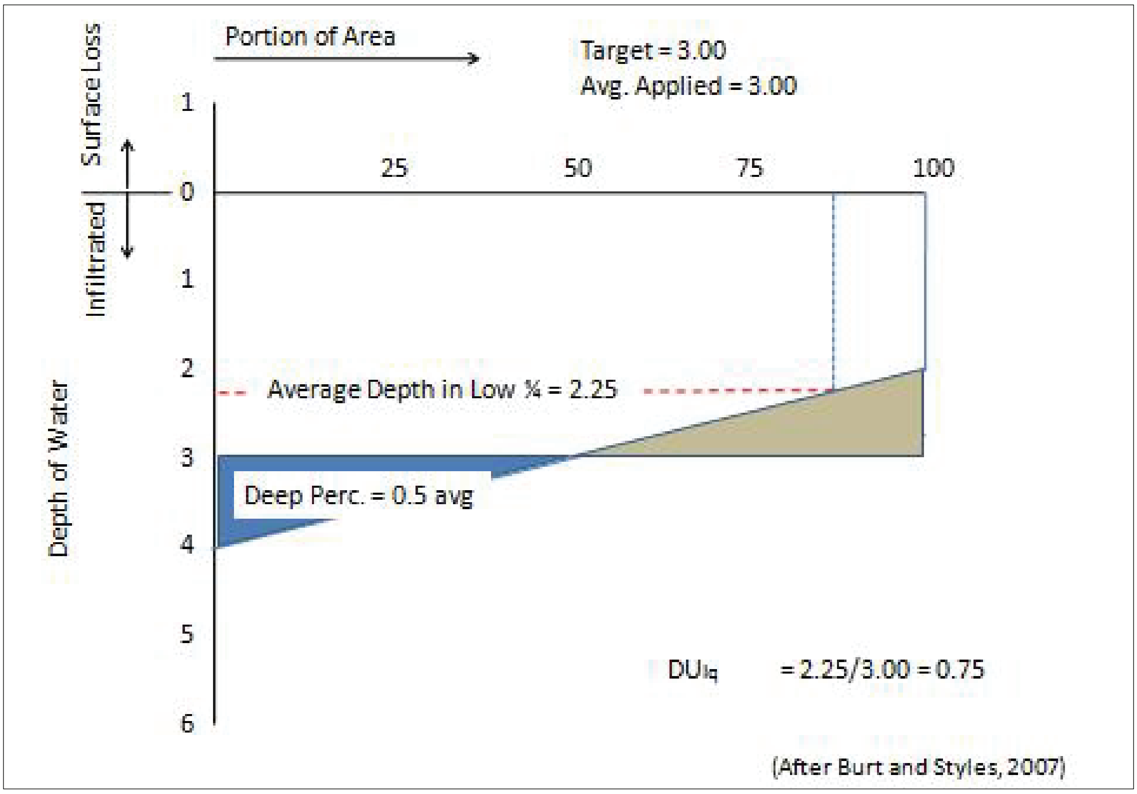


Figure 16: Water destination diagram for DU_{lq} calculation; example (Lecler, 2006)

The average of the lowest quarter of readings (between 75% and 100% of the area), was 2.25mm. By applying the DU_{lq} equation, the value is found to be 0.75 or 75%. The greater the variation between the highest and lowest discharging emitters, the smaller the DU_{lq} value will be, as the angle of the graph will be steeper. Therefore, although the average application may look to have been accurate, the DU_{lq} value gives an indication of the application variation between the emitters.

The DU_{lq} values can be interpreted according to the following scale:

>87%: excellent distribution uniformity

75-87%: good uniformity

62-75%: acceptable

<62%: unacceptable.

Variation in the emitter discharge measured in the field during evaluation depends on the pressure variations in the laterals and manifolds, the manufacturing coefficient of variation (CV) of the emitters, and possible emitter clogging.

5.2.3.4 Manufacturer's coefficient of variation

Due to processes in manufacturing, no two emitters can be identically manufactured; there will be a certain variation. The flow rate uniformity of new emitters is evaluated with the manufacturing coefficient of variation (CV). CV indicates the variability in the flow rate of a random sample of a given emitter model, just off the production line before any field operation or degradation has taken place.

The flow-rate variation in manufacturing is determined statistically. Randomly selected emitter samples or a lateral segment are tested under constant pressure. The CV is defined as the standard deviation over the average flow rate of a sample of emitters. It is expressed as a decimal fraction or percentage, (0.01 = 1%) according to the following formula:

$$CV = \frac{S_{dm}}{X_m} \% \qquad (5.4)$$

Where:

CV = manufacturing coefficient of variation,

Sdm = standard deviation,

Xm = mean flow rate.

A CV of 0.1 (10%) means normal distribution (a "bell shaped" curve), where 68 % of all emitter flow rates are more or less within 10% of the mean flow rate. The emitter design, materials used in production, and manufacturing precision determine the variation of any particular emitter type. The standard ranking of variability is as follows:

CV <0.05: excellent

0.05-0.07: average

0.07-0.11: marginal

0.11-0.15: poor

>0.15: unacceptable

5.2.3.5 Flow variation of emitters on the lateral

Flow variation of emitters on a lateral compares the maximum and minimum emitter flow rates along a single lateral.

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \qquad (5.5a)$$

or

$$q_{var} = 1 - \frac{q_{min}}{q_{max}} \qquad (5.5b)$$

Where

q_{max} = the maximum emitter flow rate in ℓ/h

q_{min} = the minimum emitter flow rate in ℓ/h

q_{var} = the emitter flow rate variation in ℓ/h

It is assumed that the manufacturer's emitter flow variation follows normal distribution so that the mean value plus two standard deviations is considered as the maximum flow rate, and the mean value minus two standard deviations is considered as the minimum emitter flow rate. This range covers over 95% of the emitter flow-rates measured in the tests.

Relating test results to the manufacturer's CV indicates that with a manufacturing CV of 0.05 = 5%, the difference between maximum and minimum flow rates on the lateral may be 15%.

5.3 Water analysis and sampling

A properly designed drip irrigation system must include provisions to prevent emitter clogging. These provisions should include a water quality analysis to identify the severity of the anticipated clogging problem, a filtration system, and/or aeration/settling ponds. The design must be complemented with a proper operational manual which includes maintenance schedules.

A water quality analysis assists with identifying potential clogging problems due to water quality and preventative measures can then be recommended and applied.

The objective of sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the material being sampled.

For design purposes, and to draw up a preventative maintenance schedule, sampling must be done at the source. For an existing system, sampling can be done behind the filter to include the impact of fertigation on the water quality.

Samples must meet the requirements of the sampling program and be handled in such a way that they do not deteriorate or become contaminated before they reach the laboratory. Before collecting samples from distribution systems, lines should be flushed sufficiently to ensure that the sample is representative of the supply. Dissolved oxygen or carbon dioxide, pH, or temperature may produce secondary changes in iron, manganese, alkalinity, or hardness. Samples should be taken in a wide mouthed bottle with an opening diameter of at least 35 mm and a capacity as specified in Table 21.

Before filling, the sample bottle should be rinsed two or three times with the water being collected. Depending on the analysis to be performed, the container should be filled completely (most organics analysis) or have space left for aeration, mixing, etc. (microbiological analysis). A record of every sample collected should be made and every bottle identified, preferably by attaching an appropriately inscribed tag or label.

Do not use the same samples for chemical, bacteriological, and microscope examinations, because the prescribed methods of collecting differ. Changes that take place in a sample are either chemical or biological. Certain cations are subject to loss by adsorption on, or ion exchange with the walls of glass containers. These include aluminum, cadmium, chromium, copper, iron, lead, manganese, silver, and zinc; which are best collected in a separate clean bottle and acidified with nitric acid to a pH below 2,0 to minimise precipitation and adsorption on container walls.

Duplicate samples should be taken, and only one set of samples submitted for analysis, keeping the other set as a backup. Records of the sample data, data submitted to the laboratory, and date of analysis should be kept: This could be important in evaluating the impact of delays. All samples should be submitted for a fixed set of analyses, ensuring that analysis for all determinants is done for all samples.

An accredited (SANAS or Agrilasa) laboratory that specialises in water analysis should be used. Details of the method used, accuracy, precision, detection limits, calibration range, number and placement of calibration points and dilutions made, if any, per determinant should be obtained from the laboratory. “Blind” artificial, as well as “blind” duplicate samples should be submitted together with the samples to evaluate the laboratory’s claims of accuracy and precision. Constant volumes should be added and a blank analysis done of the reagent, where reagents were added to the sample, e.g. acidifying the sample for iron and manganese content determination. The anion and cation sums, when expressed as mille equivalents per litre, must balance, because all potable water is electrically neutral. Analyses should only be accepted if the iron balances were of a suitable standard. The test is based on the percentage difference defined as follows:

$$\%\ \text{Difference} = 100\ \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \quad (5.6)$$

Samples should be re-analysed if ion balances were not satisfactory. The criteria for acceptance are shown in Table 20.

Table 20: Criteria for the acceptance for ion balances

Anion sum (meq/ℓ)	Acceptable difference
0-3,0	**±0,2 MEQ/ℓ**
3,0-10,0	±2%
10,0-800	±2-5%

Temperature, pH, and dissolved gasses are determined in the field. With changes in the pH-alkalinity-carbon dioxide balance, calcium carbonate may precipitate and cause a decrease in the values for calcium and for total hardness. Iron and manganese are readily soluble in their lower oxidation states, but relatively insoluble in their higher oxidation states. Therefore, these cations may precipitate out or they may dissolve from sediment, depending upon the redox potential of the sample. Sulphide, sulphite, ferrous iron, iodide, and cyanide may be lost through oxidation. Changes caused by growth of micro-organisms are highly regarded by storing the sample in the dark and at a low temperature. Immediate analysis is ideal. Storage at a low temperature (4°C) is perhaps the best way to preserve most samples until the next day. Formaldehyde affects many analyses, and should not be used.

The water quality analysis procedures should strive to meet the recommendations described in

Table **21**. When the interval between sample collection and analysis is long enough to provide changes in either the concentration or the physical state of the constituent to be measured, the prescribed preservation/handling practices should be followed.

Table 21: Summary of special sampling or handling requirements

Determination	Container	Minimum sample size (mℓ)	Preservation	Maximum storage recommended
Alkalinity	P, G	200	Refrigerate	24 hours
Electrical conductivity	P, G	500	Refrigerate	28 days
Hardness	P, G	100	Add HNO_3 to pH<2.	6 months
Metals, general	P (A), G (A)	–	For dissolved metals, filter immediately, add HNO_3 to pH<2	6 months
Nitrogen Ammonia	P, G	500	Analyse as soon as possible or add H_2SO_4 to pH <2, refrigerate.	7 days
Nitrate	P, G	100	Analyse as soon as possible or refrigerate or freeze at 20°C.	48 hours
Nitrate + nitrite	P, G	200	Add H_2SO_4 to pH <2, refrigerate.	None
Nitrite	P, G	100	Analyse as soon as possible or refrigerate or freeze at 20°C.	None
pH	P, G	–	Analyse immediately.	2 hours
Sulphate	P, G	–	Refrigerate	28 days
Sulphide	P, G	100	Refrigerate; add drops 2*N* zinc acetate/100 mℓ.	28 days
Suspended solids	P, G	1 000	Refrigerate	7 days

Refrigerate = storage at 4°C in the dark.

P = plastic (polyethylene equivalent); G = glass; G (A) or P (A) = rinsed with 1+1 HNO_3

It is important to note that the proposed preservation practices for metals and especially iron must be followed explicitly. Water must be filtered before sampling with Wahtmann 40 filter paper. If the water is not filtered and clay particles occur in the water sample, the acid can cause iron to be released in clay particles and give a higher iron reading. Except for the above, the total dissolved solids (TDS) can be measured or determined with the aid of the following equation, whilst Table 22 provides conversions to determine the suitability of water for irrigation:

$$\text{TDS (ppm)} = 0{,}6\ (\text{alkalinity}) + Na + K + Ca + Mg + Cl + SO_4 + SiO_3 + NO_3 + F \qquad (5.7)$$

Table 22: Terms, units and useful conversions for understanding water quality analysis reports

1 dS/m = 100 mS/m = 100 mmhos/m = 1 mmhos/cm = 1 000 μmhos/cm
1 mg/ℓ = 1 ppm
equivalent weight = atomic weight / number if charges of particular ion
meq/ℓ = mg/ℓ / equivalent weight
mmol/ℓ = meq/ℓ / number of charges of particular ion
Sum of cations/anions: (meq/ℓ) = EC (dS/m) × 10

5.4 Water quality

Water quality can be categorised in three sections: physical, chemical and biological. Water quality can be categorised into three sections: physical, chemical and biological. Physical factors include all inorganic materials such as sand (50-250 μm), silt (2-50 μm) and clay (<2 μm), as well as organic materials such as aquatic plants (phytoplankton and algae), aquatic animals (zooplankton and snails), bacteria (0,4-2 μm), plastic cuttings and lubricant residue. Chemical factors account for the alkaline earths and fertilizer sources. Alkaline earths consist of heavy metal cations (calcium, magnesium, iron and manganese) and anions (carbonate, hydroxide, silicate and sulphide). Fertilizer sources include aqueous ammonia, iron, copper, zinc, manganese and phosphorous. Biological factors incorporate algae, bacteria (filament and slime) and microbial decomposition (iron, manganese and sulphur).

A simple table must be compiled which can be interpreted by farmers. The water sample used to determine the clogging hazard of the water should also be taken in a relatively simple manner. The current directives, e.g. for iron, are considered too conservative, but no clear directives can be concluded from the project.

Many different directives appear in literature, which can be confusing. It was decided to combine all the relevant information and present it in an easily interpreted table. Table 23 presents the emitter-clogging hazards of different elements.

Table 23: Water evaluation scale for drip irrigation clogging hazard

Constituent	Problem severity	
	Low	High
Physical		
Suspended solids (mg/ℓ)	<50	>100
Chemical		
pH	<7,0	>8,0
Total dissolved solids (mg/ℓ)	<500	>2 000
Bicarbonate (mg/ℓ)	<100	>200
Manganese (mg/ℓ)	<0,1	>1,5
Iron (mg/ℓ)	<0,2	>1,5
Calcium (mg/ℓ)	<10	>50
Biological		
Bacterial population (per mℓ)	<10 000	>50 000

A minimum figure indicates very little or no clogging hazard. If the value in Table 23 is between the minimum and maximum, the possible clogging problem can be prevented by following the normal acceptable maintenance practices as recommended in Table 24, or the relevant water treatment methods as described in paragraph 5.1.9. An expert should be approached to identify the problem if the values are above the maximum figure.

Clogging problems, which may possibly occur with the minimum figures, can be prevented by following the maintenance practices as proposed in Section 5.5.

Eurodrip presented a water classification system, that rates water quality on a scale of one to ten and can be seen in Table 25. The final rating is presented as a three-digit number as a result of the physical, chemical and biological properties of the water source. For example, a 0-0-0 rating is excellent water, while a rating of 10-10-10 represents extremely poor water for drip irrigation purposes. A rating of 1-4-8 means that there are 10-20 mg/ℓ suspended solids, 400-500 mg/ℓ dissolved material and 0,4-0,5 mg/ℓ iron and/or manganese and 20 000-30 000 bacteria per mℓ.

Table 24: Classification of drip irrigation water quality (Eurodrip, 1999)

Quality rating No.	Physical properties	Chemical properties		Biological properties
	Suspended solids (mg/ℓ)	Dissolved material (mg/ℓ)	Iron and/or manganese (mg/ℓ)	Bacteria (No./mℓ)
0	0-10	<100	<0,1	<100
1	10-20	100-200	0,1-0,2	100-1 000
2	20-30	200-300	0,2-0,3	1 000-2 000
3	30-40	300-400	0,3-0,4	2 000-3 000
4	40-50	400-500	0,4-0,5	3 000-4 000
5	50-60	500-600	0,5-0,6	4 000-5 000
6	60-80	600-800	0,6-0,7	5 000-10 000
7	80-100	800-1 000	0,7-0,8	10 000-20 000
8	100-120	1 000-1 200	0,8-0,9	20 000-30 000
9	120-140	1 200-1 400	0,9-1,0	30 000-40 000
10	>140	>1 400	>1,0	>40 000

A water quality analysis will help to identify potential clogging problems due to water quality. Preventive measures can then be applied.

5.5 Water treatment

Farmers require simple recipes for water treatment. Solutions selected to prevent possible clogging problems are shown in Table 24. However, when manufacturers make specific recommendations for their dripper lines, these should be followed.

Table 245: Solutions for specific clogging problems

Problem	Solution
Carbonate deposit (whitish colour) HCO_3>100 mg/ℓ pH >7,5	• Continuous acid application – Maintain pH of 5 to 7. • Shock acid application at end of irrigation cycle. Maintain pH of 4 for 30 to 60 minutes.
Iron deposits (reddish colour) Iron concentration >0,2 mg/ℓ	• Aeration to oxidise iron (especially suited to high iron concentration of 10 mg/ℓ of more). • Acid application to promote iron deposits – Injection rate of 1 mg/ℓ chlorine per 0,7 mg/ℓ iron. – Application before filter so that deposits are retained. • Lower pH to ≤4 by daily acid applications for 30 to 60 minutes to dissolve iron deposits.
Manganese deposit (black colour) Manganese concentration >0,1 mg/ℓ	• Application of 1 mg/ℓ chlorine per 1,3 mg/ℓ manganese, before filter.

Problem	Solution
Iron bacteria (reddish slime) Iron concentration >0,1 mg/ℓ	Application of 1 mg/ℓ chlorine (free chlorine available) continuously or 10 to 20 mg/ℓ for up to 60 minutes as required.
Sulphur bacteria (white cotton-like slime) Sulphide concentration >0,1 mg/ℓ	• Continuous application of chlorine at 1 mg/ℓ per 4 to 8 mg/ℓ sulphur hydroxide. • Application of chlorine as required until 1 mg/ℓ free chlorine is available for 30 to 60 minutes.
Algae, slime	Application of chlorine at a continuous rate of 0,5 to 1 mg/ℓ or 20 mg/ℓ for 20 minutes at the end of each irrigation cycle.
Iron sulphide (black, sandy material) Iron and sulphide concentration >0,1 mg/ℓ	• Dissolve iron by continuous acid application to reduce pH to between 5 and 7.

5.6 Lateral spacing and wetted area

The spacing of laterals and emitters is of great importance as it influences the wetted area under an emitter. This is a function of soil type and soil texture. Table 26 illustrates the relationship between discharge rate, soil texture, emitter spacing and lateral spacing. Although this table is for surface drip irrigation, similar relationships exist for sub-surface drip irrigation.

Table 26: Percentage wetted area under emitters with different delivery rates; spacing and soil textures

Percentage wetted area (Wa) under emitters with different emitter delivery rates, -spacing and soil textures									
Emitter delivery rate	2 l/h			4 l/h			8 l/h		
Soil texture	Coarse	Medium	Fine	Coarse	Medium	Fine	Coarse	Medium	Fine
Wetted diametre under emitter (m)	0.39	0.78	1.24	0.78	1.24	1.26	1.24	1.62	2.10
Max. emitter spacing, on lateral (m)	0.30	0.60	1.00	0.60	1.00	1.30	1.00	1.30	1.70
Dripper line spacing (m)	Percentage wetted area (% Wa)								
0.8	50	100	100	100	100	100	100	100	100
1.0	40	80	100	80	100	100	100	100	100
1.2	33	67	100	67	100	100	100	100	100
1.5	26	53	80	53	80	100	100	100	100
2.0	20	40	60	40	60	80	60	80	100
2.5	16	32	48	32	48	64	48	64	80
3.0	13	26	40	26	40	53	40	53	67
3.5	11	23	34	23	34	46	34	46	57
4.0	10	20	30	20	30	40	30	40	50
4.5	9	18	26	18	26	36	26	36	44
5.0	8	169	24	169	24	32	24	32	40
6.0	7	14	20	14	20	27	20	27	34

5.7 Selection of equipment

Selecting dependable and proven irrigation equipment is important to ensure effective water utilisation. Using reliable quality products with a proven track record will help ensure low maintenance and a cost effective system. For example, the displays of direct drive flow meters tend to clog with algae, unlike indirect magnetic driven type water flow meters.

5.7.1 Pump intake

The capacity of the pump(s) should be sufficient to supply flow and pressure according to system requirements. An additional 10% flow rate should be added to the calculated system capacity to cater for lateral and manifold flushing.

In cases where surface water is utilised, suction pipes must be attached to a float to ensure that better quality water for irrigation is withdrawn near the water surface, as shown in Figure 17. The minimum water depth above a suction pipe should be adhered to in the design and during installation.

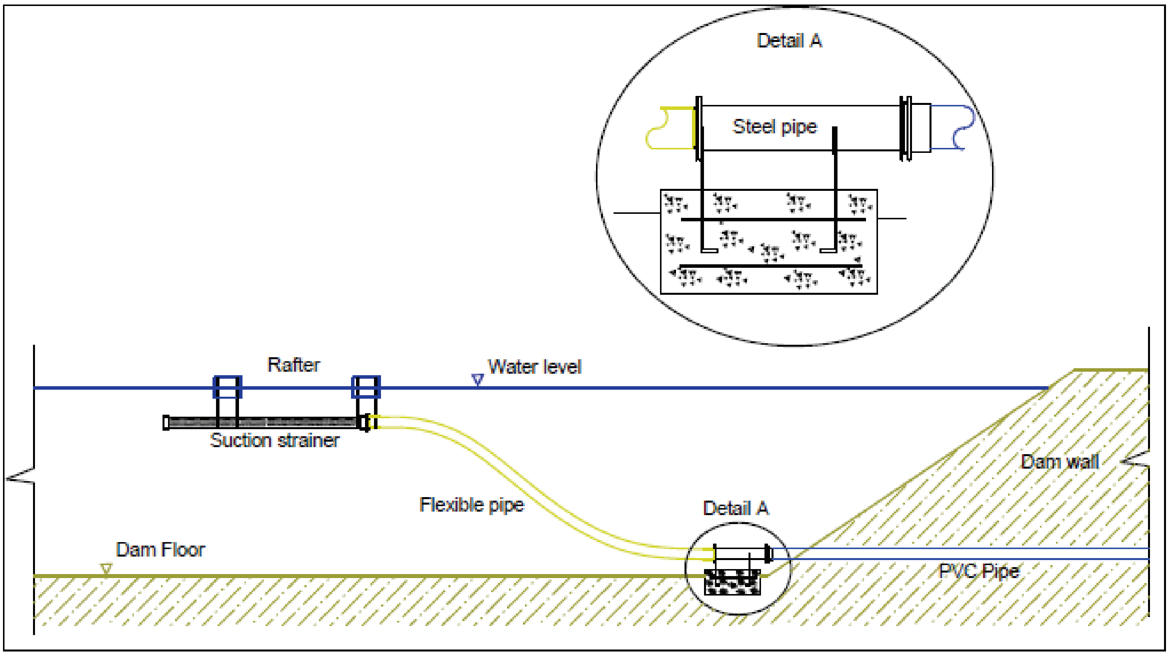


Figure 17: Mounting the suction pipe on a float (Netafim, 2008)

In the case of a storage dam, the suction pipe inlet should also ideally be located away from the point where fresh or flushed water enters the dam, and also oriented correctly relative to the dominant wind direction, as shown in Figure 18.

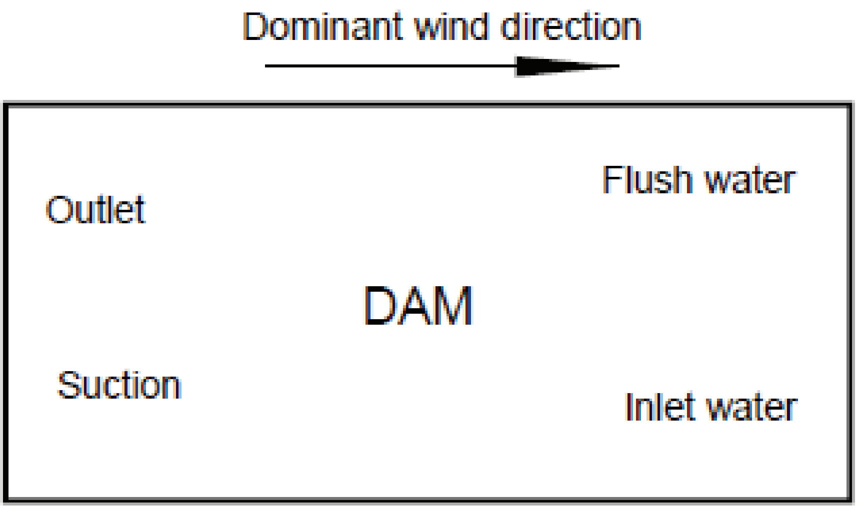


Figure 18: Ideal orientation of inlets and outlets in a storage dam (Netafim, 2008)

Pump intakes should be equipped with strainers to prevent large debris from entering the pump. Also, surface water intakes should be located below the water surface to avoid debris intake and vortex formation, and above the bottom to avoid sediment intake. Figure 19 shows the minimum water depth above a suction pipe to avoid cavitation due to possible vortex formation.

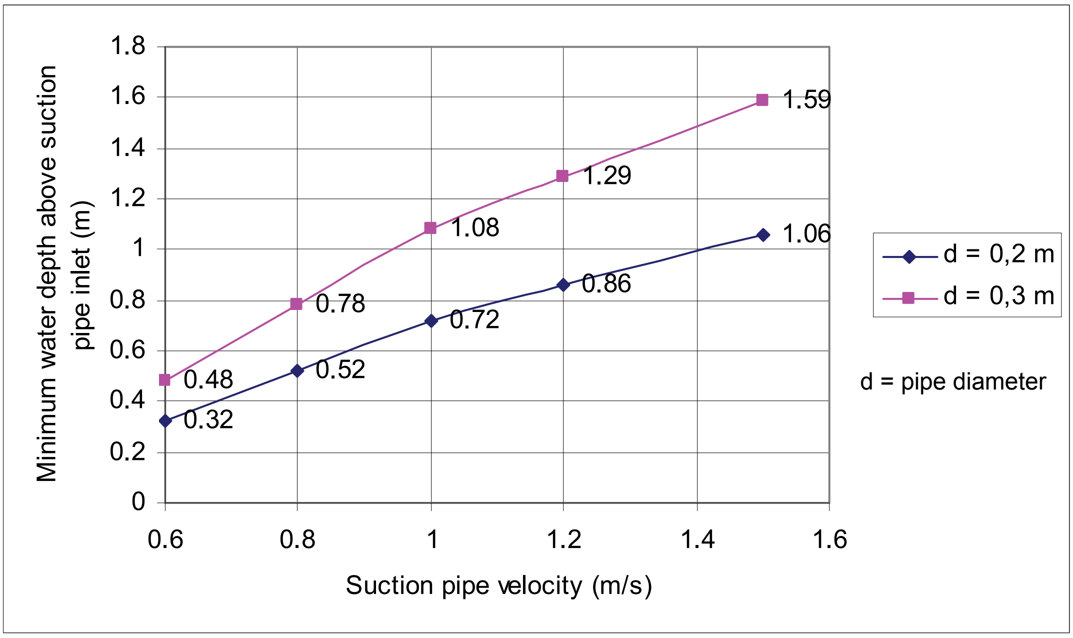


Figure 19: Minimum water depth above suction pipe inlet (T-Tape, 1998)

5.7.2 Filters

The type of filter will be determined by the water quality. Sand filters are recommended in most cases, as clogging is one of the main factors leading to system failure. The prescribed filtering guidelines of dripper manufacturers must be adhered to at all times. Filtration is addressed in section 5.9 of this chapter.

5.7.3 Air valves

Due to the fact that the sub-surface emitters are covered with soil, vacuums created in the laterals can promote the entry of soil particles into the orifices. It is therefore recommended that a vacuum breaker or air inlet valve be installed at each irrigation block. If a situation exists where the slope of the lateral is not constant, and a high point is created, an additional vacuum breaker should be installed at the highest point on the lateral.

