SUB-SURFACE DRIP IRRIGATION: FACTORS AFFECTING THE EFFICIENCY AND MAINTENANCE

Project executed by the

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March 2005

Project number: **1189/1/05**
ISBN 1-77005-304-2

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INTRODUCTION

Drip irrigation is considered as the most efficient irrigation system, but there is proof from literature that this system can also be as in-efficient as any system, due to bad water quality, mismanagement and maintenance problems. Clogging of the emitters is one of the most serious problems associated with sub-surface drip irrigation and various approaches in preventing the clogging of emitters include filtration, flushing, chemical treatment of the irrigation water and chemical treatment of the soil surrounding the dripper lines, as well as the chemical treatment of the lateral polymers. Through this project, guidelines were developed to enable irrigators with sub-surface drip irrigation systems to apply good management and maintenance schedules to enable them to adhere to the conditions of the National Water Act regarding the efficient and beneficial use of water in the public interest.

OBJECTIVES

The National Water Act (Act 36 of 1998) makes provision for water to be protected, used, developed, conserved, managed and controlled in a sustainable and equitable manner to the benefit of all people in South Africa. Currently, sub-surface drip systems account for about 7 500 hectares of the total of 140 000 hectares of drip irrigation in South Africa. To assist the users to utilise their systems effectively, the research was carried out with the following objectives:

- Determine the blockage potential of different types of emitters under field, as well as laboratory conditions.
- Establish guidelines for the choice and management of sub-surface emitters, to prevent blockage and root intrusion.

METHODS

An extensive literature study on all facets that can influence the different types of emitters under field conditions was undertaken. Aspects that are addressed in this study include water quality, water treatment methods; inherent factors that effect emitter performance, filtering, system maintenance, system installation and design.

Three drip irrigation companies' drip irrigation equipment was used in the research project. The companies are Agriplas, Netafim and T-Tape. The performance of these new emitters, five models in total, was evaluated under controlled conditions in the hydro laboratory of the ARC-Institute for Agricultural Engineering.

With regard to the field evaluation, two areas in southern Africa were identified, namely the Mpumalanga Lowveld and Swaziland. In these areas, a total of five systems were identified. These systems' performance was evaluated in the field on one occasion and the farmers were contacted again after three years to obtain their experiences. Apart from the performance evaluations, data was also collected of the maintenance schedules. Water samples were taken for water quality analysis. Questionnaires, which were completed with the farmers, supplied most of the background information.

RESULTS

New emitters

The new regular emitters' coefficient of variation (CV_q) varied from an 2,1% to a 2,4% with an average of 2,2%. The pressure compensated emitters' average CV_q was 3,2%.

Experimental site

- Untreated blocks
  In the Treflan treated blocks, the emitters showed 74% less root intrusion than the untreated blocks. The untreated blocks were 29,3% root intruded against the 7,5% of treated block and there was also a significant increase of root intrusion of 505% over the 42 month period in the untreated blocks. The impact of the clogging in the untreated blocks was evident with the 16% decrease in emitter delivery rate and the worsening of the coefficient of variation (CV_q) from an excellent 3,04% to a very poor 56,36%. There was also an average 34% of the emitters that were not functional after the 42 month testing period.
- Treated blocks
  With the treated blocks, root intrusion could not be prevented completely and after the 42 month period, 16% drippers were not functional (that is, however, 27% better than the untreated blocks). The impact of the clogged drippers was that the CV dropped from an excellent 3,04% to a poor 32,30% which was still 43% better than the untreated blocks. However the average emitter delivery rate stayed fairly constant.

Conclusions and recommendations

Proper installation and maintenance are of utmost importance for the successful long-term operation of any sub-surface drip irrigation system.

It is recommended that water quality analysis be carried out to identify the potential clogging problems due to water quality. This will assist in emitter type and filter selection and to develop 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.

Details are given for solutions of specific clogging problems, choice and management of equipment, to help ensure effective water utilisation. Design principles, operation and maintenance information for best management practices, are recommended. The importance of a complete design report with details of the system's specifications, maintenance requirements and installation guidelines is emphasized.

No formal capacity building in terms of postgraduate students took place, but through the study the research team's knowledge was enhanced tremendously and a fair amount of capacity building within the industry and that of producers took place through interaction.

The following aspects need further attention:

- Technology transfer and training of irrigators with practical demonstrations.
- The compilation of a user's guide, which describes the complete development process of an irrigation system at farm level, as well as norms for minimum acceptable standards for irrigation equipment and services.
- A further investigation is recommended where the water treatment methods for water sources with a high clogging hazard are practically and experimentally tested.
- A user-friendly manual regarding the maintenance of sub-surface drip irrigation systems should be compiled for the use by irrigators.
- Development and refinement of the installation methods and equipment to ensure accurate placement of the laterals in the underground is recommended.
- The establishment of the causes in variation of emitter performance, between sub-surface and surface applications.
- Influence of different soil types and installation depths on emitter types.
- The influence of lateral flushing methods in terms of clogging, e.g. individual lateral flushing versus manifold based flushing.

ACKNOWLEDGEMENTS

The funding of this project by the Water Research Commission and the Department of Agriculture is sincerely appreciated. The members of the Steering Committee are thanked for their significant contributions towards this project. The Steering Committee comprised of the following members:

Dr A. Sanewe	:	Water Research Commission (Chairperson)
Dr SS Mkhize	:	Water Research Commission (Chairperson up to 28 May 2003)
Dr GR Backeberg	:	Water Research Commission
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Mr J Taljaard	:	JTPScc (Committee Secretary)

We also like to personally acknowledge all those who assisted in the project, including organisations and people over and above the steering committee members who have made major contributions:

- Senior management of ARC-Institute for Agricultural Engineering who was supportive throughout the project and ensured that the research team had the full backing of the engineering and administrative services of the Institute.
- The drip irrigation companies, Agriplas, Netafim and T-Tape for their support and willingness to participate in this research project.
- The farmers who gave their fullest co-operation.

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1. INTRODUCTION

Drip irrigation is considered as the most efficient irrigation system, but there is proof from literature that this system can also be as in-efficient as other systems, as a result of water quality, mismanagement, maintenance problems and root intrusion.

The technological development of irrigation equipment over the last number of years has been immense and the application or adaptation of equipment for use in other fields has been the case with sub-surface drip irrigation, where surface drip irrigation technology has found its way to be used in sub-surface applications.

1.1 Background

Irrigators in South Africa will in future have to utilise the available water resources more effectively in order to be sustainable, because of the potential water shortages that South Africa may have to face. Irrigation in South Africa has changed from exclusively flood irrigation systems to sprinkler systems, movable irrigation system, i.e. centre pivots, micro sprayer and drip systems and more recently, sub-surface drip irrigation systems. Sub-surface drip irrigation systems arrived on the irrigation scene in the last couple of years. Although many experts (locally and overseas) claim that the sub-surface drip system's irrigation efficiency is more than 30% higher than that of other systems, there are still many questions regarding these systems which have to be answered. The choice, maintenance and management of a sub-surface drip system are a few of them.

1.2 Objectives

The objectives of the project were:

- To determine the blockage potential of different types of emitters under field, as well as laboratory conditions.
- To establish guidelines for the choice and management of sub-surface emitters to prevent blockage and root penetration.

1.3 Description of the project

An extensive literature study on all the facets that can influence the performance of different types of emitters under field conditions was undertaken. Thereafter the evaluations and study followed.

The different emitters currently used in South Africa were identified and the suppliers thereof were contacted for their permission to use their equipment in the project. The equipment of those suppliers, who agreed on the use of their products, was bought. The necessary technical information regarding the specific emitters was obtained and extensive laboratory tests were conducted. Before the installation of the equipment took place at the test site at the Agricultural Research Council's Institute for Agricultural Engineering (ARC-IAE) at Weavind Park, Pretoria, a field visit was undertaken to the Free State where a number of sites where sub-surface irrigation is used. A number of installed sub-surface systems were visited and evaluated in the Mpumalanga Lowveld and Swaziland areas.

A statistical based design and layout of 40 blocks with the five dripper types were installed sub-surface at the ARC-IAE site for evaluation under field conditions. The design and layout of the system was done on a statistical based norm. From these irrigation blocks, laterals were removed on a yearly basis for evaluation in the laboratories.

The emitter types that were used are denoted by zone numbers in the document and are listed in Table 20.

2. LITERATURE REVIEW: FACTORS WHICH INFLUENCE PERFORMANCE

The clogging of emitters is one of the most serious problems associated with the use of micro-irrigation or drip irrigation systems. Various approaches in preventing the clogging of emitters include filtration, flushing and chemical treatment of the irrigation water. The irrigation water quality determines the extent of clogging that will take place and the water treatment approach to be followed.

2.1 Water quality

Bucks *et al.* (1979) categorizes water quality 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 soils and fertilizer sources. Alkaline soils 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).

Bucks et al. (1979) compiled a water quality classification relative to its potential for drip emitter clogging. Table 1 illustrates the water classification**.**

Table 1: Water quality classification for drip irrigation blockages (Bucks et al. 1979)

Clogging factors	Hazard rating		
	Minor	**Moderate**	**Severe**
Physical (mg/ℓ)			
Suspended solids	<50	50 – 100	>100
Chemical (mg/ℓ)			
pH	<7,0	7,0 – 8,0	>8,0
Dissolved solids	<500	500 – 2 000	>2 000
Manganese	<0,1	0,1 – 1,5	>1,5
Total iron	<0,2	0,2 – 1,5	>1,5
Hydrogen sulphide	<0,2	0,2 – 2,0	>2,0
Biological (no./mℓ)			
Bacterial number	<10 000	10 000 – 50 000	>50 000

Total iron concentration needs to be measured at the water source with a portable kit as the dissolved iron can precipitate before the water sample reaches the laboratory (Nakayama and Bucks, 1986).

Eurodrip presented a water classification system, after Bucks *et al*. (1979), that rates water quality on a scale of one to ten and can be seen in Table 2. 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 2: 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.

2.1.1 Physical

The clogging of emitters often occurs as a result of sand, silt or some other suspended solid. The emitter passageway is the smallest diameter flow area that the irrigation water will flow through and will naturally be the area where clogging will occur. Clogging takes place despite the fact that suspended solids are smaller than the orifice. The suspended solids become jammed or stuck, forming a plug which prevents water from exiting the emitter. Organic matter or growth can bind or cement these particles together forming a resistant clogging (Rain Bird, 1990). The clogging of emitters usually starts with small traces of algae and microbe slime that cause agglomerations of suspended solids or bio-chemicals such as heavy metals and sulphides and is usually a slow process.

Irrigation water from surface sources is usually more heavily contaminated with suspended solids than water from sub-surface sources. The amount of sediment loads in surface water changes as the stream velocity varies. The nutrient flows into streams and dams resulting in the suspended solids being accompanied by algae or organic matter. Sub-surface water does not usually contain significant levels of suspended organic solids but may carry large amounts of sand and silts (Rain Bird, 1990).

Operating pressures and flows play a large role in clogging of drip systems. Operating systems at pressures lower than the specified operating pressures will result in reduced flow-rates that will cause increased settling of suspended solids and clogging. The effectiveness of line flushing is also reduced if the pressures within a system are lower than the designed levels. The low flows will ensure that there is an increased build-up of particles within the emitter body. Once the emitter becomes completely plugged, it is extremely difficult or even impossible to remove it (Rain Bird, 1990).

Another physical factor causing emitter clogging is the presence of microscopic to sand-size plastic materials that originate from the sawing of pipes during system installation, modification or repair

(Nakayama and Bucks, 1991). A sharp knife should be used in order to prevent such clogging. Oil and grease were also identified by Nakayama and Bucks (1991) as causing emitter clogging. Lubricant seals therefore need to be properly maintained.

2.1.2 **Chemical**

Emitter clogging due to water chemistry is mostly the result of chemical reactions forming precipitates in the water. The precipitates are formed from dissolved ions, the level of which indicates the salinity of the water, which interact with each other and promote slime growth as well (Nakayama and Bucks, 1986). When chemicals such as fertilizers and soil conditioners are added to the irrigation water, the chemical characteristics of the water changes and precipitates may form which could lead to the clogging of emitters (Thornton, 1981). Some of the more common precipitates that cause clogging in emitters include calcium and magnesium carbonate, iron and magnesium sulphide, and iron and magnesium oxides (Rain Bird, 1990).

Heavy metals such as dissolved iron are formed by iron-reducing bacteria attacking metal parts in the irrigation system. Bacteria contamination control needs to be used in such cases or the metal parts should be replaced by plastic.

If calcium and magnesium concentrations exceed 50 ppm, sedimentation of these elements will occur. If pH is higher than 7,5 (hard water) sedimentation of calcium and magnesium will occur in the laterals and result in clogging even when concentrations are 20 – 30 ppm (Eurodrip, 1999).

Fertilizer formulations with acidified forms of nitrogen and phosphorous (urea-sulphate and urea-phosphate) should be used to reduce the precipitation tendency of these elements. Water with high concentrations of sulphide anions can cause iron precipitation. Iron and manganese sulphides are very insoluble even in acid solutions and may form a scale on the inside of the pipe which will promote clogging. The dissolved sulphide anion can also react with active chlorine when the water is chlorinated, thereby reducing the effectiveness of the chlorine. The chlorination requirement of such water is therefore higher than that of typical non-sulphide irrigation water (Nakayama and Bucks, 1991).

Carbonates

Some water sources like dolomite contains concentrations of calcium and magnesium carbonate and care should be taken regarding the potential clogging hazard of the water. The calcium or magnesium carbonate can precipitate in the system filters, pipelines or emitters when the source water has a pH value higher than 7,5 and a high degree of hardness (Nakayama and Bucks, 1986). Hardness is defined as the sum of calcium and magnesium concentrations, both expressed as calcium carbonate, in milligrams per litre. The problem with precipitates is that they can form within the closed irrigation system thereby not being visible until flow reduction from the emitter is noticed. Calcium and magnesium carbonates can cause clogging of the filter if the sand grains become cemented together. Calcium carbonate ($CaCO_3$) is commonly known as lime or calcite.

Calcite formation is promoted by evaporation of the water source, for example a dripper outlet, which converts calcium bicarbonate to calcite, carbon dioxide and water. The pH values higher than eight for the water source accelerate the formation of calcite (Rain Bird, 1990). The addition of certain fertilizers will cause the pH of the irrigation water to rise and this should be monitored. The addition of heat, via the sun, also accelerates calcium carbonate formation and sub-surface laterals will therefore tend to block slower than surface laterals. Any water containing dissolved carbon dioxide (CO_2) will form calcite due to a sudden drop in pressure, such as the back-flushing action of filters. Calcite will also form on the emitter outlet, if dissolved carbon dioxide is present, when the water becomes exposed to the atmosphere and the pressure drops (Rain Bird, 1990).

The calcite formation reaction (Rain Bird, 1990) is as follows:

$$\frac{Ca\,(HCO_3)^2}{\text{Calcium bicarbonate}} \xrightarrow{\text{drying}} \frac{CaCO_3}{\text{Calcite}} + \frac{CO_2}{\text{Carbon dioxide}} + \frac{H_20}{\text{Water}} \qquad (1)$$

Calcium and magnesium carbonates do not dissolve readily in natural water which makes preventative measures rather expensive, as chemical treatment is required. Calcium can also react with bicarbonate to form calcium bicarbonate ($Ca(HCO_3)_2$) which exists only in solution and is not as solid as sodium or potassium bicarbonate. Magnesium or calcium carbonates can be identified by applying dilute hydrochloric acid onto any white precipitates that may have formed on the external surface of the emitter. If the acid causes fizzing then one of the carbonates are present. Not all white precipitates are calcium or magnesium carbonates – neutral salts or fertilizer salts may be responsible for the precipitate (Rain Bird, 1990; Burt, 1999). A clean bottle can be filled with the potential irrigation water and ammonium hydroxide added to raise the pH to between 9,2 and 9,5. After 12 hours the sample should be shaken and allowed to stand for a short while to enable precipitate settling. A light beam should then be directed at the bottom of the bottle in a dark room and the calcium carbonate will be visible in the form of white to reddish sparkling particles (Nakayama and Bucks, 1986). The Langelier Saturation index (LI) will provide the likelihood of calcium carbonate scaling taking place and should be calculated when one determines the quality of the source water. The information needed for the LI is the total dissolved solids (TDS) (mg/ℓ), calcium (mg/ℓ), alkalinity concentration (mg/ℓ as $CaCO_3$), saturation pH, pH and temperature (Pitts, 1999a). Nakayama and Bucks (1986), present a revision of the LI calculation method including the effect of temperature in the calculation. This improves the accuracy of predicting the possibility of the formation of calcium carbonate in the irrigation water.

$$LI = pH_a - pH_s \qquad (2)$$

Where: LI = Langelier saturation index
pH_a = actual measured pH
pH_s = saturation pH.

and

$$pH_s = (pK_d - pK_s) + p[Ca] + p[HCO_3] + p(ACF) \qquad (3)$$

Where: p = the negative log of the value in parentheses
(pK_d-pK_s) = dissociation constant – solubility product (see Eq. 4 below)
[Ca] = calcium concentration (me/ℓ)
[HCO_3] = bicarbonate concentration (me/ℓ)
t = solution temperature (ºC).

$$pK_d - pK_s = 2{,}586 - 2{,}.621\times10^{-2}\,t + 1{,}.01\times10^{-4}\,t^2 \qquad (4)$$

and

$$p(ACF) = 7{,}79\times10^{-2} + 2{,}16\times10^{-2}\,TDS - 5{,}477\times10^{-4}\,TDS^2 + 5{,}323\times10^{-6}\,TDS^3 \qquad (5)$$

Where: p(ACF) = activity coefficient factor (me/ℓ)
TDS = total dissolved solids (me/ℓ).

The conversion factor for mg/ℓ (or ppm) to me/ℓ is shown in Eq. 6.

$$\text{me}/\ell = [\text{mg}/\ell]/[\text{atomic mass of ions}] \quad (6)$$

The above equations are by Nakayama and Bucks (1986). Newman (2000) suggests the use of the Standards Methods for the examination of Water and Wastewater (APHA), which can be seen in the following equations. This method uses TDS in the units mg/ℓ.

For TDS < 200 mg/ℓ:

$$pH_s = -0{,}014732 \times t + 2{,}30149 + 0{,}00065 \times TDS + 9{,}70167 - \log(2{,}4972 \times Ca) - \log(\text{alkalinity}) \quad (7)$$

For 200 < TDS < 300 mg/ℓ:

$$pH_s = -0{,}014732 \times t + 2{,}30149 + 9{,}84 - \log(2{,}4972 \times Ca) - \log(\text{alkalinity}) \quad (8)$$

For TDS > 300 mg/ℓ:

$$pH_s = -0{,}014732 \times t + 2{,}30149 + 0{,}00006786 \times TDS + 9{,}8336 - \log(2{,}4972 \times Ca) - \log(\text{alkalinity}) \quad (9)$$

Where: t = temperature (^{o}C)
TDS = total dissolved solids (mg/ℓ)
Ca = calcium concentration (mg/ℓ)
Alkalinity = total alkalinity (mg/ℓ).

LI of about one unit and more indicates that scale will form, while a LI of less than minus one unit will indicate scale dissolving with the possibility of corrosion. A LI of zero will indicate stability with regard to calcium carbonate precipitation (DWAF, 1996). Table 3 shows values of LI and the level of corrosivity associated with those values.

Table 3: Prediction of water characteristics by the Langelier Index (GCCC, 2000)

LI	Tendency of water
+2,0	Scale forming and for practical purposes, non-corrosive.
+0,5	Slightly scaling and non-corrosive.
0,0	Balanced, but pitting corrosion possible.
-0,5	Slightly corrosive and non-scale forming.
-2,0	Highly corrosive.

The Ryznar Stability Index (RSI) was developed to distinguish between two water sources having the same LI values, with the one having a low-hardness while the other has a high-hardness. The RSI multiplies the pH_s by two in order to accentuate the level of stability of the water in terms of scale formation. Eq. 10 and Eq. 11 shows how the RSI is calculated, while Table 4 illustrates the interpretation of the results.

$$RSI = 2 \times pH_s - pH_a \quad (10)$$

or

$$RSI = pH_a - 2 \times LI \tag{11}$$

Table 4: Prediction of water characteristics by the Ryznar Index (GCCC, 2000)

RSI	Tendency of water
4,0 – 5,0	Heavy scale.
5,0 – 6,0	Light scale.
6,0 – 7,0	Little scale or corrosion.
7,0 – 7,5	Corrosion significant.
7,5 – 9,0	Heavy corrosion.
>9,0	Corrosion intolerable.

Another definition used to identify the level of corrosivity of water is the Aggressiveness Index (AI). The AI is mostly used for calculating the corrosion potential in an asbestos pipe and is shown in Eq. 12. Table 5 shows the interpretation of the AI.

$$AI = pH + \log_{10}(A \times H) \tag{12}$$

Where: AI = aggressiveness index
A = total alkalinity (mg/ℓ $CaCO_3$)
H = calcium hardness (mg/ℓ $CaCO_3$).

Table 5: Interpretation of the AI (DWAF, 1996)

AI	Water property
≥12,0	Non-aggressive.
10,1 – 11,9	Moderately aggressive.
≤10,0	Highly aggressive.

All three of the above indices should be determined, if possible, as one value is insufficient to make decisions on water treatment.

Sulphides

Iron and manganese sulphides are another form of precipitates that cause emitter clogging, although iron sulphide clogging is more common. Sulphides are present as a result of the bacterial reduction of sulphate (SO_4) when no oxygen is available (Nakayama and Bucks, 1986). Manganese sulphide is already a toxic threat to the plant at the concentration required to cause clogging problems. It is difficult to remove iron and manganese sulphides once they have precipitated and prevention is recommended.

Concentrations of sulphides above 0,5 ppm will cause severe clogging problems. One of the sources of sulphides is iron from deep within the earth where there is little oxygen present. The iron and manganese sulphides from this type of water are oxidized when exposed to oxygen, and hydroxy oxides, which have a reddish brown colour, are formed. Iron sulphides' accumulation on pump casings in sub-surface water supplies will limit the flow from the source and may damage the irrigation system (Rain Bird, 1990). Iron sulphides may form on stainless steel filters where the sulphides' concentration in the water is high. Surface waters are usually not common sources for sulphides, however, the floors of dams are a potential site for sulphides formation due to bacteria converting sulphates to sulphides. The presence of hydrogen sulphides during chlorination will form a sulphur precipitation which may cause clogging problems.

Oxides

Iron oxides are again more common than manganese oxides and are found in two forms, namely ferrous oxide (Fe^{2+}) and ferric oxide (Fe^{3+}). Ferrous oxide is the reduced form and is the soluble form of iron oxide, providing ferric oxide upon oxidation. Ferric oxide, more commonly known as rust, is not soluble in water and can cause emitter clogging (Rain Bird, 1990). Iron deposits (ochre) are described by Bar (1999a) as being a filamentous amorphous gelatinous type of brown-reddish slime. Iron concentrations of as little as 0,1 ppm can cause emitter clogging and the precipitation of iron oxide seems to be more prevalent in systems that are not operating continuously. Bar (1999a) states that practically any water that contains concentrations higher than 0,5 ppm of iron cannot be used in drip systems unless they are treated chemically or otherwise. Sub-surface water is one of the possible sources for the formation of iron oxides. The water oxidises once it is removed from the aquifer and precipitates fall out of the solution. Stratification of a reservoir bed during summer months will provide an excess of dissolved iron and manganese in the irrigation water that will precipitate upon oxidation and may cause problems in emitter clogging (Thornton, 1981). Some fertilizers contain phosphoric acid, ortho-phosphates or various forms of calcium that may react with dissolved iron or manganese and cause oxide precipitates (Rain Bird, 1990). A check for iron and manganese oxide problems can be done by treating a water sample with chlorine at the same concentration that it is to be used in the irrigation system. The sample should be left overnight and inspected for sediments the next day (Rain Bird, 1990).

Another factor that oxidizes iron is the presence of iron bacteria such as *Gallionella*, *Leptothrix*, *Toxothrix*, *Crenothrix* and *Sphaerotilus* as well as certain non-filamentous aerobic slime bacteria of the genus *Pseudomonas* and *Enterobacter* (Nakayama and Bucks, 1986).

2.1.3 **Biological**

Sources of biological or organic contaminants include algae and aquatic plants and animals, bacterial slimes, oils and lubricants and fertilizers, herbicides, pesticides, plant growth regulators and other organic agrichemical compounds (Rain Bird, 1990). Most biological clogging occurs due to algae and bacteria that create slime which causes agglomerations of physical components in the irrigation water (Nakayama and Bucks, 1986 and 1991). Biological clogging is proliferent where organic sediments as well as iron or hydrogen sulphide are present in the source water. The essential ingredient is the level of organic carbon which is an energy source for the bacteria. Algae in surface water can add organic carbon to the irrigation system and carbonates and bicarbonates serve as inorganic energy sources for certain slime-forming autotrophic bacteria. Slime can grow on the walls of tubing and the combination of fertilizers with the heat created by the black tubing will further enhance the growth of slime. Attempts to quantify algae are of little use as their populations vary drastically throughout the irrigation season. The most damaging effect of algae is the formation of a gelatinous matrix in tubing and emitters that will serve as a base for bacterial slime growths. Surface waters also contain naturally occurring complexing agents, such as tannins, phenols and humic acids that complex ferrous iron, up to 2 mg/ℓ. The iron bacteria are then able to precipitate the soluble complexed iron. The bacteria are also able to precipitate ferrous iron that is complexed with polyphosphates and other chelating materials used for iron fertilisation (Nakayama and Bucks, 1986). Another biological factor is the presence of snails in the irrigation system. The mature snails as well as the larvae cause restrictions in the emitter flow paths as well as the larger diameter pipes. The larvae can pass through filters and eventually mature to cause problems in the drip system (Nakayama and Bucks, 1991).

One of the more common bacteria causing clogging is sulphide-oxidising bacteria which develop when oxygen and sulphide are both present in the water at the same time. Schischa *et al*., (1997) performed drip irrigation trials using reclaimed effluent from the Burgata reservoir in Israel with Naan and Netafim emitters and found that sulphide-oxidising bacteria were the main cause of emitter clogging. Schischa *et al*. (1997) found that lateral length did not have much of an effect on the percentage of clogged emitters, as a result of sulphur bacteria, when comparing 100, 200 and 400 m lengths. Clogging mainly occurred at the end of the dripper lines and the longer laterals were therefore an advantage over the shorter laterals.

Organic compounds or biological contamination may result in filter overloading, clogging of irrigation lines and emitters and may also serve as food sources for micro-organisms that will cause clogging problems once they grow larger.

Algae and aquatic plants and animals

Algae and aquatic plants and animals exist either as suspended sediment in the source water or as a result of microbial growth within the irrigation system. The aquatic plants and animals can be removed from the irrigation system by sufficient filtration, but algae have the ability to pass through the filters. Higher algae loads require a larger filtration capacity and frequency of back-flushing, the result of which is higher capital expenditure and operational costs. Algae also assist in the growth of micro-organisms as a source of organic carbon (Rain Bird, 1990).

Table 6: Algae that cause filter clogging (Eurodrip, 1999)

Name of group	Name of species	Size (Microns)	
		Single	Colonies
Diatoms	Cyclotella	11	11
	Cymbella	12	20
	Fragilaria	5 – 8	60 – 100
	Melosira	10	20
	Navicula	3 – 5	70 – 110
	Synedra	1 – 5	90 – 150
Chlorophyta	Spyrogyra	10 – 20	
	Mougeotia	6 – 20	
Chyanophyta	Oscilatoria	3 – 8	
Flagellate	Peridinium	42 – 52	44 – 52

Bacteria and bacterial slimes

Slime-forming bacteria are a significant factor causing clogging in drip systems. The "slime" acts as an adhesive material and binds together suspended sediments, such as iron, manganese and sulphides, forming large clusters of material which pose a threat to lateral lines and emitters. These bacterial slimes can grow at virtually any point within an irrigation system and are also responsible for oxidation which may cause iron to precipitate and result in emitter clogging. The different types of slime forming bacteria are numerous. Where fertilizers are applied through the irrigation system and the sun heats up the lateral lines, bacterial slime formation is greatly accelerated. When a drip system is switched off, the laterals flowing downhill, except those correctly designed with compensated non-leakage (CNL) emitters, will drain empty and set up a vacuum behind the water moving downhill. The vacuum will draw soil particles along with bacteria into the emitters. The bacteria may then form slime which will stick to soil particles and result in emitter clogging. The bacteria may also grow and multiply in the emitter if the nutrient supply is sufficient (Rain Bird, 1990). Bacteria grow best at temperatures between 20° and 30°C, although they can develop at lower temperatures. High bacterial counts reflect the presence of increased nutrients that can support algae and bacterial populations (Nakayama and Bucks, 1986).

The best way to control bacteria in an irrigation system is to prevent the entry of bacteria into the system. Vacuum relief valves in each block will assist in combating the effect of soil and water being drawn into the emitters. Vacuum relief valves also prevent sub mains from collapsing under the negative pressures.

2.1.4 Fertilizers

Applying fertilizers through an irrigation system will result in an increase in nutrients in the water which will increase algae or microbial populations as the nutrients are a food source. Backflow of fertilizer nutrients into the water source is another issue that needs to be addressed when designing fertigation systems, as the nutrients may contaminate the water source. To be able to determine a chemical precipitation problem, the irrigator needs to know the nutrient composition of various fertilizers. Clogging in drip systems can be a result of fertilizer nutrients mixing, as might be the case when more than one chemical is applied, and the chemicals must therefore be completely soluble and inactive with each other (Nakayama and Bucks, 1986).

A simple test to ascertain whether a fertilizer will cause problems in the source water is to add fertilizer to some of the water in a bottle, at the concentration that would be used during fertilization, and to see if any precipitates are formed at the bottom of the glass container (Nakayama and Bucks, 1986).

2.1.5 Oils and lubricants

Oils and lubricants are organic compounds that are potential sources of clogging in drip irrigation systems. Pump lubricants are one of the sources for lubricant contamination and the rate of lubrication will need to be adjusted to prevent any lubricants entering the irrigation system. Contaminated surface water is another source of oils and lubricants. The contamination may be a result of runoff from sources near to the irrigation water or due to direct disposal of the contaminant into the water. Surface skimmers should be used to remove the contaminants and the pump intake should be positioned at a sufficient depth below the surface. Sub-surface aquifers may contain natural oils and a flotation pond will be required to draw irrigation water from below the water surface.

If oils or lubricants have entered an irrigation system they will most probably be trapped in the filter system. Mesh filters can be removed and cleaned with the correct solvents while sand filters may require sand replacement. Oils can sometimes be removed from a filter and downstream piping by using a detergent or strong wetting agent (surfactant). These products may damage the irrigation system and the designer should be consulted prior to adding any detergents or solvents (Rain Bird, 1990).

2.2 Water treatment methods

Irrigation water quality varies from location to location and as a result each site may require a different type of water treatment in order to prevent emitter clogging (Nakayama and Bucks, 1991). 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 unclogged emitters and the clogged emitters are not cleared (Nakayama and Bucks, 1991). A solution to this problem is to provide higher pressures with chemical treatment, thereby forcing the chemicals into the blocked emitters. Prevention is by far better than cure as far as clogged emitters are concerned.

2.2.1 Chlorination

Chlorine is a strong oxidizer and is useful in achieving the following (Netafim, 1999):

- Preventing and killing the growth of organic slime, iron slime, sulphur slime.
- Oxidation of elements such as iron, sulphur, etc.

- Cleaning systems from organic sedimentation and bacterial slime.
- Improving filtration efficiency, especially sand filtration.

Prevention of iron and manganese oxides forming in an irrigation system is achieved by causing the metals to oxidize and precipitate before the water reaches the irrigation system (Thornton, 1981). This is usually performed in settling ponds which have to be routinely cleaned. Aeration is usually performed in the settling dams by spraying water into the air (paragraph 3.4.1). Irrigators may prefer to inject chlorine into the pressurised system after the pump and prior to the filter station. The chlorine reacts with soluble iron to form insoluble iron that is collected in the filter system. Sufficient turbulence is needed to mix the chlorine so that all soluble iron precipitates (Rain Bird, 1990). If precipitation occurs after (or downstream) of the filters, iron oxide will cause clogging in the emitters. Chlorination when soluble iron is high (>0,4 mg/ℓ) can result in excessive iron precipitation in the drip system. If this scenario exists, chlorination should be performed at a sufficient distance upstream of the filter station to allow the iron to precipitate before the filtration is performed (Nakayama and Bucks, 1991). Bar (1999a) used a hydrocyclone downstream of the chlorine injection point to ensure thorough mixing of the chlorine with the irrigation water. For every 1,0 part of iron in the irrigation water, 1,4 parts of chlorine needs to be added. The ppm or mg/ℓ iron concentration therefore needs to be multiplied by 1,4 to obtain the kg chlorine/1 000 m³ of water (Rain Bird, 1990). The pH range of the irrigation water is maintained in the acidic region during chlorination and this assists in controlling the formation of certain carbonate precipitates (Rain Bird, 1990). Clark (1999) mentions a case that he investigated where the iron concentration was 2 to 4 ppm for two different locations, and the pH values were 5,5 and 7. The pH value of 5,5 did not provide any iron precipitation problems while the pH of 7 did. By lowering the pH of the irrigation water, the iron is therefore kept in solution.

When chlorine is injected into water, the *free chlorine* is composed of two compounds*:*

Hypochlorous acid (HOCl) and hypochlorite (OCl^-). The reaction is shown below for chlorine gas:

$$\underset{\text{Chlorine}}{\underline{Cl_2}} + \underset{\text{Water}}{\underline{H_2O}} \longrightarrow \underset{\text{Hypochlorous Acid}}{\underline{HOC1}} + \underset{\text{Acid}}{\underline{H^+}} + \underset{\text{Chloride}}{\underline{C1^-}} \qquad (13)$$

The HOCI then exist in a pH-dependent equilibrium as follows:

$$\underset{\text{Hypochlorous Acid}}{\underline{HOC1}} \longleftrightarrow \underset{\text{Acid}}{\underline{H^+}} + \underset{\text{Hypochlorite}}{\underline{OC1^-}} \qquad (14)$$

HOCl is 40 to 80 times more efficient than OCl^- in combating bacteria and reducing free metals. HOCl is present for a pH less than 6, while for pH levels above 7,5, OCl^- will be the predominant form of chlorine (Bar, 1999a). If iron concentrations are between 2 and 4 ppm, liquid hypochlorite works best to precipitate the iron, between 4 and 7 ppm chlorine gas works well. At concentrations above 7 ppm, sedimentation and aeration might be the only efficient means of removing the ferrous iron.

Chemical water treatment, in combination with filtration, has become the most popular method of treating water for use in drip irrigation systems. Chlorination is the most widely used chemical treatment to control microbial populations (Nakayama and Bucks, 1991). Larval organisms, that can clog emitters and restrict water-flow when they mature, are effectively controlled with chlorination.

Using chlorine to combat bacteria in a drip system is the most cost-effective method. Chlorine will need to react with any iron, manganese, hydrogen sulphide or organic matter present in the irrigation water before any “free” chlorine is made available to combat the bacteria. Chlorination may be continuous, intermittent or of a high application rate (super chlorination). Free chlorine levels need to be tested at the furthest lateral end from the chlorine injection point, allowing sufficient time for the water to travel to that point. Usually a level of 1,0 ppm free chlorine will be sufficient to kill most bacteria and viruses (Rain Bird, 1990; Mead, 1999b). Gilbert *et al*. (1979) site numerous researchers who successfully controlled biological clogging with chlorine concentrations of 0,2 to 1,0 ppm on a continual basis, or daily slug dosages of 10 ppm. The injection point for chlorine should be as close to the treated system as possible, but at a sufficient distance prior to the filters to allow the precipitation of any metals to occur before the filtration process. Chlorination may be required to improve filtration which will need the injection point as close to the filters as possible, if this is the case the irrigator needs to ensure that precipitation of metals will not be a problem in the irrigation water. Treating the filters with chlorine requires a concentration between 1 – 2 ppm after the filters for continuous chlorination and three times that concentration for intermittent doses (Netafim, 1999).

Continuous chlorination is used where the precipitation of iron or manganese needs to be achieved prior to filtration, where organic load is high in the source water and where bacteria and algae need to be controlled. Continuous chlorination needs to be automated and applied at a free chlorine concentration of 0,5 to 1,0 ppm (Rain Bird, 1990). Eurodrip (1999) suggests that continuous chlorination be performed between 1 and 10 ppm at the system inlet. Table 7 shows the recommended chlorine concentrations as suggested by Eurodrip (1999), while Table 8 shows the concentrations suggested by Netafim (1999).

Table 7: Eurodrip (1999) recommendations for chlorination concentration

Purpose	Method of application	Location at which free chlorine is measured (mg/ℓ)		
		Head of system	After filtration	End of system
Prevention of algae growth	Continuous	1 – 10	1 – 10	0,5 – 1,0
Destruction of algae and bacterial build-up	Intermittent	10 – 20	10 – 20	0,5 – 1,0
Dissolving of organic matter	Hyper-chlorination	50 – 500	50 – 500	Approx. 10
Oxidation of iron	Continuous	0,6 mg/ℓ per 1 mg/ℓ of ferrous iron	1	0,5 – 1,0
Oxidation of manganese	Continuous	0,6 mg/ℓ per 1 mg/ℓ of manganese	1	0,5 – 1,0
Sulphur	Intermittent	0,6 mg/ℓ per 1 mg/ℓ of sulphur	1	0,5 – 1,0

Table 8: Recommendations for chlorination concentration (Netafim, 1999)

Chlorination objective	Application method	Required concentration (ppm)	
		System head	System end
Prevent sedimentation	Continuous	3 – 5	0,5 – 1
	Intermittent	10	1 – 2
System Cleaning	Continuous	5 – 10	>3
	Intermittent	15	>5

Intermittent chlorination needs to be applied at free chlorine concentration levels of 10 to 20 ppm for a period of 30 to 60 minutes. The frequency of chlorination will depend on the concentration stability of chlorine at the furthest lateral. Chlorination should be repeated when the concentration of free chlorine at the furthest lateral drops drastically. If little or no drop in free chlorine concentration occurs at the furthest lateral over a few days, the number of days between treatments should be increased (Rain Bird, 1990). Netafim (1999) suggests that intermittent chlorine is administered only after the system has been completely flushed from filters through to laterals. Netafim (1999) and Mead (1999b) suggest that the injection be performed in the beginning of the irrigation cycle over a period of 30 to 60 minutes with the system being flushed for an hour after the process has been completed. Super-chlorination may be applied at concentrations of between 200 to 500 ppm to remove organic clogging in emitters (Rain Bird, 1990). Nakayama and Bucks (1986) mention a concentration of 1 000 ppm for super-chlorination to control particulate slime clogging. The high concentration is allowed to remain in the system for up to 24 hours before the main line, sub mains and laterals need to be flushed, in that order. Totally blocked emitters will mostly not be reclaimed as the chlorine will not flow through the emitters. Iron bacteria growth in well casings may be controlled by super chlorination at 20 to 50 ppm by calculating the casing volume and supplying the correct amount of chlorine. The chlorine should remain in the system for 24 hours (Rain Bird, 1990).

Swimming pool test kits are available that will provide total or free chlorine levels in the water sample. The free chlorine test kit is the one that should be used and will normally provide a range of measuring free chlorine from 0 to 3,0 ppm. If higher concentrations are required, the following procedure should be used to determine a dilution factor. A hypodermic syringe can be used to accurately withdraw 1 mℓ of the water sample and add it to 9 cc of pure, distilled water. The total volume is now 10 cc and the chlorine concentration has been reduced to a tenth of the original value by diluting it with the distilled water. The dilution factor can be increased until the sample concentration falls into the range of the test kit. The concentration factor then needs to be multiplied by the dilution factor to obtain the actual concentration of the free chlorine in the original sample. Chlorine treatment becomes much more effective, up to 80 times higher, if it is performed in slightly acidic conditions. Irrigators are therefore urged to provide acid in conjunction with chlorine in order to save on chlorine costs (Rain Bird, 1990).

The three common sources of chlorine are calcium hypochlorite ($Ca(OCl)_2$), sodium hypochlorite (NaOCl) and chlorine gas (Cl_2). Calcium hypochlorite is available in a solid or powder form and its strength is around 65% to 70% of the pure elemental chlorine. Sodium hypochlorite concentration varies from 5 to 15% and is found in most household bleaches. Swimming pool suppliers and most commercial chemical supply companies will be able to supply the hypochlorite forms of chlorine. Chlorine gas is seen as being 100% pure and it, as well as the other chlorine sources, should be treated with extreme care. The irrigator should base the decision as to which form of chlorine to use on the amounts of chlorine needed, the application requirements (such as timing), cost and availability of chlorine, equipment requirements and the system operator's capability to safely handle the material (Rain Bird, 1990). Chlorine gas is the cheapest form of chlorine treatment and it has the added advantage of being able to acidify the irrigation water, thereby making the chlorination process more efficient, whereas other chlorine sources will tend to raise the pH and reduce chlorination efficiency (Nakayama and Bucks, 1986). Mead (1999a) states that chlorine gas is cheaper than chlorine liquid solutions as far as cost per unit is concerned. It is also dangerous to handle and needs to be treated with caution. Some people utilize 6% or 12% sodium hypochlorite (NaOCl) solutions and inject the solution into the system as if it were a pesticide or fertilizer, while others use chlorine tablets such as the ones used in swimming pools (Mead, 1999a). In some cases chlorine supply may be limited and the source of chlorine may have to be changed (Rain Bird, 1990). Liquid chlorine can be injected by most fertilizer injectors (Netafim, 1999). Table 9 shows the amount of the different chlorine sources needed to supply 500 g of chlorine.

Table 9: Comparison of chlorine supplying materials (Rain Bird, 1990)

Chlorine source	Amount needed to supply 500 g Cl_2	Amount needed per 1 000 m^3 water to give 1 ppm
Calcium hypochlorite		
65% chlorine	769 g	1 538 g
70% chlorine	714 g	1 429 g
Sodium hypochlorite		
5% chlorine	10 ℓ	20 ℓ
10% chlorine	5 ℓ	10 ℓ
15% chlorine	3,3 ℓ	6,67 ℓ
Chlorine gas	500 g	1 kg

Koegelenberg (1999) provides two equations: Eq. 15 and 16, for calculating the chlorine application rate for liquid and gas chlorine respectively.

$$IR = \frac{0,1 \times Q \times C}{P} \tag{15}$$

Where: IR = chlorine injection rate (ℓ/h)
Q = flow-rate of the system (m^3/h)
C = required application concentration (ppm)
P = percentage of active chlorine in solution (%).

$$IR = 0,024 \times Q \times C \tag{16}$$

Where: IR = chlorine injection rate (kg/day)
Q = flow-rate of the system (m^3/h)
C = required application concentration (ppm).

