PERFORMANCE OF SURFACE DRIP IRRIGATION SYSTEMS UNDER FIELD CONDITIONS

by

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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 in-efficient, as a result of water quality, mismanagement and maintenance problems. Clogging of the emitters is one of the most serious problems associated with drip irrigation and various approaches in preventing the clogging of emitters include filtration, flushing and chemical treatment of the irrigation water. Through this project, guidelines were developed to enable irrigators with 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, drip systems account for 140 000 hectares under irrigation in South Africa. To assist the users to utilise their systems effectively, the research was carried out with the following objectives:

- to determine the performance of various types and ages of drippers under different water quality and typical farming conditions;
- to develop operational guidelines to make the correct dripper choice;
- to enable irrigators to maintain their drip systems effectively and ensure that available water resources are utilized efficiently.

Methodology

An extensive literature study on all facets that can influence the different types of drippers 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 and design.

Agriplas's Drip-In Regular, Agridrip PC and Netafim's Ram PC drippers were selected, as they were the most commonly used drippers for surface drip in South Africa. The performance of these new drippers, ten models in total, was evaluated under controlled conditions in the hydraulic laboratory of the ARC-Institute for Agricultural Engineering.

In the empirical study, professionals in various disciplines, e.g. design, scheduling, maintenance and supply of equipment were contacted in order to obtain information regarding clogging problems experienced in the various drainage regions in South Africa. Drippers prone to physical, chemical and biological clogging problems occurring in South Africa and used on a large scale in different regions right across the country, were included in the investigation.

With regard to the field evaluation, six catchment areas in South Africa were identified, namely the Berg, Breede, Orange, Kouga and Crocodile rivers, together with the Vivo region where farmers experience problems with drippers that clog. In these areas, a total of 42 systems were identified and selected on a basis of dripper type and dripper age. Dripper systems younger than five years and those older than five years were identified. These systems' performance was evaluated in the field twice a year for two consecutive years, according to ASAE EP 458. Apart from the performance evaluations, data was also collected of the maintenance schedules and water samples were taken for water quality analysis.

After the field evaluation, one dripper line was sampled out of the relevant block and replaced with the same dripper type. Evaluations were then carried out in the ARC-ILI Hydrolab to determine possible causes of clogging. This was repeated the following year.

Results

The new drippers' coefficient of variation (CV_q) varied from an excellent 2,1% to a good 4,2% with an average of 3,12%. The pressure compensated drippers' average CV_q was 3,45% and that of the regular drippers a better 2,63%.

There was a tendency that the Emission Uniformity (EU′) as measured in the field of all the dripper types deteriorated over time from a EU′ of 87,1% in the first evaluation to 82,4% in the fourth and last evaluation one year later. This is an indication that the performance is affected by clogging due to the water quality and lack of proper maintenance schedules.

Dripper lines from each of the 42 identified blocks were also recovered from the field for two consecutive years and tested in the laboratory. Dripper lines with regular type emitters showed a general tendency of reduced average discharge due to partial or total clogging of emitters while drip lines with pressure compensated emitters showed a general tendency of increased discharge, due to foreign objects that got stuck between the compensating membrane and the labyrinth, or the compensating membrane loosing its elasticity over time due to chemicals and the water quality. If the outlier values of CV_q are disregarded due to severely damaged drippers and heavily soiled dripper lines, the average discharge variation CV_q in the first year was a fair 6,5% for all the drip lines with a variation of 3,0% up to 21,3% for the individual drip lines. In the second year, the average discharge variation CV_q was a poor 8,2% with a variation of 2,7% up to 22,2% for the individual drip lines. This confirms the deterioration of the drippers over time and the importance of proper preventative maintenance.

With regard to the statistical uniformity discharge coefficient (U_s), the Ram PC met the requirements in 84% of the cases, the Drip-In Regular in 58% of the cases and the Agridrip PC in only 50% of the cases. For all three dripper types, no significant conclusion could be reached that the age of the pipe played a role in the degree of clogging. However, it was evident that incorrect or no maintenance of the drip systems contributed in most cases to the decreased performance.

In the laboratory a relative clogging test on new emitters was also conducted. The regular drippers were also significant more resistant to clogging compared to the pressure compensated drippers. The average percentage clogging of the regular drippers is 42,7% in comparison to the 66,6% of the pressure compensated drippers.

Conclusions and recommendations

Proper maintenance schedule and its execution is of utmost importance for the successful long-term operation of any 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 dripper type selection and to develop proper preventative measures.

Full details are given in terms of solutions for specific clogging problems, choice and management of equipment to ensure effective water utilization, design principles, operation and maintenance information for best management practices and the importance of a complete design report with details of the system's specifications, maintenance requirements and installation guidelines.

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 vast 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-friendly manual regarding the maintenance of drip irrigation systems.
- The compilation of a user's guide, which describes the complete development process of an irrigation system at farm level and 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.

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Dr S.S. Mkhize	:	Water Research Commission (Chairperson)
Dr G.R. Backeberg	:	Water Research Commission
Prof A.T.P. Bennie	:	University of the Free State
Mr G. Bloem	:	MBB Consulting Engineers Incorporated
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Mr J.P. Nell	:	ARC-Institute for Soil, Climate and Water
Mr E.J. Schmidt	:	SA Sugar Association
Mr F.P.J. van der Merwe	:	Department of Water Affairs and Forestry
Ms I. van der Stoep	:	University of Pretoria

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- Senior management of ARC-Institute for Agricultural Engineering was supportive throughout the project and ensured that the research team had the full backing of the engineering and administrative services of the Institute.

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- 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 in-efficient, as a result of water quality, mismanagement and maintenance problems. Currently, drip irrigation systems account for 140 000 hectares under irrigation in South Africa and through this project, guidelines were developed to enable irrigators to apply good management schedules in order to adhere to the conditions of the National Water Act regarding the efficient and beneficial use of water in the public interest.

1.1 Objectives

The aims of the project were therefore:

- to determine the performance of different types and ages of drippers under different water quality typical farming conditions;
- to develop operational guidelines to make the correct dripper choice;
- to enable irrigators to maintain their drip systems effectively and ensure that available water resources are utilized efficiently.

1.2 Motivation

South Africa is a dry country with a rainfall below world average which is distributed unequally over the country. This rainfall is also strongly and highly irregular in occurrence. While the average total annual surface run-off is 50 150 million m³, a total storage capacity of about 27 000 million m³, or 54% of the total run-off, has been created over the years by the construction of large dams, mainly by the Department of Water Affairs and Forestry. Presently, the annual water usage in South Africa is about 22 400 million m³, of which probably more than 60% is being used for irrigation (van der Merwe, 2001).

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. The irrigation sector must become increasingly involved in the development of balanced solutions between agriculture and other water consumers. The available water for irrigation can only be applied efficiently by means of the correct choice of an irrigation system, understanding of the soil-water-crop interactions, system maintenance and irrigation scheduling.

1.3 Description of the project

An extensive literature study on all facets that can influence the different types of drippers under field conditions was undertaken. Thereafter, the empirical study followed.

The different drippers currently used in South Africa were identified, the necessary technical information regarding the drippers was obtained and extensive laboratory tests were conducted. Six catchment areas where clogging problems with drippers are currently being experienced were also identified (Berg River, Breede River, Orange River, Kouga River, Crocodile River and Vivo region). The different ages of drippers (newer than five years and older than five years) were identified and evaluated on various farms with data collection of water quality, maintenance schedules and general management of the system.

2. METHODOLOGY

Professionals in various disciplines, e.g. design, scheduling, maintenance and equipment supply were contacted in order to obtain information regarding clogging problems experienced in the various drainage regions in South Africa (Fig. 1). Firstly, it was decided to include physical, chemical and biological clogging problems in the investigation. Secondly, drippers used on a large scale in various drainage regions of South Africa were also considered. Field tests were conducted in six regions to evaluate different drippers under field conditions. Standard laboratory tests to determine the performance of drippers under laboratory conditions were also performed.

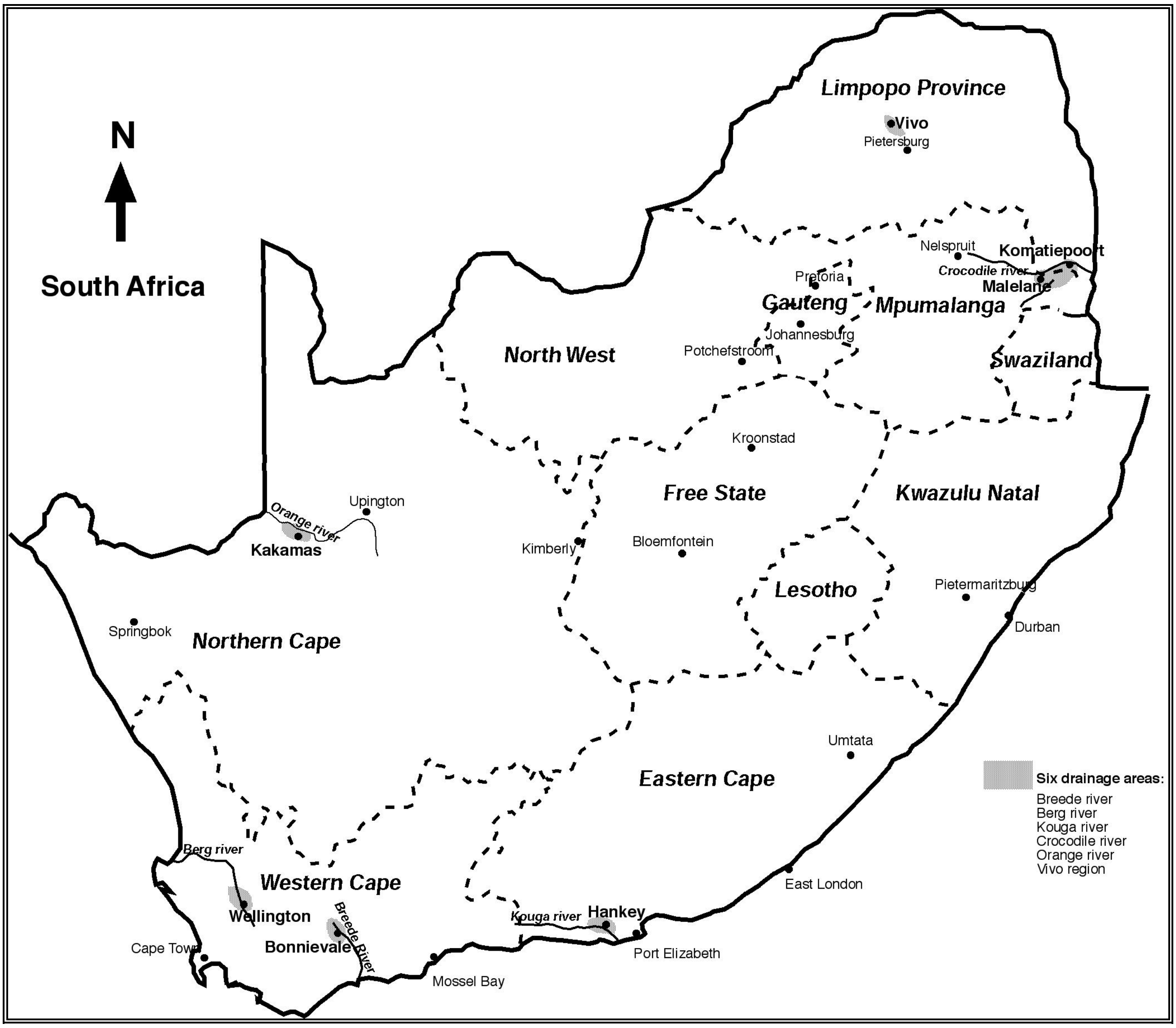


Fig. 1: Drainage regions where investigation on surface-drip irrigation took place

2.1 Emitters chosen for the investigation

Emitters for the investigation were selected on the basis of the various emitter types generally used in South Africa, and on the number of years the various emitters were in use to determine the effects of age on their performance. Ten different emitter models from two manufacturers, namely Agriplas and Netafim, were selected for the investigation. The general specifications of emitters and laterals given by the manufacturers are represented in paragraph 4.1 of this report.

2.2 Laboratory tests carried out on emitters

2.2.1 Discharge and coefficient of discharge variation (CV_q) tests

New drip lines with emitters included in the investigation were obtained from the manufacturers and tested in the laboratory (Fig. 2) for average discharge and for the manufacturing coefficient of discharge variation (CV_q). These values were used as a reference base in the evaluation of the in field performance of the particular emitter types.

To evaluate the performance of used emitters, drip lines with the various emitter types and of different age groups were recovered from the field and subjected to the same tests as the new drip lines. The drip lines selected for the laboratory tests were flushed in the field, drained and disconnected from the system, rolled up and packed in plastic bags to prevent drying out. In the laboratory the drip lines were again flushed before tests were conducted. Drip lines and emitters were also visually inspected and the observations recorded.

Fig. 2: Test bench for emitter discharge and CV_q tests

Ten segments of a drip line, each containing ten emitters, had both sides connected to the water supply manifolds of the test bench (Fig. 2) to ensure that all emitters operate at equal pressure. The pressure in the water supply manifolds is adjustable and automatically controlled at pre-set values. Each emitter discharge goes into a separate calibrated and electronically monitored measuring cylinder, which is also equipped with electronically controlled drain valves.

The test was started with the drain valves on the measuring cylinders in the open position. These valves were simultaneously closed once the operating pressure has stabilized at a preset value. The pressure and flow-rate of the water supply, and the time it takes for individual measuring cylinders to fill, was continuously monitored and recorded electronically, including the water temperature. This cycle was repeated for each pressure setting. Tests on regular emitters were carried out for operating pressures from 20 kPa with increments of 20 kPa up to 300 kPa or lesser pressure if so prescribed by the manufacturer. All tests were repeated three times.

In the case of pressure compensating emitters, the discharge rate was measured with the operating pressures 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 discharge rate was also measured with declining pressures in the same way. In accordance with International Standards Organisation (ISO) standards flow-rate measurements were taken over three minutes and CV_q measurements one hour after pressure stabilization. Since the discharge of pressure compensated emitters generally decrease slightly with time, the average discharge rates given in the discharge test might be slightly higher than the discharge given in the CV_q test.

Test results were processed (see Appendices 8.1, 8.2 and 8.3) and represented in the following manner:

- The average discharge 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 discharge curve and the mathematical equation (Burt and Styles, 1994).

$$q_e = kP^x \tag{1}$$

where: q_e = emitter discharge (ℓ/h)
k = emitter constant
P = emitter operating pressure (kPa)
x = discharge exponent.

- The discharge hysteresis of pressure compensating emitters is represented in a discharge table and graph.
- The discharge of individual emitters at a particular pressure is calculated by dividing the volume of each of the calibrated cylinders by the time it takes for the particular cylinder to fill. CV_q values, the minimum and maximum discharge and the variation in discharge are established for the total sample of 100 emitters, as well as for four groups of 25 emitters in accordance with the International Standards Organisation (ISO/TC 23/SC 18 N 89, 1983) standards. The CV_q, which is expressed in terms of the standard deviation as a percentage of the average discharge, is calculated as follows:

$$\bar{q} = \frac{1}{n}\sum_{i=1}^{n} q_i \tag{2}$$

$$S_q = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(q_i - \bar{q}\right)^2\right]^{1/2} \tag{3}$$

$$CV_q = \frac{S_q}{\overline{q}} \times 100 \qquad (4)$$

where:
- q_i = emitter discharge rate (ℓ/h)
- n = number of emitters of the sample
- $\overline{q}$ = mean of all the measured discharge rates (ℓ/h)
- S_q = standard deviation of the discharge rate of the emitter
- CV_q = coefficient of variation of discharge rate of the emitters (%).

2.2.2 **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 simultaneously tested to clog under the same conditions, and was only a qualitative test, because it is not repeatable, due to the nature of the test.

Two drip lines containing ten emitters of eight drip models were installed on the test bench in a similar way as described for the discharge test. The drip 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 drippers in that time. The discharge rate of each dripper was measured every hour and the dirtiness of the water was measured and controlled automatically on a continuous basis by a specially designed "Dirtness index meter". At the end of the test a calculation was done on the total volume of water that each (partially blocked) dripper delivered during the 100 hours and to compare that with what the dripper 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 drippers) of each dripper was used as a test result.

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

2.3 **Field test**

The identified regions were visited and a list of names of possible producers, who have irrigation blocks that satisfy the established requirements, was obtained from local irrigation designers. The producers were contacted to firstly inform them of the objectives of the project and secondly to convince them to take part in the project. Blocks with the established requirements were identified by visiting the producers who were interested in participating in the project. In most cases, farmers were not able to supply a plan of the layout with its specifications.

2.3.1 **Irrigation block information**

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

2.3.2 **Water quality analysis**

A water sample was taken twice per year during the irrigation season at the water source and at the end point of the lateral 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 and ARC-Infruitec/Nietvoorbij to determine the chemical properties of the water. A separate water sample in an acidified water bottle was taken for the analysis of iron and manganese.

Once a year, a water sample was taken at the end point of the lateral to determine the type of algae species. The analysis was conducted at laboratories in Helderberg (Aquatic Ecosystem Services) and in Pretoria (Water lab).

2.3.3 **System evaluation**

Different measurements were done twice per year to determine possible causes of clogging problems and to calculate the performance parameters of the irrigation systems. The measurements included, among others, the following: Time it takes to get clean water to the last emitter of the laterals, type of clogging materials found in the system, number of drippers plugged in the irrigation block, filter back flushing time and pressure drop over the filter before back flushing, as well as the performance of the air valves. A complete system evaluation was done according to the procedure described in ASAE EP 458 (1997). The statistical discharge uniformity (U_s) is used as parameter to describe the uniformity of dripper discharge through the block. Five dripper lines were evaluated in five positions according to the valve position, as shown in Fig. 3.

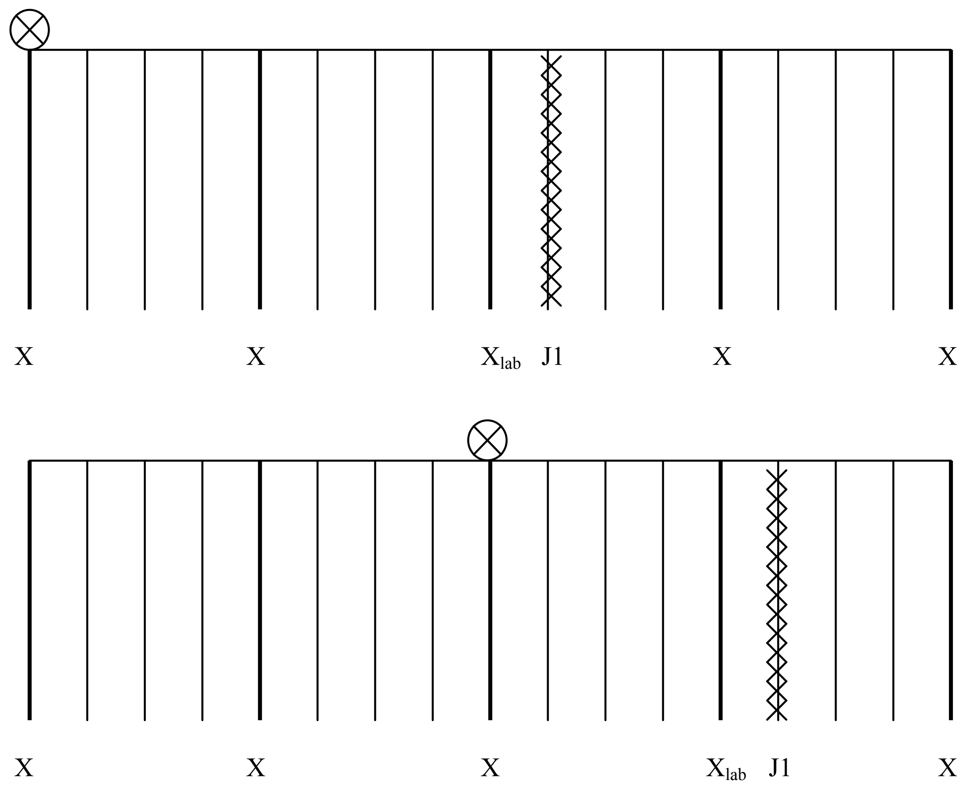


Fig. 3: The position of laterals in the irrigation block

Code: X – dripper line where 5 drippers were evaluated twice per season for a two-year period.
J1 – dripper line where 5 drippers were evaluated at end of first season and taken for lab tests.
X_{lab} – dripper line where 5 drippers were evaluated twice per season for a two-year period and dripper line was taken at the end of the second season for lab tests.
⊗ – Valve

All the drippers (5) were marked with a quick drying spray paint to ensure that the same drippers were evaluated again with each evaluation (twice a year). A yellow colour was chosen above a white colour, as the yellow colour lasts longer and the white paint can be confused with the white lime used for painting the tree trunks.

After the field evaluation, one dripper line was taken out of the relevant block and replaced with the same dripper type (Fig. 3). Evaluations were then carried out in the ARC-ILI Hydrolab to determine possible causes of cloggings.

