DEVELOPMENT AND EVALUATION OF A GRAVITY CHEMICAL DOSING SYSTEM AND TESTING ITS APPLICATION IN A ROUGHING AND SLOW SAND FILTRATION SYSTEM

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Development and Evaluation of a Gravity Chemical Dosing System and Testing its Application in a Roughing and Slow Sand Filtration System

Report to
the Water Research Commission

by

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Executive summary

A project to develop and evaluate a gravity chemical dosing system and test its application in a roughing - slow sand filtration system was undertaken by the Cape Peninsula University of Technology (Formerly Peninsula Technikon, Bellville Cape Town).

One of the research areas unveiled by previous investigations done in small water treatment plants in South Africa, is the development of simple, effective and reliable chemical dosing systems to obviate problematic chemical dosing practices reported in these plants. One of WRC's strategic plans for drinking water treatment research in small plants emphasises the introduction of simpler technologies, which encourage more community involvement to solve such problems. Conventional mechanised and electronic chemical dosing systems are not generally recommended for small and rural plants due to the stringent operation and maintenance demands which are often challenging to meet in most of these plants.

Most small, rural and urban water treatment schemes in South Africa employ conventional treatment processes (coagulation, flocculation, sedimentation and rapid sand filtration (RSF) or slow sand filtration (SSF)). The operation and maintenance of RSF is more complicated than SSF, especially the mechanised filter media cleaning processes. Because of its simplicity in design and operation and effectiveness in producing potable water, SSF is recommended in small communities. However, SSF is susceptible to rapid clogging if consistently fed with raw water having turbidity greater than 10 NTU. Roughing (or gravel) filtration (RF) is a simple raw water pre-treatment process, which is compatible with SSF and has the ability to protect SSF against raw water with turbidity greater than 10 NTU without the aid of coagulation. However, RF is not very effective in treating high turbidity raw waters largely characterised by colloidal particles. However, coagulation is expected to improve the performance of RF in treatment high turbidity raw waters. Because of the simplicity of RF-SSF systems, the attendant chemical dosing system to be used, if coagulation was incorporated, must not reintroduce any complexity.

The project therefore dealt with the development and use of a simpler chemical dosing system in a RF-SSF system and investigation of RF-SSF system thereof. The project results are reported in two parts:

→ **Part A**, which deals with the development and evaluation of the chemical dosing system and its objectives were as follows:

(1) To develop a gravity driven chemical dosing system as an alternative to conventional electronic chemical dosing equipment, appropriate for application in small and/or rural water treatment plants.

(2) To evaluate the effectiveness of the gravity chemical dosing system developed in aim (1) on a pilot roughing – slow sand filtration water treatment plant.

(3) To develop operation and maintenance guidelines for the application of the developed chemical dosing system in aim (1) and evaluated in aim (2).

→ **Part B**, which deals with the roughing – slow sand filtration system combined with coagulation achieved by chemical dosing using the system developed in Part A. Its objectives were as follows:

(1) To evaluate the performance of a combination of roughing filtration and slow sand filtration in treating coagulated turbid raw water (the dosing of the coagulant solution used in the coagulation process was achieved by the chemical dosing system reported in Part A).

(2) To develop guidelines for practical applications of a combination of coagulation, roughing filtration, and slow sand filtration in small water treatment plants.

A comparatively simple chemical dosing system was developed and indicated potential practical application that could obviate most of the chemical dosing problems in small and rural water supply systems. The system employs gravity; hence it does not require electrification. It provides a reliable and sustainable alternative to widely applied electronic dosing systems which are evidently problematic in small and rural areas, even in some urban areas. This system can serve as a stand-by chemical dosing system for chemicals dosed in solution forms.

However, the challenge of chemical availability needs to be addressed as well in these areas if the benefits of any reliable equipment are to be realised.

The incorporation of coagulant chemical dosing using the chemical dosing system developed in roughing – slow sand filtration systems provide a much more appropriate and effective water treatment system for small and rural water supplies than conventional schemes. The practice of coagulation in roughing filtration is less stringent compared to conventional sedimentation systems. The gravel media in roughing filtration provides for enhanced chemical mixing, flocculation and sedimentation in one unit.

Coagulation prior to roughing filtration showed that slow sand filtration can be adequately protected against higher and varying raw water turbidity levels, at the same time prolonging filter runs, hence reducing operational and maintenance costs.

However, care must be taken to ensure that chemical dosing is applied whenever there is high turbidity in the raw water, otherwise turbidity breakthrough can occur and cause rapid clogging of slow sand filtration.

The project also developed guidelines for the design, construction and application of the chemical dosing system developed and the investigated roughing – slow sand filtration processes. These are reported in the separate Parts A and B of the report.

These guidelines must be used by skilled persons with knowledge in hydraulics and water treatment processes. Any development of a chemical dosing system and construction of roughing – slow sand filtration from these guidelines will require individual testing and results must not be expected to be exactly the same.

The initial intention of WRC in funding this project was to accelerate water research capacity at the then Peninsula Technikon. Looking at the water research capacity progress to date in this regard as a result of this project, the experience gained and contacts made, it is without doubt that WRC has achieved its goal. The author and other individuals who were involved have had a life-long experience and are currently involved in other WRC projects and offering consultancy services to local authorities. The author and students who were involved have to date presented several conference papers and posters at local and international conferences.

At the time of finalising this report, WRC had further funded a consultancy project that is undertaking a technology transfer through investigating the treatment of coloured water at Stormsvlei, a rural and farm community, Western Cape, using the chemical dosing system and the roughing – slow sand filtration system being reported.

Acknowledgements

The research in this report emanated from a Water Research Commission project entitled *Development and evaluation of a gravity chemical dosing system and testing its application in a roughing and slow sand filtration system* (WRC project no K5/1396).

The steering committee responsible for this project consisted of the following persons:

▪ Dr G Offringa	Water Research Commission (Chairman /Researcher Manager)
▪ Prof A Lagardien	Cape Peninsula University of Technology
	(Formerly Peninsula Technikon, Bellville, Cape Town
▪ Prof P Slatter	Cape Peninsula University of Technology
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▪ Prof RE Loewenthal	University of Cape Town
▪ Mr A Parker	Department of Water Affairs & Forestry-Bellville Cape Town
▪ Mr PRA Flower	City of Cape Town
▪ Dr I Siebritz	Bergstan Africa (Former Liebenberg & Stander, Cape Town)
▪ Mr P Thompson	Umgeni Water – Durban
▪ Mr CD Swartz	CSI Water Utilisation Engineers – Mossey Bay

The financing of the project by the Water Research Commission and the contribution of the members of the Steering Committee is greatly acknowledged.

This project was only possible with the cooperation of some individuals and institutions. The author therefore wishes to record sincere thanks to the following:

▪ Benedict Arends	Former student, Peninsula Technikon – Bellville, Cape Town
▪ Yaso Zimasa	Former student, Peninsula Technikon – Bellville, Cape Town
▪ Jason White	Former student, Peninsula Technikon – Bellville, Cape Town
▪ Boikanyo Sethlare	Cape Peninsula University of Technology – Bellville, Cape Town
▪ Tyler J	Cape Metropolitan Council, Scientific Services, (Cape Town)
▪ Hilda van Zyl	Cape Peninsula University of Technology – Bellville, Cape Town
▪ Dirk Loubser	PELMANCO-Specialists in Fabrication – Parow, Cape Town

The previous Heads (Mr S Miller and Mr B Forbes) of the Department of Civil Engineering and current Dean (Dr O Franks) at the then Peninsula Technikon (Now Cape Peninsula University of Technology) are greatly acknowledged for their support and encouragement. Personnel at the water treatment plants that were visited during the project are thanked, especially for their cooperation and making available of information.

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Part A – Development and evaluation of a gravity chemical dosing system

1 Introduction

1.1 Background

A study was conducted to determine upgrading needs of small and rural water treatment plants in South Africa and guidelines were drawn up on how to address these needs (Swartz 2000). One of the needs identified related to the development and use of simple, effective and reliable chemical dosing systems for controlling chemical dosages in these plants. From a survey of 20 small plants (See Appendix A), Swartz (2000) found that electronic or gravity chemical dosing for both coagulation and disinfection purposes were problematic. The following is a list of specific problems that were reported by Swartz (2000):

- Electrical disruptions,
- Malfunctioning of equipment,
- Lack of spare parts for dosing pumps repairs,
- Uncontrollable drip-dosing,
- Lack of dosing control leading to over or under dosing,
- Lack of adequate safety measures,
- Generally poor designs,

Some of the above problems are reported by other researchers who have conducted surveys in various developing countries (Schulz & Okun (1984), Holfke (1998)). The author's experience also confirms most of these problems.

The main concern in small and/or rural plants has for some time related to the sustainability of operation and maintenance of electronic chemical dosing equipment. Hence, the development or improvement of simpler chemical systems, especially gravity driven, as alternatives is generally encouraged in such plants. The Water Research Commission (South Africa)'s strategic plan for research on water treatment in small and rural areas emphasises the introduction of simpler technologies which can also encourage more community involvement.

The above background information provided adequate rationale for the undertaking of the project entitled:

Development and evaluation of a constant head gravity chemical dosing system and testing its application in a roughing and slow sand filtration system.

This section presents Part A which deals with the development and evaluation of the chemical dosing system. Part B is presented separately and deals with the testing of the chemical dosing system developed on a pilot water treatment plant. Hence, the aims, scope and limitations, methodology and structure of the report presented in the following sections are only for Part A.

1.2 Aims of the project

The aims of the project were:

(1) To develop a gravity driven chemical dosing system as an alternative to conventional electronic chemical dosing equipment, appropriate for application in small and/or rural water treatment plants.

(2) To evaluate the effectiveness of the gravity chemical dosing system developed in aim (1) on a pilot water treatment plant.

(3) To develop operation and maintenance guidelines for the application of the developed chemical dosing system in aim (1) and evaluated in aim (2).

1.3 Scope and limitations

The scope was to develop an alternative chemical dosing system to conventional electronic dosing pumps. It is envisaged that such a system can find either direct application in small and/or rural water treatment plants or as a standby chemical dosing system in even medium plants. The system was developed to only dose chemicals which are applied in solution form. Typical characteristics of the chemical dosing system that were envisaged included the following:

a) Utilising gravity as a driving force, without any moving components prone to wear and tear.
b) Being able to consistently provide constant dosing rates.
c) Having a provision for easy adjustments of dosing rates through calibration.
d) Being able to reproduce dosing rates as desired.
e) Constructed from materials which are resistant to damage by the chemicals to be dosed.

1.4 Methodology

The project was conducted in two phases. The methodology in each phase is summarised in the paragraphs below.

PHASE 1: This was a development phase in which literature reviews, knowledge from plant visitations, consultations and innovation were the main methodologies used. The designing aspect of was very much of a desktop task. The designed chemical dosing system was fabricated by a local company, using local materials. This one year phase was shorter than the 2^{nd} phase and focussed on ensuring that the designed chemical dosing system was fabricated. Hence, the evaluation conducted was generally considered to be preliminary. It was limited to calculating dosing rates at various heads, observing material performance and identifying factors that influence dosing rates.

PHASE 2: This phase focussed on further evaluation considering factors found to influence dosing rates during phase 1. These factors as identified in phase 1 mainly relating to the behaviour of the components of the dosing systems and variation of the solution level in the system. The methods used to evaluate these factors are described in detail in chapter 3, which covers the evaluation aspects.

In both phases, the practical application of the chemical dosing system was tested on a pilot water treatment plant reported in PART B. Most of the evaluations were conducted within the in-house water laboratory using tap water and aluminium sulphate (ALUM) solutions. ALUM was selected because of its wide application and it s generally recommended in small plants. Dosing rates were measured by volumetric analysis, which involves collecting a certain volume of a fluid and recording the time taken, and then calculating the flow or dosing rate (volume divided by time). The main interest was in the consistence and reproductivity of dosing rates.

1.5 Structure of the report

Chapter 2 presents the literature review and visitations made to local water treatment plant, with focus on the relevant findings. The literature review focused on chemical dosing systems that feed water treatment chemicals applied in solution forms. The aim of visitations to some of the local (Western and Eastern Cape Provinces) small water treatment plants was to investigate the status of chemical dosing systems and gain first-hand experience.

Chapter 3 presents the details of the developed chemical dosing system and the evaluations that were conducted. The chemical dosing system details include design principles, construction materials and fabrication.

Chapter 4 outlines the guidelines for the application of the developed chemical dosing system that take into consideration practical aspects.

Chapters 5 and **6** present the conclusions and recommendations for further research, respectively.

2 Chemical solution dosing systems in application

2.1 General

The objective of this chapter is to present the results of the literature review and visitations that were conducted to water treatment plants during the project duration. The focus in the literature review was on chemical dosing systems that employ gravity and those appropriate for small and/or rural water treatment plants. As for the visitations, the interest was on the status and types of chemical dosing systems that are in use in small and/or rural water treatment plants. Particular interest was on the systems that use the force of gravity when dosing chemical solutions, usually referred to as drip-dosing. Such simple systems are appropriate in small and/or rural water supply systems.

The literature review is presented in the following section 2.2 while section 2.3 presents the results of the plant visitations. The last Section 2.4 presents summary results of the literature review and plant visitations.

2.2 Literature review

2.2.1 Background

Chemicals in water treatment plants are dosed in various forms. For instance, chemicals for coagulation are usually dosed in solution and suspension forms, while disinfection chemicals such as chlorine products can be dosed either in liquid, granular or gaseous forms. The chemical form chosen would influence the complexity of the attendant dosing system. Hence, chemical dosing systems in water treatment plants are expected to range from simple to complex types as a result of chemicals being available in various forms:

- Simple systems include those that pump predetermined dosages directly from a solution tank and those that dose dry or wet chemicals by gravity or volumetric measurements.
- Complex systems include electronically controlled pump metering systems that automatically adjust dosing rates based on water flow rates and quality.

Dosing systems for gaseous chemicals, such as chlorine gas, are usually electronically driven and are more complex than solution feeders (*Schulz and Okun, 1984*). *Schulz and Okun, (1984*) report that hydraulically and gravity driven systems are simpler and are more appropriate as solution-feeders in small water treatment plants.

Hydraulically driven systems are usually water powered and involve moving components which dose solution in proportional to the flow of water.

Gravity driven systems make use of either a tap or orifice system and are therefore comparatively simpler.

Since the project's interest was in developing and evaluating much simpler chemical solution dosing systems such as the gravity driven solution-feeders, the literature review conducted was limited to such systems. These are discussed in the following section, ultimately leading to the selection of the type upon which the chemical dosing system that was developed and evaluated is based.

2.2.2 Gravity chemical solution dosing systems

The simplest chemical dosing systems generally recommended for rural and small plants are those that dose chemical solutions by gravity (*Schulz & Okun 1984; Holfkes 1988*). In such systems, predetermined amount of a solution drips into the water at a point that has enough mixing energy.

> Gravity dosing systems usually have no moving parts and their construction is possible from local materials.

> Specific problems that Swartz (2000) found in relation to the use of gravity chemical dosing (or drip-dosing) relate to lack of control and inaccurate adjustment of dosing rates, which lead to over and/or under dosing.

The erroneous general practice reported in some plants entails drip-dosing from a solution tank using a tap or tube installed near the bottom of the tank without taking into consideration the decreasing level of the solution and its concentration (see Figure 2.1).