Liquid chlorine (sodium hypochlorite) should be stored in a clean tank without any remnants of fertilizer, and the tank should be painted white to prevent heat build-up. The in-field storage of liquid chlorine should not exceed 20 days. Chlorine gas should be stored and handled according to manufacturers' specifications (Netafim, 1999).

Some plants may be sensitive to high levels of chlorine and as a result another approach will have to be followed to solve the problem. Woody crops are sensitive to chlorine, such as citrus, avocado and berries and have a threshold of 300 ppm and if chlorination, irrigation and fertigation are done properly there should be no risk to the plants (Bar, 1999b). The concentration mentioned does not have any damaging effects on the crops. The soil acts as a de-activating material and protects the crop from any damage. Plant damage is usually a result of a high concentration of salts rather than the chlorine concentration (Nakayama and Bucks, 1991). Emitters have been designed and produced with self-flushing mechanisms to prevent cloggings. These mechanisms either have moving parts (manual or automatic) or flexible membranes that can be damaged at a high concentration level of chlorine (Schischa *et al.*, 1997). Silicone is used to prevent the membrane from being worn out (Nakayama and Bucks, 1991).

The ability of chlorine to react with iron and manganese and form a precipitate is not always to the irrigators' advantage. Thornton (1981) showed that, for a particular case study, chlorination in the irrigation system was causing the dissolved iron and manganese to precipitate in the irrigation system as there was not sufficient oxidation for the iron and manganese to precipitate before the irrigation water entered the system. The iron and manganese was a result of stratification in one of the storage reservoirs. Bar (1999a) reports on a 40 acre greenhouse drip irrigation scheme that was supplied by irrigation water containing up to 6 ppm of iron and was successfully operated for three years without any clogging of the emitters being reported. The drip system contained the following components for water treatment and filtration: gas chlorinator, hydro-cyclone, sand media filters and secondary disc filters. Bar (1999a) used the continuous injection of chlorine to precipitate the ferrous iron which was then caught in the sand media filters. Table 10 shows the concentrations of iron and chlorine within various parts of this irrigation system during an irrigation-chlorination cycle.

Table 10: Levels of free chlorine and iron in various positions of the system during an irrigation chlorination cycle (Bar, 1999a)

Minerals	Location			
	System head	After filtration	At emitter	Back-flush water
Iron (ppm)	3,5 – 6,0	3 – 5	3 – 5	30 – 45*
Chlorine (ppm)	10 – 15	2,0 – 2,5	0,4 – 0,5	0,4 – 0,5

*Estimated and calculated through dilution.

The small change in the iron concentration is as a result of the test kit measuring total iron concentration and not ferrous and ferric iron separately. The high chlorine consumption shows that most of the ferrous iron was converted to ferric. The free chlorine at the end of the system indicates that the oxidation process was brought to an end and the bacteria was inhibited by the presence of chlorine and iron slime was avoided.

2.2.2 **Acid treatment**

Water treatment using acids is an effective means of controlling carbonate precipitation in drip systems. The acid reacts with the bicarbonates in the water thereby reducing the concentration of bicarbonates and carbonates. Carbonate solubility in the water decreases with increasing temperature, and thus surface drip systems are therefore more prone to carbonate precipitation as opposed to sub-surface systems (Nakayama and Bucks, 1986). In some instances where the water source has low biological and suspended load levels, such as an underground water source, acid treatment alone may be sufficient to combat emitter clogging (Nakayama and Bucks, 1991). The most common acids used to prevent the formation of carbonate precipitates include hydrochloric acid, phosphoric acid and sulphuric acid (Rain Bird, 1990). The method of application for acids is usually a fertilizer injector, as long as the injector is resistant to the acid being utilised (Netafim, 1999).

The acid concentration in the irrigation water depends on the type of acid, its marketed concentration and its valence (Netafim, 1999). The recommended concentrations are shown in Table 11.

Table 11: Acid concentration in the irrigation water (Netafim, 1999)

Acid type	Acid percentage (%)	Recommended concentration in water (%)
Hydrochloric acid (HCI)	33 – 35	0,6
Phosphoric acid (H_3PO_4)	85	0,6
Nitric acid (HNO_3)	60	0,6
Sulphuric acid (H_sSO_4)	65	0,6

If the marked percentage of the acid is different, it should be corrected to the recommended concentration in the treated water. For example, if the acid is sulphuric acid 98%, the concentration in water should be 0,4%.

The hydrochloric acid adds chloride to the water and the irrigator should be careful not to increase the level of chlorides to toxic levels, as the crop will suffer. Padmakumari and Sivanappan (1985) treated irrigation water with hydrochloric acid at a 2% concentration and achieved an increase from 2,4 to 3,2 ℓ/h, equal to a 33% increase, on ten 1 mm diameter micro tube emitters. The same results will probably not be obtained with emitters, as their flow paths are generally a lot longer, smaller and tortuous.

Sulphuric acid has the fewest limitations to its use and is therefore the most commonly used acid. Sulphuric acid (H_2SO_4) as well as sulphurous acid (H_2SO_3) can be used to control the formation of carbonates. However, sulphurous acid should not be used where chlorination is required. The sulphurous acid reduces the effectiveness of chlorination. Sulphuric acid should therefore be used for pH control where chlorination is required (Rain Bird, 1990). The balanced chemical equation for sulphuric acid reacting with calcium and bicarbonate is given below. The calcium sulphate is more soluble than calcium carbonate.

$$Ca^{2+} + 2HCO_3^- + 2H^+ + SO_4^{2-} => Ca^{2+} + SO_4^{2-} + 2CO_2(g) + 2H_2O \qquad (17)$$

There are two methods of determining the amount of sulphuric acid that needs to be applied, namely, by evaluating the water analysis report and then calculating the amount of acid required or to perform a titration analysis. A water analysis will provide bicarbonate concentration in parts per million (ppm), milligrams per litre (mg/ℓ) or milli-equivalent per litre (me/ℓ). For each 50 ppm or mg/ℓ of bicarbonate, approximately 185 ℓ of sulphuric acid (95%) per 10 000 m³ of water passing through the irrigation system will be required to neutralise the bicarbonate. For each me/ℓ of bicarbonate in the water, approximately 153 ℓ per 10 000 m³ of sulphuric acid will be required. These values are estimates and should be treated with caution. A titration analysis is an easier method to determine the required treatment and the water analysis laboratory should be able to supply a titration curve run on the water to be used for irrigation. A quick conversion factor, when using ppm or mg/ℓ of bicarbonate per 10 000 m³, would be to multiply the bicarbonate concentration by 3,68 to get the amount of sulphuric acid (95%) required in litres. The me/ℓ factor is 152. When adding acid to the irrigation system, the irrigator should ensure that the pH never falls below six as this may result in permanent damage to components within the irrigation system. If the system is already plugged due to calcium carbonate, higher concentrations of sulphuric acid will have to be used, taking care not to reduce the pH of the water to below six (Rain Bird, 1990).

Phosphoric acid may react with some water sources and actually cause insoluble solids to form which may cause clogging of the emitters. Nutrient imbalance problems may also result from an excess of phosphate in the soil and the crop may suffer. Netafim (1999) suggests that phosphoric acid (75% – 85%) be used as a fertilizer through the drip system as a preventative measure against emitter clogging. The concentration of the acid in the irrigation system, as stipulated by Netafim (1999), should also be 0,6%. The injection time of the acid should be limited to 15 minutes once the irrigation system has reached maximum operating pressure. The amount of acid to apply, in volume, can then be calculated by dividing the acid injection rate (0,6% of system flow-rate) by four as 15 divides into 60 four times. Hard water with a very high pH may need the acid concentration in the irrigation system to be increased to 1% (Netafim, 1999).

Latymer (1999) mentions a case where bicarbonates were a problem in well-water from a 20 m depth. Nitric acid was used to bring the pH down to a value of 7,6. The nitric acid was injected at a 10% concentration and the carbonate clogging problems were solved.

Polyphosphates or polymaleic acid can be used at concentrations of around 2 to 5 ppm for every ppm of iron in the irrigation water (Prochaska, 2000). The polymaleic acid keeps iron in solution and prevents precipitants that could cause clogging problems. This approach is useful where chlorination is not possible, due to the sensitivity of the crop involved.

Hydrogen peroxide can be used where it is not possible to use chlorine, due to its pH sensitivity. The application should be done according to the recommendations.

2.2.3 Copper sulphate

Copper sulphate is inexpensive and has no effect on soluble iron and manganese. Copper can be toxic to crops, but at a concentration less than 0,75 mg/ℓ the crop should not suffer (Thornton, 1981). Eurodrip (1999) suggests a concentration of 2 ppm of copper sulphate to be used in reservoirs to control algae. It can be broadcast over the water surface or in buoys equipped with floats. Copper sulphate is administered to provide a concentration of between 0,05 to 2 ppm in the upper 1,8 m of the reservoir. The amount of copper sulphate required will vary depending on the type of algae present and an expert should be consulted to determine the correct concentration. The use of copper sulphate should be avoided if there are any aluminium pipes in the drip system.

2.2.4 Other treatments

An alternative treatment for heavy metals would be to use compounds that will inactivate the heavy metal cations and thereby prevent them from precipitating. Meyer *et al.*, 1991 preferred the homo-polymer maleic anhydride compound to complex calcium and magnesium cations so that the calcium and magnesium carbonates would not precipitate. Schwankl and Prichard (1990) added phosphonate, alkaline earth and heavy metal complexing agent. Calder (1988) used sodium silicate to prevent the soluble iron from precipitating. This treatment is limited to water with iron concentrations of less than 10 mg/ℓ and low in calcium and magnesium, as the high pH of the silicate solution would cause carbonate precipitation. Polyphosphates or polymaleic acid can be used at concentrations of around 2 ppm for every ppm of iron in the irrigation water. This chemical treatment may not be as successful with iron concentrations as high as 5 ppm and will be expensive (Pitts, 1999b).

There are various products available on the market that are a combination of chemicals which all aid in keeping irons from precipitating and causing emitter clogging. Most of these products lower the pH of the irrigation water to further prevent precipitates from forming.

Potassium permanganate is an option to precipitate iron out of solution (Bar, 1999b). The oxidation reaction for manganese is much slower than that for iron, and manganese is therefore extremely difficult to remove efficiently (Rain Bird, 1990). The use of advanced oxidation processes including ozone and peroxide to treat wastewaters has increased. Ozone is the most powerful oxidant that can be added in water treatment and has the ability to destroy bacteria, fungi and algae and will inactivate viruses as the strongest known viricide. Since odour and colour in water are most often caused by organic substances, these water pollutants are also effectively removed by ozone. Certain heavy metals in water, e.g. iron and manganese, are easily oxidized by ozone into insoluble compounds which can be deposited and removed from the water.

Bucks and Nakayama (1979) used a 20% ammonium nitrate solution in order to control calcium carbonate precipitation with high flow-rate (3,4 to 6,5 ℓ/h) on-line emitters and achieved fairly successful results as far as chemical clogging is concerned. Bucks and Nakayama (1979) injected all chemicals into the system prior to filtration in order to reduce bacterial growth within the screen and sand media filters. Care should be taken to ensure that these chemicals do not damage the filter system or cause corrosion.

2.2.5 Root intrusion prevention

One of the disadvantages that can be encountered when using a SDI system is potential rodent damage and potential root intrusion.

The prevention of potential root intrusion necessitates additional chemical treatment. This treatment can be done through either chemical injection into the irrigation water or the use of certain patented equipment where the root growth inhibitor is fused into the polymer of the dripper line.

2.2.5.1 **Treflan treatment**

The use of root growth inhibitors in the sub-surface drip irrigation (SDI) systems plays an important role in the prevention of root penetration into emitter orifices. With the treatment of the area in close proximity of the dripper outlet orifice, a buffer zone is created whereby root accumulation near the dripper orifice is prevented. The treatment of the soil with Treflan, in terms of the number of treatments per growing season, is dependent on the soil type, as well as the crop type grown. Treflan is basically a herbicide

Three known ways are used to apply Treflan to irrigated soils. The first is to apply Treflan through a chemical injection pump at the prescribed dosage and rate. The second is to use emitters which are manufactured of a plastic polymer, impregnated with slow release Treflan. This provides a continuous slow release process as water passes through it. The rate of release is dependant of the vapour back-pressure of the chemical, immediately adjacent to the emitter. This vapour back pressure “mechanism” reduces the amount of Treflan release into the soil and thereby increases the life of the needed protection.

The third method uses Treflan impregnated filter disks. With this “mechanism” Treflan is released from the disks, every time the system is operated.

2.2.5.2 **Other chemical anti-root intrusion treatments**

The introduction of Phosphorous (P), in the form of Phosphoric acid at a 15 ppm concentration, apparently reduced the problem of root plugging significantly. With limited available scientific data on the use of Phosphoric acid, it is not recommend using this method before verification. The cost of this option should also be evaluated.

Indications are that the use of chlorination or acids, as mentioned earlier, can also have an effect on the prevention of root intrusion of the emitters. The research done on these options, at this stage, does not conclusively give sound recommendations or data of application.

The application of copper sulphate (CuSO4) proved to prevent root growth in the “treated” root zones. Apparently the CuSO4 does not move quickly through the soil profile. The idea of creating a ring or barrier around the emitter area, which is composed of a CuSO4 precipitate, will prevent the growth/intrusion of roots into the area and thus the emitter orifice. This method has apparently also not been researched in to much detail yet.

2.2.6 **Safety precautions**

Any contact of acids with the skin may result in burns and contact with the eyes is extremely dangerous. Protective eyewear, in the form of goggles, needs to be used, as well as protective clothing and boots (Nakayama and Bucks, 1986; Netafim, 1999).

It should be noted that direct contact between chlorine and fertilizer would create a thermo-reaction which can be explosive. Contact of chlorine with fertilizer in the irrigation water after the chlorine has been injected is not hazardous (Netafim, 1999). However, if an acid comes into contact with any hypochlorite, chlorine gas and heat will be produced which will prove to be a hazardous situation (Nakayama and Bucks, 1986).

PVC and polyethylene tubes are resistant to acids and no precaution is needed at the concentrations required for drip systems. Aluminium, steel as well as asbestos-cement piping is easily damaged due to corrosion and as a result the system needs to be flushed for at least one hour after treatment with acid (Netafim, 1999). Acids and chlorine compounds should be stored separately in epoxy-coated plastic or fibreglass storage tanks (Nakayama and Bucks, 1986).

2.3 Inherent factors

Emitters are designed and manufactured for a specific discharge (delivery rate) of water flowing under pressure in the lateral. This pressure is reduced in the emitter and the water is delivered at the design discharge to the atmosphere or outside of lateral. To achieve this, the pressure in the lateral is dissipated (reduced) either by individual small-diameter orifices, a series of such orifices, vortex chambers, short tubes, long tubes, or tortuous flow paths. The inherent factors affecting the performance of emitters as established by a literature study is briefly discussed below.

2.3.1 Delivery rate (discharge) versus pressure relationship

The delivery rate of an emitter is given by the equation:

$$q_e = k\,P^x \qquad (18)$$

Where: q_e = emitter delivery rate (ℓh^{-1})
k = a constant, depending upon the units and flow path size
P = operating pressure (kPa)
x = emitter delivery rate exponent (dimensionless).

The effect of the emitter delivery rate exponent (x) on delivery rate for variation in operating pressure is illustrated in Figure 1.

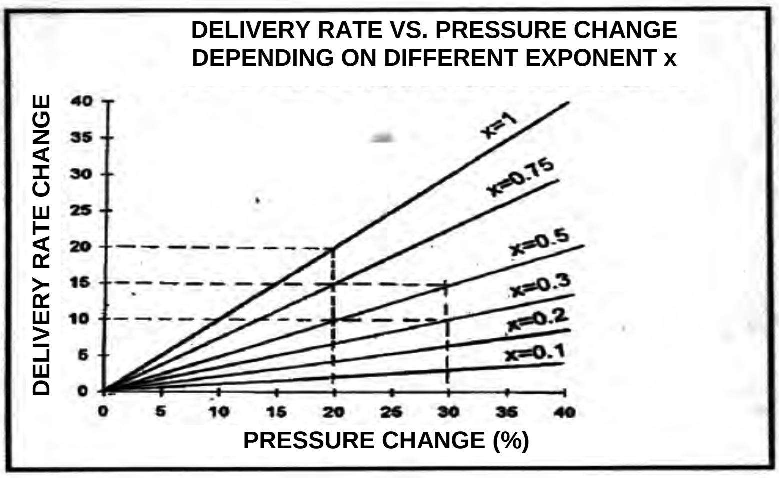


Figure 1: Delivery rate vs. pressure relationship for different exponent values (Burt and Styles, 1994)

The delivery rate of an emitter is proportional to the operating pressure raised to the power of the emitter delivery rate exponent value. This exponent is a measurement of the slope of the delivery rate-pressure curve. Low or high values of the emitter delivery rate exponent indicate respectively low or high sensitivity of emitter delivery rate to changes in operating pressure. The emitter delivery rate exponent value is of particular importance where significant variance in system pressure may occur due to undulating terrain or long laterals in the system.

The emitter delivery rate exponent value for laminar flow approaches a value of 1,0, which indicates that the delivery rate of laminar flow emitters is almost directly proportional to the pressure. The delivery rate of emitters with a tortuous flow path on the other hand varies with the square root of the pressure (emitter delivery rate exponent in the order of 0,5), indicating that these emitters are much less sensitive to pressure variation.

Pressure compensating emitters provide varying degrees of flow regulation with exponent values between 0,0 and 0,4. When the exponent values are between 0,2 and 0,35, considerable regulation is achieved, as a 50% head differential would only cause a 8 to 15% variation in delivery rate. Pressure compensating emitters all have a physical part that responds to pressure and their performance in the long term may not always be reliable.

2.3.2 Flow path type

Numerous flow path designs have been developed over the years. Some of these designs, with their respective merits and disadvantages, were described in "Drip and Micro Irrigation for Trees, Vines and Row Crops" by Charles M. Burt and Stuart W. Styles of the Irrigation Training and Research Centre of the California Polytechnic State University, (1994). These descriptions are reproduced in Table 12.

Table 12: Description, merits and disadvantages of various emitter flow paths (Burt and Styles, 1994)

Description		Merits	Disadvantages	Typical delivery rate exponent
Micro tube	Long small diameter spaghetti tube, laminar flow.	• Inexpensive	• Flow-rate sensitive to temperature. • Very sensitive to clogging. • Large manufacturing CV_q .	0,7 – 0,8
Long smooth flow path	Long, smooth spiral passageway in moulded emitter body. Laminar flow.		• Flow-rate sensitive to temperature. • Relatively sensitive to clogging.	0,7
Vortex	Water enters tangentially into chamber where it spins and then exits through a hole on the opposite side.	• Inexpensive • Flow-rate insensitive to temperature. • Low manufacturing CV_q	• Typically a small hole. • Relatively sensitive to clogging.	0,4
Tortuous	Labyrinth or zigzag path. Turbulent flow at some points in the passageway.	• Low manufacturing CV_q. • Typically a large hole. • Less susceptible to clogging than other emitters with the same hole size.		0,5 – 0,55
Porous pipe	Very small holes in the tubing itself, "sweat" or emit water.		• Flow-rate sensitive to temperature. • Typically a small hole. • Very sensitive to clogging. • Large manufacturing CV_q .	>1
Pressure compensating	Some type of flexible membrane. O-ring or other design is used to alter the path size or length at higher pressures. Quality is highly variable.	• Flow-rate insensitive to temperature. • Low manufacturing CV_q. • Typically a large hole. • Less susceptible to clogging than other emitters with the same hole size.	• Expensive • Relatively sensitive to clogging. • Large manufacturing CV with some models. • Delivery rate characteristics may change after a few years.	0 – 0,5
Multiple	Water passes through	• Typically a large hole.	• Expensive	0,7

Description		Merits	Disadvantages	Typical delivery rate exponent
flexible orifice	several orifices in flexible membranes. Dirt caught in one orifice will create backpressure, expanding the orifice and moving the dirt through.	• Less susceptible to clogging than other emitters with the same hole size.	• Delivery rate characteristics may change after a few years.	
Orifice	A single simple hole. Typical of micro sprayers.	• Inexpensive • Flow-rate insensitive to temperature. • Low manufacturing CV_q. • Typically a large hole. • Less susceptible to clogging than other emitters with the same hole size.		0,5

The properties of the more popular flow path types used in emitters are briefly described below.

Long flow path emitters

Most head loss occurs in the long flow path where the flow is laminar. The delivery rates of these emitters are determined by the following criteria:

- The delivery rate is directly proportional to the fourth power of the flow path diameter (for a circular cross section), and inversely to the length of the flow path. Relatively small flow path diameters and long flow path lengths are therefore required for low flows.
- For laminar flow the delivery rate is also directly proportional to the operating pressure, which makes emitters with laminar flow sensitive to pressure differences in the system.
- The kinematic viscosity of the water inversely affects the delivery rate, and the delivery rate of the emitter would therefore increase with rising water temperatures.
- For the same cross sectional area and length of flow path the delivery rate in an equilateral triangular cross section is higher than in a semicircular one. The delivery rate in a square cross section is higher than for other rectangular sections having the same cross sectional area and path length, but less than for a circular cross section.
- The spiral effects and other irregularities in emitters may create considerable turbulence, and the characteristics may therefore deviate considerably from that of pure laminar flow emitters.

Tortuous- and short flow path emitters

Tortuous-path emitters have relatively long flow paths. Pressure head is lost by a combination of wall friction, sharp bends, contractions and expansions.

- For equal operating pressures and delivery rates, the flow path is typically shorter and the cross section of the flow path larger for tortuous-path emitters than for emitters with laminar flow.
- Since the flow regime is almost fully turbulent, the delivery rate varies more closely to the square root of the operating pressure, and tortuous-path emitters are therefore less sensitive to pressure differences in the water supply system.
- The delivery rate is also nearly independent of the kinematic viscosity, and therefore of the water temperature.
- Short-path emitters generally behave like orifice emitters since the entrance characteristics (losses) dominate the flow regime in the short-tube section.

Orifice emitters

The class called orifice emitters includes many drip and spray emitters and also single-chamber line-source tubing. In a nozzle or orifice emitter, water flows through a small diameter opening or series of openings where most of the pressure head is lost.

- The flow regime is fully turbulent, and the delivery rate is proportional to the square root of the operating pressure, the cross sectional area of the orifice or nozzle, and the delivery rate coefficient of the particular orifice or nozzle.
- The delivery rate coefficient of a particular orifice or nozzle is close to 0,6 for a sharp orifice and approaches 1,0 for a tapered nozzle.
- The delivery rate is independent of changes in the kinematic viscosity due to temperature changes.

Pressure compensating emitters

Compensated emitters maintain the same flow-rate irrespective of the line pressure, as long as this pressure is above a minimum value, which varies between 50 a 100 kPa, depending on the type of emitter. This is achieved by making use of an elastic diaphragm inside the emitter that operates on a small v-groove. As the line pressure increases, the diaphragm is pressed into the groove which has the effect that the flow path area is reduced and therefore also the delivery rate of the emitter. The pressure head of the water is transferred to friction and velocity/turbulence of the water. Most of the compensated emitters work on this principal although they all apply it differently. Later models make use of an elastic diaphragm to open or close outlets on the turbulent flow path of the emitter, making it in effect shorter or longer and in this way the delivery rate is controlled. General characteristics of compensated emitters are:

- While the drip line pressure is building up when irrigation is started, the emitters go through a flush mode that flushes out particles that got stuck in the v-groove with the previous irrigation and cleans the emitter in this way.
- Some models can also do this cleaning while in operation.
- The diaphragms are heat and chemical resistant and durable in the long run.
- They have a wide pressure working range, ranging from a 100 to 400 kPa.

2.3.3 Manufacturing uniformity

Small manufacturing differences between emitters may cause significant variations in delivery rate. The critical dimensions of the emitter flow path are small and difficult to manufacture precisely, and very small variations in the flow path size, shape, and surface finish can result in relative large variation in delivery rate (discharge rate). Emitters with pressure compensating or self-flushing devices are particularly difficult to manufacture uniformly.

The coefficient of manufacturing variation (CV_q) is used as a measure of the anticipated variation in delivery rate for a sample of new emitters. The CV_q is a very useful parameter with rather consistent physical significance, because the delivery rate (discharge rate) for emitters, at a given pressure, is essentially normally distributed. The physical significance of CV_q is derived from the classic bell-shaped normal distribution curve shown in Figure 2.

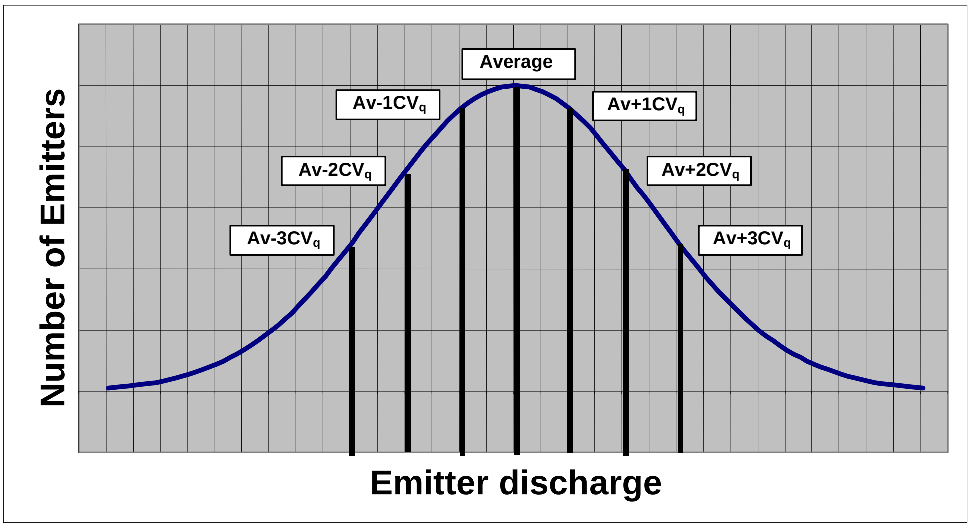


Figure 2: Normal distribution curve

In a normal distribution:

- Essentially all the observed discharge rates fall within (1±3CV_q) of the average discharge rate.
- Approximately 95% of the discharge rates fall within (1±2CV_q) of the average discharge rate.
- Approximately 68% of the discharge rates fall within (1±1CV_q) of the average discharge rate.
- The average of the lowest quarter of the discharge rates is approximately equal to (1 – 1,27 CV_q) of the average discharge rate.

2.3.4 **Sensitivity to clogging**

Not all emitter types are equally sensitive to clogging. This is clearly noticeable looking at the laboratory test results of the retrieved and tested sub-surface emitters. Some of the factors affecting the sensitivity to clogging are:

- Pressure Compensated emitters are less prone to clogging due to their self flushing qualities.
- The size of the turbulent flow path varies among emitters. The larger the flow path, the less prone to clogging.
- The position of the emitter inlet relative to the tubing wall varies with emitter types which have an influence on the sensitivity to clogging.
- High standards of quality control at the manufacturer ensure good uniformity in design specifications.

2.3.5 **Other factors influencing the performance**

- With the installation of SDI systems, special care must be taken to ensure that the lines are installed in a linier fashion and at uniform depth. This can be achieved by ensuring that field preparation, before installation, is done correctly.
- The type of soil, cultivar and root depths determine the linear and emitter spacing, depth at which the emitters are deployed and amount of water to be applied.
- The correct management of systems is important in respect of filter management, regular flushing of laterals and avoiding damage to the emitter lines when working with implements on the field.
- Water source and quality determines the type of filters and chemicals to be utilized for efficient system performance.

2.4 **Filtration**

Physical water treatment or filtration is used to remove suspended matter from the water supply prior to its use in an irrigation system. The physical quality of the water is therefore improved by the removal of harmful materials, such as sand, silt, clay and organic materials, where these occur both in quantity and concentration which could result in immediate or gradual clogging of emitters. The degree and type of filtration is determined by the type of irrigation system and emitter involved, as well as the physical quality of the water.

2.4.1 **Pre-filtering**

The pre-filtration methods of physical water treatment may include all or some of the following (Burt and Styles, 1994):

- **Settling and aeration**

  In cases where irrigation water has more solid matter in suspension than 200 ppm, it is advisable to allow the solid matter to settle in a dam, before it is filtered in the system. If the specific density of this material is very low, it may even be necessary to have it chemically flocculated before settling will be practically possible. Settling can prevent that filters are overloaded and excessively back-flushed.

  The settling dam provides an area for the mixing action and motion of the incoming water to be slowed down, thereby causing the coarse particles, such as sand and larger sizes of silt, to be removed from suspension (Rain Bird, 1990). Table 13 shows the sedimentation speed of different soil particle sizes.

Table 13: Sedimentation speed of soil particle sizes (Burt and Styles, 1994)

Soil texture	Soil size (mm)	Sedimentation speed (m/min)
Coarse sand	>0,500	38
Medium sand	0,250 – 0,500	22
Fine sand	0,100 – 0,250	5
Very fine sand	0,050 – 0,100	0,9
Silt	0,002 – 0,050	0,015
Clay	<0,002	0,0008

  Special treatments can also be used to induce the settling out of some types of clays, chemical components and organic matter. Some of the organic matter may form large accumulations, such as algae and leaves, and will float around on the surface of the pond. These impurities will have to be removed from the surface by using a skimming device. Algae can effectively be controlled by adding copper sulphate in bags equipped with floats, or by broadcasting it over the water surface (paragraph 2.2.3). Some applications to the design of basins include: the screening of intakes to prevent large debris from entering the pond two separate basins to allow the cleaning of one whilst the other basin is used for irrigation; and some basins may even have shaded covers to reduce the growth of algae and prevent any windblown debris from falling into the pond.

  Cleaning of sedimentation basins is achieved by draining the water and manually removing the debris from the floor. The frequency of cleaning is determined by the level of sediment in the pond. If incoming flow is not disturbed by the depth of the pond due to sediment accumulation, then no sedimentation will occur and the pond needs to be cleaned. Further signs that point to a fully loaded pond are: outflow water from the basin is noticeably dirty when viewed in a clear container; and the filter station becomes over-loaded and needs back-flushing too often and may become clogged.

The suction point for the water supply from the reservoir is another factor that influences the quality of the irrigation water. Generally, water from the reservoir floor will have a higher level of suspended sediment than water from levels closer to the surface. This depends highly on the reservoir shape and inlet point relative to the outlet point. The best shape of the reservoir is a long and narrow structure with the inlet and outlet points on opposite ends. The length of the reservoir will affect the settling of suspended solids and the dam should be sufficiently long to ensure that the water near the outlet has settled.

- **Sand separators**

Sand separators are installed to remove the sand from irrigation water by means of centrifugal action. Although there are advantages associated to installing the sand separator to the suction end of the pump, some features of such an installation must be carefully noted:

– The sand separator can protect the pump by removing sand, which can cause abrasion, from the water.
– Sand separators cannot remove all of the sand and they are not very effective if well sand comes in spurts, or during pump start up when large amounts of sand are delivered from a well. Therefore, for micro-irrigation systems, sand separators must always be followed by filtration.
– For effective performance of the sand separator, the flow-rate through the system must be kept relatively constant, which is seldom the case. The correct flow-rate corresponds to a pressure drop of 34 – 76 kPa. If the flow-rate drops too much, indicated by a pressure drop of less than 34 kPa across the device, there is insufficient centrifugal action to remove the solids (Burt and Styles, 1994).

Two types of sand separators are illustrated in Figure 3.

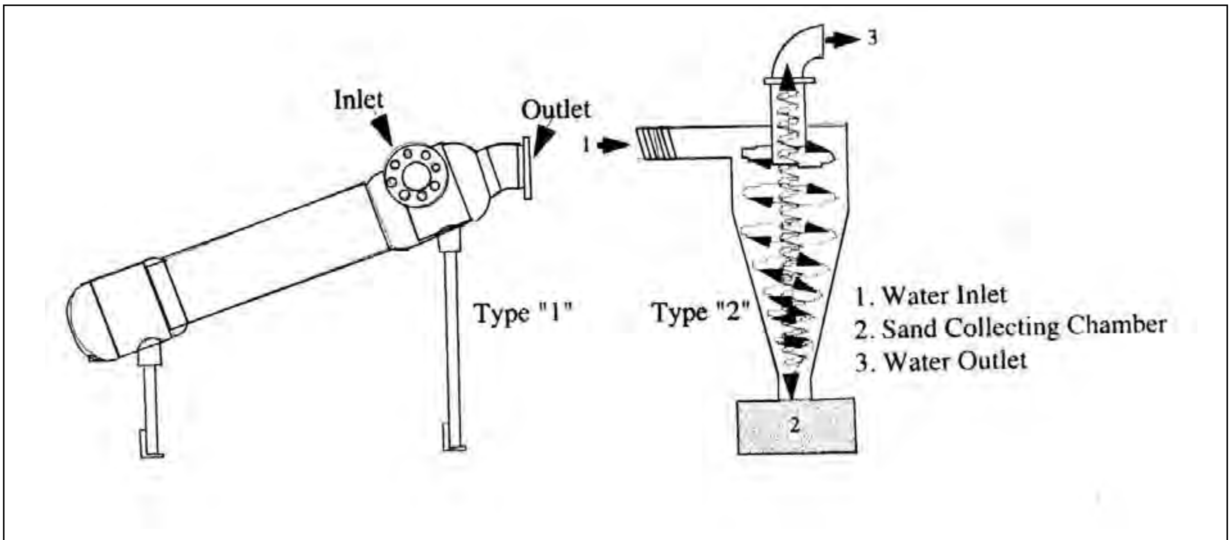


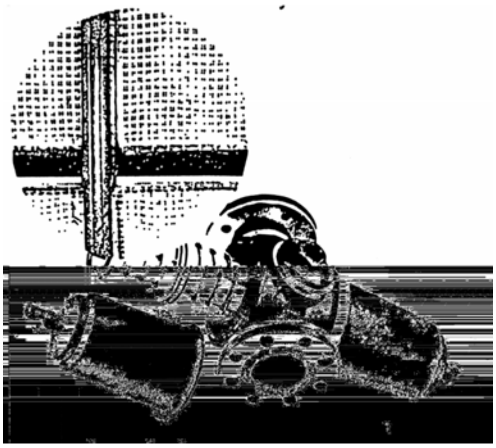
Figure 3: Two types of sand separators (Burt and Styles, 1994)

2.4.2 Filter types

The first attempts to treat irrigation water physically were performed by adapting screen or sand filters as well as centrifugal separators from other industrial applications. This was not always successful due to the flow-rate and suspended load of irrigation water. Presently, drip irrigation filter systems are designed to meet the needs of the irrigation system by using the correct combination of filters to effectively treat the water for physical impurities (Nakayama and Bucks, 1991).

- **Mesh filters**

Mesh filters (Figure 4) consist of a permeable membrane which is usually located inside a supportive cylindrical core. The mesh is usually manufactured from stainless steel or a nylon compound. The filtering qualities are determined by the size of the mesh openings, the total mesh area and the ability to clean the mesh during regular maintenance operations.



STANDARD FILTRATION GRADE

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 4: Mesh filters and mesh sizes (Burt and Styles, 1994)

The relationship between mesh and micron sizes can be interpreted with the following equation:

$$MG = 10187F^{-0,9327} \tag{19}$$

Where: MG = mesh size
F = micron size.

- **Disc filters**

Disc filters offer a three-dimensional filter action and therefore have much higher filter ability than a mesh filter of the same basic dimensions. The filter medium consists of a number of grooved circular plastic rings which are held in position tightly together in cylinder form. Water flows from the outside of the cylinder through the discs to the inside. All foreign materials larger than the permeable openings of the relevant grooves, is retained by the discs.

The debris is then removed from the discs by flushing with filtered water in an opposite direction through the discs. Some filters have the ability to loosen the discs from one another and even to let it rotate during the back-flushing action. The result is cleaner discs after back-flushing. Figure 5 illustrates the flow pattern through a typical disc filter.

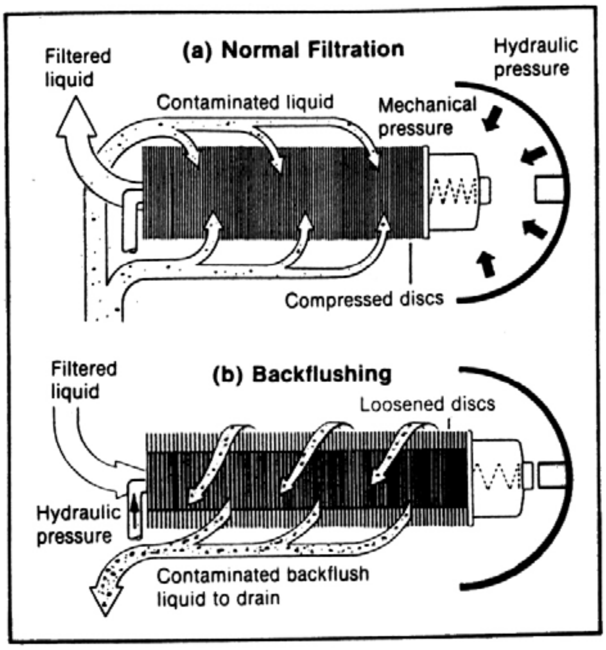


Figure 5: Filtering and back-flushing action with disc filters (Burt and Styles, 1994)

Any disc(s) that show signs of mechanical damage should be replaced. Discs, of which the channels have become chemically blocked, must be removed and chemically cleaned. If the discs cannot be cleaned effectively, they must be replaced. Always replace discs with the same colour and from the same manufacturer to ensure that the degree of filtering remains the same. It is recommended that the discs are removed from time to time and hand-cleaned.

- **Sand filters**

Sand media filters are the most useful method of filtration under a wide range of conditions. A sand media filter has the ability to remove sand, silt and organic material such as algae, weed seeds, and bacterial slime formations. Individual bacteria can, however, not be removed by sand filters. Since sand media filters are not easily plugged by algae, they can remove relatively large amounts of suspended solids before back-flushing is required. They can also, however, provide favourable conditions for increased bacterial growth (Nakayama and Bucks, 1986). Sand media filters use a bed of sharp-edge sand as a media for entrapment of the contaminants in the water (Rain Bird, 1990). Sand grains of various sizes and shape can be selected for use in sand media filters. The variety of sand sizes available for filtration provides the designer with the ability to filtrate to a particle size equal to those achieved with mesh and disc filters. When the sharp edges of the sand particles become round due to frictional wear, the effectiveness of the filter becomes reduced. Water passes through the sand, about 0,36 m deep, with a high velocity and solids become lodged in the sand while the water passes through it (Phillips, 1993). The size and shape of a sand filter plays an important role in the filtration efficiency. The most popular type of sand media filter is the cylindrical shape ranging in diameters from 0,6 to 1,2 m. The inside of the cylindrical tank contains sand up to a depth between 0,25 and 0,5 m which acts as the filtration medium. Sand filters are able to handle more contamination than screen filters, as particles are trapped to a depth of several centimetres in the sand.

The source water enters a sand media filter at the top and passes through the sand exiting the tank through a drain system in the bottom. The clean water then enters the irrigation system under pressure. The main purpose of the drain system is to prevent the sand media from entering the drain and thus the irrigation system. The range of flow through a sand filter should be from 36 to 72 m^3/hour per square metre of sand surface area. (Rain Bird, 1990). A general rule for all filters is that the filtration units should be designed/chosen to allow at least a 20% excess capacity when compared to the irrigation system peak demand requirements. This will influence the pump size and will allow sufficient pressure to facilitate back-flushing of filters and flushing of lateral lines (Nakayama and Bucks, 1986). Lategan (1999) suggests a flow-rate of 48 m³/hour per m² for sand filters that have 800 μm silica sand as a filtration media. Lategan (1999) states that the filtration efficiency will improve if the flow-rate through the filters is as low as possible. Lowering the filtration flow-rate is acceptable for normal filtration, but it should be remembered that back-flushing needs to be performed at the correct flow rate to ensure that the filter is cleaned sufficiently (Cilliers, 1997).

Cleaning a sand media filter involves reversing the flow direction of water in the filter. This requires the filter system to have at least two filters. One of the filters operates in the filter mode and provides water which is used to back-flush the other filter. The back-flush flow can be controlled by placing a restricting valve on a pipeline coming from the escape side of the back-flush system. The flow-rate should then be adjusted to ensure that the correct sand scrubbing action takes place and that no sand is lost from the filter (Rain Bird, 1990). A norm for the back-flushing flow-rate is 50% of the specified filtration flow-rate. The threshold back-flushing flow-rate is 1,25 times the filtration rate, at 1,5 times the filtration flow-rate back-flushing will cause the sand media to lift into suspension and be removed from the filter (Cilliers, 1997). The uniformity and density of the filters under drain assembly has to be sufficient to provide an even distribution of flow from below the media's surface to release the solids from the sand media more efficiently without channelling through the media (Bruce, 1985). Automatic back-flushing utilises hydraulic valves which work with hydraulic pressure to provide the energy necessary to control the valve. A solenoid valve is used to control the water under pressure and there are various methods of activating the solenoid valve. An electrical timer can be used, or a pressure differential switch which monitors the pressure differential over the filters can be installed. The best method is to use a pressure differential switch in combination with a timer. Each time the pressure differential switch is activated, the timer is reset and if the timer is activated before the preset pressure differential is reached, the filters will be back-flushed. This method of controlling filter flushing will ensure that compaction of the sand bed does not affect the filter operating efficiency. An important point to remember is that the back-flush flow-rate needs to be set correctly to ensure that none of the filter media is removed from the filter during back-flushing. The flow-rate can be adjusted by setting the back-flush restrictor valve. Back-flushing of sand media filters should as a general rule of thumb be performed once the pressure loss across the filters reaches between 35 and 70 kPa (Rain Bird, 1990). Eurodrip (1999) suggests that pressure loss can accumulate up to 100 kPa before back-flushing is required. Back-flushing duration may vary from less than one minute up to fifteen minutes per filter, depending on the quality of the water supply (Rain Bird, 1990). Visual inspection of the back-flushing water will show an initial portion of clean water that comes from the volume of water above the sand. The clean water will then be followed by dirty water and the back-flushing time will be determined by deciding when the water is sufficiently clean (Cilliers, 1997).