A sand sample from the sand filters was also taken once and investigated with an electron microscope. The ring and mesh filters were opened once to inspect the condition of the discs or mesh.

2.3.4 **Performance parameters**

The following equations were used for the calculations:

- Statistical uniformity

$$\bar{q} = \frac{1}{n}\sum_{i=1}^{n} q_1 \tag{5}$$

$$S_q = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(q_1 - \bar{q}\right)^2\right]^{1/2} \tag{6}$$

$$CV_q = \frac{S_q}{\bar{q}} \times 100 \tag{7}$$

$$U_s = 100 - CV_q \tag{8}$$

where: q_i = emitter discharge rate (ℓ/h)
n = number of emitters of the sample
$\bar{q}$ = mean of all the measured discharge rates (ℓ/h)
S_q = standard deviation of the discharge rate of the emitters
CV_q = coefficient of variation of discharge rate of the emitters (%)
U_s = statistical uniformity of emitter discharge rate (%).

Table 1: Criteria for an acceptable statistical discharge uniformity (ASAE EP458, 1997)	
Classification	**U_s-Value (%)**
Excellent	>90
Very good	80 – 90
Fair	70 – 80
Poor	60 – 70
Unacceptable	<60

A statistical discharge uniformity (U_s) value of 80% or higher is required, where fertilizer is applied through an irrigation system.

- Field emission uniformity

  The field emission uniformity (EU′) is also used to judge the uniformity of emitter discharges within an irrigation block.

$$EU' = 100\frac{q'_{min}}{\overline{q}} \tag{9}$$

and

$$EU'_a = 50\left(\frac{q'_{min}}{\overline{q}} + \frac{\overline{q}}{q'_{max}}\right) \tag{10}$$

where: EU' = field emission uniformity (%)

EU'_a = absolute field emission uniformity (%)

q'_{min} = measured mean of lowest ¼ of emitter discharge (ℓ/h)

$\overline{q}$ = measured mean emitter discharge (ℓ/h)

q'_{max} = measured mean of highest 1/8 of emitter discharge (ℓ/h).

Table 2 reveals a comparison between U_s and EU as suggested for design purposes.

Table 2: Comparison between U_s and EU for design purposes (ASAE EP458, 1997)		
Classification	**U_s (%)**	**EU (%)**
Excellent	95 – 100	94 – 100
Good	85 – 90	81 – 87
Acceptable	75 – 80	68 – 75
Poor	65 – 70	56 – 62
Unacceptable	<60	<50

- Flow variation

  The flow variation within a block can be determined as follows:

$$FV = \frac{(q_{max} - q_{min})100}{q_{max}} \qquad (11)$$

where: FV = flow variation (%)
q_{min} = lowest emitter's discharge in the block (ℓ/h)
q_{max} = maximum emitter's discharge in the block (ℓ/h).

- Flushing velocity

  The flushing velocity was calculated as follows:

$$v = \frac{0{,}3535 \times Q}{d^2} \qquad (12)$$

where v = flushing velocity (m/s)
Q = total flow at end of lateral (ℓ/h)
d = inside diameter of the lateral pipe (mm).

3. FACTORS WHICH INFLUENCE PERFORMANCE

The clogging of emitters is one of the most serious problems associated with micro-irrigation use. 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 cloggings that will take place and the water treatment approach to be followed.

3.1 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 earths and fertilizer sources. Alkaline earths consist of heavy metal cations (calcium, magnesium, iron and manganese) and anions (carbonate, hydroxide, silicate and sulphide). Fertilizer sources include aqueous ammonia, iron, copper, zinc, manganese and phosphorous. Biological factors incorporate algae, bacteria (filament and slime) and microbial decomposition (iron, manganese and sulphur).

Bucks *et al.* (1979) compiled a water quality classification relative to its potential for drip emitter clogging. Table 3 illustrates the water classification.

Table 3: 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 4. 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 4: 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.

3.1.1 **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, 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 biochemicals 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 subsurface sources. The amount of sediment loads in surface water changes as the stream velocity varies. The nutrient flows into streams and dams result in the suspended solids being accompanied by algae or organic matter. Subsurface 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 specified operating pressures will result in reduced flow-rates that will cause increased settling of suspended solids and cloggings. 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 particulate 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 cloggings. Oil and grease was also identified by Nakayama and Bucks (1991) as causing emitter cloggings. Lubricant seals therefore need to be properly maintained.

3.1.2 **Chemical**

Emitter clogging due to water chemistry is mostly the result of a chemical reaction 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 subsurface 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:

$$\underset{\text{Calcium bicarbonate}}{Ca\,(HCO_3)^2} \xrightarrow{\text{drying}} \underset{\text{Calcite}}{CaCO_3} + \underset{\text{Carbon dioxide}}{CO_2} + \underset{\text{Water}}{H_20} \qquad (13)$$

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 (1985), 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.

$$LI = pH_a - pH_s \qquad (14)$$

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

and

$$pH_s = (pK_d - pK_s) + p[Ca] + p[HCO_3] + p(ACF) \qquad (15)$$

where: p = the negative log of the value in parentheses
$(pK_d\text{-}pK_s)$ = dissociation constant – solubility product (see Eq. 16 below)
[Ca] = calcium concentration (me/ℓ)
[HCO_3] = bicarbonate concentration (me/ℓ)
t = solution temperature (ºC)

$$pK_d - pK_s = 2{,}586 - 2{,}.621 \times 10^{-2} t + 1{,}.01 \times 10^{-4} t^2 \quad (16)$$

and

$$p(ACF) = 7{,}79 \times 10^{-2} + 2{,}16 \times 10^{-2} TDS - 5{,}477 \times 10^{-4} TDS^2 + 5{,}323 \times 10^{-6} TDS^3 \quad (17)$$

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. 18.

$$me/\ell = [mg/\ell]/[\text{atomic mass of ions}] \quad (18)$$

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

$$pH_S = -0{,}014732 \times t + 2{,}30149 + 0{,}00065 \times TDS + 9{,}70167 - \log(2{,}4972 \times Ca) - \log(alkalinity) \quad (19)$$

For 200 < TDS < 300 mg/ℓ

$$pH_S = -0{,}014732 \times t + 2{,}30149 + 9{,}84 - \log(2{,}4972 \times Ca) - \log(alkalinity) \quad (20)$$

For TDS > 300 mg/ℓ

$$pH_S = -0{,}014732 \times t + 2{,}30149 + 0{,}00006786 \times TDS + 9{,}8336 - \log(2{,}4972 \times Ca) - \log(alkalinity) \quad (21)$$

where: t	=	temperature (^oC)
TDS	=	total dissolved solids (mg/ℓ)
Ca	=	calcium concentration (mg/ℓ)
Alkalinity	=	total alkalinity (mg/ℓ).

A 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 5 shows values of LI and the level of corrosivity associated with those values.

Table 5: 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. 22 and Eq. 23shows how the RSI is calculated, while Table 6 illustrates the interpretation of the results.

$$RSI = 2 \times pH_s - pH_a \qquad (22)$$

or

$$RSI = pH_a - 2 \times LI \qquad (23)$$

Table 6: 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. 24. Table 7 shows the interpretation of the AI.

$$AI = pH + \log_{10}(A \times H) \qquad (24)$$

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

Table 7: 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 subsurface 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 sulfates 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, 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. Subsurface 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 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).

3.1.3 **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 waters 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 fertilization (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 drippers 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 assists in the growth of micro-organisms as a source of organic carbon (Rain Bird, 1990).

Table 8: Algae that cause filter clogging (Eurodrip, 1999)

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

Bacteria and bacterial slimes

Slime-forming bacteria are a significant factor causing cloggings 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 cloggings. 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 still 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. Providing 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.

3.1.4 **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).

3.1.5 **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 waters are 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. Subsurface 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 media 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).

3.2 **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 an 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.

3.2.1 **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 pressurized 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 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 parts 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:

$$\underset{\text{Chlorine}}{Cl_2} + \underset{\text{Water}}{H_2O} \longrightarrow \underset{\text{Hypochlorous Acid}}{HOC1} + \underset{\text{Acid}}{H^+} + \underset{\text{Chloride}}{C1^-} \qquad (25)$$

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

$$\underset{\text{Hypochlorous Acid}}{HOC1} \longleftrightarrow \underset{\text{Acid}}{H^+} + \underset{\text{Hypochlorite}}{OC1^-} \qquad (26)$$

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 (superchlorination). 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 needs 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) suggest that continuous chlorination be performed between 1 and 10 ppm at the system inlet. Table 9 shows the recommended chlorine concentrations as suggested by Eurodrip (1999), while Table 10 shows the concentrations suggested by Netafim (1999).

Table 9: 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 10: 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. Superchlorination 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 superchlorination 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 superchlorination 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, however, 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 11 shows the amount of the different chlorine sources needed to supply 500 g of chlorine.

Table 11: Comparison of chlorine supplying materials (Rain Bird, 1990)

Chlorine source	Amount needed to supply 500 g $C1_2$	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. 27 and 28, for calculating the chlorine application rate for liquid and gas chlorine respectively.

$$IR = \frac{0,1 \times Q \times C}{P} \tag{27}$$

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 (%).

$$IR = 0,024 \times Q \times C \tag{28}$$

where: IR = chlorine injection rate (kg/day)
Q = flow-rate of the system (m^3/h), and
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 taken to solve the problem. Woody crops sensitive to chlorine, such as citrus, avocado and berries, 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, hydrocyclone, 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 12 shows the concentrations of iron and chlorine within various parts of this irrigation system during an irrigation-chlorination cycle.

Table 12: 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**	**Backflush 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 does show 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 were inhibited by the presence of chlorine and iron slime was avoided.

3.2.2 **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 subsurface systems (Nakayama and Bucks, 1985). 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 utilized (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 13.

Table 13: 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 marketed 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 drippers, 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.

$$Ca^{2+} + 2HCO_3^- + 2H^+ + SO_4^{2-} => Ca^{2+} + SO_4^{2-} + 2CO_2(g) + 2H_2O \qquad (29)$$

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 neutralize 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) suggest 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 able due to the sensitivity of the crop involved.

3.2.3 **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) suggest 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 is any aluminium pipe in the drip system.

3.2.4 **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 homopolymer 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.

3.2.5 **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).

3.3 **Inherent factors affecting emitter performance**

Emitters are designed to discharge some of the water flowing under pressure in the lateral, at low flow-rates to the atmosphere. To achieve this, the pressure in the lateral is dissipated 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.

3.3.1 **Discharge versus pressure relationship**

The discharge of an emitter is given by the equation:

$$q_e = k\,P^x \tag{30}$$

where: q_e = emitter discharge (ℓ/h)
k = a constant, depending upon the units and flow-path size
P = operating pressure (kPa)
x = emitter discharge exponent.

The effect of the emitter discharge exponent (x) on discharge for variation in operating pressure is illustrated in Fig. 4.

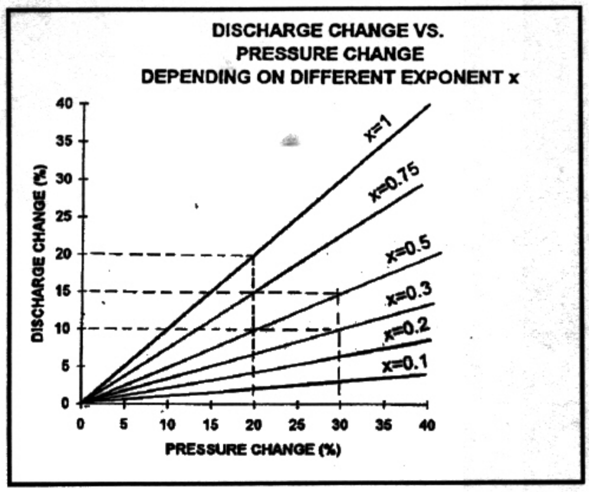


Fig. 4: Discharge vs. pressure relationship for different exponent values (Burt and Styles, 1994)

The discharge of an emitter is proportional to the operating pressure raised to the power of the emitter discharge exponent value. This exponent is a measurement of the slope of the discharge-pressure curve. Low or high values of the emitter discharge exponent indicate respectively low or high sensitivity of emitter discharge to changes in operating pressure. The emitter discharge 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 discharge exponent value for laminar flow approaches a value of 1,0, which indicates that the discharge of laminar flow emitters is almost directly proportional to the pressure. The discharge of emitters with a tortuous flow-path on the other hand varies with the square root of the pressure (emitter discharge 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 discharge. Pressure compensating emitters all have a physical part that responds to pressure, and their performance in the long term may not always be reliable.

3.3.2 **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 Center of the California Polytechnic State University in 1994. These descriptions are reproduced in Table 14.

Table 14: Description, merits and disadvantages of various emitter flow-paths (Burt and Styles, 1994)				
	Description	**Merits**	**Disadvantages**	**Typical discharge exponent**
Micro tube	Long small diameter spaghetti tube, laminar flow.	• Inexpensive	• Flow-rate sensitive to temperature. • Very sensitive to clogging. • Large manufacturing CV.	0,7 – 0,8
Long smooth flow-path	Long, smooth spiral passageway in molded 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.	>1
Pressure compen-sating	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. • Discharge characteristics may change after a few years.	0 – 0,5
Multiple flexible orifice	Water passes through several orifices in flexible membranes. Dirt caught in one orifice will create backpressure, expanding the orifice and moving the dirt through.	• Typically a large hole. • Less susceptible to clogging than other emitters with the same hole size.	• Expensive • Discharge characteristics may change after a few years.	0,7
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 is briefly described below.

Long flow-path emitters

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

- The discharge 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 discharge 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 discharge, and the discharge of the emitter would therefore increase with rising water temperatures.
- For the same cross-sectional area and length of flow-path the discharge in an equilateral triangular cross section is higher than in a semicircular one. The discharge 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-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 discharges, 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 discharge 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 discharge 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 discharge is proportional to the square root of the operating pressure, the cross-sectional area of the orifice or nozzle, and the discharge coefficient of the particular orifice or nozzle.
- The discharge 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 discharge is independent of changes in the kinematic viscosity due to temperature changes.

3.3.3 **Manufacturing uniformity**

Small manufacturing differences between emitters may cause significant variations in discharge. 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 discharge. 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 discharge for a sample of new emitters. The CV_q is a very useful parameter with rather consistent physical significance, because the discharge rate for emitters at a given pressure are essentially normally distributed. The physical significance of CV_q is derived from the classic bell-shaped normal distribution curve shown in Fig. 5.

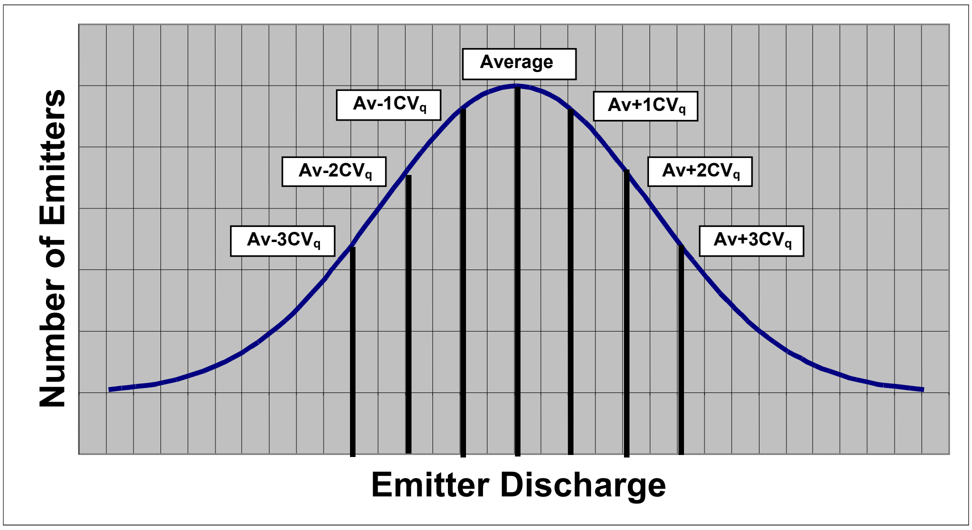


Fig. 5: Normal distribution curve

In a normal distribution:

- Essentially all the observed discharge rates fall within ($1 \pm 3CV_q$) of the average discharge rate;
- Approximately 95% of the discharge rates fall within ($1 \pm 2CV_q$) of the average discharge rate;
- Approximately 68% of the discharge rates fall within ($1 \pm 1CV_q$) of the average discharge rate; and
- The average of the lowest quarter of the discharge rates is approximately equal to ($1 - 1{,}27\ CV_q$) of the average discharge rate.

3.3.4 **Discharge versus temperature relationships**

There are three reasons why emitters may be sensitive to water temperature. Firstly, the discharge of most long flow-path emitters is affected by the changes in the viscosity of the water that changes with the temperature. Although, it is less so for emitters with mainly tortuous flow than for those with mainly laminar flow. Secondly, most emitters are somewhat sensitive to the water temperature because of dimensional changes that may take place in the flow-paths. Thirdly, the discharge from emitters with parts made of resilient materials, like diaphragms used in some pressure compensating emitters, may vary due to changes in material characteristics caused by temperature changes.

With laminar flow-path emitters installed in laterals exposed to the sun, the increase in discharge, due to the decrease in viscosity along the line as the temperature increases, may partly compensate for the decrease in discharge due to declining pressure.

3.3.5 **Friction losses in laterals**

The most common ways in which emitters are attached to the laterals, which causes additional friction in the drip lines are the following:

- On-line emitters have a "barbed" inlet port, which is inserted through a hole in the lateral.
- In-line emitters with barbed ends act as couplers between short lengths of the lateral. These emitters have a hollow center to allow the flow of water through the emitter.
- Welding of emitters to the inside of the lateral, or insertion of the emitter into the lateral as it is extruded have become popular ways of emitter attachment.

All the attachment methods, however, cause some obstruction to the flow of water in the lateral, which causes additional friction losses in the laterals. These friction losses are dependent on the size and shape of the emitter, the flow-rate and the internal diameter of the lateral. A drop in pressure along the lateral due to friction head losses results in reduced discharge from the emitters, particularly if laterals are long and flow-rates are high, and thereby negatively effects the in-field distribution uniformity of the system.

3.3.6 **Sensitivity to clogging**

The sensitivity of emitters to clogging is a most important factor affecting the sustainable performance of a drip irrigation system. Two critical parameters related to clogging susceptibility of a particular emitter are the size of the flow-path and the velocity of flow in the passage. The size of the flow-path, or cross section, determines the degree to which irrigation water should be filtered. The usual recommendation is to remove all particles larger than one-tenth the diameter of the emitter flow-path. The relationship between the minimum dimension of the flow-path's cross section and the flow-path's susceptibility to clogging, is given by Keller and Bliesner (1990) as:

- Very sensitive: less than 0,7 mm;
- Sensitive: between 0,7 mm and 1,5 mm; and
- Relatively insensitive: larger than 1,5 mm or continuously flushing emitters.

Even with filtration of the irrigation water, sedimentation of silt and mineral particles can cause slow clogging over a period. It is reported that flow velocities from 4 to 6 m/s in the laterals have resulted in reduced clogging. To reduce the possibility of clogging some emitters have been designed to include the capability of flushing. These features range from those that automatically flush at start-up and shut down, to those that flush continually. To be effective, the short flush type requires a minimum velocity and duration of flush. The automatic-flushing emitters have a series of orifices in a resilient material to dissipate pressure. When clogging occurs, line pressure builds up behind the particle and forces the orifice to expand and let the particle pass through.

The tendency to clog can, however, significantly be reduced by regular flushing of the laterals. Even when good quality water is used, lateral flushing provides an added safety factor for continual operation of a system.

3.3.7 **Other factors**

Other factors that may have an effect on the sustainable good performance of drip irrigation systems include the following:

- Resistance to ultra violet radiation. Parts or components that may be exposed to direct sunlight should be adequately resistant to ultra violet radiation.
- Flexible or moving parts. The properties and functioning of flexible or moving parts used in some emitters for pressure compensation or for self-flushing actions may in time change to the detriment of the emitter performance.
- Protection against insects. In areas where clogging of the emitter outlet by insects may be a concern, some cap or device that covers the outlet when the emitter is not in operation, is desirable.
- Root intrusion. Surface drip is normally not affected by root intrusion, but where problems do occur, preventative measures can be taken by injecting a prescribed solution of Trifluralin through the system. Another project on sub-surface drip irrigation address the issue in full.

3.4 **Filtration**

Physical water treatment is used to remove suspended matter from the water supply prior for 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 drippers. 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.

3.4.1 **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 15 shows the sedimentation speed of different soil particle sizes.

Table 15: 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 be effectively controlled by adding copper sulphate in bags equipped with floats, or by broadcasting it over the water surface (paragraph 3.2.3). 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 out and 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 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 startup when large amounts of sand are discharge from a well. Therefore, for micro-irrigation systems, sand separators must always be followed by filter.
- 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 to remove the solids (Burt and Styles, 1994).