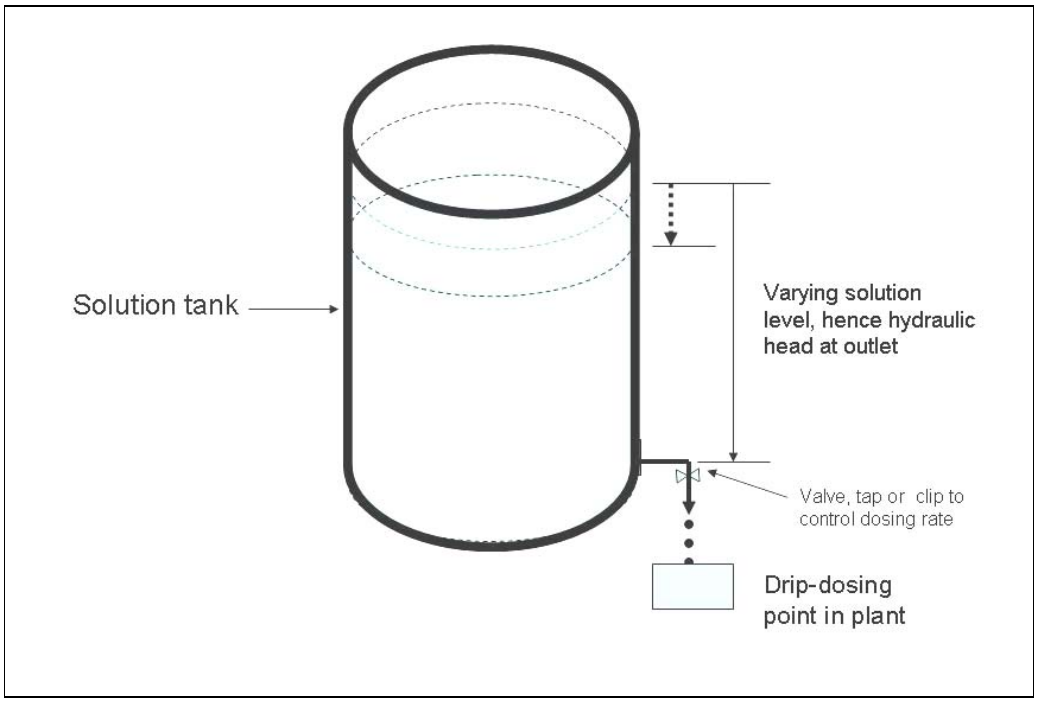

Figure 2-1: Illustration of drip-dosing without considering solution level

Schulz and Okun (1984) reports and recommends the two types of gravity chemical solution dosing systems based on the **constant-head principle**. One uses a constant-level box and the other type a constant-head orifice. It is from these systems that the basis for the development of the system reported in this report was drawn. The design and operation of these systems are discussed in the following sections.

2.2.3 Constant-level box solution feeders

The general layout of a constant-level box solution feeder is illustrated in Figure 2.2.

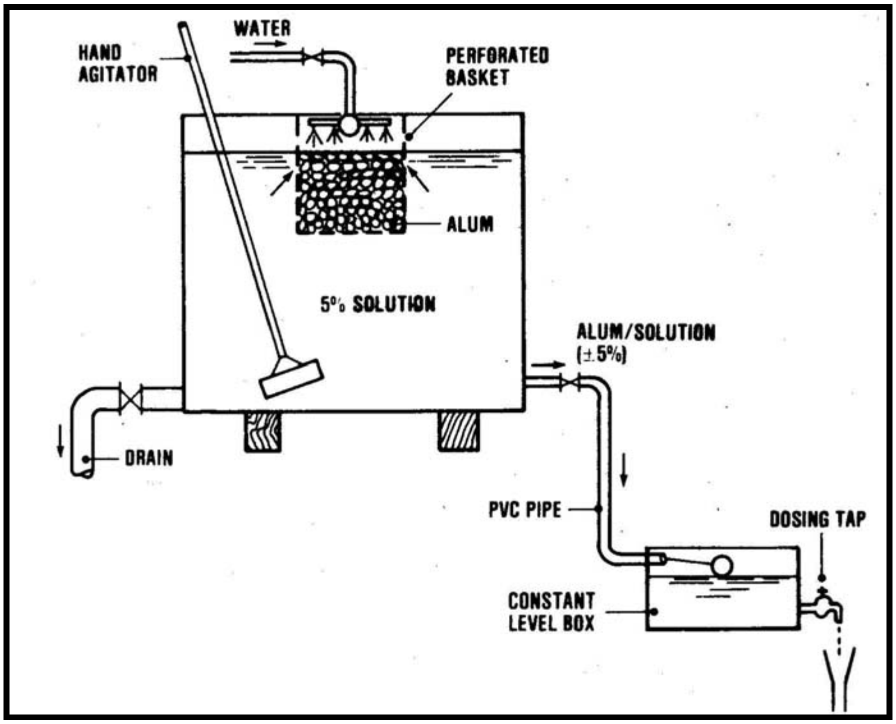

Figure 2-2: Constant - level box solution feeder (Schulz and Okun 1984)

The solution is prepared in a separate stock solution tank provided with a chemical basket, a hand agitator, inlet for clear water and an outlet pipe leading to a constant-level box. The constant level is maintained by a float-valve inlet. This box is then equipped with a dosing tap installed near its bottom (see Figure 2.2).

> The calibration of the dosing tap is not discussed in literature. However, dosing rates in constant-level box solution feeders can only be determined by regular volumetric measurements.

The main operation and maintenance challenges in constant-level box solution feeders are as follows:

(1) Calibration of dosing tap for easy adjustment of dosing rates

(2) Sustainability of the float-valve and dosing tap with respect to damage, wear and tear.

With respect to corrosion, it is recommended that all exposed parts are protected against corrosion. The use of hard rubber, glass and ceramic materials for this purpose is recommended.

To ensure uninterrupted operation, Schulz and Okun (1984) recommends that two solution tanks are provided in which both are connected to one constant-level solution box. In this way if one solution tank is being filled, the other one can still be in use.

2.2.4 Constant-head orifice solution feeders

An alternative to the constant-level box solution feeders is one that provides a constant-head over an orifice to give a constant dosing rate. Two types of constant-head orifice solution feeders can be distinguished by the illustrations in Figures 2.3 and 2.4. The descriptions of each of these types are given after each figure.

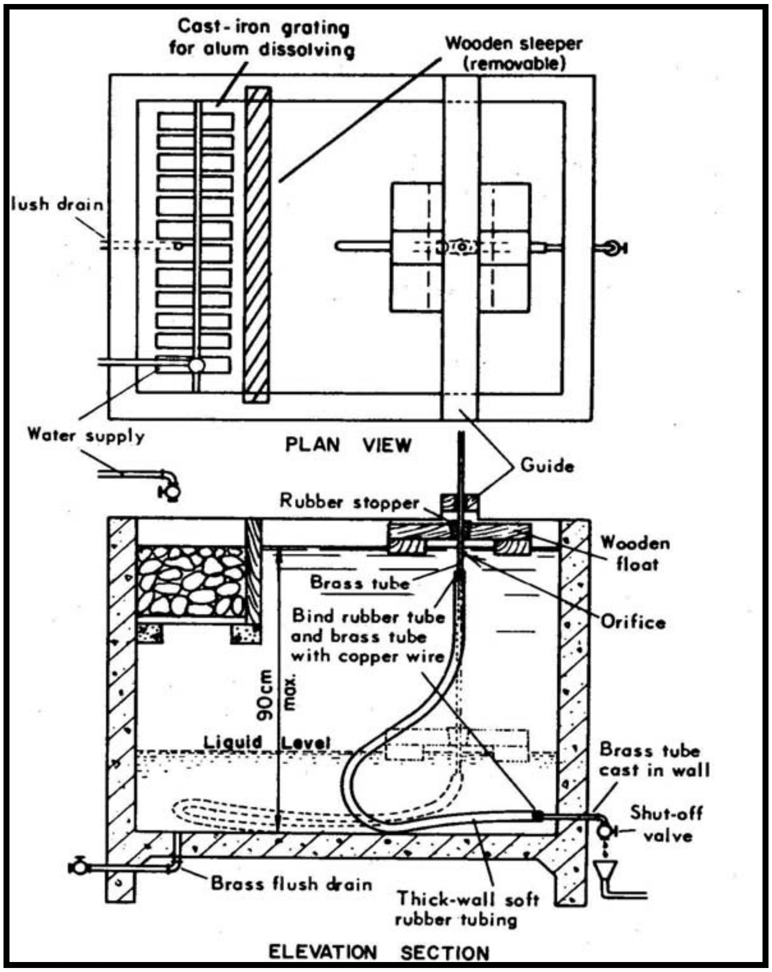

Figure 2-3: Floating-arm type solution feeder (*Schulz & Okun* 1984)

The floating arm type solution feeder consists of the following (see Figure 2.3):

- A solution tank provided with: (1) water supply; (2) a basket for holding a granular chemical; (3) a flush drain made of brass
- A dosing system consisting of: (1) a wooden float to which a brass tube (pipe) equipped with an orifice is attached using a rubber stopper; (2) a thick-walled rubber tubing connected to one end of the brass tube which has an orifice. The other end of the rubber tubing is further connected to a short brass tube (which passes through the solution tank wall) equipped with a shut-off valve at one end, leading to the dosing point.

The shut-off valve (see Figure 2.3) is not for controlling dosing rates, but for stopping the dosing when desired. Dosing rates are determined by the orifice-head (see Figure 3.4).

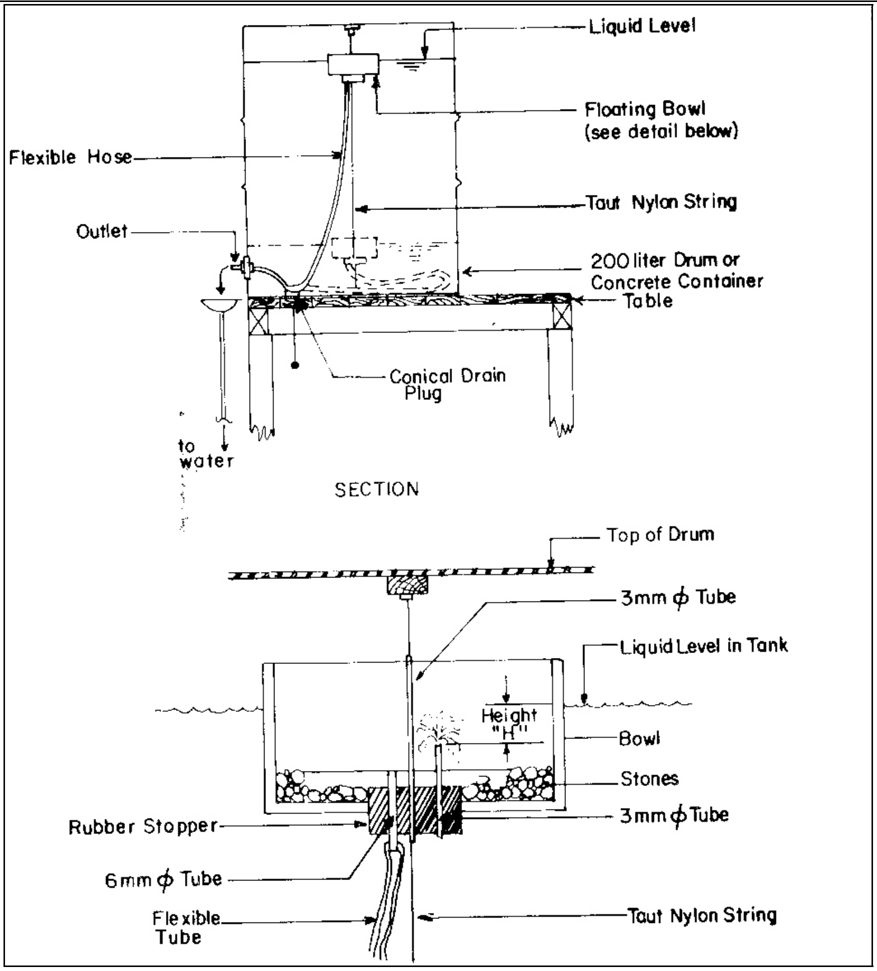

Figure 2-4: Floating-bowl type solution feeder (*Schulz & Okun* 1984)

The floating bowl type solution feeder (Figure 2.4) consists of the following:

- A 200 litre drum provided with a strong stand made of concrete and fitted with a conical drain plug.
- A dosing system consisting of: (1) a floating bowl to which a flexible tube is attached using a rubber stopper; the other end of the flexible tubing is further connected to an outlet near the bottom of the drum and leads to a dosing point.

Detailed design, operation and maintenance guidelines for the constant-head orifice chemical dosing systems in Figures 2.3 and 2.4 are not sufficiently covered in literature. The major aspects not dealt with include:

1) The calibration aspects of the orifice and dosing tubes.
2) The impacts of decreasing solution level on the bending of the flexible tubing. In figures 2.3 and 2.4, it is shown (see dotted lines) as though the flexible tubing simply sinks gently as the solution level decreases. However, in practice buoyancy is expected to influence the sinking and bending of the flexible tubing, which in turn would influence the consistency of the dosing rates.

3) The impacts of the positions of the floating bowl or wooden float on the bending of the flexible tubing, which is expected to impact on the flow of the solution during dosing.
4) General design, construction materials, installation, operation and maintenance guidelines are not sufficiently dealt with. Capacity aspects in relation to the concentration of the solution to be dosed and practical calculations thereof are not addressed.

Compared to the constant – level box (Figure 2.2) and floating - bowl (Figure 2.3), the floating-arm types (Figure 2.4) or constant-head orifice systems can be easier to calibrate, operate and maintain. The absence of float-valves, dosing taps and floating bowl filled with stones, makes the floating arm (or constant-head orifice) more sustainable.

It is for these reasons above that the constant-head orifice was selected as the basis for the development and evaluation of the gravity chemical solution dosing system. Hence a brief review of flow characteristics through an orifice became necessary and is presented in the following section.

2.2.5 Flow characteristics in orifices

The flow through an orifice is proportional to its size and velocity of flow, i.e.

$$\mathbf{Q \propto AV}$$

where:

- *Q is the actual or measured flow through the orifice (m^3/s);*
- *A is the area of the orifice in m^2;*
- *V is the velocity of flow through an orifice in m/s.*

The left-hand-side of the above relationship represents the actual or measured flow value while the right-hand-side represents the calculated or theoretical value. The actual or measured flow is expected to be different from the calculated or theoretical value due to the properties of an orifice such as shape, profile and material of construction. Hence, to generate an equation that can be used to calculate the actual or measured flow from known values of A and V, a constant 'K' is introduced into the relationship to take into account the properties of an orifice as follows:

$$\mathbf{Q = K*A*V} \quad \text{...... ....(1)}$$

The constant 'K' is different for different orifice shapes (See Figure 2.5). The velocity 'V' is also given by the following equation:

$$\mathbf{V^2/2g = h \text{ or } V = (2gh)^{1/2}.} \quad \text{...... ....(2)}$$

Where 'g' is acceleration due to gravity (~ 9.81 m/s^2); and 'h' is the head of water above the centre of the orifice;

Inserting the value of gravity into equation (2), it becomes:

$$\mathbf{V = 4.429\ h^{1/2}} \quad \text{...(3)}$$

Inserting equation (3) into equation (1), then Q can be calculated from the following equation:

$$Q = 4.429 * A * K * h^{1/2} \quad \text{……………………………………………}(4)$$

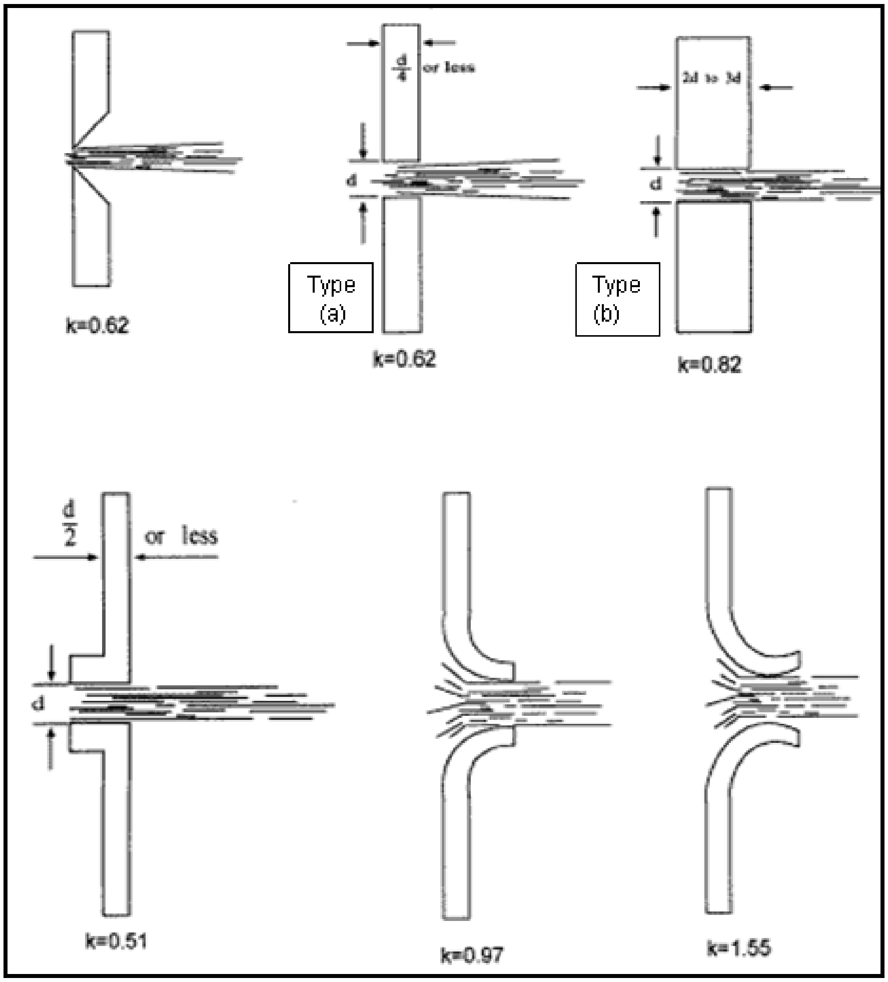

Figure 2-5: Types of orifice shapes and their K-values

Reynolds number (Re) can be used to characterise the flow through an orifice in order to give an indication of the main cause of friction losses. Re is calculated as:

$$\mathrm{Re} = \frac{Vd}{\nu} \quad \text{…………………………………………………………}(5)$$

where:

- Re is the Reynolds number (unitless)
- v is the kinematic viscosity (m^2/s);
- V is the velocity of flow through the orifice in m/s.
- d is the diameter of the orifice or pipe (m)

If Re < 2000, the flow is characterised as laminar or quiescent in which case the friction is caused by shear forces of adjacent layers (streamline flow). Examples of laminar include groundwater flow and flow in settling tanks. For **Re < 3000 - 4000**, the flow is characterised as **turbulent** in which case the friction is caused by **relative roughness (k/d)** due to the internal roughness and shear forces in laminar sub-layers near the orifice or pipe walls.