Cementing together of the sand media is as a result of bacteria, water chemistry and certain dissolved gases. The cementing may be caused by all or a combination of these factors. Cemented sand does not get broken up into particles and cleaned during the back-flush process. The combination of cemented and free sand in the filter bed results in channels being formed that will allow contaminated water to pass through the filter system into the irrigation system (Rain Bird, 1990). Injecting chlorine before the sand media filter will help prevent algae growth and subsequent problems in the sand media. A slimy mat may form in the upper layer of sand which will cause increases in head loss across the filters and cause a resultant waste of energy (Smith, 1999). Shock treatment of sand media filters is done by adding 6,3 ℓ of 12% chlorine per square metre of filtration area to each filter tank, ensuring that the field valve is closed so that no water will leak out. The tanks need to stand for 24 hours and the irrigator needs to beware of breathing in the chlorine fumes. The lids need to then be secured and the field valve opened. A flush cycle needs to be initiated (i.e. system operating as usual), with each filter being back-flushed for approximately three minutes. The full sequence (including chlorine application) needs to be repeated several times. One or two shock treatments should be sufficient to unplug an under drain that is contaminated with organics (Pierce and Mancuso, 1985). Removing the filter media from the tank and then replacing it, is an alternative to the chlorine shock treatment and is quicker, although the organics are not destroyed in this way.

Sand filters are operated together with secondary ring or mesh filters at all times. There are two reasons for this:

- The secondary filter serves as control for the operation of the filter under normal conditions. During incidental funnelling, the debris will move through the sand bed and will be intercepted by the secondary filter. This condition serves as a warning to the operator that maintenance on the sand filter is inevitable.
- If the sand filter becomes damaged internally, the filter sand will be intercepted by the secondary filter and will not land in the emitters.

The shape and function of typical sand filters are illustrated in Figure 6.

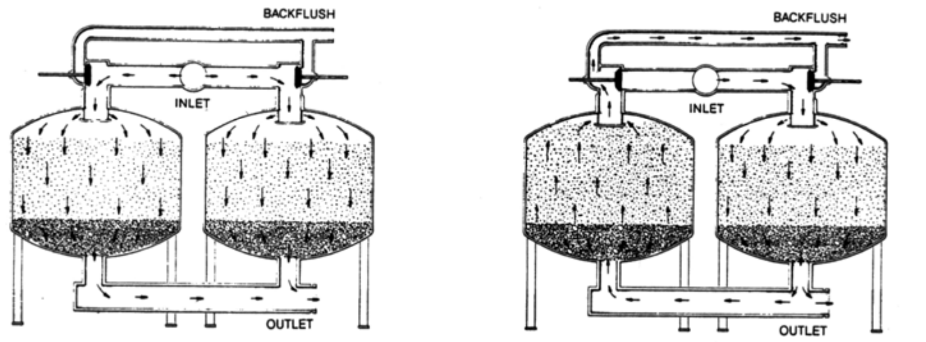


Figure 6: Filtering and back-flushing with sand filters (Burt and Styles, 1994)

2.4.3 Selection of filter

The type of filter to be used and the degree of filtration that the filter medium should handle depends largely on the system type and the degree of dirt in the water to be handled. As dripper clogging is difficult to perceive and emitters can only be repaired by means of replacement, a higher degree of filtration is required for drip irrigation in general. For drip irrigation with “normal” stored water or running water, it is recommended that sand filters, equipped with secondary filters, are used. Because mesh filters can basically not be back-flushed, disc filters are usually recommended for this purpose. In cases where irrigation is done with clean water, such as water from most boreholes, disc filters are usually sufficient. The filtration level will be sufficient enough and the only limitation will be length of the back-flush cycle.

2.4.4 Selection of filter size or filter capacity

The size and/or number of filters required for a system, depend on the following factors:

- The number of filters of a specific size required is a function of the total flow in the system and the maximum recommended flow through each filter.

- The maximum recommended flow is limited by the dirt present in the water.
- The minimum back-flush or cleaning cycle will limit the flow-rate.

Maximum flow-rate

The higher the flow-rate through the filter, the higher the pressure loss across the filter. This loss must be limited for physical and economic reasons. The following directives can be followed (Van Niekerk, 1983):

- For dirty water, a maximum loss of 10 kPa over a clean filter. This loss can be allowed to increase to a maximum of 50 kPa (30 kPa for sand filters) as a result of clogging of the element, but the actual amount that the loss can be allowed to increase with, will be determined by the hydraulics of the irrigation system. If the limit of 50 kPa is exceeded, it can lead to the drastic decrease in the efficiency of the filtration.
- For clean water (borehole water), a maximum loss of 30 kPa over a clean filter, still with the maximum limit of 50 kPa as a result of clogging of the element.

Dirtiness of the water

The largest quantity of debris collects on the outside of the element, or on top of the sand bed and very little collects inside the element itself. The thickness of the layer of dirt on the outside of the element, determines the additional friction loss or what the increase in friction loss over the filter is. The dirtiness of irrigation water is measured, for filtering purposes, with a special, though simple apparatus, called a dirtiness index meter (development of the ARC-Institute for Agricultural Engineering). The dirtiness index (DI) is measured and shown as a percentage.

The interpretation of dirtiness index is illustrated in Table 14:

Table 14: Classification of dirtiness index figures for irrigation water (Van Niekerk, 1983)

Dirtiness index (%)	Classification
<1	Clean
>1	Dirty
Approximately 5	Fairly dirty: Clogging of most filters within a few days.
Approximately 30	Very dirty: Clogging of most filters within a few hours.
Approximately 60	Extremely dirty: Clogging of most filters within a few minutes.

Back-flush cycle

During the filtering process, there is an increase in the total pressure drop over the filter as a result of clogging. The pressure loss over a typical filter is illustrated in Figure 7.

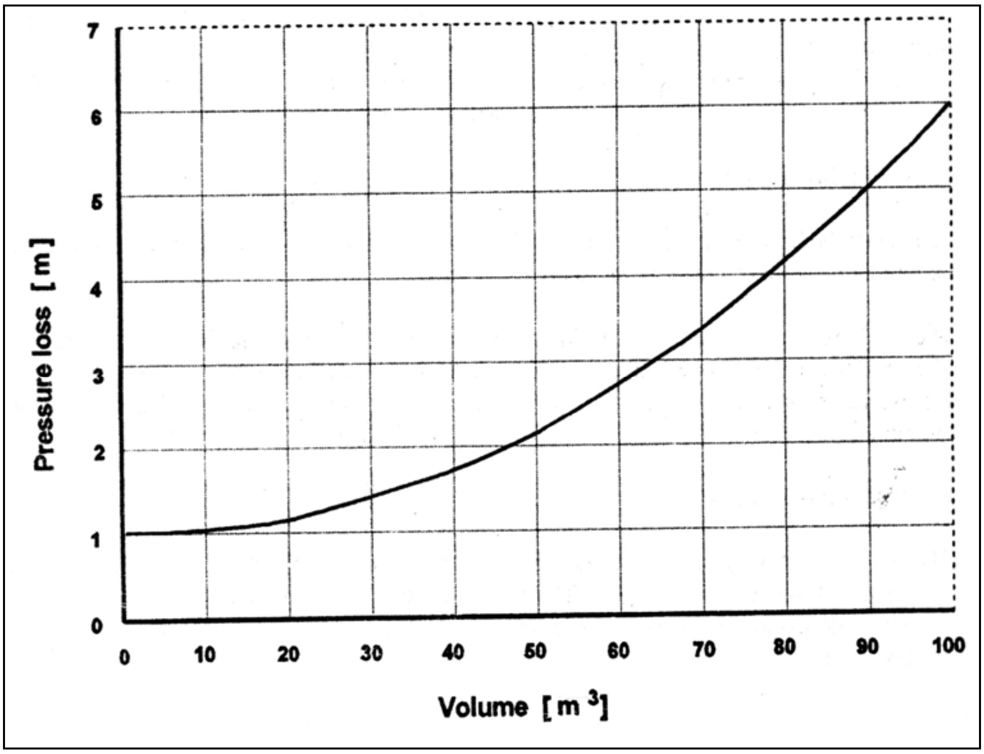


Figure 7: Typical clogging graph of a filter (Van Niekerk, 1983)

According to the results in the above graph, it is clear that an increase in the permitted pressure loss over a filter results in an increase in capacity (Van Niekerk, 1983):

- An increase of approximately 1,5 – 2,0 m can cause funnelling through filters, with resulting dirt penetration into the sandbed.
- With disc and mesh filters, excessive pressure drop can cause dirt to be pressed through the medium and can thereby decrease the efficiency.
- In some filters, especially mesh filters, which filtrate from the outside of the core to the inside, the entire element may collapse if the pressure drop is excessive. In such a case, a large concentration of dirt (that has built up on the element) can be released into the system, resulting in serious clogging of the emitters.
- Elements as well as sand that have lost its function as a result of excessive pressure losses are very difficult to clean and the back-flush efficiency decreases drastically.
- The back-flush cycle therefore depends entirely on the water quality. Impure water requires shorter back-flush cycles, or more and/or larger filters.

2.4.5 **Maintenance schedule of filters**

Effective filtration of irrigation water is of cardinal importance for the efficient performance of drip irrigation systems. Regular inspection is the key to success, and the maintenance schedule, as shown in Table 15 is recommended.

Table 15: Maintenance schedule for filters

Monitor	With each cycle	Weekly	Monthly	Bi-monthly	Quarterly
Leakages	✗				
Examine pressure loss over filters	✗				
Inspect sand level depth (± 350 mm)					✗
Inspect functioning of air valves on filter bank					✗
Service disc filter		✗			
Monitor duration of back-flush time				✗	
Evaluate water quality changes			✗		
Reset back-flush cycle if necessary			✗		

Lubricants must be used in filters where metal and rubber parts come into contact. High viscosity silicon products are the most suitable for this purpose. Pierce and Mancuso (1985) provide a trouble-shooting guide for sand filters which may be seen in Table 16.

Table 16: Troubleshooting guide for sand media filters (Pierce and Mancuso, 1985)

Probable cause	Solution
PROBLEM: POOR FILTRATION	
Probable cause	**Solution**
1. Excessive flow through filters causing coning and forcing contaminants through filter.	Reduce flow-rate or add filters.
2. Air in filters causing disruption of sand bed.	Install auto or manual air bleed device.
3. Incorrect sand medium.	Replace with proper media.
4. Excessive pressure forcing contaminants through filters.	Readjust back-flush control valve to proper setting.
5. Insufficient medium depth allowing contaminants to pass through.	Add medium to achieve depth between 31 and 33 cm.
PROBLEM: CONSISTENTLY HIGH PRESSURE DIFFERENTIAL	
Probable cause	**Solution**
6. Filter sealed over with contaminants restricting back-flush flow.	Open tanks and remove contaminants from medium surface, close tanks and back-flush until filters are clean.
7. Insufficient back-flush flow.	Re-adjust back-flush flow or partially close field valve.
8. Low filter sand medium causing inadequate back-flush.	Add medium to correct level.
PROBLEM: SAND MEDIA APPEARS DOWNSTREAM	
Probable cause	**Solution**
9. Incorrect medium, i.e. too fine.	Replace with proper medium.
10. Broken or damaged PVC lateral pipe.	Repair or replace.
PROBLEM: BACK-FLUSH VALVES LEAK	
Probable cause	**Solution**
11. Obstruction in valve seat.	Remove obstruction.
12. Rubber seating disc worn or damaged.	Replace seat disc.
13. Diaphragm damaged (leaking from port of diaphragm chamber at rear of valve).	Replace diaphragm.
14. Pinched or worn o-ring.	Replace o-ring and lubricate shaft.
PROBLEM: WATER HAMMER	
Probable cause	**Solution**
15. Air in tanks.	Bleed off trapped air. Check for leaks in pump suction line.
16. Long vacuum line causing vacuum.	Install vacuum breaker on back-flush line.
PROBLEM: INCREASING FREQUENCY OF BACK-FLUSH CYCLE	
Probable cause	**Solution**
17. Back-flush flow or duration is not adequate to remove all contaminants.	Readjust back-flush flow and/or increase duration of back-flush cycle.
18. Insufficient filter medium depth.	Add filter medium.
19. Increased concentration of contaminants in water supply (may be seasonal).	Add extra filter tanks or reduce flow-rate or increase back-flush duration and frequency.
PROBLEM: AUTOMATIC BACK-FLUSH FAILS TO CYCLE	
Probable cause	**Solution**
20. Controller power off, blown fuse or circuit breaker tripped.	Turn power on. Ensure wiring is connected. Reset circuit breaker or install new fuse.
21. Improper setting on differential pressure switch.	Inspect seal for signs of tampering.
22. Solenoid malfunctioning.	Check connections. Clean ports. Check filter screen on water pickup assembly for damage. Clean or replace screen.
23. Loss of sufficient system pressure to actuate valves.	Check system for pressure leaks. Check filter screen on water pickup assembly for damage.

2.5 System maintenance

Emitters are inclined to be extremely sensitive to particles which can cause clogging, because the flow path openings of the emitters are very small. It is recommended that irrigation water be analysed in a laboratory in order to quantify the potential clogging problems of the irrigation water (Table 14). Practices such as cleaning of storage dams and especially the flushing of filters and laterals must be done regularly.

2.5.1 Monitoring and inspection of system

SDI systems do not require a lot of time and energy when system is well planned beforehand, the field is well prepared and system installed correctly.

The following points need attention:

- Filter management.
- Regular flushing of laterals.
- Monitor leaks and pressure bursts.
- Monitor pressure at different points in the irrigation scheme and blocks.
- Monitor crop condition to determine clogged emitter positions.

2.5.2 Flushing of system

The flushing of lines is a very important maintenance measure which should be followed. For example, the entire system must be flushed after a break in the main line has been repaired. The main line should be flushed first, then the sub-main lines, the manifolds and then the laterals. Flushing valves should be connected to the ends of main lines, sub-main lines and manifolds to streamline the flushing process. The lines should be flushed one by one, with all the valves to other parts of the system closed. This will ensure that all debris that may occur in the lines and cause clogging will be flushed out.

2.5.3 Flushing of laterals

Although the filtration efficiency of most filters is very high, a certain percentage of particles in irrigation water will always go through the filter and cause clogging in emitters. Very fine particles will mostly remain in suspension and may possibly precipitate in places where the water velocity is low or if the turbulence decreases. The most likely place where precipitation will take place is at the end of the laterals. This will have the effect that these emitters will become clogged first. Although one single particle may not cause clogging, a number of particles may collect and cause the emitters to become clogged.

The easiest way of determining whether a line must be flushed is to examine the irrigation water in a glass container. Most particles that precipitate during the first minute will be sand. Clay on the other hand, will not flocculate, but will remain in suspension.

Laterals can be flushed one by one, by hand or automatically, with a flushing valve. The flushing valve would be installed on a flushing manifold, and not on each lateral. Laterals should, depending on the water quality, be flushed weekly. When regular flushing of the laterals is necessary, the use of a flushing valve on a flushing manifold is recommended. According to Keller and Bliesner (1990) a flushing of velocity of 0,3 m/s is recommended for the flushing of laterals. However, practical experience in South Africa and Israel revealed that a minimum velocity of 0,4 m/s ensures that fine particles are flushed out of laterals (T-Tape, 1998).

2.5.4 **Evaluation of the delivery rate (discharge rate) of emitters**

The continuous monitoring of the functioning of the emitters in an irrigation block is very important. The delivery rate is influenced by total/partial clogging or the physical deterioration of the dripper parts. Partial clogging is normally caused by the collection of sediments, deposits, organic particles or a combination of the before-mentioned factors. Physical deterioration can occur in pressure compensating emitters where the flow path may alter slowly as a result of changing, with time, of the pressure compensating part (diaphragm) of the dripper.

Before the evaluation of the irrigation system, the operating pressure at the valve of the relevant block must be monitored and reset if necessary. The irrigation block can then be evaluated.

Irrigators are recommended, with each irrigation, to walk through the irrigation block to observe if some areas in the irrigated field are drier than the surrounding areas, thus if plant in some spots are under water stress. Areas of excessive wetness, where water is ponding on the soil surface can also indicate a malfunctioning dripper(s). To clean the clogged emitters and repair leakages, the particular emitters should be opened up for inspection and fixing/replacement. Replace emitters with the same make and type if replacement is necessary.

The evaluation must be done at least once per season, after all the obvious clogging problems have been solved. Emitters will have to be cleaned (depending on the material causing the clogging), replaced or repaired if the field emission uniformity (EU'_a) has decreased with more than 10% in comparison with the design emission uniformity (EU_a). If necessary, the scheduling of the relevant block must be adjusted till the evaluation results obtained.

2.5.5 **Cleaning of the emitters**

The cleaning method to be used for the emitters depends on the type of dripper, as well as the type of clogging. Some types of emitters can be taken apart and cleaned by hand. Other types of emitters have the ability to flush themselves. The different solutions to the different clogging problems have already been described in paragraph 2.1. Air pressure is not recommended when cleaning emitters. High water pressure has limited possibilities for cleaning emitters. The most suitable method for cleaning emitters is to follow a reliable maintenance schedule as shown in Table 17.

Table 17: Maintenance schedule for drip irrigation systems

Monitor	With each cycle	Weekly	Monthly	Annually
Examine the system for leakages	✗			
Examine operating pressure at end of system			✗	
Examine system flow-rate (with flowmeter)		✗		
Examine functioning of air valves and pressure control valves				✗
Flush laterals (depending on water quality)		✗		
Chlorine treatment (depending on water quality and method of application)			✗	
Evaluation of system				✗

2.6 Clogging of emitters

The most serious problem of dripper irrigation is the clogging of emitters and there are different possible causes for. It is one of the irrigators' main responsibilities to prevent the clogging of emitters. Apart from the causes already mentioned, the most common causes are as follows:

2.6.1 Soil particles

Due to the small sizes of the dripper inlet and their small flow path sizes, they are quite susceptible to a wide range of soil particle sizes to block them. The partial or total blocking of a dripper renders it to deliver less or no water to its delivery area. Soil particles can either enter through the supply side or through the dripper outlet side. The first can be caused by in-effective filtering or soil that entered the supply lines during a pipe burst/breakage downstream of the filter but upstream of the lateral.

The second cause of sand particles entering the dripper is through the formation of a vacuum in the lateral and thereby the "sucking-in" of the particles into the outlet or orifice of the dripper. The use of an air inlet valve or vacuum breaker at the inlet to the block, or a suitable position according to the block topography, is of utmost importance.

2.6.2 Root intrusion of dripper orifices

With sub-surface irrigation the potential for root intrusion is extremely high, or actually a given. With the roots' function to obtain water, nutrients and other elements for the plant on the easiest shortest possible way, the presence of a water and nutrient supplying lateral in its close proximity is the ideal invitation for root intrusion. The root intrusion then causes the partial or total blockage of the specific dripper outlet. With aggressive root growth, depending on the plant type, a number of adjoining emitters can be blocked. Untreated root growth can block a whole lateral, which in turn prevents water supply to downstream emitters.

2.6.3 Precipitates

The formation of precipitates is discussed in the paragraph on chemical clogging. The management of the system according to the chemical composition of the irrigation water, as well as the application of fertilizers through the system, will help to minimise the effect of precipitate formation.

If the scheduling is done properly on a SDI system, the location of any precipitate build-up in the soil profile can be kept on the edge of the wetted profile, away from active root growth area. This, however, should be monitored closely by the producer.

2.6.4 Insects

Insects, like ants can damage emitters on a SDI system. Figure 8 is an example of an underground dripper lateral damaged by ants. Under a microscope it was apparent that the edges of the damaged area were damaged by small sharp objects. By analysing the size of the gnaw marks on the edges it, was clear that it was not due to rodent damage.

Figure 8: Enlarged photograph of hole in lateral, caused by ants

2.7 Design

A wide variety of parameters are used to describe the performance of different types of systems. For drip irrigation, the design emission uniformity (EU) is used. The acceptable directives for design and field evaluations differ considerably, as especially clogging, age and topography have a substantial influence on the field evaluation values. According to ASAE EP 405.1: "Design and installation of micro-irrigation systems", the following parameters are used for design purposes:

- Manufacturing variations (CV_q):

  This is a measure of the variability of delivery rate of a random sample of a given make, model and size of emitter, as produced by the manufacturer and before any field operation or aging has taken place (ASAE EP 405.1, 1997).

$$CV_q = \frac{S_q}{\overline{q}} \times 100 \qquad (20)$$

Where: $\overline{q}$ = the mean delivery rate of the emitters of the sample (ℓ/h)
S_q = the standard deviation of the delivery rate of the emitters of the sample.

$$\text{With } S_q = \left(\frac{\sum_{i=1}^{n} (q_i - \overline{q})^2}{n-1} \right)^{\frac{1}{2}} \qquad (21)$$

Where: q_i = the delivery rate of the i-th (specific) emitter (ℓ/h)
n = the number of emitters of the sample.

Table 18: Criteria for CV_q (%) of "point-source" emitters

Classification	ASAE EP 405.1 (1997)	Classification	ILI	ISO
Excellent	<5	Excellent	0,1 – 2,5	
Average	5 – 7	Good	2,6 – 5,0	0,1 – 5,0
Marginal	7 – 11	Fair	5,1 – 7,5	
Poor	11 – 15	Marginal	7,6 – 10	5,1 – 10
Unacceptable	>15	Poor	>10	>10

- Emission uniformity (EU):

  EU is the statistical parameter with which the expected uniformity of the emitter delivery rate within irrigation can be calculated.

  The absolute design emission uniformity (EU_a):

  The concept is identical to EU, except that this calculation also considers the maximum emitter delivery rate.

$$EU = 100\left(1{,}0 - \frac{1{,}27}{\sqrt{e}}CV_q\right)\frac{q_{min}}{\bar{q}} \tag{22}$$

$$EU_a = 50\left(1{,}0 - \frac{1{,}27}{\sqrt{e}}CV_q\right)\left(\frac{q_{min}}{\bar{q}} + \frac{\bar{q}}{q_{max}}\right) \tag{23}$$

Where: EU = design emission uniformity (%)
EU_a = absolute design emission uniformity (%)
e = number of emitters per plant ($\geq$1,0)
CV_q = manufacturer's coefficient of variation (fraction)
q_{min} = minimum dripper delivery rate (ℓ/h)
$\bar{q}$ = mean dripper delivery rate (ℓ/h)
q_{max} = maximum dripper delivery rate (ℓ/h).

Table 19: Criteria for the parameter EU for "point-source" emitters (ASAE EP405.1, 1997)

Dripper spacing (m)	Topography	Slope (%)	EU range (%)
>4	Uniform Steep or undulating	<2 >2	90 – 95 85 – 90
<4	Uniform Steep or undulating	<2 >2	85 – 90 80 – 90

For sub-surface drip irrigation the inclusion or facilitating of additional flow for flushing of the laterals or irrigation blocks should be taken into account in the design. An additional flow of 10% should be provided for this purpose.

3. MATERIALS AND METHODS

3.1 Choice of emitters

The emitters which were originally chosen were based on their type and also on their availability on the South African market. The different suppliers were contacted and their inputs were obtained. During the procurement process, one of the international suppliers withdrew their product and it was decided to use another product in its place. With the planning of the project it was decided to add two additional emitter types to the “basket” and thereby make more efficient use of the available soil and equipment.

The emitters which were chosen are listed in Table 20.

Table 20: Emitters used

Emitter Name (Manufacturer)	Delivery rate ℓ/h (Nominal)	Flow path*[1]	Lateral type*[2]	Aperture type	Zone*[3] (Code)
Super Typhoon (Netafim)	1,7	Turbulent	Tape, thin wall	1,8 mm Ø circular aperture	4 (A300)
Dripin Light (Agriplas)	1,7	Turbulent	Tube, thick wall	2 × 3 mm Ø circular aperture	5 (A500)
Ram 17L (Netafim)	1,6	Turbulent pressure compensated	Tape, thin wall	3 mm Ø circular aperture	6 (A200)
T-Tape (T-Tape)	1,0	Turbulent	Tape, thin wall	32 mm longitudinal slit	7 (A100)
DIS PC Lite (Agriplas)	2,2	Turbulent pressure compensated	Tube, thick wall	2 × 2 mm Ø circular aperture	8 (A400)

*[1]Flow path

- Turbulent flow path
  This is when obstacles are placed in the flow path of the water in an emitter, to reduce kinetic energy in the water to change it from laminar flow to turbulent flow.
- Pressure compensated
  This is when a diaphragm is introduced in an emitter that, depending on the pressure in the dripper line, to regulate the area of the flow path to maintain a constant flow rate.

*[2]Lateral type

- Tape, thin wall
  Emitter lines with a wall thickness of 0,5 mm or less.
- Tube, thick wall
  Emitter lines with a wall thickness more than 0,5 mm.

*[3]Zone refer to a group of experimental blocks of a specific flow path.

3.2 Laboratory tests carried out on emitters

3.2.1 Delivery rate and coefficient of delivery rate variation (CV_q tests)

The method in which the delivery rate and co-efficient of delivery rate variation tests were done are described as follows.

3.2.1.1 Delivery rate test

Tests are normally carried out at operating pressures varying from 20 kPa with increments of 20 kPa up to 300 kPa, and three tests are carried out. At every pressure setting, the pressure is allowed to stabilise and the flow rate reading on the flow meter is then recorded together with the pressure gauge reading. For every test the water temperature is measured.

In the case of pressure compensating emitters, the delivery rate (discharge rate) is measured with the operating pressure increasing from 20 kPa with increments of 20 kPa up to 100 kPa and from there with increments of 50 kPa up to 400 kPa. The delivery rate is also measured with decreasing pressure in the same way or step size. According to ISO test standards, flow-rate measurements are taken three minutes after pressure stabilisation and CV_q measurements one hour after pressure stabilisation. All pressure compensated emitters, however, show a slight decrease in delivery rate over time at constant pressure and therefore it will be noted in the test reports that the average delivery rate at a given pressure will be slightly higher in the delivery rate test than at the same pressure in the CV_q test.

Dripper tapes are tested to the manufacturer's maximum prescribed pressure. The minimum and maximum pressures and the pressure increments, at which these tests are performed, are the same as stated in the previous paragraph.

3.2.1.2 Co-efficient of variation (CV_q) test

A drip line of 100 emitters is installed on the test bench to deliver at an equal pressure into 100 individual calibrated measuring devices. The test bench allows that the pressure is adjustable and automatically controlled within pre-set values. The prescribed nominal working pressure by the manufacturer is used for the test.

The test is started with the drain valves of the measuring devices in the open position. These valves are simultaneously closed once the operating pressure has stabilised at the pre-set value. The pressure and flow-rate of the water supply system and the time it takes for individual measuring devices to fill is continuously electronically monitored and recorded.

The non-pressure compensated emitters (regular) were tested at the manufacturer's prescribed pressures and varied from 100 kPa to 200 kPa and the pressure compensated emitters were tested at 200 kPa.

New emitters of all the emitter lines, as installed in the test site at the ARC-Institute for Agricultural Engineering, Weavind Park, were tested in their hydro laboratory. The method and results are described in the next section (see Appendix A).

3.2.1.3 Results

The average delivery rate of the emitters at each pressure is determined by dividing the supply flow-rate by the number of emitters on test, and the test results are represented in the form of a table, a delivery rate curve, and a mathematical equation. The delivery rate hysteresis of pressure compensating emitters is represented in a delivery rate table and graph.

The delivery rate of individual emitters at a particular pressure is calculated by dividing the volume of each of the calibrated tubes by the time it takes for the particular tube to fill.
CV_q values, the minimum and maximum delivery rate and the variation in delivery rate are represented in two formats: One format is for a sample size of 100 emitters and the other for a sample size of 25 emitters. For the latter, the 100 emitters are divided into four groups of 25 emitters per group as prescribed by ISO. Each of these formats has its own set of norms, shown at the bottom of each table and the emitters are rated in accordance with them.

3.2.2 Comparative clogging test

A comparative clogging test on new emitters was conducted. This test only gave an indication of the relative clogging tendency of emitters, tested simultaneously, to clog under the same conditions. It was only a qualitative test, because it is not repeatable, due to the nature of the test.

Two dripper lines containing ten emitters of five drip models were installed on the test bench in a similar way as described for the delivery rate test. The dripper lines were installed randomly on the test bench. Contaminated water was then fed through one manifold, and the manifold on the other side of the drip lines was used to discharge the water back to the pump sump. Wooden sawdust was used as contaminant because of its characteristics, which favoured the needs of the test. A 100-hour test was conducted each time with water which had a high enough concentration of contaminants to block the emitters in that time. The delivery rate of each emitter was measured every hour and the dirtiness of the water was measured and controlled automatically on a continuous basis by a specially designed "Dirtiness Index Meter". At the end of the test, a calculation was done on the total volume of water that each (partially blocked) emitter delivered during the 100 hours and to compare that with which the emitter would have delivered, had it not blocked. This procedure was repeated and the average performance of the two tests which represent four drip lines (that is 40 emitters) of each emitter was used as a test result.

Over and above the 100-hour clogging test in which water was applied uninterruptedly, another test was done on the pressure compensated emitters, in which the water application was interrupted every hour, creating a pulsed effect, thus putting the emitters through a flush mode every hour. In this test, the regular emitter which is used as a common factor amongst all the clogging tests and against which the other emitters are compared every time, as well as the pressure compensated emitters, took 500 hours to clog.

3.3 Field tests (experimental site)

The tests on a "controlled site" were seen as a necessary part of the research project. The project team was in the fortunate position of having an area on their offices' doorstep to do the evaluation with the added advantage of having the Hydrolab on the same terrain.
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3.3.1 Block information

An area of 3 hectares on the Silverton terrain was available for the evaluation of the sub-surface drip equipment. Of this available area, 2 hectares was earmarked as the SDI experimental site. This site was then prepared and the lucerne established as is described in later paragraphs.

3.3.1.1 Design

With the five types of emitters to be tested, and the statisticians prescriptions in terms of repetition and border-effects, 40 blocks were installed (eight blocks per emitter type). The blocks were installed at random to make the layout statistically representative.

The emitter spacing on the laterals is 0,6 m and the lateral spacing is 0,9 m.

Each of the blocks has been served by a manifold which fed into seven laterals of the specific block. The length of the blocks, and thus the laterals, is 45 m. Each block has been supplied through a water flow meter, an air release valve, a pressure reduction valve and an electric solenoid cut-off valve. This valve was opened and closed via an irrigation controller or computer according to the pre-set schedule. With this peripheral equipment, the application of the required volume of water or the required depth of application could be managed accurately.

The experimental site was divided in two halves or two sections. The one halve was the untreated area, where no chemicals were applied through the system in terms of root growth inhibitors and the other halve, the treated area, was subject to the application of a root growth inhibitor or better known as Treflan. The laboratory tests on the retrieved laterals were done according to the two sections. The growth of microbiologic organisms was not seen as a problem and therefore no chlorine was applied to the system.

The water was supplied from a concrete balancing dam, which was fed from two boreholes on the terrain. From the dam, it was filtered through a twin sand filter unit. From here, it was distributed through a network of main pipelines and manifolds.

The system supply capacity was in excess of the envisaged peak crop requirement of 30 mm per week.

3.3.2 System installation and crop establishment

3.3.2.1 Preparation of the field

The first step in the preparation of the field was the removal of the existing lucerne on the experimental plot. After this the field was deep ripped in a criss-cross manner with a grid size of one metre and to a depth of 800 mm. It was recommended that the field should be withdrawn from lucerne cultivation for a period of at least six months to minimise the influence of toxicity of the previously established lucerne on the new lucerne crop.

Wheat was planted on the field as a winter crop and it was grown for a period of 13 weeks before it was ploughed into the soil. At this stage, the wheat was still in its growing stage and green in colour.

3.3.2.2 Installation of equipment

The emitter laterals were installed with a locally designed and built installation shaft, mounted on a tractor. The depth of installation was 300 mm. The lateral spacing is 900 mm and the length of the laterals does not exceed 45 m. A total of 40 blocks with seven laterals each were installed. The manifolds and block control units were assembled and consist of a pressure reducing valve, a pressure measuring point, a flow meter and solenoid cut-off valve.

Parallel to this process, the trenches for the main lines were dug. The main lines were installed. A concrete slab was cast as a base for the filters, the irrigation controller, the fertigation pump and the fertilizer tank. A steel box was built to protect the irrigation controller and fertilizer pump against possible theft or vandalism.

3.3.2.3 Crop establishment

After the installation of the irrigation system, and its testing and commissioning, the seed bed for the planting of the lucerne was prepared. The lucerne seed was planted with a fertilizer spreader and then the whole area was compacted with a steel roller. To guarantee a good germination percentage, the first number of irrigation applications was done with an overhead sprinkler irrigation system. Good rainfall just after the sowing of the lucerne helped to establish a promising crop. After proper plant establishment the irrigation was done with the installed sub-surface irrigation system.

3.3.3 **System management**

3.3.3.1 **Scheduling**

The irrigation scheduling on the terrain was done on the basis of a set of fixed applications per week. This application took place two to three times a week, based on the recommended fixed crop water requirement from the ARC's Range and Forage Institute. The neutron probe (TR 534) was used to measure the soil water levels in five installed tubes in the irrigation blocks. This neutron probe readings were then used, and compared with the accepted moisture regime limits. This soil moisture levels was according to the established field capacity and wilting points for the specific soil. The field capacity and wilting points were established by the research of a final year engineering student, in collaboration with the University of Pretoria's soil sciences laboratory. The irrigation applications were adjusted if the neutron probe readings were outside of the mentioned regime.

These irrigation applications, for each block, were recorded by the specific block flow meter. The scheme flow meter recorded the total flow for all the block flow meters. An example of the irrigation scheduling over a period is illustrated in Figure 9. The mentioned wilting and field capacity levels are illustrated by dark lines.

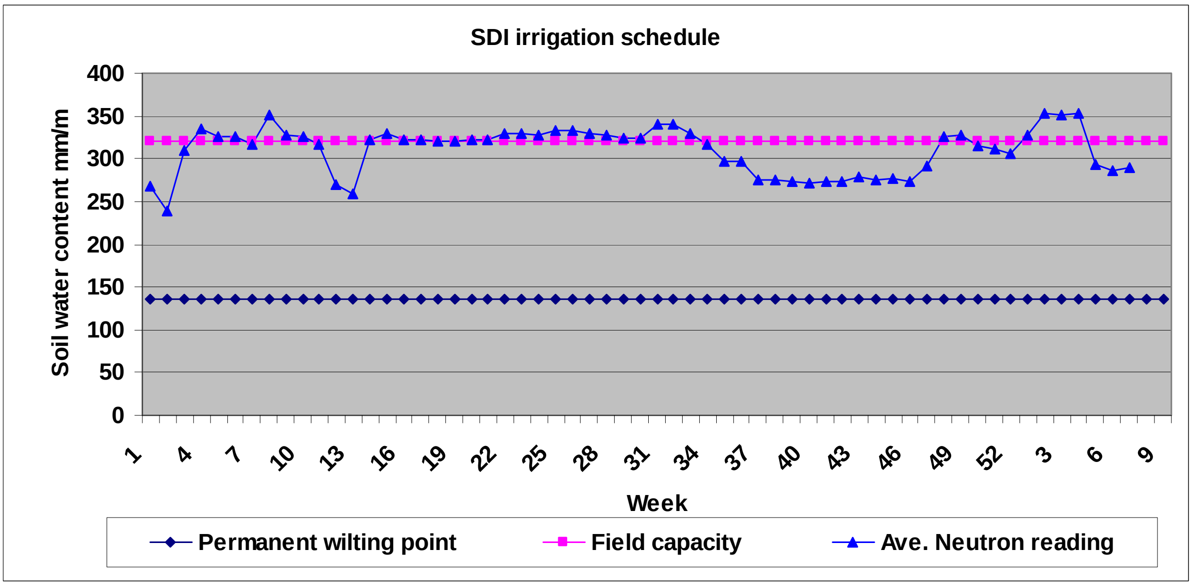

Figure 9: Irrigation scheduling record example

3.3.3.2 **Flow recording**

Flow recording was done at the individual blocks and at the main flow meter. All these readings were used in calculations and in record keeping. From these records, the irrigation history of each block was compiled and the irrigation application was calculated accordingly.

Five laterals, one of each zone, which were earmarked for retrieval, were equipped with a flow meter each and were logged for seven scheduled irrigation weeks before retrieval. (These laterals were underground for 30 months before retrieval.) After retrieval and replacement with new laterals, the flow meters were re-installed on the new laterals and logged for a further 16 scheduled irrigation weeks until the termination of the experiment.

Figure 10 illustrates the increase of the average of all the flow meter readings after week seven. This data illustrates the impact of the blockages on the emitter laterals. The gradual decline visible from week 8 onwards, gives an indication of the possible gradual blocking of the emitters. The flow meters were installed on the untreated half of the experiment.

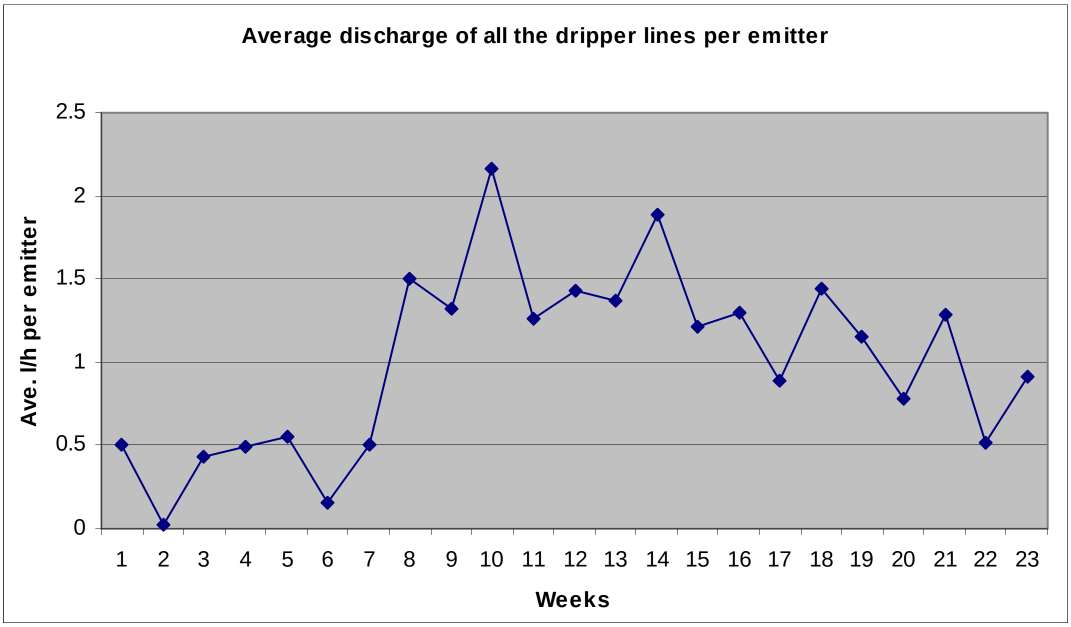

Figure 10: Average delivery rate of all emitter lines per emitter

3.3.3.3 System monitoring and maintenance

The system components which were monitored at different intervals are the flow meters after each irrigation application and the pressure difference across the filters on a weekly basis during an irrigation cycle. The total flow into the area (all the blocks) was monitored on the main flow meter, which gave a summation of the total block flow. The monitoring of the block flow meters gave direct indications of the operation of the different irrigation blocks. The water quality, in terms of algae at the lateral outlets, was checked on a monthly to bi-monthly cycle.

Flushing of the laterals took place to prevent slime build-up in the laterals. It took place on a monthly/bi-monthly basis, or as the need arose. The rinsing was done per block on a manual solenoid setting and with an increase of the pressure, so that a flow velocity of ± 0,5 m/s was reached at a specific lateral outlet. A procedure of a repeated opening and closing of the lateral for two or three times, as well as a 4 to 5 minute continuous flow was followed. This was repeated until the water at the outlet was clear of any visual algae or other material.

Any leaks or malfunctioning solenoid valves were repaired as soon as possible.

The system monitoring and maintenance programme, as was followed, is listed in Table 21.

Table 21: System monitoring and maintenance programme

Activity	Interval							
	Weekly		Monthly		6-monthly		Yearly	
	Exp.	Co.	Exp.	Co.	Exp.	Co.	Exp.	Co.
Detect and fix leakages	✗	✗						
Monitor pressure difference across filter	✗	✗						
Monitor pressure at lateral outlets			✗	✗				
Monitor system flow (main flow meter)	✗	✗						
Monitor air valves and functioning							✗	✗
Water sampling at lateral ends, evaluate changes in quality			✗	✗			✗	✗
Soil water sensor readings (neutron probe)	✗	✗						
Backwash filters (as needed)	✗	✗	✗	✗				
Flush laterals and adjust pressure reducing valves			✗	✗				
Treatment with Treflan					✗			
Monitor hydraulic and electrical connections	✗	✗						

Exp. = Experiment
Co. = Control

3.3.3.4 **Fertilizer application**

The fertilizer was mostly applied right after the cutting of the lucerne, as recommended. The fertilizer was applied through the distribution system with the chemical injection pump. The application was done according to the recommendations for lucerne as it was prescribed by the fertilizer suppliers.

3.3.3.5 **Treflan application**

The root growth inhibitor Treflan was used on the one half/section of the irrigated area and this formed the treated half or experimental part of the experiment. The Treflan was applied twice a year and the first application was done during August 2001, and the rest during February 2002, August 2002 and May 2003.

The Treflan was also applied through the chemical injection pump. The dosage which was applied was 0,14 mℓ/emitter. This is equivalent to a 1,5 litre per hectare as recommended by the manufacturer.

3.3.3.6 **Hardware maintenance**

The irrigation equipment was maintained as the need arose. Some modifications were done to the hardware to be able to divide the irrigation system into two separate halves to be able to accommodate the treated and untreated blocks. The fixing of the leaks in the laterals and manifolds was the majority of the maintenance work to be done.

3.3.3.7 **Filter cleaning**

The pressure difference or drop over the filters was monitored and the filters were backwashed if the pressure difference was more than 20 kPa. The blocking of the filters was thus monitored in this way. On a number of occasions the sand was removed from the filters and replaced little by little. After each small volume was placed in the filter, the filter was set in its back-flush mode to wash the added sand. This method proved to be successful. The secondary disc filters were also dismantled a few times and the discs were scrubbed and rinsed before re-assembling. The filter was "back-washed" on a weekly basis. Filter-sand was replaced three times during the experiment. This is equal to once per growth season.