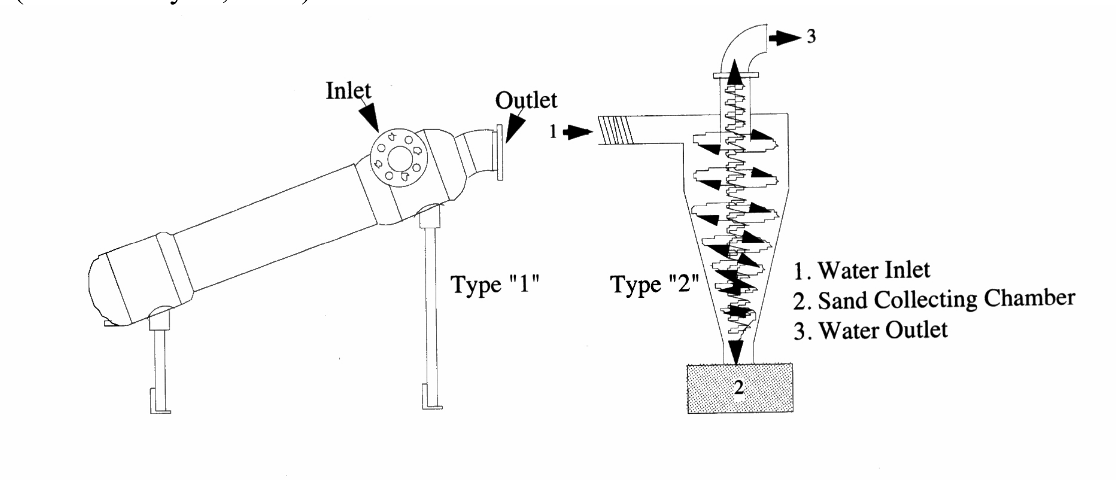


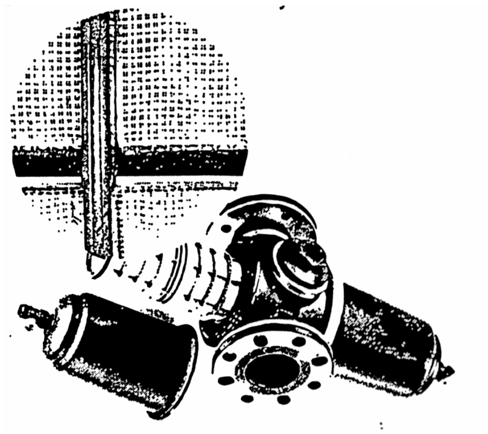
Fig. 6: Two types of sand separators (Burt and Styles, 1994)

3.4.2 **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 (Fig. 7) 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

Fig. 7: Mesh filters and mesh sizes (Burt and Styles, 1994)

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

$$MG = 10187F^{-0,9327} \qquad (31)$$

where: MG = mesh size
F = micron size

- Disc filters

  Disc filters offer a three-dimensional filter action and therefore have a 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. Fig. 8 illustrates the flow pattern through a typical disc filter.

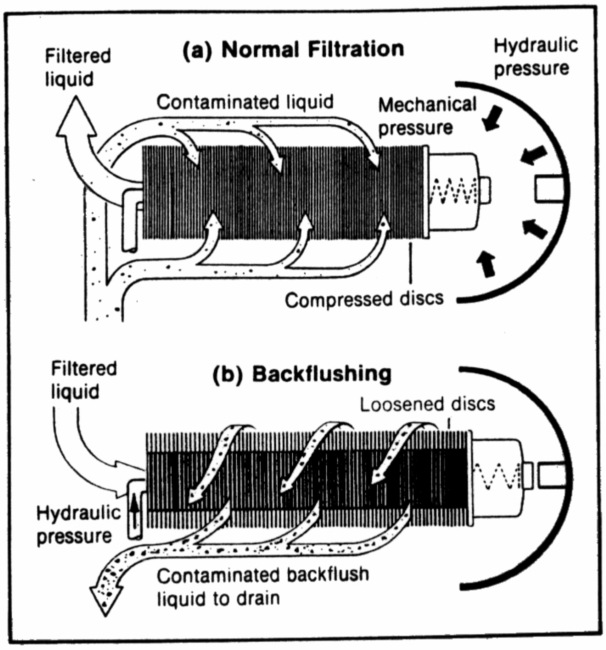


Fig. 8: Filtering and back flushing action with disc filters (Burt and Styles, 1994)

Any disc/discs 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. 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 m^3/hour per m^2 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 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 drippers.

The shape and function of typical sand filters are illustrated in Fig. 9.

FILTRATION PROCESS BACK FLUSHING PROCESS

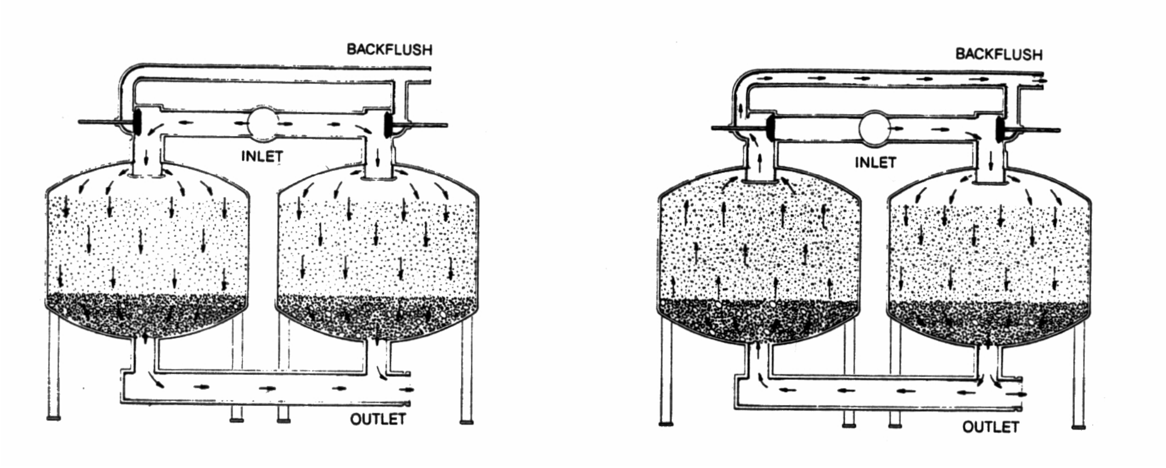


Fig. 9: Filtering and back flushing with sand filters (Burt and Styles, 1994)

3.4.3 **Selection of filter type** (Heyns *et al*, 1996)

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 drippers 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, discs filters are usually recommended for this purpose. In cases where irrigation is done with clean water, such as water from most boreholes, discs filters are usually sufficient. The filtration level will be sufficient enough and the only limitation will be length of the back flush cycle.

3.4.4 **Selection of filter size or filter capacity** (Heyns *et al*, 1996)

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 over 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 16:

Table 16: 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 Fig. 10.

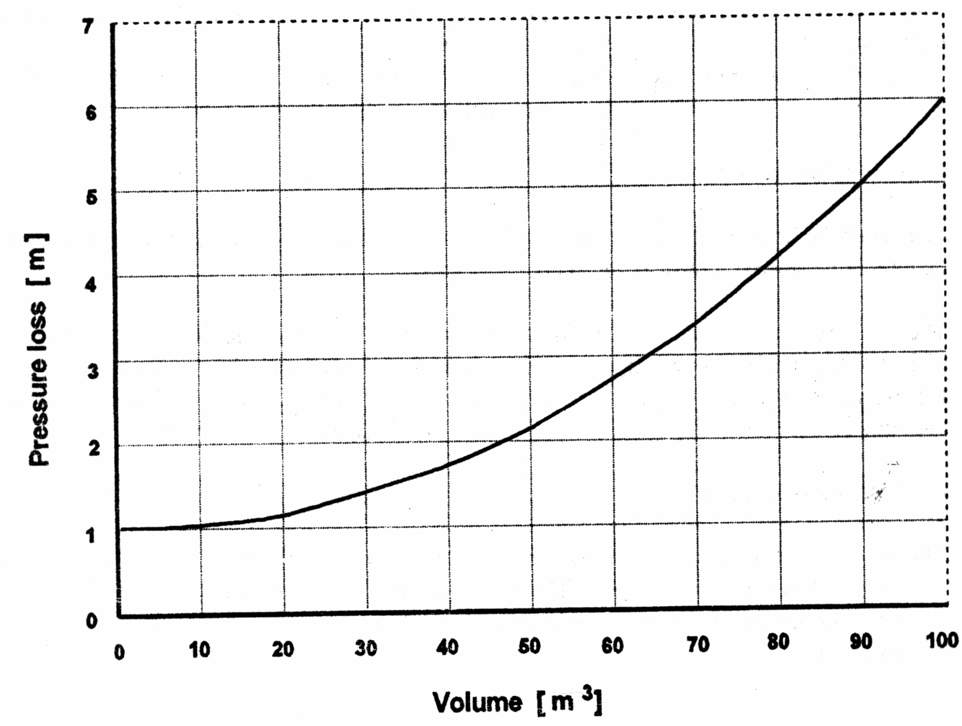


Fig. 10: Typical clogging graph of a filter (Van Niekerk, 1983)

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 funneling through filters, with resulting dirt penetration into the sand bed.
- 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 drippers.
- 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.

3.4.5 **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 17 is recommended.

Table 17: 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 18.

Table 18: Troubleshooting guide for sand media filters (Pierce and Mancuso, 1985)	
Problem: POOR FILTRATION	
Probable cause	*Solution*
1. Excessive flow through filters causing coning and forcing contaminants through filter.	1. Reduce flow-rate or add filters.
2. Air in filters causing disruption of sand bed.	2. Install auto or manual air bleed device.
3. Incorrect sand medium.	3. Replace with proper media.
4. Excessive pressure forcing contaminants through filters.	4. Readjust back flush control valve to proper setting.
5. Insufficient medium depth allowing contaminants to pass through.	5. Add medium to achieve depth between 31 and 33 cm.
Problem: CONSISTENTLY HIGH PRESSURE DIFFERENTIAL	
Probable cause	*Solution*
1. Filter sealed over with contaminants restricting back flush flow.	1. Open tanks and remove contaminants from medium surface, close tanks and back flush until filters are clean.
2. Insufficient back flush flow.	2. Re-adjust back flush flow or partially close field valve.
3. Low filter sand medium causing inadequate back flush.	3. Add medium to correct level.
Problem: MEDIA SAND APPEARS DOWNSTREAM	
Probable cause	*Solution*
1. Incorrect medium, i.e. too fine.	1. Replace with proper medium.
2. Broken or damaged PVC lateral pipe.	2. Repair or replace.
Problem: BACK FLUSH VALVES LEAK	
Probable cause	*Solution*
1. Obstruction in valve seat.	1. Remove obstruction.
2. Rubber seating disc worn or damaged.	2. Replace seat disc.
3. Diaphragm damaged (leaking from port of diaphragm chamber at rear of valve).	3. Replace diaphragm.
4. Pinched or worn o-ring.	4. Replace o-ring and lubricate shaft.
Problem: WATER HAMMER	
Probable cause	*Solution*
1. Air in tanks.	1. Bleed off trapped air. Check for leaks in pump suction line.
2. Long vacuum line causing vacuum.	2. Install vacuum breaker on back flush line.
Problem: INCREASING FREQUENCY OF BACK FLUSH CYCLE	
Probable cause	*Solution*
1. Back flush flow or duration is not adequate to remove all contaminants.	1. Readjust back flush flow and/or increase duration of back flush cycle.
2. Insufficient filter medium depth.	2. Add filter medium.
3. Increased concentration of contaminants in water supply (may be seasonal).	3. 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*
1. Controller power off, blown fuse or circuit breaker tripped.	1. Turn power on. Ensure wiring is connected. Reset circuit breaker or install new fuse.
2. Improper setting on differential pressure switch.	2. Inspect seal for signs of tampering.
3. Solenoid malfunctioning.	3. Check connections. Clean ports. Check filter screen on water pickup assembly for damage. Clean or replace screen.
4. Loss of sufficient system pressure to actuate valves.	4. Check system for pressure leaks. Check filter screen on water pickup assembly for damage.

3.5 System maintenance

Drippers are inclined to be extremely sensitive to particles which can cause clogging, because the flow-path openings of the drippers 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 16). Practices such as cleaning of storage dams and especially the flushing of filters and laterals must be done regularly.

3.5.1 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.

3.5.2 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 drippers. 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 drippers will become clogged first. Although one single particle may not cause clogging, a number of particles may collect and cause the drippers 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. Laterals should, depending on the water quality, be flushed weekly. When regular flushing of the laterals is necessary, the use of a flushing valve 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).

3.5.3 Evaluation of the discharge of drippers

The continuous monitoring of the functioning of the drippers in an irrigation block is very important. The discharge 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 mixture of the before-mentioned factors. Physical deterioration can occur in pressure compensating drippers where the flow-path may alter slowly as a result of changing, with time, of the pressure compensating part (diaphragm) of the dripper.

Irrigators are recommended to, with each irrigation, to walk through the irrigation block to clean the clogged drippers and repair leakages. Replace drippers with the same make and type if necessary. 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. The evaluation must be done at least once per season, after all the obvious clogging problems have been solved. Drippers 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 to the evaluation results obtained.

3.5.4 Cleaning of drippers

The cleaning method to be used for the drippers depends on the type of dripper, as well as the type of clogging. Some types of drippers can be taken apart and cleaned by hand. Other types of drippers have the ability to flush themselves. The different solutions to the different clogging problems have already been described in paragraph 3.1. Air pressure is not recommended when cleaning drippers. High water pressure has limited possibilities for cleaning drippers. The most suitable method for cleaning drippers is to follow a reliable maintenance schedule as shown in Table 19.

Table 19: 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 flow-meter)		×		
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				×

3.6 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:

- 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:

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}} \times 100 \qquad (32)$$

where: q_{var} = flow variation in the block (%)
q_{max} = maximum emitter's discharge in the block (ℓ/h)
q_{min} = lowest emitter's discharge in the block (ℓ/h).

Table 20: Criteria for the parameter q_{var}	
Classification	**Value (%)**
Desirable	<10
Acceptable	10 – 20
Unacceptable	>20

- Manufacturing variations (CV_q): This is a measure of the variability of discharge 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).

$$CV_q = \frac{S_q}{\overline{q}} \times 100 \qquad (33)$$

where: $\overline{q}$ = the mean discharge of the drippers of the sample (ℓ/h)
S_q = the standard deviation of the discharge of the drippers of the sample.

$$\text{With } S_q = \left(\frac{\sum_{i=1}^{n} (q_i - \overline{q})^2}{n-1} \right)^{\frac{1}{2}} \qquad (34)$$

where: q_i = the discharge of the drippers (ℓ/h)
n = the number of drippers of the sample.

Table 21: Criteria for CV_q (%) of "point-source" drippers				
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 dripper discharge 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 discharge.

$$EU = 100\left(1{,}0 - \frac{1{,}27}{\sqrt{e}} CV_q\right)\frac{q_{min}}{\bar{q}} \qquad (35)$$

$$EU_a = 50\left(1{,}0 - \frac{1{,}27}{\sqrt{e}} CV_q\right)\left(\frac{q_{min}}{\bar{q}} + \frac{\bar{q}}{q_{max}}\right) \qquad (36)$$

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

Table 22: Criteria for the parameter EU for "point-source" drippers (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

4. RESULTS

4.1 Description of emitters chosen for the investigation

Ten different emitter models of the two different manufacturers, Agriplas and Netafim were selected for the research. The general specifications of emitters and laterals as given by the manufacturers are represented in Tables 23 to 26.

Table 23: Particulars of Agriplas Drip-In regular and Agridrip pressure compensating emitters

ARC-ILI Code	Emitter description	Nominal discharge (ℓ/h) @ 100 kPa	Flow-path (labyrinth) particulars			
			Depth (mm)	Width (mm)	Length (mm)	Type
GA	12 mm 2 ℓh regular	2	0,9	1,0	155	Non compensating long flow-path turbulent flow in line emitter.
GB	12 mm 4 ℓh regular	4	0,9	1,0	49	
GC	16 mm 2 ℓ/h regular	2	0,95	1,0	183	
GD	16 mm 4 ℓ/h regular	4	1,28	1,4	158	
KE	16 mm 2,2 ℓ/h pressure compensating (PC)	2,2	1,0	0,95	40 – 250	Pressure compensating varying flow-path length, turbulent flow in line emitter.
KF	16 mm 3,6 ℓ/h pressure compensating (PC)	3,6	1,35	0,95	40 – 250	

Flow-path: Labyrinth
Outlets: 2 of 2 mm diameter
Construction material: LDPE
Permissible operating pressure: Regular: Maximum 250 kPa, minimum not applicable, PC: Maximum 350 kPa, minimum 60 kPa. The pressure compensation process is achieved by a silicone membrane, which controls the emitter's labyrinth length that alters from a minimum length of 40 mm to a maximum length of 250 mm when pressure changes occur within the drip lateral.
Nominal discharge: This is not the measured actual discharge, but the descriptive discharge.

Table 24: Particulars of Agriplas laterals

Characteristic	Regular emitters		PC emitters
	12 mm	16 mm	16 mm
Material (virgin)	LLDPE	LLDPE	LLDPE
Pipe inside diameter (mm ± 0,1)	11,15	14	13,5
Pipe outside diameter (mm ± 0,1)	13,15	16	15,5
Pipe wall thickness (mm ± 0,05)	1,0	1,0	1,0
Pipe burst pressure (kPa)	1 200	1 200	1 200

Table 25: Particulars of Netafim Ram pressure compensating (PC) emitters						
ARC-ILI Code	Emitter description	Nominal discharge (ℓ/h) @ 100 kPa	Flow-path (labyrinth) particulars			
			Depth (mm)	Width (mm)	Length (mm)	Type
KG	17 mm 2,3 ℓ/h PC	2,3	1,15	1,15	22	Pressure compensated integral lateral, turbo net flow-path, self-flushing with pressure difference.
KH	17 mm 3,5 ℓ/h PC	3,5	1,20	1,75	22	
KJ	20 mm 2,3 ℓ/h PC	2,3	1,15	1,15	22	
KK	20 mm 3,5 ℓ/h PC	3,5	1,20	1,75	22	

Flow-path: Turbo net flow-path
Outlets: 1
Construction material: Polyethylene
Permissible operating pressures: 30 kPa till burst pressure of pipe. Pressure compensation: 30 kPa – 400 kPa.
All tests are performed on PC drippers with GPDM membranes.
Nominal discharge: This is not the measured actual discharge, but the descriptive discharge.

Table 26: Particulars of Netafim laterals		
Characteristic	**17 mm**	**20 mm**
Material (virgin)	LLDPE	LLDPE
Pipe inside diameter (mm ± 0,1)	14,5	17,6
Pipe outside diameter (mm ± 0,1)	16,5	20,0
Pipe wall thickness (mm ± 0,05)	1,00	1,20
Pipe burst pressure (kPa)	4 × operating pressure	4 × operating pressure

4.2 Laboratory tests on emitters

Performance and clogging tests were carried out on new drippers in the laboratory and only performance tests were carried out on emitters recovered from the field.

4.2.1 New emitters

The results of the discharge/pressure relationship and the coefficient of discharge variation (CV) tests performed in the laboratory on emitters are summarized in Tables 27 to 29. The results given are the average of three repetitions on a test sample of 100 emitters.

Table 27: Laboratory results of Agridrip pressure compensating (PC) emitters											
Emitter description			Discharge test (Average P)				CV_q Test (P = 200 kPa nominal)				
			Discharge (ℓ/h)				Discharge (ℓ/h)				CV_q (%)
Code	mm	(ℓ/h)	100 kPa	200 kPa	300 kPa	400 kPa	Max	Min	Av	Var (%)	
KE	16	2,2	2,56	2,44	2,38	2,38	2,7	1,6	2,4	45,8	4,2
KF	16	3,6	3,84	3,58	3,57	3,66	3,8	3,3	3,6	13,9	3,4
									Average CV_q		3,8

Table 28: Laboratory results of Ram pressure compensating (PC) emitters											
Emitter description			Discharge test (Average P)				CV_q Test (P = 200 kPa nominal)				
			Discharge (ℓ/h) at:				Discharge (ℓ/h)				CV_q (%)
Code	mm	(ℓ/h)	100 kPa	200 kPa	300 kPa	400 kPa	Max	Min	Av	Var (%)	
KG	17	2,3	2,47	2,41	2,45	2,51	2,4	2,1	2,3	13,0	2,6
KH	17	3,5	3,72	3,65	3,78	3,74	4,2	2,5	3,6	47,2	4,0
KJ	20	2,3	2,53	2,40	2,46	2,45	2,5	2,0	2,3	21,7	3,9
KK	20	3,5	3,68	3,50	3,60	3,47	3,6	3,2	3,4	11,8	2,6
									Average CV_q		3,3

Table 29: Laboratory results of Drip-In regular emitters											
Emitter description			Discharge test				CV_q Test (P =100 kPa nominal)				
			Discharge (ℓ/h) at			Discharge exponent	Discharge (ℓ/h)				CV_q (%)
Code	mm	(ℓ/h)	100 kPa	200 kPa	300 kPa		Max	Min	Av	Var (%)	
GA	12	2	2,23	3,19	3,93	0,5163	2,5	2,1	2,2	18,2	2,1
GC	16	2	2,26	3,25	4,01	0,5207	2,6	2,2	2,3	17,4	2,4
GB	12	4	4,07	5,77	7,07	0,5016	4,5	3,8	4,1	17,1	3,8
GD	16	4	4,25	6,07	7,46	0,5115	4,7	4,1	4,3	14,0	2,2
									Average CV_q		2,6

Abbreviations used in the tables

P: Operating pressure (kPa)
Max: The discharge of the emitter with the highest discharge in the sample (ℓ/h)
Min: The discharge of the emitter with the lowest discharge in the sample (ℓ/h)
Av: The average discharge of the sample of 100 emitters (ℓ/h)
Var: The variation in discharge between the emitters with the highest and lowest discharge (%)
CV_q: Coefficient of discharge variation of the sample (%)

CV_q norms according to ILI's criteria on Table 21:

CV_q = 0,1 to 2,5% : Excellent
CV_q = 2,6 to 5,0% : Good
CV_q = 5,1 to 7,5% : Fair
CV_q = 7,6% to 10,0%: Marginal
CV_q > 10% : Poor

In the Appendices, examples of the test reports are shown (see 8.1, 8.2 and 8.3).