> In the evaluation of dosing rates, it will be necessary to note whether the flow through the orifice is laminar or turbulent so as to have an idea of the influence of friction.

2.2.6 Chemical dosing systems in small water treat plants (South Africa)

The third column of the Table in Appendix A presents the then status of the chemical dosing facilities in 20 small water treatment plants as investigated by Swartz (2000). These plants were only selected to be representative samples for the entire country. There are many other small and rural water treatment plants that could have better, similar or worse situations.

Swartz (2000)'s study found that chemical dosing systems, for both coagulation and disinfection purposes, are problematic in the small plants surveyed. Specific findings include

- Some plants do not even have dosing facilities to start with; dosing is simply done adding pre-determined amounts of chemicals intermittently.
- For the plants that have chemical dosing systems, a number of them are either malfunctioning or not in use at all.
- Optimisation and adjustment challenges of dosing systems where raw water quality is varying.
- In most cases they are reported to be out of operation and waiting for spare parts.
- Electricity interruptions where electronic dosing pumps are used.
- Lack of adequate safety measures for gas chlorinators.
- Poor designs and installations of gas chlorinators.
- Any problems with chemical dosing facilities at the pre-treatment (pre-filtration) stage, subsequently places great pressure on sand filtration stage.
- Sand filters were reported to frequently clog thus increasing operation and maintenance costs.
- Compromised disinfection due to poor final water as a result of poor chemical control in the coagulation stage, which causes floc (turbidity) break-through in filter.

Although lack of adequate financial resources contributes to lack of sustainability of most chemical dosing systems, technical inappropriateness seems to be most common. Some chlorine gas dosing facilities are also reported to be unsafe. Ongoing WRC projects on small water treatment plants at the time of writing this report had also made numerous findings pertaining to poor chemical dosing practices in most small water treatment plants.

> However, it is also worthwhile to note that a number of good practices pertaining to chemical dosing in small water treatment plants exist as well

2.3 Plant visitations – Western and Eastern Cape

2.3.1 Plants visited

During the project period, a number of small and rural water treatment plants were visited both in the Western and Eastern Cape provinces. The aim was to visit and survey practical operation and maintenance of the plants, with particular interest on the status of the chemical dosing systems.

The plants visited in the Western Cape where in the following towns/areas:

- Ashton, Montagu, Tulbagh, Bredasdorp, Portberg, Stellenbosch (Paradyskloof), Malgas, Swellendam, Riviersonderend,

The plants visited in the Eastern Cape where in the following towns:

- Alice, Fort Beaufort, Seymour, Sada, Lady Frere (Macubeni plant), Cofimvaba, Hogsback

2.3.2 Review of chemical dosing systems

All the plants visited have electrification and where or had been using electronic chemical dosing systems. However, some common problems found for electronic dosing pumps include the following:

(1) Absence of standby dosing pumps,

(2) Inability to repair broken dosing pumps due to lack of spare parts,

(3) Inability to replace malfunction dosing pumps,

(4) Lack of calibration information on the dosing pumps,

(5) Operators lacking the capacity or not having the knowledge to control dosing rates.

There were four plants, two in the Western Cape (Ashton and Bonnievale) and two in the Eastern Cape (Fort Beaufort and Cofimvaba), that were found to be using gravity dosing systems at the time of visitation. Since the interest of study was gravity dosing systems, the descriptions and discussions of these gravity chemical dosing applications are presented separately in the following paragraphs.

(a) Ashton water treatment plant (AWTP): Western Cape

Ashton Water Treatment Plant is a conventional plant of capacity of up 5 Ml/d, which has three production lines, each with a different filtration process (rapid sand, slow sand and pressure filtration). The pre-treatment processes included pH-adjustment, coagulation, rapid mixing, baffled flocculation, and horizontal flow sedimentation and upflow sludge blanket clarifiers.

pH- adjustment is achieved by dosing lime using gravity lime dosing hoppers, while coagulation is achieved using ALUM. The ALUM is supplied in granular form and has to be dissolved before dosing. The dosing of ALUM solution was usually achieved by dosing pumps. At the time of visit, the dosing pumps were not operational and were reported to have been broken down over 3 months ago. The dosing was being achieved by drip-dosing as shown in picture given Figure 2.6.

Figure 2-6: Drip chemical dosing system - Ashton, Western Cape

When the plant was visited later, it was found that new dosing pumps were still being awaited but a new dosing system was developed and replaced the drip-dosing in order to achieve effective control of dosing rates (See Figure 2.7).

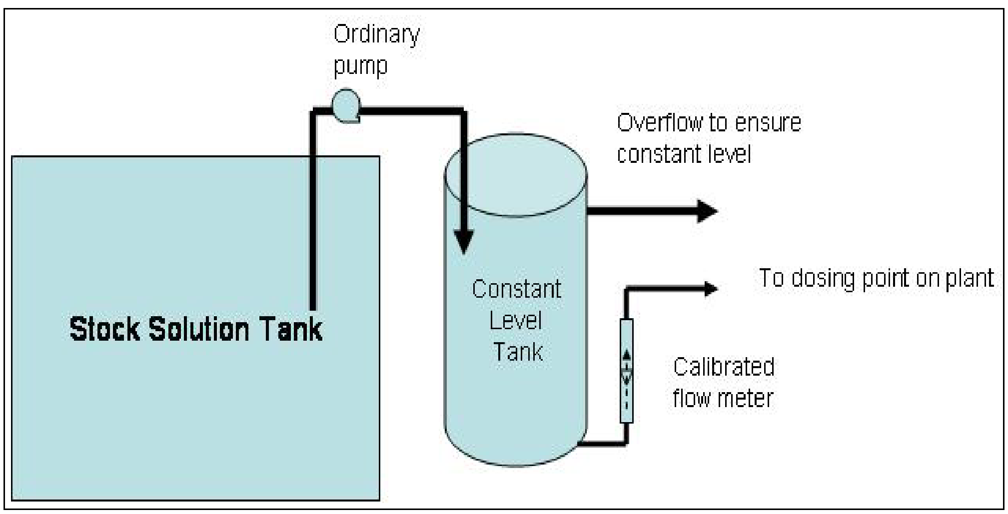

Figure 2-7: Constant level-flow meter dosing system – Ashton, Western Cape

The chemical dosing system in Figure 2.7 employed an ordinary water pump feeding the chemical solution to a constant level tank. This tank was equipped with a calibrated flow meter through which the solution flowed by gravity to the dosing pumps. This system provided a better solution although attendant calibration information was not developed.

At the time of writing this report, dosing pumps were acquired for AWTP, but the system in Figure 2.7 can still be applied when required.

(b) Bonnievale water treatment plant (BWTP): Western Cape

The BWTP uses pressure filtration as a main water treatment process (see Figure 2.8). Conventional pre-treatment comprising coagulation, baffled flocculation and sedimentation is used to treat the surface raw water before filtration.

Figure 2-8: Pressure filtration units in Bonnievale – Western Cape

The coagulation is achieved by using ALUM.   This plant doses its ALUM solutions by drip-dosing from two solution tanks through a tap (See Figure 2.9).

Figure 2-9: Gravity chemical dosing tanks in Bonnievale – Western Cape

Operators have to regularly check the dosing rates by collecting a pre-determined volume over a period of 60 seconds. A calibration table has been drawn which assists in adjusting dosing rates in relation to the amount of water being treated.

(c) Cofimvaba water treatment plant (CWTP): Eastern Cape

The CWTP is a conventional plant that employs rapid mixing, coagulation, flocculation, sedimentation and rapid sand filtration. Coagulation is achieved by ALUM.

At the time of visit, this plant was found to dose ALUM solutions by drip-dosing from one solution tank through a tube at the bottom (see Figure 2.9). There was no control of the dosing rate and the operator did not know the concentration of the solution.

(L) ALUM Solution tank on previous location for electronic pumps that are out of operation for over a year; (R) Operator adjusting dosing rate by twisting and wire-clamping hose-pipe connected to the solution tank.

Figure 2-10: Gravity chemical dosing system in Cofimvaba – Eastern Cape

The operator at the CWTP reported that previously, electronic chemical dosing pumps were used and have since broken down about 2 years ago. The picture on the left –hand -side in Figure 2.10 shows the previous locations of the electronic dosing pumps.

(d) Fort Beaufort water treatment plant (FBWTP): Eastern Cape

The FBWTP is also a conventional plant that employs rapid mixing, coagulation, flocculation, circular-radial flow sedimentation and gravity rapid sand filtration. Coagulation is achieved by poly-electrolytes coagulants (ultra-floc) which are dosed using electronic dosing pumps.

Disinfection at this plant is usually achieved by gas chlorination, but at the time of visit the chlorine gas ran out. As an emergency measure, a solution of chlorine was prepared using bleaching powder (HTH) and drip-dosed from a drum equipped with a tap (see Figure 2:11). However, there was no control on the dosing rates, which were allowed to vary with the solution level in the tank.

Figure 2-11: Emergency gravity chemical dosing system-Fort Beaufort, Eastern Cape

2.4 Summary of findings from literature and pant visitation

The summary of findings presented here relate to the challenges with the use of electronic dosing equipment and the design and application of gravity chemical dosing systems as drawn from both literature reviewed and plant visitations that were made.

Electronic chemical dosing systems

The challenges with the use of electronic dosing equipment in small plants mainly relate to the lack of capacity to operate and maintain the dosing equipment. On-site operators are not usually given sufficient operation and maintenance training. Availability of operation and maintenance manuals is also another challenge.

In most cases external personnel, through consultants, not stationed on the plant, are usually responsible for advising operators on how to adjust dosing rates

A further challenge is related to inadequate funding or simply the lack of technical capacity to motivate for funding required for repairing malfunction units and/or to purchase standby or replacement units.

Gravity chemical dosing systems

Gravity dosing systems that use orifices were generally found to be more appropriate for further development. The absence of the need to maintain a constant solution level once the orifice system is set makes such systems easy to operate and maintain. Flow through an orifice can also be easier to calibrate, hence the control of dosing rates can be more simpler and more accurate.

Chemical dosing systems that use a tap require regular volumetric measurements and adjustment of the tap opening to maintain a pre-determined dosing rate if the level in the solution tank is not kept constant. However, systems utilising an orifice are designed to maintain a constant dosing rate while allowing the solution level to vary within a reasonable range. These systems thus obviate the need to regularly adjust the equipment.

For the gravity chemical dosing systems, information relating to the design, construction, operation, monitoring and maintenance is not adequately covered in literature. E.g.:

- Basic calculations and guidelines on the dosing rates and systems capacities are not covered.
- Calibration aspects are not dealt with.
- For dosing systems that use a float and flexible tubing system (See Figure 2.2), the impact of the bending effect of the flexible dosing tube as the solution level decrease was not dealt with.
    - Logically, as the solution level gets decrease, the flexible tube is expected to rise due to buoyancy, and this will affect the flow.

Where gravity chemical dosing systems are applied, the plant visitations revealed the following:

- Lack of calibration information.
- Lack of control and adequate adjustment of the dosing rates.
    - → This led to over and/or under dosing of chemical solutions, which subsequently affects the water treatment efficiency.
- Personnel lack basic knowledge on hydraulic calculations.
- Absence of operation and maintenance manuals

The challenges that have been outlined with regards to chemical dosing systems in small and/rural water treatment plants give sufficient rationale for the need to develop appropriate systems. Hence, the development of an appropriate chemical dosing system presented in the next chapter.

3 Development and evaluation of the chemical dosing system

3.1 Introduction

Before developing the chemical dosing system, a number of requirements had to be established against which to measure the results. The following were the design requirements that were taken into consideration when developing the chemical dosing system:

a) The dosing was to be achieved by gravity.

b) The system should be able to provide desired constant dosing rates for 24 hours per day

c) The constant dosing rate should be independent of the solution level.

d) The system should be able to be calibrated (e.g. Using graphs, charts and/or tables) to ensure easy setting and adjustments of dosing rates.

e) The system should have a means of manually mixing the chemical solution.

f) The system should be constructed of non-corrosive materials.

Based on the above design requirements, a chemical dosing system that utilises a constant head orifice and gravity was developed. Hence it is called '**constant head gravity chemical dosing system.**

- **Section 3.2** presents the details of the design, materials and construction of the chemical dosing system
- **Section 3.3** presents the evaluation of the chemical dosing system developed.

After the evaluation of the chemical dosing system developed, some guidelines for design, operation, maintenance and maintenance were developed and separately presented in chapter 4.

3.2 Design, materials, fabrication and construction details

3.2.1 Main components

The main components of the chemical dosing system developed are:

(1) **A constant-level inlet system,** which maintains a constant level of the chemical solution in the chemical solution tank.

(2) A **chemical solution tank,** which is supplied with a lid that has provisions to hold a hand-mixer, constant-level inlet system and dosing tube.

(3) A **constant-head orifice** and **dosing tube system** to provide desired dosing rates and deliver the solution to the dosing point on the water treatment plant.

(4) A **hand-mixer and mixer blades** to be able to manually mix the solution in the chemical solution tank. The mixer blades were provided with a special housing to prevent the entanglement of dosing tubes with the mixer blades.

The chemical dosing system was fabricated by LABSCHEME – ALLCHEM, a local company specialised in laboratory fittings and plastic fabrication. Its contact details are:

- o PO BOX 170, Elsie's River 7480, R.S.A), Tel no: + 27 21 593 9736; Fax no. +27 21 593 9735
- o Contact person: Dirk Loubser, Cell no. 082 905 1264, email: dirk@labschemeallchem.co.za

Figure 3.1 shows the complete and developed chemical dosing system. The design details of its components are described separately in the following sections. Drawings are given in Appendix A .