In fields where water is pumped uphill in a lateral, a vacuum breaker should be installed at the highest point. If a flushing manifold is installed, the vacuum breaker should be installed at the highest point of the block. The topography of the main line will determine if an additional vacuum breaker is necessary. For more information, please refer to Chapter 6 of the Irrigation Design Manual (Burger et al., 2003).

5.7.4 Flow meters

It is recommended that a flow meter be installed in every drip system. It can provide valuable information on whether the system is operating correctly by comparing the measured flow rate into the system with the design flow rate, providing early warning of possible dripper clogging or leaks. It is also a useful scheduling tool through which the amounts water applied can be verified if meter readings are collected regularly, and is required to operate fertiliser injection systems. Installing the meter behind the filter in the system will protect it from possible breakdowns due to physical impurities in the water.

5.7.5 Pressure control valves

Reliable pressure control valves can be installed to ensure that the drip irrigation system always irrigates at the design pressure, especially if undulating topography is present on the site. For more information please refer to Chapter 9 of the Irrigation Design Manual (Burger et al., 2003).

5.7.6 Emitters

Thick walled pressure compensating emitter types are more expensive than thin walled regular emitter types, and can also operate over a greater pressure range. In the case of subsurface drip irrigation (SDI), thick walled pressure compensating emitter types appear to be the most efficient type due to their intrinsic resistance to root intrusion, clogging and flow regulating capabilities. Thick walled emitter laterals, compared to thin walled laterals are also less prone to compression, deformation and blockage, when installed in SDI applications. These lateral couplings are also less complicated and more effective, compared to thin walled emitter types.

5.7.7 Start connectors

Laterals can be connected to manifolds in various ways, often depending upon the material of the pipes used. Care should be taken to include friction loss through the start connector in the hydraulic calculations as these values vary for the different types of connectors used. Whatever type is used, it is important to ensure the joints do not leak. In the case of subsurface manifolds, a blank piece of pipe (pipe without emitters) is usually fitted between the manifold and the soil surface, where the dripper lateral is then connected.

5.7.8 Flushing laterals

Small particles of both organic (e.g. algae) and inorganic (e.g. clay or silt) materials pass through filters and into drip irrigation systems. These particles settle and accumulate in pipelines and emitters, eventually clogging the emitters. To minimise sediment build-up, regular flushing of drip irrigation laterals is required. In the case of surface drip irrigation, each lateral can be flushed individually by opening the lateral end and letting the water from the lateral flow until it is clean. It is also possible to connect a number of laterals together with a flushing manifold fitted with a valve, a practice mostly followed with SDI systems. The laterals can then be flushed together by opening the flush valves (see Figure 20), a system that can also be automated.

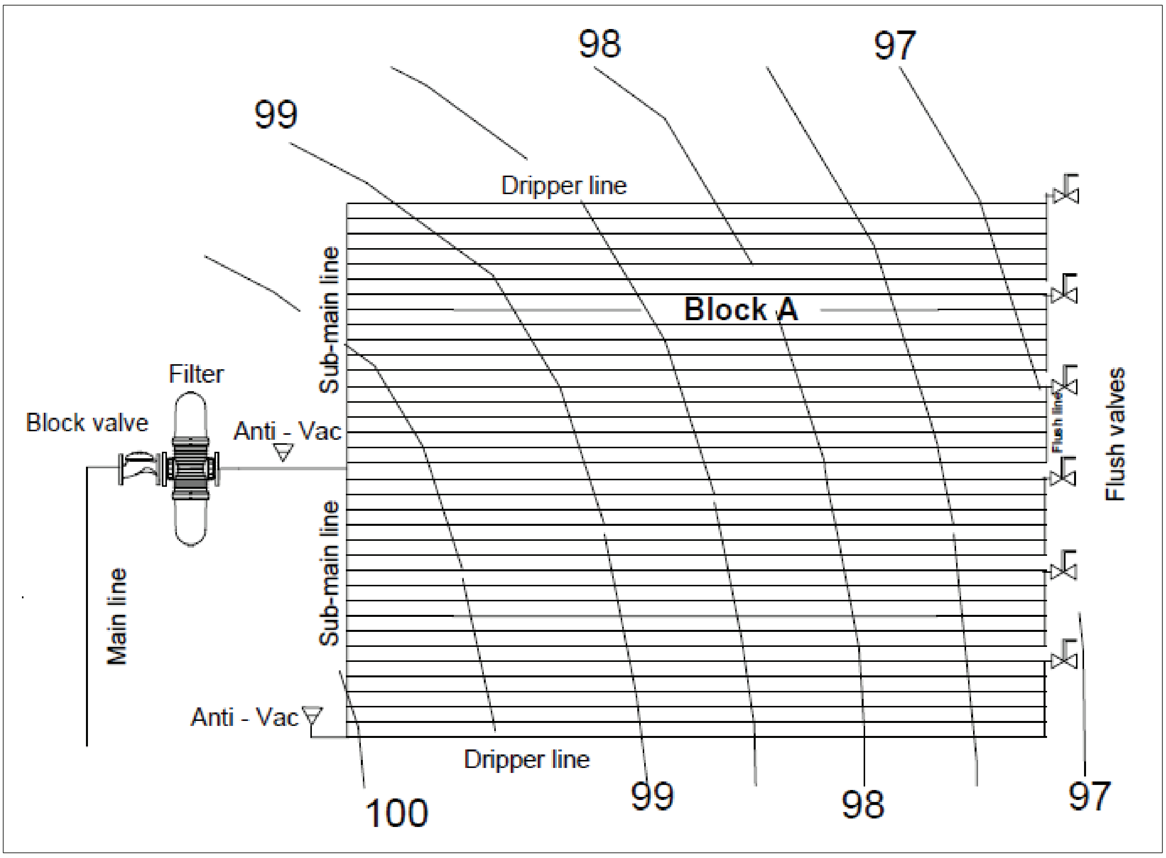


Figure 20: Example of a system with flushing manifolds (Netafim, 2008)

Detailed information on the design of flushing manifolds can be found in the "Manual for Lucerne under subsurface drip irrigation" (Netafim, 2008).

5.8 Design principles

5.8.1 Water source

It is important in the system design process that the farmer/producer/irrigator, crop and soil scientists should take the information regarding the water, nutritive and scheduling requirements of the crop into consideration and make recommendations accordingly. This will enable the designer to design an optimal irrigation system for a specific set of circumstances. The evaluation of the availability and suitability of the water forms an important part of the design for irrigation purposes and the identification of possible clogging hazards for the drip system. The operational rules of the available water sources should be investigated to determine water availability.

5.8.2 Number of operating hours per week

A design approach should be taken that maximises the number of hours during which the system is operated, as this will minimise the required flow rates in the pipes and lead to a more economical system to purchase and operate. As drip irrigation systems can be automated, the suggested maximum number of irrigation hours per week is 144 hours, but this should be discussed with the irrigator to make provision for ESKOM tariff plans, labour availability, breakdowns and other management requirements.

5.8.3 Emission uniformity

Minimum recommended EU is needed to determine the available pressure loss for the lateral and manifold design. All manufacturers of emitters are responsible for providing the necessary information to designers for the determination of the design pressure loss. Recommended EU values are shown in Table 257. The South African Irrigation Institute recommends that an EU value of greater than 90% should be reached.

Table 257: Recommended EU values for different emitter and topography combinations

Emitter type	Number of emitters per plant	Topography/Slope	EU (%)
Point source	≥3	≤2%	90-95
Point source	<3	≤2%	85-90
Point source	≥3	Rolling terrain or incline >2%	85-90
Point source	<3	Rolling terrain or incline >2%	80-90
Line source	Any	≤2%	80-90
Line source	Any	Rolling terrain or incline >2%	70-85

5.8.4 Filters

- **Filtration degree:** If a sand filter is used, there must be a 200 μm control mesh or ring filter downstream of the sand filter to prevent dirt or filter sand from clogging the emitters if the sand filter should fail.
- **Maximum allowable flow-rate through a clean sand filter:** Flow rate <50 m³/h per m² of filter area, with a maximum pressure loss over a clean sand filter of <10 kPa.
- **Maximum allowable pressure loss over the sand filter, with a secondary ring- or mesh filter:** Total pressure loss over the clean filter bank (including sand and ring filter) ≤40 kPa. Maximum allowable pressure differential over filter bank before back-flushing ≤60 kPa.

As a result of the many problems that have been observed regarding the backwashing of sand filters, the following operational rules are recommended:

- At least 50% of the maximum filtration rate (50 m³/h per m² sand surface) is necessary to backwash filters effectively. The maximum backwash rate may not be more than 1,2 times the filtering rate.
- A minimum inlet pressure of 6 m (60 kPa) is required during backwashing.
- The backwashing time of sand filters can be anything from 90-180 seconds. When the flushing action is started, the raw water on the sand bed is flushed first and may appear to be clean. Immediately afterwards, the dirt trapped in the sand bed is flushed out. Backwashing time must be long enough to remove all impurities from the filter.
- The use of compressed air to break up clods in the sand and assist with the backwashing action is recommended if problems are experienced with tunnelling in the sand.

- Filters must be backwashed on a pressure difference basis to maintain the filtration efficiency of filters. The evaluation and setting of sand filter flushing times (approximately three minutes, but until flushing water is clean) must be done regularly.

More details on filtration are provided in section 5.9.

5.8.5 Flushing velocity of laterals

To minimise sediment build-up, regular flushing of sub-surface drip irrigation pipelines and laterals is required. Valves should be installed for flushing of mainlines and manifolds, as well as blocks. Flushing should be done as needed, based on water quality and the amount of material found in pipelines or at lateral outlets. If considerable sediment build-up occurs, laterals should be equipped with automatic flush valves that flush at the start of each irrigation cycle.

A minimum flushing velocity of 0,4 m/s at the end of the furthest lateral is required and this should form part of the design process. The flushing time should be sufficient to purge all foreign materials from the laterals and pipelines. The time should be equal to the replacement of at least the blocks' water volume.

5.8.6 Design report

The design report is an important control mechanism or tool to monitor all the aspects in the design process and help the designer and farmer to guarantee a complete design. An example of this is presented in Table 268.

Table 268: Design report: Drip irrigation system

1. GENERAL INFORMATION

Client's name: . . . . Farm name. . . . .

Contact address: . . . .

E-mail . . . . Tel . . . . .Cell . . . .

Block number:	Unit	Value
2. CLIMATE		
Month	state	
Weather station	state	
Reference evapotranspiration	mm/month	
3. CROP		
Type	state	
Area	ha	
Planting distance	m	
Row spacing	m	
Natural root depth	m	
4. SOIL		
Effective soil depth	m	
Water holding capacity $(WHC)_{100}^{*}$	mm/m	
Readily available water	mm	
5. EMITTER		
Make/model	state	
Type	State	
Discharge rate	l/h	
Operating pressure	kPa	
Application efficiency	%	
Emitter spacing	m	
Lateral spacing	m	
Wetted diameter	m	
Gross application rate	mm/h	
Delivery rate of block	m^3/h	
6. SCHEDULING	state	
Crop coefficient	Des.	
Evapotranspiration	mm/month	
Net irrigation requirement	mm/month	
Gross irrigation requirement	mm/month	
Theoretical cycle length	days	
Theoretical standing time	hours	
Practical cycle length	days	

Practical standing time	hours	
Working days per week	days	
Irrigation hours per day	hours	
Gross application per practical cycle	mm	
7. HYDRAULICS		
Allowable pressure variation in the block	m	
Required pressure at the block inlet	m	
Maximum flow velocity in mainline	m/s	
Minimum flow velocity in lateral	m/s	
8. PUMP		
Type, model	state	
Impellor size	mm	
Pump operating pressure at duty point	m	
Pump delivery rate at duty point	m^3/h	
Efficiency at duty point	%	
Shut-off pressure	m	
Power requirements at duty point	kW	
Power rating of electrical motor	kW	
Motor speed	r.p.m	
9. FILTER		
Type, model, size	state	
Amount	number	
Filter fineness	micron	
Pressure drop over filter		
Clean	m	
Dirty	m	
10. DESIGNER		
Name	state	
Company	state	
Contact details	state	

5.8.7 Installation of subsurface systems

The installation of SDI laterals should preferably take place in homogenous soils, or at least in fields where the laterals can be installed at a constant depth and constant sub-surface slope. This is to eliminate the problem of specific laterals being installed with high and low points along their length. Installing laterals with varying longitudinal profiles (e.g. undulating topography) can lead to air-locks and thereby the formation of vacuums and the suction of soil particles into the emitter apertures.

The preparation of the field to at least 300 mm deeper than the planned depth of the laterals will help to guarantee constant depth of installation. A tractor mounted ripper with a top mounted reel for the dripper line rolls is the basic implement for installing dripper laterals. A curved steel tube is mounted at the back of the ripper shaft, with a horizontal section just above the lowest point of the ripper shaft. The dripper line is fed through this tube and the dripper line should be held manually in its position at the field edge when the installation process starts. A system of depth-adjusting wheels on the implement can provide a constant depth of installation. Modern day GPS technology installations are also carried out with great accuracy for improved performance.

The testing of the system after installation is important to detect and fix any leaks and thereby prevent the possible entry of soil, etc. It is important that laterals should be flushed thoroughly before the first irrigation commences.

5.8.8 Operation and maintenance

The maintenance of a drip system is of paramount importance for the effective operation. Regular maintenance of the filters system, vacuum valves, the prompt fixing of leaks, the prevention of damage to equipment, the scheduled application of root growth inhibitors and lateral cleaning chemicals are important maintenance aspects, especially in the case of SDI systems.

It is important to inspect the irrigation block after each irrigation cycle to identify possible clogging problems (dry patches or under-performing plants) at an early stage. If leaks occur, they must be repaired as soon as possible.

5.8.8.1 Filter operation

The filters should be operated according to the indicated guidelines in Section 5.9. A filter maintenance schedule is listed in Table 306.

5.8.8.2 Lateral flushing

The regular flushing of the laterals plays an important role in the maintenance of the systems. A flush velocity of at least 0.4 m/s is a necessity in the design of the system, especially in cases where water of a quality outside the indicated norms is used.

Visual evaluation of the presence of any solids or organic matter in the water at the lateral outlets can assist the farmer in establishing the required cycle for lateral flushing. The presence of any foreign matter requires an increased flushing cycle and the rectifying of the cause(s). A lateral flushing cycle of at least one flush per two irrigation cycles or per 14 days is recommended, depending on the quality of the water at the inlets and outlets of the laterals.

The recommended flushing velocity for drip laterals must be greater than 0.4 m/s. It is necessary to determine the velocity by calculating the theoretical flow rate for a required minimum flushing velocity of 0.4 m/s at the lateral outlet. This is done by multiplying the velocity by the cross-sectional area of the dripper lateral. This flow rate is then used to calculate the time needed to fill a one litre container at the lateral end.

If this value is exceeded in field conditions, it means that the flow velocity in that lateral exceeds the minimum required velocity. The graph in Figure 21 can be used to establish the time in seconds needed to fill a one litre container for a specific internal dripper lateral diameter. Care should be taken that the pump is able to supply an additional 10% flow above the system's required flow, for the flushing of the laterals and manifolds.

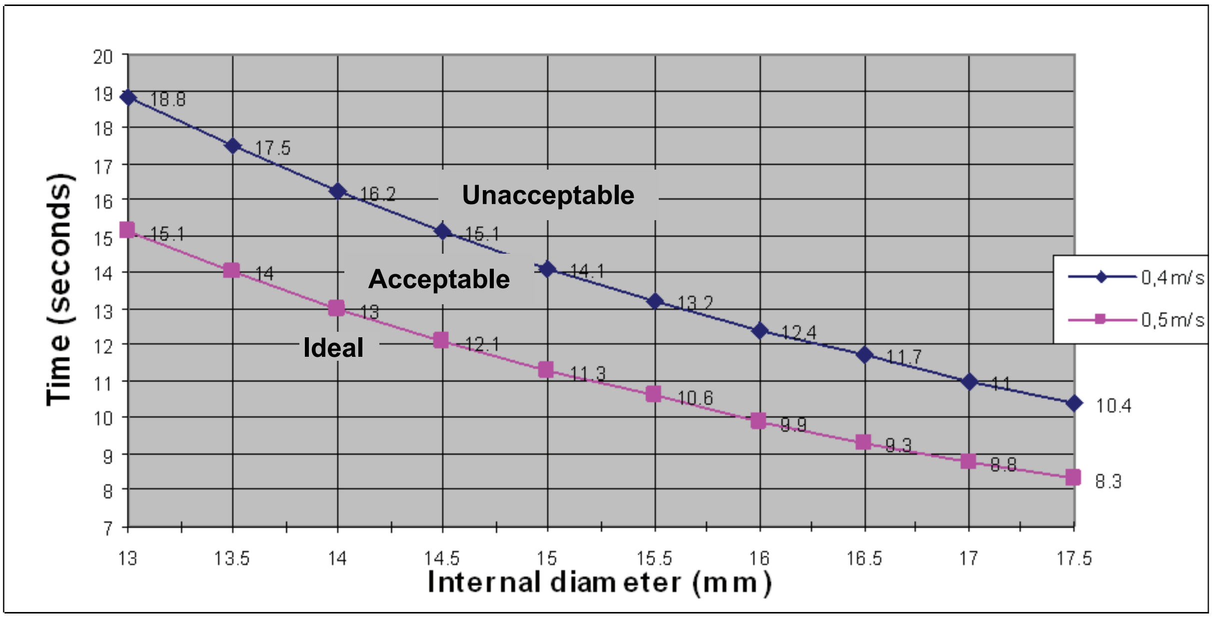


Figure 21: Time to fill a one litre container for a specific diameter lateral

5.8.8.3 Use of chemicals: acids, chlorines and fertilisers

Chemicals can be used for the elimination of biological and chemical build-up. Irrigation water quality varies from site to site, and as a result each site may require a different type of water treatment in order to prevent emitter clogging. Prevention is by far better than cure as far as clogged emitters are concerned: reclaiming clogged emitters by using chemical treatment is neither practical nor economical due to the high concentration of chemicals required.

A major problem is that the injected chemicals end up flowing through the clogged emitters and the clogged emitters are not cleaned. A solution to this problem is to provide higher pressures with chemical treatment, thereby forcing the chemicals into the blocked emitters.

Details on the application of acid and chlorine can be obtained from the manufacturers of drip irrigation equipment. A good example is the "Maintenance Manual" published by Netafim (2008).

5.8.8.4 Use of root growth inhibitors

The use of root growth inhibitors is important and necessary for the effective functioning of dripper line emitters that is installed under the surface. Growth inhibitors are usually used with sub surface drip irrigation and root growth inhibitors in the SDI system should be used according to the recommendations from the suppliers of the relevant chemicals. This is to establish the registration (legal approval) of the specific product for use on the specific crop for SDI applications.

Recommendations are that *Treflan*, or an equivalent, should be applied at least twice per year with the first application soon or not more than three weeks after the first irrigation application. *Treflan* should only be allowed to accumulate in the area directly around the emitters if applied through the system and not impregnated in the emitters. Any accumulation of water on the soil surface during or directly after *Treflan* application could damage the crops. *Treflan* should not be applied into wet soil profiles, or just after rain. The procedure for the application of *Treflan* is as follows.

- Start the irrigation system.
- 20 minutes after working pressure is reached, investigate and observe any puddles or water accumulation starting on the soil surface. The formation of puddles on the surface can indicate that the soil is not suitable for *Treflan* application.
- Investigate the whole irrigated area for leaks and rectify/repair.
- Recalculate the number of emitters in the irrigation blocks and the volume of *Treflan* to be applied. An application rate of 0,125 mℓ/emitter is recommended.
- Check the couplings and inlet filter of the chemical injector pump and repair necessary.
- Calibrate the injector pump for at least a 10 minute cycle to establish the delivery rate.
- Ensure that only the sub-surface system is supplied by the pump system during the Treflan application.
- The distribution time for the *Treflan* application is determined by the delivery rate and spacing of the emitters, as well as the lateral length. The distance from the injection point to the furthest emitter determines the distribution time.
- After the application, allow 24 hours before normal irrigation commences.

Treflan application is not recommended in the following cases:

- Sandy soils with less than 8% clay.
- With seedlings, just after transplanting.
- Too wet soils.
- With laterals which were installed at too shallow a depth.
- When the use of *Treflan* is prohibited by law.

The commencement of *Treflan* applications for various crops varies: suggested times are detailed in Table 279.

Table 279: Suggested *Treflan* treatment commencement for various crops

Crop	Treatment commencement
Perennials	Three weeks after irrigation commencement.
Orchards	Six weeks after planting. Assure sufficient weed control to prevent root intrusion from the weeds. From second year, application to start four weeks after irrigation season's commencement.
Seasonal crops and vegetables	Approximately five weeks after the commencement of the normal irrigation and after the germination and establishment phase has passed.
Perennial cash and vegetable crops, asparagus, lucern	First year: four weeks after planting or six weeks after sowing. Second year: four weeks after the start of "normal" irrigation".
Grass and lawns	Four weeks after planting and 2-3 weeks after lawn establishment.

The number of *Treflan* treatments required is a function of crop type, climate and soil type. Table 30 indicates the number of treatments needed per year.

Table 30: Suggested number of *Treflan* treatments

Crop	Effective irrigation period*	Number of treatments	
		Medium and heavy soils (50-80% sand fraction)	Light soils (>80% sand fraction)
All crops	< 2 months	1	1
	< 4 months	1	2
	< 8 months	2	3
	During year	3	4

*The effective irrigation period is the period during which the crops are continuously irrigated. For example, cotton planted during October and the first irrigation application starts during the first week of December, last irrigation at the end of February. In this example, the "effective irrigation period" will be three months.

5.8.8.5 General

The operating pressure of the system must be higher or equal to the design pressure at all times to prevent precipitation of suspended solids. Low operating pressures also influence the effectiveness of the flushing of the laterals.

Before the irrigation is stopped at the end of a season, the following procedures should be followed:

- Flush the lines.
- Treat the lines with chlorine or acid or appropriate chemicals, depending on the water quality and blockage problems experienced.
- Ensure that no foreign matter can enter the distribution system.

All maintenance precautions are equally important and dependent on the clogging hazard present in the water sample. It is the duty of the suppliers to give the farmers a complete maintenance schedule via the designers of the systems and to explain the procedures to them. The success of a sub-surface drip system is also dependent on the operation and maintenance of the system. The maintenance schedule as shown in Table 31 is proposed for manually cleaned filters. For automatically cleaned filters, the manufacturers' recommendations must be followed.

Table 31: System monitoring and maintenance programme for drip irrigation

Activity	Interval			
	Weekly	Monthly	6-monthly	Yearly
Detect and fix leakages	×			
Monitor pressure difference across filter	×			
Adjust filter back-flush cycle		×		
Monitor pressure at lateral outlets		×		
Monitor system flow (main flow meter)	×			

Activity	Interval			
	Weekly	Monthly	6-monthly	Yearly
Monitor air and pressure control valves				×
Water sampling at lateral ends, evaluate changes in quality		×		×
Moisture sensor readings (e.g. neutron probe)	×			
Backwash filters (as needed)	×	×		
Flush laterals and adjust pressure reducing valves		×		
Treatment with Treflan or root growth inhibitor (see Table)			×	
Monitor hydraulic and electrical connections	×			
Replace sand of sand filters				×
Chlorine treatment (depending on water quality and application method)				×
Check hydraulic valves and filters to inspect moving parts				×
Clean filter thoroughly		×		

5.8.9 Management of soil water levels

Soil water can influence the susceptibility of emitters to root intrusion. With the plant roots' function to seek water and nutrients, their tendency is to grow toward the sources of it. In situations where stressed soil moisture conditions exist, it is "natural" for the plants' roots to attempt intrusion of the emitter apertures. The exact influence of soil water levels on emitter clogging by roots needs specific research, but the management of soil water levels, in terms of accurate scheduling, can possibly help prevent the clogging of the emitters by plant roots.

5.8.10 Salinity management

Frequent and small water applications with drip irrigation lead to shallow and compact root systems, which increases crop sensitivity to heat spells and stress. Large plants with shallow root systems are also prone to uprooting by strong winds. On the other hand, due to improved aeration and nutrition in the drip irrigated soil volume, the density of roots is usually significantly higher than the roots of crops growing under overhead types of irrigation such as sprinkler systems (Sne, 2006).

The active root system and most root hairs of drip-irrigated orchard trees converge in the wetted soil volume, with the highest density of the active roots in the aerated upper soil layers, provided there is no accumulation of salts. At the margins of the wetted volume, where salt accumulates, active roots are sparse (Figure 22).

In low rainfall areas, salt accumulation may damage the soil and the crop. Dissolved salts accumulate at the perimeter of the wetted zone, particularly at the soil surface where the water content of the soil is relatively low. Salts typically build up on the soil surface along the margins of the wetted circles, as well as at a depth below the soil surface and root zone to which irrigation water typically leaches (Figure 22).

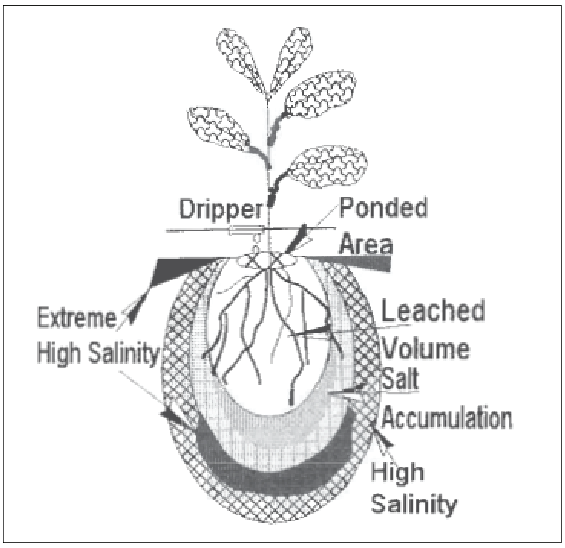


Figure 22: Salt distribution in the wetted soil volume (Sne, 2006)

As long as adequate irrigation water is applied regularly to replenish the water abstracted by the roots within the wetted soil volume, the soil water content stays high enough in this region to keep the salt concentration low in the soil around the roots. If inadequate water should be applied, the roots would try to grow beyond the area of normal wetting and will then encounter the saline soil volume, which will hinder their further development and negatively influence the plants. If there is a high salt risk and it is not possible to leach out the salts with national rain or the drip irrigation, an additional moveable overhead system might be considered.

Salt accumulated on the soil surface and in the uppermost soil layer requires preventative management measures with the first rain after the dry season. Irrigation should be applied as long as the rain lasts in order to prevent the salt from leaching into the active root zone (Figure 23).

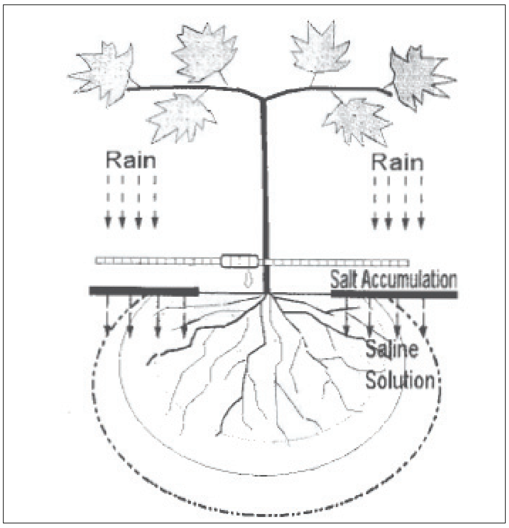


Figure 23: Leaching of salt into the active root zone by rain (Sne, 2006)

The nutrients applied with the irrigation water follow the same distribution pattern as the salts, but also depend on the interaction between the nutritional elements and the soil. Potassium ions are absorbed on the surface area of clay minerals, and their movement with irrigation water in fine and medium textured soils is limited. Most applied potassium remains in the upper soil layer.