4.2.2 **Emitters recovered from the field**

The results of laboratory CV_q and discharge tests on new emitters and on emitters in drip lines recovered from the field in the various regions are given in Table 30 to 37. The percentage of emitters with discharges between the average discharge of new emitters $\pm 1CV_q$, $\pm 1CV_q$ to $\pm 2CV_q$, $\pm 2CV_q$ to $\pm 3CV_q$, and more than $\pm 3CV_q$ are also shown. Observations with regard to the physical conditions of the drip lines are recorded in the remarks column.

Table 30: Results of laboratory tests on Ram PC emitters recovered from the field during the year 2000													
REGION AND PROPERTY	**NAME AND CODE OF DRIPPER TESTED**	**AGE GROUP YEARS**	**SAMPLE SIZE UNITS**	**DRIPPER CV (%)**	**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*	
KOUGA	**Ram 3,5 ℓ/h 17 mm KH**	**NEW**	**100**	**4,0**	**3,6**	**7**	**5**	**17**	**39**	**15**	**10**	**7**	
1,1		<5	95	5,8	3,6	8	11	17	20	16	6	22	*Clean.*
1,3		<5	100	5,7	3,7	10	4	7	17	11	11	40	*Lightly soiled.*
1,6		<5	100	3,0	3,7	1	3	7	23	22	11	33	*Clean.*
1,5		>5	100	8,3	3,8	16	2	7	13	5	10	47	*Lightly soiled.*
1,2		>5	84	5,8	3,7	20	7	6	10	6	10	42	*Lightly soiled.*
ORANGE	**Ram 3,5 ℓ/h 17 mm KH**	**NEW**	**100**	**4,0**	**3,6**	**7**	**5**	**17**	**39**	**15**	**10**	**7**	
2,4		<5	80	4,2	3,4	49	8	10	5	3	0	26	*Lightly soiled.*
2,6		<5	95	7,5	3,8	3	2	0	11	5	6	73	*Lightly soiled.*
2,5		>5	100	14,1	4,0	1	0	1	11	4	6	77	*Lightly soiled.*
2,3		>5	90	3,2	3,7	4	7	7	14	18	13	37	*Soiled.*
2,9		>5	100	7,0	3,7	6	4	5	14	18	11	42	*Lightly soiled.*
ORANGE	**Ram 3,5 ℓ/h 20 mm KK**	**NEW**	**100**	**2,6**	**3,4**	**21**	**7**	**10**	**20**	**14**	**8**	**20**	
2,10		<5	100	64,5*	5,4*	2	0	0	0	0	0	98	*Soiled. Two drippers damaged with high discharges.*
BERG	**Ram 3,5 ℓ/h 17 mm KH**	**New**	**100**	**4,0**	**3,6**	**7**	**5**	**17**	**39**	**15**	**10**	**7**	
4,1		<5	100	8,4	3,6	6	6	12	20	23	9	24	*Clean. One dripper blocked with foreign object.*
4,3		<5	84	3,0	3,5	35	12	14	13	7	1	18	*Lightly soiled.*
4,5		<5	100	6,8	3,4	57	12	9	15	3	2	2	*Lightly soiled.*
4,2		>5	100	13,7	3,9	41	8	3	12	10	2	24	
4,4		>5	100	6,0	3,8	9	2	7	18	11	9	44	*Soiled. Button dripper removed before test.*
4,8		>5	100	5,0	3,6	23	6	8	16	10	8	29	*Soiled.*
CROCO-DILE	**Ram 3,5 ℓ/h 17 mm KH**	**NEW**	**100**	**4,0**	**3,6**	**7**	**5**	**17**	**39**	**15**	**10**	**7**	
5,1		<5	100	180,9*	9,7*	66	0	0	0	2	0	32	*Heavily soiled. Eleven drippers pierced with high discharges.*
5,4		>5	94	4,5	3,6	18	11	6	19	9	10	28	*Soiled.*

*Values not included in analysis, because of unnatural damages to drippers.

Table 31: Results of laboratory tests on Agridrip PC emitters recovered from the field during the year 2000														
REGION AND PROPERTY	**NAME AND CODE OF DRIPPER TESTED**	**AGE GROUP YEARS**	**SAMPLE SIZE UNITS**	**DRIPPER CV (%)**	**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*	
ORANGE	**Agridrip PC 3,6 ℓ /h 16 mm KF**	**NEW**	**100**	**3,4**	**3,6**	**19**	**9**	**16**	**20**	**9**	**7**	**20**	
2,1		<5	100	4,8	4,0	1	0	0	1	0	0	98	*Soiled.*
BREEDE	**Agridrip PC 3,6 ℓ/h 16 mm KF**	**NEW**	**100**	**3,4**	**3,6**	**19**	**9**	**16**	**20**	**9**	**7**	**20**	
3,1		<5	100	4,3	4,4	1	0	0	0	0	0	99	*Lightly soiled.*
3,2		<5	100	15,4	4,4	0	0	0	0	0	0	100	*Lightly soiled. One dripper damaged with high discharge.*
3,4		>5	100	11,8	4,6	0	0	0	0	0	0	100	*Heavily soiled.*

Table 32: Results of laboratory tests on Drip-In regular emitters recovered from the field during the year 2000

REGION AND PROPERTY	NAME AND CODE OF DRIPPER TESTED	AGE GROUP YEARS	SAMPLE SIZE UNITS	DRIPPER CV (%)	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*	
ORANGE	**Drip-In REG 4 ℓ/h 16 mm GD**	**NEW**	**100**	**2,2**	**4,3**	**28**	**4**	**8**	**18**	**5**	**12**	**25**	
2,12		<5	100	4,1	3,9	99	1	0	0	0	0	0	*Lightly soiled.*
2,2		<5	100	5,8	4,4	7	4	3	3	7	3	73	*Soiled.*
2,8		<5	70	3,1	4,4	0	0	0	4	1	7	87	*Lightly soiled.*
2,7		>5	100	1,8	4,0	99	1	0	0	0	0	0	*Lightly soiled.*
2,13		>5	100	2,0	4,4	1	2	6	11	8	4	68	*Soiled.*
2,11		>5	70	3,4	4,5	0	0	0	1	4	6	89	*Lightly soiled.*
BREEDE	**Drip-In REG 4 ℓ/h 16 mm GD**	**NEW**	**100**	**2,2**	**4,3**	**28**	**4**	**8**	**18**	**5**	**12**	**25**	
3,5		<5	40	3,0	4,4	7	3	0	20	13	10	47	*Lightly soiled, combination pipe.*
3,3		>5	50	26,4*	3,9*	62	4	2	8	0	8	16	*Soiled. Three drippers blocked due to muddy sediment.*
3,8		>5	46	21,3	4,0	39	7	7	17	2	9	20	*Lightly soiled. One dripper blocked. Combination pipe.*
3,9		>5	50	5,0	4,3	22	12	6	32	8	8	12	*Lightly soiled. Leakages repaired.*
BERG	**Drip-In REG 4 ℓ/h 16 mm GD**	**NEW**	**100**	**2,2**	**4,3**	**28**	**4**	**8**	**18**	**5**	**12**	**25**	
4,7		>5	87	10,0	4,6	40	9	5	13	5	2	26	*Lightly soiled. One dripper damaged with high discharge.*
4,9		>5	50	6,0	3,8	2	2	4	4	2	2	84	*Soiled, combination pipe.*
4,6		>5	90	65,5*	3,0*	28	9	4	12	4	2	40	*Heavily soiled. One dripper pierced and five drippers partially blocked.*
CROCO-DILE	**Drip-In REG 2 ℓ/h 16 mm GC**	**NEW**	**100**	**2,4**	**2,3**	**5**	**11**	**17**	**37**	**15**	**8**	**7**	
5,3		<5	50	9,4	1,7	0	0	0	0	0	0	100	*Heavily soiled.*
5,5		<5	70	4,9	2,0	100	0	0	0	0	0	0	*Soiled, combination pipe.*

*Values not included in analysis, because of unnatural damages to drippers.

Table 33: Results of laboratory tests on Drip-In regular emitters recovered from the field during the year 2000

REGION AND PROPERTY	NAME AND CODE OF DRIPPER TESTED	AGE GROUP YEARS	SAMPLE SIZE UNITS	DRIPPER CV (%)	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*	
BREEDE	**Drip-In REG 4 ℓ/h 12 mm GB**	**NEW**	**100**	**3,8**	**4,1**	**30**	**7**	**5**	**19**	**4**	**12**	**23**	
3,5		<5	40	5,2	4,3	7	3	0	20	13	10	47	*Lightly soiled, combination pipe.*
3,6		<5	50	4,6	4,0	0	46	18	20	4	2	10	*Lightly soiled.*
3,7		>5	50	3,0	4,5	0	0	0	0	0	0	100	*Clean.*
3,8		>5	26	3,7	4,1	0	12	12	65	12	0	0	*Lightly soiled. One dripper blocked, combination pipe.*
3,9		>5	50	3,8	4,2	22	12	6	32	8	8	12	*Lightly soiled, combination pipe.*
BERG	**Drip-In REG 4 ℓ/h 12 mm GB**	**NEW**	**100**	**3,8**	**4,1**	**30**	**7**	**5**	**19**	**4**	**12**	**23**	
4,9		>5	50	11,3	3,8	2	2	4	4	2	2	84	*Soiled, combination pipe.*
CROCO-DILE	**Drip-In REG 2 ℓ/h 12 mm GA**	**NEW**	**100**	**2,1**	**2,2**	**5**	**10**	**21**	**36**	**14**	**8**	**6**	
5,5		<5	30	8,6	1,9	93	6	1	0	0	0	0	*Soiled, combination pipe.*
VIVO	**Drip-In REG 2 ℓ/h 12 mm GA**	**NEW**	**100**	**2,1**	**2,2**	**5**	**10**	**21**	**36**	**14**	**8**	**6**	
6,2		<5	100	3,0	2,1	87	6	2	4	1	0	0	*Heavily soiled.*
6,3		<5	100	3,0	2,0	89	3	3	5	0	0	0	*Heavily soiled. One dripper blocked with foreign object.*

Table 34: Results of laboratory tests on Ram PC emitters recovered from the field during the year 2001													
REGION AND PROPERTY	**NAME AND CODE OF DRIPPER TESTED**	**AGE GROUP YEARS**	**SAMPLE SIZE UNITS**	**DRIPPER CV (%)**	**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*	
KOUGA	**Ram 3,5 ℓ/h 17 mm KH**	**NEW**	**100**	**4,0**	**3,6**	**7**	**5**	**17**	**39**	**15**	**10**	**7**	
1,1		>5	80	5,8	3,6	4	9	19	31	16	11	10	*Clean.*
1,3		>5	100	7,2	3,8	11	19	17	25	10	8	10	*Clean. Three leaks repaired before tests were conducted.*
1,6		>5	97	14,6	3,8	0	3	25	65	3	0	4	*Soiled.*
1,5		>5	92	14,1	4,7	9	1	7	53	13	3	14	*Soiled. One leak repaired before tests were conducted.*
1,2		>5	82	6,7	3,8	32	7	4	21	6	6	24	*Lightly soiled.*
ORANGE	**Ram 3,5 ℓ/h 17 mm KH**	**NEW**	**100**	**4,0**	**3,6**	**7**	**5**	**17**	**39**	**15**	**10**	**7**	
2,4		<5	87	5,9	3,5	11	9	17	33	8	9	11	*Clean.*
2,6		>5	96	4,0	4,0	22	10	14	19	13	4	19	*Soiled.*
2,5		>5	100	6,4	4,0	17	11	15	32	7	4	14	*Soiled.*
2,3		>5	89	3,4	3,8	27	7	11	17	16	8	15	*Soiled. Three leaks repaired before tests were conducted.*
2,9		>5	100	2,9	3,7	22	13	6	16	8	10	25	*Soiled.*
ORANGE	**Ram 3,5 ℓ/h 20 mm KK**	**NEW**	**100**	**2,6**	**3,4**	**21**	**7**	**10**	**20**	**14**	**8**	**20**	
2,10		>5	100	22,1	4,3	62	5	6	7	4	2	14	*Soiled.*
BERG	**Ram 3,5 ℓ/h 17 mm KH**	**New**	**100**	**4,0**	**3,6**	**7**	**5**	**17**	**39**	**15**	**10**	**7**	
4,1		>5	98	5,3	3,7	13	12	19	32	11	3	9	*Lightly soiled.*
4,3		<5	88	4,4	3,6	13	6	18	26	14	3	20	*Lightly soiled. One leak repaired before tests were conducted.*
4,5		<5	100	6,5	3,7	17	15	16	21	9	6	16	*Soiled.*
4,2		>5	100	12,7	3,9	21	24	10	15	5	5	20	*Heavily soiled.*
4,4		>5	99	14,6	3,9	4	24	31	22	4	2	12	*Soiled. Two leaks repaired before tests were conducted.*
4,8		>5	100	14,1	4,0	17	8	8	27	12	7	21	*Heavily soiled. Two leaks repaired before tests were conducted.*
KOMATI POORT	**Ram 3,5 ℓ/h 17 mm KH**	**NEW**	**100**	**4,0**	**3,6**	**7**	**5**	**17**	**39**	**15**	**10**	**7**	
5,1													*No drip line supplied.*
5,4													*No drip line supplied.*

Table 35: Results of laboratory tests on Agridrip PC emitters recovered from the field during the year 2001

REGION AND PROPERTY	NAME AND CODE OF DRIPPER TESTED	AGE GROUP YEARS	SAMPLE SIZE UNITS	DRIPPER CV (%)	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*	
ORANGE	**Agridrip PC 3,6 ℓ /h 16 mm KF**	**NEW**	**100**	**3,4**	**3,6**	**19**	**9**	**16**	**20**	**9**	**7**	**20**	
2,1		<5	100	3,7	4,7	22	11	15	12	11	9	20	*Soiled. One leak repaired before tests were conducted.*
BREEDE	**Agridrip PC 3,6 ℓ/h 16 mm KF**	**NEW**	**100**	**3,4**	**3,6**	**19**	**9**	**16**	**20**	**9**	**7**	**20**	
3,1		<5	100	7,5	4,5	8	9	19	37	5	8	14	*Lightly soiled.*
3,2		<5	100	5,8	4,4	15	9	13	30	10	10	13	*Soiled.*
3,4		>5	99	14,1	4,7	14	8	9	24	10	9	21	*Heavily soiled. One leak repaired before tests were conducted.*

Table 36: Results of laboratory tests on Drip-In Regular emitters recovered from the field during the year 2001

REGION AND PROPERTY	NAME AND CODE OF DRIPPER TESTED	AGE GROUP YEARS	SAMPLE SIZE UNITS	DRIPPER CV (%)	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*	
ORANGE	**Drip-In REG 4 ℓ/h 16 mm GD**	**NEW**	**100**	**2,2**	**4,3**	**28**	**4**	**8**	**18**	**5**	**12**	**25**	
2,12		>5	100	3,0	4,0	33	10	4	9	7	0	37	*Lightly soiled.*
2,2		<5	97	5,3	4,5	4	2	13	32	19	10	20	*Soiled. Three leaks repaired before tests were conducted.*
2,8		>5	76	3,1	4,3	37	7	4	14	3	4	32	*Heavily soiled.*
2,7		>5	82	4,3	4,0	10	10	13	18	16	15	18	*Soiled.*
2,13		>5	65	4,2	4,3	22	5	5	14	14	18	23	*Soiled.*
2,11		>5	72	2,7	4,3	28	7	7	19	6	1	32	*Heavily soiled.*
BREEDE	**Drip-In REG 4 ℓ/h 16 mm GD**	**NEW**	**100**	**2,2**	**4,3**	**28**	**4**	**8**	**18**	**5**	**12**	**25**	
3,5		<5	50	5,4	4,3	34	2	8	16	8	2	30	*Lightly soiled.*
3,3		>5	50	6,4	4,1	14	8	12	18	2	22	24	*Soiled, combination pipe.*
3,8		>5	66	9,2	4,3	15	15	18	30	15	2	5	*Soiled.*
3,9		>5	50	2,9	4,1	22	2	12	20	12	4	28	*Soiled, combination pipe.*
BERG	**Drip-In REG 4 ℓ/h 16 mm GD**	**NEW**	**100**	**2,2**	**4,3**	**28**	**4**	**8**	**18**	**5**	**12**	**25**	
4,7		>5	89	4,4	3,8	22	4	13	13	10	9	27	*Soiled.*
4,9		>5	50	13,2	4,0	20	8	16	14	8	16	18	*Heavily soiled, combination pipe.*
4,6		>5	52	22,2	3,8	6	4	12	37	23	13	6	*Lightly soiled. Two leaks repaired. Two drippers partially blocked.*
CROCO-DILE	**Drip-In REG 2 ℓ/h 16 mm GC**	**NEW**	**100**	**2,4**	**2,3**	**5**	**11**	**17**	**37**	**15**	**8**	**7**	
5,3		<5	52	11,2	1,6	15	4	6	29	25	17	4	*Heavily soiled.*
5,5		<5	100	5,1	1,9	16	7	8	28	15	15	11	*Heavily soiled. 80 x 12 mm drip line and 20 x 16 mm drip line.*

*Values not included in analysis, because of unnatural damages to drippers.

Table 37: Results of laboratory tests on Drip-In Regular emitters recovered from the field during the year 2001														
REGION AND PROPERTY	**NAME AND CODE OF DRIPPER TESTED**	**AGE GROUP YEARS**	**SAMPLE SIZE UNITS**	**DRIPPER CV (%)**	**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*	
BREEDE	**Drip-In REG 4 ℓ/h 12 mm GB**	**NEW**	**100**	**3,8**	**4,1**	**30**	**7**	**5**	**19**	**4**	**12**	**23**	
3,5		<5	50	5,4	4,3	34	2	8	16	8	2	30	*Lightly soiled, combination pipe.*
3,6													*No drip line supplied.*
3,7		>5	89	21,4	4,7	4	20	40	34	0	0	1	*Soiled. Two leaks repaired. One dripper damaged with high discharge*
3,8		>5	66	9,2	4,3	15	15	18	30	15	2	5	*Soiled, combination pipe.*
3,9		>5	50	2,9	4,1	12	14	6	28	10	2	28	*Soiled, combination pipe.*
BERG	**Drip-In REG 4 ℓ/h 12 mm GB**	**NEW**	**100**	**3,8**	**4,1**	**30**	**7**	**5**	**19**	**4**	**12**	**23**	
4,9		>5	50	13,2	4,0	18	2	6	14	8	22	30	*Heavily soiled, combination pipe.*
CROCO-DILE	**Drip-In REG 2 ℓ/h 12 mm GA**	**NEW**	**100**	**2,1**	**2,2**	**5**	**10**	**21**	**36**	**14**	**8**	**6**	
5,5													
VIVO	**Drip-In REG 2 ℓ/h 12 mm GA**	**NEW**	**100**	**2,1**	**2,2**	**5**	**10**	**21**	**36**	**14**	**8**	**6**	
6,2		<5	69	32,2*	2,2*	0	0	14	84	0	0	1	*Lightly soiled. One leak repaired before tests were conducted.*
6,3		<5	79	41,8*	2,4*	8	0	73	11	0	0	8	*Heavily soiled. Five drippers blocked. Five drippers pierced with high discharge.*

*Values not included in analysis, because of unnatural damages to drippers.

Discharge of used emitters

The percentage of drip lines recovered from the field of which the average discharge of the emitters in the line showed: (a) a *reduction* relative to the average discharge of new emitters, (b) *no significant deviation* from the average discharge, and (c) an *increase* relative to the average discharge of new emitters, are shown in Table 38 for two consecutive years of sampling.