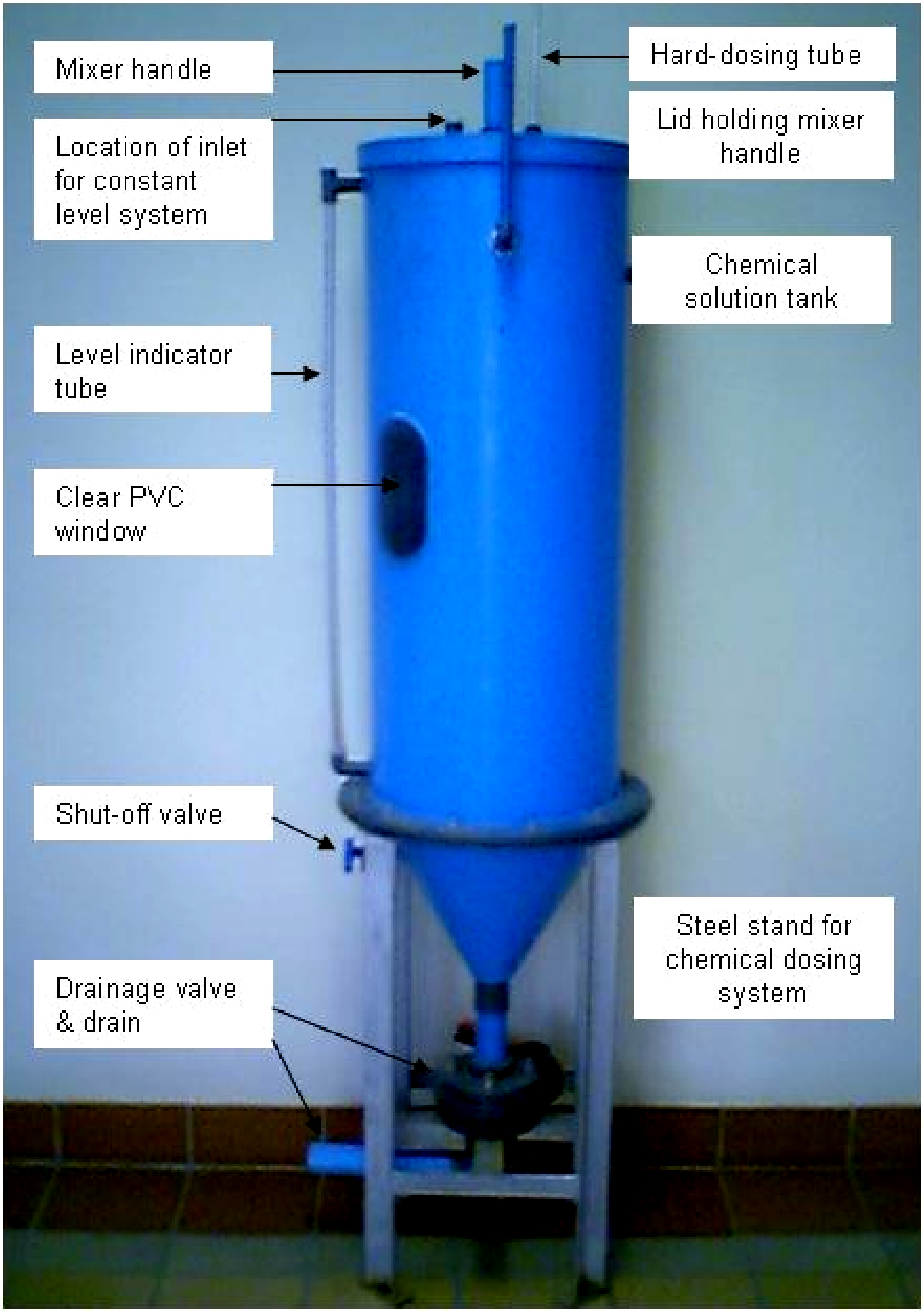

Figure 3-1: Picture of the chemical dosing system developed and fabricated

3.2.2 Constant-level inlet system

One of the operation requirements of the chemical dosing system is to maintain the solution level in the chemical dosing tank as constant as possible. Initially, a conventional float-valve was considered, but this was rejected after sustainability considerations since it usually has moving parts that wear and tear.

A mechanism, called '**constant-level inlet system'**, to replace a float-valve and achieve constant level requirement was development (see Figure 3.2).

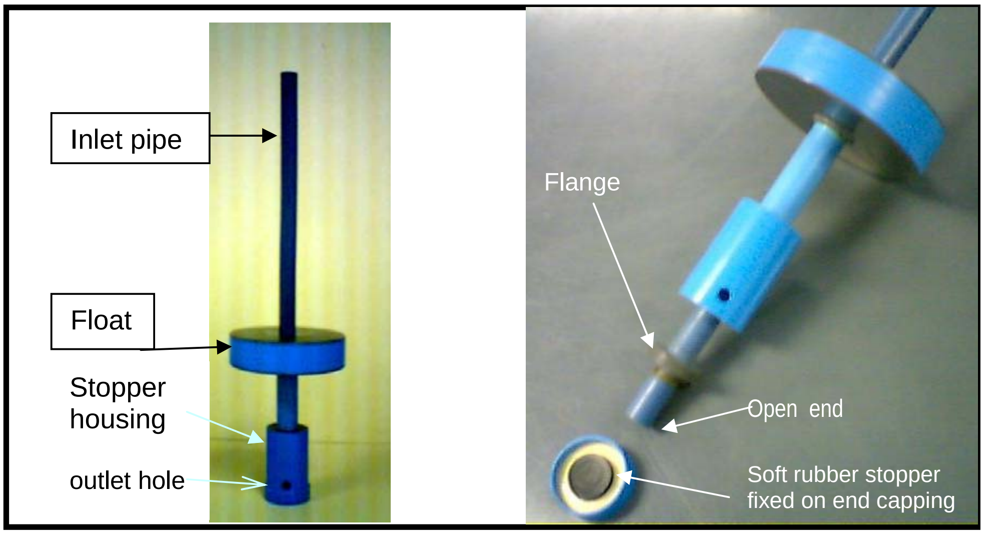

Figure 3-2: Pictures showing components of the constant level inlet system

With reference to Figure 3.2, the following are the descriptions of the constant-level inlet float system:

- The float, connecting pipe, stopper housing and end capping (with a rubber stopper) are fabricated in one piece.
- The inlet pipe and flange are fabricated in one piece.
  - The inlet pipe is allowed to move up and down through the float, connecting pipe and stopper housing, but the flange keeps a portion of the inlet pipe within the stopper housing.
- When the system is assembled, the end capping, with a soft rubber stopper, is firmly fixed to the stopper housing.
- The inlet pipe, with the float attached to it, is fixed at a desired position with respect to the lid of the chemical solution tank.

During the operation of the gravity chemical dosing system, the inflow rate into the chemical dosing tank should always be slightly larger than the actual dosing rate. Once this is achieved, the operation of the constant level float system is described as follows:

- The chemical solution flows from a stock chemical solution tank into the inlet pipe by gravity. Then it flows into the chemical dosing tank through an outlet hole made on the stopper housing (see Figure 3.2).

- When the tank is empty, the solution flows freely while the float system (float, stopper housing and connecting pipe) is held to the inlet pipe by the flange in the stopper housing.
- When the level of the chemical solution reaches the float and continues to rise, the float system moves upwards as well, guided by the fixed inlet pipe.
- The upward movement of the float system eventually brings the open end of the inlet pipe in contact with the rubber stopper, which blocks the inflow of the chemical solution.
- When the inflow is stopped, the gravity chemical dosing system continues to dose and as soon as the solution level in the tank drops, the float system moves downwards.
- The downward movement of the float system allows the rubber stopper to lose full contact with the open end of the inlet pipe and the chemical solution starts to flow in again.

3.2.3 Chemical solution tank, lid, mixer and stand

The chemical solution tank, lid (or cover) and hand mixer were made of uPVC material. The stand for the chemical solution tank was made of steel which was protected from corrosion by a triple layer of a non-corrosive paint.

The design drawings for the chemical solution tank, lid, mixer and stand are given in Appendix A. Reference is also made to Figure 3.3 which shows the top of the lid for the chemical dosing tank.

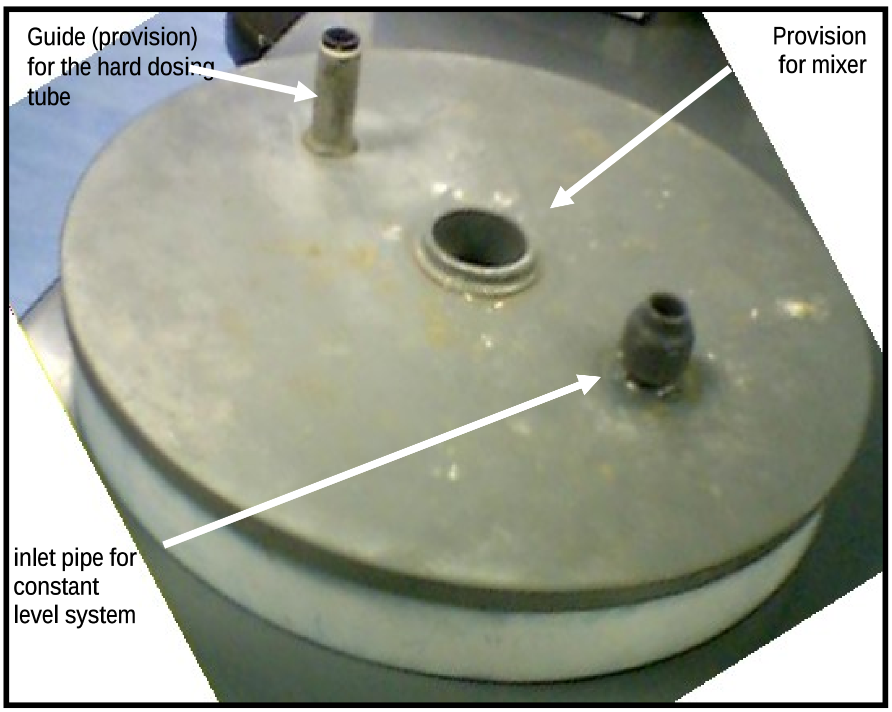

Figure 3-3: Picture of lid showing necessary provisions

For the pilot chemical dosing system developed, the chemical solution tank has an effective capacity of about 70 litres when dosing at a minimum rate of about 6 *l*/h.

3.2.4 Orifice constant-head float and dosing tubes

Figure 3.4 shows the details of the **orifice constant-head float and dosing tubes system**. This system is the most important component of the chemical dosing system.

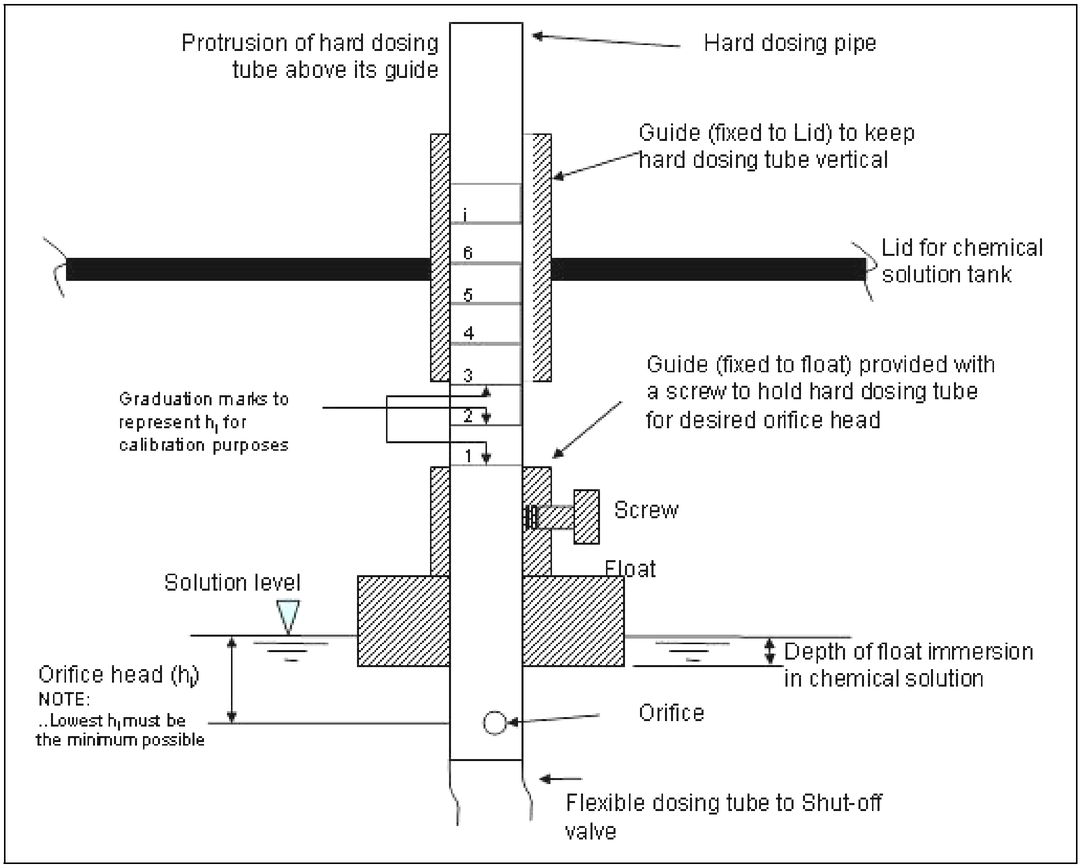

Figure 3-4: Details of orifice constant-head float and dosing tubes

The descriptions of the individual components are as follows:

(1) **Hard dosing tube:** this tube was made of a clear hard PVC pipe. It's outside diameter was 12.70 mm and with a wall thickness (t) of 1.5 mm).The investigated 2 and 5 mm diameter orifices were drilled on this tube, both at about 10 cm from the end which connects with the flexible dosing tube

(2) **Flexible dosing tube:** This tube was made of flexible silicone tubing and it linked the hard dosing tube with a shut-off valve.

(3) **Float:** The casing of the **cylindrical float** (14 cm diameter, 5 cm high) was made of uPVC and it was filled with polystyrene form. It was provided with an extension to be able to clamp the hard dosing tube to the float when setting/fixing the **orifice-head** (See Figure 3.4 - height between centre of orifice and solution level). Once the orifice-head was set, it remained constant within a large variation of the solution level, hence providing a constant dosing rate.

(4) **Shut-off valve:** This valve (see Figure 3.1) was used to stop chemical dosing when necessary. A flexible tube is also connected to the shut-off valve to deliver the chemical solution to the dosing point.

(5) The **screw** used to fix/clamp the position of the hard dosing tube was made of stainless steel.

3.3 Evaluation of the chemical dosing system developed

3.3.1 Specific objectives

The following were the objectives for the evaluation of the chemical dosing system:

(1) To determine whether it can provide nearly constant dosing rates against the variation of the solution level and bending of the flexible dosing tube.

- The extent of the bending of the flexible dosing tube was also found to be affected by the solution level and the position of the float relative to the outlet point.

(2) To determine a range of flow (dosing) rates that is possible in relation to its design and operation.

(3) To study its reliability in terms of the reproductivity of the dosing rates, i.e., can it reproduce or repeat its performance?

The chemical dosing system's dosing rates were compared with the theoretical calculations of flow rates through an orifice.

3.3.2 Methodology

Tap water was used during the laboratory studies to represent the chemical solution. In the pilot application of the chemical dosing system on a water treatment plant, the actual chemical (ALUM) solution was used.

For each of the objectives in 3.3.1, the methodology used is summarised as follows:

Specific objective No 1:

This investigation was done by calculating dosing rates for a fixed orifice-head (see Figure 3.4) under the following conditions:

– After filling the solution tank to the maximum allowable level, no inflow was allowed and as the chemical dosing system was in operational the solution/water level was allowed to drop/decrease.

– The position of the float (which holds the orifice and dosing tubes) with respect to the outlet point (location of the shut-off valve) was also noted as it influences the extent of bending of the flexible dosing tube, which in-turn has an influence on dosing rates.

– Dosing rates were calculated at selected time intervals and results presented graphically. The determination of the dosing rate was done manually by collecting a fixed volume in a graduated measuring cylinder and noting the time taken.

Specific objective No 2:

It is important that the range of flow rates possible for a given chemical dosing system are known. This helps in determining the appropriate dosing rates. Any desired dosing rate is dependent on the combination of the following factors:

– Size (diameter) of the orifice
– Orifice – head (see Figure 3.4),
– The solution level in the solution tank

Two orifice diameters (2 and 5 mm) were drilled at one end of the hard dosing tube. After filling the chemical solution tank, the flow rates were then investigated for each diameter and for a chosen value of the orifice–head. During these investigations, the solution level in the solution tank was allowed to drop without refilling. In this way, it was then possible to associate the flow rates with the solution level and position of float mechanism.

Specific objective No 3:

The investigation of whether the chemical dosing system can repeat its performance was achieved by repeating the flow (dosing) rate measurements and then statistically comparing the deviations.

3.3.3 Analysis of dosing rates

During the analysis of dosing rates, it was important that the practical dosing rates were compared to theoretical rates so that it would be possible to estimate expected dosing rates to be achieved from the chemical dosing system developed. Hence it was necessary to analyse theoretical dosing rates (flows) through an orifice. This analysis is presented in the following paragraph after which analysis results and discussions of dosing rates of chemical dosing system developed are presented. The presentation is done separately for Phase 1 and Phase 2 of the investigations.

Theoretical flows or dosing rates through an orifice:

The orifice size that was extensively investigated had a diameter of 2 mm. A 5 mm diameter orifice was also briefly studied. Both orifices were classified as either type (a) or type (b) in Figure 2.5 and their theoretical flows at orifice-head of 3 cm were calculated using equation 4 in Section 2.2.5 (see Table 3.1 for the results) .

Table 3-1: Theoretical flow rates through an orifice at orifice-head (h) of 3 cm

Orifice diameter (mm)	Dosing rate or flow (l/h)	
	Orifice Type (See Fig 2.5)	
	Type (a); k=0.62	Type (b); k=0.82
2	5.38	7.12
5	38.84	44.49

In order to classify the investigated orifices, the flow rates in Table 3.1 were compared to actual dosing rates of the chemical dosing system developed. This comparison was also important in order to know also where theory fell away from practice.

Phase 1: Development and preliminary analysis of chemical dosing system

Phase one of the project was a developmental phase. It was the phase in which the chemical dosing system was developed and only basic analysis was conducted. It was from the results of this phase that factors that influence the dosing rates were identified and further analysed in Phase 2 of the project. The results of phase 2 are presented separately.