In alkaline and neutral soils, phosphorous precipitates from the soil solution with calcium and magnesium as insoluble salts. In acidic soils, it precipitates with iron and aluminum, and remains in the upper soil layer. Application of phosphorous in deeper soil layers by subsurface drip irrigation therefore increases its availability to the root system.

5.9 Filtration systems

5.9.1 Guidelines for the selection of filters and accessories

Filter performance has been tested both in the field and the laboratories of the ARC-IAE. Filters must be selected and operated according to the specified capacity, water quality and maintenance requirements taking the following into account:

- Matching the filter type with the water quality and the irrigation system;
- System components upstream of the filter station
- Design principles with respect to:
    - Commissioning the filter
    - Filtration
    - Backwashing
    - Size of filter
    - Filter operation, and
    - Maintenance of filters

5.9.1.1 Matching filter type with water quality and the irrigation system

The primary factor that determines the kind of filter to be used is the type of system being designed. More than one type of filter may be suitable, with the choice next being based on the dirtiness of the water and the type of dirt in it.

It is simple and advisable to take a water measurement using a mobile Dirtiness Index Meter. This will determine the amount and type of dirt in the water, from interpreting the reading and from observing the dirt physically caught in the screen of the meter.

Another factor that plays a role in selecting the filter type is the kind of backwash management that will be done once the filters are installed. From the dirtiness measurement and filtration capacity tests, a filter station can be designed that has enough filtration capacity to match the kind of backwash management envisaged.

Sand filters with secondary disc filters (also known as control filters) are preferred for use in drip systems. The control filter allows monitoring of the sand filter to ensure that it is operating efficiently and also to act as a safety filter if problems develop with the sand filter.

Disc filters with a filtration fineness of not more than 100 µm can be used if borehole water is used for irrigation, or if the water used is of a high quality throughout the season.

5.9.1.2 Selection of equipment

Only irrigation filtration units from reputable irrigation companies must be used, and preferable only those units that have been tested by an independent testing laboratory. Full specifications and design parameters must accompany the equipment.

5.9.1.3 Accessories for the sand filter station

Accessories for the filter station must be reliable to ensure the protection of the filter station and the irrigation system from inorganic sands or organic materials such as algae which may be present in the water supply. Inorganic particles are usually heavy and can easily be removed by a settling basin. Organic materials are lighter and must be removed by sand filters. Floating materials may be skimmed from the water surface.

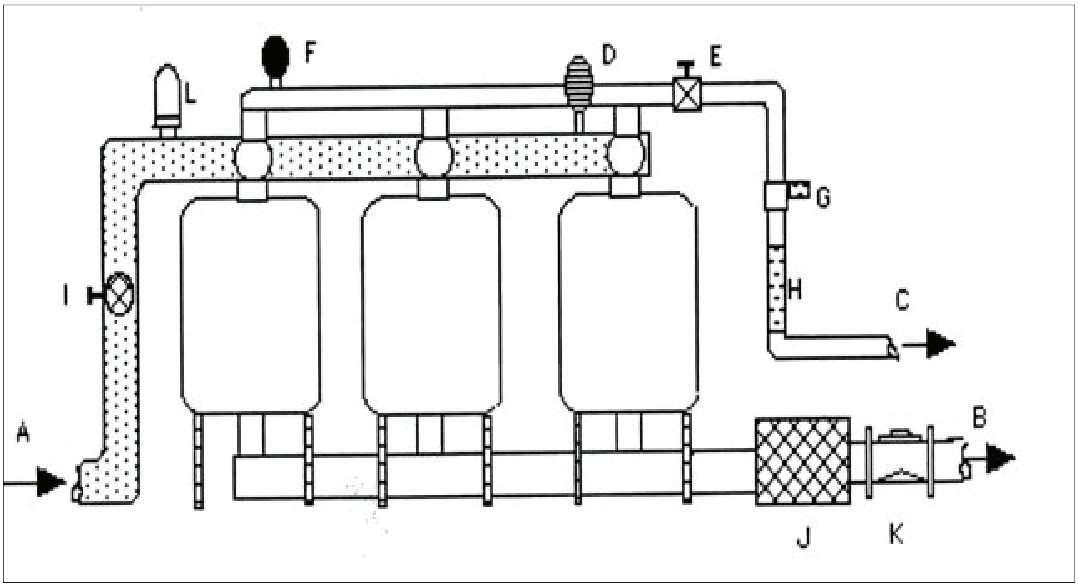


Figure 24: Typical layout of sand filter bank (adopted from Burt & Styles, 1994)

Where:

A – Irrigation water source
B – Clean water outflow to irrigation system
C – Backwash water disposal
D – Combination air valve
E – Backwash flow-rate adjustment valve
F – Vacuum release valve
G – Sighting port
H – Clear plastic tube
I – Rinse valve
J – Disc/screen filter (200 µm)
L – Pressure release valve
K – Pressure sustaining valve

Some of the accessories for the sand filter station are essential, and others are optional. Essential accessories referred to in Figure 24 are:

- Backwash flow-rate adjustment valve, E
- There are ways to determine if the backwash water is dirty or clean and if there is sand loss during backwash. These includes inspecting:

- The backwash discharge line end, C, which is exposed to the air and is accessible. If the discharge line is too long, too small or goes uphill to the extent that it is impossible to develop enough backwash flow, the backwash valve must be re-adjusted.
- A specially designed sighting and sampling port, G, which continually passes a portion of the backwash flow through a small attached glass jar allowing the operator to see if the backwash water is dirty or clean.
- A section of clear plastic in the backwash line, H, (which should otherwise be covered to protect it from sunlight damage).

- A secondary disc/screen filter, J, located downstream of the sand filter to prevent dirt from clogging the emitters if the sand filter should fail.
- A combination air valve, D, located at the downstream end of the supply manifold. The combination air valve has a kinetic as well as automatic function, so it releases small, as well as large volumes of air when necessary.
- A vacuum release (kinetic) valve, F, located at the upstream end of the backwash manifold. This valve will release large quantities of air during the filling of the system.
- A pressure release valve, L, located upstream of the filters discharges excessive pressure to the atmosphere and thereby protecting the filters against sudden pressure increases.
- A pressure sustaining valve, K, located downstream of the filters. The function of the valve is to maintain a minimum pre-set upstream pressure irrespective of changes in pressure and flow through the system to ensure that enough pressure is available for the filter to backwash and to meet the minimum pressures specified by the manufacturers.

As sand filters cannot be cleaned manually, at least two filters should be installed so that clean water from one filter can be used to back flush the other filter, as shown in Figure 25.

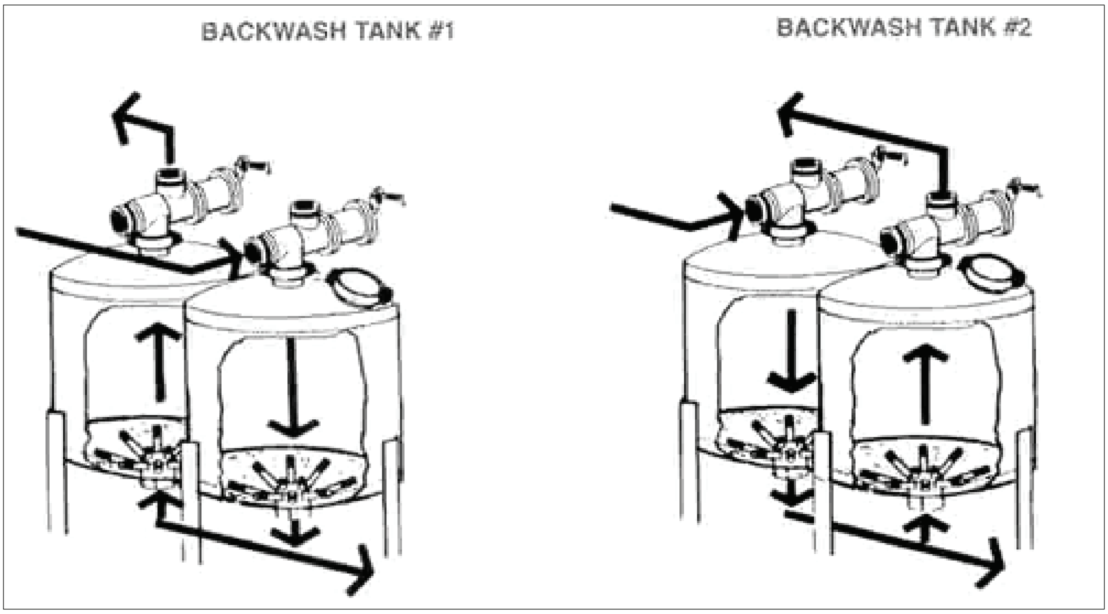


Figure 25: Back washing of sand filters

5.9.1.4 Screen filter stations

Screen filters can be cleaned in three ways:

1) Removal of the element: The screen can be removed from the housing and cleaned manually. In some cases it may be easier to have a spare screen that can be used while the dirty screen is allowed to dry. The screen filter may be easier to clean when dry than when it is wet, especially if the dirt particles are fine clay or silt, or organic matter such as algae.

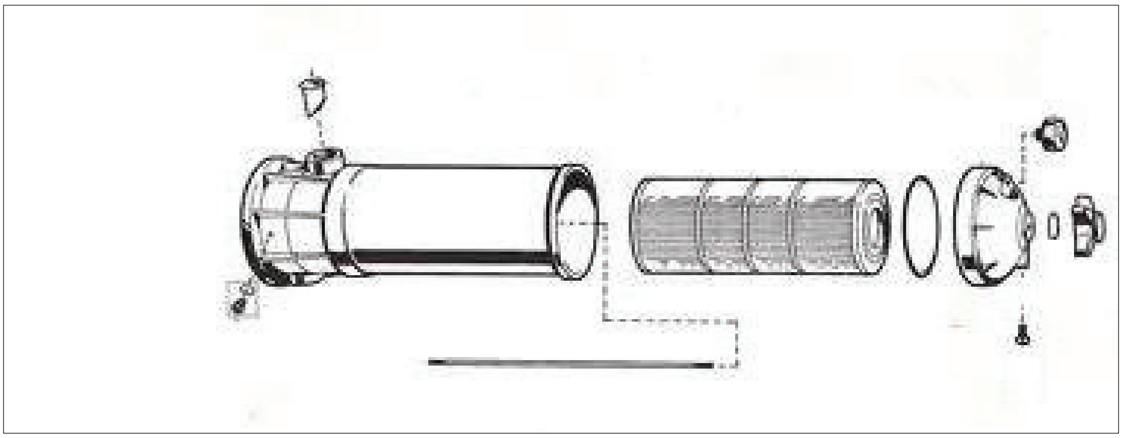


Figure 26: Removal of screen filter element for manual cleaning

2) Flushing the filter: Most of the bigger automatic screen filters can be set to flush automatically at set intervals during operation. Release of the flushing water usually coincides with a mechanical cleaning action inside the screen.

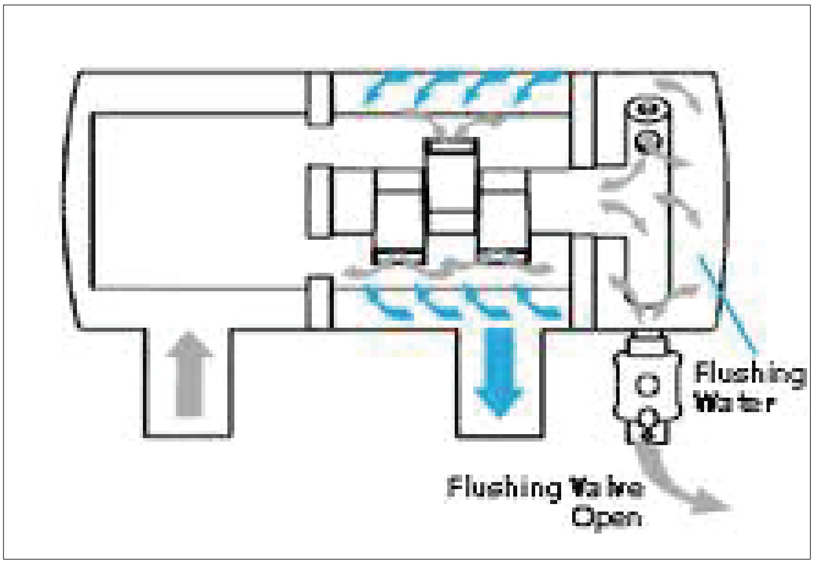


Figure 27: Flushing the screen filter

3) Backwashing the filter: If more than one filter is installed in parallel, clean water from the one filter can be used to backwash the other, as in to the process shown for sand filters in Figure 25. The process is shown diagrammatically in Figure 28.

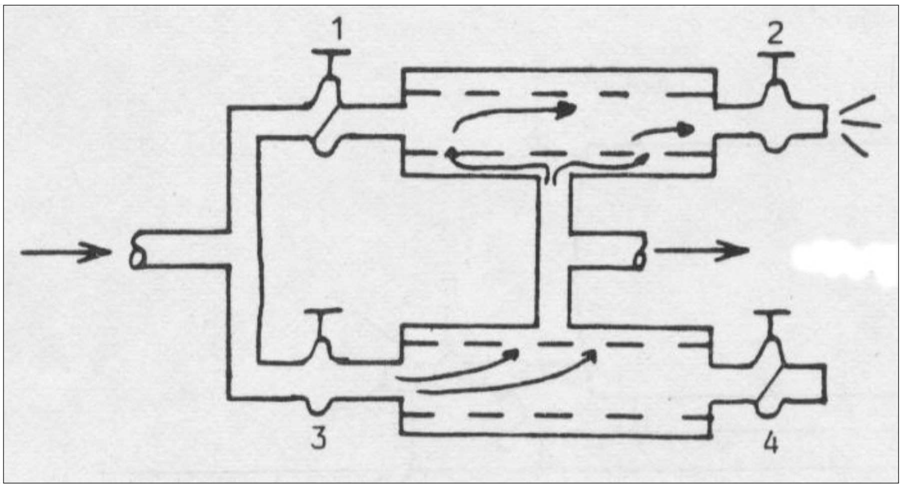


Figure 28: Backwashing the screen filters

5.9.1.5 Disc filter stations

In some cases disc filter installations are not equipped with backwash valves and their elements must be removed to clean them, as in the case of the screen filters. To ensure that no dirt enters the irrigation system when the filters are being cleaned, the following procedures for two different types of filter installations are recommended:

Installation option 1:

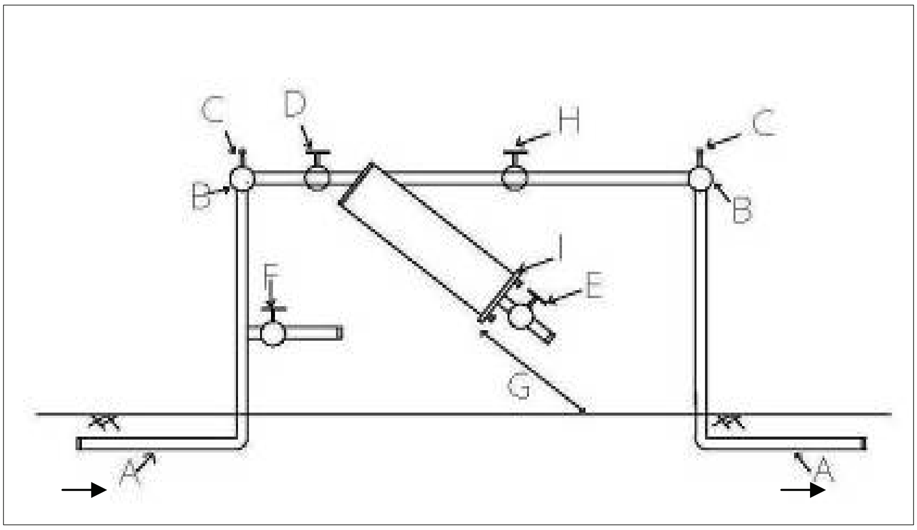


Figure 29: Typical components of disc filter installation; option 1

Where:

A = Pipe

B = Manifold for parallel installation of filters

C = Pressure measuring points

D = Cut-off valve

E =Waste water valve for flushing or back washing water

F = Small tap and hose pipe for cleaning the elements

G = Space for the element to be removed beneath the filter

H = Cut-off valve

I = Removable lid

Filters that can be flushed

1) Open valve E and close valve H. (The filter is flushed with unfiltered water.)
2) When the water form valve E is clean, close E and open valve H.
3) Repeat the process for the other filter(s) and continue with filtration.

Filters that can be backwashed

In this case, the process will only work if there is more than one filter installed in parallel.

1) Open valve E and close valve D. (The filter is backwashed with the filtrated water from the other filters flowing from B.)
2) When the water from valve E is clean, close E and opens valve D.
3) Repeat the process for the other filter(s) and continue with filtration.

Removal of the filtering element

1) Open valve E and flush out the worst dirt.
2) Close valves D and H (The filter is totally isolated)
3) Loosen lid I and remove the element.
4) Clean the element with the hose or replace it with a clean element if available.
5) Put the element back, close valve E, open valves D and H and continue with filtration.
6) Repeat the process for the other filter(s).

Remark: If valves D, H and E are replaced with hydraulic valves, procedures A and B can be done automatically with additional equipment.

Installation option 2:

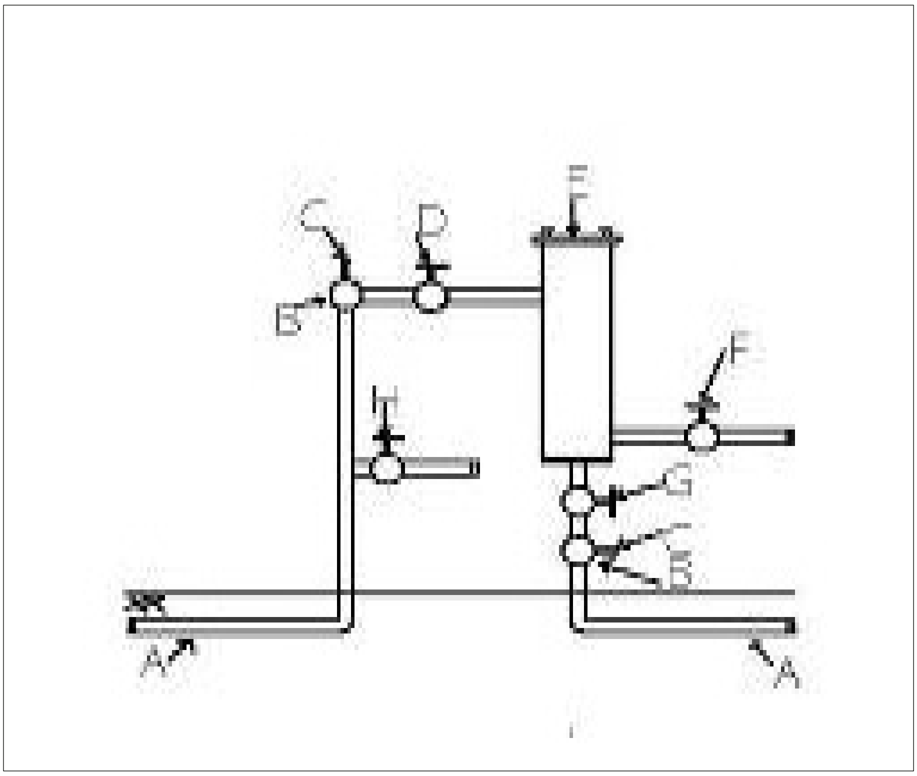


Figure 30: Typical components of disc filter installation; option 2

Where:

A = Pipe line

B = Manifold for parallel installation of filters

C = Pressure measuring points

D = Cut-off valve

E = Removable lid

F = Drainage valve and waste water valve for flushing or backwashing water

G = Cut-off valve

H = Small tap and hose pipe for cleaning the elements

Filters that can be flushed

1) Open valve F and close valve G. (The filter is flushed with unfiltered water)
2) When the water from valve F is clean, close F and open valve G.
3) Repeat the process for the other filter(s) and continue with filtration.

Filters that can be backwashed

1) Open valve F and close valve D. (The filter is backwashed with the filtrated water of the other filters.)
2) When the water from F is clean, close F and open valve D.
3) Repeat the process for the other filter(s) and continue with filtration.

Removal of the filtering element

1) Open valve F and flush out the worst dirt.
2) Close valves D and G.
3) Loosen lid E, let all the water in the filter drain through valve F and remove the element.
4) Clean the element with the hose or replace it with a clean element if available.
5) Put the element back, close valve F, open valves D and G and continue with filtration.
6) Repeat the process for the other filters.

Remark: If valves D, F and G are replaced with hydraulic valves, procedures A and B can be done automatically with additional equipment.

5.9.1.6 System components upstream of the filter

The way in which water enters into or is supplied to the filter has a significant impact on the effective and efficient operation thereof. The most common system components that can be found upstream of the filter are discussed here.

A. Settling basin

In cases where the irrigation water contains solid particles in suspension in excess of 200 parts per million (DI = 900%), it is advisable to have a settling basin where the particles can be sedimented before the water is filtered. This will prevent overloading the filter as well as excessive backwashing.

The following points are important when settling basins are used:

- The outlet of the basin should be as far as possible from its inlet.
- The backwash water from the filters should be dumped as far as possible from the inlet (preferably not back into the basin)
- It must be possible to clean the basin with the minimum effort.

- Water for filtration should be drawn from the upper layer of the dam (suction pipe mounted on float).
- A long, narrow settling basin is more effective than a square one.

Where there is iron in the water, it necessary to aerate the water so that the iron may oxidise. The iron oxide will then sedimented in the basin and the water for irrigation may be drawn off from the surface of the basin.

B. Pump

The suction pipe of the pump must be deep enough beneath the water level to prevent a vortex being formed and air sucked in. In cases where surface water is utilised, suction pipes must be attached to a float to ensure that the higher quality water for irrigation is withdrawn near the water surface. Directives are given in Table 32 for the minimum water depth above the suction pipe inlet, according to the inlet flow velocity of the water in the suction pipe.

Table 32: Minimum water depth above suction pipe inlet

Inlet flow velocity (m/s)	Minimum water depth (m)
1,0	0,5
2,0	1,1
3,0	2,0

Bell-shaped inlets are recommended, because they have the benefit that the flow speed at the inlet is low and that sand and stones cannot be sucked in as easily. It is also important that the distances shown in Figure 31 are maintained.

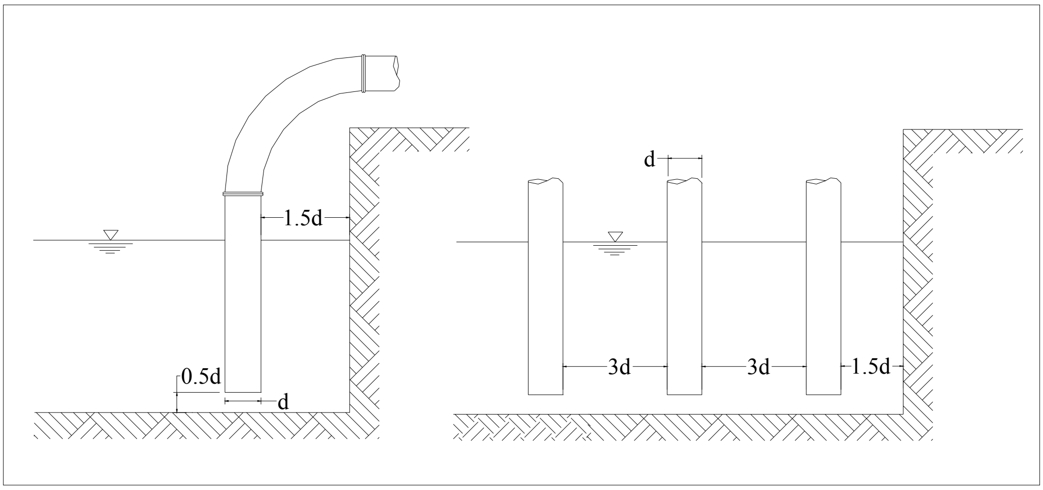


Figure 31: Minimum distances between suction pipes and sides, and bottom of pump sump

The following distances should be maintained:

- The free-area of foot valves must be at least 1½ times the suction pipe diameter. Where suction head is a limiting factor, foot valves, which usually result in a high friction loss, must be avoided.

- The free area of the screen before the suction pipe must be at least four times that of the suction pipe to prevent alien materials from blocking the foot valve.
- Guide screens must be mounted at least eight times the suction pipe diameter in front of the suction eye of the pump to prevent turbulence causing cavitation. If it is necessary to mount the screen closer to the pump, a stream aligner must be mounted.
- Screens must have holes with a diameter of 6 mm to 12 mm, and the total area of the holes must be six times that of the suction pipe area.
- The water supply to the pump hole must also be such that it does not cause the suction pipe to suck in air. It is especially a problem where the pump hole is fed by another pipeline. In that case the supply pipeline must be placed away from the suction pipe, so that the suction pipe does not suck in air bubbles that form when the water enters the pump hole.
- Suction pipes or drainage pipes must fit naturally and not be forced in by means of flange bolts. They must also be supported independently near the pump so as not to place stress on the pump casing.
- A foot valve's open area must be four times that of the open area of the suction hose, thus ensuring that the velocities through the foot valve does not exceed those of the suction hose by more than 25%.

The following is proposed:

Suction hose (absolute maximum):	≤ 1,5 m/s
Suction strainer:	≤ 0,4 m/s
Maximum permissible velocity in filter station manifold:	≤ 0,5 m/s

5.9.2 Design guidelines for filters

5.9.2.1 Filtration

The following design guidelines are recommended:

- If a sand filter is used, there must be a 200 µm control screen/disc filter downstream of the sand filter.
- The maximum allowable flow-rate through a clean sand filter must be ≤ 50 m^3/h per m^2 of the filter sand surface.
- The recommended maximum allowable pressure difference over the different types of filter/filter station are as shown in Table 33:

Table 33: Maximum allowable pressure differences over the filters/filter stations

Type	Clean water (kPa)		Maximum pressure build-up (kPa)	Pressure difference before backwashing (kPa)	
	Filter	Filter station		Filter	Filter station
Disc/Screen filter	10	30	40	50	70
Sand filter	10	40	20	30	60

The filter station includes all the fittings, valves and in the case of a sand filter-station, also the secondary filter.

5.9.2.2 Backwashing

- At least 50% of the maximum filtration rate (50 m^3/h per m^2 sand surface) is necessary to backwash sand filters effectively. The maximum backwashing rate must not be more than 1.2 times the filtration rate.
- A minimum inlet pressure of 6 m (60 kPa) during backwashing is required.
- The backwash outlet pipe must be sized to allow maximum flow velocity: the general rule is to have at least one normal pipe size bigger than the backwash outlet size on the filter.

5.9.2.3 Filter size

The size or number of filters required for a specific irrigation system in a certain area under a particular type of management depends on the following factors:

- The flow-rate which each filter will have to handle
- The dirtiness of the irrigation water
- The total pressure drop which can be allowed across the filter (consisting of the pressure drop across a clean filter plus the additional pressure drop for possible blocking of the element)
- The minimum cycle required for the cleaning of the filters

A. The allowable flow-rate through a filter

The faster the water flows through the filter, the more friction loss will occur across the filter. For economic and physical reasons, this loss has to be restricted. The following guidelines can be followed:

- For dirty water (DI > 1%): a maximum loss of 10 kPa is allowed across a clean filter. This loss can increase to a maximum of 50 kPa (30 kPa for sand filters) due to blocking of the element, but the actual allowable increase will be determined by the hydraulics of the irrigation system, as will be discussed later on. If the 50 kPa limit is exceeded, it could drastically lower the efficiency of filtration.
- For clean water (DI < 1%, e.g. borehole water): a maximum allowable loss of 30 kPa across a clean filter, and a maximum limit of 50 kPa across a dirty filter.