3.3.3.8 **Lateral removal and installation of new laterals**

With the removal of the sets of laterals from the field, the soil was removed around the lateral at the inlet side, the laterals' inlets and was cut before the implement was engaged. The lateral was manually pulled from the loose soil as the implement moved through the soil, rolled up, marked (tagged) and transported to the laboratory for testing. These laterals were then replaced by the same kind (make) of lateral as was removed. This was done to keep the hydraulics of the blocks constant over the duration of the project.

The replacement laterals were installed in the same way and with the same implement as was used with the initial installation. After the installation the soil-surface was smoothed with a scraper. The replacement laterals were connected to the manifold and flushed before irrigation started again. The strips, where the laterals were removed, were subject to weed growth due to the disturbance which was done to the lucerne during the lateral removal process and its inability to regain its original plant growth.

3.3.4 **Water quality analyses**

The water was analysed for its chemical composition and tested in terms of suitability for utilisation on lucerne. The analysis was done by the ARC-Institute for Soil, Climate and Water in Pretoria. The test results proved it as a C2-S1. It is therefore suitable for irrigation purposes. The C-S classification system is the system used internationally and was developed by the United States Department of Agriculture (USDA). The C-value indicates the concentration of dissolved solids and it is expressed in terms of electrical conductivity. The S-value refers to the sodium concentration and it is expressed in terms of the Sodium adsorption ratio (SAR). The C-S classification system is used to a lesser extent because the soil water-plant combination method gives more user orientated values.

3.3.5 **Tests on emitters retrieved from the experimental site**

The emitters that were recovered from the experimental site were handled carefully, marked and stored to be installed at a later stage on the test bench. It was done in the same sequence as it was installed sub-surface in the experimental site.

After the emitter line was installed on the test bench, it was lightly flushed, with open ends, before the delivery rate and CV_q tests were conducted. The tests were conducted with the same procedure and method as with the testing of new emitters. Clogged emitters were identified physically, while at operating pressure on the test bench and marked with a marker to be cut out of the line for inspection after the completion of the test.

3.3.6 Physical inspection of clogged emitters

Clogged emitters, as identified in the laboratory, were examined under a microscope to determine the reason for the clogging. The clogging hazard was categorized in the following categories:

- **Apparent clean aperture**

  Those emitters clogged without any apparent visible reasons, as viewed from the outside. Further inspection is then carried out by cutting it open.

- **Soiled aperture**

  This category is for those emitters which are blocked due to a slimy substance clogging the aperture or labyrinth of the emitter from the inside.

- **Soil in aperture**

  Emitters clogged by soil from the outside.

- **Root in aperture**

  Where root intrusion is visible under the microscope.

3.4 Field test (farm-sites)

Areas in the Mpumalanga Lowveld and Swaziland where sub-surface drip irrigation is used were identified. The South African Sugar Growers Association was contacted and informed of the purpose of this research project. The project team were brought into contact with the relevant extension officers who then organised visits to specific farmers.

During the month of July 2000, a total of three different sites in the Mpumalanga Lowveld and Swaziland were visited. On all these sites, sugar cane is grown on sub-surface drip irrigation systems. Our aim with this visit was to evaluate the performance of the sub-surface drip irrigation systems under field conditions and share the experiences of the farmers in terms of sub-surface drip irrigation.

3.4.1 Block information

The required information was obtained from the participating producers by means of the completion of a prepared questionnaire (see Annexure B) for each block, regarding the irrigation system, water source, water management, maintenance schedules followed by the producers and the filtering and fertilizer application practices.

3.4.2 Water quality analyses

Water samples at the different sites were taken as follows: A water sample was taken at the water source and at the in- and outlets of the filters for complete water analysis of elements that can have an influence on the water quality. The tests were done at the laboratories of ARC-Institute for Soil Climate and Water (ARC-ISCW) and Water Lab. The first laboratory did the chemical analysis and the second laboratory did the analysis on the biological (algae) content. Separate water samples, in acidified water bottles, were taken for the analysis of iron and manganese. The water samples were taken before and after the filtration system to determine the suspended solids in the water. By means of equation 24, the filter efficiency of the relevant filter was calculated.

3.4.3 **Filtration**

The filters at the different sites were evaluated in terms of the pressure drop across the filters at that moment in time. Water samples were taken at the in- and outlet of the filter to establish the filtration efficiency.

The formula which was used is as follows:

$$E_f = 100\left(1 - \frac{S_{out}}{S_{in}}\right) \tag{24}$$

With: E_f = filtration efficiency (%)
S_{out} = total suspended solids after filtration
S_{in} = total suspended solids before filtration.

A water sample was also taken at the end of a lateral to determine the type and number, per algae species. These samples were analysed by Waterlab in Pretoria.

New information shows that problems exist with the measurements and accompanying use of the formula. It is therefore recommended that the dirtiness index meter is used to establish a filter's management. The use of this dirtiness index meter is described in paragraph 2.4.4.

3.4.4 **System evaluation**

Different measurements were taken to determine possible causes of clogging problems and to calculate the performance parameters of the irrigation systems. The measurements included, among others, the following: type of clogging materials found in the system, estimated number of emitters clogged in the block, pressure drop over the filter, as well as the performance of the air valves. The statistical delivery rate uniformity (U_s) is used as parameter to describe the uniformity of emitter delivery rate in the block. Five emitter lines were evaluated at five positions, as shown in Figure 11. The delivery rate of 25 emitters per irrigation block was measured. Pressure readings were taken at the same points and also at the block inlets and along the manifolds.

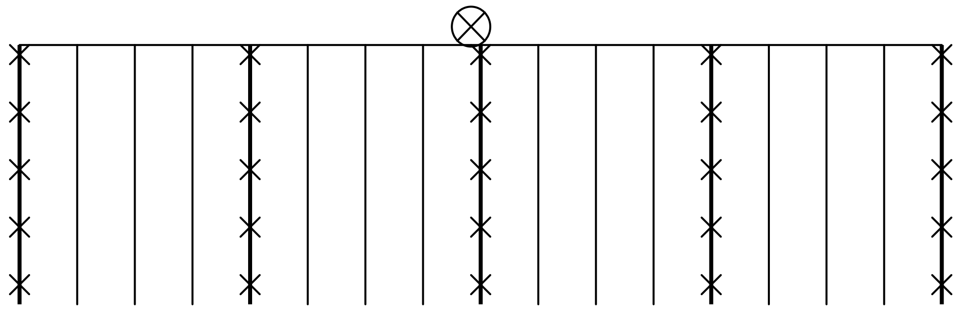

Figure 11: Position where emitters were evaluated

Code: X – Emitters were evaluated at five positions.
⊗ – Valve

The following equations were used for the calculations:

$$q_{ave} = \frac{1}{n}\sum_{i=1}^{n} q_i \quad (25)$$

$$S_q = \frac{1}{n-1}\left[\sum_{i=1}^{n}(q_i - q_{ave})^2\right]^{1/2} \quad (26)$$

$$CV_q = \frac{S_q}{q_{ave}} \quad (27)$$

$$U_s = 100(1 - CV_q) \quad (28)$$

With:
- q_i = emitter delivery rate (ℓ/h)
- n = number of emitters of the sample
- q_{ave} = mean of all the measured delivery rates (ℓ/h)
- S_q = standard deviation of the delivery rate of the emitters of the sample
- CV_q = co-efficient of variation
- U_s = statistical uniformity (%).

Table 22: Criteria for an acceptable statistical uniformity (U_s)

Classification	Value (%)
Excellent	>90
Very good	80 – 90
Fair	70 – 80
Poor	60 – 70
Unacceptable	<60

A statistical uniformity value of 80% or greater will be required, where fertilizer is applied through an irrigation system.

The actual emission uniformity (EU´) is sometimes used to judge the uniformity of emitter delivery rates within an irrigation block.

$$EU' = 100\frac{q'_{e\,min}}{q'_{e\,ave}} \quad (29)$$

and

$$EU'_a = 50\left(\frac{q'_{e\,min}}{q'_{e\,ave}} + \frac{q'_{e\,ave}}{q'_{e\,max}}\right) \quad (30)$$

Where:
- EU´ = actual emission uniformity (%)
- EU_a' = absolute actual emission uniformity (%)
- $q_e'{}_{min}$ = measured average of lowest ¼ of emitter delivery rates (ℓ/h)
- $q_e'{}_{ave}$ = measured average emitter delivery rate (ℓ/h)
- $q_e'{}_{max}$ = measured average of highest ⅛ of emitter delivery rates (ℓ/h).

Table 23 gives a comparison between U_s and EU_a as suggested for design purposes.

Table 23: Comparison between U_s and EU_a for design purposes (ASAE, EP 405.1. 1997)

Classification	U_s (%)	EU_a (%)
Excellent	95 – 100	94 – 100
Good	85 – 90	81 – 87
Acceptable	75 – 80	68 – 75
Poor	65 – 70	56 – 62
Unacceptable	<60	<50

The flow variation within a block can be determined with Eq. 31 (Eurodrip):

- Flow variation (q_{var}):

  The flow variation gives an indication of the ratio between the difference between the maximum and the minimum flow to the maximum flow:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \times 100 \qquad (31)$$

Where: q_{var} = flow variation in the block (%)
q_{max} = maximum emitter’s delivery rate in the block (ℓ/h)
q_{min} = lowest emitter’s delivery rate in the block (ℓ/h).

Table 24: Criteria for the parameter q_{var} (ASAE, EP 405.1. 1997)

Classification	Value (%)
Desirable	<10
Acceptable	10 – 20
Unacceptable	>20

4. RESULTS AND DISCUSSIONS

4.1 Description of emitters chosen for the investigation

See paragraphs 3.1, Table 20 for the choice and characteristics of the emitters used.

4.2 Results of laboratory tests on emitters

4.2.1 Tests on new emitters

Tests were carried out as described in paragraph 3.2. Listed below is a summary of the test results of the new dripper lines.

Table 25: New emitter test results

Name and code of dripper tested	**Sample size units**	**Dripper CV_q (%)**	**Average q (ℓ/h)**	**Percentage emitters in discharge category**						
				Discharge <=Av-3CV	*Discharge <=Av-2CV >Av-3CV*	*Discharge <=Av-1CV >Av-2CV*	*Discharge <Av+1CV >Av-1CV*	*Discharge >=Av+1CV <Av+2CV*	*Discharge >=Av+2CV <Av+3CV*	*Discharge >=Av+3CV*
A300	100	2,1	1,7	2	7	15	51	18	4	2
A500	100	4,2	2,2	10	9	11	37	14	12	6
A200	100	2,1	1,6	2	8	15	49	12	9	4
A100	100	2,4	1,23	2	2	15	61	14	5	1
A400	100	4,4	2,0	6	12	14	33	17	9	8

Graphical illustrations of the emitters' discharge categories are included in the test results paragraphs 4.2.3.2.

4.2.2 **Tests on emitters retrieved from the experimental site**

The test results of the tests on the retrieved emitters are discussed in terms of clogged and functional emitters. The clogged emitters are discussed in terms of root clogged and other clogged emitters. The functional emitters are divided into three discharge categories namely the *reduced discharge*, the *average discharge* and the *increased discharge* categories. The definition of the categories is described in paragraph 4.2.3.2. A graphical illustration of the categories can be seen in Figure 12.

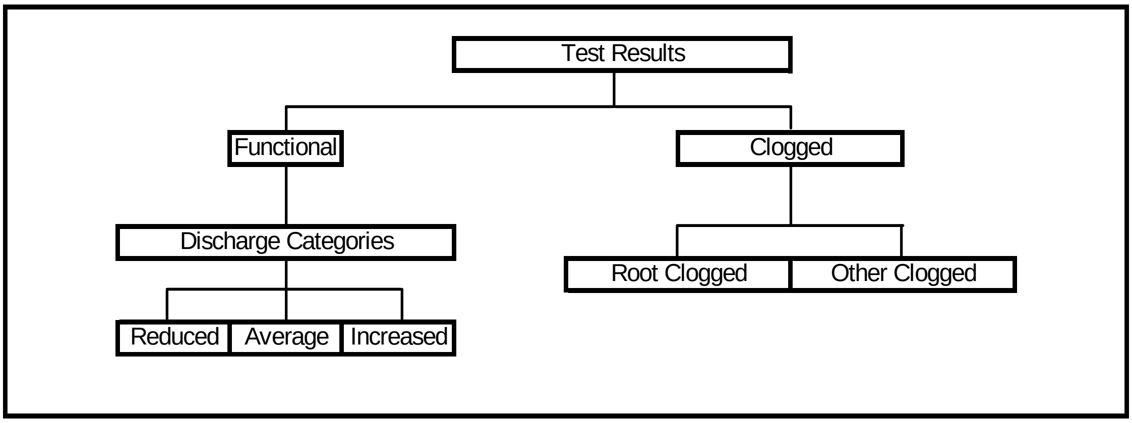

Figure 12: Graphical structure of test result discussion

Definitions:

Functional emitters indicate those emitters which delivered water, independent of what flow-rate, with a delivery rate at more than zero litres per hour. The variance in discharge rates (delivery rates) of the functional emitters is discussed in the relevant paragraphs under discharge categories.

The categories are based on the CV_q values of the tests of the specific dripper laterals. An explanation for these categories is given in paragraph 4.2.3.2.

Clogged emitters indicate either root clogged or other clogged with the following definition:

> **Root clogged emitters** indicate emitters which were clogged by roots, as observed in the orifices or in the labyrinths or dripper mechanisms.
>
> **Other clogged emitters** indicate those emitters clogged by soil, organic matter, e.g. algae or any foreign matter, excluding roots.

The results of the tests carried out on the emitters are discussed per zone (dripper type). These zones are discussed in terms of treated and untreated procedures respectively.

4.2.3 **Laboratory test results of retrieved emitters**

In Table 26, the results of the individual dripper types are listed, showing the performance of the emitters retrieved from the field.

Table 26: Summary of retrieved dripper performance, as tested in the laboratory

Table 26: Summary of retrieved drippers' performance, as tested in the laboratory									
	Year	Zone	Total Emitters Tested	Functional emitters		Emitters clogged by root intrusion		Emitters clogged by other means	
				number	%	number	%	number	%
Untreated	2002	4	215	176	81.9	21	9.8	18	8.4
		5	385	344	89.4	25	6.5	16	4.2
		6	275	272	98.9	0	0.0	3	1.1
		7	277	249	89.9	22	7.9	6	2.2
		8	123	102	82.9	5.0	4.1	16.0	13.0
	2003	4	237	159	67.1	44	18.6	34	14.3
		5	315	224	71.1	79	25.1	12	3.8
		6	266	254	95.5	6	2.3	6	2.3
		7	314	193	61.5	111	35.4	10	3.2
		8	185	133	71.9	48	25.9	4	2.2
	2004	4	160	95	59.4	44	27.5	21	13.1
		5	224	142	63.4	70	31.3	12	5.4
		6	244	228	93.4	15	6.1	1	0.4
		7	229	140	61.1	86	37.6	3	1.3
		8	205	112	54.6	90	43.9	3	1.5
Treated	2002	4	242	205	84.7	5	2.1	32	13.2
		5	483	459	95.0	9	1.9	15	3.1
		6	268	265	98.9	0	0.0	3	1.1
		7	233	215	92.3	10	4.3	8	3.4
		8	73	71	97.3	0	0.0	2	2.7
	2003	4	191	150	78.5	13	6.8	28	14.7
		5	-	-	-	-	-	-	-
		6	266	261	98.1	0	0.0	5	1.9
		7	262	197	75.2	45	17.2	20	7.6
		8	465	323	69.5	77	16.6	65	14.0
	2004	4	203	160	78.8	11	5.4	32	15.8
		5	244	192	78.7	15	6.1	37	15.2
		6	267	256	95.9	4	1.5	7	2.6
		7	219	176	80.4	38	17.4	5	2.3
		8	259	228	88.0	18	6.9	13	5.0

The first set of dripper laterals were removed during February to March 2002, 18 months after installation. The second set of dripper laterals were removed during April to May 2003, after 30 months of use in the field. The third set of dripper lines were removed from the field during February to April 2004, after 42 months of use, and the final laboratory tests were concluded at the end of May 2004. Graphical presentations of the results are illustrated in the following paragraphs.

4.2.3.1 **Functional and clogged emitters**

The results of the functional and clogged emitters are presented per zone. The zone number indicates the dripper type used. The following graphs (Figures 13 to 22) illustrate the performance of the retrieved emitters over time.

- **Test results in Zone 4**

  A summary of the test results in Zone 4 is shown in Table 27 with a graphical presentation in Figures 13 and 14.

Table 27: Zone 4: Test results

The percentage of functional drippers to drippers tested in zone 4			
	Percentage		
	2002	2003	2004
Untreated block	81.9	67.1	59.4
Treated block	84.7	78.5	78.8

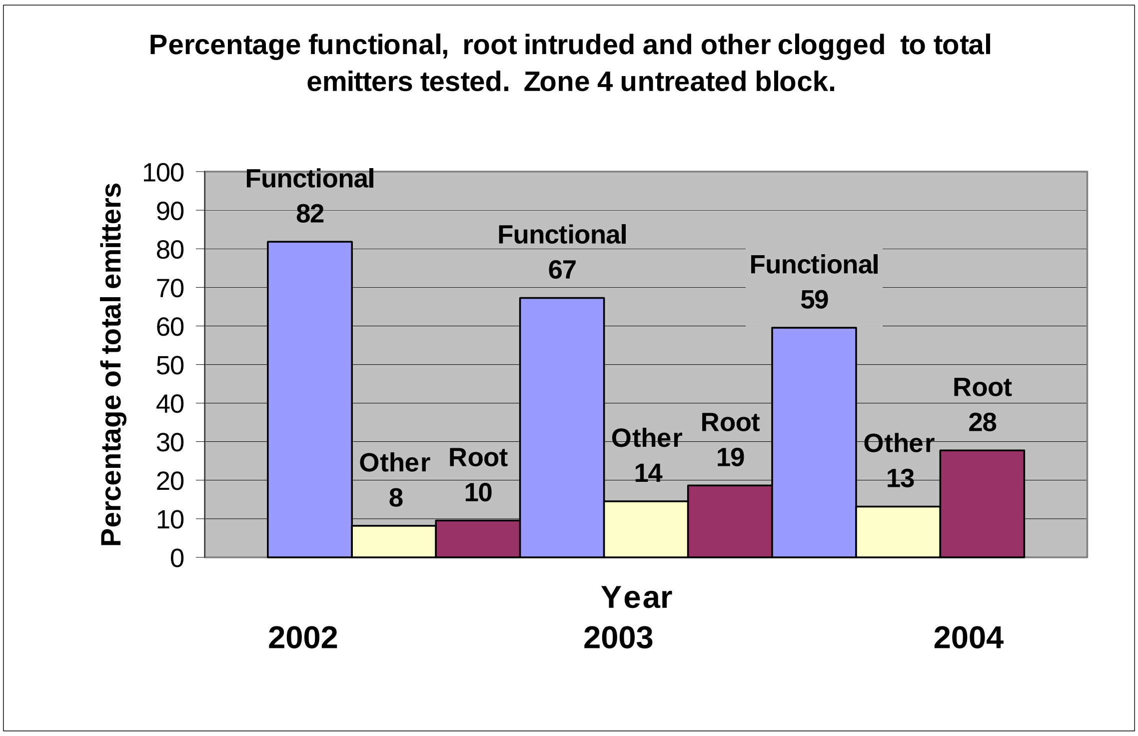

Figure 13: Percentage functional, root intruded and other clogged to total emitters tested, Zone 4: Untreated block

From Figure 13 (untreated block), a considerable increase in percentage of root and other clogged emitters over the duration of installation can clearly be seen. The decrease in functional emitters coincided with the increase in root and other clogged percentages over the same time.

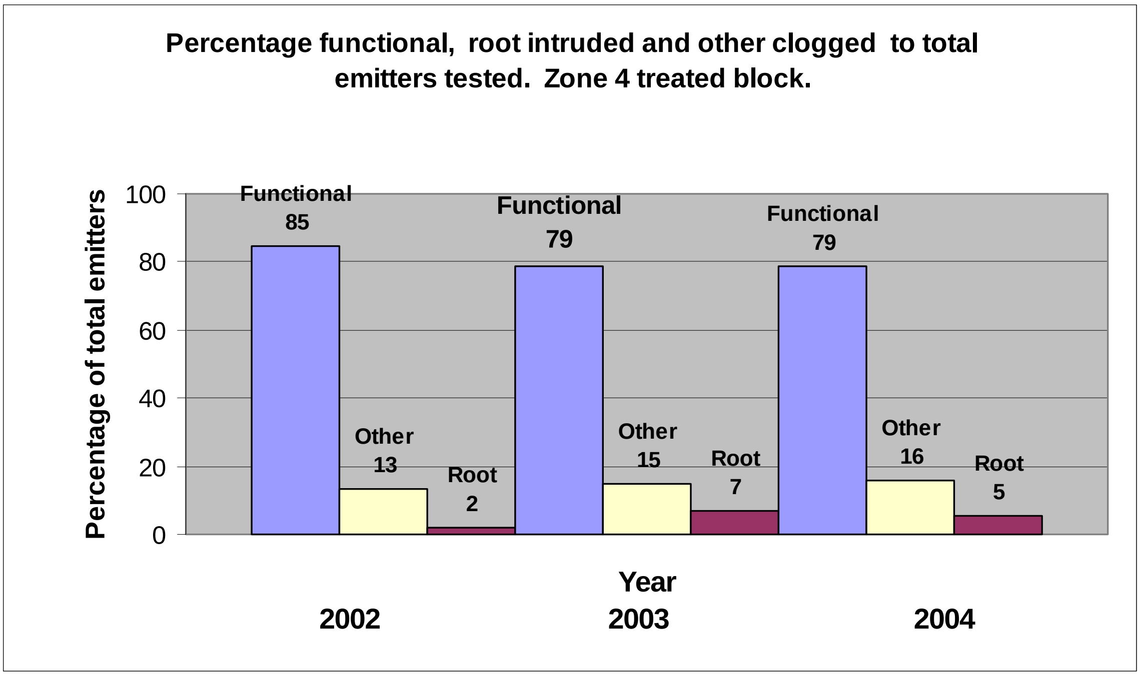

Figure 14: Percentage functional, root intruded and other clogged to total emitters tested, Zone 4: Treated block

From Figure 14 (treated block), a small increase in percentage of root and other clogged emitters over the duration of installation can be noted. The decrease in functional dripper percentage coincided with the nominal increase in percentages of root and other clogged emitters over the same time.

From Figures 13 and 14, the percentage of functional emitters in the untreated block decreased by 28% over the three years and the percentage root intruded emitters increased 180% (from 10 to 28%) in the same period, whereas in the treated block the percentage of functional emitters decreased by only 7% over the three years, with the root intruded emitters increasing with 150%. With the treated blocks versus the untreated blocks, 25% more drippers were functional after the three year period.

- **Test results in Zone 5**

  A summary of the test results in Zone 5 is shown in Table 28 with a graphical presentation in Figures 15 and 16.

Table 28: Zone 5: Test results

The percentage of functional drippers to drippers tested in zone 5			
	Percentage		
	2002	2003	2004
Untreated block	89.4	71.1	63.4
Treated block	95.0	-	78.8

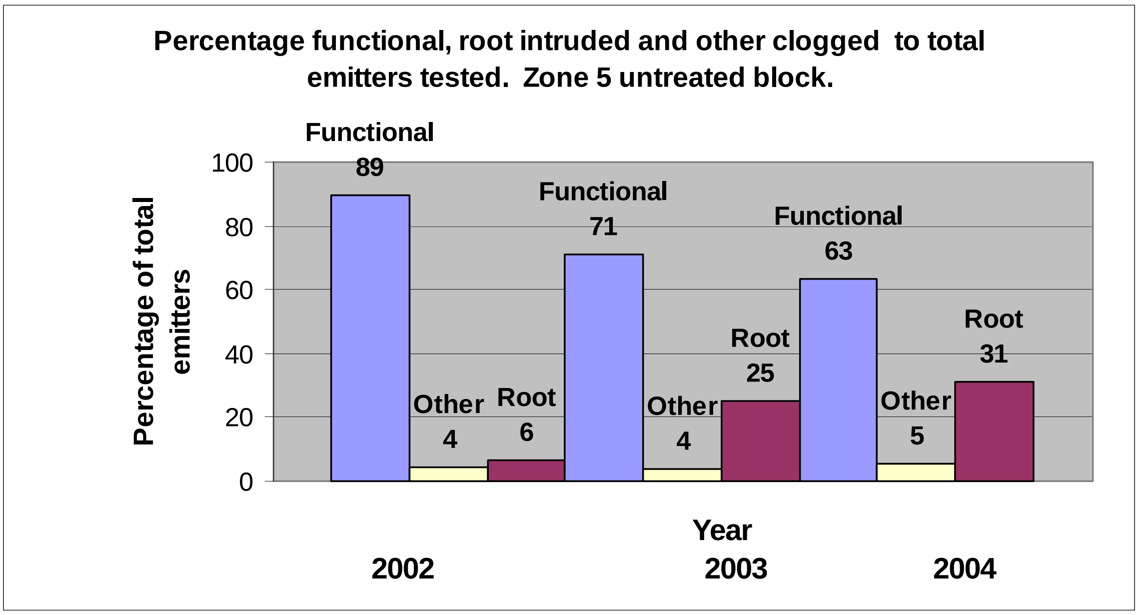

Figure 15: Percentage functional, root intruded and other clogged to total emitters tested, Zone 5: Untreated block

From Figure 15 (untreated block), a considerable decline in percentage functional emitters (29%) over the evaluation period can clearly be noted. This decrease in functional emitters coincided with the considerable increase in root clogged percentage (416%) and a nominal increase in the other clogged percentage over the 42 months of installation.

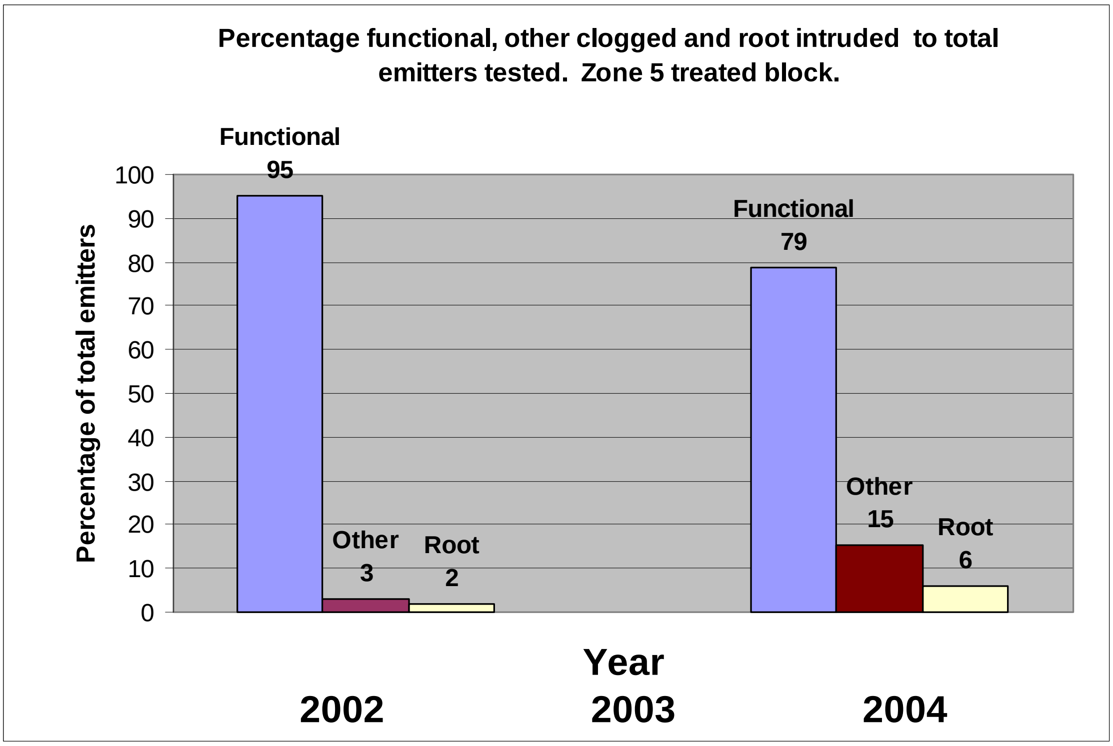

Figure 16: Percentage functional, root intruded and other clogged to total emitters tested, Zone 5: Treated block

From Figure 16 (treated block), a decline in percentage functional emitters over the duration of installation can be noted. This decrease in functional dripper percentage coincided with the increase in root and other clogged percentages over the same time. The percentage of functional emitters in the treated blocks decreased by 16,8%. An increase from of 200% of root clogged emitters occurred over the same period of installation. No data was recorded for 2003 in the treated blocks of this zone.

When comparing the treated blocks with the untreated blocks, 25% more functional emitters existed in the treated blocks than the untreated blocks.

- **Test results in Zone 6**

  A summary of the test results in Zone 6 is shown in Table 29 with a graphical presentation in Figures 17 and 18.

Table 29: Zone 6: Test results

The percentage of functional drippers to drippers tested in zone 6			
	Percentage		
	2002	2003	2004
Untreated block	98.9	95.5	93.4
Treated block	98.9	98.1	95.9

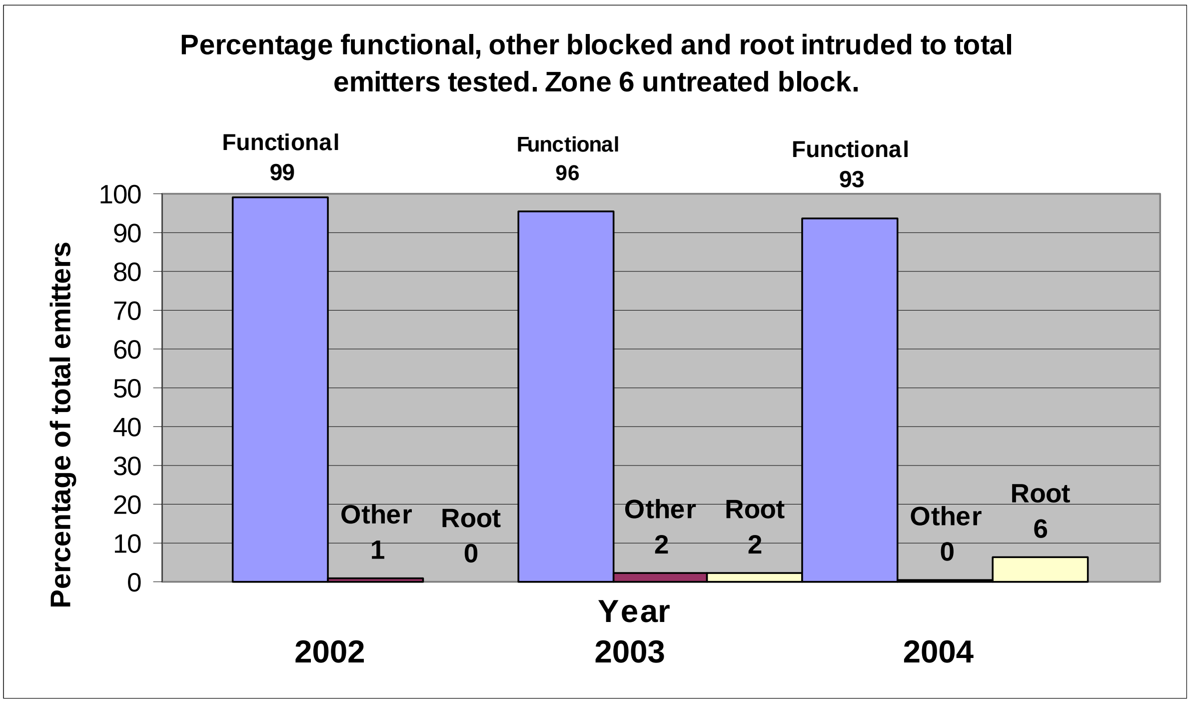

Figure 17: Percentage functional, root intruded and other clogged to total emitters tested, Zone 6: Untreated block

From Figure 17, a slight decline in the functional percentage emitters over the time of installation can be noted. This coincided with a slight increase in the percentage of root clogged emitters

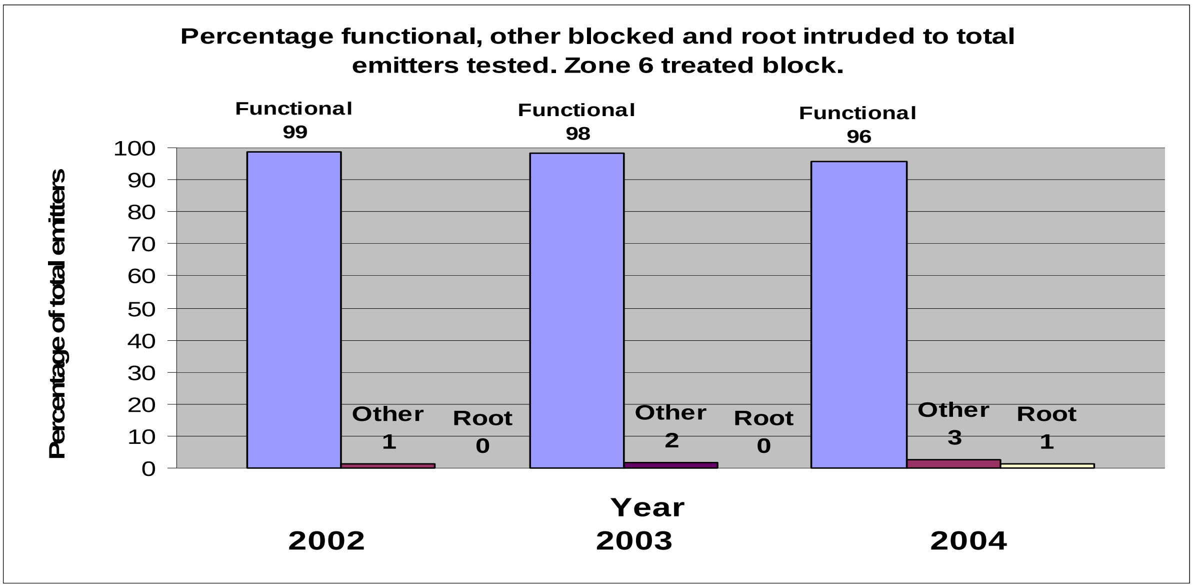

Figure 18: Percentage functional, root intruded and other clogged to total emitters tested, Zone 6: Treated block

From Figure 18, it can be seen that a near constant functional percentage existed over the time of installation, with a minor increase in the percentages of root and other clogged emitters.

From Figures 17 and 18, a minor decrease of 6% in the untreated blocks and 3% decrease in the treated blocks occurred in the functional emitters over the 42 months of installation. Only a minor increase in the percentage of root clogged emitters, from 0% to 6%, occurred in the untreated blocks and from 0% to1% in the treated blocks, in the same period. The small difference in the functional emitters' percentage of treated and untreated emitters indicates that the emitter type (mechanism) played a major role in the prevention of root intrusion or root clogging.

- **Test results in Zone 7**

  A summary of the test results in Zone 7 is shown in Table 30 with a graphical presentation in Figures 19 and 20.

Table 30: Zone 7: Test results

The percentage of functional drippers to drippers tested in zone 7			
	Percentage		
	2002	**2003**	**2004**
Untreated block	89.9	61.5	61.1
Treated block	92.3	75.2	80.4

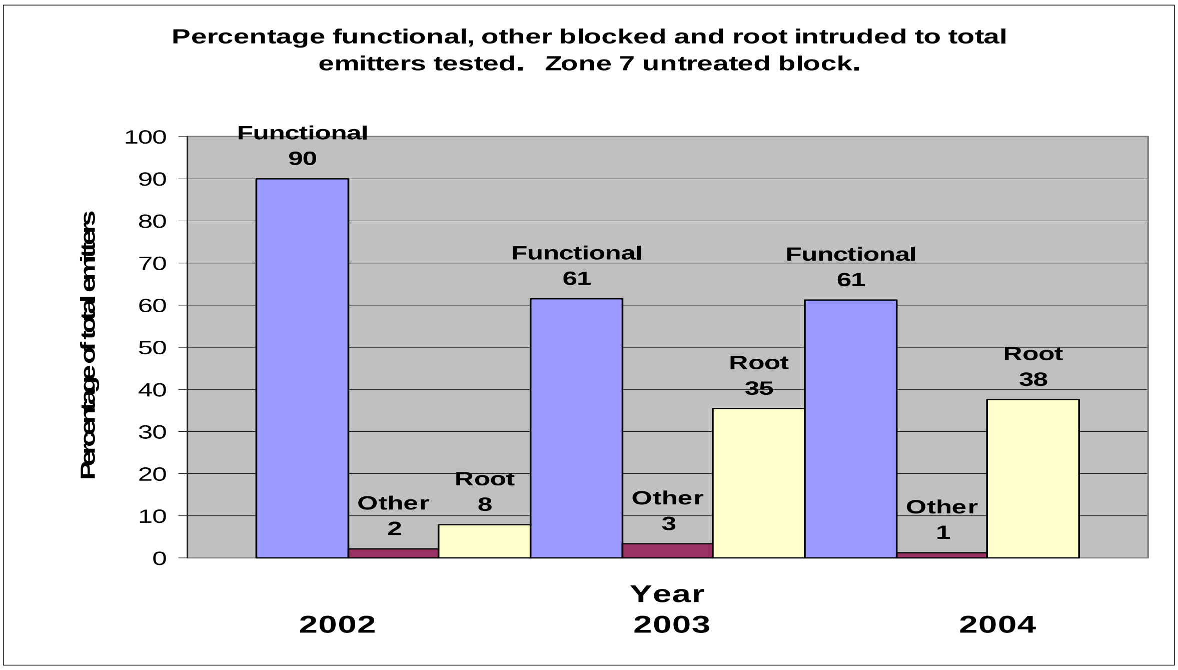

Figure 19: Percentage functional, root intruded and other clogged to total emitters tested, Zone 7: Untreated block

From Figure 19 (untreated block), a considerable decline in percentage functional emitters over the duration of installation can clearly be seen (29%). This decrease in the percentage functional emitters coincided with the considerable increase in root clogged percentage and a nominal increase and a later decrease in the other clogged percentage, over time.

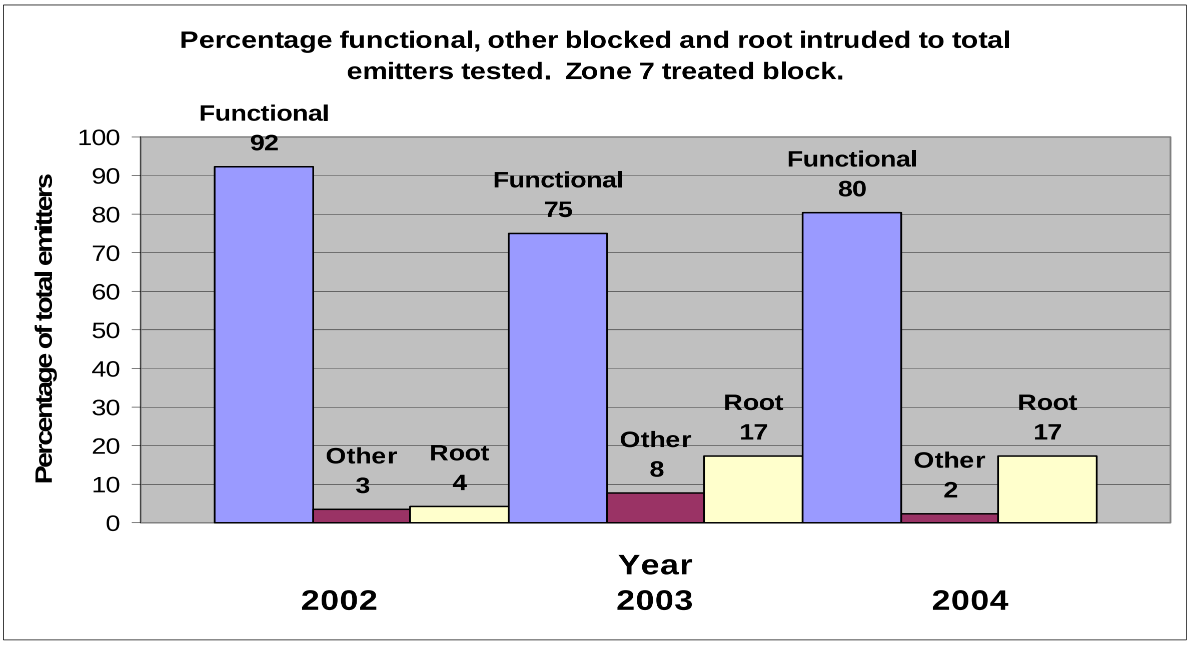

Figure 20: Percentage functional, root intruded and other clogged to total emitters tested, Zone 7: Treated block

From Figure 20 (treated block), a decline in percentage functional emitters over the duration of installation can be noted. This decrease in functional emitter percentage coincided with the considerable increase in root clogged percentage over the same time. A varying percentage other clogged emitters can be noted for the duration of the experiment.

To summarise from Figures 19 and 20, the results indicate a 33,7% decrease in the percentage of functional emitters in the untreated blocks over the three years. Root intrusion seems to be the main cause of this percentage functional emitter decrease and increased with 375% (8 to 38%) in the same period. In the treated blocks, the percentage functional emitters decreased by 13%. The percentage of root intrusion increased in the treated blocks from 4% to 17% which equals an increase of 325% over the 42 months of installation. A 31% more functional emitters existed in the treated blocks versus the untreated blocks.

- **Test results in Zone 8**

  A summary of the test results in Zone 8 is shown in Table 31 with a graphical presentation in Figures 21 and 22.