Flow rates at various orifices heads were calculated using volumetric measurement and results are summarised in Appendix C. Analysis of the individual sets of data are hereby presented.

(a) **Analysis of 1st data set:** Appendix C Table C (i)

The first set of flow rates were determined using tap water and the results are presented in Appendix C Table C (i). For each orifice -head, five (5) measurements were taken and the results were plotted graphically as shown in Figures 3.5. Each rectangular box in Figure 3.5 contains all the five (5) values of the flow (dosing) rates that were measured at each orifice-head.

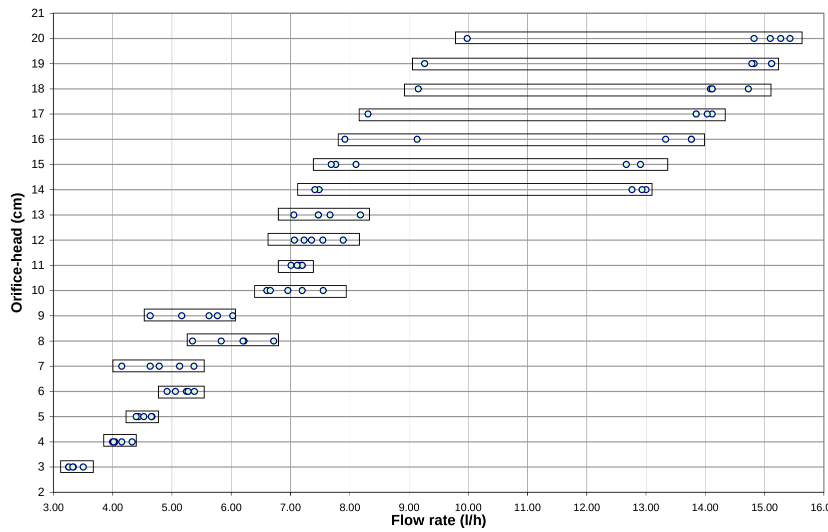

Figure 3-5: Actual dosing rates for a 2 mm diameter orifice

Each orifice-head was further plotted against the average of its five (5) flow rates together with the theoretical/expected flow rates in the same graph (See Figure 3.6). The expected flow rates were calculated using equation 4 and an average K value of 0.69.

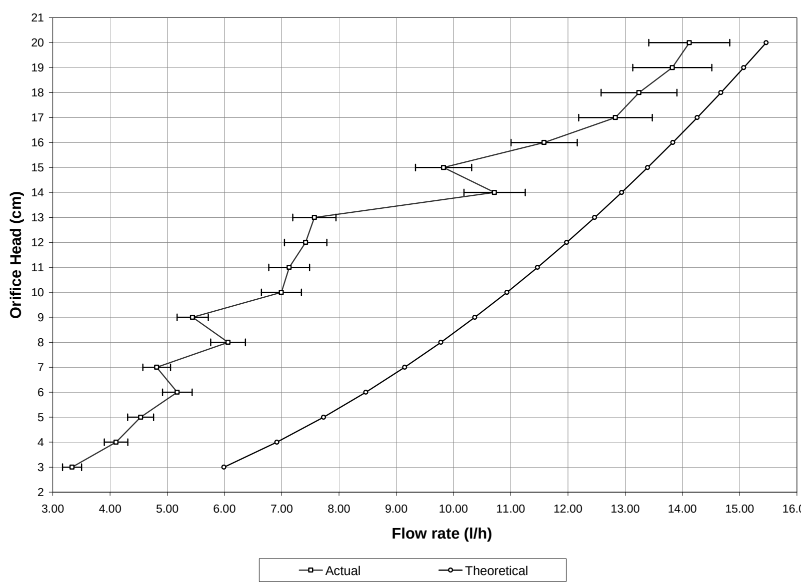

Figure 3-6: Comparison of actual average and theoretical flow rates - 2 mm diameter orifice

Observations, discussions and further analysis of the results in Figures 3.5 and 3.6

(1) Overall, the flow rate through an orifice exhibits a non-linear increase with an increase of an orifice-head. This is mathematically expected as shown by the theoretical plot in Figure 3.6. However, the average actual flow rate did not increase when an orifice-head was increased from 6 cm to 7 cm, 8 cm to 9 cm, and 14 cm to 15 cm (Figure 3.6).

- The decrease in the flow rates even if an orifice-head is increased to a desired value can only be attributed to the fact that the actual or operating orifice-head becomes less than the set/desired value during the operation of the chemical dosing system.
- The reduced orifice-head can be due to the insufficient immersion of the float as a result of the inability of the hard dosing tube to freely move downwards as the water level dropped.
- The restricted movement of the hard dosing tube could be attributed to its friction with its guide pipe (see Figures 3.3 and 3.4). It was observed that the hard dosing tube was almost tight fitting into its guide and that the guide material was of higher friction.

Hence prior to further evaluation of the chemical dosing system, it was recommended that the guide for the hard dosing tube be lined with a lower friction material and that its internal diameter be slightly increased to permit free movements of the hard dosing tube.

(2) Ideally, actual flow rates in the five measurements done for each orifice-head (Figure 3.5) are expected to be very close to each other in value. However, the values differed from each other in each data set and the standard deviation (variation) increased as the orifice-head increased (see Figure 3.5). As a result of these variations, it was difficult to establish trends in the data. Hence, it was necessary to eliminate **<u>outliers</u>** and return consistent values for further analysis.

In any data set, **outliers** are values that are seen to be generally and statistically far from other values (see Table 3.2 for an example).

Table 3-2: Example of the statistical analysis for the determination of outliers for dosing rates at orifice-head 3 cm

Average dosing rate and standard deviation including all values			Average dosing rate and standard deviation excluding the outlier value	
Dosing rate (l/h)	**% Difference with Average**		**Dosing rate (l/h)**	**% Difference with Average**
3.34	0.0		3.34	-1.2
3.26	2.4		3.26	1.1
3.26	2.3		3.26	1.1
3.33	0.3		3.33	-1.0
3.50	-5.0		Outlier	-
❖ Average dosing rate = 3.34 l/h ❖ Standard deviation = 0.100			❖ Average dosing rate = 3.30 l/h ❖ Standard deviation = 0.043	
❖ The dosing rate of 3.504 l/h was considered as an outlier since its % difference from the average was much higher than others. After eliminating this value, the standard deviation reduced by 50% and the % differences of the remaining dosing rates with the average where generally close to each other				

Actual average dosing rates at orifice-heads of 7, 9 and 15 cm were also considered outliers as it is scientifically impossible for flow rates to decrease when the head causing flow is increased.

After eliminating all outliers, the remaining data was plotted as shown in Figures 3.7 and 3.8.

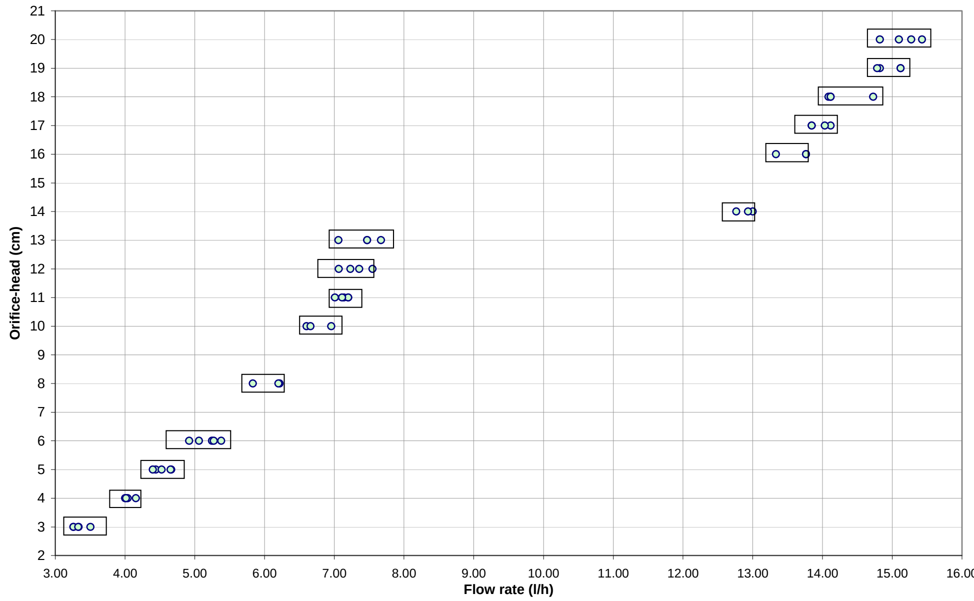

Figure 3-7: Actual average dosing rates after excluding outliers - 2 mm diameter orifice

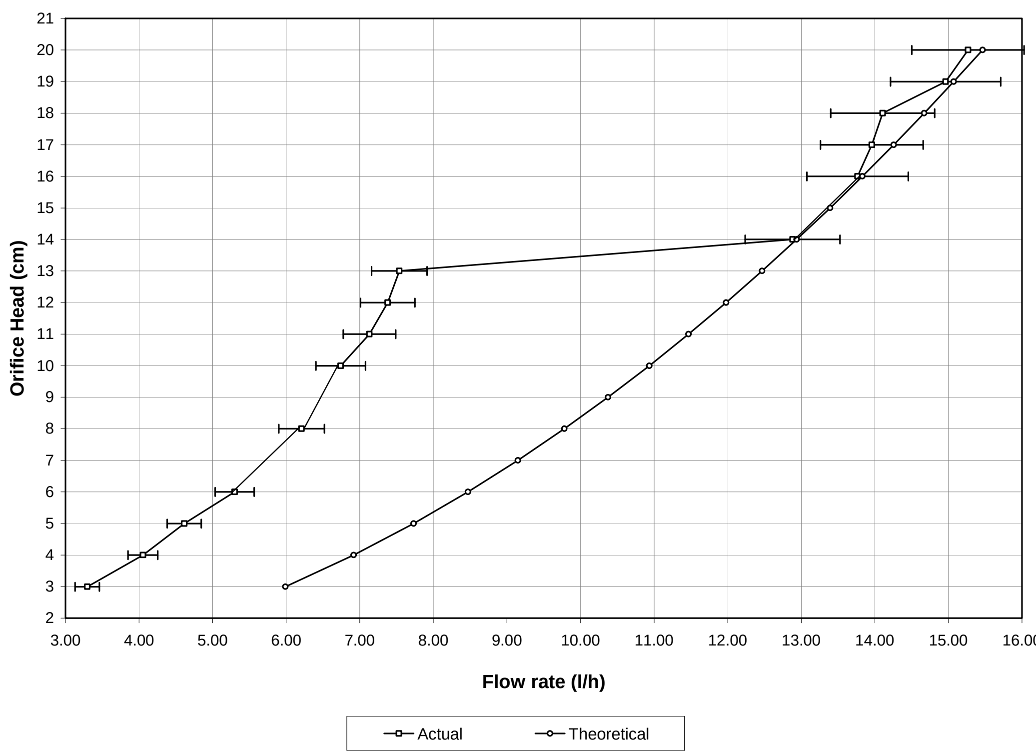

Figure 3-8: Comparison of actual average (without outliers) and theoretical dosing rates - 2 mm diameter orifice

(3) After eliminating outliers, it became evident in Figure 3.7 that something had gone wrong between an orifice-head of 13 cm and 14 cm. A comparison of the actual and theoretical flow rates in Figure 3.8 suggest that from an orifice-head of 14 cm onwards, actual flow rates became close to the theoretical expectations/values.

> This sudden change, almost doubling of values, of flow rates was traced to a wrong setting of the orifice-head.
>
> Hence great care is recommended when setting orifice-heads!

(b) **Analysis of 2nd data set:** Appendix C Table C (ii)

The 2nd data set was collected after taking the following measures to minimise friction so that the hard dosing tube can freely move downwards while the solution level was dropping during the operation of the chemical dosing system:

(1) The guide diameter was increased by a millimetre.

(2) The inside of the guide for the hard dosing tube was lined with a lower friction pipe made of high density poly-ethylene (HDPE) to ensure much smoother movements of the hard dosing tube. It was also ensured that this pipe's alignment was truly vertical to the lid's top surface.

The above modifications were expected to improve the accuracy and stability of the flow rates. The flow rates results after these modifications were made are presented in Appendix C, Table C (ii) and summarised in Figure 3.9 and 3.10. In this trial, an ALUM solution of 5% strength, as applied in practice, was used instead of tap water to get envisaged performance of the chemical dosing system when dosing actual chemical solutions.

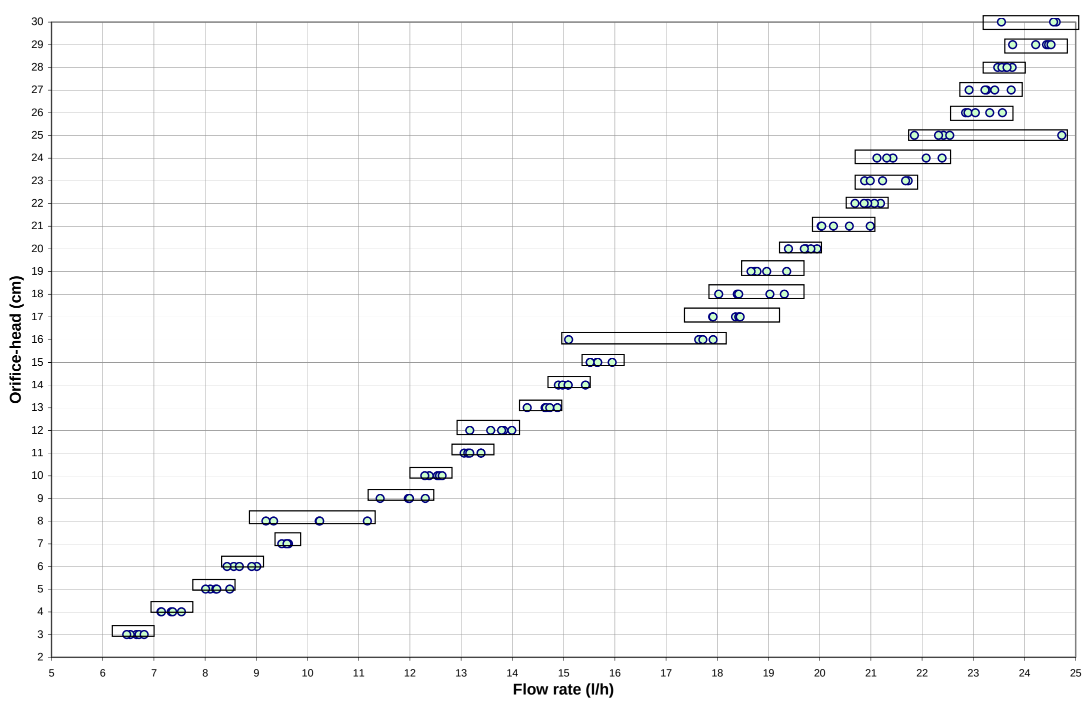

Figure 3-9: Actual flow rates after improving guide for hard dosing tube- 2 mm dia Orifice

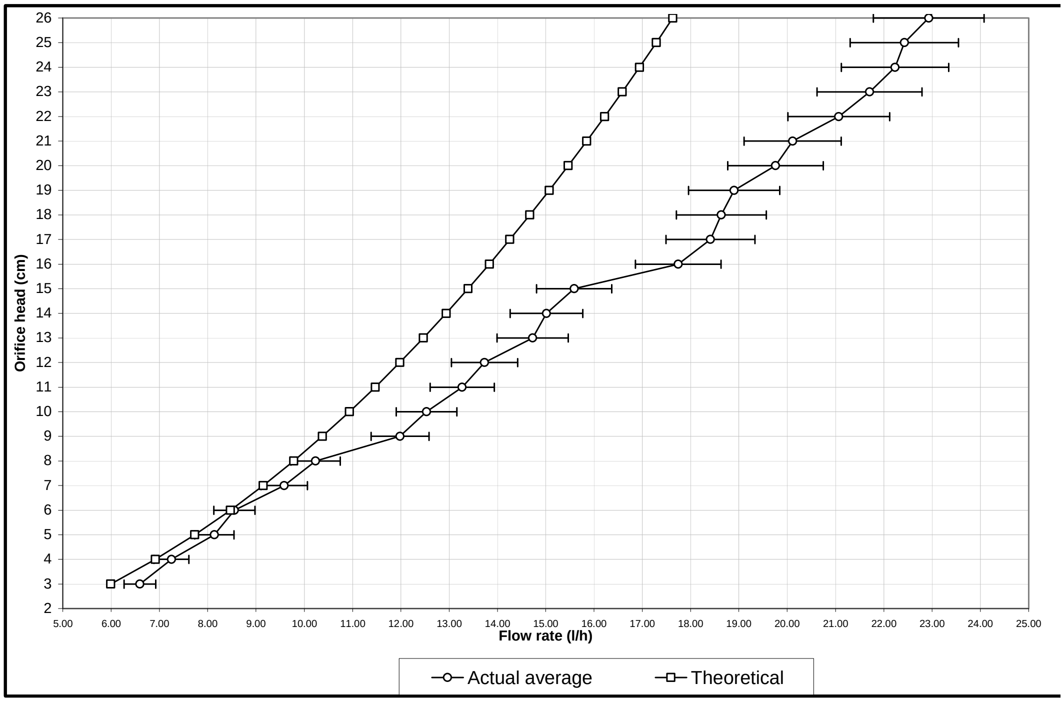

Figure 3-10: Comparison of actual average and theoretical flow rates after improving guide - 2 mm diameter orifice

Results in Figure 3.9 and 10 were more consistent and flow rates increased steadily with an increase of an orifice-head. Visual observations of the movements of the hard dosing tube revealed that the use of the HDPE material greatly enhanced the smooth movement of the tube in its guiding pipe.