The friction loss curve of the filter should be consulted to determine what the loss across a clean filter will be when a specific irrigation system's water moves through it. Where two or more parallel filters are used, the total flow-rate of the system must first be divided by the number of filters. The friction loss resulting from this flow-rate can then be read from the friction loss graph. If the friction loss exceeds the above limits, it means that the flow-rate is too high for the filter, and that a larger filter or additional filters should be chosen.

B. The dirtiness of the irrigation water

Figure 32 is the friction loss graph of the Silicon II sand filter. According to the previous paragraph, the recommended flow-rate for this filter would be 33 m^3/h because this is the flow-rate that gives a friction loss of 10 kPa over the clean filter.

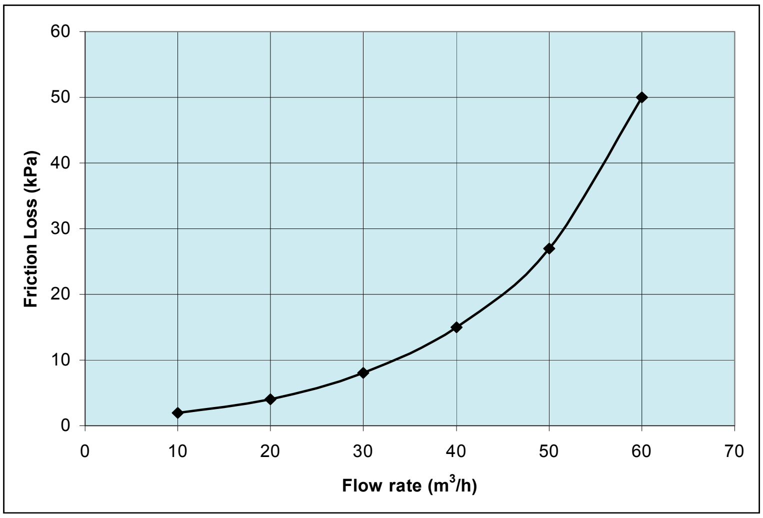


Figure 32: Friction loss graph of the Silicon II sand filter

Figure 33 is the dirty water capacity graph of the Silicon II sand filter, which must be interpreted as follows: If a pressure difference increase of only 20 kPa is allowable over the filter (as is the case for sand filters) and if the irrigation system can supply it, then it means that the filter can clean only 30 m^3 of water before it must be cleaned again, with a DI of the water equal to 10% for example.

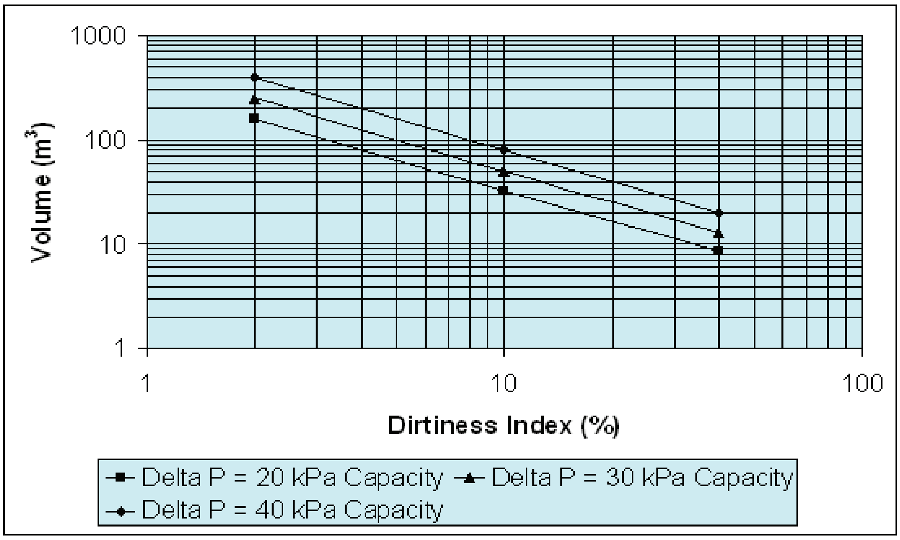


Figure 33: Dirty water capacity graph for the Silicon II sand filter

With an allowable volume of 30 m^3 and an allowable flow-rate of 33 m^3/h, this filter will be clogged in less than one hour. If the farmer's style of backwash management entails manually cleaning filters, it will be very impractical to clean the filters every hour. It might be more practical to clean the filters every six hours. If this is the case, six Silicon II filters will be required in the filter station to provide enough filter capacity for this backwash management style.

C. The total pressure drop allowed across a filter

When the internal losses of an irrigation system increase, e.g. due to a filter starting to block, the delivery of the system will decrease. Delivery should not be allowed to decrease too much, with a maximum decrease in delivery of 10% taken as a good norm. As soon as delivery decreases by more than 10%, the distribution becomes disproportionate. The volume of the internal losses which accompany the 10% decrease in flow is unique to each system, and can be calculated from the system's hydraulics, as illustrated in Figure 34.

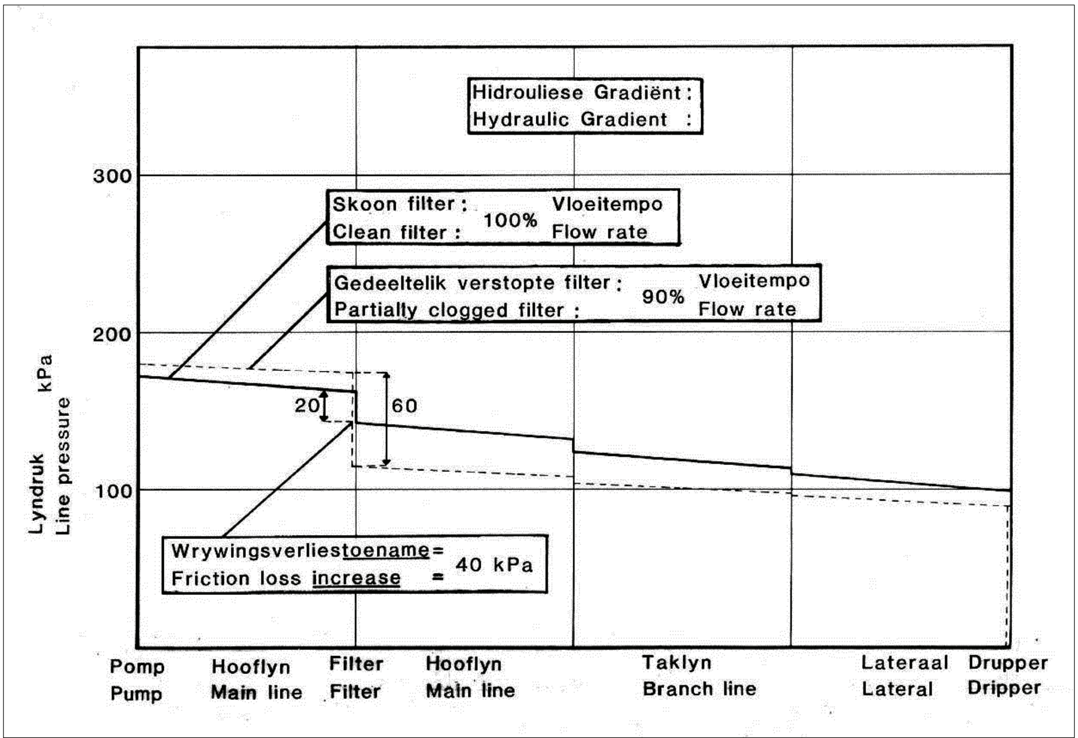


Figure 34: Permissible friction loss increase over a filter

To determine what additional losses the irrigation system can absorb without impairing the efficiency of the system, the pressures of the system are calculated from the pump up to the filter, and then again from the dripper backwards until directly behind the filter. (In the graph, it would thus be from left to right up to the filter, and then from right to left up to the filter

The calculation is done for 100% flow (clean filter) and for 90% flow (dirty filter). The first calculation will thus for example show a pressure drop of 20 kPa across the theoretical filter and the second calculation a pressure drop of 60 kPa. This means that the system can absorb an additional 40 kPa pressure drop across the filter without affecting the efficiency of the system adversely. Given that the total recommended pressure drop across the filter is only 50 kPa, it means that only 30 of the 40 kPa can be utilised by the filter because the initial loss was already 20 kPa, as can be seen in the diagram.

D. The cleaning cycle of a filter

The exact stage at which a filter must be cleaned is usually determined by one of the following:

- The allowable reduction of flow in the irrigation system, resulting from the increased resistance against flow in the blocked filter: It causes reduction in the system efficiency. The flow rate in the system can be measured with a flow meter and must not reduce by more than 10%.

- The allowable pressure drop over the filter elements: Too great a pressure drop over a filter element causes dirt to be forced into the element, which later hampers effective cleaning. The sand filters are therefore cleaned when the total pressure drop of 60 kPa over the filter banks is reached, given that the flow rate must not drop by more than 10% (See Table 34):

Table 284: Allowable pressure difference over filter banks

Type	Clean filter bank (kPa)	Maximum pressure build-up (kPa	Pressure difference before backwashing (kPa)
Disc / mesh filter	30	40	70
Sand filter	40	20	60

- As a filter cleans the dirt from the water, the pressure drop across the filter increases, as was previously indicated. The more the pressure drop across a filter can be increased, the more water will be filtrated. This pressure drop cannot, however, be increased to an unlimited degree and should preferably be limited to 70 kPa (60 kPa for sand filters) for the following reasons:
    - If the pressure drop increases too much, the dirt will eventually be forced through the element and the efficiency of filtration will start decreasing.
    - With certain filters, the element may give way if the pressure drop becomes too much, and a concentration of dirt (which has in the meantime built up in the element) will enter the system and most likely immediately block the system.
    - Elements that often get blocked under a too high pressure drop become more difficult to clean, and the efficiency of backwashing is drastically reduced.
- A further method is to limit the time lapse between cleanings. An easy way to determine the time lapse is to first calculate the volume that can be safely filtered and then divide the figure by the flow rate of the filter.

$$T = \frac{V}{Q} \qquad (5.8)$$

where

T = Time lapse (h)

V = Volume that can be filtered (m³)

Q = Flow rate through the filter (m³/h)

The latter is the most convenient method, but problems can occur if the degree of dirtiness of the water changes.

If the dirtiness of the water is known, as well as the additional pressure drop which can be allowed across the filter for blockage, then the dirtiness capacity graph of the filter can be used to determine how much water a filter will clean under the given circumstances. If the quantity of water that a filter can clean is known, as well as the flow-rate at which the filter operates, the time it will take the filter to clean this given quantity can be calculated. This time constitutes the cleaning cycle of the filter.

However, with very dirty water choosing a filter on this basis may result in a very short cleaning cycle. The only way to extend an impractically short cleaning cycle is to use larger or additional filters in parallel, so that their common cleaning cycle can be lengthened to a practical time. This decision will have to be made by the producer or the manager of the filters.

It will also lower the flow-rate per filter, and the friction loss across each individual clean filter will be less than the 10 kPa previously advised. This is no longer of importance, however, because the dirty water capacity of the filter becomes the main consideration rather than the flow-rate through the filter. In the case of very dirty water, combinations of different filters are often necessary. Table 35 provides guidance on how to choose and combine them.

Table 295: Filter selection guide; quick reference

Flow-rate	Solids concentration		Product (s) recommendation
	Inorganic	Organic	
Less than 11,4 m^3/h	L	L	A
	L	M	C + A or B
	L	H	C + A or B
	M	L	D + A
	M	M	C + D +A or B
	M	H	C + D + A or B
	H	L	D or D + A
	H	M	C + D + A or B
	H	H	C + D + B
11,4-45,4 m^3/h	L	L	B
	L	M	C + B
	L	H	C + B
	M	L	D or B or D + B or D + B
	M	M	C + D or F or D + F
	M	H	C + F or C + D + F or C + D + F
	H	L	D + B or F or D + F
	H	M	C + D + F or C + F or D + E
	H	H	C + D + F or C + D + F
Greater than 45.4 m^3/h	L	L	B
	L	M	C + F or E only
	L	H	C + F or E only
	M	L	D + B or D + F or E only
	M	M	C + F or C + D + F or E only
	M	H	C + B or C + D + F or C + E
	H	L	D + B or D + F

Flow-rate	Solids concentration		Product (s) recommendation
	Inorganic	Organic	
	H	M	C + D + F or C + F or D + E
	H	H	C + D + F
Solids Concentration Code:		Recommendation Product Code:	
L – Less than 5 ppm M – 5-50 ppm H – More than 50 ppm		A – Strainer B – Screen/Disc Filter C – Suction Screen Filter D – Suction or Discharge Separator E – Gravity Screen Filter F – Sand Filter	

Underlined options above indicate potential Pump Protection systems to minimise abrasive pump wear.

5.9.3 Guidelines for the commissioning of filters

During the commissioning of a new filter station, some specific steps have to be followed in a definite sequence: one step cannot be taken before another is finished. Every situation is unique, but in general, the following order of steps will largely be the correct approach:

- Ensure that all pipe connections, hydraulic pipe and electrical connections are in place.
- Manually test electronic meters for correct operation. Remove the pressure sensor from its mounting and put pressure on to it by blowing it up with your mouth and check if the display reacts. Take the flow meter mechanism out of its casing, blow onto the impellor, and check if the display reacts.
- When a computer or any other electronic device is connected to the instrumentation, check if there is communication between them.
- Check if the elements of the filters are in place and well fastened.
- Check if all pipe and electrical connections are in place at the pump and if the water supply is in place.
- Close the valve behind the pump and start the pump.
- Open the valve very slowly and only partially at first so that the system can fill up slowly.
- Check for water leaks.
- If there are leaks, close the valve first, switch off the pump, and repair the leaks.
- Try again and let the water flow slowly for a while whilst the functionality of the station is tested in full.
- Open the valve fully, bring the system to full pressure, and do all checks again. Leave it on for an hour or so to check its stability.
- Put the system in use and check if all controls and programs work as they should.
- Observe the system closely for at least a month to make sure that everything is working well in the long run.

5.9.4 Guidelines for the operation of filters

Whilst the theoretical backwashing cycle can be calculated, it is, however, just a theoretical cycle which must initially be monitored to see if it is applicable in practice. For example the cycle can change during the season as the water quality changes. Changes in water quality can easily be established by taking regular DI measurements: The same tools that were used to establish the theoretical cycle can be used to make corrections to it.

If the water is very clean, backwashing should be done once daily to prevent sedimentation of the sand-bed. Stirring the sand with the hand can elevate sedimentation. It may sometimes be necessary to replace the sand. Bacterial growth on the sand sometimes leads to sedimentation of the sand, resulting in tunnel forming. Bacterial growth can be prevented by chemically treating the water.

The backwashing duration must be sufficient to remove all impurities from the filter. A backwashing duration of at least 60 seconds is generally recommended. It is, however, good practice to physically backwash the filter, monitoring the time it takes until all the discolouration and alien material disappears from the water. It is also very important to take a sample of the backwashing water with a clean container before the backwashing process is completed and to inspect it to ensure that it is clean. The evaluation and setting of sand filter backwashing times must be done regularly. If the duration is too short, or the flow-rate is too low, the pressure differential over the filter station after backwash will gradually increase with time.

Backwashing usually takes place while irrigation continues. To operate both the backwashing and irrigation system simultaneously, the flow-rate to the irrigation system must be reduced to build-up the pump pressure and to allow backwashing by using a pressure-sustaining valve. It is, however, beneficial to backwash the system from time to time (bi-weekly), with all blocks closed, so that a greater volume of water can flow through the filters to accomplish a more effective backwashing action. A pressure before the filters of ±5 m higher than the normal functioning pressure is sufficient during this action. The use of compressed air to break up clods in the sand and assist with the backwashing action is recommended if problems are experienced with tunneling. Discolouration of water during backwashing is normal and indicates the effective functioning of the filters.

The backwashing flow-rate is very important and must be set to ensure effective backwashing. Too high a flow-rate will cause the sand to wash out, while too low a flow-rate will prevent impurities from being washed out. Backwashing can be performed on a time, volume, or pressure difference basis. The backwashing on a pressure difference basis is recommended, since it takes water quality changes into consideration.

5.9.5 Guidelines for the maintenance of filters

5.9.5.1 Maintenance schedule

The following maintenance schedule for filters is recommended (See Table 36):

Table 306: Minimum maintenance schedule requirements for filters of drip irrigation systems

Monitor	Weekly	Monthly	Quarterly	Annually
Inspect filters for leaks.	✓			
Check pressure difference across filters	✓			
Monitor filter backwash cycle and adjust if necessary		✓		
Check the hydraulic and electrical connectors		✓		
Service screen filters. Replace screen element if necessary		✓		
Inspect sand level (± 360 mm) and shape of sand grains. Add sand or replace if necessary*			✓	
Service disc filters. Replace filter discs if necessary.				✓
Service backwash and air valves				✓

*The sand should have sharp edges to be effective. The effectiveness of the filter is reduced if the sand particles become round due to frictional wear.

Where aggressive water occurs, metal parts of the filters must receive epoxy treatment. Lubricants extend the lifespan of synthetic discs in filters where metal and rubber parts are in contact. High viscosity silicon products have proved to be the most suitable product for general usage. Lithium grease, but definitely not oil, is very suitable for valve axles and other moving parts.

5.9.5.2 Replacing sand in filters

The rule of thumb is to replace the sand annually. However, it may be necessary to investigate the condition of the sand. If the sand feels smooth when rubbed between the fingers it has been worn down and will no longer filter effectively. Replacement sand particles must be angular and not round.

It is essential to half-fill the filter with water before replacing the sand, to prevent damage to the underdrain system of the filter. The water forms a cushion and protects the internal parts. Sand filters normally have a sand depth of ±360 mm. Always use prescribed graded sand from a reputable supplier. Sand particle sizes that vary from 0,71 mm to 1,85 mm are recommended.

When layer has formed causing the sand to become dirty or blocked, and even causing sedimentation, it may not be necessary to remove all the sand from the filter. The layer can be scraped off and removed and the correct amount of sand replaced. It usually occurs as a result of a low backwashing flow-rate or too long a backwashing cycle.

5.2.5.2 Replacing filter discs

It is strongly recommended that the discs should be removed periodically and cleaned manually. Discs with chemically blocked channels must be removed and cleaned chemically. If the discs cannot be cleaned effectively, they must be replaced. Any disc that shows signs of mechanical damage should be replaced. Always replace discs with the same colour, and from the same manufacturer, to ensure that the degree of filter disc remains the same.

6 PLANNING AND DESIGN PROCEDURES FOR DRIP IRRIGATION

6.1 Introduction

This chapter presents the planning and design procedure applicable to drip irrigation, as summarised in the following main points:

Planning:

1. Determine irrigation requirement (from SAPWAT or another reliable source of information)
2. Calculate the cycle length, gross irrigation requirement per cycle, standing time and emitter discharge for the peak irrigation period using the planning flow diagram
3. Select a suitable emitter from a manufacturer's catalogue based on required emitter discharge
4. Calculate the system discharge, number of groups/blocks and the group/block size
5. Undertake a preliminary block lay-out

Hydraulic design:

6. Decide on required EU for the design according to the relevant norms to calculate the allowable emitter discharge variation
7. Calculate the allowable pressure variation in a block and divide between laterals and branch line (Manifold: 0.5 m; Lateral: remaining part of Δp – use this division as starting point)

Lateral design:

8. Determine optimum lateral position along the length of the manifold
9. Determine the lateral pipe size(s) taking topographic slope into account
10. Calculate the required lateral inlet pressures and actual Δp (compare with allowable)
11. If the actual pressure variation is too big, choose larger diameter pipes or change block dimensions.
12. Repeat steps 8 to 11 for each block.

Manifold design:

13. Use remaining allowable pressure to determine suitable pipe sizes, taking topographic slope into account.
14. Check maximum discharge variation against allowable variation calculated in point 7.
15. Calculate the required inlet pressure and discharge to each block.
16. Select a suitable control valve (and secondary filter if applicable) for each block
17. Repeat for all blocks

Main line design (on critical path from pump to hydraulically most remote block inlet):

18. Calculate most economic diameter for main line.
19. Select practical pipe sizes, calculate the hydraulic gradient and select correct pipe classes.
20. Determine maximum pressure and discharge required at the source (pump duty point).

Non-critical path main line design:

21. Use up available pressure difference from critical path take-off point to point of application to size the sub-mainlines to the block inlets.

Water supply system and accessories:

22. Select, position and size suitable air valves for the whole system
23. Select a suitable primary filter or filter bank
24. Select suitable control and automation accessories for the pump station
25. Determine a suitable suction pipe size
26. Choose pump and motor to satisfy the peak system requirement
27. Calculate maximum static suction head for installation

Not every point in this summary is dealt with in detail in this manual, and the designer is referred to the Irrigation Design Manual of the ARC – Institute for Agricultural Engineering for more information.

6.2 Planning

Irrigation planning entails investigations, data gathering and surveys that should be conducted in preparation for the design of the drip system.

Example 1: *(Refer to Figure 35 for abbreviations)*
Information gathered:

Crop:
Sweet melons, tramway planting, 2.46 x 0.3 x 0.3 m; NRD = 0.5 m;α = 50% ; f =0.7 (the crop coefficient k_c *can also be used instead of the crop factor f, if Reference Evapotranspiration data is used instead of A-pan Evaporation data)*
Soil:
Loamy sand with good lateral distribution; ESD≥1 m, therefore ERD=NRD; WHC_{100} *= 90 mm/m; infiltration rate = 10 mm/h*
Climate:
Geographic – Cradock district ; $R_e = 0$ *;* E_o *= 9.8 mm/d (Reference Evapotranspiration* ET_o *can also be used instead of A-pan Evaporation* E_o*, then in conjunction with the crop coefficient* k_c *instead of the crop factor f as mentioned above)*
Water:
Borehole discharge (Q) = 30 m³/h; C1-S1; no chemical or physical limitations.
Management aspects
Higher level management potential, especially with computerised management system which can utilise the largest portion of a 24 hour workday.
Choice of system type and components:
Drip irrigation with one dripper line per double row of plants, i.e. L_d *= 2.76 m and* L_e *= 0.6 m (experimentally really only about 1 m, but for the sake of germination, cultivation and forced lateral distribution, placed somewhat closer to one another); farmer's preference: Ripin, pressure sensitive; ideal* q_e *= 2.0 or 4.0 ℓ/h (nominal at 100 kPa).*
Topographic survey:
A proper survey should be conducted with all the necessary data that is required. The topographic map to be used for the design should meet the following requirements:

Contour interval:	*Smallest scale:*
0.5 m	*1: 500 (narrow row spacing: ≤ 3 m)*
1.0 m	*1: 1 000 (wide row spacing: > 3 m)*

6.3 Emitter discharge

With all the relevant data both the cycle length and the gross irrigation requirements have to be determined, as well as the practical emitter discharge and the application rate.

Example (continued)

The development of the planning diagram is illustrated in Figure 35.

According to this t_c (practical) = 1 day, GIR_c = 7.2 mm/d en q_e = 2.0 ℓ/h.

Please note:

- *The practical cycle length of one day implies that every day of the week is a working day. This has two important consequences:*
    - *The normal practice of a working week of less than seven days could not be maintained. The only way in which this safety factor could be included was to implement working days of less than 24 hours.*
    - *Initially, efforts were made to maintain standing times of 7 h each to allow for three settings per day. However, this meant an impractically low emitter discharge and the standing time was decreased to 6 h, with the result that the daily working hours accordingly decreased to 18 h.*
- *Although the theoretical rate of drip irrigation is very high, distribution of the water to a certain extent occurs above-ground, and also laterally underground, with the distribution capacity of the soil and the hydraulic gradient in the soil as co-operating factors.*

A practical emitter can now be selected from a manufacturer's catalogue. The KBase developed by the ARC can be used to view a large selection of commercially available products. For design purposes, it is necessary to obtain at least the following information on the selected emitter:

- Design emitter discharge (q_e, l/h)
- Design emitter pressure (p, kPa)
- Discharge coefficient (K)
- Discharge exponent (x)
- Manufacturer's coefficient of variation (CV)

In the case of integral drippers, the available pipe sizes and emitter spacing should be obtained.

In the case of pressure compensating emitters, it is also important to obtain the minimum and maximum pressure between which the emitter will regulate the discharge.

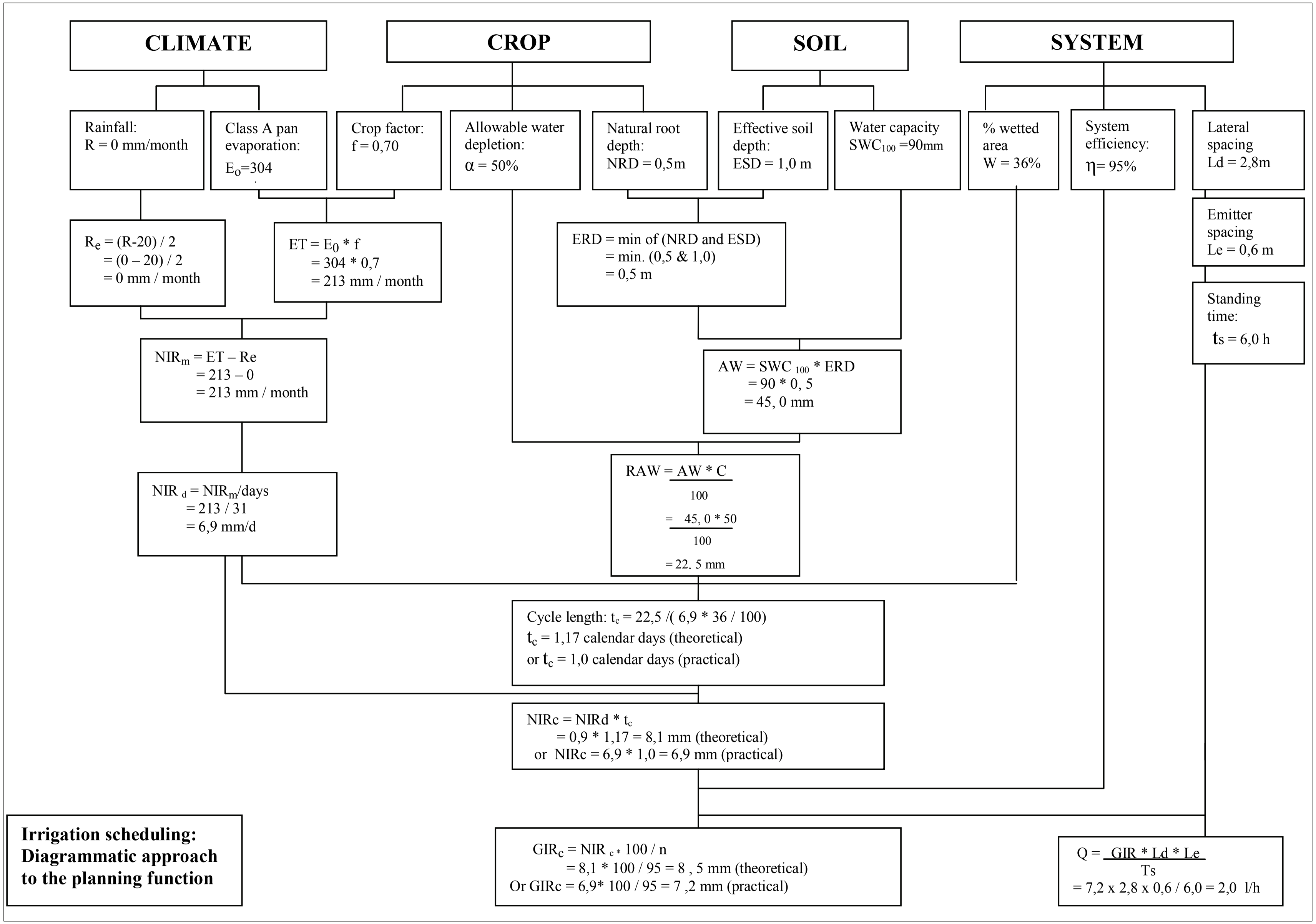


Figure 35: Scheduling planning; example

6.4 Theoretical size of irrigation group

The system flow, the number of emitters per group and also the group area respectively, can be calculated theoretically:

$$Q = \frac{GIR_c \, A_T}{t} 10 \qquad (6.1)$$

Where:

Q = total system discharge per crop [m³/h]

GIR_c = gross irrigation requirement per cycle [mm/cycle]

A_T = total system area [ha]

t = operating hours per cycle [h]

$$n_e = 1000 \frac{Q}{q_e} \qquad (6.2)$$

Where:

n_e = number of emitters

q_e = emitter discharge [ℓ/h]

$$A_g = \frac{n_e \, L_d \, L_e}{10\,000} \qquad (6.3)$$

Where:

A_g = group area [ha]

n_e = number of emitters

L_d = lateral spacing [m]

L_e = emitter spacing [m]

Example (continued)

The farmer concerned wants to eventually cultivate a total area of about 4½ ha. Although the final calculation of irrigable soil has not yet been established at this stage, the preliminary indications are that this requirement may be within reach.