Table 31: Zone 8: Test results

The percentage of functional drippers to drippers tested in zone 8			
	Percentage		
	2002	2003	2004
Untreated block	82.9	71.9	84.7
Treated block	97.3	69.5	88.0

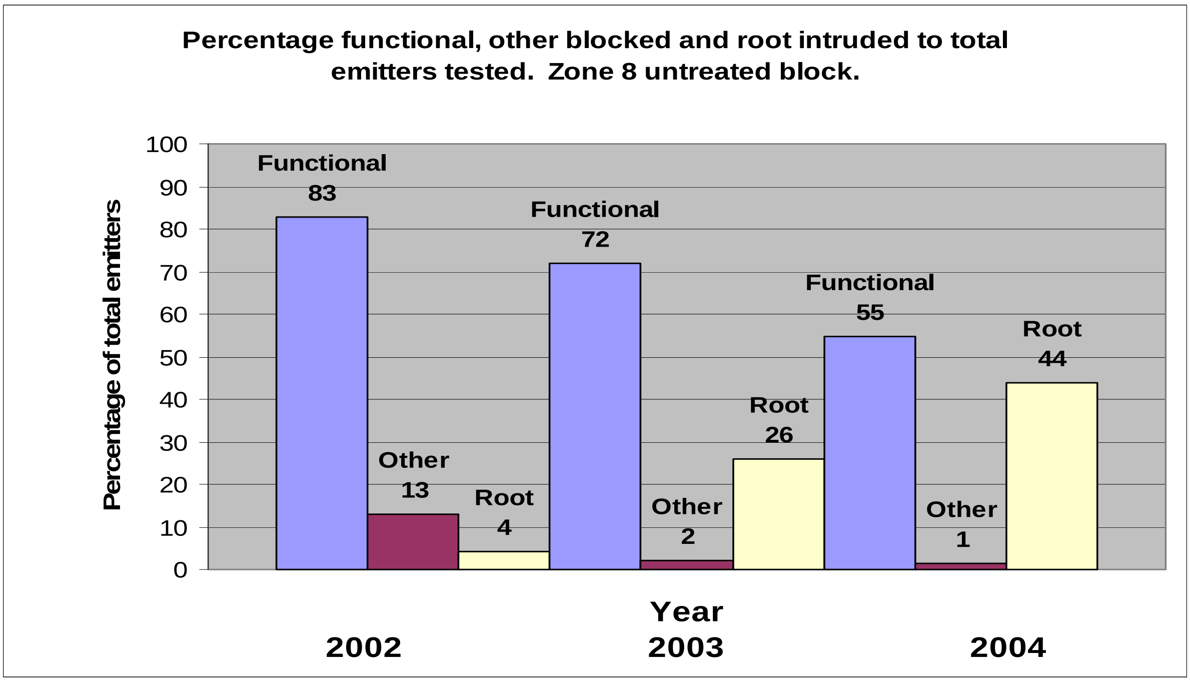

Figure 21: Percentage functional, root intruded and other clogged to total emitters tested, Zone 8: Untreated block

From Figure 21 (untreated block), a considerable decline in percentage functional emitters over the duration of installation can clearly be seen. This decrease in functional emitters' percentage coincided with the dramatic increase in percentage root clogged and a decrease in the other clogged percentage, over time.

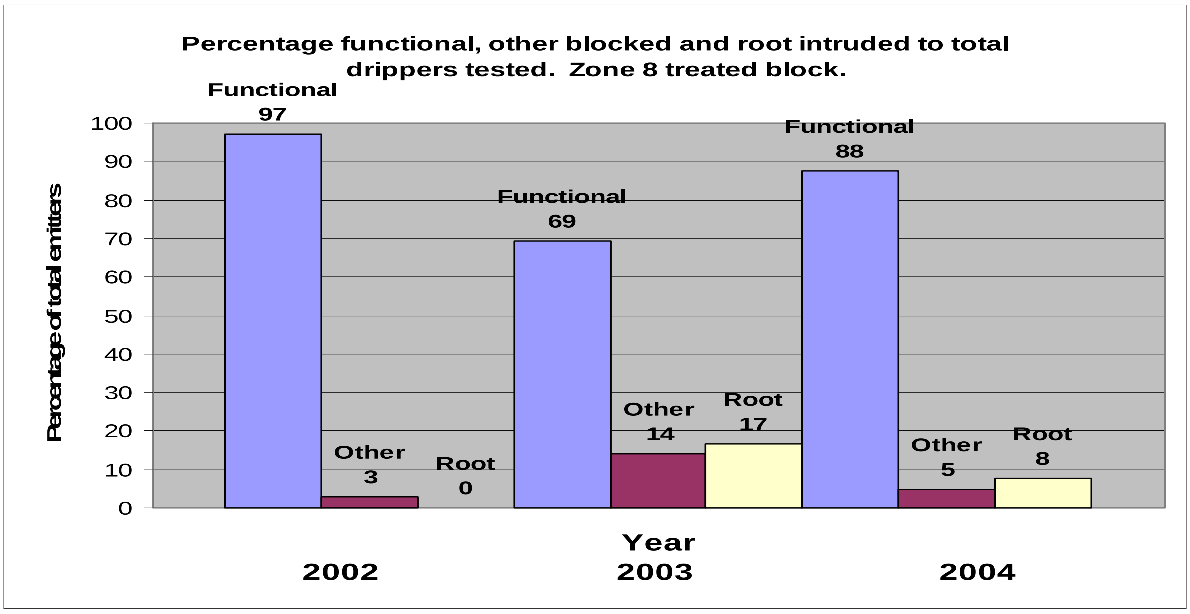

Figure 22: Percentage functional, root intruded and other clogged to total emitters tested, Zone 8: Treated block

From Figure 22 (treated block), a decline in percentage of functional emitters over the first 30 months since installation, can be noted. An increased percentage functional emitters can be noted for the laterals which were removed after 42 months since installation. This coincided with the variance in percentages root- and other clogged emitters.

From Figures 21 and 22), the untreated blocks show a dramatic 66,2% decrease in the percentage of functional emitters occurred over the forty two months of installation. This is linked to the 1 000% increase from 4% to 44% of root intruded emitters over the same period. The treated blocks show a 28,8% decrease and then a 27,5% increase in the percentage of functional emitters. With the root intruded emitters, an increase from 0 to 17% and then a decrease to 8% or 52,9% were measured. The cause of the decrease and the increase in the functional percentages can possibly be ascribed to a possible leakage during the Treflan treatment cycle, and thereby loosing the effect of the Treflan treatment.

4.2.3.2 **Emitter discharge categories**

In a further analysis to understand the impact of clogging better, the data of the different zones are divided into different discharge categories.

The retrieved emitters' tested emitter discharge values are categorised according to the CV_q and discharge values of the similar new dripper lines' values.

The functional emitters' discharges were tabled into three different categories. The categories are the following:

- Reduced discharge
- Average discharge
- Increased discharge

The **Average discharge** is written as **Av** and the **Coefficient of variation** as $\mathbf{CV_q}$ (for the definition of CV_q, see paragraphs 2.7 and 3.4.4).

The “**Reduced discharge category**” is where the discharge rates of the emitters fall below the discharge rate of Av ***minus*** $2 \times (CV_q)$.

The “**Average discharge category**” is where the discharge values fall between Av ***minus*** $2 \times (CV_q)$ and Av ***plus*** $2 \times (CV_q)$.

The **“Increased discharge category**” is where the discharge values are more than Av ***plus*** $2 \times (CV_q)$ (see paragraph 3.3.3: *Manufacturing uniformity*, for further details).

Tables 32 to 36 are presented according to the zones or dripper types, and in each table the results are tabled according to the year of testing (2002 represents 18 months of installation; 2003 represents 30 months of installation and 2004 represents 42 months of installation).

4.2.3.2.1 **Discharge categories of Zone 4**

The discharge categories for Zone 4 are presented in Figures 23 to 25.

Table 32: Results of laboratory tests on Zone 4 emitters retrieved from the experimental field during the years 2002 to 2004

Year. Dripper number		SAMPLE SIZE UNITS	DRIPPER CV_q (%)	AVERAGE q (ℓ/h)	PERCENTAGE EMITTERS IN DISCHARGE CATEGORY – RELATIVE TO NEW EMITTERS							REMARKS
					Discharge <=Av-3CV	*Discharge <=Av-2CV >Av-3CV*	*Discharge <=Av-1CV >Av-2CV*	*Discharge <Av+1CV >Av-1CV*	*Discharge >=Av+1CV <Av+2CV*	*Discharge >=Av+2CV <Av+3CV*	*Discharge >=Av+3CV*	
2002	Zone 4	**100**	**2.1**	**1.7**	**2**	**7**	**15**	**51**	**18**	**4**	**2**	**New**
Untreated						**76.0**		**20.1**		**3.9**		**Avg category %**
3402		62	44.5	1.4	87.1	4.8	4.8	1.6	0.0	0.0	1.6	
5402		43	34.3	1.5	30.2	2.3	30.2	20.9	9.3	4.7	2.3	
10402		49	96.2	1	93.9	0.0	0.0	2.0	0.0	0.0	4.1	
Treated						**78.1**		**17.4**		**4.5**		**Avg category %**
25402		69	36	2	44.9	2.9	13.0	21.7	5.8	4.3	7.2	
27402		48	42	1	97.9	0.0	2.1	0.0	0.0	0.0	0.0	
32402		65	41	2	67.7	10.8	10.8	7.7	0.0	1.5	1.5	
41402		60	44	1	91.7	5.0	1.7	0.0	0.0	0.0	1.7	
2003		**100**	**2.1**	**1.7**	**2**	**7**	**15**	**51**	**18**	**4**	**2**	**New**
Untreated						**67.9**		**26.6**		**5.5**		**Avg category %**
3404		53	137.3	0.7	86.8	7.5	0.0	5.7	0.0	0.0	0.0	
5404		57	70.7	1.1	49.1	1.8	8.8	29.8	5.3	5.3	0.0	
10404		63	80.5	1.2	65.1	7.9	11.1	7.9	4.8	0.0	3.2	
19404		64	92.5	1.2	56.3	0.0	3.1	23.4	4.7	4.7	7.8	
Treated						**58.6**		**24.1**		**17.3**		**Avg category %**
25404		59	103.2	0.8	79.7	10.2	6.8	1.7	0.0	0.0	1.7	
27404		54	142.1	0.8	61.1	3.7	14.8	7.4	7.4	3.7	1.9	
32404		55	30.6	1.5	27.3	1.8	1.8	20.0	20.0	9.1	20.0	
41404		23	47.7	1.5	34.8	0.0	0.0	4.3	4.3	0.0	56.5	
2004		**100**	**2.1**	**1.7**	**2**	**7**	**15**	**51**	**18**	**4**	**2**	**New**
Untreated						**69.4**		**22.5**		**8.1**		**Avg category %**
5406		50	58.5	1.5	64.0	10.0	12.0	6.0	6.0	2.0	0.0	
10406		51	101.3	0.8	66.7	2.0	2.0	5.9	3.9	2.0	17.6	
19406		59	68.2	1.3	52.5	13.6	8.5	15.3	6.8	1.7	1.7	
Treated						**43.3**		**36.5**		**20.2**		**Avg category %**
25406		56	48.5	1.5	0.0	0.0	50.0	0.0	0.0	0.0	50.0	
27406		61	52.2	1.4	45.9	4.9	14.8	18.0	8.2	4.9	3.3	
32406		56	41.2	1.5	44.6	5.4	12.5	17.9	5.4	3.6	10.7	
41406		30	29.9	1.5	83.3	13.3	0.0	3.3	0.0	0.0	0.0	

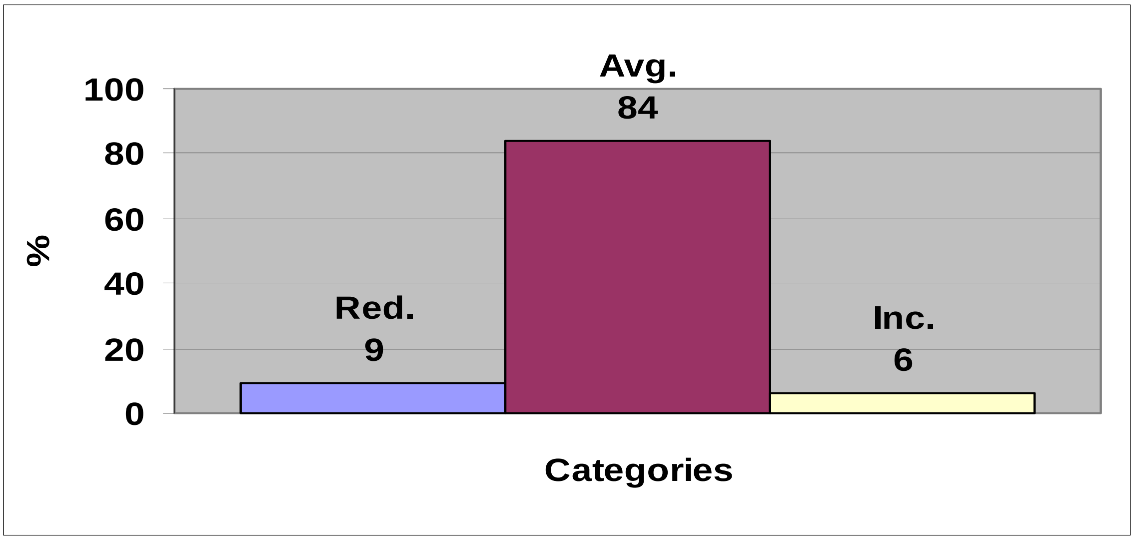

Figure 23: Zone 4: Discharge categories: New

From Figure 23 and in relation to the said categories, as stated in paragraph 4.2.3.2, the average discharge rate (delivery rate) for this emitter is only 84% which is lower than the accepted 95% industry norm.

The CV_q value for the new emitter is 2,1%. According to the ARC-ILI Hydrolab's criteria for "point source" emitters, it is classified as "Excellent".

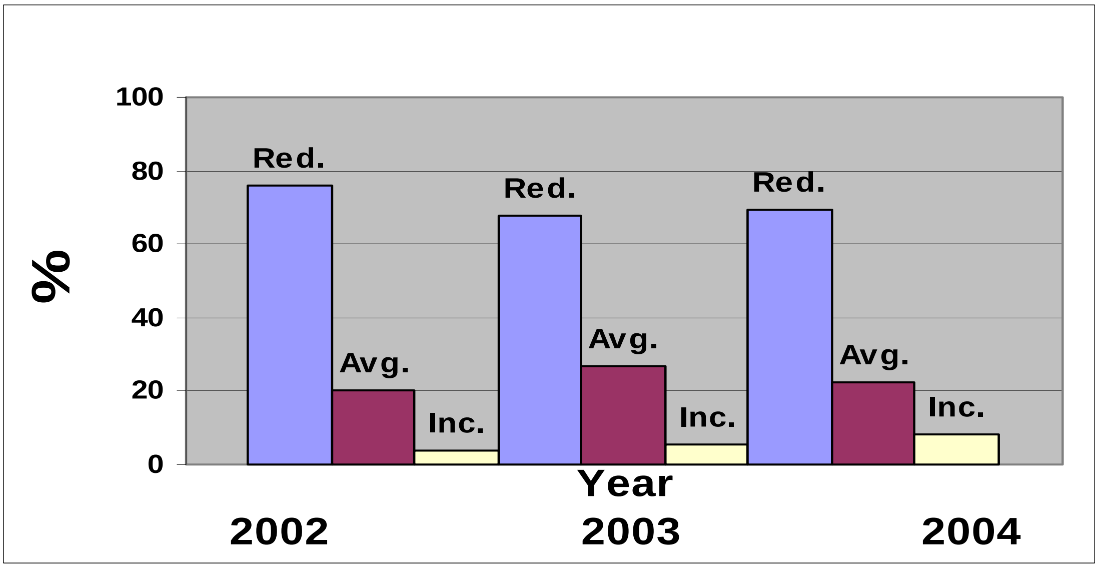

Figure 24: Zone 4: Discharge categories: Untreated

The *average discharge category* for the retrieved emitters in the untreated block varied from 20,1% to 26,6% over the 42 month period. The *reduced discharge category* "stabilised" at 67% over the 42 months. The reduced discharge percentage indicates the clogging of emitters and it is further discussed with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration (see Tables 45 and 46).

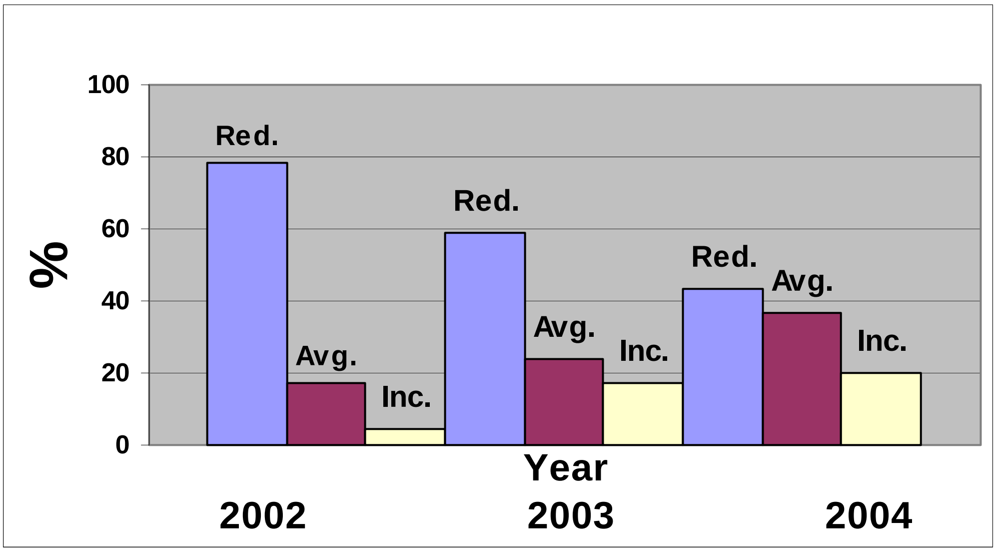

Figure 25: Zone 4: Discharge categories: Treated

The *average discharge category* for the retrieved emitters in the treated block varied from 17,4% to 26,5% over the 42 month period. The *reduced discharge category* decreased from 78,1% to 43,3% over the 42 months. An increase in the *increased discharge category* reached 20,2% after 42 months.

The decrease in the *reduced discharge category* can possibly indicate "self-cleaning" of emitters over time and is further discussed with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration (see Tables 45 and 46).

Comparing untreated to treated discharge categories, in both instances the average discharge remained constant at ±20% where in the treated blocks discharges changed more dramatically from reduced to increased over the three years, compared to the untreated blocks.

4.2.3.2.2 **Discharge categories of Zone 5**

The discharge categories for Zone 5 are presented in Figures 26 to 28.

Table 33: Results of laboratory tests on Zone 5 emitters retrieved from the experimental field during the years 2002 to 2004

Year. Dripper number	Zone 5	SAMPLE SIZE UNITS	DRIPPER CV_q (%)	AVERAGE q (ℓ/h)	PERCENTAGE EMITTERS IN DISCHARGE CATEGORY – RELATIVE TO NEW EMITTERS							REMARKS
					Discharge <=Av-3CV	*Discharge <=Av-2CV >Av-3CV*	*Discharge <=Av-1CV >Av-2CV*	*Discharge <Av+1CV >Av-1CV*	*Discharge >=Av+1CV <Av+2CV*	*Discharge >=Av+2CV <Av+3CV*	*Discharge >=Av+3CV*	
2002		**100**	**4.2**	**2.2**	**10**	**9**	**11**	**37**	**14**	**12**	**6**	**New**
Untreated						**57.9**		**14.5**		**27.5**		**Avg category %**
2502		57	13.0	1.9	84.2	5.3	7.0	3.5	0.0	0.0	0.0	
4802		66	7.3	2.3	12.1	1.5	4.5	18.2	15.2	13.6	34.8	
12802		66	30.8	2.5	28.8	1.5	1.5	3.0	3.0	4.5	57.6	
16802		67	35.9	2	28.4	0.0	1.5	17.9	3.0	9.0	40.3	
11502		64	12.8	1.9	84.4	9.4	1.6	4.7	0.0	0.0	0.0	
15502		65	16.9	1.7	96.9	1.5	0.0	1.5	0.0	0.0	0.0	
Treated						**45.0**		**15.8**		**39.2**		**Avg category %**
24502		67	8	2.8	6.0	0.0	0.0	0.0	0.0	1.5	92.5	
30502		70	8.6	1.9	78.6	14.3	2.9	2.9	0.0	0.0	1.4	
33502		68	8.6	2	67.6	7.4	16.2	7.4	1.5	0.0	0.0	
37502		68	25.6	1.7	73.5	1.5	1.5	10.3	1.5	1.5	10.3	
34802		68	5.5	2.3	17.6	1.5	2.9	11.8	7.4	7.4	51.5	
38802		72	9.3	2.3	18.1	2.8	2.8	11.1	8.3	16.7	40.3	
40802		69	30.8	2.1	20.3	5.8	0.0	8.7	13.0	15.9	36.2	
2003		**100**	**4.2**	**2.2**	**10**	**9**	**11**	**37**	**14**	**12**	**6**	**New**
Untreated						**73.6**		**9.1**		**17.3**		**Avg category %**
2504		62	27.2	1.6	93.5	1.6	0.0	1.6	0.0	0.0	3.2	
4804		67	67.8	1.4	61.2	4.5	6.0	9.0	6.0	4.5	9.0	
8504		64	59.8	1.5	65.6	0.0	1.6	0.0	0.0	0.0	32.8	
16804		68	98.3	1	70.6	4.4	1.5	10.3	1.5	1.5	10.3	
18804		69	48.3	1.7	63.8	4.3	1.4	4.3	1.4	1.4	23.2	
Treated												**No test**
2004		**100**	**4.2**	**2.2**	**10**	**9**	**11**	**37**	**14**	**12**	**6**	**New**
Untreated						**75.8**		**7.0**		**17.2**		**Avg category %**
4806		63	34.5	1.8	71.4	3.2	4.8	0.0	0.0	6.3	14.3	
12806		58	32	1.8	63.8	3.4	3.4	3.4	6.9	3.4	15.5	
16806		54	27.4	1.5	72.2	3.7	0.0	1.9	3.7	0.0	18.5	
18806		52	33.8	1.5	86.5	0.0	0.0	1.9	1.9	0.0	9.6	
Treated						**41.9**		**15.7**		**42.3**		**Avg category %**
26806		53	14.3	2.2	34.0	5.7	1.9	9.4	5.7	3.8	39.6	
30506		66	30.8	2.5	28.8	1.5	1.5	3.0	3.0	4.5	57.6	
34806		62	24.6	2	56.5	3.2	6.5	6.5	4.8	1.6	21.0	
400806		67	19	2	30	9	1	13	6	9	31	

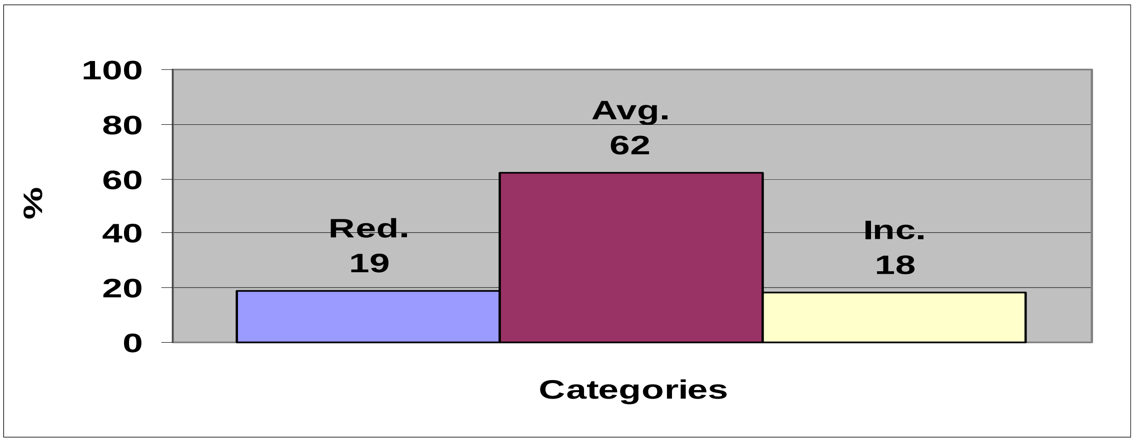

Figure 26: Zone 5: Discharge categories: New

From Figure 26, and in relation to the categories, as stated in paragraph 4.2.3.2, the average discharge for this tested emitters is a low 62% which is much lower than the 95% industry norm.

The CV_q value for the new emitter is 4,2%. According to the ARC-ILI Hydrolab's criteria for "point source" emitters, it is classified as "Good".

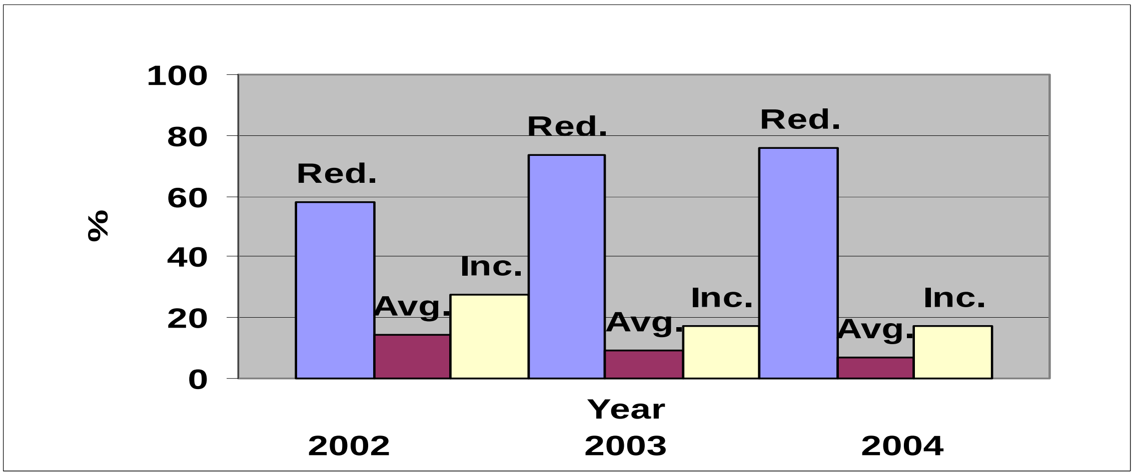

Figure 27: Zone 5: Discharge categories: Untreated

The *average discharge category* for the retrieved emitters in the untreated block varied from 14,5% to 7,0% over the 42 month period. The *reduced discharge category* increased to more than 75% over the 42 months. This is a clear indication of root intrusion and the impact in clogging.

It is discussed further with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

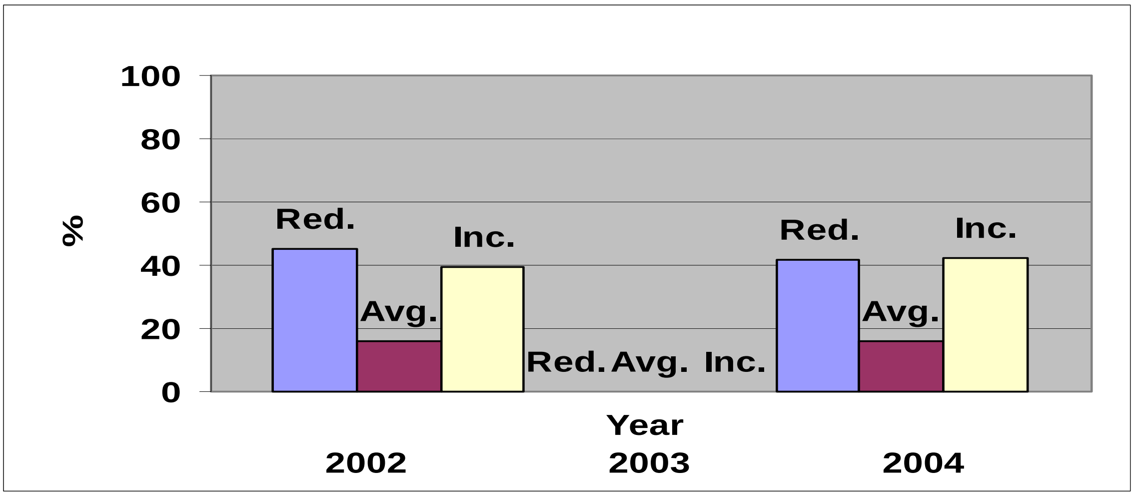

Figure 28: Zone 5: Discharge categories: Treated

The *average discharge category* for the retrieved emitters in the treated block varied around 15,7% over the 42 month period. The *reduced discharge category* percentages were in the lower 40% values over the 42 months. An increase in the *increased discharge category* reached 42,3% after 42 months and is further discussed with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

4.2.3.2.3 **Discharge categories of Zone 6**

The discharge categories for Zone 6 are presented in Figures 29 to 31.

Table 34: Results of laboratory tests on Zone 6 emitters retrieved from the experimental field during the years 2002 to 2004

Year. Dripper number	Zone 6	SAMPLE SIZE UNITS	DRIPPER CV_q (%)	AVERAGE q (ℓ/h)	PERCENTAGE EMITTERS IN DISCHARGE CATEGORY – RELATIVE TO NEW EMITTERS							REMARKS
					Discharge <=Av-3CV	*Discharge <=Av-2CV >Av-3CV*	*Discharge <=Av-1CV >Av-2CV*	*Discharge <Av+1CV >Av-1CV*	*Discharge >=Av+1CV <Av+2CV*	*Discharge >=Av+2CV <Av+3CV*	*Discharge >=Av+3CV*	***REMARKS***
2002		**100**	**2.1**	**1.6**	**2**	**8**	**15**	**49**	**12**	**9**	**4**	**New**
Untreated						**11.6**		**21.8**		**66.5**		**Avg category %**
1602		68	22.4	1.7	14.7	0.0	1.5	4.4	8.8	11.8	58.8	
7602		64	9.6	1.7	17.2	0.0	0.0	9.4	7.8	12.5	53.1	
9602		70	12.2	1.8	4.3	0.0	2.9	18.6	8.6	8.6	57.1	
13602		73	14	1.8	9.6	1.4	1.4	16.4	6.8	11.0	53.4	
Treated						**16.8**		**25.4**		**57.8**		**Avg category %**
23602		68	13.8	1.6	16.2	11.8	10.3	26.5	11.8	8.8	14.7	
29602		62	6.2	1.6	12.9	4.8	3.2	27.4	6.5	6.5	38.7	
31602		67	8.2	1.7	13.4	1.5	1.5	10.4	6.0	11.9	55.2	
35602		71	18.8	1.6	7.0	0.0	0.0	0.0	0.0	1.4	91.5	
2003		**100**	**2.1**	**1.6**	**2**	**8**	**15**	**49**	**12**	**9**	**4**	**New**
Untreated						**19.9**		**10.4**		**69.7**		**Avg category %**
1604		63	40	2.1	22.2	0.0	0.0	0.0	0.0	0.0	77.8	
7604		69	22	1.7	13.0	1.4	4.3	4.3	4.3	7.2	65.2	
13604		69	14.7	1.7	23.2	0.0	5.8	7.2	4.3	7.2	52.2	
Treated						**15.7**		**20.9**		**63.4**		**Avg category %**
23604		73	6.8	1.7	8.2	2.7	0.0	13.7	9.6	15.1	50.7	
29604		64	14.4	1.9	6.3	0.0	4.7	4.7	3.1	4.7	76.6	
31604		64	17.8	1.7	21.9	0.0	1.6	7.8	9.4	0.0	59.4	
35604		67	13.4	1.7	20.9	3.0	1.5	25.4	1.5	6.0	41.8	
2004		**100**	**2.1**	**1.6**	**2**	**8**	**15**	**49**	**12**	**9**	**4**	**New**
Untreated						**16.4**		**8.2**		**75.4**		**Avg category %**
1606		65	21.6	1.8	7.7	0.0	0.0	3.1	4.6	4.6	80.0	
7606		63	27.9	1.6	15.9	3.2	0.0	12.7	1.6	11.1	55.6	
9606		62	40.3	1.7	25.8	0.0	1.6	3.2	0.0	3.2	66.1	
13606		54	40.3	1.7	13.0	0.0	1.9	3.7	0.0	1.9	79.6	
Treated						**8.2**		**8.6**		**83.1**		**Avg category %**
23606		72	20.7	1.8	8.3	0.0	1.4	4.2	4.2	1.4	80.6	
29606		65	12.9	1.8	6.2	1.5	0.0	7.7	6.2	3.1	75.4	
31606		62	15.6	1.8	9.7	1.6	0.0	3.2	0.0	3.2	82.3	
35606		68	7.5	1.7	4.4	1.5	0.0	4.4	2.9	13.2	73.5	

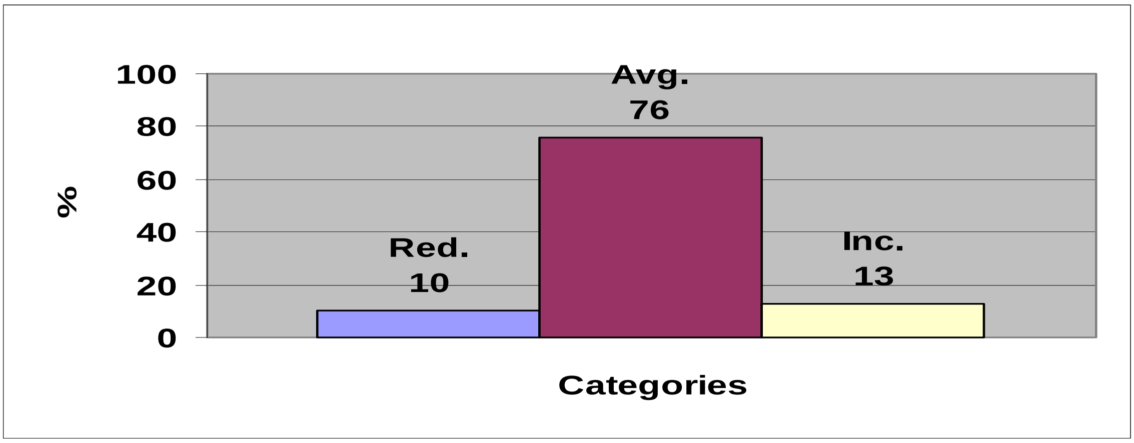

Figure 29: Zone 6: Discharge categories: New

From Figure 29, and in relation to the categories, as stated in paragraph 4.2.3.2, the average discharge rate for this emitter is only 76%. This is lower than the 95% norm for emitter discharge values.

The CV_q value for the new emitter is 2,1%. According to the ARC-ILI Hydrolab's criteria for "point source" emitters, it is classified as "Excellent".

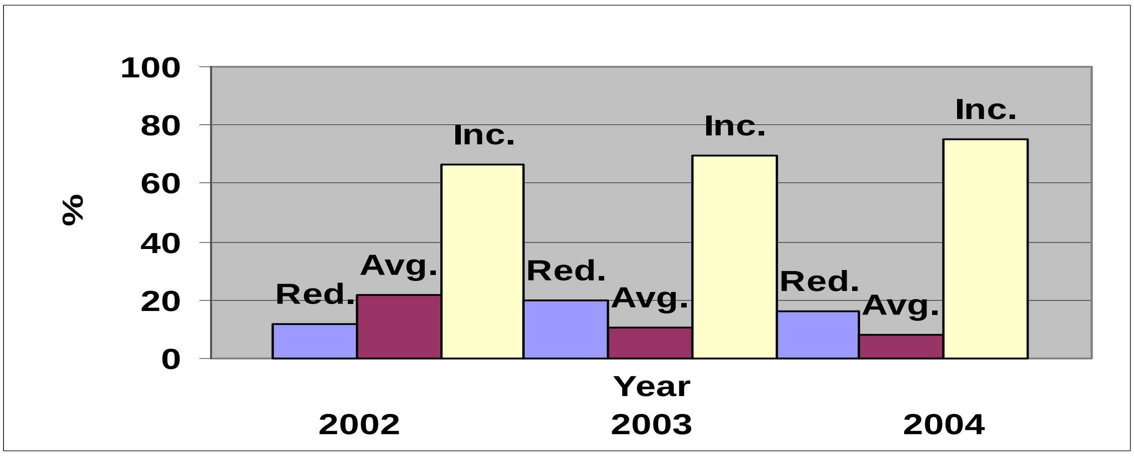

Figure 30: Zone 6: Discharge categories: Untreated

The *average discharge category* for the retrieved emitters in the untreated block varied from 21,8% to 8,2% over the 42 month period. The *reduced discharge category* increased from 11,6% to more than 16,0% over the 42 months. The *increased discharge category's* increase from 66,5 to 75,4% indicates malfunctioning or "irritated" outlet mechanisms which can be caused by root intrusion. Pressure compensated emitter mechanisms can increase their delivery rates if the diaphragm is subject to root intrusion and it is further discussed with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

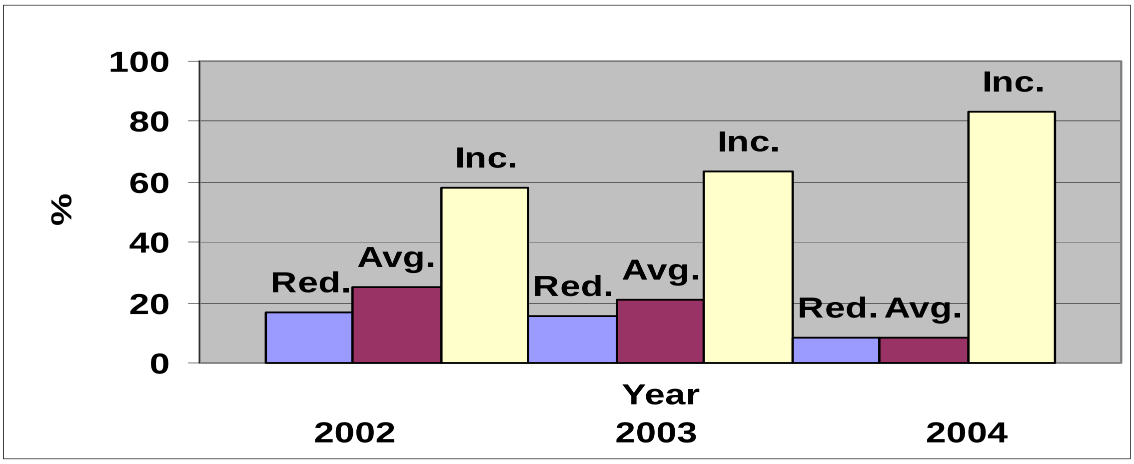

Figure 31: Zone 6: Discharge categories: Treated

The *average discharge category* for the retrieved emitters in the treated block varied from 25,4% to 8,6% over the 42 month period. The *reduced discharge category* decreased from 16,8 to 8,2% over the 42 months. The *increased discharge category's* increase from 57,8 to 83,1% indicates a malfunctioning or "irritated" outlet mechanisms. The cause could be root intrusion and it is further discussed with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

4.2.3.2.4 **Discharge categories of Zone 7**

The discharge categories for Zone 7 are presented in Figures 32 to 33.

Table 35: Results of laboratory tests on Zone 7 emitters retrieved from the experimental field during the years 2002 to 2004												
Year. Dripper number	Zone 7	**SAMPLE SIZE UNITS**	**DRIPPER CV_q (%)**	**AVERAGE q (ℓ/h)**	**PERCENTAGE EMITTERS IN DISCHARGE CATEGORY – RELATIVE TO NEW EMITTERS**							
					Discharge <=Av-3CV	*Discharge <=Av-2CV >Av-3CV*	*Discharge <=Av-1CV >Av-2CV*	*Discharge <Av+1CV >Av-1CV*	*Discharge >=Av+1CV <Av+2CV*	*Discharge >=Av+2CV <Av+3CV*	*Discharge >=Av+3CV*	***REMARKS***
2002		**100**	**2.4**	**1.23**	**2**	**2**	**14**	**61**	**14**	**5**	**1**	**New**
Untreated						**29.6**		**9.0**		**61.4**		**Avg category %**
6702		68	21.6	1.3	20.6	2.9	0.0	1.5	1.5	2.9	70.6	
28702		60	90.8	0.8	33.3	0.0	1.7	3.3	10.0	11.7	40.0	
36702		70	34.3	1.2	37.1	2.9	1.4	1.4	8.6	18.6	30.0	
14702		79	37.5	1.2	22.8	0.0	1.3	2.5	3.8	7.6	62.0	
Treated						**22.7**		**29.6**		**47.6**		**Avg category %**
17702		67	34	1	17.9	0.0	0.0	7.5	4.5	6.0	64.2	
20702		68	36	1	22.1	1.5	11.8	32.4	23.5	1.5	7.4	
39702		40	27	1	27.5	5.0	10.0	20.0	7.5	17.5	12.5	
42702		58	24	2	20.7	0.0	0.0	0.0	0.0	1.7	77.6	
2003		**100**	**2.4**	**1.23**	**2**	**2**	**14**	**61**	**14**	**5**	**1**	**New**
Untreated						**46.8**		**8.3**		**61.3**		**Avg category %**
6704		84	54.9	1.1	34.5	1.2	1.2	11.9	3.6	6.0	41.7	
14704		74	107.9	0.7	59.5	2.7	1.4	4.1	1.4	4.1	27.0	
17704		77	69.7	0.9	36.4	0.0	2.6	1.3	0.0	5.2	54.5	
20704		79	93.6	1.2	54.4	0.0	0.0	3.8	1.3	0.0	40.5	
Treated						**40.8**		**22.1**		**36.8**		**Avg category %**
28704		64	61.5	1	39.1	0.0	4.7	4.7	0.0	6.3	45.3	
36704		76	57	0.9	47.4	2.6	3.9	11.8	7.9	11.8	14.5	
39704		69	56.4	1	30.4	1.4	2.9	10.1	11.6	8.7	34.8	
42704		53	58	0.9	39.6	1.9	3.8	18.9	9.4	5.7	20.8	
2004		**100**	**2.4**	**1.23**	**2**	**2**	**14**	**61**	**14**	**5**	**1**	**New**
Untreated						**49.6**		**7.8**		**42.6**		**Avg category %**
6706		54	51.9	1.2	37.0	1.9	3.7	0.0	7.4	7.4	42.6	
14706		56	88.2	1.3	58.9	1.8	0.0	0.0	0.0	0.0	39.3	
17706		60	60.8	1.1	38.3	1.7	1.7	3.3	3.3	5.0	46.7	
20706		60	76.4	1	55.0	3.3	1.7	5.0	5.0	3.3	26.7	
Treated						**29.1**		**5.0**		**65.9**		**Avg category %**
28706		57	34.4	1.2	26.3	0.0	0.0	5.3	0.0	17.5	50.9	
36706		54	62.3	1.2	42.6	0.0	0.0	3.7	0.0	1.9	51.9	
39706		53	9.4	1.3	3.8	0.0	1.9	3.8	3.8	1.9	84.9	
42706		56	59.5	1.3	42.9	0.0	0.0	1.8	0.0	0.0	55.4	

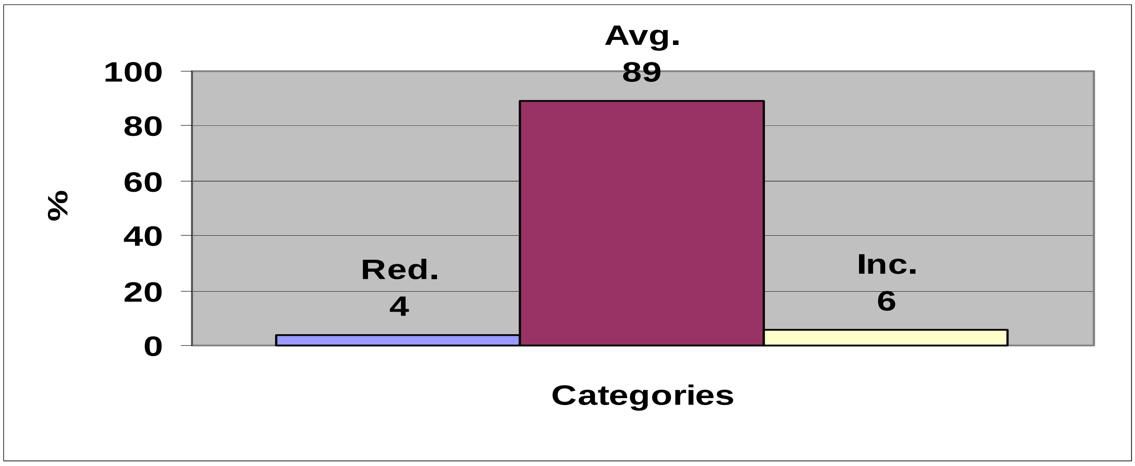

Figure 32: Zone 7: Discharge categories: New

From Figure 32, and in relation to the categories, as stated in paragraph 4.2.3.2, the average discharge for this emitter is 89% which is lower than the 95% norm for emitter discharge values.