Table 38: Percentages of drip lines with emitter discharges deviating from the average discharge of new emitters

Emitter type	Reduced discharge (%)		Average discharge (%)		Increased discharge (%)	
Year of sampling	***2000***	***2001***	***2000***	***2001***	***2000***	***2001***
Agriplas Drip-In (Non-compensated)	50	54	8	25	42	21
Agriplas Agridrip (Pressure compensating)	0	0	0	0	100	100
Netafim Ram (Pressure compensating)	16	6	21	12	63	82

Drip lines with regular type emitters showed a general tendency towards reduced average discharge due to partial or total clogging of emitters. In some cases where the average discharge increased, it was attributed to the extraordinary high discharge of some emitters on the line which were pierced with an awl or similar object apparently in an effort to open clogged emitters.

Drip lines with pressure compensated emitters on the other hand showed a general tendency towards increased discharge, possibly due to foreign objects that got stuck between the compensating membrane and the labyrinth, or the compensating membrane loosing some of its elasticity over time. Both causes result in ineffective regulation of the discharge rate. Pierced emitters were also observed.

Discharge variation of used drip lines

If values of the coefficient of variation (CV_q) of the new pipes is compared to the CV_q of the used pipes for the two consecutive years (see Table 39), a general tendency of worsening is observed.

Table 39: Summary of the average Coefficient of Variation (CVq) of the new and used drip lines

Emitter type	New CV_q (%)	Used 2000 CV_q (%)	Used 2001 CV_q (%)
Drip-In 2 ℓ/h, 12 mm	2,1	4,9	-
Drip-In 4 ℓ/h, 12 mm	3,8	5,3	10,4
Drip-In 2 ℓ/h, 16 mm	2,4	7,2	8,2
Drip-In 4 ℓ/h, 16 mm	2,2	5,6	6,6
Agri PC 3,6 ℓ/h, 16 mm	3,4	9,1	7,8
Ram 3,5 ℓ/h, 17 mm	4,0	6,6	8,0
Average CV_q	**3,0**	**6,5**	**8,2**

The average CV_q of new pipes worsened from a good value of 3,0% to a fair value of 6,5% in 2000. For the year 2001, it worsened even further to a marginal value of 8,2%. Individual CV_q values of the used pipes in Tables 32 to 37 were even up to a poor 22,2%. Factors contributing to these worsening results are clogging and/or increased discharges due to ineffective pressure compensation.

General remarks

Drip lines recovered from the field were generally in good condition, although some were in bad to very bad shape. A common observation was that especially where drip lines were heavily soiled and emitters badly clogged, many of the emitters were pierced, apparently in an effort to open clogged emitters.

One or two cases also occurred where the drip line itself was badly damaged and with leaking holes in it. In other cases, button emitters were added to a drip line where the original emitters were heavily clogged, or drip lines consisted partly of one make of emitter and partly of a different make and/or model of emitter. The lack of clear identification marks on emitters or the pipes also made it difficult or impossible to positively identify the model of emitters.

4.2.3 **Clogging tests on new emitters**

The results of the clogging tests are summarised in Table 40. In this table the average percentage that the drippers got clogged during the test is shown and it includes the sum of the totally clogged as well as the partially clogged drippers. The Drip-In 2 ℓ/h, 16 mm drip line was used as a reference in all the different clogging tests.

Table 40: Summary of the clogging tests on new emitters

Case study	**Unpulsed**	**Pulsed**
Dripper model	*% Clogged*	*% Clogged*
Drip-In 2 ℓ/h, 12 mm	35,8	
Drip-In 2 ℓ/h, 16 mm	48,6	48,6
Drip-In 4 ℓ/h, 12 mm	42,4	
Drip-In 4 ℓ/h, 16 mm	44,0	
Agri PC 2,2 ℓ/h, 16 mm	63,4	76,9
Agri PC 3,6 ℓ/h, 16 mm	72,3	78,3
Ram 2,3 ℓ/h, 17 mm	63,4	58,8
Ram 3,5 ℓ/h, 17 mm	67,4	54,0

From Table 40, the following tendency is evident:

- It seems as if the 2 ℓ/h drippers have slightly more resistance against clogging than the 4 ℓ/h drippers. If the regular drippers are taken into account, the average percentage clogging for the 2 ℓ/h drippers in the laboratory is 42,2% against 43,2% for the 4 ℓ/h drippers and in the case of the pressure compensated drippers, the average percentage clogging of the 2 ℓ/h drippers is 63,4% against 69,9% for the 4 ℓ/h drippers.

- The regular drippers were also significant more resistant to clogging compared to the pressure compensated drippers. The average percentage clogging of the regular drippers is 42,7% against 66,6% of the pressure compensated drippers.
- It took five times longer in the pulsed clogging test to get the same degree of clogging for all the drippers than when the drippers were not pulsed. This indicates that it is better in practice to pulse the irrigation system, rather than to irrigate continuously.
- In the pulsed test there is not much difference in the percentage clogging of the Agri PC drippers, but the Ram drippers showed a markedly lower clogging percentage.

It must be emphasised that the clogging test only gave an indication of the relative clogging tendency of emitters simultaneously tested to clog under the same conditions, and was only a qualitative test and is not repetitive due to the nature of the test.

4.3 Field evaluations

The performance of the different drippers under field conditions is discussed on the basis of field evaluations and water analysis done over a two-year period. The dripper clogging potential that may occur per area is identified on the basis of the analytic results and the clogging hazard table of Bucks and Nakayama (1979). In closing, the influence of the types of drippers that were used, the design directives and maintenance schedules, which were followed on the clogging that occurred, are discussed.

4.3.1 The potential clogging hazard due to the water quality in the different regions

Bucks and Nakayama (1979) compiled a water quality classification relative to its potential for drip emitter clogging. Table 3 in paragraph 3.1 shows the water classification. The South African Water Quality Guidelines (DWAF, 1996) contain similar information to that which is available in international literature as shown in Table 41.

Table 41: Effects of different elements on irrigation equipment (DWAF, 1996)

Clogging factors	Hazard rating		
	Minor	Moderate	Severe
• Physical (mg/ℓ) Suspended solids	<50	50 – 100	>100
• Chemical pH Manganese (mg/ℓ) Iron (mg/ℓ)	 <6,5 <0,1 <0,2	 6,5 – 8,4 0,1 – 1,5 0,2 – 1,5	 >8,4 >1,5 >1,5
• Biological (no. /mℓ) Bacterial number	<10 000	10 000 – 50 000	>50 000

The current water classification standards lack information regarding guidelines for calcium and magnesium precipitation. Calcium and magnesium can cause clogging especially if the concentrations exceed 50 ppm. If the pH is 7,5 or higher with high bicarbonate levels of 100 ppm, sedimentation will take place if comparable levels of calcium are naturally present in the system or if a compound containing calcium is injected into the system (Schwankl and Prichard, 1990). Iron and manganese will precipitate across a wide range of pH (iron, for example, will precipitate at pH 4,0 – 9,5), which include the pH levels of almost all naturally occurring waters. The above-mentioned guidelines and Table 31 will be used to evaluate the water analysis results of the water sources.

Water analysis was done on water samples obtained from all six identified regions by laboratories of the ARC-Infruitec/Nietvoorbij and ARC-Institute for Soil, Climate and Water. The water quality data sets of the Kouga River, Orange River, Breede River and Berg River were further evaluated for apparent errors and suspect data because of faulty ion balances. Four sets of water quality data for each of Kouga River, Orange River, Breede River and Berg River were combined into standardized data sets. Atypical concentration and atypical samples were identified and ion balances were calculated to reflect on analytical accuracy and precision. Typical compositions of the source waters were determined for each of the sources, together with an indication of variability per determinant, and comparisons between analytical batches were done to show up possible analytical errors. The analysis for atypical samples of the elements that can cause clogging for different regions are shown in the tables below. The reason that only the results of the last two periods are shown, is due to the fact that all the elements were not tested during the first two periods. The correlation between the results of the elements tested during all four periods, show a good relationship. Average summer and winter water quality data obtained from DWAF stations situated in the catchment areas are shown in the Appendices (paragraph 8.4) and differ from the data shown in Table 42 and Table 46 due to seasonal water changes.

Kouga River (Region 1)

Table 42: The water analysis results of the water source from the Kouga River

Date	Suspended solids (mg/ℓ)	pH	Manganese (mg/ℓ)	Total iron (mg/ℓ)	Calcium (mg/ℓ)	Magnesium (mg/ℓ)	Bicarbonate (mg/ℓ)
10/00	14,0	7,3	0,03	0,4	4,7	3,8	90,9
04/01	4,6	7,6	0,20	0,8	4,2	4,0	74,8

From Tables 41 and 42 it seems that the iron content of the water samples may have a moderate clogging hazard for the drippers.

Orange River (Region 2)

Table 43: The water analysis results of the water source from the Orange River

Date	Suspended solids (mg/ℓ)	pH	Manganese (mg/ℓ)	Total iron (mg/ℓ)	Calcium (mg/ℓ)	Magnesium (mg/ℓ)	Bicarbonate (mg/ℓ)
10/00	26,6	8,4	0,1	0,4	29,0	13,3	142,1
04/01	99,7	8,1	0,1	1,3	21,8	10,3	150,3

From Tables 41 and 43 it appears that the iron content and the suspended solids (04/01) may have a moderate clogging hazard and that the calcium and bicarbonate content of the water may have a high clogging hazard for the drippers. The high pH value of the water source can encourage the formation of chemical deposits such as calcium carbonate and iron oxide.

Breede River (Region 3)

Table 44: The water analysis results of the water source from the Breede River

Date	Suspended solids (mg/ℓ)	pH	Manganese (mg/ℓ)	Total iron (mg/ℓ)	Calcium (mg/ℓ)	Magnesium (mgℓ)	Bicarbonate (mg/ℓ)
10/00	30,3	7,3	0,00	0,6	17,5	13,6	134,6
04/01	15,6	7,5	0,01	0,4	7,1	8,4	101,3

From Tables 41 and 44 it seems that the iron content of the water may have moderate clogging hazard for the drippers. Although the bicarbonate content of the water poses a high dripper-clogging hazard, it should not be a problem as a result of the low calcium and magnesium content of the water.

Berg River (Region 4)

Table 45: The water analysis results of the water source from the Berg River							
Date	**Suspended solids (mg/ℓ)**	**pH**	**Manganese (mg/ℓ)**	**Total iron (mg/ℓ)**	**Calcium (mg/ℓ)**	**Magnesium (mg/ℓ)**	**Bicarbonate (mg/ℓ)**
10/00	51,7	7,2	0,10	0,4	6,7	4,1	88,6
04/01	87,9	7,2	0,03	0,6	3,0	1,7	88,5

From Tables 41 and 45 it is noted that the iron content and the suspended solids of the water may have a moderate clogging hazard. Although the suspended solids in the water source indicates only a moderate clogging hazard, the value increased to 330 mg/ℓ, where the water was first stored in a storage dam before irrigation, which indicates a high clogging hazard. This can be attributed to the fact that the dam is not lined and built from a clayish material. The water level in the dam was also very low and this aggravated the clogging hazard.

Crocodile River (Region 5)

Table 46: The water analysis results of the water source from the Crocodile River							
Date	**Suspended solids (mg/ℓ)**	**pH**	**Manganese (mg/ℓ)**	**Total iron (mg/ℓ)**	**Calcium (mg/ℓ)**	**Magnesium (mg/ℓ)**	**Bicarbonate (mg/ℓ)**
10/00	58,4	8,2	*	*	14,3	9,1	83,9
04/01	18,5	7,9	0,12	0,8	13,1	9,7	78,5

*The specific analysis was not done during this period.

Tables 41 and 46 show that the iron and manganese content of the water has a moderate clogging hazard for the drippers, while the suspended solids content has a moderate hazard of clogging for the dripper during certain times of the year (10/2000). The high pH value can promote the formation of chemical deposits such as manganese and iron oxide.

Vivo Region (Region 6)

Table 47: The water analysis results of the water source from boreholes in the Vivo region							
Date	**Suspended solids (mg/ℓ)**	**pH**	**Manganese (mg/ℓ)**	**Total iron (mg/ℓ)**	**Calcium (mg/ℓ)**	**Magnesium (mg/ℓ)**	**Bicarbonate (mg/ℓ)**
10/00	2,2	8,4	*	*	45,7	76,2	335,5
04/01	0,4	6,6	0,01	0,6	37,4	51,9	475,8

*The specific analysis was not done during this period.

From Tables 41 and 47 it seems that the iron content of the water may have a moderate clogging hazard, while the high magnesium and calcium content of the water, together with the bicarbonate content, may have a high dripper-clogging hazard.

4.3.2 Algae analysis

Analysis for the occurrence of algae in the water were also performed. The results are shown in Table 48. According to Harding (2000) any algae if present in high enough numbers, especially the filamentous genera like the diatoms and blue greens, can cause clogging of filters. The results of the analysis showed that above-mentioned algae are present in all the regions. Attempts to quantify algae are of little use as their populations vary drastically throughout the irrigation season. Associative problems such as the presence of colloidal materials (sediments) in the irrigation water of all the regions exacerbate the problem over and above that which would normally be the case with the algae alone. Bacterial growth as a result of the dead algae parts and sediments in the water, are in most cases responsible for the clogging of drippers in the most regions.

Table 48: The dominant algae in the water sources of the regions (June 2001)

Algae general	Kouga River	Orange River	Breede River	Berg River	Crocodile River	Vivo Region
Diatoms (Bacillariophyta)						
Aulacoseira granulata	×	×	×	×		
Aulacoseira varians				×		
Cocconeis				×		
Cyclotella		×				
Melosira					×	
Stephanodiscus					×	×
Blue-greens (Cyanophyta)						
Anabaena				×		
Microcystis robusta		×				
Oscillatoria	×			×		
Dinoflagellates (Pyrrophyta)						
Ceratium hirundunella		×				
Green algae (Chlorophyta)						
Oocystis		×			×	
Pediastrum		×				
Scenedesmus			×			×
Closreriopsis						×
Euglenophyta						
Euglena					×	
Trachelomonas						×

Nitrogen in the irrigation water has a stimulatory effect on nuisance growth of algae and aquatic plants in irrigation structures like canals, storage, dams, etc. (DWAF, 1996). According to the available water analysis of all the regions the nitrogen level are in most cases below 2,5 mg/ℓ, which will encourage the occasional growth of algae (Table 49).

Table 49: Effects of nitrogen on irrigation equipment (DWAF, 1996)	
Target water quality range (mg/ℓ)	**Effects on irrigation equipment**
≤0,5	Oligotrophic conditions. No nuisance growth of aquatic plants or blue-green algae blooms in irrigation structures (canals and storage dams).
0,5 – 2,5	Mesotrophic conditions. Occasional growth of nuisance plants and blue-green algae in irrigation structures.
2,5 – 10	Eutrophic conditions. Frequent growth of nuisance plants and blue-green blooms in irrigation structures, in the absence of other limiting growth factors.
>10	Hypertrophic conditions. Almost continuous growth of nuisance plants and blue-green algae bloom in irrigation structures in the absence of other growth-limiting factors.

4.3.3 **Dripper performance in the different regions**

The statistical uniformity of the dripper discharge rate (U_s-value) was determined for all the types of drippers in the different regions. The reasons why the system evaluation results do not all conform to the accepted norms are discussed per dripper-type. The U_s-value higher than 80% is considered as acceptable for dripper systems if fertilizer is applied through the systems (ASAE EP458, 1997). The average dripper discharge rate as determined during the evaluation of May 2001,was also compared to the nominal discharge as obtained from the various manufacturers. The block numbers in the different regions where low U_s-values were obtained during field evaluations are shown in brackets.

Ram PC

Table 50: The number of systems that performed within the prescribed range in the different regions (May 2001)						
Dripper age	**U_s value guideline (%)**	**Kouga River**	**Orange River**	**Berg River**	**Crocodile River**	**Total**
<5 years	≥80	2	3	2	1	8
	<80	0	0	1 (4.1)*	1 (5.4)*	2
>5 years	≥80	2	3	3	-	8
	<80	1 (1.1)*	0	0	-	1

Table 51: Comparison between the average dripper discharge during the evaluation (May 2001) and the nominal discharge				
Dripper age	**U_s value guideline (%)**	**Number of systems**		
		< Nominal discharge	**= Nominal discharge**	**> Nominal discharge**
<5 years	≥80	0	0	8
	<80	1 (5.4)*	0	1 (4.1)*
>5 years	≥80	0	0	8
	<80	1 (1.1)*	0	0

*The causes of the low U_s-values of the different blocks are as follows:

Block 1.1: Pressure too low in system as a result of a design error.
Block 4.1: Leaking and clogging occur in the block.
Block 5.4: Faulty design, as well as leaking and clogging, which occur in the block.

The evaluation results of the Ram PC drip systems fulfill the U_s-requirements in 84% of the number of cases. In certain regions, e.g. Berg River and Crocodile River, the Ram PC dripper performed poorer than in the other regions. This can be mainly attributed to the following of wrong maintenance practices. The influence of the maintenance practices, which were followed on the performance of the drippers, is discussed in paragraph 4.3.4.

From the Tables 50 and 51, it seems that age did not play a significant role, because the amount of clogging was not higher with the older drippers. Although the dripper discharge fulfilled the U_s-requirements in most cases, the average dripper discharge in 89% of the cases, was higher than the nominal dripper discharge. The increase in dripper discharge can lead to over-irrigation if producers irrigate on a time basis and not on a volume basis. As the dripper discharge of pressure compensated drippers is constant over a wide pressure range, there were certain factors that influenced the consistency of the discharge.

These factors could be as follows:

- Manufacture of the drippers

  A problem may have arisen during the manufacturing process. It is accepted that this is not the likely cause, taking into account the high standard of quality control that is applied during manufacturing.

- Management of irrigation systems

  Although the drippers are supposed to have a constant discharge within the prescribed working pressure range, there may be cases where the operating pressure of the system decreases to below the minimum value and increases to above the maximum value as a result of the absence of an automatic pressure control valve at the block inlet as also a faulty design. No automatic pressure control valves were installed at any of the blocks, which could keep the pressure constant at the block inlet.

- Elasticity of the diaphragm

  The position of the diaphragm regarding the dripper flow-path determines whether the discharge is constant within the prescribed operating pressure range of the dripper. New samples of the drippers were provided to the Institute for Polymer Science Department of Chemistry, University of Stellenbosch to perform testing whereby the drippers were subjected to various solutions (Table 52) to establish the deterioration effect on the diaphragms.

Table 52: Solutions and concentrations of different solutions used to determine the deterioration effect on the dripper diaphragms	
Solutions	**Concentrations**
Ca $(OH)_2$	30%
Fe $(SO_4)_2$	30%
HCI	3 N
NPK	30%
Chlorine (swimming pool)	30%
NaOH	3 N

The diaphragms were exposed to these solutions at 50°C in an air-circulated oven for a period of two weeks. The modulus of elasticity of each of these diaphragms were measured by Dynamic Mechanical Analysis (DMA). DMA measured the modulus (stiffness) and the damping (energy dissipation) properties as a material deforms under periodic stress. The results showed (Table 53) that the samples diaphragms are mostly affected by sodium (NaOH) when the difference in elasticity modulus of elasticity was compared to these of new samples when exposed to the solutions mentioned in Table 52. A positive percentage change indicates that the diaphragm has become more flexible, while a negative change indicates a stiffer diaphragm.

Table 53: The change in the elasticity modulus of a new Ram PC dripper due to the different solutions		
Solution	**Elasticity modulus (Pa)**	**% Change**
NPK	2 763 400	-10
Untreated	3 070 600	0
$Ca(OH)_2$	3 965 300	12
$Fe(SO_4)_2$	3 559 000	16
HCl	3 445 900	29
Chlorine	4 198 300	37
NaOH	10 525 000	242

The elasticity of the diaphragms of four drippers (>5 years), of which the discharge was higher than the nominal discharge, was also determined by the DMA method. The results are shown in Table 54 and reveals that the elasticity of the diaphragms decreased, which means that the diaphragms became stiffer and less movable with time, which can result in increased discharge (Roediger, 2002).

Table 54: The change in the elasticity modulus of used Ram PC drippers as recovered from the field		
Area	**Elasticity modulus (Pa)**	**% Change**
New dripper	3 070 600	
Orange River	2 982 200	-2,9
Orange River	2 390 100	-22,2
Berg River	2 267 000	-26,2
Berg River	2 039 400	-33,6

- Cleaning practices for drippers

  Various producers follow the wrong cleaning practices, such as opening or hitting the drippers with a hard object and pinching dripper with pliers.

- Clogging of the flow-path

  A further cause may be that dirt has accumulated in the flow-path, which prevents the diaphragm from regulating the flow-path opening as the pressure varies to keep the discharge constant. Fig.1 shows the relationship between the average discharge and the operating pressure for the system in the Berg River region (younger than five years, and a U_s value less than 80%) varied during a two-year evaluation period.