Solution:

- *System discharge*

According to equation 6.1:

$$\begin{aligned} Q &= \frac{GIR_c \; A_T}{t} 10 \\ &= \frac{7{,}2 \times 4{,}5}{18} \times 10 \\ &= 18{,}0 \;\; m^3 / h \end{aligned}$$

- *Number of drippers per group*

According to equation 6.2:

$$n_e = 1000\frac{Q}{q_e}$$
$$= 1000\times\frac{18{,}0}{2{,}0}$$
$$= 9\,000 \text{ drippers}$$

- *Group area (theoretical)*

According to equation 6.3:

$$A_g = \frac{n_e\ L_d\ L_e}{10\,000}$$
$$= \frac{9\,000\times 2{,}76\times 0{,}6}{10\,000}$$
$$= 1{,}5 \text{ ha}$$

In effect there will therefore be 3 groups of blocks of 1,5 ha each (4,5 ÷ 1,5), which will be irrigated every day. A group may consist of one or more blocks, which need not be adjacent to each other.

6.5 Block layout

This process involves a more accurate determination of the area of arable soils, and thereafter the subdivision into blocks. Attention should be paid to a number of practical aspects which may influence the process, including among others:

- Optimal utilisation of available soil is always a high priority.
- It is preferable to maintain practical shapes and layouts of the system, but this should go hand in hand with minimal soil wasting.
- The same adaptable and versatile approach is preferable with regard to block and even group layout, especially in the case of seasonal crops which are cultivated on a rotation system.
- Block sizes should be practical as far as access, cultivation, pest control and other farming practices are concerned.
- Maximum lateral lengths of the smallest possible diameters should be maintained from a cost point of view.
- In order to simplify both design and installation, attempt to minimise the use of different pipe diameters (especially with dripper lines).
- For logistical reasons, use the minimum number of branch lines per block. This is especially important with seasonal crops where systems are moved in their entirety and where branch lines are usually located above the ground. Laterals should also not be broken up unnecessarily for coiling and storage purposes.

The designer is usually confronted with one of two options, or a combination thereof, as a given situation:

6.5.1 Existing crops

With existing crops (especially of permanent nature) the direction of the rows is basically fixed, and the designer is given no choice regarding lateral and branch line directions. Lateral positions are also fixed. Only the sensible positioning of the branch lines is therefore necessary in terms of ideal layout and size, as well as practical considerations regarding soil cultivation and other practices.

If existing windbreaks are a further premise, block sizes and shapes are more or less pre-determined, allowing little room for innovative planning in terms of theoretical requirements.

6.5.2 Newly planted crops

When a system is designed for newly planted crops, it is advisable to integrate system characteristics and layout requirements for optimum results:

- All the factors under consideration should be taken into account in an integrated manner with no individual factor predominating.
- The location of existing borders, planted crops and infrastructure should be taken into account so that soil utilisation will be optimal and no impractical row directions and block shapes will develop with respect to existing infrastructure and operational practices and directions.
- When pressure compensating emitters are considered (or even necessitated due to prevailing conditions), topographic tendencies become less important due to the inherent compensating characteristics of the emitters.
- With the use of pressure sensitive emitters, however, it is advisable to position the row direction (and also the lateral direction) such that it lies downhill, against an inclination, along which the topographic gradient is almost equivalent to the hydraulic gradient of the most economical lateral diameter. In this way, the longest possible laterals (from both cost and practical viewpoints) can be used with the least number of branch lines.
- Likewise, it is advisable to locate the branch line in such a position (usually perpendicular to the lateral direction) that the flow direction will also be downhill. It is indeed advantageous to utilise topographic gradients in a balanced way to the benefit of both components.
- Block sizes should be structured in such a way that they form an even fraction of the theoretical group area. Uneven fractions are acceptable, as long as the whole situation is taken into account. Uneven fractions should add up to totals which, once again, are close to the theoretical group areas.
- Different crops and cultivars should be accommodated separately as far away as possible and such that the total of the blocks again corresponds with that of the theoretical group areas.

6.5.3 Block grouping

Blocks can now be compiled into practical groups, of which the total areas more or less correspond to the theoretical group areas. Some basic considerations apply here and an effort should be made to maintain a practical balance at all times.

- Specific operational practices often compel the grouping together of blocks involved. Newly planted crops usually consist of crops and cultivars which are grouped together for obvious reasons. It is also easier to control the operation of one valve, as well as maintenance activities which are limited to a single area. However, this practice should be implemented with caution, especially when the farmer insists upon it without first considering other options.
- Distribution of blocks within a group over the entire area which is to be served by the system has the result that the water, which flows to a group at any time, is canalised in different directions through the distribution network. This has the effect that less water flows through each pipe section and that diameters can accordingly become smaller and cheaper. Such a group will obviously utilise multiple valves operating simultaneously. The cost incurred with this approach must therefore be compared to the cost of groups of adjacently situated blocks, which are often supplied by only one (larger) valve.
- Automation also plays an important role and can have a drastic impact on group composition and should likewise be taken into account.

6.5.4 Block or group area (practical)

Calculating the average group area has been discussed in Section 6.4. It is necessary at this stage to determine how this function is affected by the practical block and group composition and then to effect essential practical adjustments. Practical group areas should therefore be tested against the theoretical calculations, as well as possible limitations that may arise through existing physical conditions, such as limited discharge rate of the water source or pump unit, or possibly limited power supply from an existing transformer. If necessary, the whole process should be repeated until all the requirements are met.

Example (continued)

The contour plan of arable area shows the extent of the lands that were initially identified as available area, both soil scientifically and logistically. This area should now be subdivided into blocks which meet the following requirements:

- *Group area (ideal): 1,5 ha (according to Section 6.4).*
- *Block area (ideal): 1,5 ha or fractions thereof, such as ½ (0.75 ha each), or 1/3 (0.5 ha each). The smaller unit is deemed to be impractically small as far as marketing limitations are concerned, and blocks of ¾ ha each will be the objective.*
- *Block shape (ideal): As uniform as possible because the materials should be exchangeable for crop rotation and for purposes of re-using.*
- *Dripper line diameter: Smallest possible, uniform diameter, which will stretch continuously along the entire block, for purposes of interchange ability.*
- *Emitter spacing: Already established experimentally on 0.6 m.*
- *Discharge difference: $\leq$ 10%, according to recommended norms.*

- *Branch line diameter: A combination of diameters and lengths which will also make interchange ability of the branch lines possible.*

Solution:

- *Synoptically, it seems that the larger part of the land (Blocks 1.1 to 1.4) will play a predominant role in the decision-making process.*
- *A rectangle of about 440 m long and 65 m wide can be fitted in reasonably easy, covering an area of 2.86 ha.*
- *It will be adequate for two groups of 1.43 ha each, which compares well with the theoretical target of 1½ ha.*
- *Plant rows (and therefore also dripper lines) will preferably run parallel to the border fence to meet the requirements established for practical and economic reasons.*
- *Maximum tentative dripper line lengths are now determined by means of graphic iteration between topographic gradients (of varying lengths and a variety of representative positions), and the hydraulic gradients as supplied by the manufacturers (see section 6.7).*
- *Accordingly, it seems that this sub-area can possibly be subdivided into four blocks of slightly less than 0.75 ha each, which once again corresponds well with the theoretical target.*
- *Consequently, an attempt will now be made to fit another two identical blocks onto the remaining area.*
- *It does not seem to be practically possible, and it should be accepted, that the shape and layout of the arable land determined that one block will deviate from the ideal.*
- *The rectangular block that was formed here can also create problems because of the steep gradient. This aspect will be dealt with in greater detail in block hydraulics.*

This investigation showed that the entire area can be divided into three groups, as was required theoretically, and that each group can be subdivided into two blocks of more or less the required size. ***Error! Reference source not found.*** *indicates the preliminary results.*

The practical number of crop rows is subsequently indicated on the plan. In this case, 23 rows of 2.76 m fit into each block without exceeding the provisional boundaries. The layout is done as shown in ***Error! Reference source not found.****.The pipe sizing of which the results are shown is only done at a later stage of the design – the figure is presented here to show the lateral and manifold lay-out.*

The six block areas therefore cover practically 110 x 23 x 2.76 = 6 983 m^2 or 0.70 ha each, with three group areas of 1.4 ha each. The total practical area of 4.2 ha compares well with the initial theoretical calculations of 4½ ha, and the next steps can now be taken.

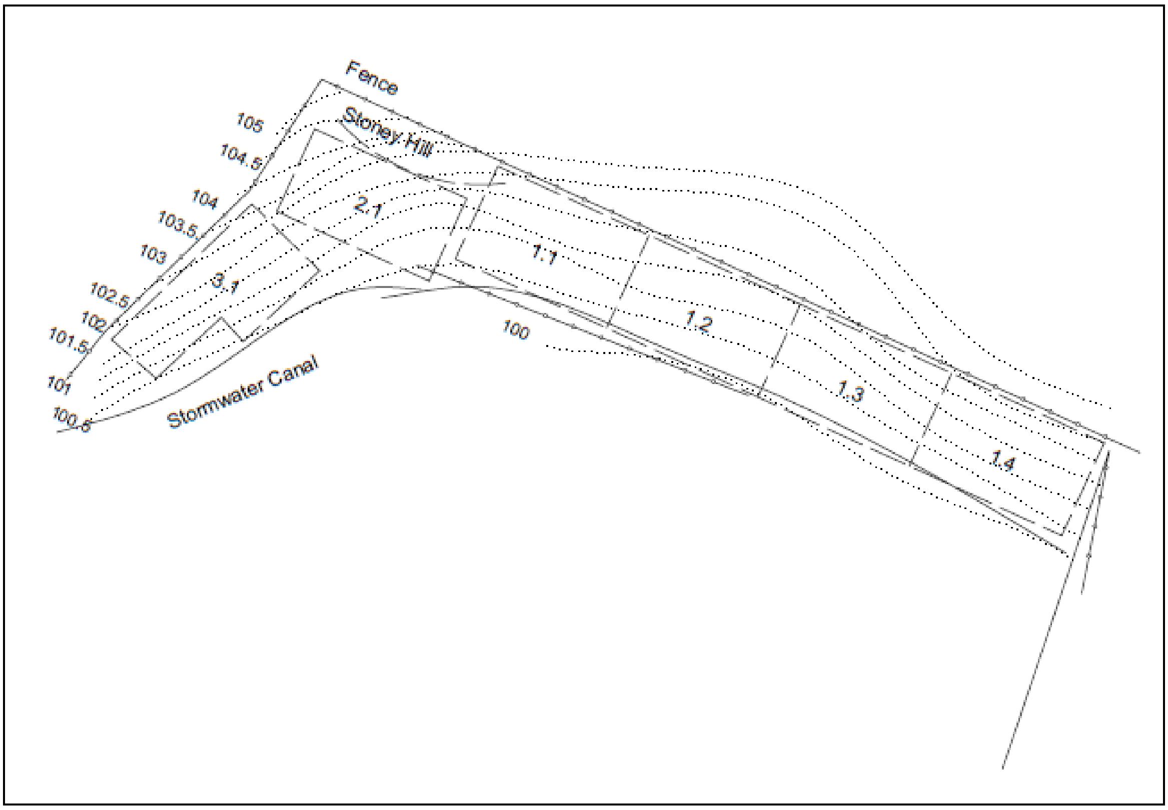


Figure 36: Preliminary block lay-out of the design example

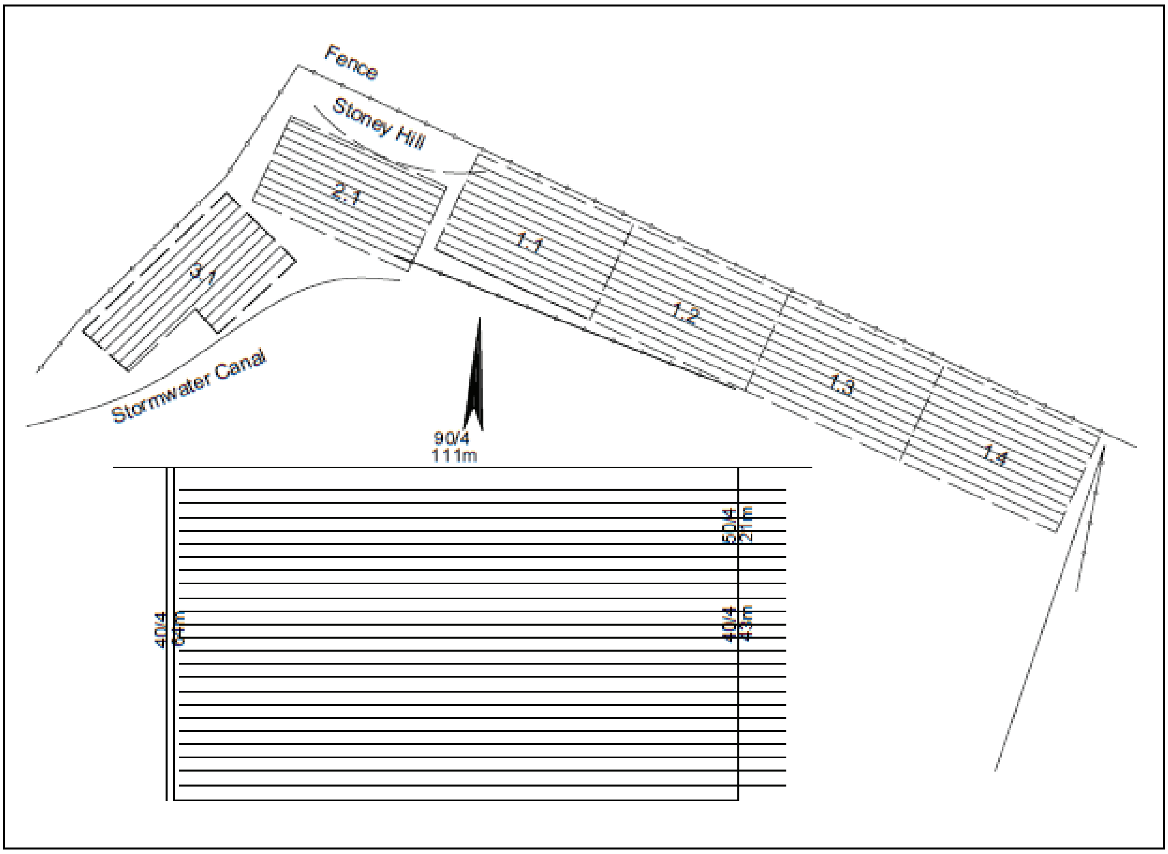


Figure 37: Preliminary lateral and manifold lay-out,

6.6 System capacity (practical)

System capacity is now calculated according to the number of emitters in the largest practical group, at the average nominal emitter discharge. A number of aspects need special attention:

- It should be assumed that there often are practical circumstances causing deviations from the theoretic average group area. The result is that the total emitter discharge between groups may differ, and could even result in significant deviations. The largest group naturally determines the system capacity in terms of pump and control centre capacities.
- There is a physical difference between drip and micro systems which should be taken into account:
  - Micro sprayers and on-line drippers are fitted onto the laterals after the laterals are already in position, and in most cases movement due to thermal and mechanical characteristics have already been taken up in the form of snaking. Although there is an increase in pipe length, the number of emitters remains constant because they are installed according to the design.
  - Drippers, on the other hand, are mostly fitted into the dripper line during manufacturing. This causes an increase in emitters in proportion to the extent of the snaking in the lateral, usually about 3% of the design length. This naturally affects the total discharge of the block and the group, and the total system capacity will have to make provision for this.

System capacity can therefore be established according to the following equation:

$$Q_s = \frac{L_L \; n_L}{L_e} \times \frac{q_e}{1\,000} \times 1{,}03$$

where

Q_s = system capacity [m^3/h]

L_L = lateral length [m]

n_L = number of laterals per group

L_e = emitter spacing [m]

q_e = average emitter discharge [ℓ/h]

Example (continued)

According to the layout of this particular system, each group consists of two blocks, each with 23 laterals 110 m long, onto which emitters have been mounted at 0.6 m intervals. In addition, provision has to be made for the effect of snaking.

Solution:

According to the system capacity equation:

$$
\begin{aligned}
Q_s &= \frac{L_L\ n_L}{L_e} \times \frac{q_e}{1000} \times 1{,}03 \\
&= \frac{110 \times 23 \times 2}{0{,}6} \times \frac{2{,}00}{1000} \times 1{,}03 \\
&= 17{,}4\ m^3/h
\end{aligned}
$$

6.7 Emission uniformity

In any irrigation system where plant nutrients and other chemicals are applied with the irrigation water, it is of the utmost importance that the EU of those emitters that function simultaneously should be maintained within relatively low tolerance levels, in accordance with the concept known as emission uniformity of the system, indicated by the internationally accepted symbol, EU.

In a drip lateral (and manifold), the flow rate in the pipe decreases at a steady rate over the length of the lateral, as water is delivered through each emitter. This flow pattern which develops in the lateral is called steady uneven flow. Friction loss occurs along the length of any pipe, resulting in a drop of pressure from the inlet to the bottom end (assuming 0% slope). This friction loss can be represented graphically as an HG when drawn relative to the position of the pipe (ground surface), and in the case of a pipe with no emitters where the flow Q enters at the one end and flows out the other end, the HG will be a straight line (Figure 36).

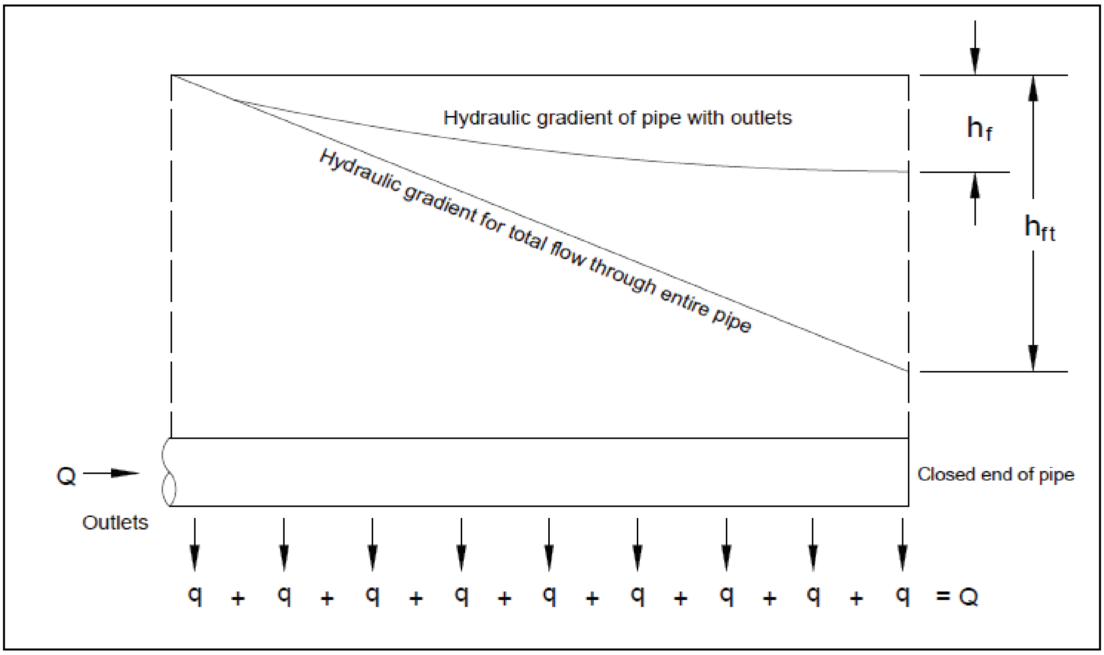


Figure 36: Steady uneven flow in a typical irrigation lateral

In the case of a lateral with steady uneven flow and a closed end, the rate of friction loss will decrease over the length of the pipe because the flow rate in the pipe decreases after every emitter as water exits the pipe. HG is then no longer represented by a straight line but rather by a parabolic line that flattens out towards the closed end of the lateral as the flow rate (and friction loss) in the pipe decreases (Figure 36).

The HG therefore shows the pressure variation (Δp) over the length of the lateral, which can be defined at the difference between the maximum pressure occurring anywhere in the lateral (p_{max}) and the minimum pressure occurring in the lateral (p_{min}). In the case of a horizontal lateral (at 0% slope), p_{max} will always occur at the inlet of the lateral and p_{min} at the closed end of the lateral (Figure 37).

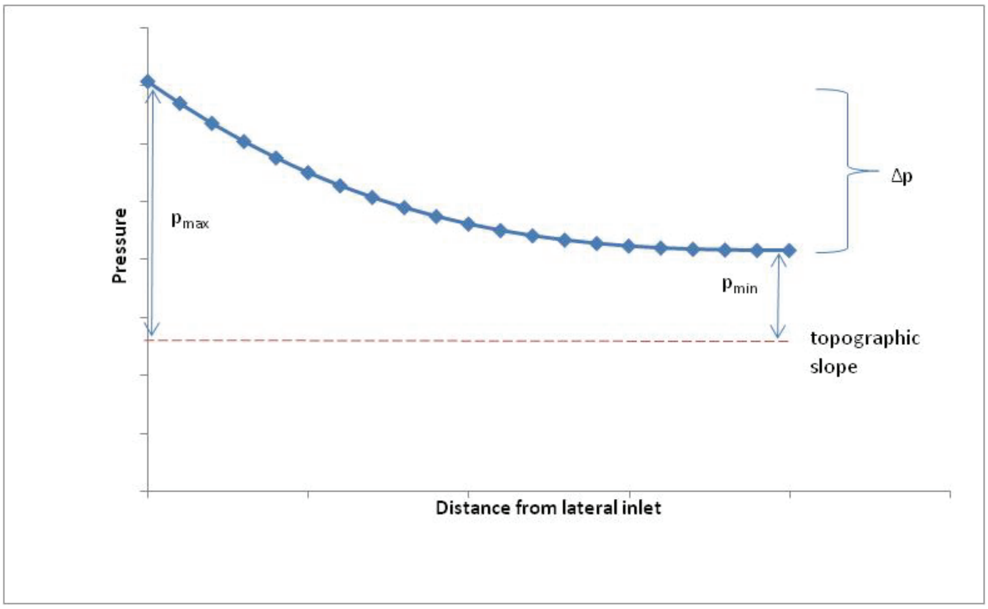


Figure 37: Hydraulic gradient of a lateral on a 0% slope

Should the lateral be sloping uphill, p_{max} will still always occur at the inlet of the lateral and p_{min} at the closed end of the lateral, but Δp will be much greater (Figure 38).

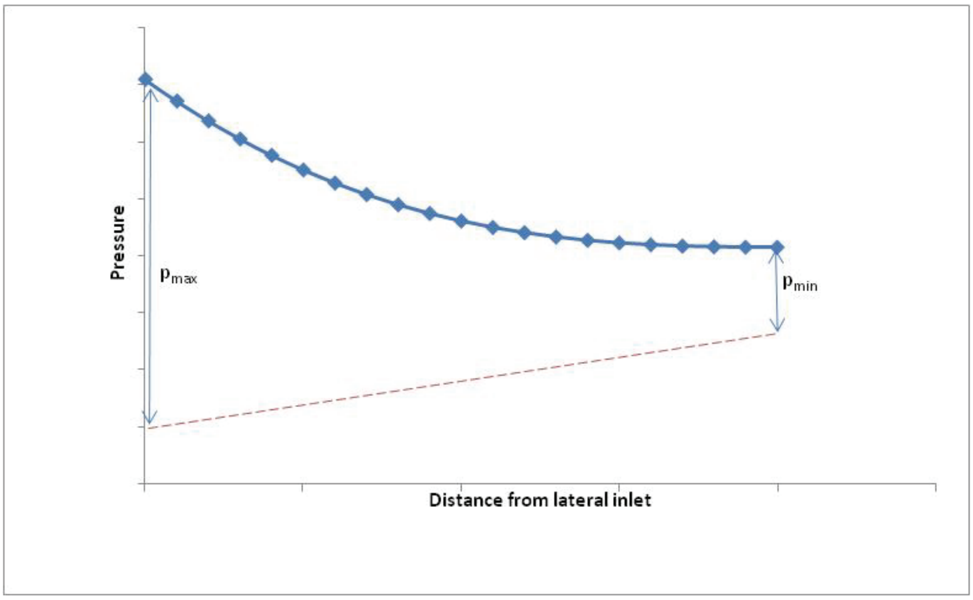


Figure 38: Hydraulic gradient of a lateral running uphill

In the case of a lateral running slightly downhill, the decrease in height will counteract the increase in friction loss, resulting in almost parallel hydraulic and topographic gradients and therefore a smaller Δp.

The p_{max} will still occur at the inlet but p_{min} will occur some distance before the closed end, depending on the slope.

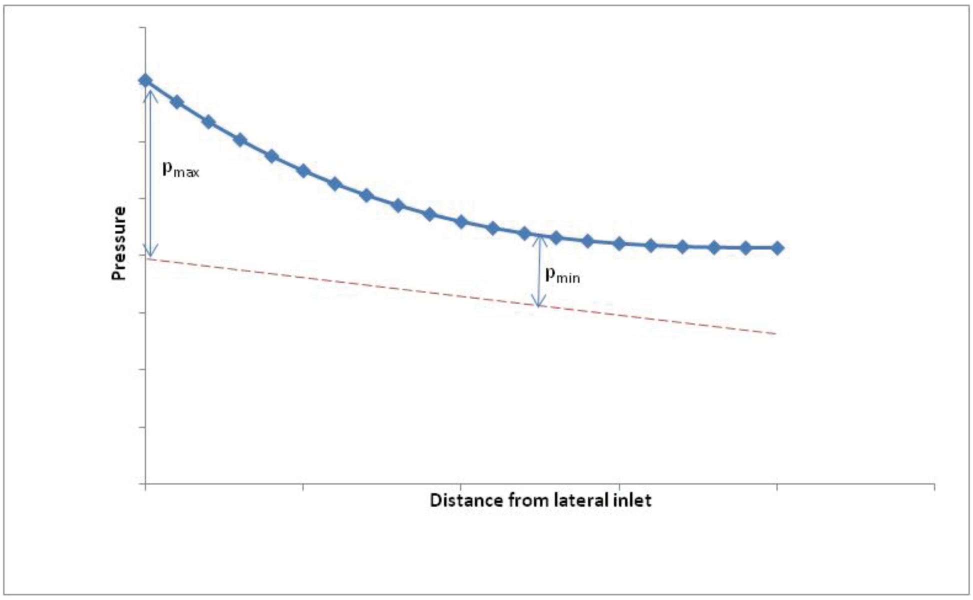


Figure 39: Hydraulic gradient of a lateral running slightly downhill

If the lateral were to run downhill steeply, the two gradients will first approach each other (to p_{min}) before diverging so that p_{max} will occur at the closed end of the lateral, again resulting in a larger Δp.