The CV_q value for the new emitter is 2,4%. According to the ARC-ILI Hydrolab's criteria for "point source" emitters, it is classified as "Excellent".

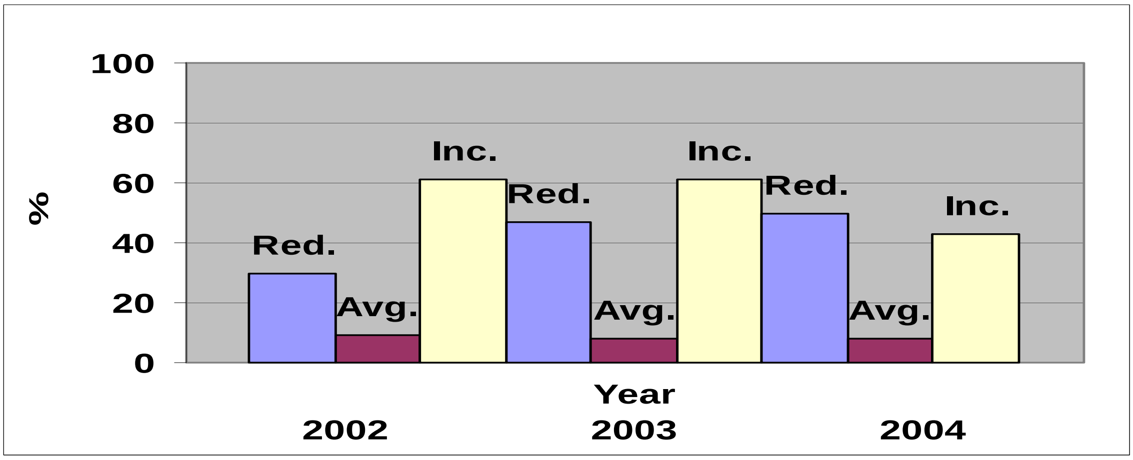

Figure 33: Zone 7: Discharge categories: Untreated

The *average discharge category* for the retrieved emitters in the untreated block varied from 9,0 to 7,8% over the 42 month period. The *reduced discharge category* increased to more than 49% over the 42 months. This is an indication of root intrusion and therefore clogging. The increased discharge category declined from 61,4 to 42,6% over the same period which is an indication of clogging over time and it is further discussed with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

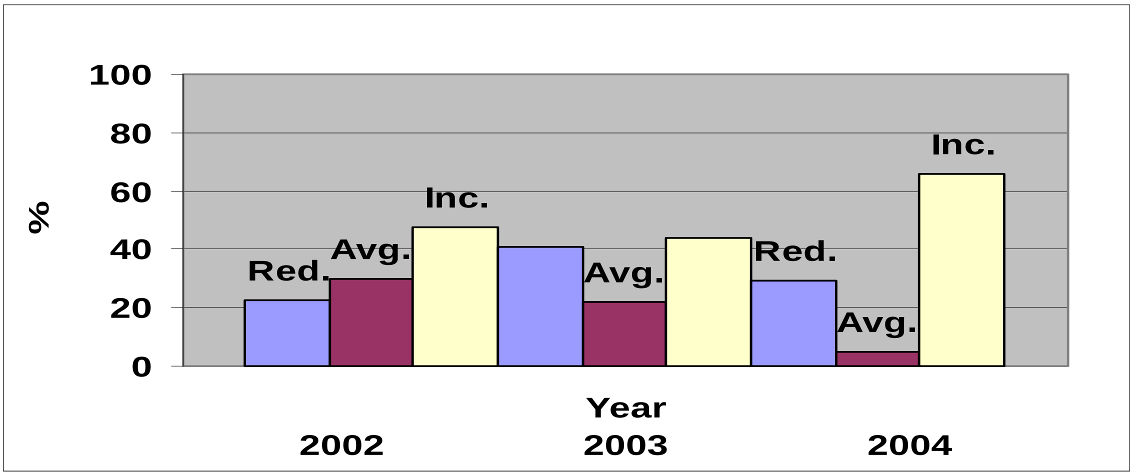

Figure 34: Zone 7: Discharge categories: Treated

The *average discharge category* for the retrieved emitters in the treated block varied from 29,6 to 5,0% over the 42 month period. The *reduced discharge category* increased from 22,7 to 29,1% over the 42 months. The *increased discharge category's* increase from 47,6 to 65,9%. The cause could be root intrusion, and is further discussed with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

4.2.3.2.5 **Discharge categories of Zone 8**

The discharge categories for Zone 8 are presented in Figures 35 to 37.

Table 36: Results of laboratory tests on Zone 8 emitters retrieved from the experimental field during the years 2002 to 2004

Year. Dripper number		SAMPLE SIZE UNITS	DRIPPER CV_q (%)	AVERAGE q (ℓ/h)	PERCENTAGE EMITTERS IN DISCHARGE CATEGORY – RELATIVE TO NEW EMITTERS							REMARKS
					Discharge <=Av-3CV	*Discharge <=Av-2CV >Av-3CV*	*Discharge <=Av-1CV >Av-2CV*	*Discharge <Av+1CV >Av-1CV*	*Discharge >=Av+1CV <Av+2CV*	*Discharge >=Av+2CV <Av+3CV*	*Discharge >=Av+3CV*	
2002	Zone 8	**100**	**4.4**	**2**	**6**	**12**	**14**	**33**	**17**	**9**	**8**	**New**
Untreated						**33.3**		**46.7**		**20.0**		**Avg category %**
8502		60	13	2.6	25	8.3	5	31.7	10	11.7	8.3	
Treated						**6.8**		**90.4**		**2.7**		**Avg category %**
26802		73	36.5	2.1	6.8	0	1.4	82	6.8	0	2.7	
2003		**100**	**4.4**	**2**	**6**	**12**	**14**	**33**	**17**	**9**	**8**	**New**
Untreated						**13.0**		**85.4**		**1.6**		**Avg category %**
12804		68	80.1	1.1	0	0	26.5	52.9	20.6	0	0	
11504		63	52.3	2	27.0	11.1	14.3	30.2	14.3	1.6	1.6	
15504		54	94.4	0.9	0	0	0.0	74.1	24.1	1.9	0	
Treated						**10.8**		**89.2**		**0.0**		**Avg category %**
26804		62	77.7	1.5	0	0	40.3	50.0	9.7	0	0	
34804		58	92.7	1.5	0	0	51.7	44.8	3.4	0	0	
38804		54	81.4	1.3	0	0	33.3	33.3	33.3	0	0	
40804		49	88.5	1.2	0	0	40.8	30.6	28.6	0	0	
24504		57	40.4	1.6	19.3	0.0	3.5	66.7	10.5	0	0	
30504		57	44.8	1.5	21.1	0.0	3.5	61.4	14.0	0	0	
33504		62	55.5	1.6	0.0	25.8	1.6	67.7	4.8	0	0	
37504		66	44.8	1.7	18.2	0.0	6.1	43.9	31.8	0	0	
2004		**100**	**4.4**	**2**	**6**	**12**	**14**	**33**	**17**	**9**	**8**	**New**
Untreared						**10.7**		**89.3**		**0.0**		**Avg category %**
2506		47	58.5	1.5	0	0	0	74.5	25.5	0	0	
8506		44	100	1	0	0	0	84.1	15.9	0	0	
11506		56	73.8	1.7	0	39.3	3.6	26.8	30.4	0	0	
15506		58	81.4	1.6	0	0.0	46.6	27.6	25.9	0	0	
Treated						**38.6**		**60.6**		**0.8**		**Avg category %**
24506		66	46.8	2.6	10.6	1.5	3.0	83.3	1.5	0.0	0.0	
33506		61	57.1	2	24.6	3.3	3.3	19.7	47.5	1.6	0.0	
38806		65	16	2.7	1.5	1.5	0.0	0.0	3.1	0.0	93.8	
37506		67	42.9	2.4	11.9	3.0	3.0	40.3	40.3	0.0	1.5	

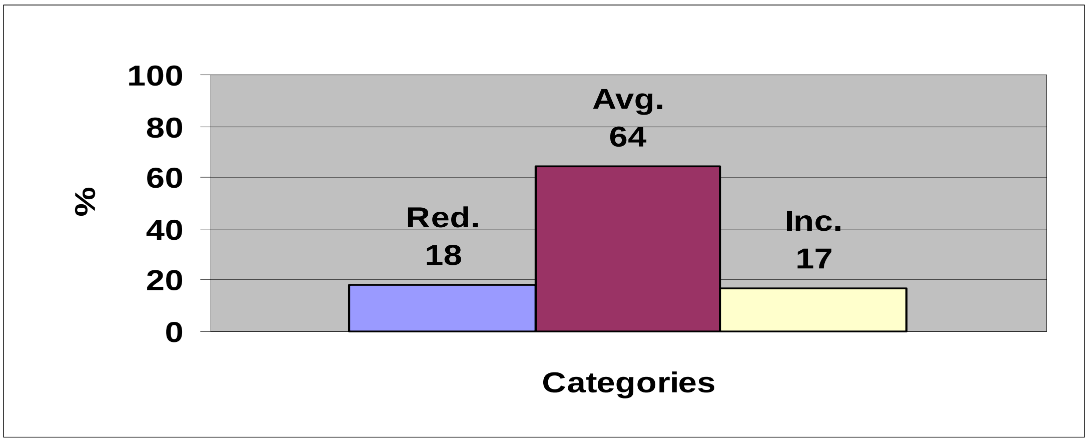

Figure 35: Zone 8: Discharge categories: New

From Figure 35, and in relation to the categories, as stated in paragraph 4.2.3.2, the average discharge for this emitter is a low 64% which is lower than the 95% accepted industry norm.

The CV_q value for the new emitter is 4,4%. According to the ARC-ILI Hydrolab's criteria for "point source" emitters, it is classified as "Good".

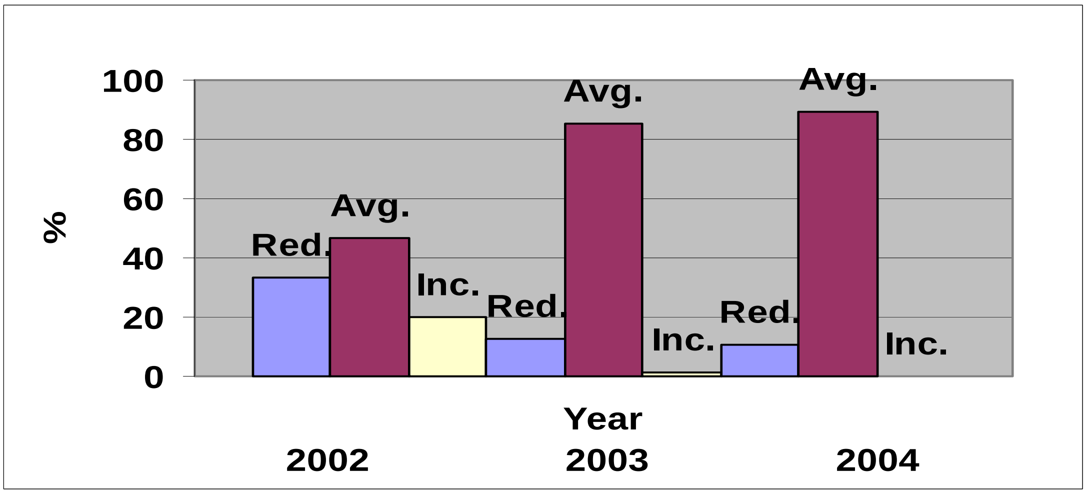

Figure 36: Zone 8: Discharge categories: Untreated

The *average discharge category* for the retrieved emitters in the untreated block increased from 46,7 to 89,3% over the 42 month period. The *reduced discharge category* decreased to 10,7% over the 42 months.

The performance of the dripper is further discussed with regard to inherent characteristics in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

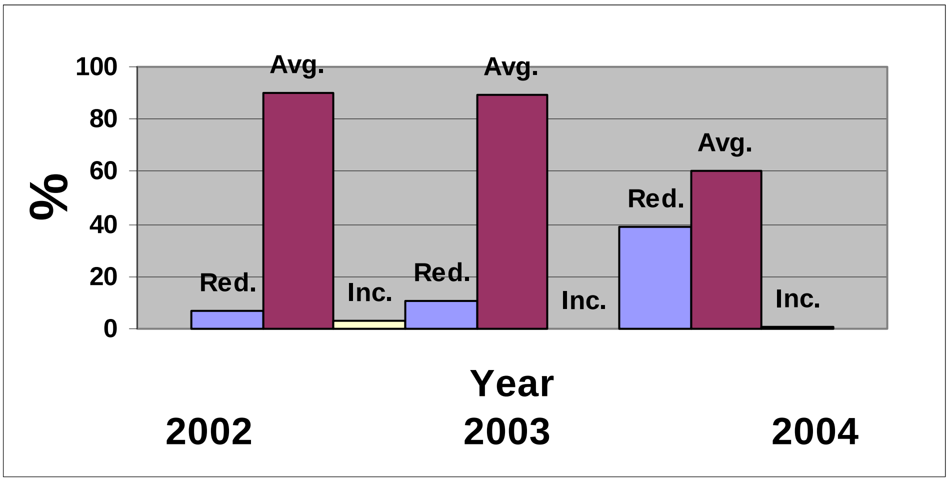

Figure 37: Zone 8: Discharge categories: Treated

The *average discharge category* for the retrieved emitters in the treated block varied from 90,4 to 52,6% over the 42 month period. The *reduced discharge category* increased to 46,9% over the 42 months which is an indication of root intrusion and it is further discussed with regard to inherent characteristics of this emitter type in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

4.2.3.3 **Root intruded and other clogged emitters**

In these tests, the emitters were analysed in terms of clogged emitters and was categorised according to the definitions set out in paragraph 4.2.2. The results are listed in Tables 37 to 39 and graphically presented in Figures 38 to 47.

The clogged emitters was further examined under a microscope and categorized as follows:

- Apparent clean aperture
- Soiled aperture
- Soil in aperture
- Root in aperture

The full description of the category is described in paragraph 4.2.3.4 with photographs on their appearance.

Table 37: 2002. Labotatory test results.

Zone 4	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.% other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
3402	Aug -02	63	10	44.5	1.4		3	2	5	50.0	9.8	15.9	8.4	1.5	62.6	Untreated
5402	March 02	43	5	34.3	1.5		2	2	1	20.0		11.6				47.2
10402	Sept 02	49	16	96.2	1.0	5			11	68.8		32.7				
19402	Sept 02	60	8	75.2	1.9		3	1	4	50.0		13.3				
25402	Feb 02	69	12	35.5	1.6		9	2	1	8.3	2.1	17.4	13.2	1.5	40.6	Treated
27402	Okt 02	48	6	41.8	1.3	6				0.0		12.5				12.9
32402	Okt 02	65	8	41.3	1.5	6			2	25.0		12.3				
41402	Okt 02	60	11	43.8	1.4		6	3	2	18.2		18.3				
Zone 5	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.% other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
2502	May-02	57	6	13	1.9	2		2	2	33.3	6.5	10.5	4.2	2.1	19.5	Untreated
4802	July 02	66	2	7.3	2.3				2	100.0		3.0				71.0
12802	April 02	66	14	30.8	2.5		4	4	6	42.9		21.2				
16802	April 02	67	8	35.9	2.0	1		3	4	50.0		11.9				
11502	Jun-02	64	4	12.8	1.9				4	100.0		6.3				
15502	Jun-02	65	7	16.9	1.7				7	100.0		10.8				
24502	March 02	67	1	8	2.8			1		0.0	1.9	1.5	3.1	2.2	13.8	Treated
30502	April 02	70	1	8.6	1.9			1		0.0		1.4				24.8
33502	May-02	68	2	8.6	2.0			2		0.0		2.9				
37502	May-02	68	5	25.6	1.7			3	2	40.0		7.4				
34802	April 02	68	5	5.5	2.3	4		1		0.0		7.4				
38802	April 02	72	4	9.3	2.3	2			2	50.0		5.6				
40802	July 02	70	6	30.8	2.1			1	5	83.3		8.6				
Zone 6	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.% other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
1602	May-02	68	3	22.4	1.7	2	1			0.0	0.0	4.4	1.1	1.8	14.6	Untreated
7602	May-02	64	0	9.6	1.7					0.0		0.0				0.0
9602	Jun-02	70	0	12.2	1.8					0.0		0.0				
13602	Jul 02	73	0	14	1.8					0.0		0.0				
23602	Feb 02	68	1	13.8	1.6			1		0.0	0.0	1.5	1.1	1.6	11.8	Treated
29602	March 02	62	0	6.2	1.6					0.0		0.0				0.0
31602	Jun-02	67	0	8.2	1.7					0.0		0.0				
35602	Jun-02	71	2	18.8	1.6			2		0.0		2.8				
Zone 7	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.% other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
6702	March 02	68	4	21.6	1.3				4	100.0	7.9	5.9	2.2	1.1	46.1	Untreated
28702	Okt 02	60	14	90.8	0.8	4			10	71.4		23.3				82.4
36702	Okt 02	70	4	34.3	1.2	1			3	75.0		5.7				
14702	Aug -02	79	6	37.5	1.2		1		5	83.3		7.6				
17702	Aug -02	67	6	33.8	1.2	1			5	83.3	4.3	9.0	3.4	1.2	30.0	Treated
20702	Sept 02	68	6	35.9	1.1	1			5	83.3		8.8				41.7
39702	Sept 02	40	3	26.7	1.1	2	1			0.0		7.5				
42702	Okt 02	58	3	23.6	1.5	1	1	1		0.0		5.2				
Zone 8	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.% other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
8502	April 02	60	7	13	2.6	1	2	1	2	28.6	4.1	11.7	13.0	2.6	13.0	Untreated
18802		63	15	Not tested	Not tested	11		1	3	20.0		23.8				24.3
26802	March 02	73	2	36.5	2.1	1		1		0.0	0.0	2.7	2.7	2.1	36.5	Treated
																0.0

Table 38: 2003. Labotatory test results.

Zone 4	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
3404	Apr.03	53	21	137.3	0.7		3	11	7	33.3	18.6	39.6	14.3	1.1	95.3	Untreated
5404	May 03	57	19	70.7	1.1	3	3	1	12	63.2		33.3				57.2
10404	Apr.03	63	16	80.5	1.2			5	11	68.8		25.4				
19404	Apr.03	64	22	92.5	1.2	2	2	4	14	63.6		34.4				
25404	Apr.03	59	14	103.2	0.8	2	7	1	4	28.6	6.8	23.7	14.7	1.2	80.9	Treated
27404	Apr.03	54	18	142.1	0.8	2	7	2	7	38.9		33.3				28.1
32404	May 03	55	5	30.6	1.5		2	2	1	20.0		9.1				
41404	Apr.03	23	4	47.7	1.5		2	1	1	25.0		17.4				
Zone 5	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
2504	May 03	62	4	27.2	1.6	1	1		2	50.0	24.8	6.5	3.8	1.4	60.3	Untreated
8504	May 03	54	15	59.8	1.5			1	14	93.3		27.8				78.2
4804	May 03	67	19	67.8	1.4			3	16	84.2		28.4				
16804	May 03	68	32	98.3	1.0		4		28	87.5		47.1				
18804	May 03	68	25	48.3	1.7	1	1		19	76.0		36.8				
No Drippers Tested																Treated 0
Zone 6	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
1604	May 03	63	6	40.0	2.1	0	1	0	5	83.3	2.3	9.5	2.3	1.8	22.6	Untreated
7604	May 03	69	2	22.0	1.7	0	1	0	1	50.0		2.9				33.3
9604	Apr.03	65	2	13.7	1.7	1		1		0.0		3.1				
13604	Apr.03	69	2	14.7	1.7	1		1		0.0		2.9				
23604	Apr.03	73	2	6.8	1.7	1		1		0.0	0.0	2.7	1.9	1.8	13.1	Treated
29604	Apr.03	64	2	14.4	1.9	1	1			0.0		3.1				0.0
31604	Apr.03	64	1	17.8	1.7			1		0.0		1.6				
35604	Apr.03	67	2	13.4	1.7					0.0		3.0				
Zone 7	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
6704	May 03	84	22	54.9	1.1	3			19	86.4	35.4	26.2	3.2	1.0	81.5	Untreated
14704	May 03	74	36	107.9	0.7	4		2	30	83.3		48.6				91.8
17704	May 03	77	23	69.7	0.9				23	100.0		29.9				
20704	May 03	79	40	93.6	1.2	1			39	97.5		50.6				
28704	May 03	64	19	61.5	1.0	8			11	57.9	17.2	29.7	7.6	1.0	58.2	Treated
36704	May 03	76	17	57.0	0.9	4			13	76.5		22.4				70.0
39704	May 03	69	15	56.4	1.0	6			9	60.0		21.7				
42704	May 03	53	14	58.0	0.9	2			12	85.7		26.4				
Zone 8	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
12804	May 03	68	21	80.1	1.1			1	20	95.2	25.9	30.9	2.2	1.3	75.6	Untreated
11504	May 03	63	15	52.3	2.0			1	14	93.3		23.8				92.0
15504	May 03	54	16	94.4	0.9			2	14	87.5		29.6				
26804	May 03	62	25	77.7	1.5	2		17	6	24.0	16.6	40.3	14.0	1.5	65.7	Treated
34804	May 03	58	30	92.7	1.5	3	1	4	22	73.3		51.7				54.5
38804	May 03	54	18	81.4	1.3	4	1	7	6	33.3		33.3				
40804	May 03	49	20	88.5	1.2	3	1	2	14	70.0		40.8				
24504	May 03	57	11	40.4	1.6			1	10	90.9		19.3				
30504	May 03	57	11	44.8	1.5			10	1	9.1		19.3				
33504	May 03	62	16	55.5	1.6	2		4	10	62.5		25.8				
37504	May 03	66	11	44.8	1.7	1		2	8	72.7		16.7				

Table39: 2004. Labotatory test results.

Zone 4	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
3406	Not Tested									0.0	27.5	0.0	13.1	1.2	76.0	Untreated
5406	19-Feb	50	21	58.5	1.5	1	9	0	11	52.4		42.0				66.8
10406	Feb-04	51	23	101.3	0.8	0	1	0	22	95.7		45.1				
19406	Feb-04	59	21	68.2	1.3	0	8	2	11	52.4		35.6				
25406	Feb-04	56	14	48.5	1.5	1	8	2	3	21.4	5.4	25.0	15.8	1.5	43.0	Treated
27406	Feb-04	61	15	52.2	1.4	2	9	2	2	13.3		24.6				27.4
32406	Jan 04	56	10	41.2	1.5	1	3	1	5	50.0		17.9				
41406	Feb-04	30	4	29.9	1.5	0	3	0	1	25.0		13.3				
Zone 5	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
4806	Apr 04	63	20	34.5	1.8	1	3	3	13	65.0	31.3	31.7	5.4	1.7	31.9	Untreated
12806	May 04	58	14	32.0	1.8				14	100.0		24.1				86.4
16806	May 04	51	21	27.4	1.5			1	20	95.2		41.2				
18806	May 04	52	27	33.8	1.5		2	2	23	85.2		51.9				
26806	May 04	53	1	14.3	2.2			1		0.0	6.1	1.9	15.2	2.2	22.2	Treated
30506	Jan 04	62	35	30.8	2.5	7	9	13	6	17.1		56.5				32.4
34806	May 04	62	8	24.6	2.0	1	1	1	5	62.5		12.9				
40806	May 04	67	8	18.9	2.2		1	3	4	50.0		11.9				
Zone 6	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
1606	Mar 04	65	1	21.6	1.8				1	100.0	6.1	1.5	0.4	1.7	26.2	Untreated
7606	Jan 04	63	5	27.9	1.6				5	100.0		7.9				97.2
9606	Mar 04	62	9	40.3	1.7	1			8	88.9		14.5				
13606	Mar 04	54	1	15.0	1.8				1	100.0		1.9				
23606	Mar 04	72	3	20.7	1.8	2			1	33.3	1.5	4.2	2.6	1.8	14.2	Treated
29606	Mar 04	65	2	12.9	1.8				2	100.0		3.1				41.7
31606	Apr 04	62	3	15.6	1.8		1	1	1	33.3		4.8				
35606	Apr 04	68	3	7.5	1.7		3			0.0		4.4				
Zone 7	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
6706	Mar 04	54	15	51.9	1.2	2	1		12	80.0	37.6	27.8	1.3	1.2	69.3	Untreated
14706	Mar 04	55	30	88.2	1.3				30	100.0		54.5				95.0
17706	Mar 04	60	20	60.8	1.1				20	100.0		33.3				
20706	Mar 04	60	24	76.4	1.0				24	100.0		40.0				
28706	Mar 04	57	10	34.4	1.2		1		9	90.0	17.4	17.5	2.3	1.3	41.4	Treated
36706	Feb-04	54	21	62.3	1.2	1	1		19	90.5		38.9				90.6
39706	Mar 04	53	1	9.4	1.3				1	100.0		1.9				
42706	Mar 04	55	11	59.5	1.3			2	9	81.8		20.0				
Zone 8	Date Tested	Number of Emitters	Emitters Clogged	CV %	Ave. Disch. l/h	Soiled aperture	Clean aperture	Soil in aperture	Root in aperture	% Root Clogged	Ave. % Root/total	% Clogged Emitters	Ave.%other clogged	Ave. l/h Discharge	Ave. CV %	Ave % root clogg/clogg
2506	Apr 04	47	21	58.5	1.5		1		20	95.2	43.9	44.7	1.5	1.5	78.4	Untreated
8506	Apr 04	44	24	100.0	1				24	100.0		54.5				97.0
11506	Apr 04	56	21	73.8	1.7				21	100.0		37.5				
15506	Apr 04	58	27	81.4	1.6	1		1	25	92.6		46.6				
24506	Apr 04	66	4	46.8	2.6	1			3	75.0	6.9	6.1	5.0	2.4	40.7	Treated
33506	May 04	61	18	57.1	2.0	2	2	3	11	61.1		29.5				57.2
38806	May 04	65	2	16.0	2.7			1	1	50.0		3.1				
37506	Apr 04	67	7	42.9	2.4	1	2	1	3	42.9		10.4				

4.2.3.3.1 **Percentage emitters root intruded to total emitters clogged: Zone 4**

From Tables 37 to 39, the following graphs are derived.

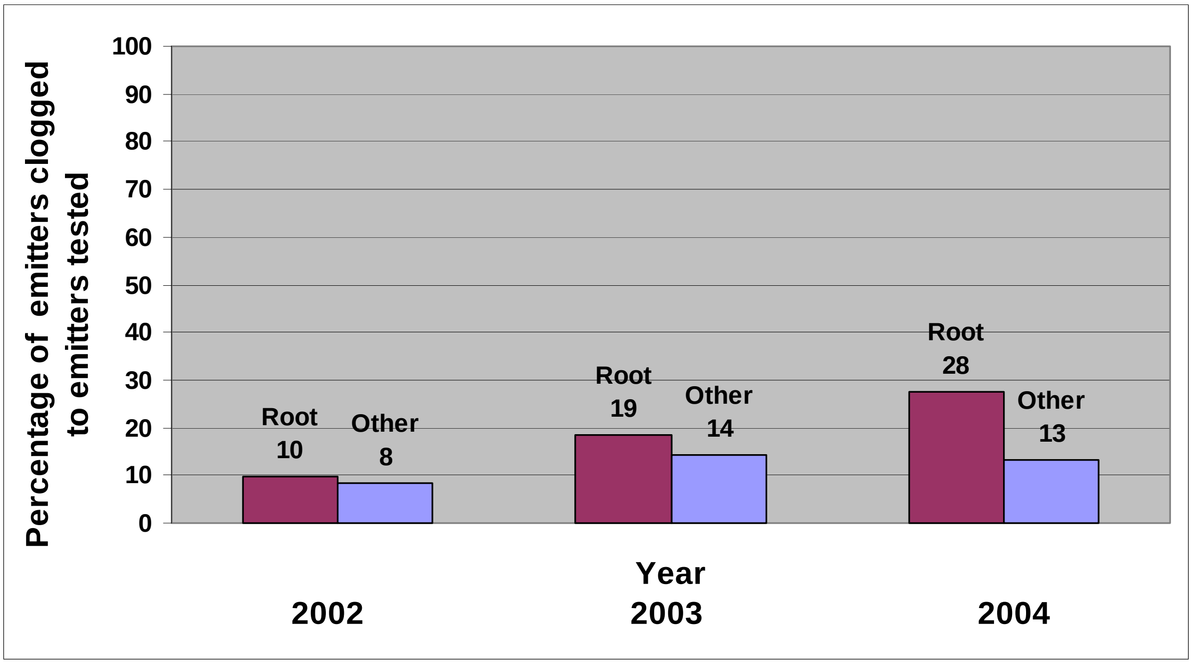

Figure 38: Zone 4: Percentage emitters root intruded to total clogged: Untreated

In Figure 38, the increase in the percentage of root clogged emitters in relation to the percentage other clogged emitters, gives an indication of the increase (109% from 2002 to 2004) of root clogging over time for the untreated zone.

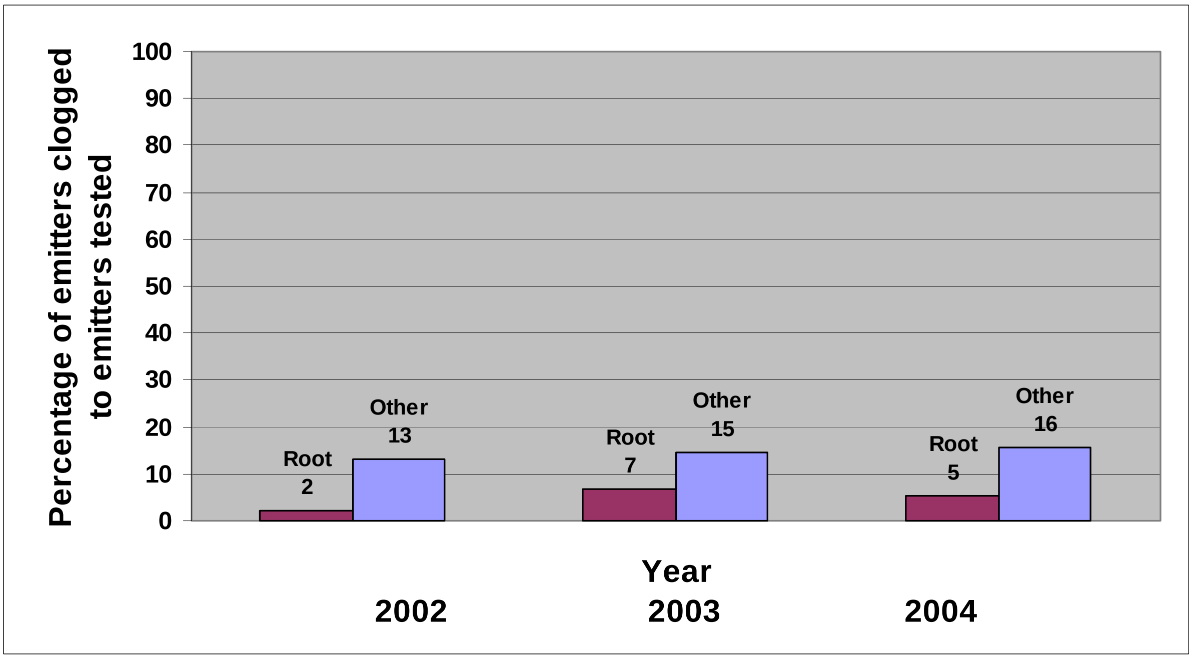

Figure 39: Zone 4: Percentage emitters root intruded to total clogged: Treated

The relative low percentage of root clogged emitters in relation to the percentage of other clogged emitters indicates the effect of the Treflan treatment.

In the treated blocks, root intrusion increased with 150% from 2% in 2002 to 5% in 2004.

4.2.3.3.2 **Percentage emitters root intruded to total emitters clogged: Zone 5**

From Tables 37 to 39, the following graphs are derived.

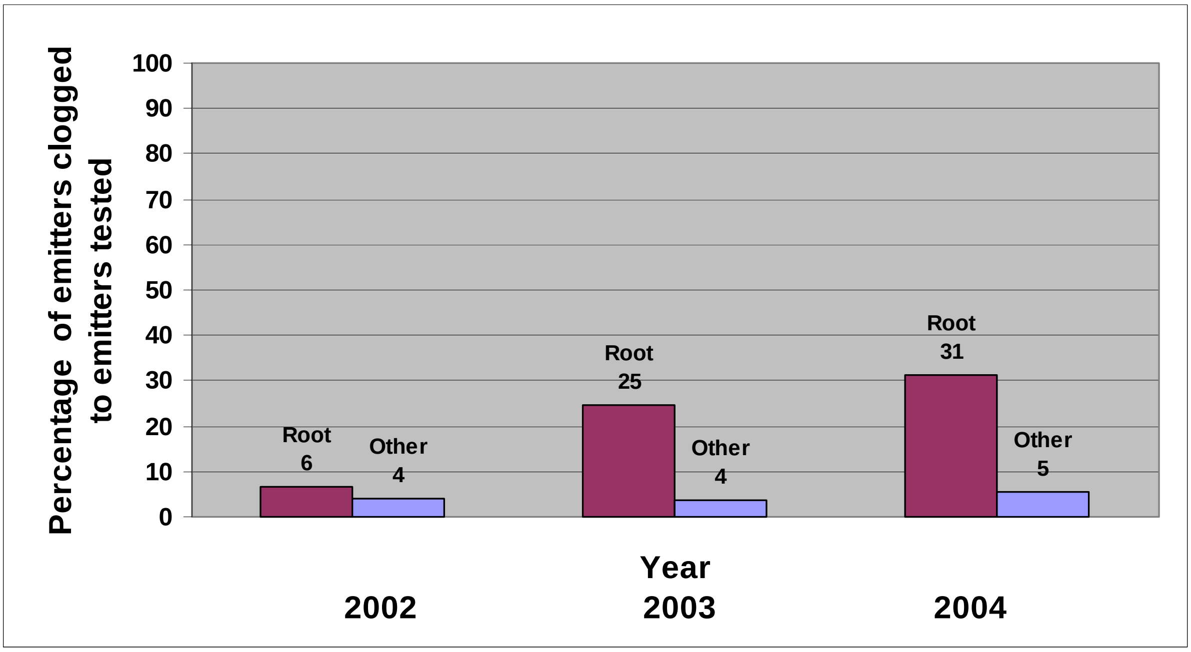

Figure 40: Zone 5 – percentage emitters root intruded to total clogged: Untreated

The high percentage of root clogged emitters in comparison to the total number of clogged emitters, illustrates the vulnerability of the emitters to root clogging in untreated condition. It increased with 416% over time.

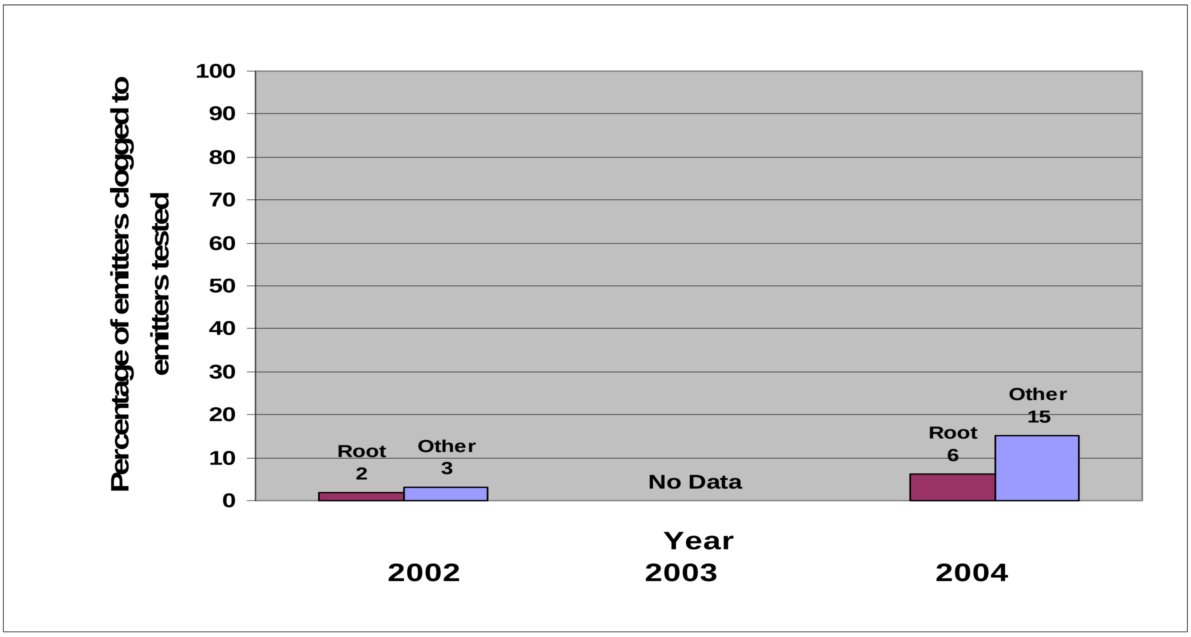

Figure 41: Zone 5: Percentage emitters root intruded to total clogged: Treated

The relative low percentage of root clogged emitters in relation to the total number of clogged emitters indicates the effect of the Treflan treatment over time.

In the treated blocks, root intrusion increased from 2 to 6% from 2002 to 2004. (An increase of 200% over time.)

4.2.3.3.3 **Percentage emitters root intruded to total emitters clogged: Zone 6**

From Tables 37 to 39, the following graphs are derived.

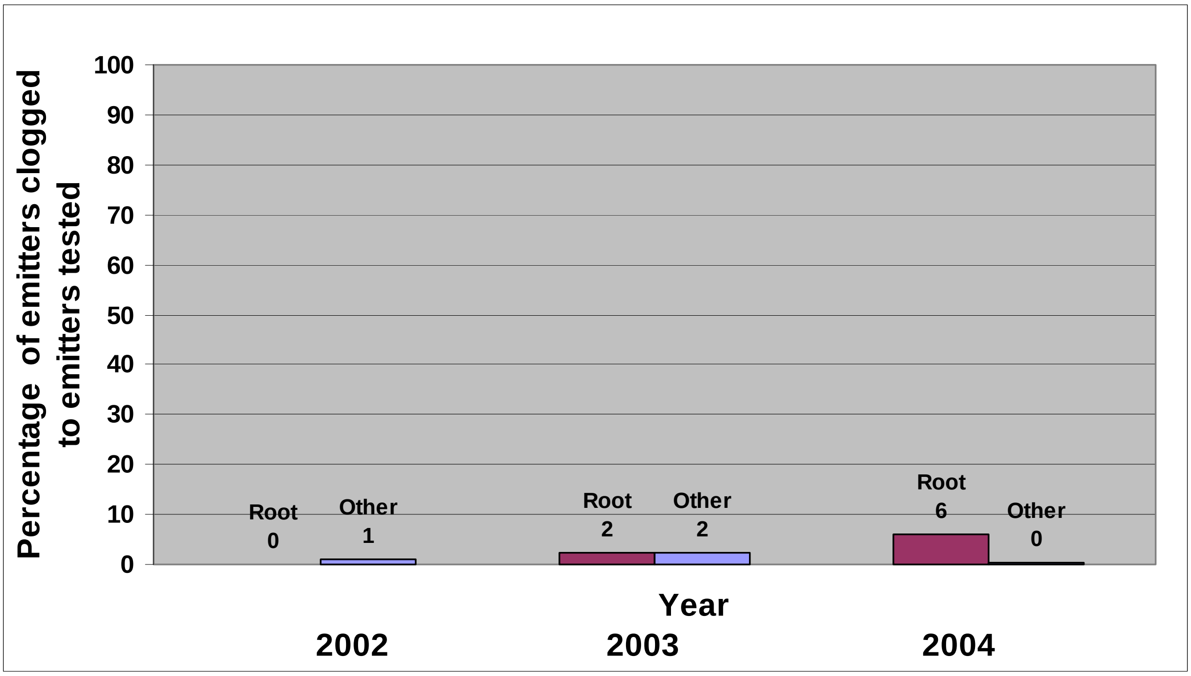

Figure 42: Zone 6: Percentage emitters root intruded to total clogged: Untreated

The low percentage of clogged emitters illustrates this emitter's resistance to root intrusion without any treatment in untreated applications.