Figure 10 shows that the actual/measured values are now greater than theoretical values. However, the difference between the measured and theoretical flow rates increased with an increase in the flow rates.

The 5% error bars in Figures the 3.6, 3.8 and 3.10 indicate that the variation of flows in each group of values increases as the orifice-head increased. It can therefore be deducted that at lower flows the error margin is smaller.

Hence, care must be taken when setting higher dosing rates as a small error in setting the orifice-head can result in a big error in dosing rate.

(c) **Analysis of 3rd data set:** Appendix C Table C (iii)

Since the chemical dosing system is expected to be used to dose much higher rates for full-scale plants, a **5-mm orifice** was also evaluated and the corresponding flow rates were measured (see Appendix C Table C (iii) and sample plot in Figures 11 and 12).

- The actual flow rates were more stable and closer to and lower than theoretical values.
- However, in each set of the five (5) measurements for each orifice-head, the variation of the actual flow rates was lower and less outliers. Nevertheless, the variation in each set increased as the orifice-head increased: this was the same trend observed in the 1st and 2nd Data sets.
- The higher dosing/low rates were closer to each other and could practically be easier to work with.

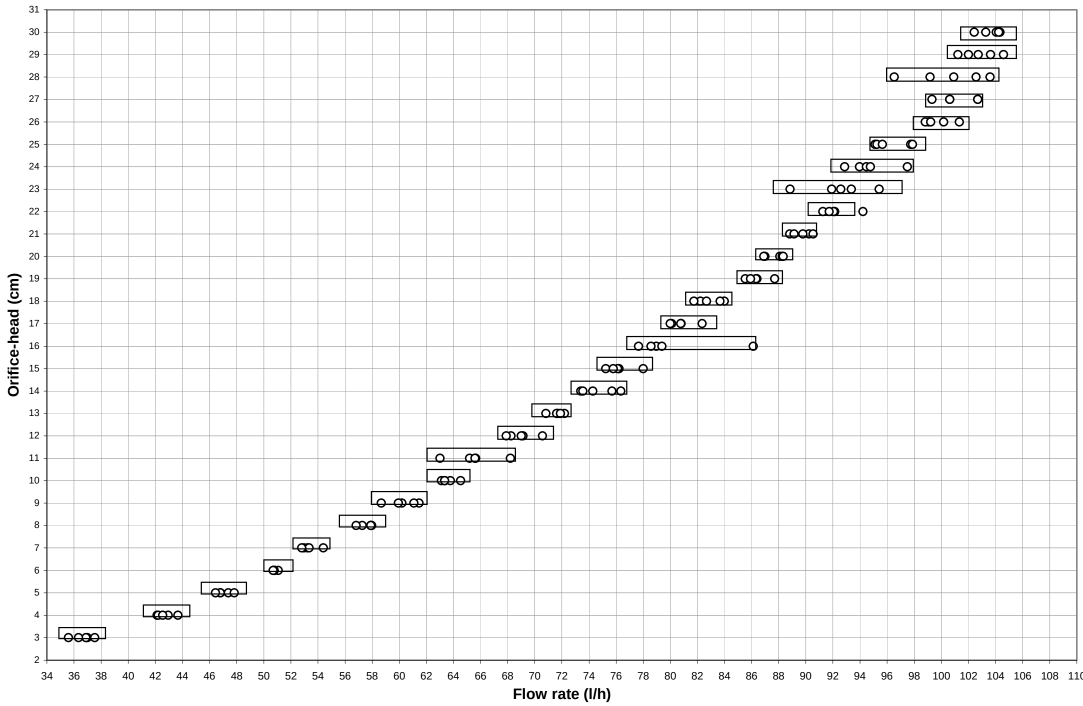

Figure 3-11: Actual ALUM solution (5%) flow rates for a 5 mm diameter orifice

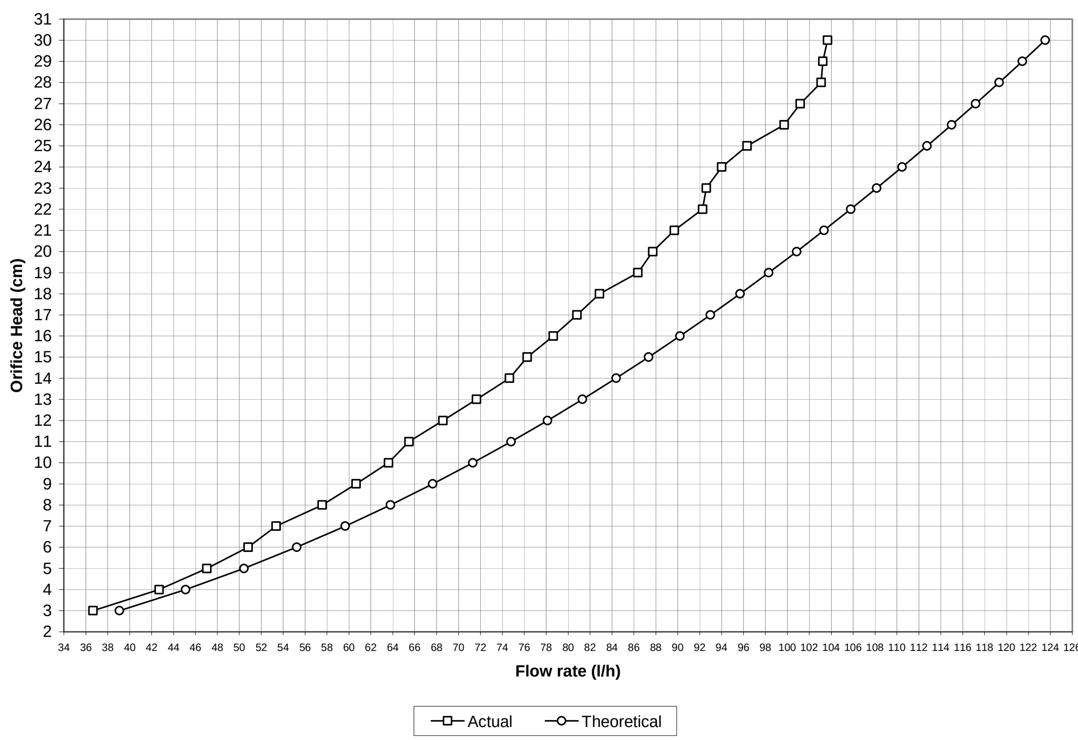

Figure 3-12: Actual average and theoretical ALUM solution (5%) flow rates without outliers

(d) **Analysis of the 4th data set collected during the application of the chemical dosing system on a pilot water treatment plant: Appendix C Tables C (iv)**

The chemical dosing was then tested on the pilot water treatment plant. The results of the analysis of the 3rd data set (Part (c) and Figure 9 and 10 were used to set the dosing rate of the chemical dosing system when tested on the pilot water treatment plant. However, due to the smaller capacity of the plant, it was only possible to study smaller dosing rates. It was decided to study dosing rates that can be produced by an orifice-head of 3 cm and 1. 5 cm.

- The results for the orifice-head of 3 cm were collected between 16th September and 15th October 2001 and those for the orifice-head of 1.5 cm were collected between 19th and 28th October 2001(See Appendix C Table C (iv)). The statistical analysis of these results is presented in Table 3.3.

Table 3-3: Statistical analysis of dosing rates after testing chemical dosing system on a pilot water plant

	Orifice-head of 3 cm	**Orifice-head of 1.5 cm**
Number of samples	42	15
Minimum dosing rate (l/h)	5.64	3.00
Maximum dosing rate (l/h)	6.12	3.16
Average dosing rate (l/h)	5.94	3.24
Standard deviation	0.11	0.08

The statistical analysis of the results in Table 3.3 indicates that the chemical dosing systems can consistently dose a desired rate within acceptable deviations.

- The lower standard deviation at an orifice-head of 1.5 cm confirmed the deduction made prior to testing the chemical dosing system on the plant that the variation of low dosing rates is less than those at higher values.

Hence it should generally be recommended that lowest possible dosing rates are applied in practice

SUMMARY FINDINGS AND DEDUCTIONS IN PHASE 1:

(1) the chemical dosing system is able to consistently produce desired dosing rates

(2) the reproductivity of the same dosing rates is more accurate at lower orifice-heads

(3) it is possible for the chemical dosing system to be designed to dose any desired rates by changing the size of an orifice and its head, although a minimum orifice-head of 3 cm is recommended (which corresponds to about 6 l/h).

(4) An indication of a minimum solution level in the chemical dosing system, after which the rates are out of range, is recommended

(5) The position of the float has an influence on the dosing rates as it affects the flow hydraulics in the flexible tube

A detailed analysis of the effects of the solution level and the position of the float was analysed in phase 2, presented in the following section.

Phase two: Detailed analysis of chemical dosing systems

Phase 2 entailed a much more detailed analysis of the chemical dosing system's dosing rates to investigate the effects of the solution level and the float position with respect to the outlet point.

The position of the float relative to the outlet point (see Figure 3.13) in combination with the solution level affects the extent to which the flexible dosing tube bends (see Figure 3.14). This in turn influences the flow characteristics in the tube and dosing rates.

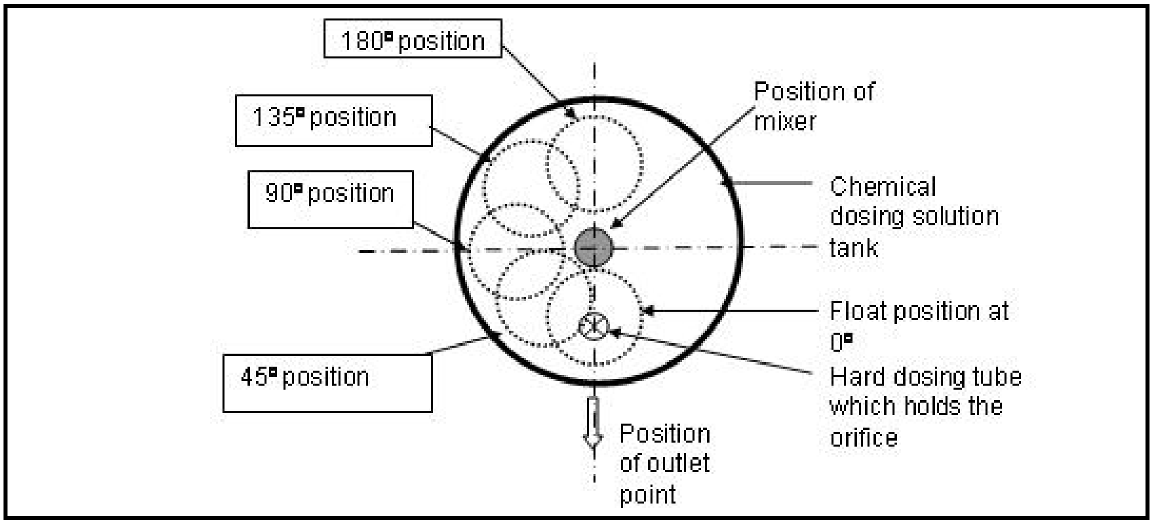

Figure 3-13: Plan view of CDS showing float position in O^{o} measured from the outlet point

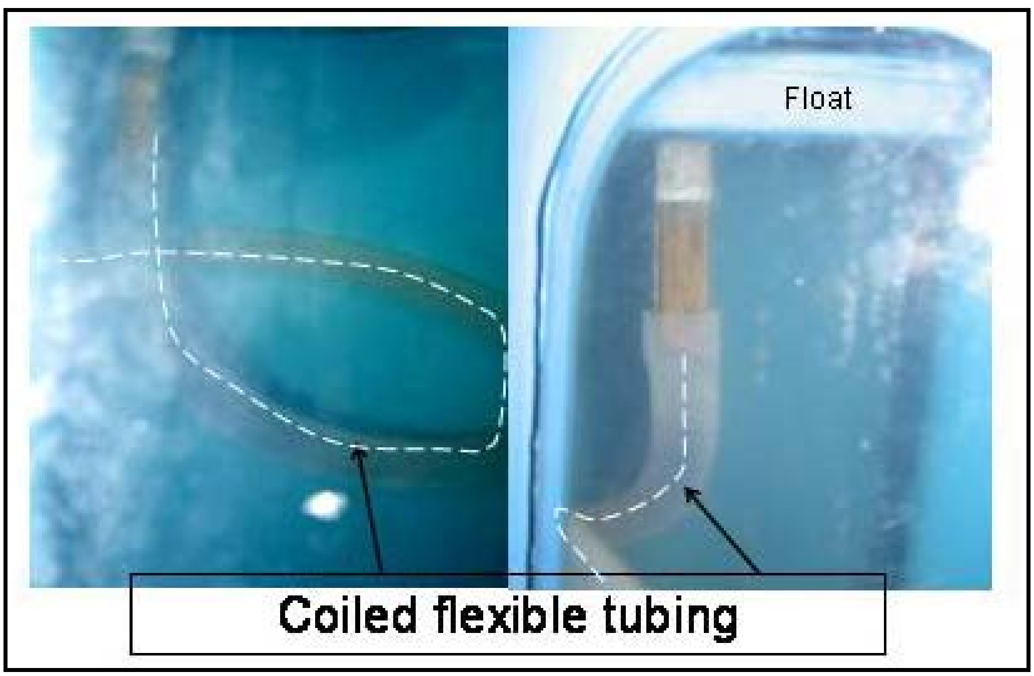

Figure 3-14: Photographs of the flexible tubing bending taken through the transparent window

During the analysis of the effect of the float position:

- The orifice-head was kept constant for each position investigated and three runs of dosing rate measurements were done.
- The dosing rates were calculated using volumetric analysis.
- A stop watch was used to record time at which each dosing rate was recorded after having selected an appropriate interval
- The dosing rate was plotted against time elapsed from the start of each run.

Phase 2 also included a field testing of the chemical dosing system on a pilot water treatment plant located in the field in addition to the one based in laboratory during Phase 1.

Sample analysis results of the effect of float position and solution level on dosing rates

The results presented are for an orifice-head of 3 cm. This is the practically recommended minimum orifice-head taking into consideration the immersion of the float as determined in Phase 1 of the study. This head was chosen because it was the one that was able to provide the dosing rate applicable on the pilot water treatment plant.

Figure 3.15 shows some of the photographs taken during the flow rate measurements.

Figure 3-15: Photographs of volumetric analysis (L) & level measurement (R)

- The flow rates were measured at intervals averaging 30 minutes.
- The time (T) from the starting of the volumetric analysis in each run was also recorded:
    - Each run began with the water level at maximum level and ended when the flow rates started to drop sharply.
    - 3 runs were conducted for each position to study the re-productivity of the flow rates.
- The drop in solution level was also monitored in order to assess the effect of friction on the movement of the hard dosing tube.
- The solution level with respect to the flange of the solution tank was also recorded in order to analyse the capacity aspects of the chemical dosing system.

Table 3.4 presents flow rate results for the various positions, plotted in Figures 3.16 to 3.20.