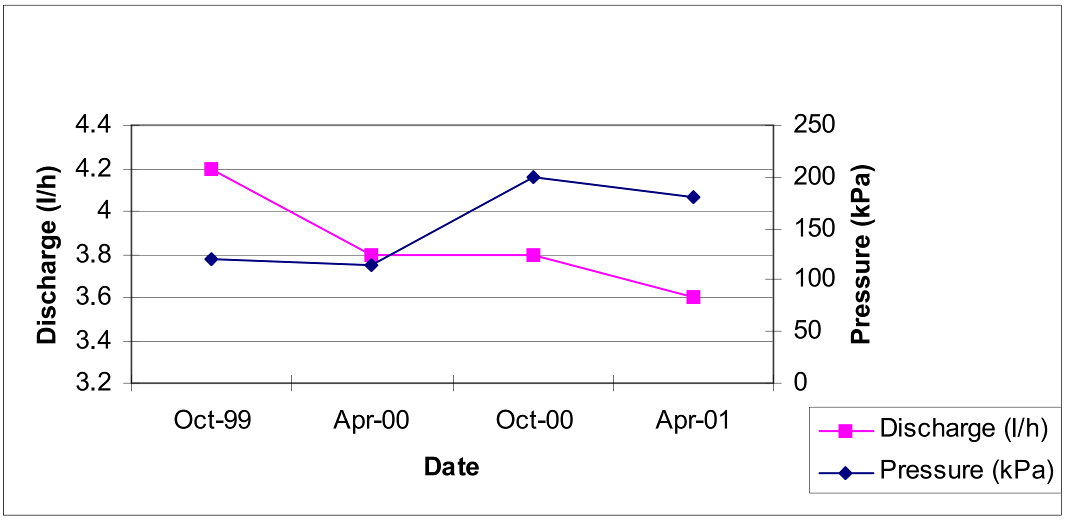


Fig. 11: The influence of clogging on dripper discharge

The above graph illustrates that there was a decrease in discharge over the evaluation period, despite the system pressure. Clogging could therefore have played a role. From the results of the tests as done by the University of Stellenbosch, it seems that clogging in the form of iron, calcium and potassium precipitation did occur in the dripper flow-path. From the results of Tables 53 and 54, it is clear that the increase in discharge was due to the build up of dirt in the flow-path and cleaning practices, and not to the application of fertilizers, except possibly for NPK.

Agridrip PC

These drippers are relatively new on the irrigation market in South Africa and only drippers younger than five years were evaluated.

Table 55: The number of systems that performed within the prescribed range in the different regions (May 2001)

Dripper age	U_s value on 05/2001	Orange River	Breede River	Total
<5 years	>80	1	1	2
	<80	0	(3.1 and 3.4) 2*	2

Table 56: Comparison between the dripper discharge during the evaluation in May 2001 and the nominal discharge

Dripper age	U_s value on 05/2001	Number of systems		
		< Nominal discharge	= Nominal discharge	> Nominal discharge
<5 years	>80	0	0	2
	<80	0	1 (3.1)*	1 (3.4)*

*The causes of the low U_s-value at the different blocks are as follows:

Block 3.1: Faulty design and clogging as a result of poor maintenance
Block 3.4: Clogging as a result of insufficient maintenance

From Tables 55 and 56, the following can be concluded:

The evaluation results of the Agridrip PC drip systems fulfil the required U_s requirements in only 50% of the number of cases. The main cause for the low U_s-value is clogging as a result of insufficient system maintenance and faulty design. The tested dripper discharge was higher than the nominal dripper discharge in 75% of the cases. As the dripper discharge of pressure compensated drippers is constant over a wide pressure range, there must have been factors which influenced the discharge, similar to the factors discussed under the RAM PC drippers. The same tests as those done on the RAM PC drippers, were performed on the diaphragms of the drippers by the University of Stellenbosch. From the modulus of elasticity test results on new diaphragms, it can be seen that chlorine and sodium (NaOH) affect the samples the most.

Table 57: The change in the elasticity modulus of a new Agridrip PC dripper due to the different solutions

Solution	Elasticity modulus (Pa)	% Change
Untreated	3 189 100	
$Ca(OH)_2$	2 753 100	-13,7
$Fe(SO_4)_2$	2 952 400	-7,4
Chlorine	2 102 400	-34,1
NaOH	2 188 500	-31,4
HCl	3 189 100	0
NPK	3 391 200	6,3

The elasticity of the diaphragms of four drippers (<5 years) with a discharge higher than the nominal discharge was also determined with the DMA method. The results are shown in Table 58 and show that the elasticity of the diaphragms became stiffer and less movable with time, which can result in increased discharge (Roediger, 2002). This means that the pressure compensated function of the diaphragms can be influenced by the application of fertilizers.

Table 58: The change in the elasticity modulus of used Agridrip PC drippers as recovered from the field

Area	Elasticity modulus (Pa)	% Change
New dripper	3 189 100	-34,1
Breede River	2 575 900	-31,4
Breede River	2 375 800	-13,7
Breede River	2 174 300	-7,4
Breede River	1 500 200	0

In this case it appears that the increased flow was a combination of the fertilizer practices, the cleaning practices of the drippers and build up dirt in the flow-path preventing the diaphragm from regulating the flow.

Drip-In Regular

The Drip-In Regular dripper is the dripper type that has been used in South Africa for the longest period of time.

Table 59: The number of systems that performed within the prescribed range in the different regions (May 2001)

Dripper age	U_s-value on 05/2001	Orange River	Breede River	Berg River	Crocodile River	Vivo Region	Total
<5 years	>80	2	2	-	0	2	6
	<80	1 (2.12)*	1 (3.6)*	-	2 (5.3 and 5.5)*	0	4
>5 years	>80	2	2	1	-	-	5
	<80	1 (2.7)*	1 (3.7)*	2 (4.6 and 4.9)*	-	-	4

Table 60: Comparison between the dripper discharge during the evaluation in May 2001 and the nominal discharge				
Dripper age	**U_s-value on 05/2001**	**Number of systems**		
		< Nominal discharge	**= Nominal discharge**	**> Nominal discharge**
<5 years	>80	1	0	5
	<80	0	2 (5.3 and 5.5)*	2 (2.12 and 3.6)*
>5 years	>80	0	0	5
	<80	1 (4.6)*	0	3 (2.7; 3.7 and 4.9)*

*The cause of the low U_s value at the different blocks are as follows:

Block 2.7: Faulty design
Block 2.12: Block was flooded during the rainy season and the required maintenance has not yet been done
Blocks 3.6, 3.7, 4.6 and 4.9: Clogging as a result of insufficient maintenance
Blocks 5.3 and 5.5: Clogging as a result of insufficient maintenance, e.g. dirty filters

From Tables 59 and 60 it was noted that:

The evaluation results of the Drip-In Regular drip systems fulfil the U_s requirements in only 58% of the cases. Age did not play a significant role, because the systems which did not comply with the requirements being 40% at the systems <5 years and 44% at the systems >5 years. The average tested dripper discharge was in 81% of the cases larger than the nominal dripper discharge. The high dripper discharge can be attributed to the wrong maintenance practices such as the cleaning of the drippers and the absence of pressure control at the blocks, which will be discussed in paragraph 4.3.4.

4.3.4 Maintenance practices affecting emitter performance

It was decided to classify the existing maintenance practices followed by the producer, according to existing literature sources as acceptable (A) if it will not influence the performance of the system adversely and unacceptable/ineligible (U) if it will impair the performance. The acceptable values are viewed as the absolute minimum values for the sustaining of an acceptable U_s-value in the system.

The maintenance practices, which influence performance and that were followed by the producers, are divided into three groups. The following criteria was used to classify these practices:

- Water treatment methods

  Acid treatment:
  A An acid treatment is applied at least once a year.
  U An acid treatment is applied sometimes.

  Chlorination:
  A Chlorination is done at least once a year.
  U Chlorination is done sometimes.

- Filter maintenance

  Pre-filtration:
  A Water for irrigation is withdrawn from near the water surface.
  U Water for irrigation is withdrawn from close to the bottom of the water source.

  Sand replacement:
  A Sand is replaced at least once a year.
  U Sand replacement frequency is more than once a year.

  Filter back flushing method:
  A Filter back flushes on a pressure difference basis.
  U Filter back flushes on a flow or volume basis.

- System maintenance

  Leakages in the systems:
  A No leaks occur.
  U Leaks do occur.

  Lateral flushing frequency:
  A Laterals are flushed at least once a month.
  U Lateral flushing frequency is higher than one month.

  Cleaning methods of drippers:
  A Drippers are cleaned in an acceptable manner, e.g. chemically or by rubbing off the exterior clogging.
  U Drippers are cleaned in an unacceptable manner, e.g. by hitting or pinching.

The total number of practices (acceptable (A) / unacceptable (U)) per group for each dripper per region is shown in table form and discussed, e.g. $U_s \geq 80\%$:

A	U
7	3

means at 7 blocks with a U_s value of ≥80% acceptable maintenance practices (A) were followed and at 3 blocks with a U_s value of ≥80% unacceptable maintenance (U) practices were followed.

Kouga River

The following can be concluded from Table 61:

In the Konga River region, the filtration and system maintenance practices are acceptable. Water treatment methods are neglected despite the fact that biological clogging and sedimentation can occur.

Table 61: The influence of maintenance practices on system performance of the different drippers in the Kouga River region							
Dripper type	**U_s-value %)**	**Water treatment method**		**Filter maintenance**		**System maintenance**	
		A	**U**	**A**	**U**	**A**	**U**
Ram PC	≥80	1	7	2	1	8	4
	<80	0	2	1	2	1	2

Two of the producers enrich their water and do pH control, which ensures that the iron does not precipitate. Filter maintenance is considered very important because water grass in the water causes clogging of the sand filters. Three of the producers have already replaced their sand filters with automatic flushing ring filters, which has solved the problem to a large extent. The results of the filter maintenance practices of these filters were not included in Table 60. A follow-up project on filters will address the impact of filter efficiencies. In order to prevent clogging in the future, it is recommended that the producers chlorinate at least once a year, as described in paragraph 5.3.

Orange River

The following can be concluded from Table 62:

Much attention is given to system maintenance in the region, which can be attributed to the fact that external clogging as a result of carbonate deposits cause the most problems. Brushing off the precipitates on a regular basis solves the problem. A combination of poor filter maintenance and insufficient water treatment methods lead to the clogging of Drip-In drippers. Acid treatment, as described in Table 72, is considered necessary, in order to prevent precipitation of calcium carbonate, which can lead to external clogging. The replacement of the sand on an annual basis is also recommended.

Table 62: The influence of maintenance practices on system performance of the different drippers in the Orange River region							
Dripper type	**U_s-value (%)**	**Water treatment method**		**Filter maintenance**		**System maintenance**	
		A	**U**	**A**	**U**	**A**	**U**
Ram PC	≥80	5	7	2	16	14	4
	<80	0	0	0	0	0	0
Agridrip	≥80	2	0	0	3	3	0
	<80	0	0	0	0	0	0
Drip-In Regular	≥80	3	5	2	10	12	0
	<80	1	3	0	6	6	0

Breede River

The following can be concluded from Table 63:

All the maintenance practices in this region is sub-standard, with the result that clogging of drippers occur. Following a fixed maintenance schedule such as chlorination at least once a year, the annual replacement of the sand of the sand filters, filter flushing on a pressure difference basis and the flushing of laterals on a monthly basis is recommended.

Table 63: The influence of maintenance practices on system performance of the different drippers in the Breede River region

Dripper type	U_s-value (%)	Water treatment method		Filter maintenance		System maintenance	
		A	U	A	U	A	U
Agridrip	≥80	0	2	1	2	2	1
	<80	0	4	1	5	2	4
Drip-In Regular	≥80	0	8	3	9	5	7
	<80	2	2	2	4	3	3

Berg River

The following can be concluded from Table 64:

Notwithstanding the fact that the water quality of the Berg River along with that of Malelane, is of the lowest quality, maintenance is neglected in most of the cases. This leads to the clogging of all three types of drippers. It is recommended that the proposed maintenance schedule in paragraph 5.6 is followed, in order to solve the current clogging problems and to prevent future problems.

Table 64: The influence of maintenance practices on system performance of the different drippers in the Berg River region

Dripper type	U_s-value (%)	Water treatment method		Filter maintenance		System maintenance	
		A	U	A	U	A	U
Ram PC	≥80	2	8	3	12	6	9
	<80	1	1	1	2	1	2
Drip-In Regular	≥80	0	2	0	3	1	2
	<80	1	3	2	4	4	2

Crocodile River

The following can be concluded from Table 65:

Quite a few of the drippers experienced clogging problems, which can be attributed to insufficient water treatment, as well as poor filter maintenance. Chlorination and the following of correct filtering practice, such as the correct back flushing practices and regular replacement of the filter sand, will assist in preventing the current clogging problems.

Table 65: The influence of maintenance practices on system performance of the different drippers in the Crocodile River region							
Dripper type	**U_s-value (%)**	**Water treatment method**		**Filter maintenance**		**System maintenance**	
		A	**U**	**A**	**U**	**A**	**U**
Ram PC	≥80	0	2	1	2	3	0
	<80	0	2	1	2	1	2
Drip-In Regular	≥80	0	0	0	0	0	0
	<80	1	3	2	4	5	1

Vivo Region

The following can be concluded from Table 66:

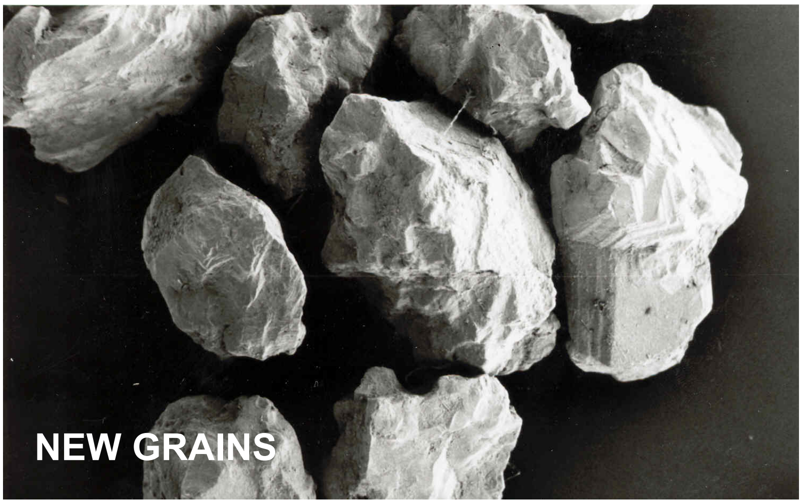
Acceptable filtering/system maintenance practices are followed, but proper chlorination was neglected. The acceptable U_s-value can possibly be attributed to the above. It is recommended that chlorination should be done at least at the beginning of the irrigation season to especially prevent biological clogging.

Table 66: The influence of maintenance practices on system performance of the different drippers in the Vivo region							
Dripper type	**U_s-value (%)**	**Water treatment method**		**Filter maintenance**		**System maintenance**	
		A	**U**	**A**	**U**	**A**	**U**
Drip-In Regular	≥80	0	4	4	2	5	1
	<80	0	0	0	0	0	0

General remarks

The flushing velocities, as measured at the end of the laterals, were higher than the recommended value of 0,4 m/s in all cases. Pressure control, to ensure that the blocks irrigate up to the design pressure, is absent in most cases. This can lead to over-irrigation or under-irrigation, if irrigating is done on a time basis. Back flushing of most sand filters takes place on a time or volume basis, which causes the maximum allowable pressure differential to be exceeded. Dirt then penetrates the irrigation water and causes clogging. It is important that all maintenance practices are followed precisely, according to a fix maintenance schedule as described in paragraph 5.6.

In most cases, the sand replacement frequency was insufficient and could have lead to filtration problems. Sand loses its irregular form, which is necessary for good filtration. It becomes round in form with time. The filtration capacity is adversely affected as it prevents dirt from being retained by the sand-bed. From the photographs in Fig. 12, the difference between worn and new grains of sand can be seen clearly. Sand should have sharp edges to be effective. If the sand particles become round due to frictional wear, the effectiveness of the filter is reduced.



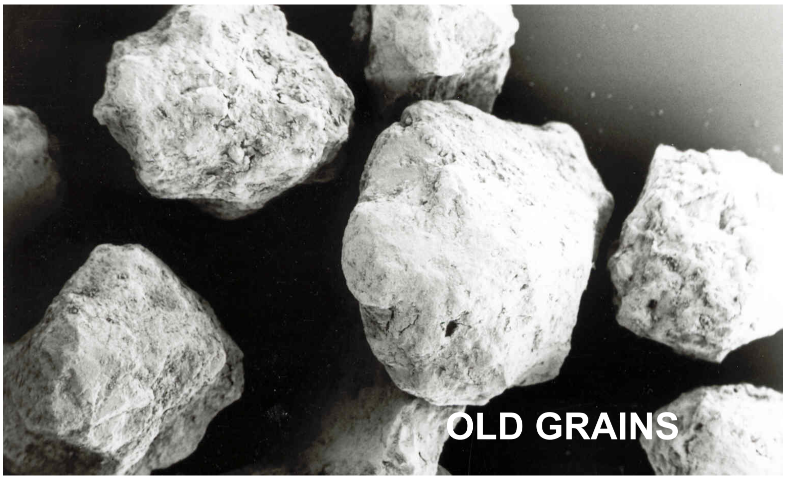
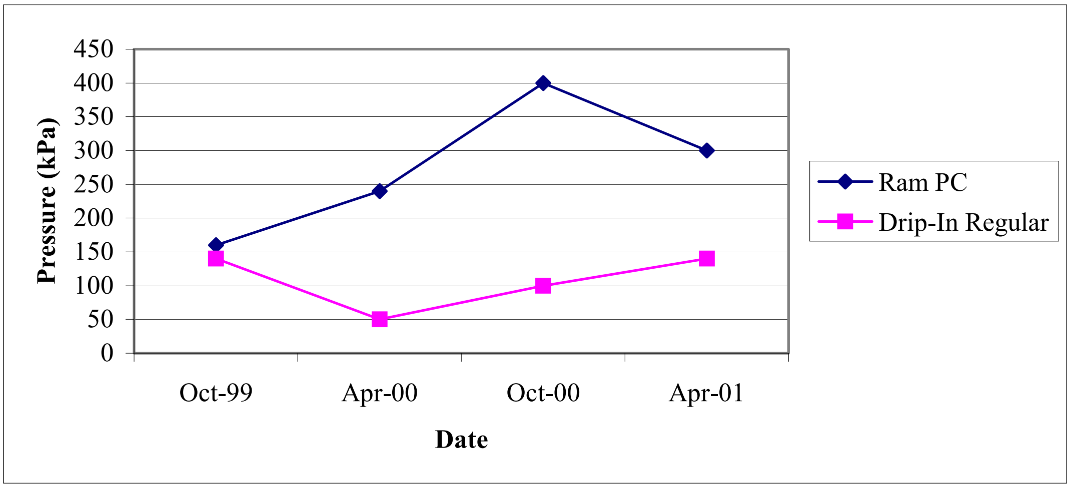


Fig. 12: Grains of sand of different ages (Scale 25:1)

4.3.5 **Different dripper types sensitivity to clogging**

The performance of two types of drippers with an age >5 years and where the same maintenance practices were followed, was compared. The design pressure of the block with Ram PC drippers is 250 kPa and the block with Drip-In regular drippers is 120 kPa. From Fig. 13, it seems that the Ram drippers (Block 4.8) complied with the U_s deductives, while the Drip-In regular drippers (Block 4.9) performed poorly; independent the variation working pressure. In this case it can therefore be concluded that Ram PC drippers perform better than Drip-In drippers, when a lower quality water is available for irrigation and where sub-standard maintenance practices are followed.



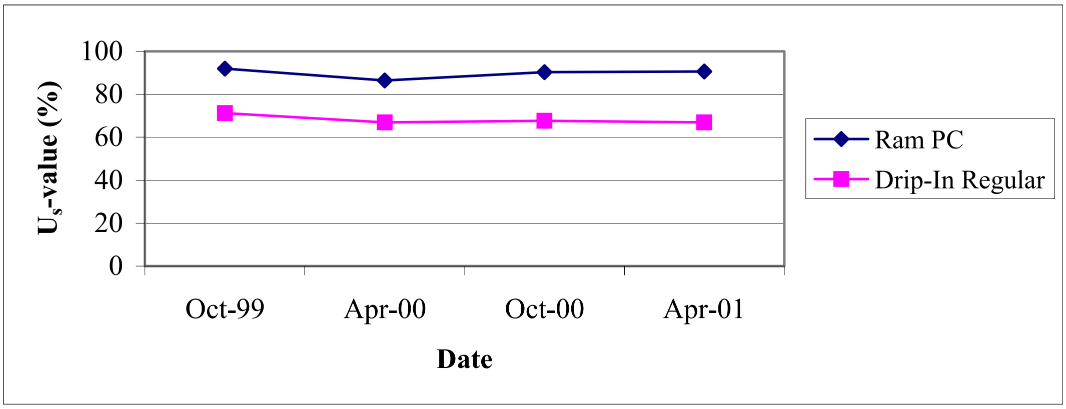


Fig. 13: Comparison between the performance of Ram PC and Drip-In regular drippers

4.3.6 **The influence of design on the performance of the drippers**

It was found that most designs comply with the current norms of the South African Irrigation Institute (SABI). Unfortunately there is a problem with the application and usage of equipment, which influences the performance adversely. The absence of pressure control valves at the blocks has the result that the design discharge in the blocks is, in many cases, not possible, although the use of pressure compensated drippers reduces the problem. Further problems occurred where designers designed laterals with pressure compensated drippers which were too long.