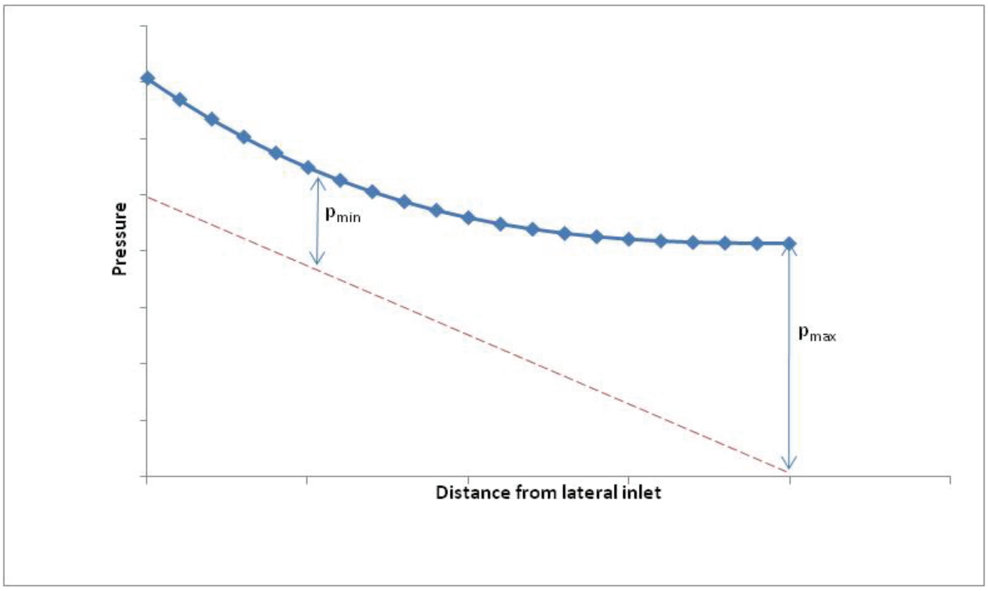


Figure 40: Hydraulic gradient of a lateral running steeply downhill

The ideal topographic gradient for a lateral is therefore one that matches the shape of the hydraulic gradient, resulting in a constant pressure over the whole length of the lateral. Unfortunately this situation is seldom encountered.

From the pressure-discharge relationship of an emitter (equation 2.1) and the design EU equation (equation 5.1), it follows that Δp will largely determine the discharge variation (Δq_e) in the lateral, thereby determining the EU. If a designer wants to design a system that complies with a certain EU requirement, especially in the case of pressure sensitive emitters, the laterals and manifolds have to be laid out and sized so that a specific Δp is not exceeded anywhere in the irrigation block under normal operating conditions.

By implication, it is impossible for all the emitters to be operating at the same pressure. Some emitters in a block will be subject to pressure higher than the design operating pressure p_{ave} (where the selected emitter will discharge the design emitter discharge q_e), and will be discharging water a rate higher than q_e. Some emitters will be subject to pressure lower than p_{ave}, and will be discharging water at a rate less than q_e.

The objective is to design a system where the total volume of water discharged in the whole block is equal to the average emitter discharge q_e multiplied by the number of emitters in the block. The volume of water discharged by the emitters operating above the design pressure should therefore cancel out the volume of water discharged by the emitters operating below the design pressure.

The graphic representation of a typical hydraulic gradient of an emitter line shown in Figure 41 illustrates this principle.

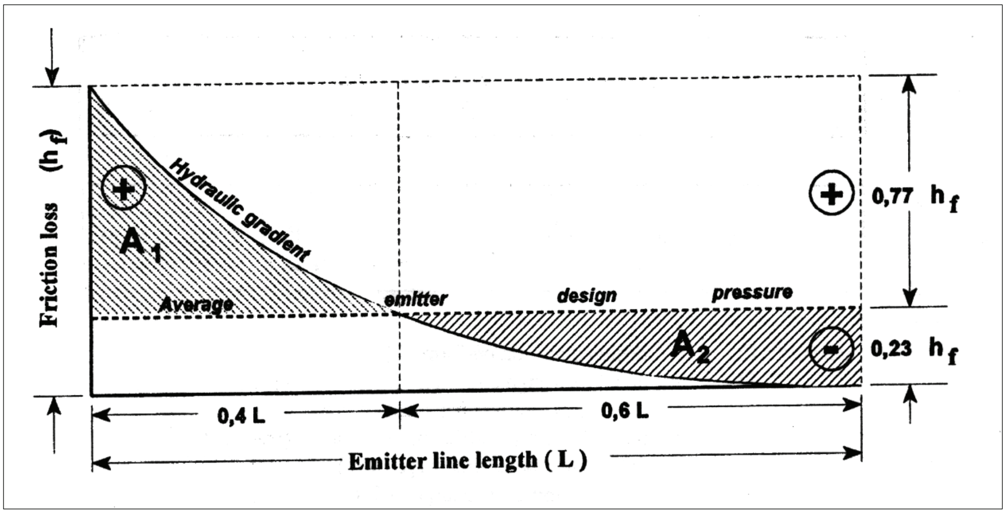


Figure 41: Hydraulic gradient of typical drip emitter line

The following comments refer to Figure 41:

- The emitter design pressure at which the design discharge will be achieved (as selected form the manufacturer's catalogue) can be represented graphically as a line situated above the ground at a distance equal to the design pressure and parallel to the topographic inclination of the soil. This line is therefore horizontal on level soil, as indicated in Figure 41 ("Average emitter design pressure").
- Ideally the diameter(s) for the lateral (or manifold) will be selected in such a way that the HG and the design pressure line are parallel to one another. Because ideal conditions almost never occur in reality, the selection has to be made so that the HG curve and design pressure curve cross one another in a specific way. In order to ensure that the desired average emitter pressure is indeed obtained within limits, the two (or more) areas encompassed by the HG and emitter pressure curves

(shaded areas A_1 and A_2) should more or less be equal, so that the positive areas (A_1) and the negative areas (A_2) cancel each other out: A_1 (+) plus A_2 (-) ≈ 0.

- An emitter line with a homogeneous diameter on level soil will experience the positive pressure deviation over the first 40% of the length of the lateral, while the negative deviation will occur over the last 60%.
- At the same time, the required average design pressure will be attained when a maximum of about ¾ of the total friction losses (hf) over the entire emitter line deviates positively, while a maximum of about ¼ thereof could be negative. These deviation limits should be strictly maintained during the graphic designing process.

6.8 Hydraulic design

All the relevant principles, techniques, approaches and equations concerned according to the Irrigation Design Manual of ARC-IAE must be followed.

6.8.1 Allowable pressure variation

Block hydraulics integrates the design of laterals as well as manifolds: As the total available discharge variation may be utilised in a balanced manner between these two components, an integrated design process for this function is unavoidable.

The blocks must be designed such that no more than the allowable discharge variation takes place within the entire system. A universally accepted discharge variation is 10% of the design discharge. Former design approaches based on rules of thumb (such as a maximum allowable pressure variation of 20% of the operating pressure) did not take into account the CV of the emitters. These design approaches could lead to systems in which the EU was higher than the desired value. The new approach for determining the allowable pressure variation described here takes into consideration both the desired EU as well as the CV of the selected emitter. The norms for drip irrigation are shown in Table 37.

Table 317: Recommended EU values for drip irrigation

Type of emitter	Number of emitters per plant	Topography/Slope	EU(%)	
			Min	Max
Point - source	≥ 3	≤ 2%	90	95
Point - source	< 3	≤ 2%	85	90
Point - source	≥ 3	Undulating terrain or slope > 2%	85	90
Point - source	< 3	Undulating terrain or slope > 2%	80	90
Line - source	All	≤ 2%	80	90
Line - source	All	Undulating terrain or slope > 2%	70	85

The procedure for the determination of the allowable pressure variation requires that the following information is known:

- The desired design (average) emitter discharge (according to planning calculations);
- The desired emitter uniformity (EU) (according to norms);
- The coefficient of variation (CV);
- The operating pressure (p_{ave}) at which the emitter will provide the desired discharge q_e;
- The discharge exponent (x) of the selected emitter (from the manufacturer's tables);
- The number of emitters per plant.

It is recommended that the maximum EU is used as far as possible during the calculation of the pressure band. Lower EU values will result in a greater pressure variation and consequently greater discharge variation.

The EU equation can then be used to calculate the ratio between the minimum allowable emitter discharge (q_e min) and the design emitter discharge (q_e ave). The equation is repeated here from Chapter 5:

$$EU = 100\left(1{,}0 - \frac{1{,}27}{\sqrt{e}}CV\right)\left(\frac{q_{e\,min}}{q_e}\right) \qquad (5.1)$$

The q_e min:q_e ave ratio is then used in the following equation, to calculate the minimum allowable emitter operating pressure (p_{min}):

$$\left(\frac{p_{min}}{p_{ave}}\right) = \left(\frac{q_{e\ min}}{q_e}\right)^{1/x} \qquad (6.1)$$

The total pressure variation (Δp) can then be calculated with the following equation:

$$\Delta p = 2{,}5\ (p_{ave} - p_{min}) \qquad (6.2)$$

The allowable pressure band makes provision for variation as a result of friction and topographic differences in the block.

Example (continued)

- *A tentative decision was made earlier during the process to use Ripin drippers with a nominal discharge of 2.00 ℓ/h, which is obtained at an operating pressure of 100 kPa.*
- *As runner crops are to be irrigated, strip wetting is required;*
- *Assume from a contour chart that the slope of the rows is level and less than 2%.*
- *Seeing that the rows are relatively short, the norm for the slopes < 2% will be used.*

- *According to Table 37, the desired EU will therefore be 90%.*
- *The manufacturer's tables indicate that the CV of the dripper is 2.83% and the delivery exponent, x is equal to 0.6.*

If the values in the equation are replaced, with the acceptance that there is one emitter per plant:

From equation 5.1:

$$90 = 100\left(1 - \frac{1,27 \times 0,0283}{1}\right)\left(\frac{q_{min}}{q_{ave}}\right)$$

$$\left(\frac{q_{min}}{q_{ave}}\right) = 0,93$$

From equation 6.1:

$p_{min}/10$ = 0.931/0.6

p_{min} = 8.92 m

Thus from equation 6.2:

Δp = 2.5 ($p_{ave} - p_{min}$)

= 2.7 m

$q_{e\ min}$ = 0.93 x 2 l/h = 1.86 l/h

$q_{e\ max} = q_e$ x (p_{max}/p_{ave})x = 2 x (11.6/10)0.6 = 2.19 l/h

The results can be summarised as follows:

EU [%]	Lower limit		Higher limit		Allowable pressure variation from average		Total pressure band
	p_{min} [m]	$q_{e\ min}$ [ℓ/h]	p_{max} [m]	$q_{e\ max}$ [ℓ/h]	+ [m]	- [m]	[m]
90	8.92	1.86	11.6	2.19	1.60	1.10	2.70

***Please note that these tolerance figures include the total allowable change over the entire block**. It includes friction losses as well as static height differences in both the laterals and the branch lines. During the design process proportional charge of this total will have to be taken in consideration between the two relevant components.*

6.8.1.1 Allowable discharge variation

In some cases, the EU method to determine the allowable pressure variation gives an allowable discharge variation greater than 10%. In the example above, the allowable pressure variation is 27% which will result in a discharge variation of 16.5% which is much higher than the universally excepted 10%, even though the EU norm is satisfied.

In cases where the plants are entirely dependent on the irrigation water during the growing season (such as in the winter rainfall areas), or when fertiliser is applied through the irrigation system, it is recommended that the universally accepted 10% maximum discharge variation be honoured, as the effect of water and/or fertiliser applied through a system with a greater variation will be seen on the crop in terms of growth and yield.

In such cases, the graphs in Figure 42 can be used to determine the allowable pressure variation at 10% discharge variation for an emitter with a specific discharge exponent, x.

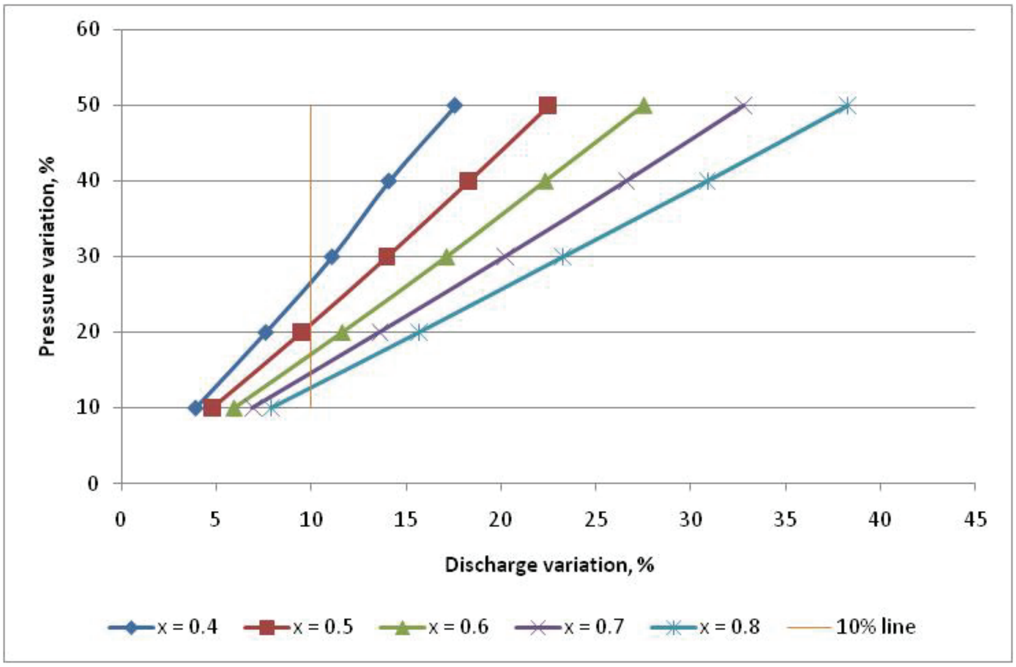


Figure 42: Pressure and discharge variations for different discharge exponents (after Sne, 2006)

As the graphs in Figure 42 do not account for the manufacturer's CV and the number of emitters per plant, the resulting allowable discharge variation value that is obtained can be adjusted slightly lower if a conservative approach is required during the design.

If the values from the example discussed above are applied to Figure 42 allowing only 10% discharge variation, the emitter which has a discharge exponent of 0.6 will be allowed a pressure variation of 17%, which is much less than the 27% obtained from the EU method.

A smaller allowable discharge variation therefore always results in a smaller allowable pressure variation, which means that block lay-out and pipe sizing have to be done with more care. Larger pipes may be required and/or lateral lengths may need to be reduced to limit friction losses (and thereby pressure variation), leading to more expensive systems than those with a greater allowable pressure variation.

6.8.1.2 Pressure compensating emitters

In the case of pressure compensating emitters, neither the EU method nor the 10% discharge variation method can be used, as the discharge exponent of such emitters is equal to 0, rendering the equations used above meaningless. In order to calculate pipe sizes and finalise block lay-outs, it is however still necessary to determine an allowable pressure variation for the irrigation block.

The recommended approach to determining the allowable variation is to use the manufacturer's information regarding the pressure range over which the emitter will deliver regulated discharge. The manufacturers usually provide a minimum and maximum pressure value, and it is recommended that the minimum value provided by the manufacturer is used as p_{min}, while 75% of the maximum value provided by the manufacturer is used as p_{max} for design purposes.

Example:

The pressure range over which an emitter will regulate its discharge is provided by the manufacturer as 50 to 400 kPa.

The allowable pressure variation in the block for design purposes will therefore be:

p_{min} *= 50 kPa (or 5 m)*

p_{max} *= 0.75 x 400 = 300 kPa (or 30 m)*

Δp = 30 – 5 = 25 m

The allowable pressure variation in a pressure compensated system is usually much greater than in a system with pressure sensitive emitters, allowing longer laterals and smaller pipe sizes, and larger block sizes. Although the pressure compensating emitters are usually more expensive than the pressure sensitive versions, savings can be achieved because of the larger block sizes and smaller pipe sizes.

6.8.2 Pipe sizing

At this stage, tentative decisions have already been made on the selection and design of the laterals, manifolds and mainlines. Final decisions now have to be made, taking into account the relevant norms. The tentative decisions may need to be reconsidered, and in exceptional cases, (especially in the case of new developments) it may even be necessary to reconsider the entire lay-out.

6.8.2.1 Allocating the allowable pressure variation to laterals and the manifold

The proportional allocation of the pressure difference figures between laterals and manifolds must be done at this stage. A distinction can be made between two different component compositions:

- Dripper systems with in-line or integral emitters are limited to a choice between only a few available lateral diameters. The result is that it needs a relatively large part of the available difference to be designed within practical and economical parameters. Only a nominal allocation of 0.5 m (5 kPa) is usually allocated to the manifolds and the rest to the dripper line. This is however not a set rule and can be changed according to circumstances.
- On-line dripper systems use standard PE pipe for lateral as well as for manifolds. The choice of diameters is therefore as a whole greater for the laterals and is also identical for both components. The same argument applies to uPVC manifolds. It is therefore standard practice to begin with an equal division of the available difference and if necessary, adjust the division during the design process. A valid reason for an adjustment can occur when there is a large difference in topographical gradient between the two components, or where longer laterals can be designed more economically with smaller diameter pipes.

6.8.2.1 Optimal manifold positioning

The orientation and positioning of the laterals and manifolds can influence pressure variation and system costs. The different lay-outs shown in Figure 43 can be applied for different reasons. The simple comb lay-out is used if the flow in the laterals is downhill (as in the case shown in Figure 39 or Figure 40) and/or if the farmer regularly removes the laterals from the field to cultivate the soil.

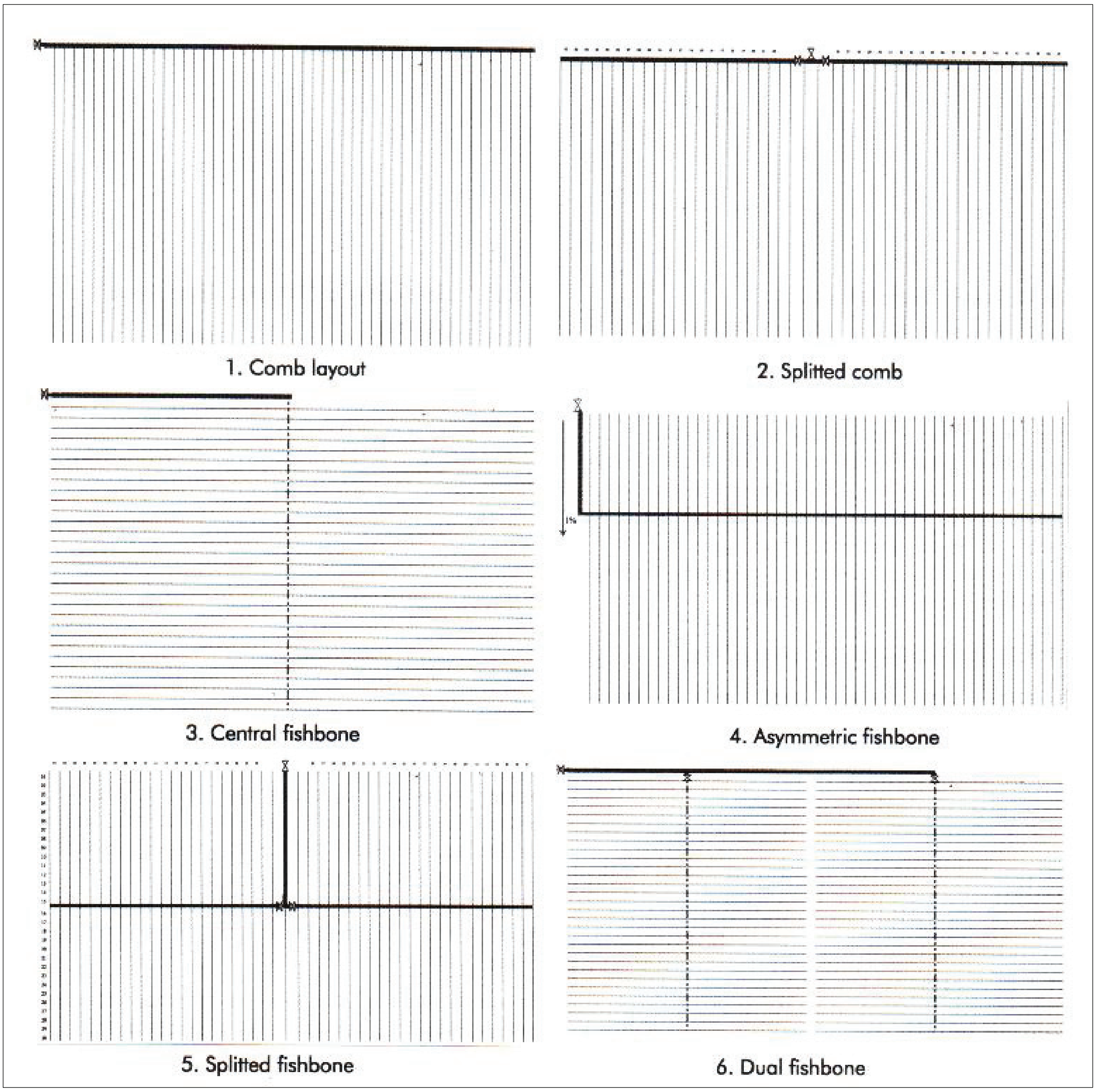


Figure 43: Different lateral and manifold lay-outs (Sne, 2006)

The splitted comb lay-out is similar, but will result in smaller manifold pipe sizes as only half the block's flow rate is flowing into each manifold.

The central fishbone lay-out will be used if the soil surface in the direction of the laterals is horizontal, as it will result in two similar hydraulic gradients mirror-imaged back-to-back on each side of the manifold, thereby reducing the pressure variation Δp by more than half as shown in Figure 44, as well as the required inlet pressure to the manifold (if the same pipe sizes are used). If Δp is available, smaller pipe sizes can then be used resulting in a cheaper system, although a decision will have to be made between saving on capital or operational costs.

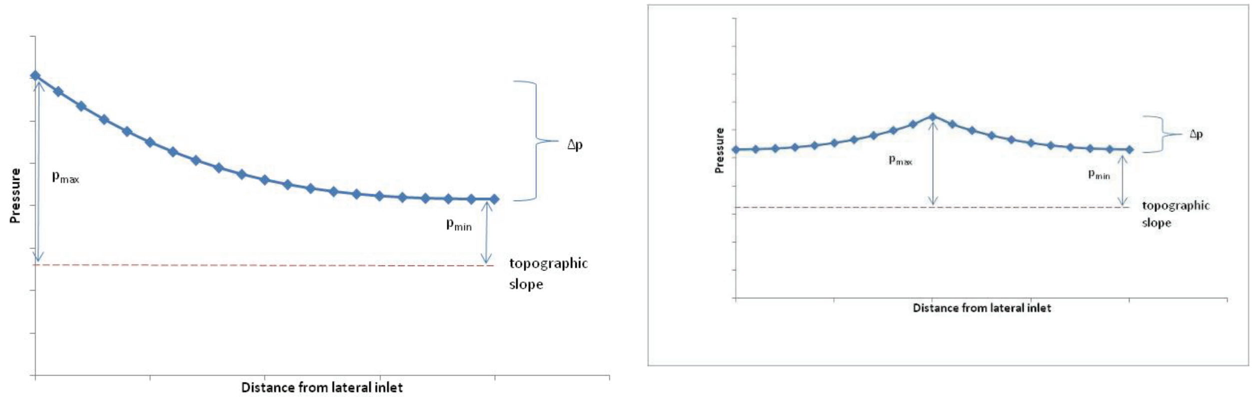


Figure 44: Reducing pressure variation through the central fishbone lay-out

In the case of the laterals having to be laid out at a steep slope (as shown in Figure 40), improved hydraulic conditions with a smaller difference between p_{max} and p_{min} can be obtained by positioning the manifold as an asymmetric fishbone, as shown in Figure 45.

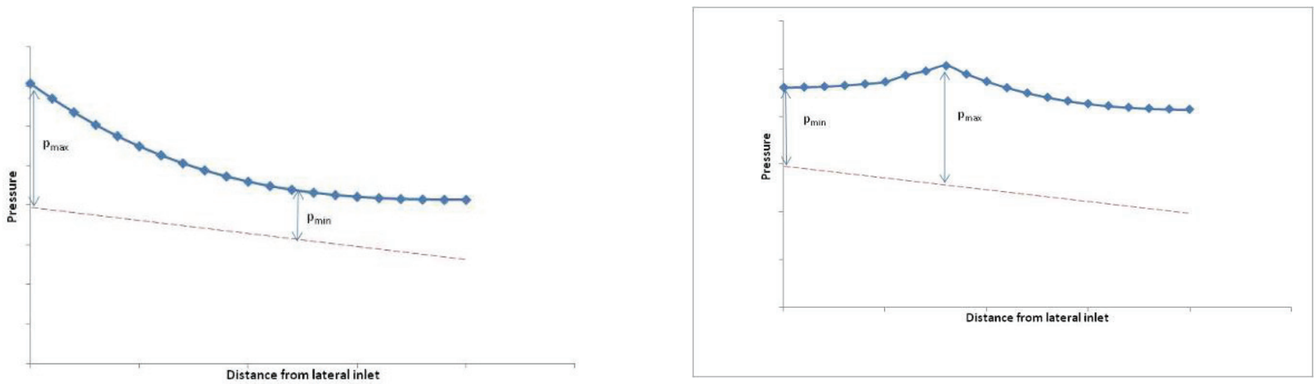


Figure 45: Reducing pressure variation through the asymmetric fishbone lay-out

The optimal asymmetrical position for the manifold can be calculated according to a procedure developed by Keller and Bliesner in 1990. The elevation change over the length of the whole lateral is divided by the friction loss calculated for a pipe equal in size and diameter as the proposed lateral, but as if the total flow of all the emitters were to flow through the whole pipe length as if there were no emitters ("Total h_f").

This value can then be used to look up a "z" factor in Table 38. The z value is multiplied by the total lateral length to obtain the distance to the optimal manifold position along the length of the lateral, as measured from the most downhill end of the lateral.

Table 38: Keller-Bliesner optimum manifold positioning method

Elevation change "Total h_f"	z
0.00	0.50
0.10	0.56
0.20	0.60
0.30	0.65
0.40	0.69
0.50	0.72
0.60	0.75
0.70	0.78
0.80	0.81
0.90	0.83
1.00	0.85
1.10	0.87
1.20	0.89
1.30	0.91
1.40	0.92
1.50	0.93
1.60	0.94
1.70	0.95
1.80	0.96
1.90	0.97
2.00	0.98
2.10	0.98
2.20	0.99
2.30	0.99
2.40	1.00
2.70	1.00

6.8.2.2 Design process

Once the laterals and manifold in each block are designed, the distribution network from the pump to the block inlets must be designed to provide adequate flow at specific pressures at the inlet points of the manifolds. This is followed by the selection of the pump and motor and the compilation of the schedule of quantities, drawings and other supporting documentation that makes up the design report.

The lengths and diameters of the laterals, manifolds and mainlines can be determined by means of basic hydraulic equations, but it is a tedious and time-consuming process. Graphical methods give acceptable results with a relatively high measure of accuracy, but computer programmes are the state of the art. Tailor-made programmes are available but many of the drip manufacturers also provide their clients with software that can be used to design systems that make use of their products.

Example:

The laterals and manifolds were sized using the Jobling Polyplot graphical method, and the results showed that 16 mm pipe can be used over the whole length of the lateral and 40 mm class 4 uPVC can be used for the manifold (Figure 46).