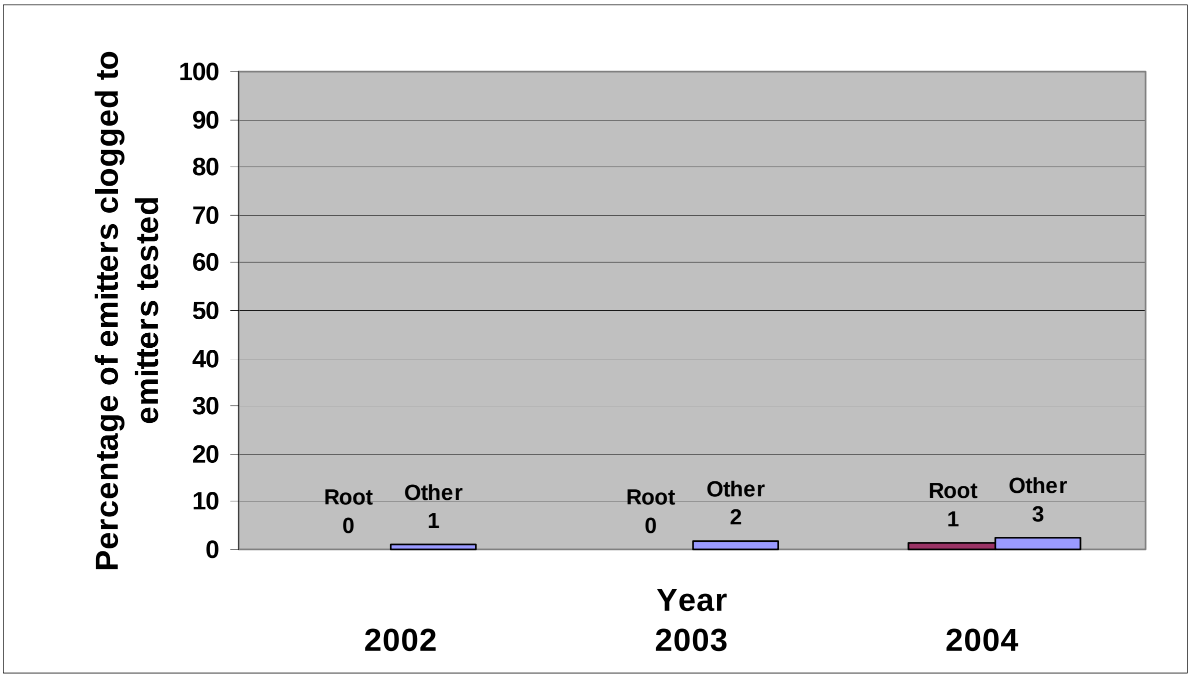

Figure 43: Zone 6: Percentage emitters root intruded to total clogged: Treated

The low percentage of root clogged emitters illustrates the high effectiveness of the Treflan treatment, combined with this emitter's resistance to root clogging.

Root intruded emitters in the untreated block increased from 0% to 6% from 2002 to 2003. In the treated blocks, root intrusion remained constant at 0% from 2002 to 2003, but increased slightly to 1% in 2004.

4.2.3.3.4 **Percentage emitters root intruded to total emitters clogged: Zone 7**

From Tables 37 to 39, the following graphs are derived.

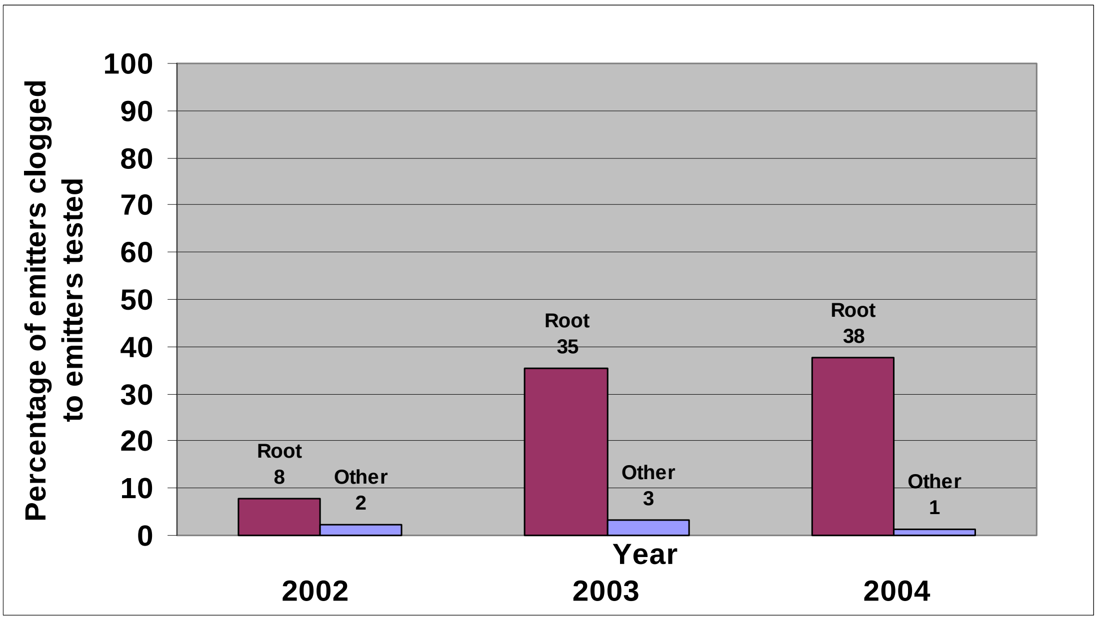

Figure 44: Zone 7: Percentage emitters root intruded to total clogged: Untreated

The high percentage of root clogged emitters in relation to the total number of clogged emitters illustrates the emitter type's vulnerability to root intrusion in applications where no root growth inhibitors are applied or used. The root intrusion increased with 375% over time (from 8% in 2002 to 38% in 2004).

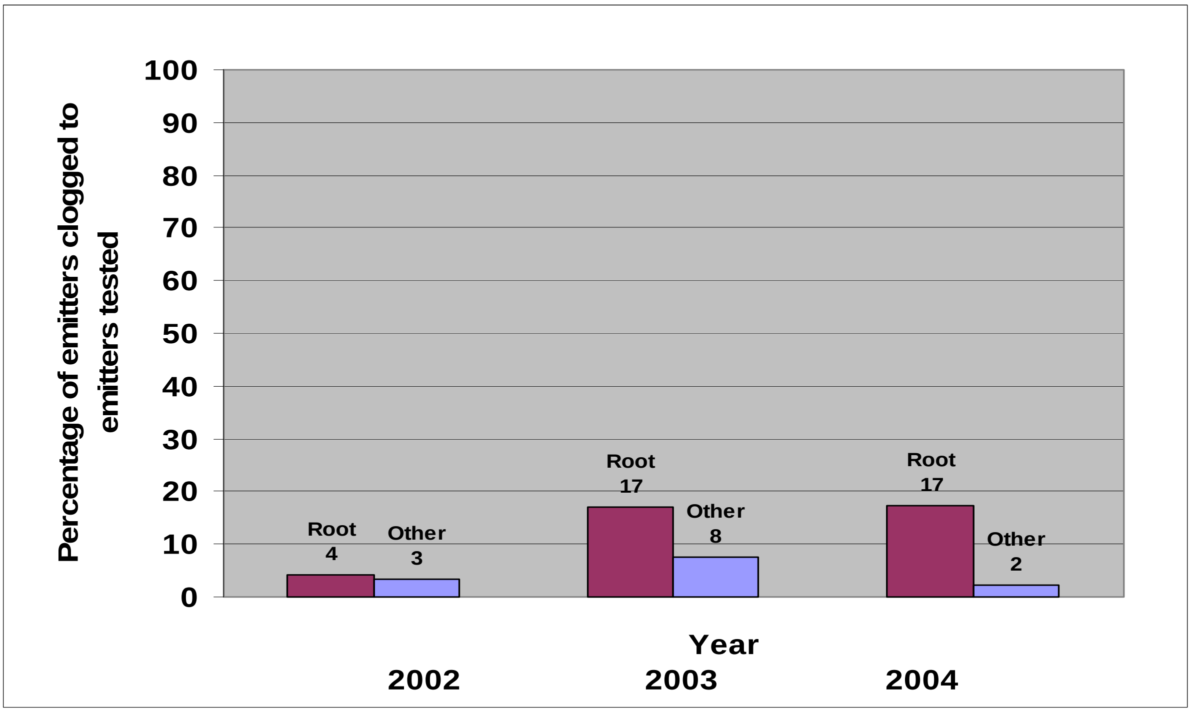

Figure 45: Zone 7: Percentage emitters root intruded to total clogged: Treated

The moderate percentage of root clogged emitters to the total number of clogged emitters illustrates the "limited" effect which the Treflan treatment had in this case. However, the increase over time was still 325%.

If compared with the untreated blocks, it can be seen that the treated blocks had less than 50% of root clogging of the untreated block.

4.2.3.3.5 **Percentage emitters root intruded to total emitters clogged: Zone 8**

From Tables 37 to 39, the following graphs are derived.

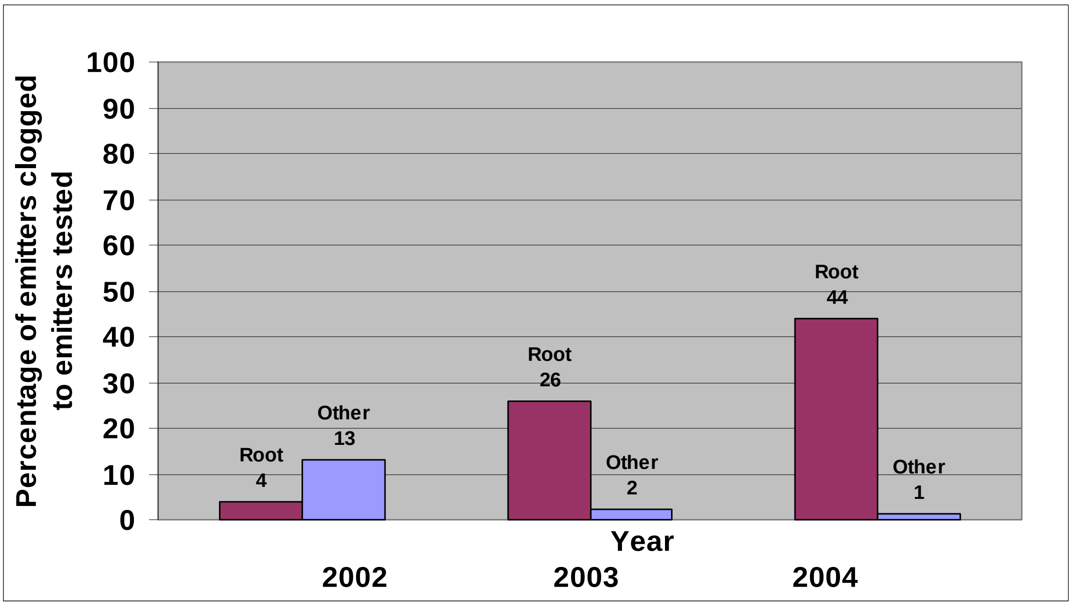

Figure 46: Zone 8: Percentage emitters root intruded to total clogged: Untreated

The high percentage of root clogged emitters in relation to the total number of clogged emitters illustrates the emitter type's vulnerability to root intrusion in applications where no root growth inhibitors are applied or used. The increase in root clogging was 1 000% over time (4% to 44% from 2002 to 2004).

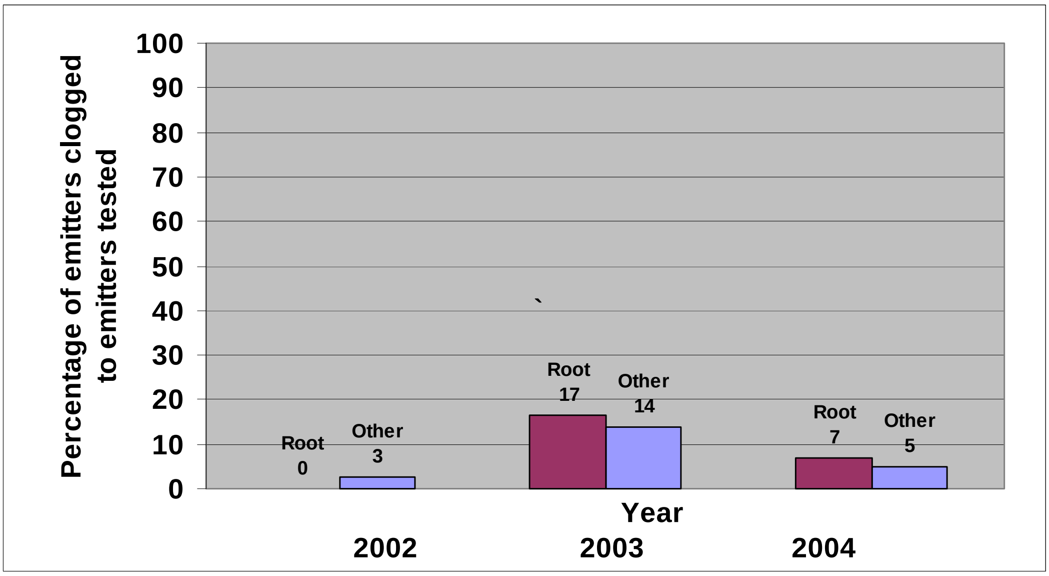

Figure 47: Zone 8: Percentage emitters root intruded to total clogged: Treated

In the treated blocks, the Treflan was quite effective and the root intrusion increased from 0% in 2002 to 17% in 2003 and then decreased to 7%.

Deductions:

- **Clogged emitters**

  From the tables, graphs and observations, the following deductions can be made from the percentage of emitters clogged to emitters tested.

Untreated: All five emitter types showed an increase in the percentage of clogged emitters to emitters tested in the untreated blocks over the 42 months.

The absence of treatment with a root growth inhibitor, and thus the ‘non-prevention’ of root intrusion, led to an increase in clogging of the emitters. The percentage of other means of clogging nearly remained constant. The increase in clogging can therefore be ascribed to mainly root intrusion.

Treated: In the treated blocks, all five emitters showed an increase in the clogging. As with the untreated emitters, the percentage was low.

The clogging is further discussed with regard to inherent characteristics of emitter types in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

- **Root intruded emitters**

  The following deductions can be made from the percentage of emitters clogged by root intrusion to emitters clogged. All five dripper types showed an increase in the percentage of root intruded emitters to emitters clogged in the untreated blocks over the three year period.

In the treated blocks, all five dripper types increased in the percentage of root intruded emitters to emitters clogged over the 42 month period but it was much lower than the untreated zones.

This illustrates the importance of root growth inhibitors, if this percentage is compared to the treated blocks’ percentages for root clogging.

The emitter type plays a determining role of the vulnerability to clogging. The treatment with root growth inhibitors like Treflan is more important than the emitter outlet mechanism and this is further discussed with regard to inherent characteristics of the emitter type in relation to its filter and flow path design and configuration as listed in Tables 45 and 46.

4.2.3.4 **Physical inspection of clogged emitters**

Clogged emitters, as identified and isolated in the laboratory, were examined under a microscope to determine the reason for the blockage. Photographs of the different clogging categories can be seen in Figures 48 to 51. The numbers on the photographs depicts the lateral number of the emitter and was used for identification and tracking purposes. The visible clogging was categorized as follows:

- **Apparent clean aperture** (Figure 48)

  Where no apparent clogging was visible, the emitter was cut open for further inspection. On several occasions roots were identified inside the emitter. The presence of microbial growth clogging the outlet of the emitter from the inside and clogging of the labyrinth, were also reasons for no apparent clogging as viewed from the outside.

Figure 48: Clean aperture

- **Soiled aperture** (Figure 49)

  Several emitters were clogged due to a slimy substance clogging the aperture or labyrinth of the emitter from the inside (see paragraph 2.3.5).

Figure 49: Soiled aperture

- **Soil in aperture** (Figure 50)

  Several emitters were clogged by soil tightly compacted in the aperture from the outside. Possibly, this particular air valve that was installed was not operating effectively and could have caused this.

Figure 50: Soil in aperture

- **Root in aperture** (Figure 51)

  Root intrusion is clearly visible under the microscope. In some instances the roots were only visible inside the emitter, which indicates that the root could have been severed during the retrieval process.

Figure 51: Root in aperture

4.2.4 Laboratory: Comparative clogging tests on new emitters

New sets of laterals out of all the driplines that were used in this project were also subjected in the ARC-ILI Hydrolab to comparative clogging tests. The aim of these tests was to establish how susceptible each emitter type was to clogging by particles from the irrigation water in the worst case scenario. These results are necessary when the results from the field tests are to be studied and interpreted.

Two driplines of every emitter type, with 10 emitters each, were mounted on the test bench. They were installed apart from each, with other types between them, so that an even distribution of all the emitters on the test bench could be achieved. Pinewood saw dust was mixed with the test water and maintained at a concentration of 150 ppm (on a volume basis) for the whole duration of the tests which lasted for about one month.

These Hydrolab tests are mostly a testing of the capability or efficiency of the inlet filters of the emitters to keep the emitters clean. The results can be interpreted as follows:

- The emitters with a high clogging percentage firstly have a small flow path and then a small inlet filter area. This means that an emitter with a small flow path and an inlet filter whose filtering openings are large, will clog first during such a test and the clogging percentage will be the highest.

- If the filtering openings of an emitter are small enough to keep the emitter flow paths clean, then clogging will start to take place at the filter itself. If the total filtering area of such a filter is not very big, it will clog up completely in a fairly short time, and those emitters will show the second highest clogging percentage.

- The emitters with the lowest clogging percentage have the largest and most effective inlet filters. This means that the filtering openings are small enough to not let dirt through that can get stuck in the flow paths of the emitters. These emitters have big enough filtering areas that do not clog up quickly.

In Tables 40 and 41, a summary is given of the factors and emitter characteristics that control emitter behaviour and both must be read together.

Table 40: Criteria to compare emitters according to emitter characteristics

Criteria	Characteristics that support the criteria	Characteristics that do not support the criteria	Other conditions
Clogging resistance	1) Efficient inlet filter with many filtering openings, resulting in a large inlet filter area (see Table 42). 2) Large turbulent flow path. 3) Self-cleaning capability. 4) High emitter flow rate.	1) Inefficient inlet filter. (An inefficient filter is when the filter opening dimensions are larger than that of the flow path). 2) Small, non-turbulent flow path. 3) Non-self-cleaning. 4) Low emitter flow rate.	1) If an emitter has an efficient inlet filter, it will clog slower with low quality water than when the filter has a large inlet area (see Table 42).
Root intrusion resistance	1) Root irritating mechanisms just before outlet like moving or pinching parts of pressure regulation mechanism.	1) Wide open flow paths without root irritating mechanisms before outlet.	1) If favourable soil water conditions prevail, roots should intrude emitters to a lesser extent.

Table 41: Emitter geometry and mechanisms that determine emitter characteristics

Geometry and mechanisms	Factors that promote supportive characteristics	Factors that promote non-supportive characteristics	Other conditions
Emitter filter size	1) Dimensions must be equal or smaller than the flow path dimensions, to be effective. 2) The more openings the filter has, the better clogging resistance it has over time.	1) When the inlet filter has larger dimensions than the flow path, the emitter will clog in the flow path rather than at the filter.	1) Clogging in emitter flow paths happens much quicker than at the inlet filters of the emitters.
Emitter flow path size	1) The larger the flow path dimensions of the emitter the less it tends to clog. 2) More turbulent flow paths clog less easily with low quality water than less turbulent flow paths.	1) Emitters with long flow paths and low flow rates stand a better chance to clog. 2) Low turbulent flow paths clog easy with low quality water.	1) When the emitter inlet filter has larger dimensions than the flow path, the emitter will clog in the flow path rather than at the filter.
Pressure compensating mechanisms	1. Emitters with a good flush mode at start–up, reduce clogging. 2. If the mechanisms can flush out dirt while in operation, clogging of the emitters is greatly eliminated.	1. Pressure compensating mechanisms *always have very small flow paths while in operation* and if they don't have a good start-up flush mode, or if they are not self-flushing, then such emitters will be very susceptible to clogging.	1. Emitters with self-flushing pressure compensating mechanisms can not prevent clogging at the inlet filters.

Table 42: Technical information regarding the internal dimensions of the different emitters (according to the manufacturers or our own measurements)

Zone	Flow path dimensions			Inlet filter data		
	Width (mm)	Depth (mm)	Number of inlets	Width (mm)	Height (mm)	Tot. area (mm^2)
4	0,7	0,7	22	1,0	0,6	13
5	1,0	0,9	5	1,7	0,8	7
6	1,0	0,8	4	1,7	0,6	4
7	1,0	0,3	370	0,4	0,3	44
8	1,0	1,0	4	2,5	1,0	10

In Figures 52 and 53, a summary is given of the emitters that were clogged by soil in the field over the 42 month period and the ARC-ILI Hydrolab's comparative clogging tests respectively. One thing to keep in mind is that the emitters in the field, operated under supposedly clean conditions, and the emitters in the lab operated under severe clogging conditions and therefore they must not be compared directly, but the tendencies under the two conditions can be noted.

Table 43: ARC-ILI Hydrolab's comparative clogging test results on new emitters

Zone	Percentage clogging
Zone 4	79
Zone 5	45
Zone 6	88
Zone 7	10
Zone 8	91

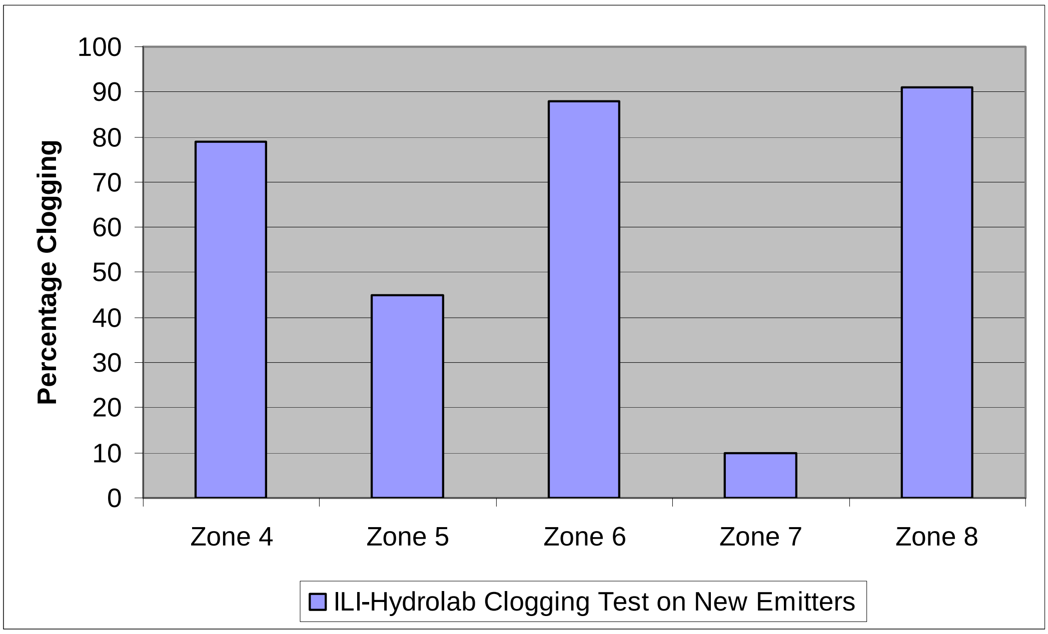

Figure 52: Summary of the ARC-ILI Hydrolab's comparative clogging test results

Comparing the histographs in Figures 52 and 53, it appears that, except for the emitter types in Zone 6 and Zone 8, there is a good relationship between the tendencies of the field and the lab test results for the different emitter types. The emitters in these zones are of the pressure-compensating types. The passages in the pressure compensating mechanisms of these emitters are very small and prone to clogging. According to the criteria in Tables 40 and 41 it will have the highest clogging percentage, which is the case. In these tests, though, the emitters of Zone 6 did not clog internally, because they have the capability to "clean themselves" while in operation. The reason for its high clogging percentage in the lab tests is because it has the smallest inlet filters, again in accordance with the criteria.

Table 44: Clogging results of retrieved emitters as a result of clogging from the inside of the dripper lines by particles only

Zone	Percentage clogging 2002	Percentage clogging 2003	Percentage clogging 2004
Zone 4	8,2	7,0	11,1
Zone 5	3,0	1,5	4,7
Zone 6	0,7	1,5	1,5
Zone 7	1,7	0,0	1,8
Zone 8	1,7	0,9	2,7

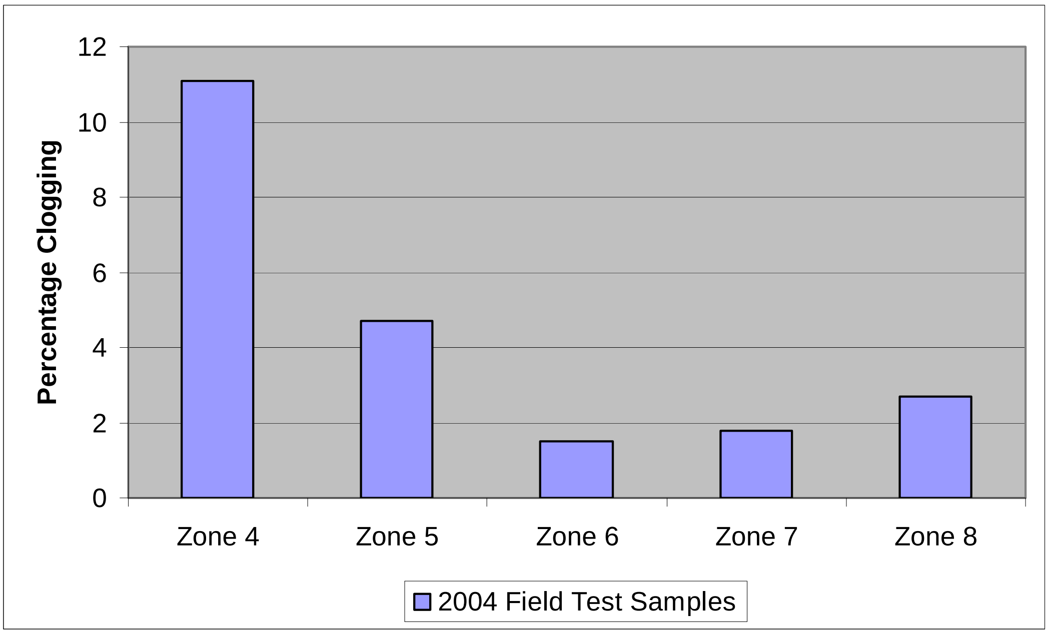

Figure 53: Summary of the clogging results of the retrieved emitters for the last year of the project (2004)

The reason why there is such a big difference in the test site results and the lab results of Zone 6's emitters is that under relatively clean water conditions, there is not enough dirt to clog its filters and it can keep itselves clean. The inlet filters of the emitters in Zone 7 on the other hand, are effective and it has very large filtering areas (see Table 42). For this reason these emitters had good performance in the lab and in the field.

It is clear that emitter performance depends on many external and internal factors. In many cases the performance is predictable, but there are also times that emitters can react total differently to external factors. An in-depth knowledge and understanding of the emitters and of their operation is then necessary to be able to explain the difference in behaviour. In this paragraph an effort was made to bring all this to the attention of the reader and to help him/her to also understand a little bit more about the operation and behaviour of the different emitters which are available for sub-surface drip irrigation. This can be used, so that an informed decision can be made when it comes to the choice of emitters for sub-surface drip irrigation. It will depend on unique situations what the best emitter will be to use for different circumstances. To make this a little bit easier, an overall summary of all the relevant factors of emitter performance is given in Table 45 and a ranking of the emitters according to certain criteria is given in Table 46.

Table 45: Summarising overview of emitter characteristics and emitter performance test results

Emitter type	**Regular emitters**			**Pressure compensated emitters**	
Zone	**4**	**5**	**7**	**6**	**8**
Outlet aperture dimensions	1,8 mm diameter orifice	2 × 3,0 mm diameter orifice	13 mm slit	3,0 mm diameter orifice	2,0 mm diameter orifice
Inlet filter aperture dimensions (mm)	1,0 × 0,6	1,7 × 0,8	0,4 × 0,3	1,7 × 0,6	2,5 × 1,0
Number of apertures	22	5	370	4	4
Total inlet filter area (mm^2)	13	7	44	4	10
Flow path dimensions (mm)	0,7 × 0,7	1,0 × 0,9	1,0 × 0,3	1,0 × 0,8	1,0 × 1,0

Emitter type	Regular emitters			Pressure compensated emitters	
Zone	**4**	**5**	**7**	**6**	**8**
Ratio*	1,43	1,89	1,33	2,13	2,50
Percentage clogging of the emitters by *particles* from *inside* the dripline (%)					
Laboratory clogging tests	79	45	10	88	91
Clogged field emitters	11,1	4,7	1,8	1,5	2,7
Percentage clogging of the emitters by *roots* only from *outside* the dripline (%)					
Untreated emitters	28	31	38	6	44
Treated emitters	5	8	17	1	8
Discharge category					
Untreated emitters	Reduced discharge	Reduced discharge	Increased discharge	Increased discharge	Reduced discharge
Treated emitters	Reduced discharge	Reduced discharge	Increased discharge	Increased discharge	Average discharge

$$* \text{Ratio} = \frac{\text{LIFID}}{\text{SFPD}}$$

The *smaller* this ratio or number is, the *more effective* the inlet filter is.
LIFAD = Largest Inlet Filter Aperture Dimension
SFPD = Smallest Flow path Dimension

Table 46: Ranking of the emitters according to certain criteria

Criteria:	**More ⟵ (theoretical resistance) ⟶ Less**				
Clogging resistance	**Zone 7**	**Zone 5**	**Zone 4**	**Zone 6**	**Zone 8**
Ratio value (table 45)	1,33	1,89	1,43	2,13	2,50
Min. flow path size (mm)	0,3	0,9	0,7	0,8	1,0
Total inlet filter area (mm^2)	44	7	13	4	10
Percentage clogging (lab)	10	45	79	88	91
Percentage clogging (field)	1,8	4,7	11,1	1,5	2,7
Root intrusion resistance	**Zone 6**	**Zone 4**	**Zone 5**	**Zone 8**	**Zone 7**
% Clogging (untreated)	6	28	31	44	38
% Clogging (treated)	1	5	8	8	17
Determinative dimensional size (mm)	0,8	0,7	0,9	1,0	13 mm slit

Considerations to follow for the ranking of the emitter's resistance against clogging:

Consideration one: How effective is the inlet filter of the emitter? (100% efficiency is when the "ratio" value in Table 45 is <1).

Consideration two: If the efficiency is 100%, then the emitters with the largest total filtration area on their inlet filters, (see Table 45) will be more resistant against clogging.

Consideration three: With less than 100% efficiencies, the emitters with the smallest "ratio" values will be more resistant against clogging than the emitters with the larger values.

Consideration four: If the efficiencies are less than 100%, and two emitters have "ratio" values close to each other, then the emitter with the largest flow path dimensions will be more resistant against clogging, even if it's "ratio" value is larger than that of the other emitter.

Considerations to follow for the ranking of the emitter's resistance against root intrusion:

Consideration one:	Is there a pressure compensating mechanism just before the outlet of the emitter that can “irritate” roots?
Consideration two:	If present, is there any “open space” inside the dripper line between the emitter’s outlet and the outlet hole in the emitter lateral’s wall? Roots can still accumulate there and cause clogging. Emitters with larger spaces will be more resistant against clogging, because more roots will have to build-up inside these spaces before they can cause clogging.
Consideration three:	Emitters with no pressure compensating mechanisms, but with small internal passages, are more resistant against clogging by root intrusion than the emitters with the larger internal passages.
Consideration four:	Is there any “open space” inside the dripper line between the emitter’s internal passage-outlet and the outlet aperture in the drip pipe’s wall? Roots can accumulate there and cause clogging. Emitters with smaller spaces and larger apertures will be less resistant because faster root intrusion and build-up will sooner lead to complete clogging.

Table 47: Ease of installation aspects

Subject	Factors that promote supportive characteristics	Factors that promote non-supportive characteristics	Other conditions
Ease of installation	1) Uniform pipe walls make better watertight connections. 2) Standardised pipe diameters fit best and easiest connection to standard pipe connectors.	1) Non-uniform pipe walls with “ribs” make watertight connections almost impossible or difficult.	1) Specialised machines for the handling of drip laterals eliminate many installation problems.

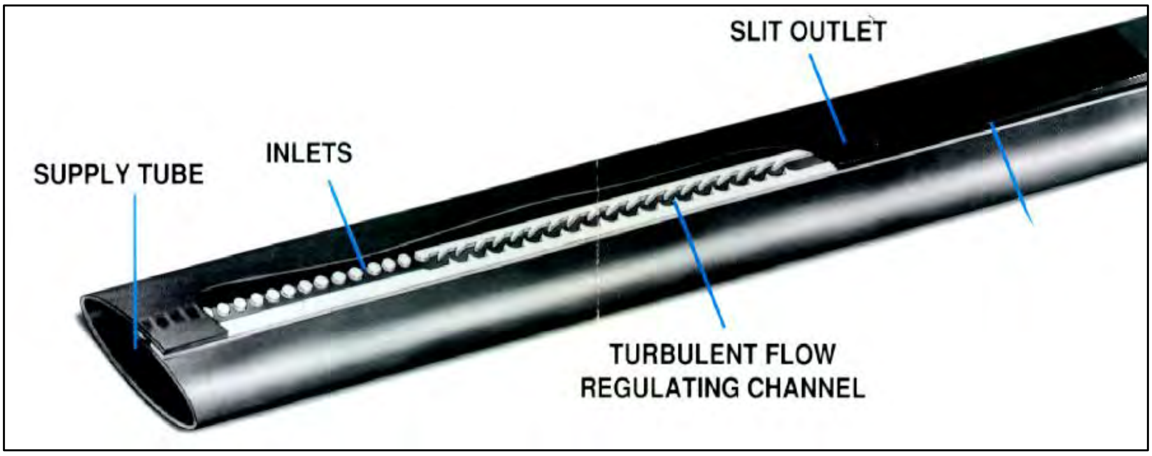

Figure 54: Example of turbulent pressure compensated emitter (T-Tape)

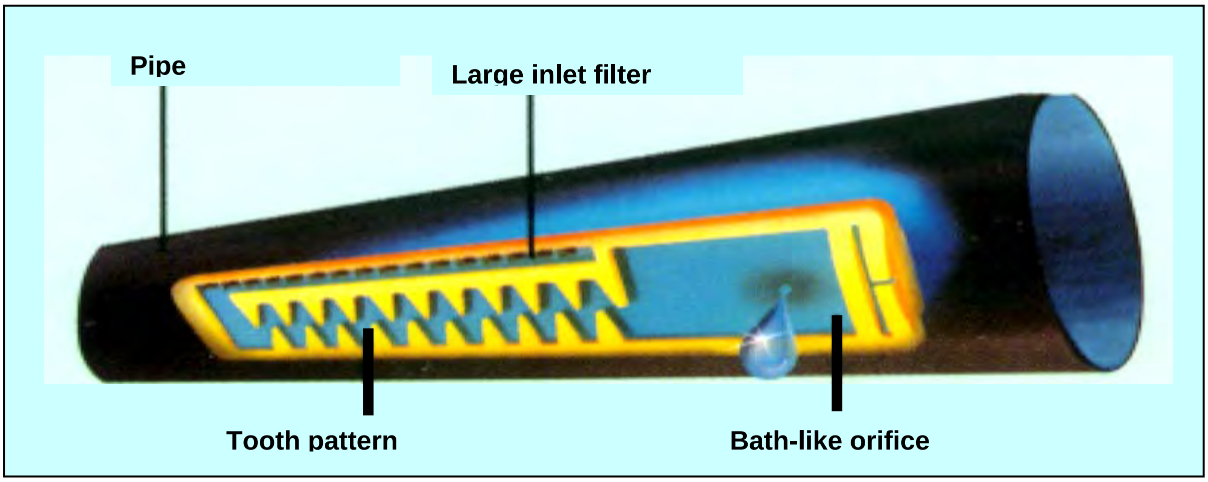

Figure 55: Example of a turbulent emitter (Netafim, 2004)

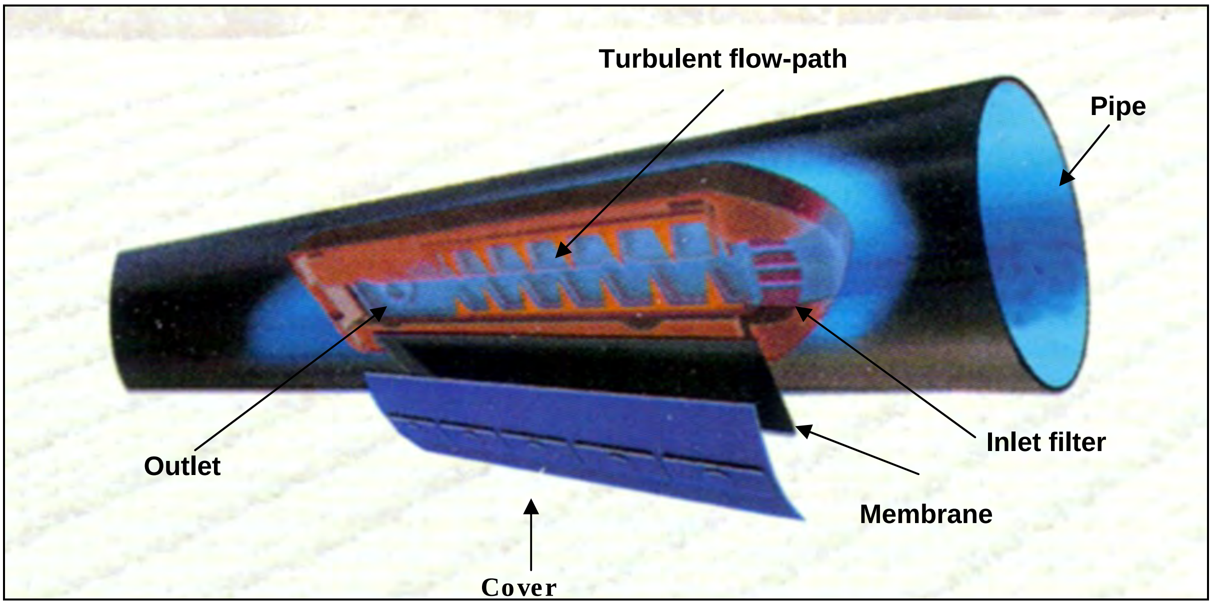

Figure 56: Example of a turbulent pressure compensated emitter (Netafim, 2004)

4.2.5 Lateral flow comparisons: In-field versus laboratory

A total of five flow meters on individual laterals, one on each of the five emitter types were installed seven weeks before retrieval on the second set of laterals to be retrieved. The last recorded readings before retrieval, in average litres per hour per emitter, were compared with the readings for the specific lateral on the laboratory test bench (Figure 57). Those flow meters were then re-installed on the newly installed laterals in the field and records were kept on the flow of each of these laterals for further investigation.

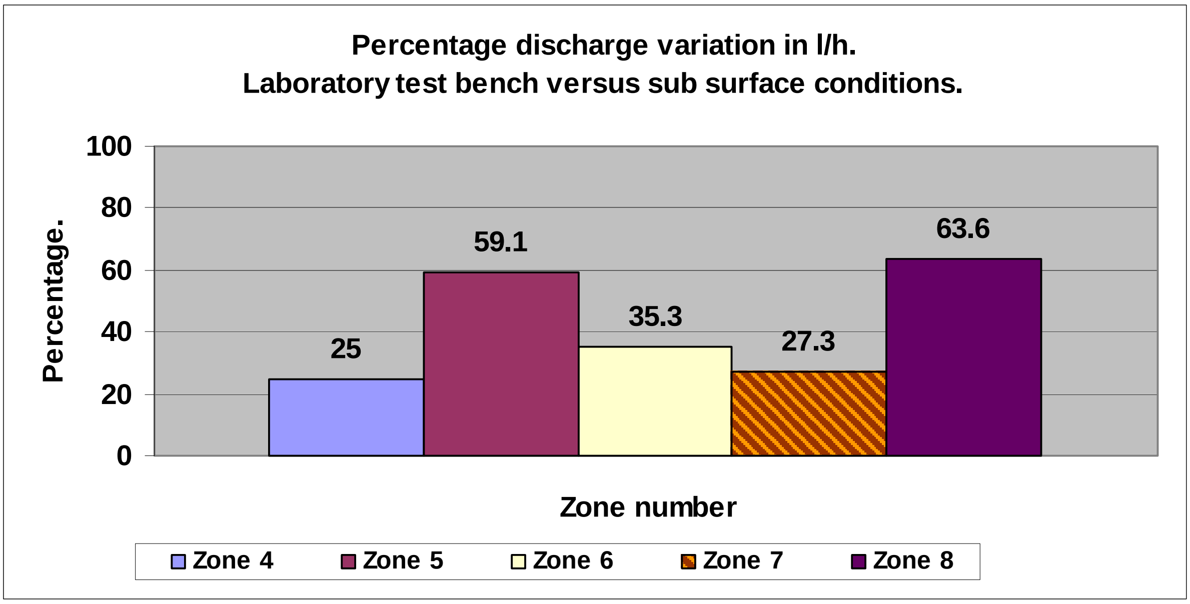

Figure 57: Percentage delivery rate variation

4.2.6 Summary of results from emitters from experimental site

In Table 48, a summary of all the end results of the treated and untreated emitters is shown. The discussions follow after Table 49

Table 48: Summary of the impact on emitters

Zone	% Functional				Root clogged				CV_q (%)					Delivery rate (ℓ/h)				
	Untreated		Treated		Untreated		Treated		New	Untreated		Treated		New	Untreated		Treated	
	2002	2004	2002	2004	2002	2004	2002	2004		2002	2004	2002	2004		2002	2004	2002	2004
4	82	59	85	79	10	28	2	5	2,1	62,6	76,0	40,6	43,0	1,7	1,5	1,2	1,5	1,5
5	89	63	95	79	6	31	2	6	4,2	19,5	31,9	13,8	22,2	2,2	2,1	1,7	2,2	2,2
6	99	93	99	96	0	6	0	1	2,1	14,6	26,2	11,8	14,2	1,6	1,8	1,7	1,6	1,8
7	90	61	92	80	8	38	4	17	2,4	46,1	69,3	30,0	41,4	1,23	1,1	1,2	1,2	1,3
8	83	55	97	88	4	44	0	8	4,4	13,0	78,4	36,5	40,7	2,0	2,6	1,5	2,1	2,4
Average	**87**	**66**	**94**	**84**	**5,6**	**29,4**	**2,6**	**7,4**	**3,04**	**31,16**	**56,36**	**26,54**	**32,3**	**1,75**	**1,82**	**1,46**	**1,72**	**1,84**
% Decrease	**26**		**10**		**-**		**-**		**-**	**-**		**-**		**-**	**16**		**-**	
% Increase	**-**		**-**		**505**		**307**		**-**	**144**		**27**		**-**	**-**		**7**	

Table 49: Summary of the impact on emitters (comparing 2004 values)

Zone	% Functional		% Root clogged		CV_q %		Delivery rate (l/h)	
	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated
Average	66	84	29.3	7.5	56.36	32.30	1.46	1.84
% Increase	27						26	
% Decrease			74		43			

- Untreated blocks

In the Treflan treated blocks, the emitters showed 74% less root intrusion than the untreated blocks. The untreated blocks were 29,3% root intruded against the 7,5% of treated block and there was also a significant increase of root intrusion of 505% over the 42 month period in the untreated blocks. The impact of the clogging in the untreated blocks was evident with the 16% decrease in emitter delivery rate and the worsening of the coefficient of variation (CV_q) from an excellent 3,04% to a very poor 56,36%. There was also an average 34% of the emitters that were not functional after the 42 month testing period.