Table 3-4: Flow rates at different float positions for an orifice-head of 3 cm on a 2 mm diameter orifice

(Bold and underlined values were considered outliers and were not plotted in Figures 16 to 20)

Time (min)	0 º Position			45 º Position			90 º Position			135 º Position			180 º Position		
	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3	Run 1	Run 2	Run 3
0	7.42	7.19	7.13	7.50	7.75	7.28	7.64	7.72	7.62	7.63	7.62	7.69	7.62	7.47	7.36
30	7.08	6.80	6.37	7.39	7.52	6.75	7.52	7.17	7.50	7.59	7.64	7.59	7.64	7.64	7.25
60	6.69	6.76	6.50	7.13	7.15	6.70	7.49	7.75	7.51	7.74	7.39	7.61	7.10	7.17	7.12
90	6.56	6.56	6.38	6.37	6.90	6.45	7.37	7.51	7.36	7.62	7.39	7.61	7.63	7.04	7.16
120	6.20	6.16	6.43	6.50	6.63	6.09	7.15	7.41	7.25	7.50	7.48	7.40	7.50	7.24	7.40
150	5.20	6.16	6.41	6.38	6.64	5.60	6.68	6.82	7.01	7.51	7.39	7.34	7.48	7.27	7.28
180	5.30	5.73	5.68	6.43	6.57	5.25	6.65	7.17	7.00	7.39	7.28	7.36	7.38	7.19	7.29
210	5.34	5.72	6.53	6.41	6.43	5.77	6.67	7.15	6.99	7.36	7.41	7.38	7.37	7.17	7.17
240	5.67	5.83	6.32	5.68	6.67	5.96	7.04	7.08	7.12	7.63	7.39	7.53	7.28	7.16	7.40
270	5.73	5.52	6.77	6.32	6.77	5.83	6.86	7.16	7.14	7.50	7.47	7.37	7.40	7.15	7.27
300	5.77	6.44	5.72	6.77	6.71	5.97	7.03	7.28	7.22	7.63	7.59	7.36	7.59	7.27	7.28
330	6.72	6.55	5.50	**5.72**	**4.51**	**6.21**	6.79	7.18	7.16	7.50	7.37	7.26	7.50	7.27	7.28
360	**5.36**	**3.94**	**4.17**	**5.50**	**2.74**	**3.34**	6.90	7.27	7.55	7.44	7.40	7.39	7.38	7.17	7.33
390	**1.58**	**3.22**	**3.69**	**4.17**	**2.27**	**2.16**	**6.20**	**4.83**	**5.52**	7.61	7.65	7.27	7.14	7.14	7.41
420	**0.29**	**2.38**	**2.27**	**3.69**	**1.67**	**1.45**	**4.42**	**5.12**	**5.31**	7.50	7.47	7.16	7.52	7.04	7.39
450	-	-	-							**4.29**	**4.40**	**4.84**	**4.17**	**4.17**	**7.39**
480										**2.85**	**2.74**	**3.05**	**3.57**	**3.34**	**6.08**

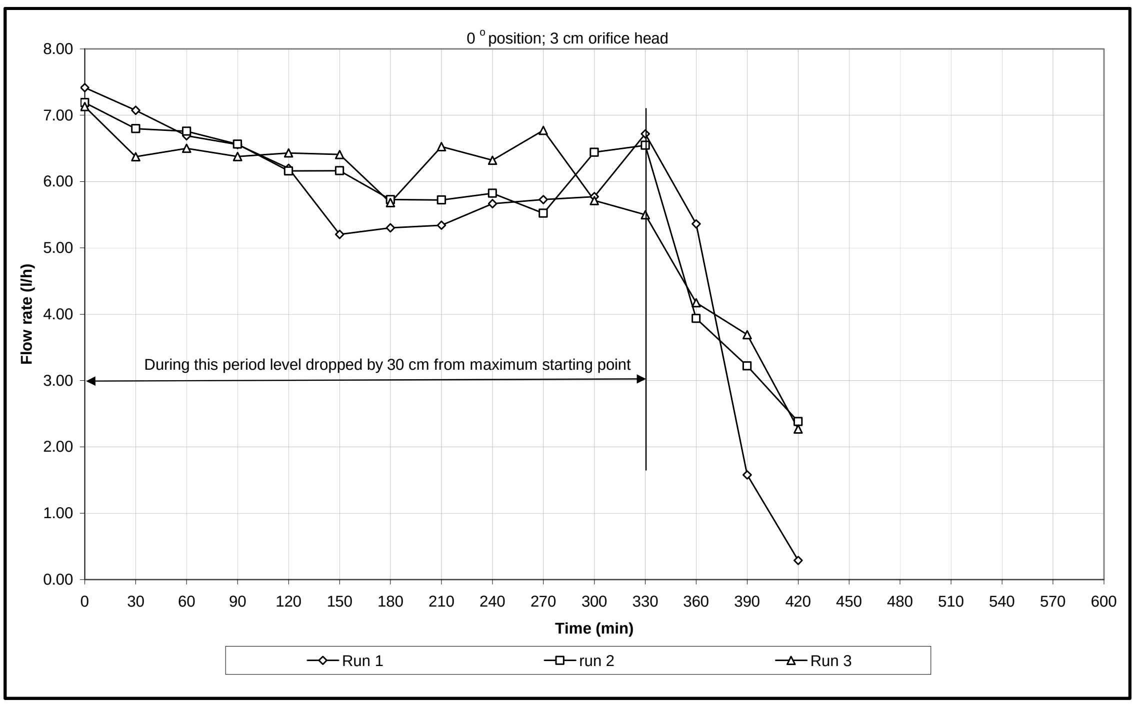

Figure 3-16: Flow rates when the float is positioned in line with the outlet point

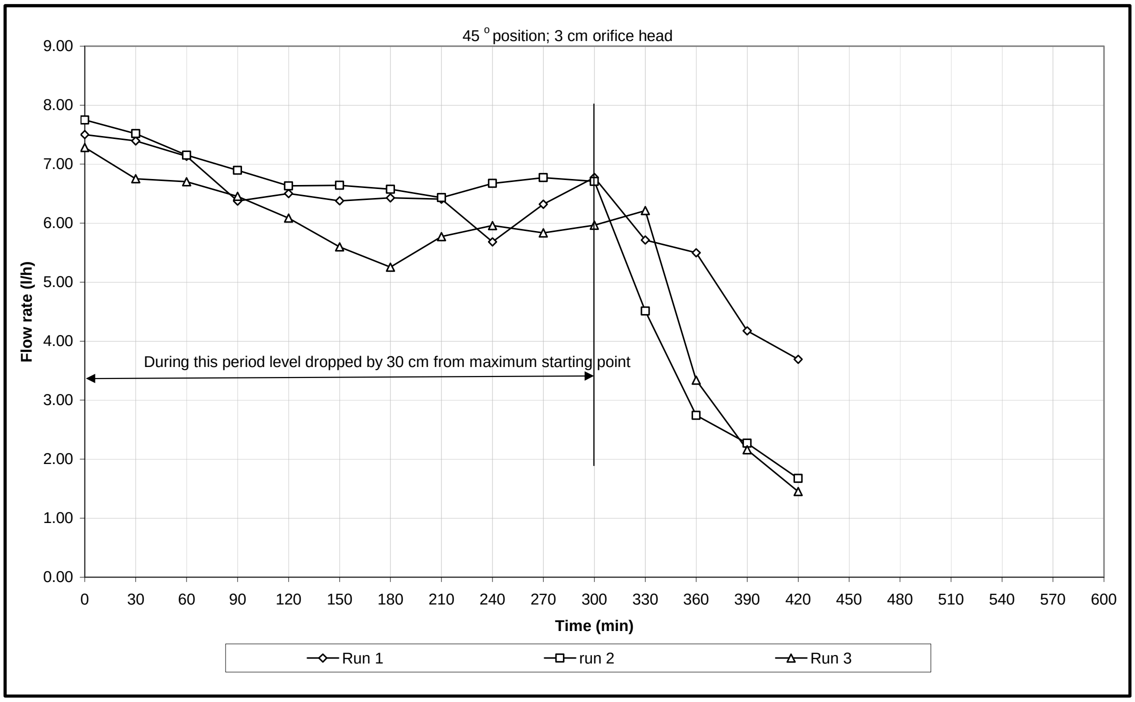

Figure 3-17: Flow rates when the float is positioned at 45° from the outlet point

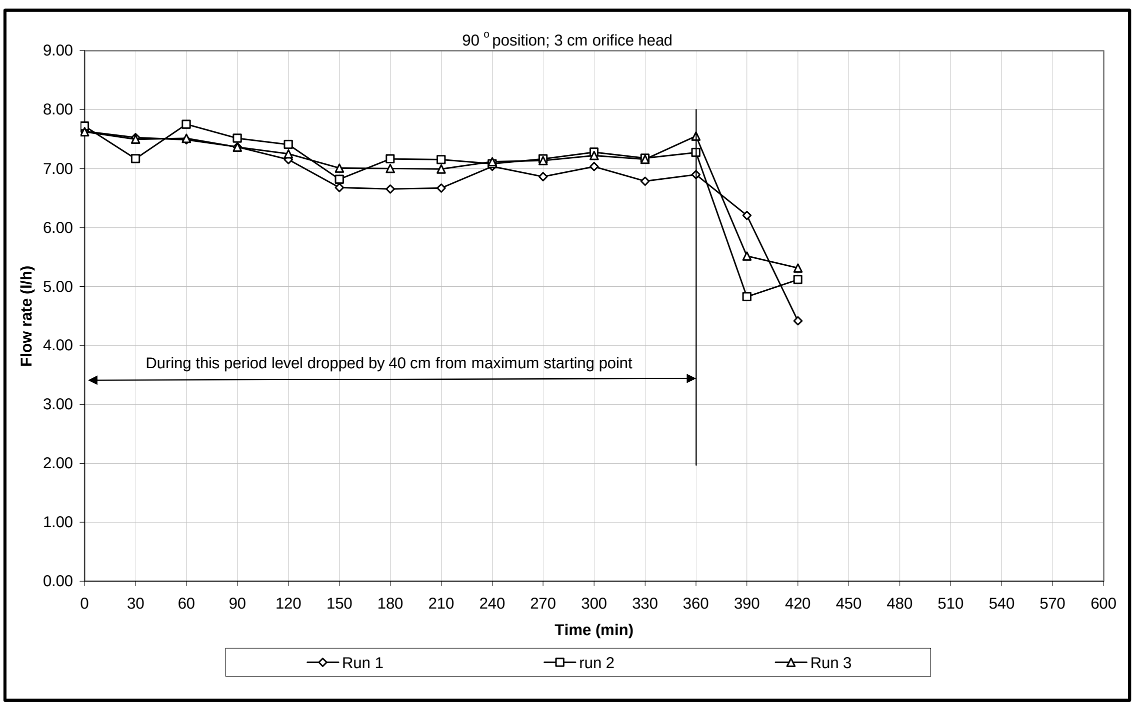

Figure 3-18: Flow rates when the float is positioned at 90° from the outlet point

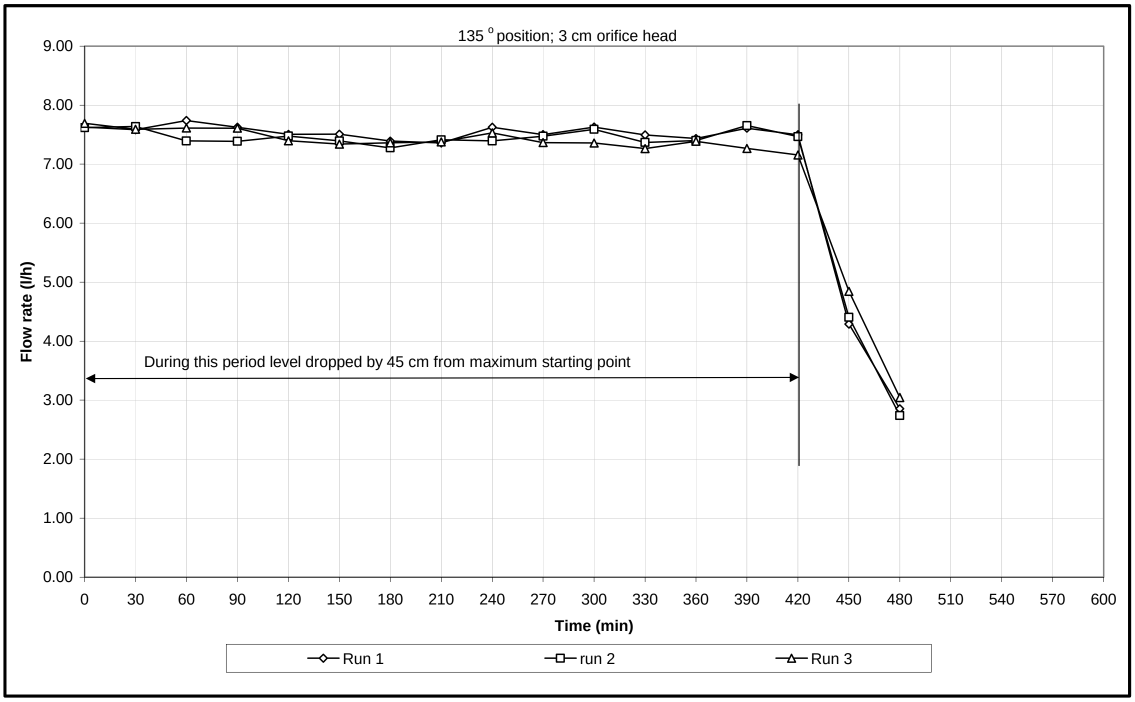

Figure 3-19: Flow rates when the float is positioned at 135° from the outlet point

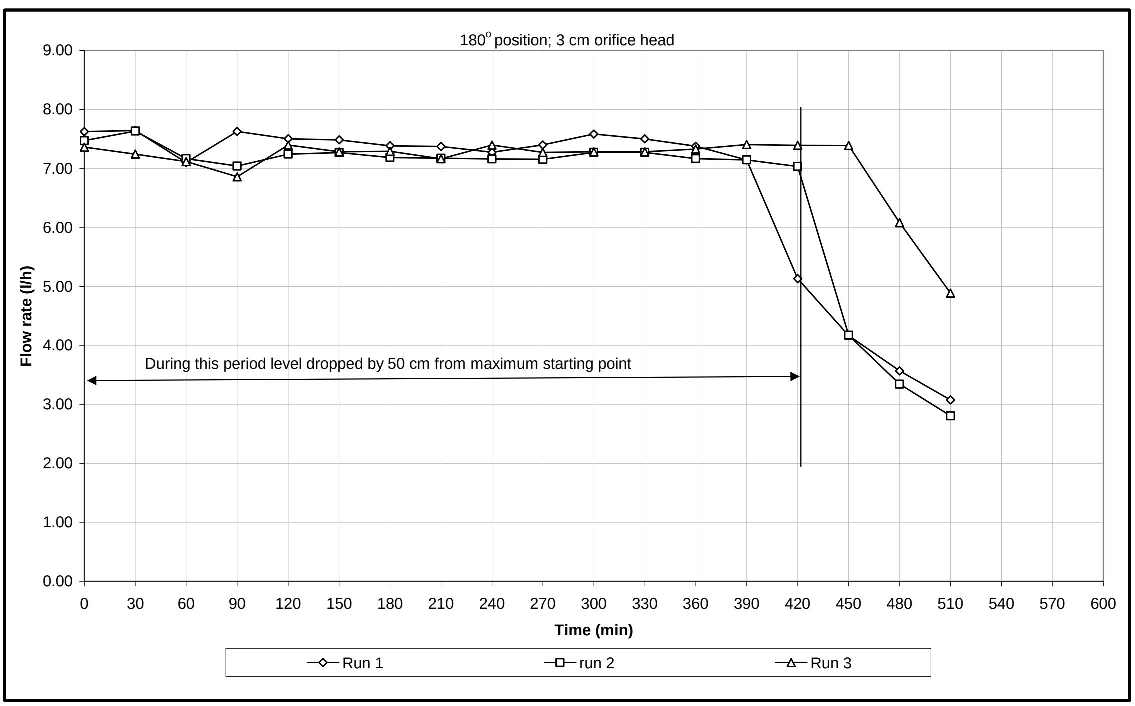

Figure 3-20: Flow rates when the float is positioned at 180° from the outlet point

From Figures 3.16 – 20, the following deductions were made:

- Flow rates become more stable as the float is moved away from the outlet point. This was measured by how close each of the data points were in each of run on a given float position.
- The time (retention) through which the flow rates remain within acceptable values increases as the float is moved away from the outlet point.
- Visual observations indicated that the bending of the flexible tubing was less as the float is moved away from the outlet position.
- The sudden drop in flow rate after a certain period of time in each of the positions investigated can be explained as follows:
    - At the point where the flow rates start to decrease dramatically, the level of the chemical solution too low such that the bending and buoyancy effects cause a portion of the flexible dosing tube to rise and to be within the orifice-head depth, hence submerging the orifice. This effectively reduces the effective orifice-head. Figure 3.21 illustrates this explanation.