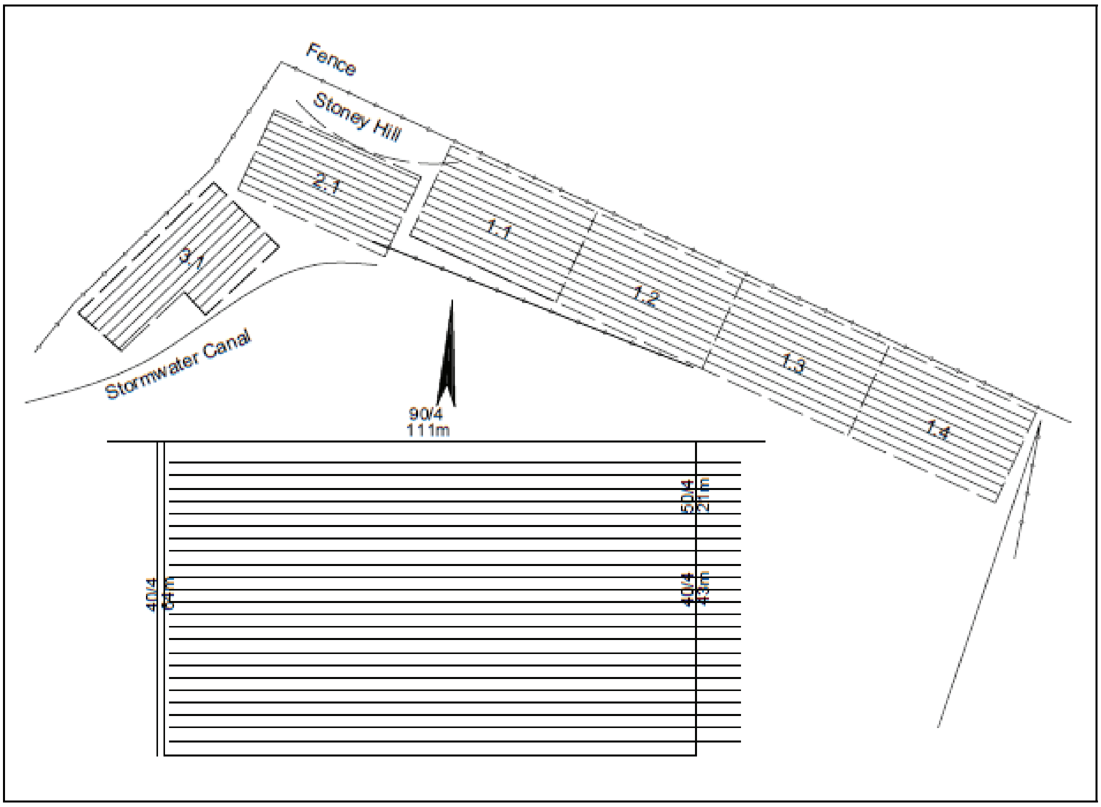


Figure 46: Results of the block design; example

Figure 47 shows the solution for the distribution system in the continuous example. The design had to conform to a number of unique instructions. Some aspects which influenced decision-making are discussed here:

- *Interchange ability, and therefore temporary status, of all block equipment*
- *Any single block, or number of blocks, can be under cultivation due to limited market demand or crop rotation circumstances*
- *The distribution system had to be able to supply blocks 2.1 and 3.1 (group 1) simultaneously.*
- *The pipeline from block 2.1 to block 3.1 inevitably only supplies block 3.1, thus the choice of smaller diameter.*
- *The pipe route of the last section is deliberately snaked to make use of the communal trenches.*

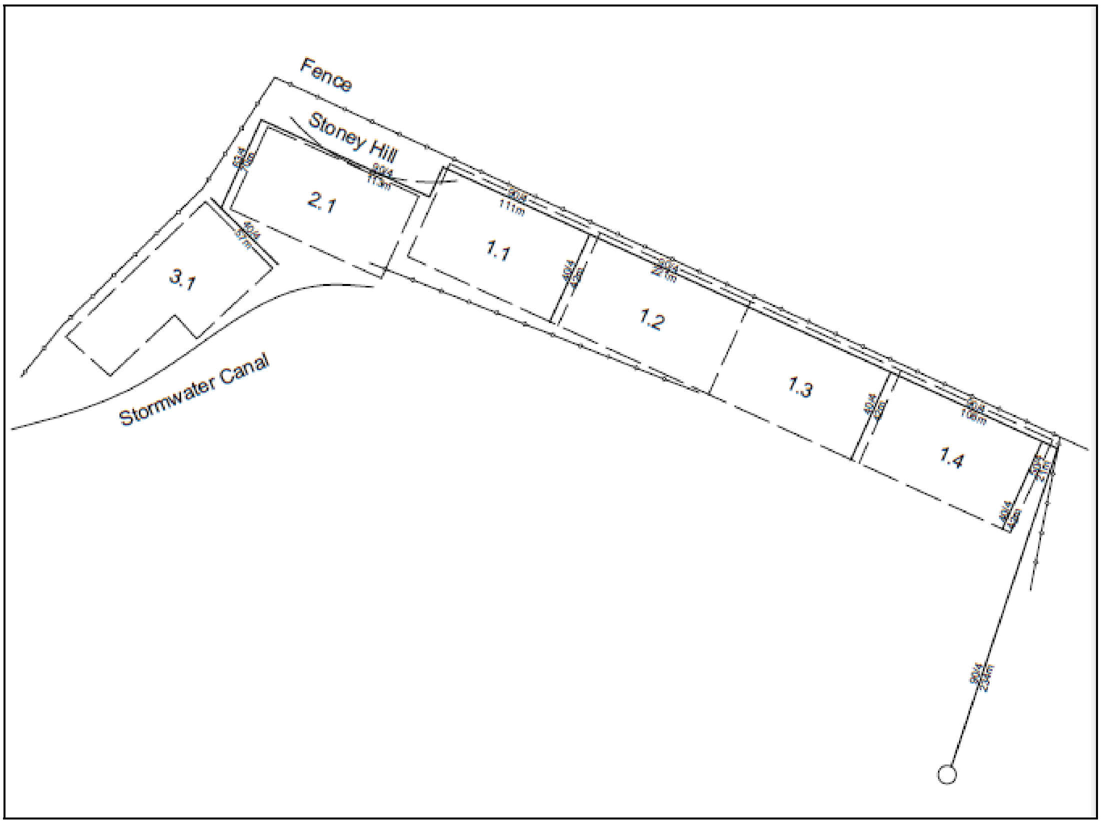


Figure 47: Mainline lay-out and results; example

6.8.3 Computer aided design

Computer aided design is imperative in order to design accurately and correctly, especially in cases where topography varies and laterals and emitters are closely spaced. A good programme will incorporate:

- a digital terrain model to develop an accurate contour map;
- drawing functions to facilitate the lay-out of the blocks and other infrastructure;
- a comprehensive parts and pipes database of equipment that is to be used in the design;
- an accurate hydraulic model to size the pipes with analytical functions to check pressures and velocities, and
- practical additional applications such as the drawing of the longitudinal section of the mainline and determination of the total dynamic head.

7 COST ESTIMATING PROCEDURES FOR DRIP IRRIGATION SYSTEMS

7.1 Introduction

The investment in a new irrigation system cannot be made by simply comparing different price quotations. The annual operating costs of specific irrigation systems are becoming increasingly important, and should be considered thoroughly when acquiring such a system. The situation dependency of irrigation complicates the use of average values for irrigation costs, even within the same irrigation area. Variances in factors such as the area under irrigation, the type of soil irrigated and the pumping heights necessitate the estimation of the fixed and variable costs of each system.

Cost estimations should be made for a specific irrigation system design, as a strong link exists between the specific design specification of an irrigation system and the fixed and operating costs. Design criteria that will impact on the costs include:

- General design criteria
  - the working days per week,
  - the pumping hours per day,
  - the irrigation cycle,
- the irrigation system,
  - emitter type,
  - emitter spacing,
- total area irrigated, and
- area divided in blocks.

Soils, crops and region also have a distinct impact on system capacities that need to be considered. Another important aspect is the emitter specification. Emitter specifications include type, outlet size, output, water pressure, spacing, application rate, standing time per cycle, and flow rate per block. Together and in combination these design specifications impact on the cost of irrigation.

The IRRICOST (Meiring et al., 2002) program was developed to estimate both the annual fixed and variable irrigation costs. During a WRC funded project "*Cost estimating procedures for micro-, drip- and furrow-irrigation systems as well as economic analyses of the relevant irrigation systems for large- and small-scale farmers in the Onderberg/Nkomazi region*" the IRRICOST (Meiring et al., 2002) procedure for estimating annual fixed and variable cost was extended to incorporate cost estimation procedures for drip irrigation systems. The drip irrigation procedure was programmed in Excel, but the layout of the spreadsheet model was cumbersome. As part of this project, the procedure was reprogrammed in Excel to provide a more user-friendly layout that is easier to apply than the previous spreadsheet model.

The spreadsheet model has a wide range of applications, including the following features:

- The annual irrigation cost of almost any irrigation system can be estimated in order to do economic analyses.

- Various system designs can be compared on the basis of the annual fixed and variable costs.
- The variable cost of existing systems can be analysed to consider possible adjustments with the purpose of decreasing operating cost.
- Electricity costs for Landrate and Ruraflex can be compared.
- Optimal irrigation quantities can be determined, because the marginal factor cost of water is known.
- The total cost of each irrigation system can be calculated.
- The importance of the different variables in irrigation costs can be determined by means of sensitivity analyses.

7.2 IRRICOST Spreadsheet model

The IRRICOST model's purpose is not to carry out a design but to calculate capital costs and operational costs of a drip irrigation system. The optimized design must be carried out according to the ARC-Institute for Agricultural Engineering's Irrigation Design Manual and information provided in this manual.

The spreadsheet makes a distinction between information required for the mainline and information required for each of the irrigation systems that utilises the mainline. In the spreadsheet, cells where input parameters are required are formatted red, to aid data input into the model, while calculations (answers) are formatted green. Drop down lists allow choices between predefined alternatives. Figure 49 shows the screen capture of the information required for the mainline, and the resulting output that is generated from the IRRICOST model.

7.2.1 Mainline section

7.2.1.1 Section1: General information

The general information that should be captured for the mainline section is mainly concerned with:

- The layout and characteristics of the mainline,
- Identification of irrigation systems that utilises the mainline,
- Insurance costs,
- Repair and maintenance costs, and
- The electricity tariff.

Although most of the inputs required are self-explanatory, some aspects require clarification:

Firstly, once an irrigation system is identified, a macro button will guide the user to the appropriate sheet for the specific irrigation system.

Secondly, the calculation of the kilowatts required to pump water through the system is highly dependent on the correct specification of the node network used to represent the layout of the system. The correct specification is best explained by means of the layout of the irrigation systems represented in Figure 48.

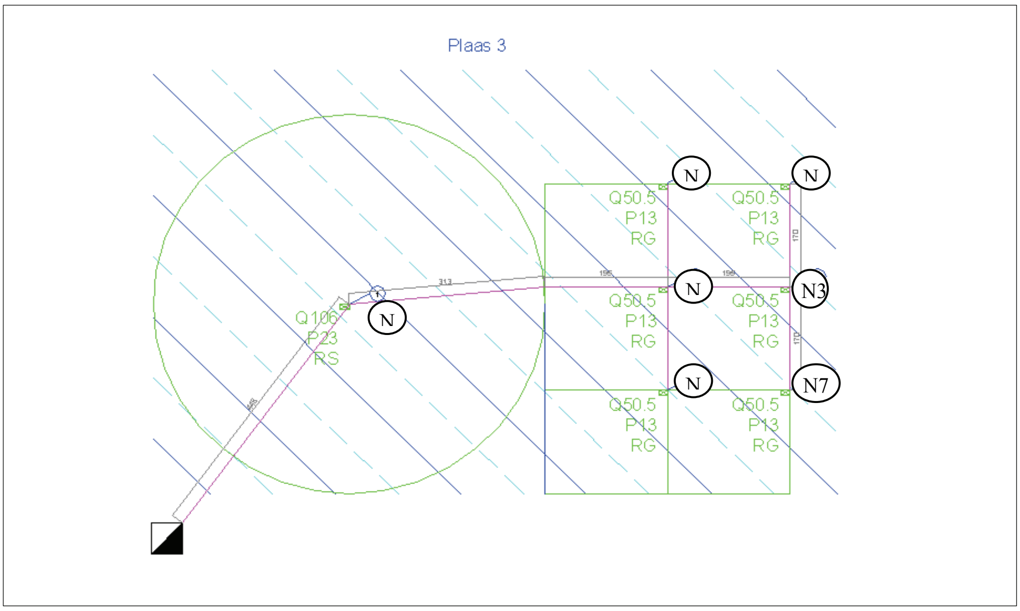


Figure 48: Layout of a combination of irrigation systems

Notes for Figure 50:

- The layout comprises a centre pivot irrigation system and a drip irrigation system.
- The drip irrigation system consists of six blocks, where one block at a time is irrigated.
- Specific phases are characterised by the same type of pipe with the same diameter, and demarcated by a node identifying the beginning of the phase and a node representing the end of the phase.
- Nodes should be added to indicate an irrigation system off-take or a branch line.
- NB. The end nodes should be ranked from the smallest to the largest number.

A third aspect which requires clarification is that two different equations for calculating friction are incorporated into the model:

- The same general friction formula incorporated in the previous versions of IRRICOST, and
- The Darcy, Weisbach, and Jain formula.

To facilitate better design, a table of results is included in the general section to assist with the selection of the kilowatts required to pump water in the system. The Mainline Pressure column can be used to determine phases where surplus pressure exists. If the end node of a phase with surplus pressure does not constitute the beginning of another phase, the design of the phase should be reconsidered.

7.2.1.2 Section 2: Initial investment and annual fixed cost

A fixed cost is a one that occurs no matter how much is produced. For the mainline, fixed costs usually include:

- depreciation,
- interest,
- insurance and
- the fixed electricity charge.

The fixed costs are based upon the initial investment. The capital investment in the components of the mainline (including VAT and installation costs) are entered under investment costs in order to calculate fixed cost components. The capital recovery method is then used to estimate depreciation and interest costs, which is more accurate than the traditional methods where depreciation and interest are estimated separately. The formula is:

Capital recovery = [(Purchase price – salvage value) x (capital recovery factor)] + [(salvage value) x (real interest rate)]

The real interest rate must be used when current purchase/list prices are used; with historical prices the nominal interest rate should be used.

7.2.1.3 Section 3: Annual operating cost of the mainline

The annual operating cost is based on the planned amount of water pumped. In order to calculate the costs, an estimate of the amount of water to be pumped annually, the corresponding number of pumping hours and the kilowatt hours necessary to pump the water are calculated. These values, together with information supplied in Section 1, are then used to calculate the annual operating cost associated with electricity, and repair and maintenance costs. With respect to electricity cost, a user-specified percentage allocation is made between different electricity tariffs, i.e. Landrate and Ruraflex.

7.2.1.4 Section 4: Summary of costs

This section summarises the annual fixed costs and operating costs for the planned water applications. These are used to calculate the fixed cost per ha, as well as the variable costs per cubic metre of water applied. The marginal factor cost of pumping one cubic metre of water is also estimated.

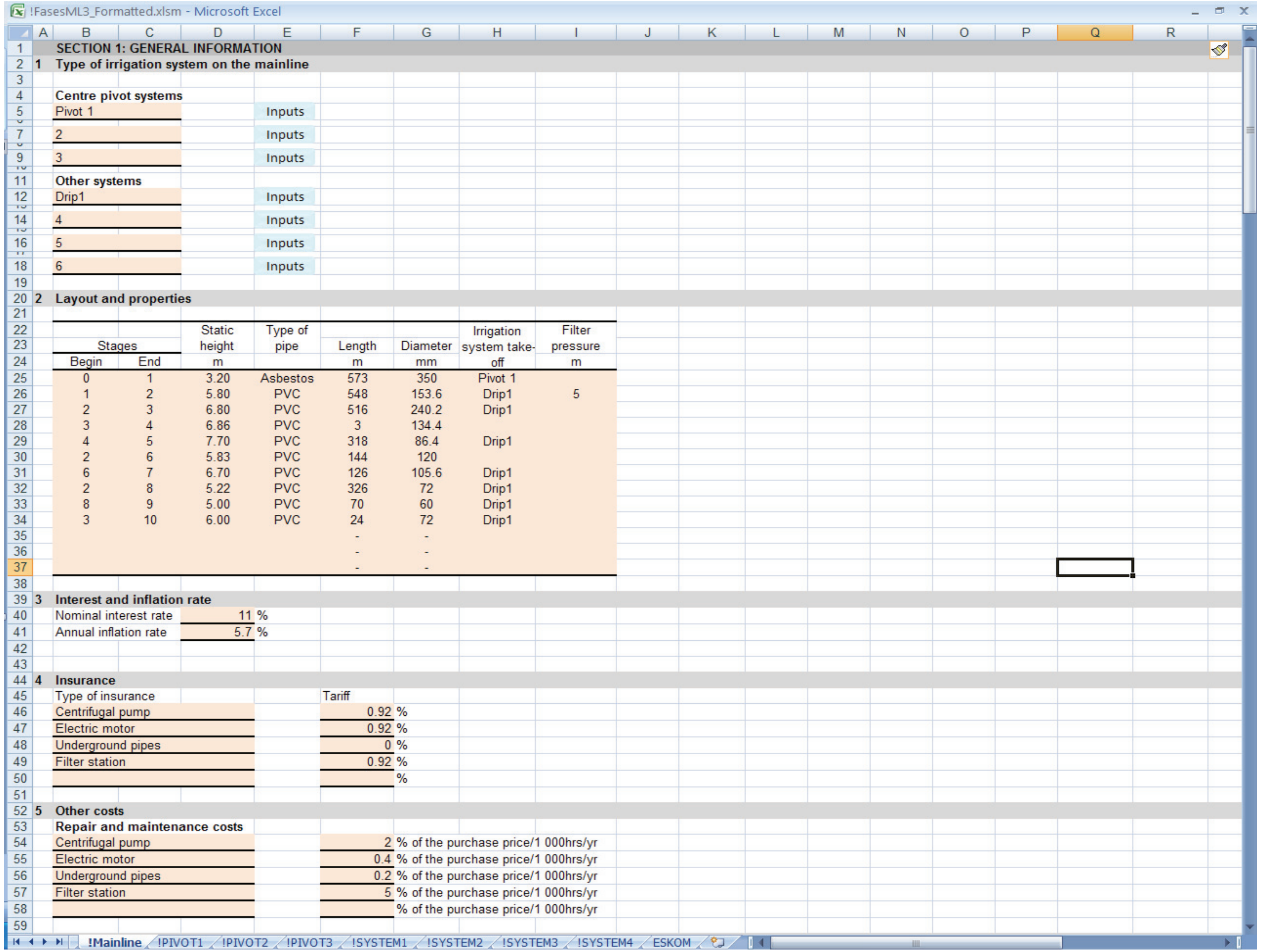


Figure 49: Excel screen capture indicating information required for the Mainline

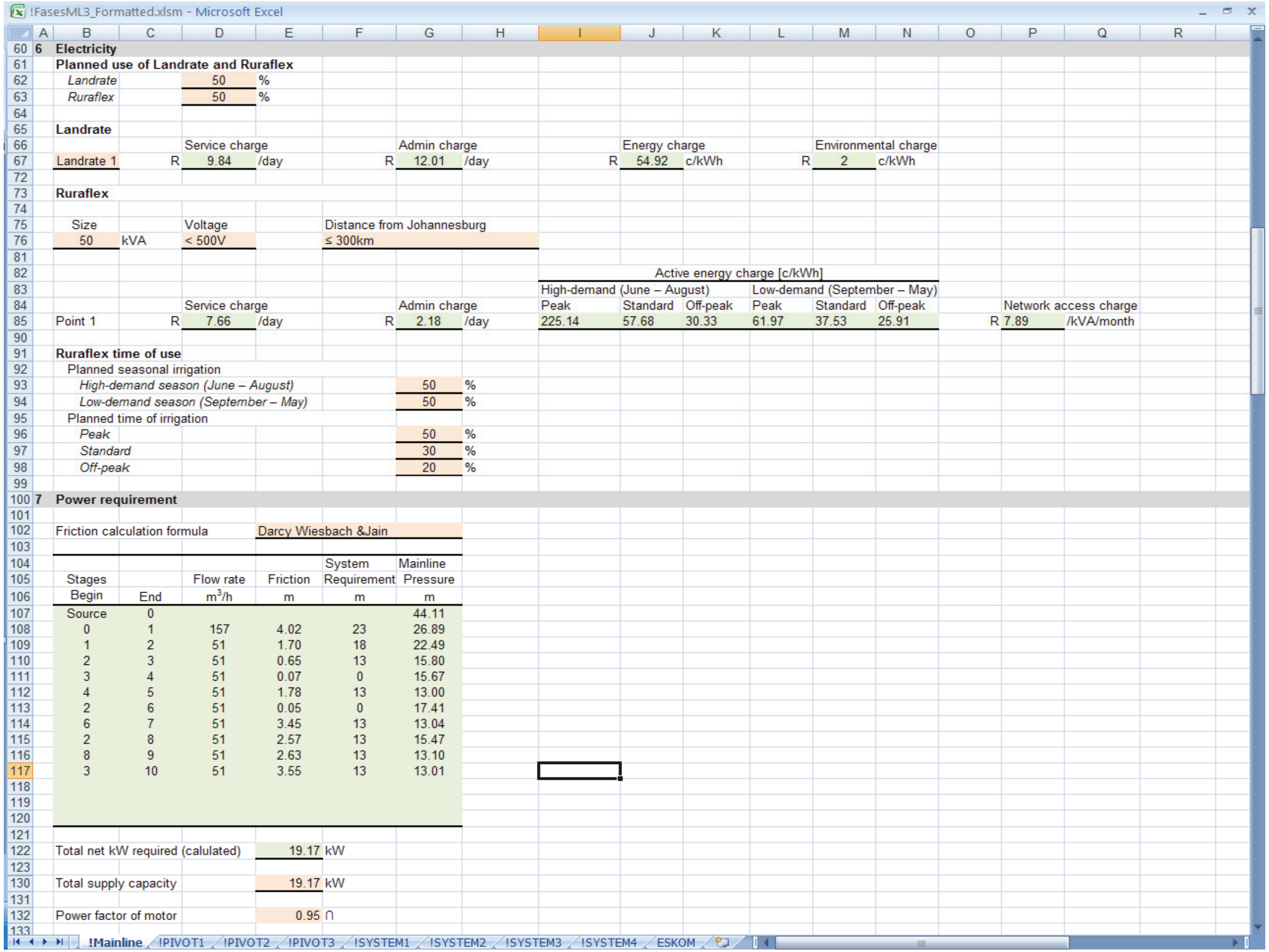


Figure 51: (Continued): Excel screen capture indicating general information required for the Mainline

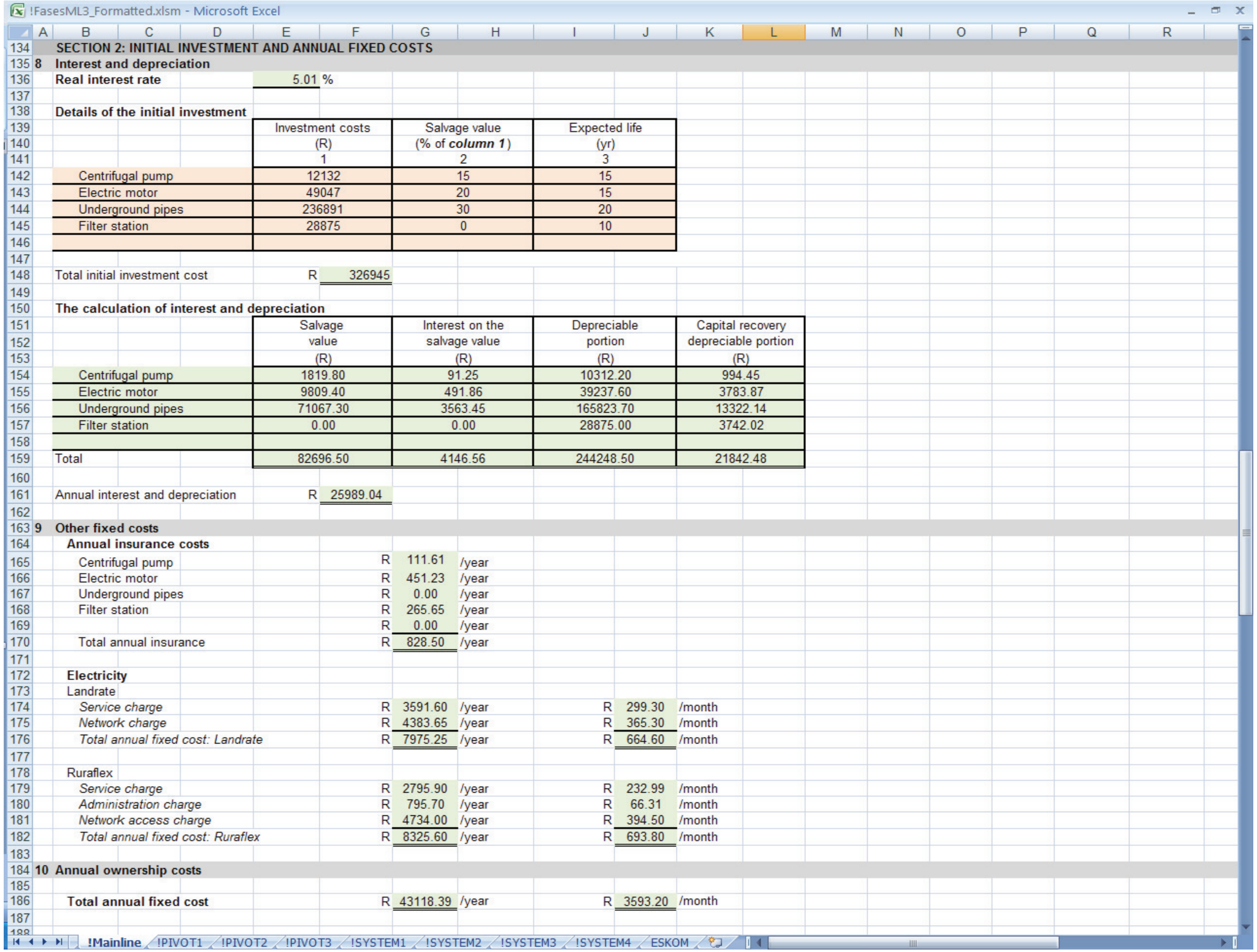
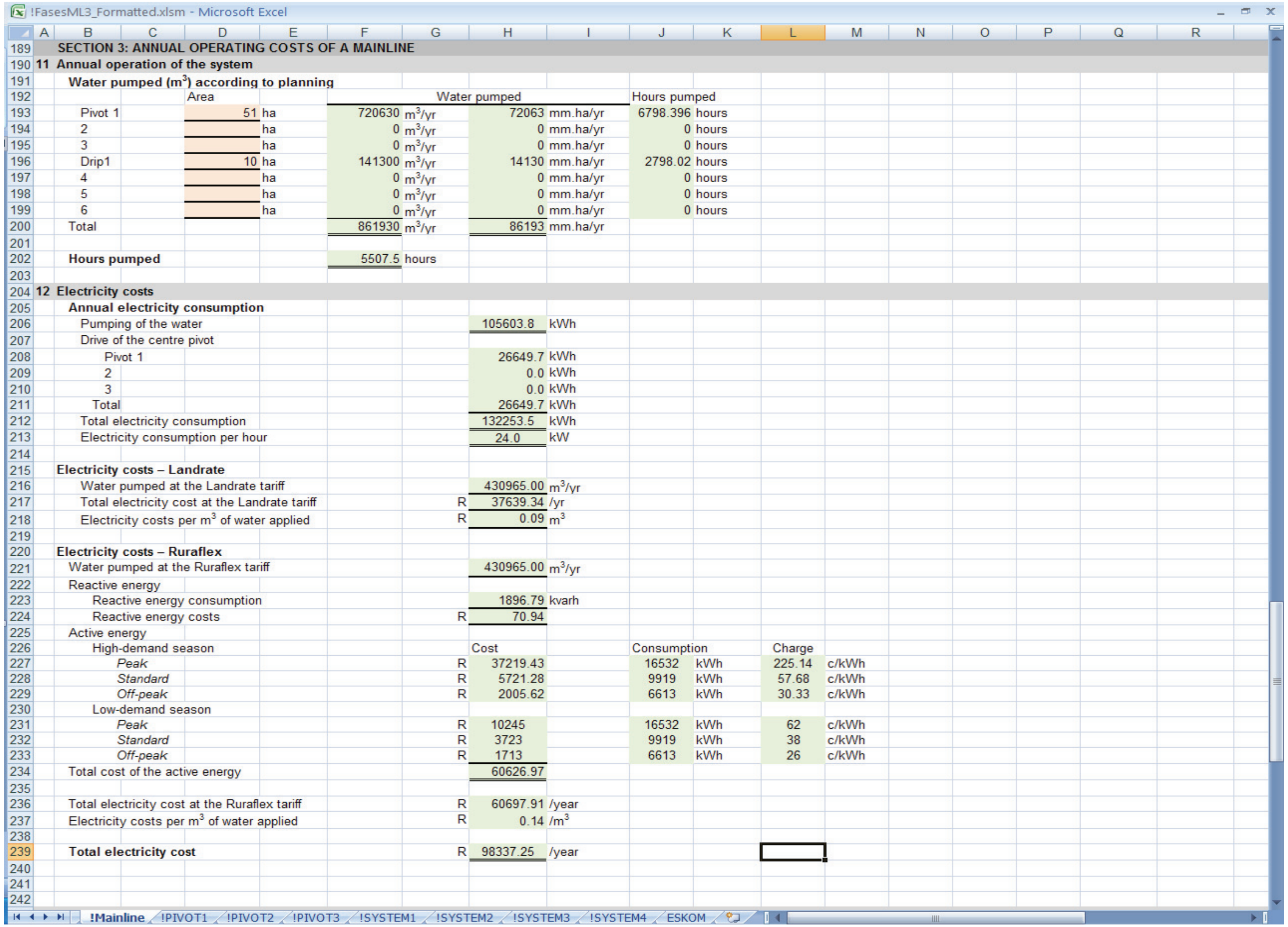