In the Kouga River region, a faulty design was responsible for an unacceptable U_s value in a block older than five years. From Fig. 14 it is apparent that the trees in row 5, the row furthest from the valve of the block at point 5.3 and the emitter in the centre of the lateral (3), received insufficient water. The reason was that the manifold was on the side of the block and the relative height in the centre portion of the block was higher than the side of the block. Installing and setting pressure control valves on the manifold could solve the problem.

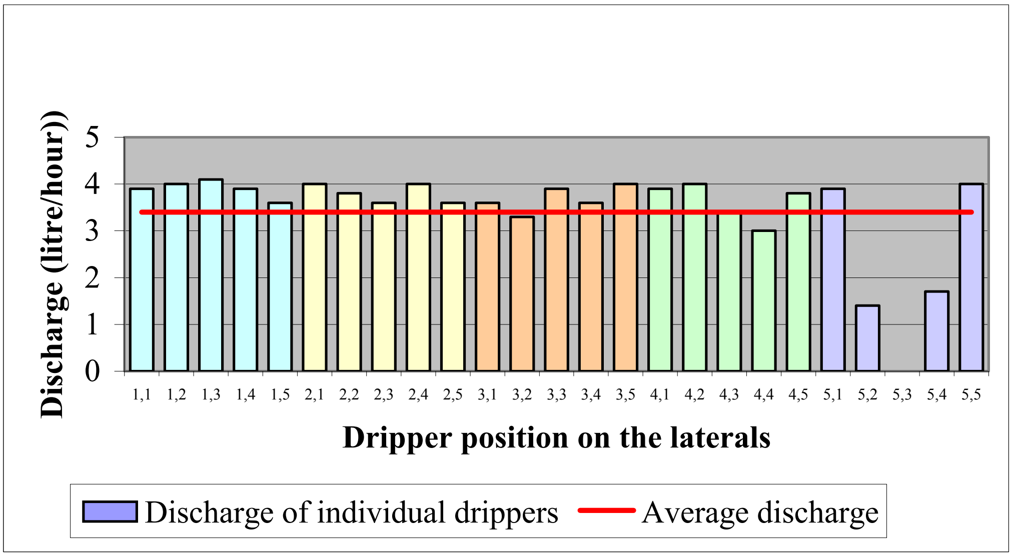


Fig. 14: The influence of faulty design on dripper discharge in a block

The field emission uniformity values (EU´) were also determined for the drip irrigation systems. This figure is multiplied with the percentage water loss that takes place between the water leaving the emitter and the water penetrating the soil in order to determine the application efficiency of dripper systems. The average EU´ values per dripper type per age group are shown in Table 67. It is clear that the application efficiency of drip irrigation systems is much lower than the acceptable 95%.

Table 67: The average EU´ values per dripper type per age group under field conditions in percentage

Dripper type	Age	Date			
		10/99	05/00	10/00	04/01
Ram PC	<5 year	88,5	87,6	86,3	84,8
	>5 year	89,8	88,7	88,6	88,2
Agridrip PC	<5 year	89,5	86,3	86,9	75,2
Drip-In Regular	<5 year	86,4	82,9	76,6	80,9
	>5 year	81,2	80,9	79,8	82,7
Average EU´		**87,1**	**85,3**	**83,6**	**82,4**

The average EU´ of all the systems drop from 87,1% to 82,4%, which is an indication that the performance of the systems is affected by clogging due to water quality and lack of proper maintenance schedules.

5. RECOMMENDATIONS

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

5.1 Water analysis and sampling

A water quality analysis will assist to identify potential clogging problems due to water quality. Preventative measures can then be recommended or 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 after 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 analysed. 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 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 al*, 1992):

$$\%\ \text{Difference} = 100\frac{\sum \text{cations} - \sum \text{anions}}{\sum \text{cations} + \sum \text{anions}} \qquad (37)$$

The criteria for acceptance are as in Table 68:

Table 68: 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 out two or three times with the water being collected. Depending on the analysis to be performed, fill container fully (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 mouth bottle having an opening diameter of at least 35 mm and a capacity as recommended in Table 69. Do not use the same samples for chemical, bacteriological, and microscoping examinations, because the prescribed methods of collecting differ. Changes that take place in a sample are either chemical or biological. Certain cations are subject to loss by adsorption on, or ion exchange with the walls of glass containers. These include aluminum, cadmium, chromium, copper, iron, lead, manganese, silver, and zinc; which are best collected in a separate clean bottle and acidified with nitric acid to a pH below 2,0 to 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 a 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 analysis, therefore do not use it.

The water quality analysis procedures should strive to meet the recommendations as described in Table 69. 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 practices.

Table 69: Summary of special sampling or handling requirements (Franson, 1995)				
Determination	**Con-tainer**	**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 possible or refrigerate or freeze at 20°C.	None
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. 38 (Greenberg, *et al.* 1992).

$$\text{TDS (ppm)} = 0{,}6\ (\text{alkalinity}) + Na + K + Ca + Mg + Cl + SO_4 + SiO_3 + NO_3 + F \qquad (38)$$

Table 70 provides conversions to determine the suitability of water for irrigation.

Table 70: 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

5.2 Water evaluation scale for drip irrigation 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 71 shows the degree of the clogging hazards of drippers for different elements.

Table 71: 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
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 75. 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 75 and the relevant water treatment methods as described in paragraph 5.3.

5.3 Water treatment

On various occasions 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 Table 72. However, some manufacturers have specific recommendations for their dripper lines and these should be followed.

Table 72: Solutions for specific clogging problems (Schwankl, 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 shown in paragraph 3.2.

5.4 Choice and management of equipment

The choice of dependable and proven irrigation equipment is very important to ensure effective water utilization.

Pump

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, but above the bottom to avoid sediment. Fig. 15 shows the minimum water depth above a suction pipe to avoid cavitation.

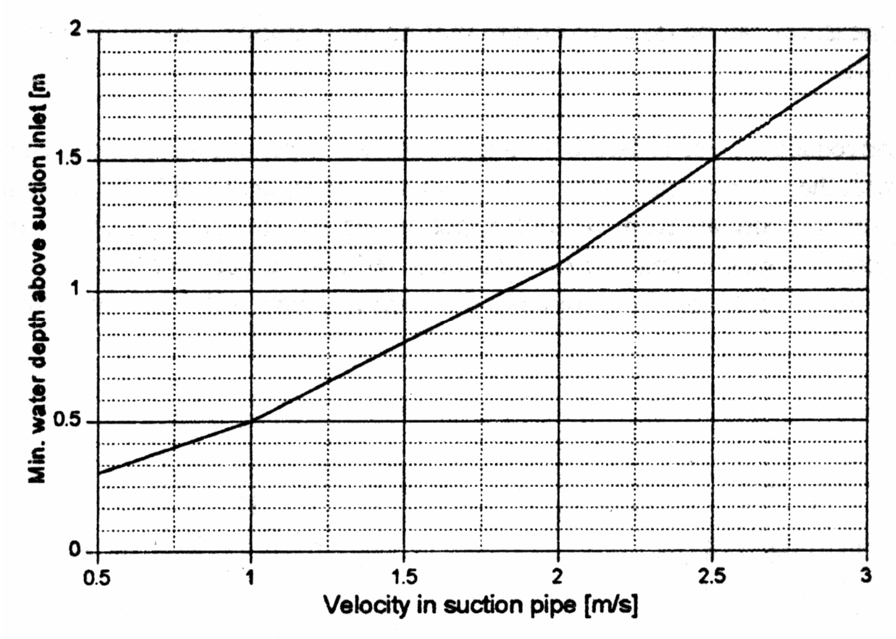


Fig. 15: Minimum water depth above suction pipe inlet

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.

Air valves

Long laterals with a slope as low as 0,5% may have soil ingestion problems if enough vacuum breakers are not provided in the system. At least one vacuum breaker must be provided on the supply manifold.

Pressure control valves

The use of reliable pressure control valves to ensure that the drip irrigation system always irrigates at the design pressure, must be installed.

Flushing manifolds

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 problems. To minimize sediment build-up, regular flushing of drip irrigation pipelines is required. Valves should be installed for flushing of mainlines and manifolds. Flushing should be done as needed, based on water quality and the amount of materials found in pipelines. If considerable sediment build-up occurs, laterals should be equipped with automatic flush valves that flush at the start of each irrigation.

Choice of dripper type

The results of the project showed that there are no differences in the performance of the drippers when a proven maintenance schedule is followed. The drippers with the bigger flow-path perform the best under severe water conditions.

5.5 Design principles

It is important in the system design process that the producer, crop and soil scientists should take into consideration the information regarding the water, nutritive and scheduling requirements of the crop and make recommendations. This will enable the designer to design an optimal irrigation system for a specific set of circumstances. The evaluation of the suitability of water quality for irrigation purposes and identification of possible clogging hazards for the dripper systems, the determination and operation of the available water sources, e.g. boreholes, peak and annual water requirements, analysis of water retention and infiltration capabilities, should be discussed by means of multi-disciplinary concurrence.

The following norms for the design of drip irrigation systems are proposed (Koegelenberg, 2001):

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

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 from clogging the drippers if the sand filter should fail.

Maximum allowable flow-rate through a clean sand filter:

Flow-rate $\leq$50 m^3/h per m^2 with a maximum pressure loss over a clean sand filter $\leq$10 kPa.

Maximum allowable pressure loss over the sand filter with a ring or mesh filter:

Total pressure loss over the clean filter bank (including sand and ring filter) $\leq$40 kPa. Maximum allowable pressure differential over filter bank before back flushing $\leq$60 kPa.

Emission uniformity

Minimum emission uniformity (EU) to determine the available pressure loss for the lateral and manifold design. All manufacturers of drippers are responsible for providing the necessary information to designers for the determination of the design pressure loss. EU values are recommended as shown in Table 73.

Table 73: 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

Flushing velocity of laterals

A minimum flushing velocity of 0,4 m/s at the end of the furthest lateral is required.

5.6 Report

It is recommended that designers provide a design report (Table 74) which include design specifications and information of the specific system, in addition to the necessary plans, quantity lists, maintenance and installation guidelines.

Table 74: 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 Discharge	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 Discharge 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		

Continue . . .

Continued . . .

Table 74: Design form – Drip irrigation system		
	Block number	
	Unit	
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	
10. PUMP		
10.1 Type, model	state	
10.2 Impellor size	mm	
10.3 Pump pressure	m	
10.4 Delivery rate	m³/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	

*WHC_{100} is an indication of the total depth of water per metre depth of soil, between field capacity and of a tension of -100 kPa.

5.7 Operation and maintenance of the system

The success of a drip system is also very dependent on the operation and maintenance of the system. The following aspects are important:

- It is important to inspect the irrigation block with each irrigation cycle to identify possible clogging problems early. Practices like hitting and pinching of drippers to remove clogging problems are discourage because it can damage the drippers and lead to higher dripper discharges. During the project, a syringe was successfully used to remove internal cloggings in all dripper types. If leaks occur, they must be repaired immediately.
- 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.
- 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.
- Flush laterals regularly, depending on the water quality, e.g. weekly at the Orange River where a large amount of silt occurs in the water. Suction pipes must be attached to a float to ensure

that the higher quality water for irrigation is withdrawn. The minimum water depth above suction pipe as shown in Fig. 15 must be maintained.

- Chemical treatment of irrigation water by chlorination can solve 80% of clogging problems. Have at least one water analysis early done to identify clogging hazards.
- 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 and if necessary, measures must be taken to prevent clogging.
- Dripper lines for cash crops should preferably be rolled up and be stored away from soil surface to prevent rodent damage. Before the lines are rolled up, the following procedures should be followed:
  – flush the lines,
  – treat the lines with chlorine or acid, depending on the water quality and blockage problems experienced,
  – roll the lines up during the cool time of the day and store as recommended.

From the investigation it is clear that all maintenance precautions are equally important and dependant on the clogging hazard present in the water sample. It is the duty of the suppliers to give the producers a complete maintenance schedule via the designers of the systems and to explain the procedures to them. The maintenance schedule as shown in Table 75 is proposed for manually cleaned filters. For automatically cleaned filters, the manufacturers' recommendations must be followed.

Table 75: Minimum maintenance schedule requirements for drip irrigation systems

Monitor	Every cycle	Monthly	Yearly
Inspect system for leaks and calcium carbonate precipitation	×		
Check pressure difference across filters and system operating pressure	×		
Adjust filter back flush cycle		×	
Flush laterals (depending on water quality)		×	
Clean filters thoroughly		×	
Service air valves and pressure control valves			×
Check hydraulic and electrical connectors			×
Check hydraulic valves and filters to inspect moving parts			×
Replace sand of sand filters			×
Chlorine treatment (depending on water quality and application method)			×
Take water samples at end of the laterals and evaluate changes in water quality			×

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 m^3/h per m^2 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.
- Minimum inlet pressure of 6 m (60 kPa) during back flushing is required.
- The back flushing 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 then 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 are recommended if problems are experienced with tunnelling to break up the sand.

6. CONCLUSIONS

6.1 Reaching the project objectives

The purpose of this project was to determine the performance of drip emitters that were of different ages and types, which used water of different quality, and where the farming conditions varied. The end result was to propose directives for the selection and operation of the drip emitters. The age of the drip emitters is not the only cause of poor performance of drip emitters. Factors such as leakages, faulty design and equipment have a negative effect on the performance of drip emitters under field conditions. Some aspects that resulted in a faulty design were the absence of equipment such as pressure control valves and air valves, and laterals that were too long. It is recommended that designers follow the recommended design norms of the South African Irrigation Institute and provide irrigators with a complete design report including a maintenance manual.

The decrease in the delivery rate of regular drip emitters and the increase in the delivery rate of pressure compensated drip emitters can be attributed to the clogging of the flow-path of the drip emitters. The increase in the delivery rate of the regular drip emitters was due to incorrect practices, such as the pinching of drip emitters with pliers by the irrigators. Drip emitters with smaller flow-paths are more likely to clog than drip emitters with larger flow-paths. The drip 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 drip emitters should function effectively if the irrigators are following the prescribed maintenance schedule.

Unfiltered water, for example when a pipe has burst, is inclined to clog drip emitters with smaller filter inlet openings.

Most of the irrigators in the different regions followed acceptable maintenance practices with respect to the repair of leakages and the regular flushing of laterals. However, they neglected to follow sound water treatment methods, such as chlorination, and filter maintenance practices, such as the annual replacement of sand.

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 as a result of a too high pressure differential. To ensure high filter efficiency at all times, the media of sand filters should be replaced when it loses its irregular form.
- Laterals must be flushed monthly, or even weekly where necessary, to flush out silt that may precipitate out in the laterals.
- Chlorination must be done at least once a year to clean the irrigation system.

Potential clogging problems due to water quality can be identified well in advance by carrying out water analysis during the summer and winter seasons. 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 should not encounter problems with clogging. From this investigation, 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 investigation. If the water quality therefore exhibits a severe clogging potential, an expert in the field must be approached for advice, as water with a high clogging potential did not form part of this investigation.

Training of producers did not form part of the investigation and will be undertaken if sufficient funds are made available.

6.2 The way forward

A few aspects that were identified, need attention:

- Technology exchange sessions should be presented in every region where the investigation was done to make the research results available. The sessions must include the practical demonstration of the proposed maintenance schedules.
- A user-friendly manual regarding the maintenance of drip irrigation systems should be compiled for the use by producers. 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 prescribe 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.

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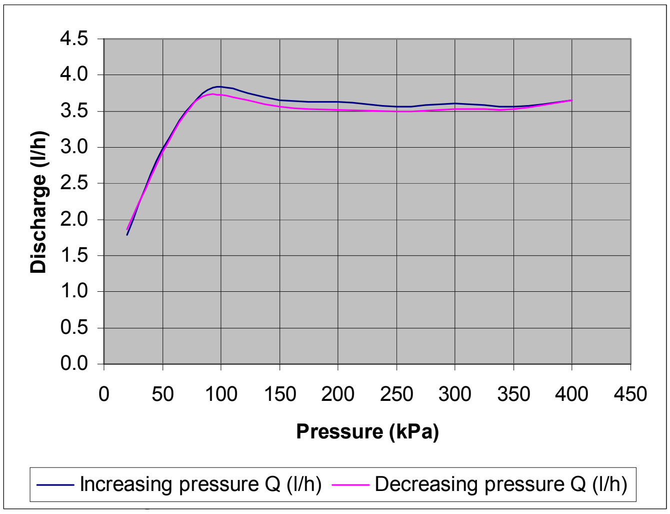
8. APPENDICES

8.1 Example of Agridrip PC dripper test report

ILI products	DISCHARGE AND CV TEST RESULTS ON AGRIDRIP PC 3,6l/h @ 0,6m 16mm (PC)		
		Page:	2 of 2
		Report no:	D99010A
		Date:	September 1999

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



Pressure (kPa)	Discharge (l/h)
20	1.79
40	2.63
60	3.24
80	3.68
100	3.84
150	3.65
200	3.63
250	3.56
300	3.60
350	3.56
400	3.66
350	3.53
300	3.53
250	3.50
200	3.52

Test results for a sample size of 100 drippers:

Tests:	**Test 1**	**Test 2**	**Test 3**	**Average**
Test pressure (kPa)	199.7	199.3	198.9	199.3
Average discharge (l/h)	3.6	3.6	3.6	3.57
Coefficient of variation (%)	3.8	3.4	3.3	3.5
Maximum discharge (l/h)	3.9	3.8	3.8	3.8
Minimum discharge (l/h)	3.2	3.3	3.3	3.3
Variation in discharge (%)	19.1	13.7	13.7	15.5

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: **Good**

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)	199.7				199.3				198.9				199.3
Groups:	Group1	Group2	Group3	Group4	Group1	Group2	Group3	Group4	Group1	Group2	Group3	Group4	All
Average discharge (l/h)	3.6	3.6	3.5	3.5	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6
Coefficient of variation (%)	3.5	2.8	3.9	4.4	3.4	2.8	3.8	3.2	3.4	2.8	3.9	2.9	3.4
Maximum discharge (l/h)	3.8	3.8	3.8	3.9	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
Minimum discharge (l/h)	3.4	3.3	3.3	3.2	3.4	3.3	3.3	3.3	3.4	3.3	3.3	3.4	3.3
Variation in discharge (%)	11.0	12.1	14.3	19.2	11.1	12.7	13.8	12.6	11.5	12.2	13.8	10.4	12.9

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

Rating: **Good**

Water temperature: **18,8 °C**

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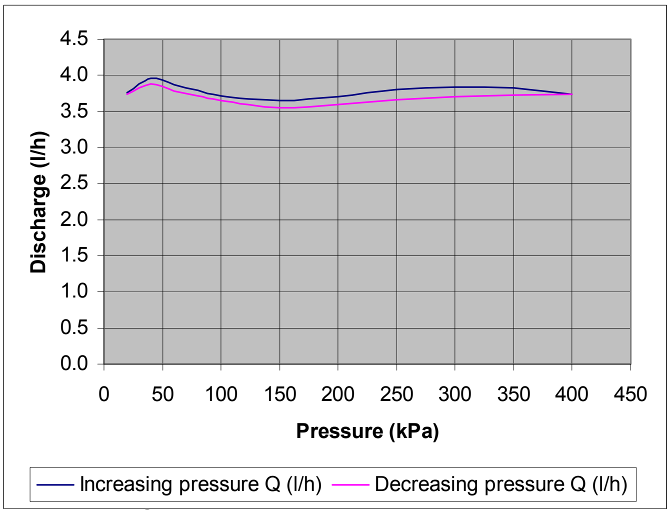
8.2 Example of Drip-In Regular dripper test report

ILI products	DISCHARGE AND CV TEST RESULTS ON NETAFIM RAM 3,5l/h @ 0,6m 17mm (PC)	Page:	2 of 2
		Report no:	D99003A
		Date:	September 1999

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



Pressure (kPa)	Discharge (l/h)
20	3.76
40	3.96
60	3.87
80	3.80
100	3.72
150	3.65
200	3.71
250	3.80
300	3.84
350	3.83
400	3.74
350	3.73
300	3.71
250	3.66
200	3.59

Test results for a sample size of 100 drippers:

Tests:	Test 1	Test 2	Test 3	Average
Test pressure (kPa)	198.4	198.4	199.8	198.9
Average discharge (l/h)	3.5	3.5	3.6	3.55
Coefficient of variation (%)	4.4	4.2	4.5	4.4
Maximum discharge (l/h)	4.3	4.2	4.2	4.2
Minimum discharge (l/h)	2.5	2.6	2.4	2.5
Variation in discharge (%)	50.4	47.1	51.7	49.7