- Treated blocks

With the treated blocks, root intrusion could not be prevented completely and after the 42 month period, 16% drippers were not functional (that is, however, 27% better than the untreated blocks). The impact of the clogged drippers was that the CV_q dropped from an excellent 3,04% to a poor 32,30% which was still 43% better than the untreated blocks. However the average emitter delivery rate stayed fairly constant.

4.3 Farm-site evaluations

Areas in the Mpumalanga Lowveld and Swaziland where sub-surface drip irrigation is used were identified. The South African Sugar Growers Association was contacted and informed of the purpose of the research. We were brought into contact with the relevant extension officers who then organised visits to specific farmers.

Three different sites in the Mpumalanga Lowveld and Swaziland were visited and tests conducted. On all these sites, sugar cane is grown with sub-surface drip irrigation systems. Our aim with this visit was to evaluate the performance of the sub-surface drip irrigation systems under field conditions and share the experiences of the farmers in terms of sub-surface drip irrigation performance.

4.3.1 Block information

The required information was obtained from the participating farmers/irrigators by means of the completion of a prepared questionnaire for each evaluated block. This evaluation regarded the irrigation system, water source, water management and maintenance schedules followed by the producers and the filtering and fertilizer application practices. An example of the questionnaire is included in Appendix B.

4.3.2 **Water quality analyses**

Water samples at the different sites were done as follows:

A water sample was taken at each water source and at the in- and outlets of the filters to establish the filters' effectiveness. These samples were subject to complete water analysis of elements that can have an influence on the water clogging characteristics. A water sample was also taken at the end of a lateral to determine the type and number, per algae species. The tests were done at the laboratories of the Institute for Soil Climate and Water (ISCW) and Waterlab. The first laboratory did the chemical analysis and the second laboratory did the analysis on the biological (algae) content. Separate water samples, in acidified water bottles, were taken for the analysis of iron and manganese. The water samples were taken before and after the filtration system to determine the suspended solids in the water.

4.3.3 **Water samples**

The water analysis can be summarised as follows:

Table 50: Chemical water analysis: Summary

Site ID	pH	Iron (Fe) mg/ℓ	Manganese (Mn) ppb	TDS mg/ℓ	Danger of clogging
Inyon.	6,95	0,39	65	8,0	Minor
Savan.	7,13	2,43	566	2050,0	Moderate
Simu1	7,35	0,65	74	13,6	Minor
Simu2	7,31	2,80	875	430,8	High

ppb – parts per billion

Water: Organic analysis summarised in Table 51.

Table 51: Biological water analysis: Summary

Site ID	Organic Chlorophyta	Clogging potential
Inyon.	<20	Low
Savan.	+200	High
Simu1	<20	Low
Simu2	<100	Medium

4.3.4 **Soil samples**

Soil samples were taken at all the sites to establish the clay percentages. At two of the sites, holes were dug to establish the wetted pattern under the emitters.

The clay content for the soils can be summarised as follows:

Table 52: Clay percentages

Site ID	Clay percentage
Inyon.	8 – 22
Savan.	39 – 69
Simu1	23
Simu2	35

From Table 52, the lower values represent the top layer of the specific soil. The holes, which were dug underneath the laterals, showed that the lateral movement of the water was good. From the observations no problems with the formation of wet and dry strips or areas in the irrigated field were observed.

4.3.5 Filtration

The filters at the different sites were evaluated in terms of the pressure drop across the filters at that moment in time. The filter efficiency of the relevant filter was calculated by means of equation 24.

The filters' performance are summarised as follows:

Table 53: Filtration efficiency summary

Site identification	Filter type	Filter efficiency
Inyon.	Sand	46%
Savan.	Sand	40%
Simu1	Spinkleen	75%
Simu2	Spinkleen	64%

For the explanation of the performance parameters see paragraph 2.4.

These filters were tested and the filter efficiency was calculated according to the formulae as stated in equation 24, paragraph 3.4.3. Please take note of the last comment in paragraph 3.4.3.

4.3.6 System evaluation

Different measurements were taken to determine possible causes of clogging problems and to calculate the performance parameters of the irrigation systems. The measurements included, among others, the following:

- Type of clogging materials found in the system
- Estimated number of emitters clogged in the block
- Pressure drop over the filter
- The performance of the air valves

The statistical discharge uniformity (U_s) is used as parameter to describe the uniformity of emitter discharge in the block. Five dripper lines were evaluated in five positions, as described in paragraph 3.4.4. The delivery rates of 25 emitters per irrigation block were measured. Pressure readings were taken at the same 25 points, at the block inlets and along the manifolds.

The different emitter performance values were calculated and summarised in Table 54 follows:

Table 54: Emitter performance values

Site ID	EU %	EU_a %	Us %	CV_q %	q_{max}	q_{min}	q_{ave}	FV %
Inyon.	90,9	89,1	90,9	9,1	1,3	1,0	1,1	20
Savan.	81,3	80,6	83,3	16,2	2,0	1,3	1,6	70
Simu1	93,8	89,0	83,1	16,9	1,9	1,5	1,6	40
Simu2	61,6	61,6	57,2	42,8	2,9	0	1,8	290

For the explanation of the performance parameters see Tables 19, Table 23 and Table 25.

The results of the evaluation were communicated to the relevant farmers. The cause of the low values for Simu2 can be ascribed to the water quality (high clogging danger) and the medium clogging potential due to the organic content of the water and the low filter efficiency.

From feedback of three of the farmers, it was established that:

- At the Savan. site, the farmers abandoned their SDI system.
- At the Inyon. site, the farmer abandoned one area, but established another area.
- At the Simu. site, the farmers are still in the process to enlarge their area under sub-surface drip irrigation.

This feedback from the farmers illustrates the importance of the high level of maintenance needed on a continuous basis to maintain the performance of the system.

5. CONCLUSIONS

5.1 Reaching the project objectives

The purpose of this project was to:

- Determine the blockage potential of different types of emitters under field, as well as laboratory conditions.
- Establish guidelines for the choice and management of sub-surface drippers to prevent root intrusion and clogging.

A third objective was envisaged, namely "To investigate the sub-surface water distribution of various delivery rate drippers in different soil texture classes." The steering committee decided that this was outside the scope of this project. However this is an important aspect in drip irrigation design and should be addressed accordingly.

Factors such as leakages, faulty design and equipment have a negative effect on the performance of emitters under field conditions. It is recommended that designers follow the recommended design norms of the South African Irrigation Institute and provide irrigators/farmers with a complete design report, including a maintenance manual.

Emitters with smaller flow paths are more likely to clog than emitters with larger flow paths. The emitters with the larger flow paths are thus inclined to perform better when using water that has a severe clogging potential, especially where irrigators do not make use of reliable maintenance schedules. If the irrigation water indicates a low to moderate clogging potential, all emitters should function effectively, if the irrigators/farmers follow the prescribed maintenance schedule.

The following maintenance practices are considered very important:

- The timely repair of leaks in the irrigation system, especially to prevent the suction of soil particles into the system.
- The flushing of filters on a pressure differential basis in order to prevent dirt from exiting the filter and entering the system, as a result of a too high pressure differential. To ensure high filter efficiency at all times, the media of sand filters (sand) should be replaced when it loses its irregular form and is spherical in form for most of the particles. The irregular form of the sand particles wears away with filtering during the filtering and backwashing processes and should therefore be replaced regularly.
- Laterals must be flushed monthly, or even weekly where necessary. This is to flush out unwanted foreign material that may precipitate in the laterals or clog emitters.
- Chlorination or an equivalent procedure must be followed at least once a year to clean the irrigation system.
- Treflan, a root growth inhibitor or equivalent product, should be applied to prevent root intrusion. The number of treatments necessary is a function of the crops, climate and soil types (Netafim, 2003).

Potential clogging problems, due to water quality, can be identified well in advance by carrying out water analysis during low water availability conditions. Sampling must meet the requirements of the sampling program and an accredited laboratory must be used for the analysis.

If the proposed operational guidelines for irrigation water, with low and moderate clogging potential are followed, producers/farmers should not encounter problems with root intrusion and clogging. From this research, it was not possible to test possible solutions for specific problems. Therefore, assumptions, as well as recommendations for operational guidelines, could only be made from observations made during the research. If the water quality therefore exhibits a severe clogging potential, an expert in this field must be approached for advice.

5.2 The way forward

The following aspects that were identified need attention:

- A user-friendly manual regarding the maintenance of sub-surface drip irrigation systems should be compiled for the use by producers/farmers. The manual must include examples and photographs as practical demonstration of the maintenance schedules.
- A huge need exists for the compilation for a user's guide, which describes the complete development process of an irrigation system at farm level and prescribes minimum acceptable standards for irrigation equipment and services.
- A further investigation is recommended where the water treatment methods for water sources, with a high clogging hazard is practically tested and from which guidelines can be compiled.
- The establishment of the causes of variation in emitter performance, between sub-surface and surface systems.
- Influence of different soil types and installation depth on emitter types.
- The performance of different root growth inhibitors or methods was not researched in this project, and only one product, namely Treflan was used.
- The influence of flushing laterals, individually or via connecting laterals to a manifold for simultaneous flushing, on clogging can be investigated.
- New emitter types were brought on the market, and they did not form part of this research. An evaluation of the new emitters' performance in field applications could be done in future.

6. RECOMMENDATIONS

The similarity in the equipment used and management aspects of the surface and sub-surface irrigation systems allowed the project team to use the same recommendations where applicable. Where differences existed, it was addressed in this report. For example, the importance of the correct installation of the SDI equipment. For more information, the Koegelenberg F.H. *et al*. 2002, *Performance of surface drip irrigation under field conditions*, WRC report 1036/1/02can be consulted.

It should be remembered by the user of a SDI system that the sub-surface irrigation system is only a tool like any other tool, which must be used correctly. If not well planned, installed and managed the SDI system will not make life easier, but more complicated**.**

6.1 Water analysis and sampling

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

A water quality analysis will assist to identify potential clogging problems due to water quality. 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. Duplicate samples should be taken and only one set of samples submitted for analysis, keeping the other set as a backup. Keep records on the sample data, data submitted to the laboratory, and date of analysis. This could be important in evaluating the impact of delays. Submit all samples for a fixed set of analysis, i.e. make sure analysis for all determinants was done for all samples. Use an accredited (SANAS or Agrilasa) laboratory that specialises in water analysis. Insist on obtaining data from the laboratory on method used, accuracy, precision, detection limits, calibration range, number and placement of calibration points and dilutions made, if any, per determinant. Submit together with the samples, "blind" artificial, as well as "blind" duplicate samples to evaluate the laboratory's claims of accuracy and precision. Add constant volumes and do a blank analysis 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. Only accept analysis if the ion balances were of an acceptable standard. The test is based on the percentage difference defined as follows (Greenberg *et a*l, 1992):

$$\%\ \text{Difference} = 100\ \frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \qquad (32)$$

The criteria for acceptance are as in Table 55.

Table 55: Criteria for the acceptance for ion balances (Greenberg, *et al*. 1992)

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

Insist on re-analysis of samples if ion balances were not satisfactory.
Sampling must meet the requirements of the sampling programme and handled in such a way that it does not deteriorate or become contaminated before it reaches the laboratory. Before filling, rinse the sample bottle two or three times with the water being collected. Depending on the analysis to be performed, fill container completely (most organics analysis) or leave space for aeration, mixing, etc. (microbiological analysis). Make a record of every sample collected and identify every bottle, preferably by attaching an appropriately inscribed tag or label. Before collecting samples from distribution systems, flush lines 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. Take a sample in a wide mouthed bottle having an opening diameter of at least 35 mm and a capacity as recommended in Table 46. 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 aluminium, 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 minimize precipitation and adsorption on container walls.

Determine temperature, pH, and dissolved gasses 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 retarded 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, therefore do not use it.

The water quality analysis procedures should strive to meet the recommendations as described in Table 56. 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, follow the prescribed preservation/handling practices.

Table 56: Summary of special sampling or handling requirements (Franson, 1995)

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	Analyze as soon as possible or add H_2SO_4 to pH <2, refrigerate.	7 days
Nitrate	P, G	100	Analyze 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	Analyze as soon as	None

Determination	Container	Minimum sample size (mℓ)	Preservation	Maximum storage recommended
			possible or refrigerate or freeze at 20°C.	
pH	P, G	–	Analyze 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 Eq. 33 (Greenberg, et al. 1992).

$$\text{TDS (ppm)} = 0{,}6\ (\text{alkalinity}) + Na + K + Ca + Mg + Cl + SO_4 + SiO_3 + NO_3 + F \qquad (33)$$

Table 57 provides conversions to determine the suitability of water for irrigation.

Table 57: Terms, units and useful conversions for understanding water quality analysis reports (Fipps, 1999)

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

6.2 Water evaluation scale for SDI clogging hazard

A simple table must be compiled, which can be used and interpreted by producers. It must also be possible to take the water sample used to determine the clogging hazard of the water, in a relatively simple manner. The current directives such as for iron are considered too conservative, but no clear directives can be concluded from the project. Many different directives appearing in literature confuse the users. It was decided to combine all the relevant information and present this in a table, which is easy to interpret. Table 58 shows the degree of the clogging hazards of emitters for different elements.

Table 58: Water evaluation scale for drip irrigation clogging hazard (T-Tape Africa, 2000)

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

Constituent	Problem severity	
	Low	High
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 none or very little clogging problems, whereas, if the values are above the maximum figure, an expert must be approached to identify the problem. The clogging problems, which may possibly occur with the minimum figures, can be prevented, by following the maintenance practices as proposed in Table 62. If the figure is between the minimum and maximum value, the possible clogging problem can be prevented by following the normal acceptable maintenance practices as recommended in Table 62, the relevant water treatment methods as described in paragraph 6.3.

6.3 Water treatment

On various occasions during discussions and during the investigation, producers expressed the need for simple recipes for water treatment. Solutions by Schwankl and Prichard (1990) were selected for this purpose for use by producers to prevent possible clogging problems and are shown in Table59. However, some manufacturers have specific recommendations for their dripper lines and these should be followed.

Table 59: Solutions for specific clogging problems (Schwankl and Prichard, 1990)

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 oxidize 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 – 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.
Iron bacteria (reddish slime) Iron concentration >0,1 mg/ℓ	• Application of 1 mg/ℓ chlorine (free chlorine available) continuously or 10 – 20 mg/ℓ for 0 – 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 – 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 – 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	• Dissolving of iron by continuous acid application to reduce pH to between 5 and 7.

Methods for the calculation of the amounts of chlorine and acid required for water treatment are discussed in paragraph 2.2**.**

6.4 Choice of equipment

The choice of 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 use of direct drive flow meters, as used during the research, tend to clog up with algae in their displays, contrary to indirect magnetic driven type water flow meters.

6.4.1 Pump intake

The capacity of the pump(s) should be sufficient to supply flow and pressure according to the systems' requirements. An additional 10% flow to cater for lateral and manifold flushing is recommended.

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. The minimum water depth above a suction pipe should be adhered to with the design and installation of it.

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, but above the bottom to avoid sediment intake. Figure 58 shows the minimum water depth above a suction pipe to avoid cavitation due to possible vortex formation.

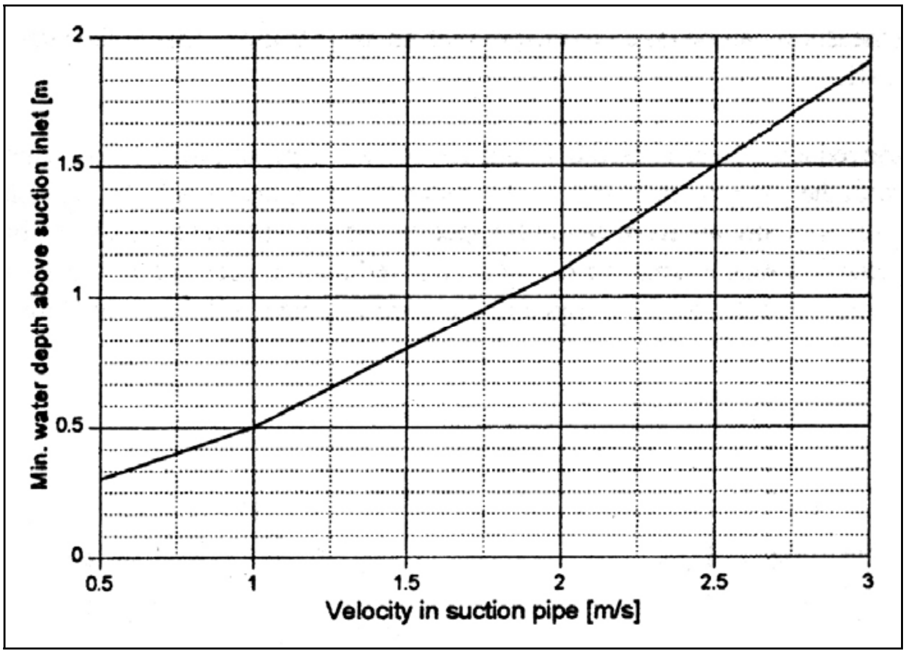

Figure 58: Minimum water depth above suction pipe inlet

6.4.2 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.

6.4.3 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 lateral's slope 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 and if a flushing manifold is installed, the vacuum breaker should be installed at the highest point of it, for the block. The topography of the main line will determine if an additional vacuum breaker is necessary.

6.4.4 Pressure control valves

The use of reliable pressure control valves to ensure that the sub-surface drip irrigation system always irrigates at the design pressure, must be installed, especially if dulating topography is present on the site.

6.4.5 Flushing manifolds and laterals

Small particles of both organic (such as algae) and inorganic (such as clay or silt) materials will pass through filters and into drip irrigation systems. These particles can settle and accumulate in pipelines and emitters, eventually leading to clogging of the emitters. To minimize sediment build-up, regular flushing of sub-surface drip irrigation pipelines is required. This necessitates the addition of flushing manifolds or above surface lateral outlets and the equipment to enable the manual/electronic opening of different irrigation block combinations for flushing.

6.4.6 Emitter type

Thick walled pressure compensating emitter types appear to be the most efficient types for SDI systems due to their intrinsic resistance to root intrusion, clogging and flow regulating capabilities. Thick walled emitter laterals, compared to thin walled laterals are less prone to be compressed or deformed and blocked, with installation in SDI applications. These lateral couplings are less complicated and more effective, compared to thin walled emitter types. Thick walled pressure compensating emitter types are more expensive than thin walled regular emitter types.

6.5 Design principles

It is important in the system design process that the farmer/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 SDI systems. The determination and operation rules of the available shared water sources should be discussed by means of multi-disciplinary concurrence involving all role players to establish water availability.

The following norms for the design of drip irrigation and sub-surface drip irrigation systems are proposed (Koegelenberg, *et al*., 2002):

Application efficiency:	$\geq$90%
Irrigation hours per week:	$\leq$144 hours

6.5.1 **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 were observed concerning the back-flushing 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 back-flush filters effectively. The maximum back-flushing rate may not be more than 1,2 times the filtering rate.
- A minimum inlet pressure of 6 m (60 kPa) during back-flushing is required.
- The back-flushing time of sand filters can be anything from 90 – 180 seconds. It must be kept in mind that when the flushing action is started, the raw water on the sand bed are flushed first and might look clean. Right after that, the dirt trapped in the sand bed is flushed out. It is important that the back-flushing time must be long enough to remove all impurities from the filter.
- The use of compressed air, to assist with the back-flushing action, is recommended if problems are experienced with tunnelling in the sand. This is effective to break up clods in the sand.
- Filters must be back-flushed 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.

6.5.2 **Emission uniformity**

Minimum recommended emission uniformity (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 as shown in Table 60. The South African Irrigation Institute recommends that an EU value of greater than 90% should be reached.

Table 60: Recommended EU values for different emitter and topography combinations (Keller and Bliesner, 1990)

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

6.5.3 **Flushing velocity of laterals**

To minimize sediment build-up, regular flushing of sub-surface drip irrigation pipelines and laterals are 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 materials 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 ample to purge all foreign materials from the laterals and pipelines. The time should at least be equal to the replacement of at least the blocks' water volume.

6.5.4 **Design form/report**

The design form/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 61.

Table 61: Design form: Drip irrigation system

1. GENERAL INFORMATION		
1.1 Client's name:		
1.2 Contact details: Address: . . . . Tel.		
	Block number	
	Unit	
2. CLIMATE		
2.1 Month	state	
2.2 Weather station	state	
2.3 A-pan evaporation	mm/month	
3. IRRIGATOR MANAGEMENT REQUIREMENTS		
4. CROP		
4.1 Type	state	
4.2 Area	Ha	
4.3 Planting distance	m	
4.4 Row spacing	m	
4.5 Natural root depth	m	
5. SOIL		
5.1 Effective soil depth	m	
5.2 Water holding capacity (WHC)$_{100}^{*}$	mm/m	
5.3 Readily available water	mm	
6. EMITTER		
6.1 Type	state	
6.2 Nozzle size	mm	
6.3 Delivery rate	ℓ/h	
6.4 Pressure	kPa	
6.5 Application efficiency	%	
6.6 Emitter spacing	m	

6.7 Lateral spacing	m	
6.8 Wetted diameter	m	
6.9 Gross application rate	mm/h	
6.10 Delivery rate of block	m^3/h	
7. SCHEDULING	state	
7.1 Crop factor	Des.	
7.2 Evapotranspiration	mm/month	
7.3 Net irrigation requirement	mm/month	
7.4 Gross irrigation requirement	mm/month	
7.5 Theoretical cycle length	days	
7.6 Theoretical standing time	hours	
7.7 Practical cycle length	days	
7.8 Practical standing time	hours	
7.9 Working days per week	days	
7.10 Irrigation hours per day	hours	
7.11 Gross application per practical cycle	mm	
7.12 Gross application per month	mm	
8. SCHEDULE OF BLOCKS THAT MUST BE IRRIGATED TOGETHER		
9. HYDRAULICS		
9.1 Allowable pressure range over lateral	m	
9.2 Required pressure at hydrant	m	
9.3 Flow velocity in mainline	m/s	
9.4 Flow velocity in laterals/supply line	m/s	
10. PUMP		
10.1 Type, model	state	
10.2 Impellor size	mm	
10.3 Pump pressure	m	
10.4 Delivery rate	m^3/h	
10.5 Efficiency at service point	%	
10.6 Closing pressure	m	
10.7 Power requirements at service point	kW	
10.8 Power requirements of electrical motor	kW	
10.9 Motor speed	r.p.m.	
11. FILTER		
11.1 Type, model, size	state	
11.2 Amount	number	
11.3 Filter fineness	mikron	
11.4 Pressure drop over filter		
Clean	m	
Dirty	m	
12. DESIGNER		
12.1 Name	state	
12.2 Company	state	
12.3 Contact details	state	

6.6 Installation

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 its length. Situations where laterals are installed with varying longitudinal profiles (e.g. undulating topography),

can cause the formation of air-locks in the laterals and thereby the formation of vacuums and the potential suction of soil particles into the emitter apertures.
The preparation of the field to a depth of at least 300 mm deeper than the planned depth of the laterals will help to guarantee constant depth of installation. This can be done with a tractor drawn ripper where soil ripping is done in chequered pattern on the field. The basic implement to install dripper laterals consists of a tractor mounted ripper. On top of this a reel, for the dripper line rolls, is mounted. 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 as soon as the installation process starts, the dripper line should be held manually in its position at the field edge. A system of depth adjusting wheels on the implement can provide a constant depth of installation.

Figure 59: Example of lateral installation implement, as used at experimental site

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

6.7 Maintenance

The maintenance of a SDI system is of paramount importance for the effective operation of such a system. The effective operation 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 needed lateral cleaning chemicals, are the important maintenance aspects for a successful SDI system.

It is important to inspect the irrigation block with 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.

6.7.1 Filter operation

The filters should be operated according to the indicated guidelines in paragraph 2.4 and paragraph 6.5.1. A filter maintenance schedule is listed in Table 15.

6.7.2 Lateral flushing

The regular flushing of the laterals plays an important role and the design of the system to create a flush velocity of at least 0,4 m/s is a necessity. This is important especially in cases where water with quality which is 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 is >0,4 m/s. To calculate the theoretical flow rate for a required minimum flushing velocity of 0,4 m/s at the lateral outlets, the velocity must be multiplied by the cross sectional area of the dripper lateral. This flow rate is then used to calculate the time needed for the filling of 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 60 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 will be able to supply an additional 10% flow above the systems' required flow, for the flushing of the laterals and manifolds.

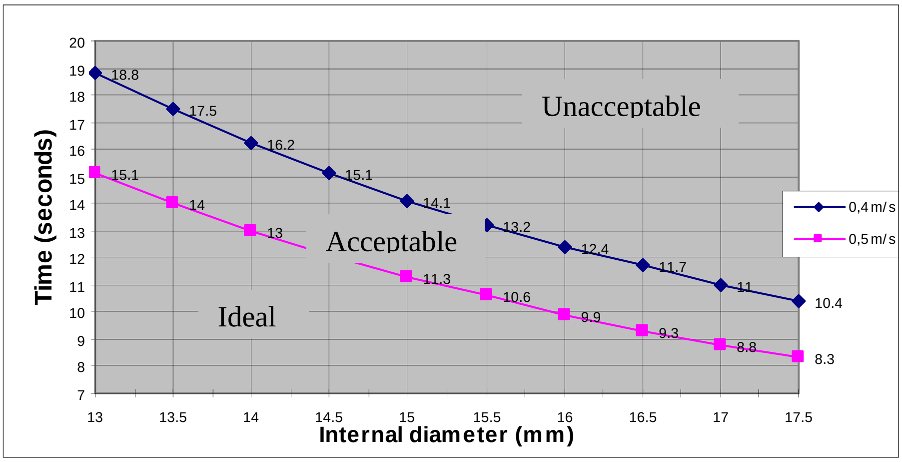

Figure 60: Time to fill one litre container for a specific diameter lateral (Koegelenberg, 2003)

6.7.3 Use of chemicals, e.g. acids, chlorines and fertilizers

The use of chemicals for the elimination of biological and chemical build-up is done on the same basis as for surface drip irrigation systems, as described in paragraph 2.2.

When applying fertilizers through the drip system, one must be aware of the fact that it will result in an increase in nutrients in the water, which will increase algae or microbial populations which can necessitate additional measures to prevent clogging.

Chemical treatment of irrigation water by chlorination can solve 80% of clogging problems. Have at least one water analysis done early to identify possible clogging hazards. The use of acids is discussed in paragraph 2.2.2.

The use of other chemicals and safety precautions are listed in paragraphs 2.2.3 to 2.2.5.

6.7.4 Use of root growth inhibitors

The use of root growth inhibitors in the SDI system should be done according to the relevant recommendations from the suppliers of the chemicals. This is to establish the registration (legal approval) of the specific product for use on the specific crop for SDI applications.

The indications from this research are that the use of root growth inhibitors is important and necessary for the effective functioning of dripper line emitters.

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 direct area around the emitters that is if the Treflan is applied through the system and is not impregnated in the emitters, etc. Any accumulation of water on the soil surface during or directly after Treflan application could damage the crops.

Procedures with the application of Treflan can be summarised as follows. (Netafim, 2003)

- Start the irrigation system and 20 minutes after it reached working pressure, investigate and observe if any puddles or water accumulation started 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 leakages and rectify/repair it.
- Treflan should not be applied into wet soil profiles, or just after rain.
- Recalculate the number of emitters in the irrigation blocks and the needed volume of Treflan to be applied. Application rate of 0,125 mℓ/emitter is recommended.
- Check the couplings and inlet filter of the chemical injector pump and repair if necessary.
- Calibrate the injector pump for at least a 10 minute cycle to establish its 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, a time of 24 hours should be allowed 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 too shallow.
- When the use of Treflan is prohibited by law.

Table 62: Suggested Treflan treatment commencement for various crops. (Netafim, 2003)

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, lucerne	First year – four weeks after planting or six weeks after sowing. For second year, four weeks after the start of “normal” irrigation”.
Grass and lawns	Four weeks after planting and 2-3 weeks after lawn establishment.

Number of treatments

The number of treatments is a function of crops, climate and soil type. Table 63 indicates the number of treatments needed per year.

Table 63: Suggested number of Treflan treatments. (Netafim, 2003)

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. E.g. cotton planted during October and the fist 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.

6.7.5 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.

From the research, it is clear that 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 maintenance schedule as shown in Table 15 is proposed for manually cleaned filters. For automatically cleaned filters, the manufacturers' recommendations must be followed.

The success of a sub-surface drip system is also dependent on the operation and maintenance of the system. The following aspects listed in Table 64 are important:

Table 64: System monitoring and maintenance programme for sub-surface 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)	✘			
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 61)			✘	
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		✘		

6.8 Management of soil water levels

Indications are that the soil water can have an influence on 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 will be "natural" for the plants' roots to attempt intrusion of the emitter apertures. The influence of soil water levels on emitter clogging by roots will need specific research.

The management of the system, in terms of accurate scheduling, can possibly help prevent the clogging of the emitters by plant roots.

6.9 Lateral spacing and wetted area.

Although it did not form part of this project, the lateral and emitter spacing are of great importance as it influences the wetted area under an emmitter. This is a function of soil type and soil texture.
Table 65 illustrates the relationship between discharge rate, soil texture, emiiter spacing and lateral spacing. Although this table is for surface drip irriagtion, similar relationships exist for sub-surface drip irrigation.

Table 65: 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

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TECHNOLOGY TRANSFER

The following actions can be taken to help in the technology transfer:

Target group	Technology transfer content	Media used
Irrigation designers	Report	SABI magazine, congress paper(s)
Irrigation research institutions	Report	WRC website
Farmers, general irrigation	Abstracts from report	General agricultural media
Farmers using SDI	Report	WRC website, agricultural media, farmer's days
Equipment manufacturers/designers	Report	WRC website, SABI magazine

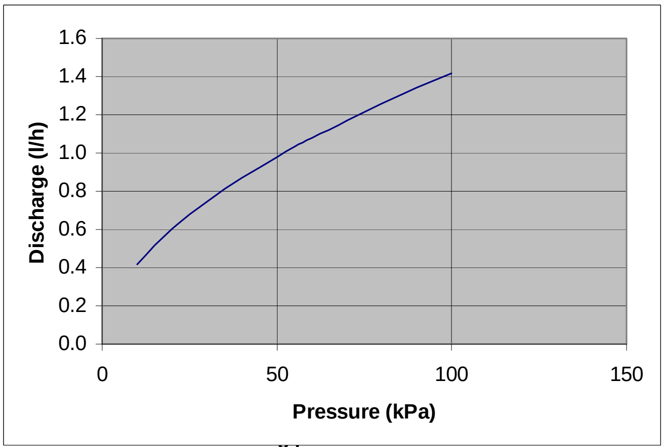
CAPACITY BUILDING

Person	Inputs	Required for	Duration
Johan Hiesterman	Scheduling input data establishment, crop measurements	Final year, university subject	12 months
Meschak Gaduza	Scheduling programming, maintenance, installation	Practical report, tech diploma studies	18 months
Jaco van Zyl	Installation	Experience, first year after tech study	12 months
Hendrik Jordaan	Planning, design, procurement, installation	Experience, first year after university study	14 months
Benett Mdaka	Installation, maintenance, lateral retrieval, laboratory testing	Project assistant	42 months
Steve Bunton	Management, maintenance, scheduling, laboratory testing	Project team member	36 months

EXAMPLE OF A REGULAR DRIPPER TEST REPORT

ILI products	DISCHARGE AND CV TEST RESULTS ON Product name Product code	**Page:** 1 of 1 **Report no:** D00009A **Date:** August 2000

AVERAGE PRESSURE (P) AND DISCHARGE (Q) RELATIONSHIP FOR 100 DRIPPERS:



Pressure (kPa)	Discharge (l/h)
10	0.42
15	0.52
20	0.60
25	0.68
30	0.75
35	0.81
40	0.87
45	0.93
50	0.98
55	1.03
60	1.08
70	1.17
80	1.26
90	1.34
100	1.42

Maximum recommended working pressure: 100 kPa

Discharge formula: $Q = 0.1225 \times P^{0.5317}$

Test results for a sample size of 100 drippers:

Tests:	Test 1	Test 2	Test 3	Average
Test pressure (kPa)	83.2	82.8	82.5	82.8
Average discharge (l/h)	1.2	1.2	1.2	1.23
Coefficient of variation (%)	2.5	2.6	2.5	2.5
Maximum discharge (l/h)	1.3	1.3	1.3	1.3
Minimum discharge (l/h)	1.1	1.1	1.1	1.1
Variation in discharge (%)	13.2	14.4	14.9	14.2

Hydrolab Norms:						
	CV-value:	0,1 - 2,5	2,6 - 5,0	5,1 - 7,5	7,6 - 10,0	More than 10
	Classification:	Excellent	Good	Fair	Marginal	Poor

Rating: **Excellent**

To determine the CV values in accordance with ISO standards, the 100 drippers tested simultaneously were divided into four groups of 25 drippers per group, and the tests repeated three times.

Test results for a sample size of 25 drippers in accordance with ISO standards:

Tests:	Test 1				Test 2				Test 3				Av.
Test pressure (kPa)	83.2				82.8				82.5				82.8
Groups:	Group1	Group2	Group3	Group4	Group1	Group2	Group3	Group4	Group1	Group2	Group3	Group4	All
Average discharge (l/h)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Coefficient of variation (%)	1.7	2.5	3.0	2.1	1.6	2.6	3.2	2.2	1.6	2.6	3.2	2.0	2.4
Maximum discharge (l/h)	1.2	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
Minimum discharge (l/h)	1.2	1.1	1.1	1.2	1.2	1.2	1.1	1.2	1.2	1.1	1.1	1.2	1.2
Variation in discharge (%)	7.0	10.5	12.7	7.3	6.7	11.1	14.0	9.4	6.7	11.3	14.9	7.1	9.9

ISO Norms:				
	CV-value:	0,1 - 5,0	5,1 - 10,0	More than 10
	Classification:	Good	Mediocre	Poor

Rating: **Good**

Water temperature: **13.5 °C**

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ILI products

APPENDIX B

QUESTIONNAIRE: WRC DRIPPER PROJECT

PROPERTY CODE ______________________
BLOCK NUMBER ______________________
DATE ______________________

A. MAINTENANCE SCHEDULE FOR DRIP IRRIGATION SYSTEMS

A1. If normal flow occurs at e.g. emitters, joints and grommets, describe the cause thereof:

____

A2. If a dripper pipe is tied to a wire above the ground, does the water flow down from the pipe? ____

Does some of the dripper pipe hang through? ___________________________________

A3. Is the suction of soil into the system a problem? ________________________________

____

If yes, what is the reason? ____

A4. Is the function of all air valves and pressure control valves sufficient? ________________

____

A5. How long does it take to obtain clean water at the end point of the furthest lateral during the flushing process? ____

A6. Describe the quantity and type of material that comes out of the end point of the furthest lateral (visual observation, e.g. with a sock).

____

A7. How many emitters became blocked on the laterals that were evaluated? (Count the emitters) ____

What is the reason for the blockage?

Carbonates	Insects	Sand
Plastic	Iron	Algae

Is there any carbonate/algae blockage on the outside of the emitters? ________________

A8. Make an estimate of the total number of blockages in the block (%)? ________________

PROPERTY CODE ______________________

BLOCK NUMBER ______________________

DATE ______________________

A9. Is the chlorine concentration measured at the end point of the laterals? _______________

What is the concentration (ppm)? ____

A10. What type of chlorine is used? ____

B. **MAINTENANCE SCHEDULE OF FILTERS**

B1. Do any leakages occur at the filters? ____

B2. Pressure before and after filters/filter bank before back-flushing action (kPa):

____

Pressure before and after filters/filter bank after back-flushing action (kPa):

____

Describe filters in full (type and micron filter fineness):

At central filter station ____

At block ____

B3. How long do the filters take to flush? ____

Do the filters flush automatically? ____

Do any problems occur? ____

Take a photograph of the filter station. Take water samples (500ml) before (S_{in}) and after (S_{out}) the filter for analysis of the total suspended matter larger than 75 μm to determine filtering effectiveness (E_f):

$$E_f = 100\left(1 - \frac{S_{out}}{S_{in}}\right) = \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_$$

SAND FILTERS

B4. How regularly is the sand in the sand filter replaced? _________________________________

How (and with what chemicals) is the sand cleaned? ___________________________________

____

PROPERTY CODE ______________________
BLOCK NUMBER ______________________
DATE ______________________

RING/MESH FILTERS

B5. What is the condition of the rings/mesh of the ring/mesh filter? ________________________

____

How regularly are the filters opened and cleaned? ___________________________________

Are the rings of the Sprinkleen cleaned by hand? ___________________________________

What chemical are used for cleaning the rings? _____________________________________

B6. pH, TDS and EC Measurements

Position of measurements	**pH measurements**	**EC measurements (mS/m)**	**TDS (mg/ℓ)**
End point of one lateral (after being flushed)			

NB:

- One water sample must be taken at the source and three samples at the furthest lateral's end point after the lateral has been flushed clean. One sample must be acidified to a level pH of 2 for determining of metals (100 ml) – only at the lateral's end point. One sample for algae analysis (500 ml) – only at lateral's end point and one sample for determining of non-metals (500 ml) at the source and lateral endpoint.
- DWAF must be contacted regarding water quality measurements, which are done at the measuring stations nearest to the inspection area.

FERTILIZER APPLICATION

B7. In what form is fertilizer administered?

Water-soluble dry fertilizer	Liquid fertilizer

List all the fertilizer products that are being administered:

Liquid: ____

Water soluble: ____

Are fertilizer products administered periodically or as enriched water? __________________

____

Is clean water applied through the system after fertilizer application?

____

PROPERTY CODE ______________________

BLOCK NUMBER ______________________

DATE ______________________

B8. Give your impressions on the producer's maintenance schedule for the system, as well as for the filter. Mention the factors that may have an influence on problems encountered, e.g. a shortage of high quality water throughout the irrigation season. What can be done to help in order to follow a reliable maintenance schedule?

B9. Draw a sketch of the block layout, indicating the hydrant position.

Sketch

PROPERTY CODE ______________________
BLOCK NUMBER ______________________
DATE ______________________

C. **SAMPLING FOR THE LABORATORY (ONCE DURING MAY)**

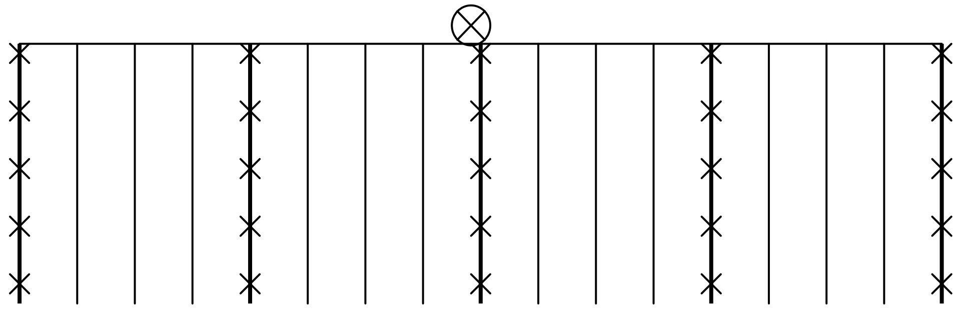
C1. Measuring of five emitters from beginning of lateral taken at the end of the season for lab tests (see sketches for position of emitters). Mark emitters with paint.

Dripper number from supply line connection	1	2	3	4	5
Delivery (mℓ/min)					
Delivery (ℓ/h)					

What is the flow in the lateral measured at the end point (ℓ/h)*? ______________________

What is the total flow in the lateral measured at the beginning (ℓ/h*)? ___________________

*Wait until flow through the water meter has stabilised before taking the flow reading.



Code: X – emitters are evaluated at five positions per lateral
⊗ – valve

C2. **EVALUATION OF THE DELIVERY UNIFORMITY OF THE EMITTERS**

Operating pressure measured (kPa) ____

Operating pressure according to designer (kPa) __________________________________

POSITION ON LATERAL	**LATERAL POSITION ON SUPPLY LINE**														
	STARTING POINT			**¼ FROM STARTING POINT**			**½ FROM STARTING POINT**			**¾ FROM STARTING POINT**			**FURTHEST POINT**		
	Delivery		**Pressure**	**Delivery**		**Pressure**	**Delivery**		**Pressure**	**Delivery**		**Pressure**	**Delivery**		**Pressure**
	(mℓ/m)	**(ℓ/h)**	**kPa**	**(mℓ/m)**	**(ℓ/h)**	**kPa**	**(mℓ/m)**	**(ℓ/h)**	**kPa**	**(mℓ/m)**	**(ℓ/h)**	**kPa**	**(mℓ/m)**	**(ℓ/h)**	**kPa**
Starting point															
¼ From starting point															
½ From starting point															
¾ From starting point															
End point															

*Lines must be flushed before measurements are done. Evaluation is done at design pressure.

APPENDIX C

PHOTOGRAPHS

Hydro laboratory dripper test bench

Assembling of control equipment in hydro-laboratories