Figure 51: (Continued): Excel screen capture indicating general information required for the Mainline

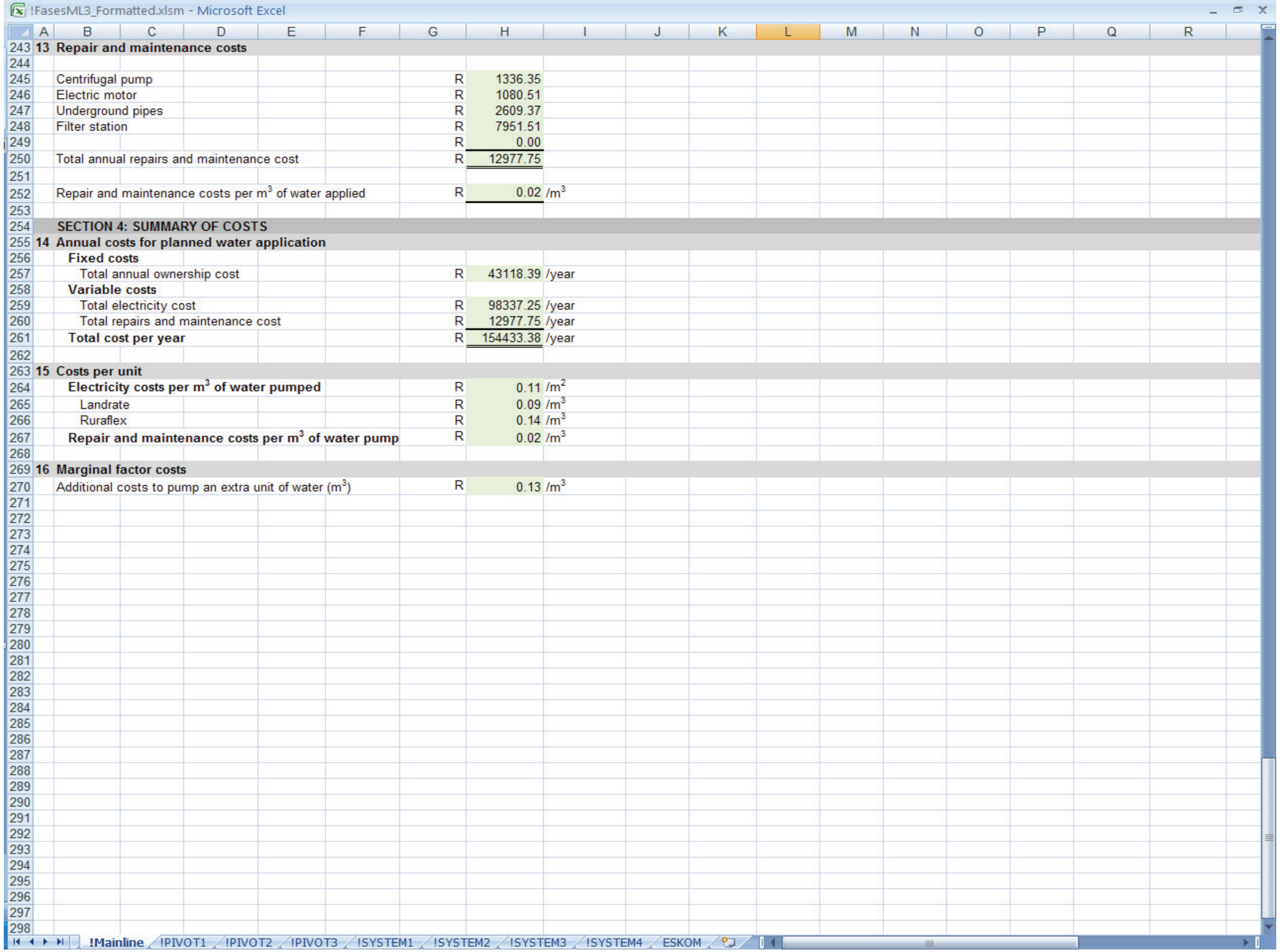


!FasesML3_Formatted.xlsm - Microsoft Excel

	A–C	D	E	F	G	H	I	J	K	L	M
189	**SECTION 3: ANNUAL OPERATING COSTS OF A MAINLINE**										
190	**11 Annual operation of the system**										
191	**Water pumped (m^3) according to planning**										
192		Area			Water pumped			Hours pumped			
193	Pivot 1	51	ha	720630	m^3/yr	72063	mm.ha/yr	6798.396	hours		
194	2		ha	0	m^3/yr	0	mm.ha/yr	0	hours		
195	3		ha	0	m^3/yr	0	mm.ha/yr	0	hours		
196	Drip1	10	ha	141300	m^3/yr	14130	mm.ha/yr	2798.02	hours		
197	4		ha	0	m^3/yr	0	mm.ha/yr	0	hours		
198	5		ha	0	m^3/yr	0	mm.ha/yr	0	hours		
199	6		ha	0	m^3/yr	0	mm.ha/yr	0	hours		
200	Total			861930	m^3/yr	86193	mm.ha/yr				
201											
202	**Hours pumped**			5507.5	hours						
203											
204	**12 Electricity costs**										
205	**Annual electricity consumption**										
206	Pumping of the water					105603.8	kWh				
207	Drive of the centre pivot										
208	Pivot 1					26649.7	kWh				
209	2					0.0	kWh				
210	3					0.0	kWh				
211	Total					26649.7	kWh				
212	Total electricity consumption					132253.5	kWh				
213	Electricity consumption per hour					24.0	kW				
214											
215	**Electricity costs – Landrate**										
216	Water pumped at the Landrate tariff					430965.00	m^3/yr				
217	Total electricity cost at the Landrate tariff				R	37639.34	/yr				
218	Electricity costs per m^3 of water applied				R	0.09	m^3				
219											
220	**Electricity costs – Ruraflex**										
221	Water pumped at the Ruraflex tariff					430965.00	m^3/yr				
222	Reactive energy										
223	Reactive energy consumption					1896.79	kvarh				
224	Reactive energy costs				R	70.94					
225	Active energy										
226	High-demand season					Cost		Consumption		Charge	
227	*Peak*				R	37219.43		16532	kWh	225.14	c/kWh
228	*Standard*				R	5721.28		9919	kWh	57.68	c/kWh
229	*Off-peak*				R	2005.62		6613	kWh	30.33	c/kWh
230	Low-demand season										
231	*Peak*				R	10245		16532	kWh	62	c/kWh
232	*Standard*				R	3723		9919	kWh	38	c/kWh
233	*Off-peak*				R	1713		6613	kWh	26	c/kWh
234	Total cost of the active energy					60626.97					
235											
236	Total electricity cost at the Ruraflex tariff				R	60697.91	/year				
237	Electricity costs per m^3 of water applied				R	0.14	/m^3				
238											
239	**Total electricity cost**				R	98337.25	/year				
240											
241											
242											

!Mainline / !PIVOT1 / !PIVOT2 / !PIVOT3 / !SYSTEM1 / !SYSTEM2 / !SYSTEM3 / !SYSTEM4 / ESKOM

Figure 51: (Continued): Excel screen capture indicating general information required for the Mainline



13	Repair and maintenance costs			
	Centrifugal pump	R	1336.35	
	Electric motor	R	1080.51	
	Underground pipes	R	2609.37	
	Filter station	R	7951.51	
		R	0.00	
	Total annual repairs and maintenance cost	R	12977.75	
	Repair and maintenance costs per m^3 of water applied	R	0.02	/m^3
	SECTION 4: SUMMARY OF COSTS			
14	Annual costs for planned water application			
	Fixed costs			
	Total annual ownership cost	R	43118.39	/year
	Variable costs			
	Total electricity cost	R	98337.25	/year
	Total repairs and maintenance cost	R	12977.75	/year
	Total cost per year	R	154433.38	/year
15	Costs per unit			
	Electricity costs per m^3 of water pumped	R	0.11	/m^2
	Landrate	R	0.09	/m^3
	Ruraflex	R	0.14	/m^3
	Repair and maintenance costs per m^3 of water pump	R	0.02	/m^3
16	Marginal factor costs			
	Additional costs to pump an extra unit of water (m^3)	R	0.13	/m^3

Figure 51: (Continued): Excel screen capture indicating general information required for the Mainline

7.2.2 Drip irrigation system

A separate sheet of information must be provided for each drip irrigation system on the mainline. Figure 50 shows the screen capture of the information required for a drip irrigation system, and the resulting output that is generated.

7.2.2.1 Section1: General information

Section 1 of the drip irrigation system sheet consists of information regarding the management of the irrigation system, properties of the system and information to calculate the total water charge, insurance, labour and repair and maintenance costs.

The vertical height of the drip irrigation system should be zero. The information required to calculate insurance and repair and maintenance follows the same format as for the mainline. The listed area together with the planned water use per hectare is used to work out the total planned amount of water that will be pumped. Thus it may differ from the area irrigated. The user is able to enter a schedule of water charges that might increase with increase water use.

7.2.2.2 Section 2: Investment and annual fixed costs

The same information that is required for the mainline with respect to investment cost, salvage value and expected life should be specified for each irrigation system.

7.2.2.3 Section 3: Annual operating cost of the drip irrigation system

Operating or variable costs are those costs over which the irrigator has control in the short term. The variable costs of the drip irrigation systems are based on the planned annual water application. All variable costs, namely electricity, water, labour and repairs should be estimated as a cost per cubic metre of water pumped.

No further inputs are required to calculate the annual operating cost of the drip irrigation system. In addition to the calculations done for the mainline, the cost calculations for the drip irrigation system also include the water charges. It is however important to note that the costs exclude the cost of pumping the water to the irrigation system.

7.2.2.4 Section 4: Summary of costs

The last section summarises the costs and calculates the marginal factor cost (additional cost to apply a unit of water) from which the next irrigation application on the total irrigated area can be estimated. This should be compared to the extra crop income as a result of the additional irrigation. Again, it should be remembered that the cost excludes the cost to pump the water.

7.2.3 ESKOM

The sheet named ESKOM is used to input the electricity costs of the electricity tariffs Landrate and Ruraflex. The information contained in the sheet is available from the official ESKOM website at: http://www.eskom.co.za/live/content.php?Category_ID=26

The sheet should be updated once a year.

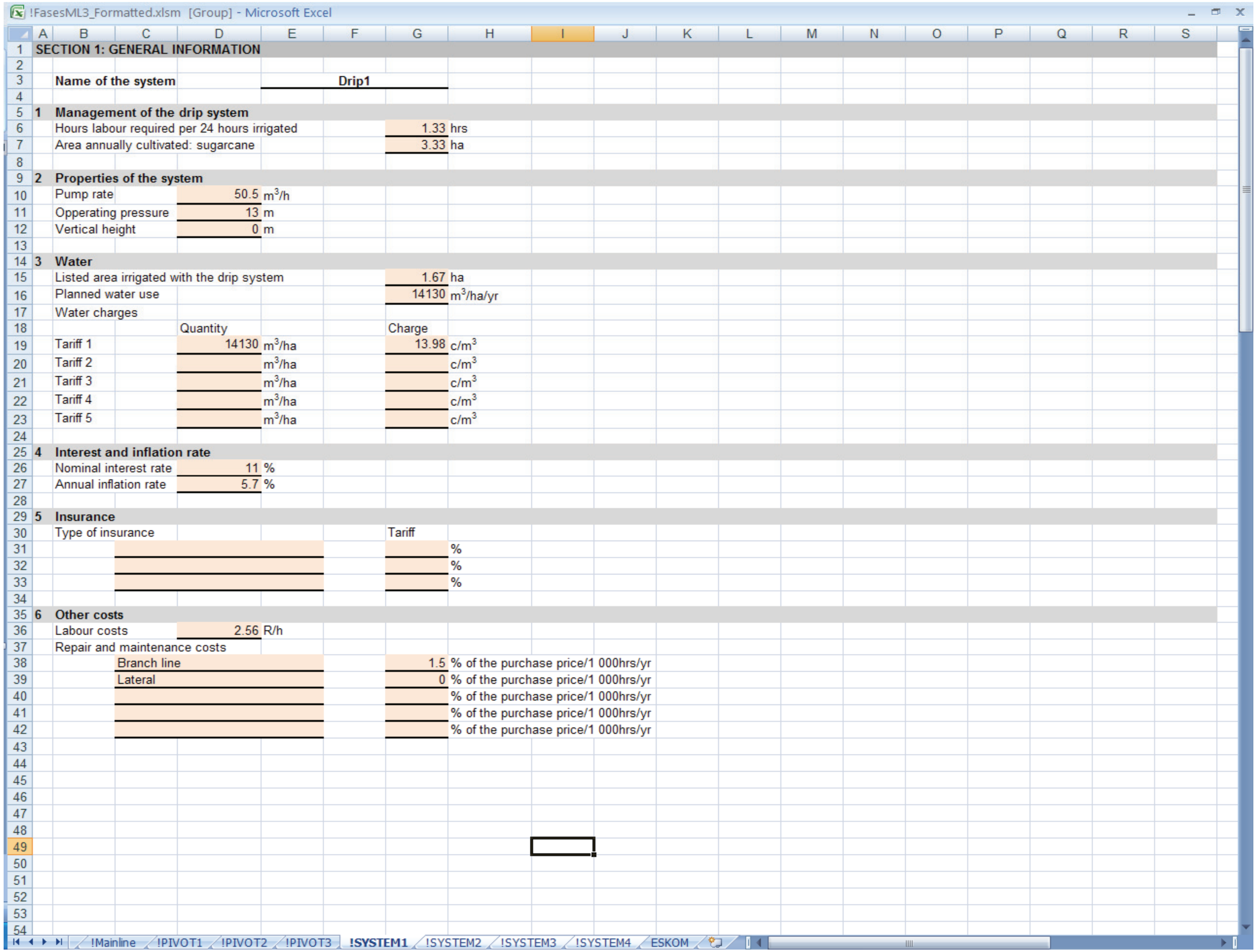


Figure 50: Excel screen capture indicating information required for the drip irrigation system

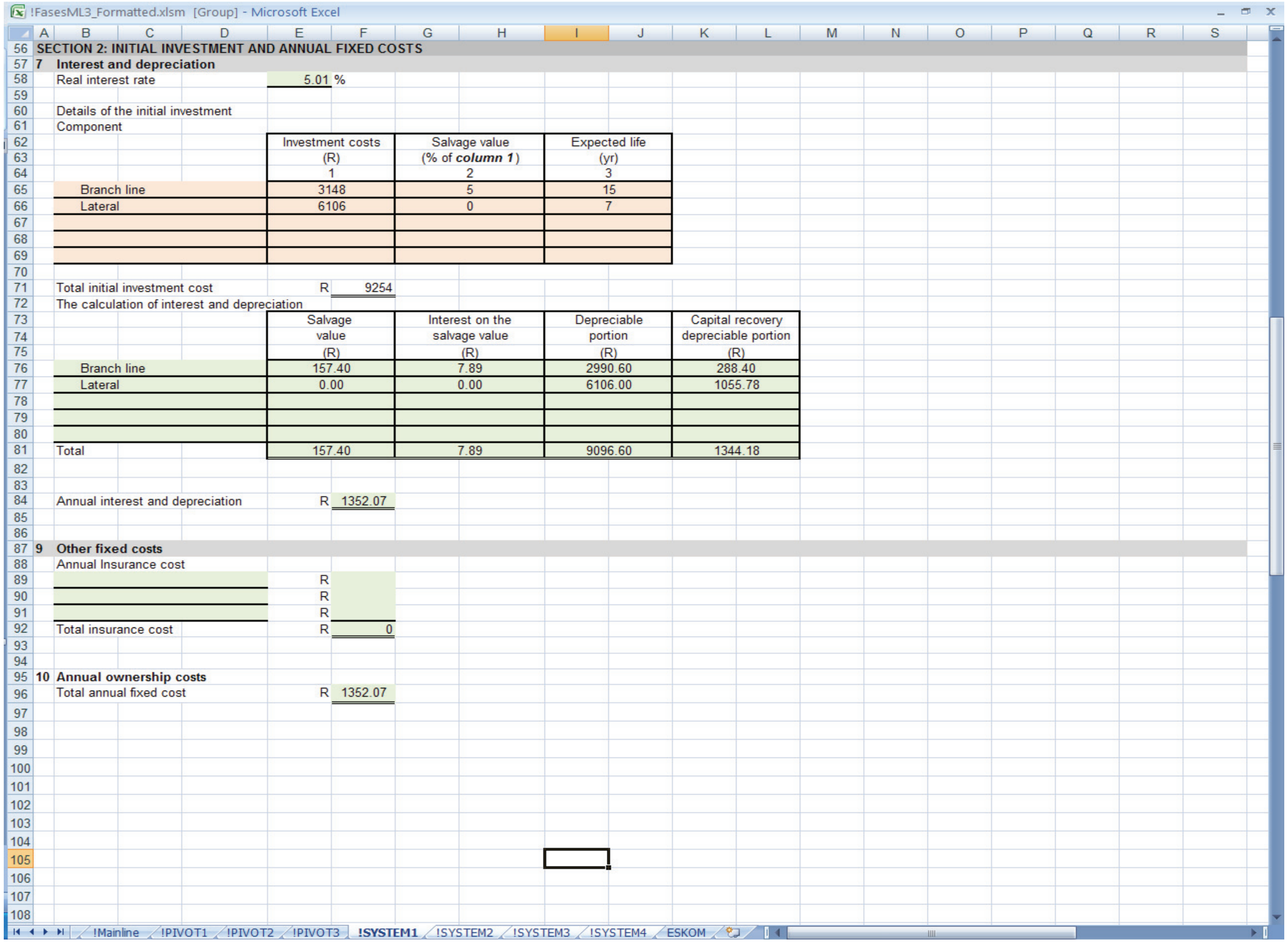
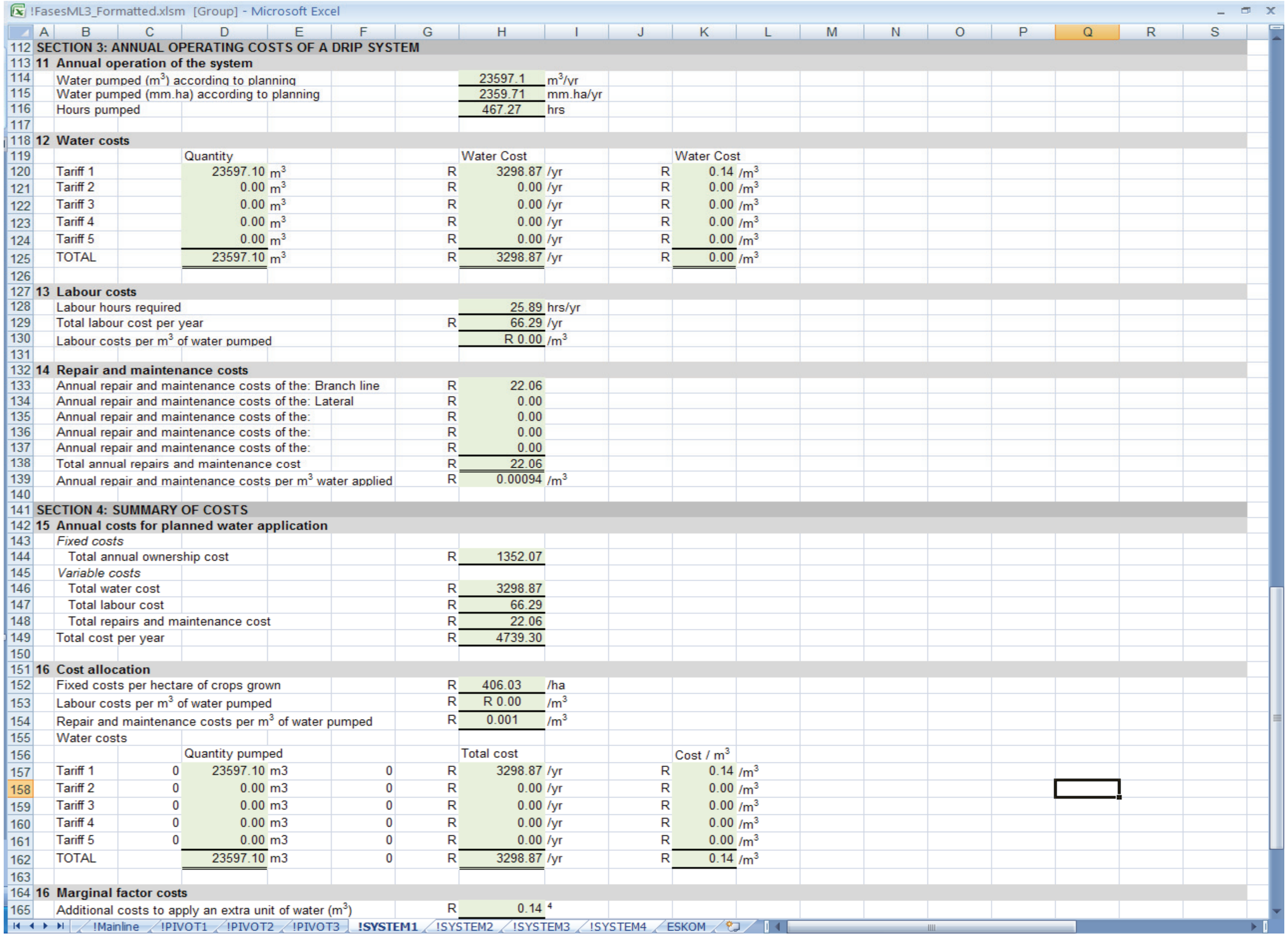


Figure 52: (Continued): Excel screen capture indicating information required for the drip irrigation system



		C	D	E	F	G	H	I	J	K	L
112	SECTION 3: ANNUAL OPERATING COSTS OF A DRIP SYSTEM										
113	11 Annual operation of the system										
114	Water pumped (m^3) according to planning						23597.1	m^3/yr			
115	Water pumped (mm.ha) according to planning						2359.71	mm.ha/yr			
116	Hours pumped						467.27	hrs			
117											
118	12 Water costs										
119			Quantity				Water Cost			Water Cost	
120	Tariff 1		23597.10	m^3		R	3298.87	/yr	R	0.14	/m^3
121	Tariff 2		0.00	m^3		R	0.00	/yr	R	0.00	/m^3
122	Tariff 3		0.00	m^3		R	0.00	/yr	R	0.00	/m^3
123	Tariff 4		0.00	m^3		R	0.00	/yr	R	0.00	/m^3
124	Tariff 5		0.00	m^3		R	0.00	/yr	R	0.00	/m^3
125	TOTAL		23597.10	m^3		R	3298.87	/yr	R	0.00	/m^3
126											
127	13 Labour costs										
128	Labour hours required						25.89	hrs/yr			
129	Total labour cost per year					R	66.29	/yr			
130	Labour costs per m^3 of water pumped						R 0.00	/m^3			
131											
132	14 Repair and maintenance costs										
133	Annual repair and maintenance costs of the: Branch line					R	22.06				
134	Annual repair and maintenance costs of the: Lateral					R	0.00				
135	Annual repair and maintenance costs of the:					R	0.00				
136	Annual repair and maintenance costs of the:					R	0.00				
137	Annual repair and maintenance costs of the:					R	0.00				
138	Total annual repairs and maintenance cost					R	22.06				
139	Annual repair and maintenance costs per m^3 water applied					R	0.00094	/m^3			
140											
141	SECTION 4: SUMMARY OF COSTS										
142	15 Annual costs for planned water application										
143	*Fixed costs*										
144	Total annual ownership cost					R	1352.07				
145	*Variable costs*										
146	Total water cost					R	3298.87				
147	Total labour cost					R	66.29				
148	Total repairs and maintenance cost					R	22.06				
149	Total cost per year					R	4739.30				
150											
151	16 Cost allocation										
152	Fixed costs per hectare of crops grown					R	406.03	/ha			
153	Labour costs per m^3 of water pumped					R	R 0.00	/m^3			
154	Repair and maintenance costs per m^3 of water pumped					R	0.001	/m^3			
155	Water costs										
156			Quantity pumped				Total cost			Cost / m^3	
157	Tariff 1	0	23597.10	m3	0	R	3298.87	/yr	R	0.14	/m^3
158	Tariff 2	0	0.00	m3	0	R	0.00	/yr	R	0.00	/m^3
159	Tariff 3	0	0.00	m3	0	R	0.00	/yr	R	0.00	/m^3
160	Tariff 4	0	0.00	m3	0	R	0.00	/yr	R	0.00	/m^3
161	Tariff 5	0	0.00	m3	0	R	0.00	/yr	R	0.00	/m^3
162	TOTAL		23597.10	m3	0	R	3298.87	/yr	R	0.14	/m^3
163											
164	16 Marginal factor costs										
165	Additional costs to apply an extra unit of water (m^3)					R	0.14				

Figure 52: (Continued): Excel screen capture indicating information required for the drip irrigation system

8 CONCLUSIONS

8.1 Technical aspects

Proper selection, planning, design, installation and maintenance of surface- and subsurface drip irrigation systems are of utmost importance for the successful long term operation of the system.

Water quality analysis must be carried out to identify the potential clogging problems due to water quality. This will assist with emitter type and filter selection and with developing proper preventative measures. The use of a root growth inhibitor is also of critical importance with a sub-surface drip system to prevent root intrusion.

It is important that a complete design report with details of the system's specifications, maintenance requirements and installation guidelines accompany all drip irrigation systems.

8.2 Cost procedures

Technical, economic and financial factors should be considered when choosing a drip irrigation system. Cost estimating procedures and models provide the necessary tools to give decision support to producers when changing from a present irrigation system to a drip irrigation system.

A distinction should be made between the mainline and the irrigation system, and care should be taken when combining the costs to represent the total irrigation costs of a specific irrigation system.

The profitability and financial feasibility analyses normally consider predefined crop mixes: in situations where the cash flow needs to be maximised other models and methods may be necessary. Only crop yields and prices are considered as a major source of risk and other sources of risk such as interest rate changes, etc. should also be considered.

9. ACKNOWLEDGEMENT AND REFERENCES

The information provided in this manual is a combination of published reports by the WRC and the ARC-IAE on drippers and filters (technical information and cost analysis). These organisations are duly acknowledged.

The following reports were analysed and information extracted:

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