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: **Good**

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)	198.4				198.4				199.8				198.9
Groups:	Group1	Group2	Group3	Group4	Group1	Group2	Group3	Group4	Group1	Group2	Group3	Group4	All
Average discharge (l/h)	3.6	3.6	3.5	3.6	3.6	3.6	3.5	3.6	3.6	3.6	3.5	3.6	3.5
Coefficient of variation (%)	4.7	2.4	6.7	1.6	4.7	2.5	6.2	1.4	4.3	2.3	7.3	2.0	3.9
Maximum discharge (l/h)	4.3	3.8	3.7	3.7	4.2	3.8	3.7	3.7	4.2	3.8	3.7	3.7	3.9
Minimum discharge (l/h)	3.3	3.4	2.5	3.5	3.2	3.4	2.6	3.5	3.4	3.4	2.4	3.3	3.2
Variation in discharge (%)	25.5	11.2	35.3	7.0	28.7	11.2	32.6	6.5	22.3	10.6	38.0	10.2	19.9

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

Rating: **Good**

Water temperature: 18,8 °C

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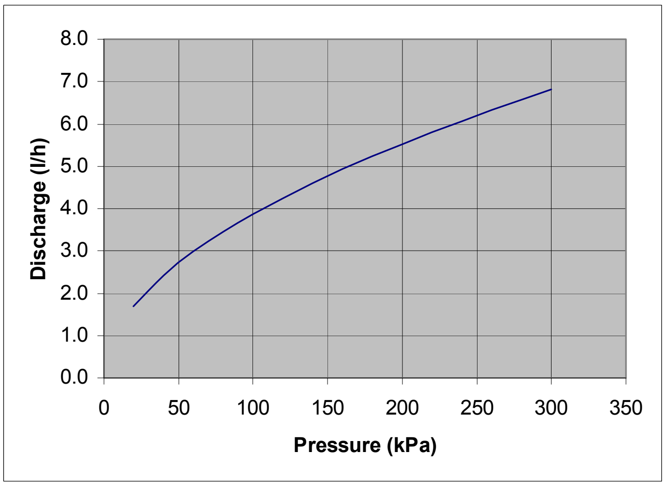
8.3 Example of Ram PC dripper test report

ILI products	DISCHARGE AND CV TEST RESULTS ON Drip In 4l/h @ 0,6m 16mm (Regular)	Page: 1 of 1 Report no: D00008A Date: AUGUST 2000

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



Pressure (kPa)	Discharge (l/h)
20	1.70
40	2.42
60	2.98
80	3.45
100	3.87
120	4.25
140	4.60
160	4.93
180	5.24
200	5.53
220	5.81
240	6.07
260	6.33
280	6.57
300	6.81

Discharge formula: $Q = 0.3641 \times P^{0.5135}$

Test results for a sample size of 100 drippers:

Tests:	Test 1	Test 2	Test 3	Average
Test pressure (kPa)	100.8	100.9	101.0	100.9
Average discharge (l/h)	3.9	3.9	3.9	3.87
Coefficient of variation (%)	3.2	3.3	3.2	3.2
Maximum discharge (l/h)	4.2	4.2	4.2	4.2
Minimum discharge (l/h)	3.5	3.5	3.5	3.5
Variation in discharge (%)	17.3	17.3	17.3	17.3

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: **Good**

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)	100.8				100.9				101.0				100.9
Groups:	Group1	Group2	Group3	Group4	Group1	Group2	Group3	Group4	Group1	Group2	Group3	Group4	All
Average discharge (l/h)	3.9	3.9	3.8	3.8	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9	3.9
Coefficient of variation (%)	2.1	3.2	3.4	3.8	2.1	3.2	3.6	3.9	2.2	3.2	3.4	3.9	3.2
Maximum discharge (l/h)	4.0	4.1	4.2	4.1	4.0	4.1	4.2	4.1	4.0	4.1	4.2	4.1	4.1
Minimum discharge (l/h)	3.7	3.5	3.6	3.6	3.7	3.5	3.6	3.6	3.7	3.5	3.6	3.6	3.6
Variation in discharge (%)	7.2	14.3	14.4	10.7	7.9	14.3	14.4	11.9	7.9	14.2	14.4	12.2	12.0

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

Rating: **Good**

Water temperature: 13 °C

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8.4 **Average summer and winter water quality data obtained from DWAF stations situated in the different catchment areas**

KOUGA RIVER (REGION 1)

Summer data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
L8H004Q01	-33,74	24,58806	Number of Readings	159	159	157	157	157	157	157	157	159	155	24
			Minimum	5,48	0	18,8	2,8	0	3,8	21,2	2,4	14,7	1,3	0,979
			25% Percentile	6,94	0,151	22,1	3,746	0,01	8,8	37,5	4,3	19,15	1,792	1,767
			Median	7,213	0,243	23,9	4,226	0,014	11,3	41,2	4,9	21,4	1,92	1,925
			75% Percentile	7,395	0,429	26	4,747	0,024	14,06	47	5,609	23,65	2,012	2,17
			Maximum	8,15	0,725	58,3	13,1	0,134	34,2	82,1	32,6	53,4	2,43	2,404
			Mean	7,142	0,2933	24,41	4,324	0,01948	11,73	42,37	5,588	21,85	1,906	1,86
L8H005Q01	-33,7906	24,03056	Number of Readings	134	111	111	112	111	111	111	112	134	106	15
			Minimum	5,257	0	10,9	1,847	0,003	1,1	16,5	2	9,87	0,88	0,125
			25% Percentile	7,02	0,0195	15,91	2,9	0,011	6,1	28,75	3,278	14,53	1,471	2,439
			Median	7,27	0,03	18,4	3,5	0,019	9	32,9	3,9	17,1	1,655	2,56
			75% Percentile	7,47	0,0585	22,05	4,125	0,0255	11,4	37,64	4,5	19,23	1,855	2,661
			Maximum	8,713	0,533	39,4	5,9	0,5	23	70,9	11,3	32,2	3,37	4,914
			Mean	7,202	0,05635	19,38	3,584	0,02791	8,871	34,28	4,077	17,08	1,688	2,605

Winter data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
L8H004Q01	-33,74	24,58806	Number of Readings	167	167	166	166	166	166	166	166	167	159	21
			Minimum	5,68	0	14,8	2,3	0,005	0	27	3,5	12,6	1,38	1,666
			25% Percentile	7,085	0,0845	21,67	4	0,011	8,2	36,4	4,5	19,15	1,735	1,854
			Median	7,22	0,166	23,9	4,4	0,0155	10,4	40,6	5,3	21,2	1,87	1,919
			75% Percentile	7,417	0,2675	26,4	4,8	0,025	12,98	46,72	5,9	23,25	2	2,048
			Maximum	7,78	0,7	42,3	8,8	0,213	55,3	66,6	13,3	37,2	2,4	2,514
			Mean	7,178	0,1899	24,07	4,439	0,02301	11,09	41,6	5,426	21,48	1,869	1,988
L8H005Q01	-33,7906	24,03056	Number of Readings	163	149	149	149	149	149	149	149	163	144	16
			Minimum	3,05	0	9,6	1,7	0,002	2,1	11,9	1,4	8,5	0,931	0,713
			25% Percentile	6,885	0,025	16,2	2,9	0,01	5,5	29,4	3,165	14,7	1,518	2,11
			Median	7,158	0,055	18,2	3,4	0,017	7,8	32,9	3,8	16,7	1,64	2,375
			75% Percentile	7,38	0,139	20,6	3,9	0,025	11,2	36,4	4,5	18,25	1,81	2,463
			Maximum	8,339	0,969	37,6	6,6	2,631	18,6	78,7	9	32,1	2,76	3,014
			Mean	7,047	0,1107	18,86	3,512	0,0553	8,371	34,2	3,844	17,01	1,671	2,252

ORANGE RIVER (REGION 2)

Summer data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
D7H014Q01	-28,7681	20,72056	Number of Readings	24	24	24	24	24	24	24	24	24	23	14
			Minimum	7,46	0,02	6,349	7,437	0,01	13,2	5	19,33	21,7	0,311	0,014
			25% Percentile	8,156	0.02	13.06	9.457	0.019	18.8	10.55	23.82	26.63	0.589	0.0415
			Median	8.235	0,0395	15,5	10,73	0,0275	21,94	12,67	25,85	30,2	0,655	0,1405
			75% Percentile	8,365	0,1028	19,89	11,64	0,03475	30,23	16,4	27,16	32,55	0,816	0,414
			Maximum	8,54	0,332	25,6	14,55	0,091	65,16	25,7	32,45	42,1	1	0,766
			Mean	8,241	0,08621	16,21	10,67	0,03221	26,03	13,35	25,65	30,05	0,6737	0,2342
D8H004Q01	-28,7356	19,30611	Number of Readings	265	264	260	260	260	260	260	260	471	254	4
			Minimum	6,07	0	6,8	5,3	0	5,5	3,7	17,3	18,1	0,33	0,289
			25% Percentile	8,03	0,019	18,08	10,17	0,01375	18	13,48	24,7	25,35	0,7525	0,3047
			Median	8,3	0,031	23,25	12,19	0,0195	27,45	17,75	27,8	31	0,935	0,3235
			75% Percentile	8,42	0,1005	30,7	14,7	0,028	40,03	24,63	30,6	37,6	1,15	0,4005
			Maximum	8,81	0,77	87,4	28,9	0,132	134,5	102,5	50,4	74,1	2,92	0,591
			Mean	8,114	0,1031	25,98	12,78	0,0234	32,45	21,09	27,98	32,81	0,9959	0,3818

Winter data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
D7H014Q01	-28,7681	20,72056	Number of Readings	51	51	51	51	51	51	51	51	51	49	6
			Minimum	7,75	0,012	8,2	4,9	0,01	11	4,8	19,2	20,8	0,4	0,005
			25% Percentile	8,1	0,071	17,85	9,65	0,018	23,95	12,9	23,6	28,65	0,77	0,1148
			Median	8,183	0,274	21,5	12,4	0,03	31,6	17,6	26,77	34,6	0,89	0,1705
			75% Percentile	8,23	0,41	28,4	14,35	0,038	39,85	25,84	28,8	38,3	1,06	0,2255
			Maximum	8,62	0,614	45,9	19,2	0,405	57,9	51,3	38,1	51,2	1,51	0,32
			Mean	8,157	0,2749	22,35	12,24	0,04192	31,79	19,35	26,44	34,45	0,8886	0,1677
D8H004Q01	-28,7356	19,30611	Number of Readings	288	285	285	285	283	285	285	285	472	278	4
			Minimum	6,02	0	8	7	0	5,3	4,7	18,5	11,3	0,39	0,176
			25% Percentile	7,798	0,029	16	9,8	0,012	16,8	11,8	23,4	26,6	0,68	0,1895
			Median	8,17	0,117	19,6	11,4	0,018	24,4	16,5	26,3	30,95	0,81	0,205
			75% Percentile	8,33	0,4	27,1	13,8	0,0305	36,6	23,8	30,5	35,85	1,027	0,236
			Maximum	8,72	1,24	63,2	26,1	0,14	72,5	64,4	41,8	59,6	2,08	0,296
			Mean	7,982	0,2275	23,04	12,33	0,02501	27,96	19,19	26,93	32,41	0,8875	0,2205

BREEDE RIVER (REGION 3)

Summer data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
H4H017Q01	-33,8181	19,69472	Number of Readings	511	481	471	471	471	471	471	471	545	468	34
			Minimum	3,41	0	2,5	0,6	0	0	6,5	0,3	2,3	0,6	1,046
			25% Percentile	6,4	0,02	20,65	4,4	0,009	12,85	34,15	4,3	18,8	1,64	1,486
			Median	7,23	0,04	26,1	5,5	0,016	16,8	43,7	5,6	22,8	1,89	2,008
			75% Percentile	7,515	0,242	34,88	8	0,024	23,7	60,4	8,15	31,2	2,15	2,344
			Maximum	8,55	4,85	83,4	18,6	0,152	57,5	134,5	17,6	66	3,32	2,976
			Mean	6,975	0,1606	28,65	6,279	0,01872	18,65	48,34	6,436	25,26	1,901	1,974
H5H002Q01	-33,8886	20,01333	Number of Readings	181	179	171	171	171	171	171	171	398	170	
			Minimum	5,7	0	11,7	2,6	0	2,9	18,1	2,4	11,6	1,02	
			25% Percentile	7,07	0,04	88	17,25	0,004	47,55	141,5	14,85	67,03	3,618	
			Median	7,43	0,12	133,4	24,7	0,01	65,7	213,5	21,7	97,55	4,6	
			75% Percentile	7,83	0,295	195	34,85	0,017	90,05	291,7	29	143,5	5,923	
			Maximum	8,87	2,37	573,8	98	0,482	233,1	924,3	66,7	369	10,46	
			Mean	7,471	0,2352	156,6	29,06	0,01584	74,44	247,2	23,55	111,7	4,845	

Winter data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
H4H017Q01	-33,8181	19,69472	Number of Readings	525	504	504	504	504	504	504	504	532	500	34
			Minimum	3,6	0	3	0,8	0	0	7,7	0,6	3,8	0,59	1,132
			25% Percentile	6,29	0,15	17,78	4,1	0,01	13,08	30,35	4,7	17,38	1,4	1,548
			Median	7	0,3625	26,9	5,9	0,017	18,64	45,1	6,4	24,1	1,825	2,011
			75% Percentile	7,43	0,66	37,21	8,335	0,027	25,99	63,73	8,71	33	2,22	2,357
			Maximum	8,56	1,646	182,2	36	0,174	98	314,7	45,8	152	4,89	3,465
			Mean	6,822	0,4272	29,14	6,536	0,02129	20,45	49,86	6,952	26,16	1,83	2,119
H5H002Q01	-33,8886	20,01333	Number of Readings	211	211	211	211	211	211	211	211	429	211	
			Minimum	5,23	0	8,1	2,1	0	2,1	10,8	1,4	6	0,94	
			25% Percentile	6,705	0,16	37,6	7,65	0,006	21,55	61,1	7,9	26,9	2,26	
			Median	7,2	0,31	64,4	12,4	0,012	34,9	106	11,8	45	3,1	
			75% Percentile	7,48	0,49	122,7	22,8	0,0195	61,15	187,1	20,65	79,7	4,335	
			Maximum	8,75	2,09	508,1	95,9	0,334	240,1	809,4	58,4	355,2	9,51	
			Mean	7,084	0,3642	90,44	16,95	0,01683	46,03	143,7	15,88	61,6	3,439	

BERG RIVER (REGION 4)

Summer data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
G1H013Q01	-33,1328	18,86194	Number of Readings	626	623	602	602	593	602	601	602	639	599	36
			Minimum	3,48	0	7,8	0	0	0	12	0	3,5	0,85	1,106
			25% Percentile	6,613	0,02	21,8	4,46	0,006	7,1	37,4	5,1	19,95	1,675	1,483
			Median	7,26	0,07	27,2	5,5	0,015	9,95	46,6	6,3	24,2	1,91	1,85
			75% Percentile	7,63	0,39	33,85	7	0,025	12,88	60,5	8	29,35	2,16	2,127
			Maximum	8,8	1,69	87,5	14,6	0,69	89,1	152	29,5	67,1	6,18	2,651
			Mean	7,106	0,2552	29,17	5,923	0,02088	10,35	50,93	6,838	25,29	1,949	1,841
G1H031Q01	-32,9969	18,77889	Number of Readings	632	632	609	609	623	609	609	609	645	607	33
			Minimum	4,29	0	3,1	1,3	0	0	5,6	0,8	4,2	0,5	0,797
			25% Percentile	6,67	0,03	32,6	6,8	0,004	11,6	58,1	7	28,8	2,06	1,125
			Median	7,11	0,13	40	8,8	0,012	14,3	73,7	8,8	34,9	2,34	1,429
			75% Percentile	7,675	0,4005	50,7	11	0,024	17,3	93,7	11,1	42,5	2,6	1,724
			Maximum	9,75	9,68	158,9	25,2	1,609	102	309,8	33,5	106	5,45	2,247
			Mean	7,128	0,2593	42,52	9,037	0,02185	15,28	78,54	9,328	36,39	2,347	1,441

Winter data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
G1H013Q01	-33,1328	18,86194	Number of Readings	636	630	626	626	592	625	626	626	652	622	36
			Minimum	4,24	0	4	0,6	0	0	5,1	1	4,2	0,21	0,08
			25% Percentile	6,568	0,27	21	3,9	0,014	7,9	33,63	5,1	18,5	1,663	1,622
			Median	7,22	0,7	29,9	5,4	0,026	11,6	50,35	6,4	25,15	2,09	1,979
			75% Percentile	7,57	1,021	41,5	7,4	0,045	15,8	71	8	32,65	2,558	2,162
			Maximum	9,4	19,35	305,5	50,6	3,017	80,28	508,3	39,99	222	7,573	2,531
			Mean	7,062	0,731	33,08	5,974	0,04548	12,49	56,15	7	27,11	2,161	1,846
G1H031Q01	-32,9969	18,77889	Number of Readings	637	637	626	626	637	626	626	626	659	623	38
			Minimum	2,75	0	9,1	1,881	0	0	16,84	0,3	9,1	0,89	1,039
			25% Percentile	6,5	0,308	33,43	6,1	0,012	12,02	56,18	6,7	27,95	2,17	1,481
			Median	7,02	0,67	44,4	8,15	0,025	16,1	79,6	8,6	36,4	2,63	1,695
			75% Percentile	7,6	0,971	60,53	11,4	0,044	21,1	108,9	10,7	47,2	3,15	1,839
			Maximum	10,14	3,869	224,6	42,4	1,196	87,7	427,8	44,9	164	6,24	2,885
			Mean	7,015	0,7137	50,23	9,139	0,0365	18,12	89,92	9,417	40,08	2,705	1,742

CROCODILE RIVER (REGION 5)

Summer data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
X2H046Q01	-25,3989	31,61056	Number of Readings	203	203	203	203	203	201	203	203	204	199	45
			Minimum	6,58	0,001	6,376	4,511	0,002	3,4	5	7,7	13,7	0,366	0,037
			25% Percentile	7,645	0,0945	13,65	9,8	0,015	15,4	11,6	12,1	22,3	0,6995	0,307
			Median	7,941	0,489	18,3	14,26	0,025	19,87	14,4	16,2	28,3	0,82	0,441
			75% Percentile	8,16	0,6805	25,15	17,3	0,034	26	18,8	19,7	36,3	0,98	0,552
			Maximum	8,68	1,664	60,3	31,2	14,6	54,5	36	75,87	63,2	1,85	1,395
			Mean	7,885	0,4519	20,2	14,2	0,1003	20,96	15,73	16,31	29,73	0,8558	0,4597
X2H048Q01	-25,4597	31,53556	Number of Readings	130	125	125	125	125	125	125	125	130	124	
			Minimum	6,66	0,007	6,8	4,3	0,001	0,6	5,4	7,1	12,4	0,43	
			25% Percentile	7,55	0,164	13,8	10	0,014	12,2	11,1	11,6	21,63	0,69	
			Median	7,925	0,495	18	12,5	0,022	15,5	14,8	14,7	26,65	0,84	
			75% Percentile	8,198	0,8	22	16,6	0,033	21	17,5	17,7	33,38	0,9225	
			Maximum	8,75	1,665	183	51,4	0,087	101,6	114,3	35,4	132	4,88	
			Mean	7,886	0,5192	24,11	14,47	0,02433	17,73	18,76	15,29	30,73	0,9727	

Winter data

Stations	Latitude	Longitude	Type of Statistics	pH	NO3+NO2-N (mg/ℓ)	Na (mg/ℓ)	Mg (mg/ℓ)	PO4-P (mg/ℓ)	SO4 (mg/ℓ)	Cl (mg/ℓ)	Ca (mg/ℓ)	EC (mS/m)	SAR	LANGL-Index
X2H046Q01	-25,3989	31,61056	Number of Readings	217	217	217	217	217	217	217	217	217	213	59
			Minimum	6,87	0,001	3	3,2	0,003	4,475	3,2	3,322	9,6	0,16	0,009
			25% Percentile	7,85	0,423	18,3	14,5	0,017	17,22	13,7	16	29	0,78	0,1655
			Median	8,144	0,668	24,6	18,9	0,026	23,3	16,7	19,4	36,2	0,942	0,325
			75% Percentile	8,285	0,872	31,12	22,3	0,036	28,8	21,6	22,4	42,3	1,114	0,4675
			Maximum	8,674	1,675	52,8	31,8	0,203	42,3	36,36	31,93	55,2	2,847	1,081
			Mean	8,044	0,6409	25,05	18,6	0,02925	23,44	17,5	19,02	35,69	0,9626	0,3609
X2H048Q01	-25,4597	31,53556	Number of Readings	134	134	134	134	134	134	134	134	134	124	1
			Minimum	6,7	0,009	10,8	9,2	0,001	2,7	7,6	10,1	19,5	0,56	0,532
			25% Percentile	7,773	0,35	19,9	15,72	0,012	16,2	12,8	16,4	30,1	0,8	0,532
			Median	8,11	0,7105	22,45	17,45	0,019	20,8	16,55	18,2	33	0,9	0,532
			75% Percentile	8,28	0,9817	26,75	20,65	0,0335	25,35	19,88	20,8	38,4	1,02	0,532
			Maximum	8,98	2,149	162,8	55,6	0,455	45,6	101,4	57,6	116,7	4,16	0,532
			Mean	8,048	0,6737	27,29	18,64	0,02719	20,96	19,31	19,35	36,27	0,9933	0,532

Vivo (Region 6)

There is no data available for this region.