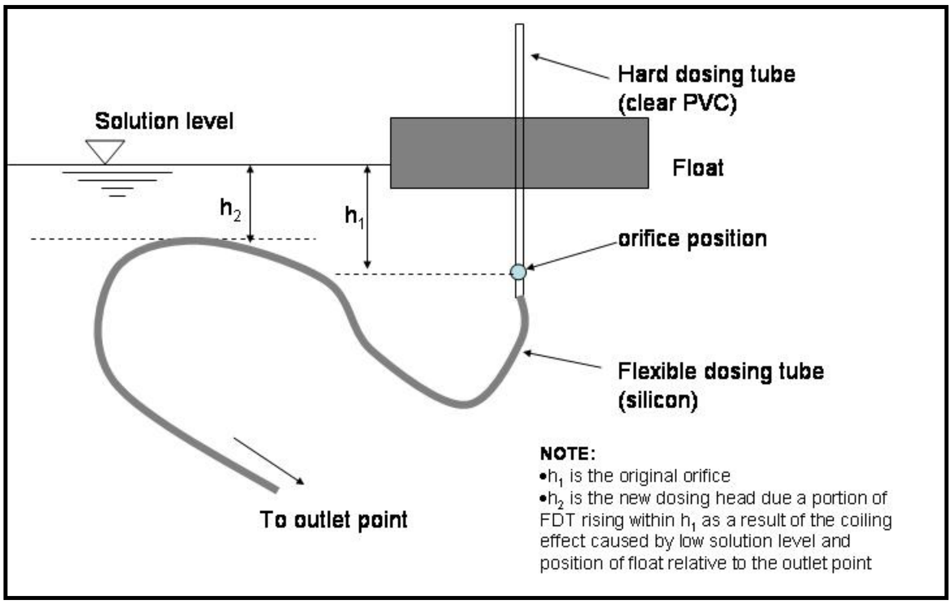

Figure 3-21: Effect of the solution level on the bending of the flexible dosing tube and hence on an orifice-head

Table 3.5 presents a summary of the statistical analysis of the results in Table 3.4, excluding outliers.

Table 3-5: statistical analysis of dosing rates at various float positions

Parameter	**0^{o} position :** retention time = 330 min	**45^{o} position :** retention time = 300 min	**90^{o} position :** retention time = 360 min	**135^{o} position** : retention time = 420 min	**180^{o} position** : retention time = 420 min
Minimum (l/h)	5.20	5.25	6.65	7.16	7.04
Average (l/h)	6.25	6.55	7.20	7.48	7.32
Maximum (l/h)	7.42	7.75	7.75	7.74	7.64
STDV	**0.576**	**0.589**	**0.292**	**0.132**	**0.164**

Discussions and conclusions from the statistical analysis results (Ref to Table 3.5)

- The standard deviation values confirm the stability and consistency of flow rates as the float is moved away from the outlet point, with the greatest consistency achieved at positions 135^o and 180^o.
- The retention time for acceptable dosing rates also increased as the float was moved away from the outlet point.
- The average flow rates increases as the float is moved away from the outlet point
- The low and more variable flow rates at float positions 0 and 45^o would be attributed to the bending effects on the flexible dosing tube as the solution level decreases.
- The increase in the flow rates as the float is moved away from position 0^o (closest position to outlet point) is due reduced bending of the flexible tubing in which case flow resistance is reduced.

3.3.4 Construction materials

There were no leakages observed throughout the investigation period and the materials did not show any corrosion from the chemical solutions and water. This indicates the good performance of the materials used. The flow through the orifice was sufficient to ensure a self-cleansing effect; as such there was no fouling of the orifice. The mixer did not give any difficulties although the handle can be improved to give a good grip.

3.3.5 Operation and maintenance aspects

Key operation aspects established include the following:

- it is important to mark the maximum and minimum solution level whenever the chemical dosing is in operation,
- using the minimum and maximum solution levels, the detention time must be determined to ensure timely preparation of the solution,
- the measurement of dosing rates must be done regularly using the volumetric methods,
- the positioning of the float must be as away as possible from the outlet point to ensure consistent and constant dosing rates.
    - An appropriate means of fixing the float at the desired position is recommended; such as a wire pin or clamp
- Calibration of the chemical dosing system must be done on site and must be related to the plant capacity and its variations.

One of the key maintenance aspects of the chemical dosing system relates to ensuring that the orifice is not fouled. Although the period of investigation did not give an indication of fouling of the orifice, it is likely that suspended particles can foul the orifice. Therefore, it is important to regularly inspect the status of the orifice.

4 Guidelines for design, fabrication and practical applications

4.1 General

The guidelines given in this chapter are meant to guide someone through the design, fabrication and practical applications of the gravity chemical dosing system that has been developed.

To ensure successful use of the guidelines, it is important for the user to have good knowledge of hydraulics, especially flow measurement.

It is recommended that the construction/fabrication must be done by specialised fabricators.

The guidelines are presented separately for the following aspects:

- Design and fabrication or construction guidelines
- Guidelines for practical installation and application
- Operation and monitoring guidelines
- Maintenance guidelines

The guidelines for the above aspects were drawn from the development of the chemical dosing system and evaluation thereof as presented in Chapter 3.

4.2 Guidelines for design, fabrication and construction

Chapter 3.2 forms part of the design, fabrication and construction guidelines. A summary of the specific design guidelines is as follows:

(1) **Guidelines for the solution tank, lid and mixer are:**

(a) The solution tank must be equipped with a level indicator, with marks to indicate the minimum and maximum levels.

(b) The bottom of the solution tank must be conical to ensure effective drainage when necessary.

(c) The outflow valve/point must be located in the conical bottom of the solution tank.

(d) The lid for the solution tank must fit tightly and must be lockable at a desired position. Use of a pin and hole is recommended.

(e) A hand-mixer must be provided for stirring the solution if necessary and must be such that it does not damage the dosing tubes.

(f) The lid must have provisions to allow fitting of other parts such as hand mixer, inflow and guide for the hard dosing tube.

(g) To control the supply of the chemical solution to the chemical dosing system's solution tank, a constant level mechanism must be incorporated. This can be achieved in either of the following two ways:

- Using a conventional float valve on the inlet line to the solution tank
- Using the inlet's constant level float mechanism as described in Section 3.2.2

The use of the Inlet's constant level float mechanism is recommended since it does require maintenance or spare parts compared to a float valve

(2) **Guidelines for the float mechanism are:**

(a) The shape of the float must be circular and sized to ensure stability when floating; a minimum diameter of 15 cm is recommended.

(b) The float must be equipped with a guide (located at the centre of the float) which must be equipped with a screw. This guide and screw are used to attach the hard dosing tube to the float and hence set a desired orifice-head (see Section 3.2.4).

(c) The float must be made of any floating materials which are resistant from any attack by the chemical solution to be dosed.

> It is recommended that the depth of immersion of the float into the solution shall be at least half of its thickness of the float.

(3) **Guidelines for the dosing tubes and orifice are as follows:**

(a) The hard dosing tube must be made of hard clear PVC pipe with a minimum internal diameter of 5 mm. Its length must be such that when the solution level is at its minimum, the tube sufficiently protrudes above its guide located on the lid. Figure 4.1 illustrates the estimation of the length of the dosing tubes.

(b) One orifice must be drilled at about 2 cm from one end of the hard dosing tube which connects with the flexible tube. A minimum diameter of 2 mm is recommended to prevent fouling.

(c) The flexible dosing tube must be made of flexible clear silicon tubing with a recommended internal diameter of at least 5 mm. it should be able to connect tightly with the hard dosing tube.

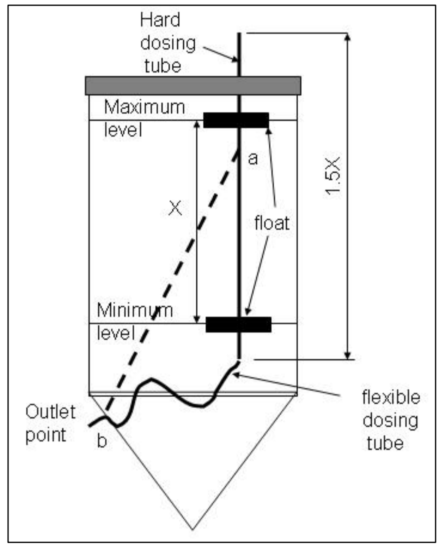

Figure 4-1: Estimation of the length of the hard and flexible dosing tubes

Its length must be equivalent to the distance between the point at which the hard and flexible tubes are connected when the float is at maximum position and furthest from the outlet point (point 'a' in Figure 4.1) and the outlet point (point 'b' in Figure 4.1).

> The furthest position of the float from the outlet is the position at which stable and consistent dosing rates are achieved (see Figures 3.13 and 3.20)

(d) The guide for the hard-dosing tube must be made of a material that is characterised by low friction (such as Teflon or HDPE) to ensure its smooth downwards and upwards movements when the solution level is varying.

(4) **Guidelines for the fabrication and construction:**

(a) Skilled personnel in PVC fabrications must be engaged for the fabrication and construction of the chemical dosing system

(b) Detailed drawings of the design must be produced and discussed with the fabricator

(c) Local materials must be used for all components

(d) Once all components are fabricated, the construction can be made in house or in-situ

4.3 Guidelines for practical installation and application

4.3.1 General

The guidelines for practical installation and application are about some practical aspects that must be considered when planning to install and apply the developed chemical dosing system. These include the following:

- ❖ Advantages and disadvantages in comparison to conventional dosing pumps
- ❖ Types and properties of solutions that can be dosed
- ❖ Guidelines for the capacity and location
- ❖ Calculation of dosing rates and Calibration aspects

The above aspects are discussed separately in the following sections.

4.3.2 Advantages and disadvantages

The advantages and disadvantages (see Table 4.1) of the developed chemical dosing system were drawn in comparison to conventional dosing pumps and also considering the fact that the technology is intended for small and/or rural communities.

Table 4-1: Advantages and disadvantages of the developed chemical dosing system

Advantages		**Disadvantages**
(1) Can easily be designed and installed and will not need skilled labour to operate and maintain.		(1) Cannot automatically increase or decrease the dosing rate in proportion to flow of water to be treated and quality variations
(2) Does not need stocking of spare parts since it is not made of components that wear and tear, and would require regular replacement.		(2) Adjustment of the dosing rate may not be done as quickly and accurately
(3) Can be fabricated and installed from local materials resistant to water and chemical corrosion		(3) Dosing rates may not be as accurate and consistent as pump systems
(4) Does not need electricity since it operates by gravity		(4) The variation of dosing rates is higher at large dosing rates, but system is more accurate at low dosing rates.

The fact that the developed chemical dosing system is earmarked for small and/or rural community application, the disadvantages presented in Table 4.1 will not limit its application.

- ❖ Disadvantage (1): in practice dosing rates are usually kept constant for chosen raw water and quality variations. Flow variations of $\pm$ 10% of the desired operating flow would be acceptable and not require changes in dosing rates.

- ❖ Disadvantage (2): Although a calibration graph can be utilised to give an indication of the dosing rate, once the adjustment has been done, it is still necessary to check the dosing rate using volumetric analysis .

4.3.3 Types and properties of chemicals to be dosed

The chemical dosing system developed is only for dosing chemicals that are added in solution form. The chemicals that are usually supplied in granular form such as Aluminium Sulphates (trade name ALUM), Iron Salts and Sodium Hypochlorite – (trade name HTH) must therefore be prepared in solution form.

Any chemical solution to be dosed must not easily form precipitates that can clog the inlet float or pipe systems, orifice, dosing tube and shut-off valves.

‘Lime suspensions / solutions are not recommended to be dosed by gravity chemical dosing systems that use an orifice

The chemical solution to be dosed must never be corrosive to any of the components that make up the chemical dosing system.

4.3.4 System capacity and location guidelines

It is important that the capacity and location of the chemical dosing system ensures reliability and sustainability. With regards to the system capacity, including the preparation and quantity of chemical solutions, and location, the following are the guidelines:

(1) There must be at **least two (2) chemical solution preparation tanks,** which can independently supply the chemical dosing system.

These tanks must be graduated to show how much chemical must be added for various levels.

Each chemical preparation tank must have at least a retention time of 24 hours within which the dosing rate is expected to be constant.

(2) The **chemical dosing system tank,** which houses the dosing components , must have a retention time of at least 8 hours (necessary to allow for the preparation of the stock chemical solution if it ran out as a result of monitoring lapses) and must be graduated using a level indicator to show allowable minimum and maximum solution levels.

(3) The location of the chemical solution preparation tanks and chemical dosing system itself must allow gravity flow between them and to the dosing point on the plant. (Figure 4.2).

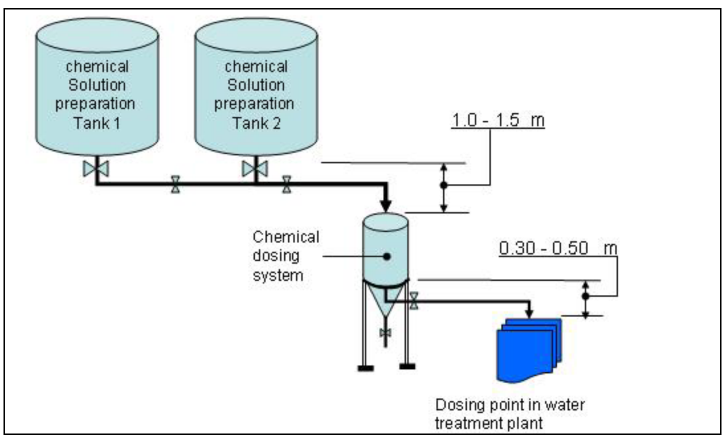

Figure 4-2: Location profile of the chemical dosing system

The supply of water required for the preparation of the chemical solution should be drawn from the clear water wells using either pumping or labour force within the local community.

4.3.5 Guidelines for the calculation of dosing rates

Once the optimum chemical dosage is determined, it is then possible to calculate the expected dosing rate (q), usually expressed in litres per hour (*l*/h), using the **mass-transfer and mass-balance principles.** The following variables must be known in order to calculate 'q':

- Concentration (C_1) of chemical solution, usually expressed in % (1% = 10 000 mg/l), because of being of high concentrations which would require large numbers if mg/l was used.
- Optimum dosage (concentration) (C_2) in the water to be treated expressed in mg/*l*
- Initial concentration (C_o) of the chemical in the water to be treated, expressed in mg/*l*. C_o is usually zero (0).
- Flow rate (Q) of the water to be treated, usually expressed in M*l*/d or m^3/d (1 M*l* = 1000 m^3)

The schematic relationship of the above parameters is shown in Figure 4.3.

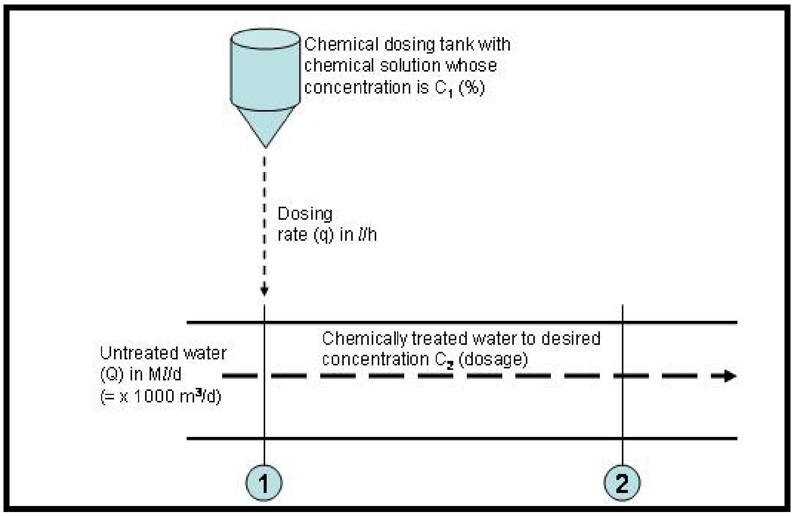

Figure 4-3: Schematic diagram to aid calculations in chemical solution dosing

Assuming that there is complete mixing after adding the chemical solution at Point 1 in Figure 4.3, the following equation would represent the mass-transfer balance at points 1 and 2:

$$Q*C_o + q*C_1 = (Q + q) * C_2$$

Where:

- Q ➔ flow rate (Q) of the water to be treated (m^3/d)
- C_1 ➔ concentration of stock chemical solution (if given as % it must be changed to mg/l).
- C_2 ➔ the dosage in milligrams per litre (mg/*l)*
- C_o ➔ initial concentration of the chemical to be dosed in water being treated (mg/l)

From the above equation, 'q' is calculated by making it the subject of the formula as follows:

$$q = (1000/24) * Q*C_2 / (C_1 - C_2)$$

Where computers facilities are available, a spreadsheet (e.g. using excel) can be developed to speed-up calculations (see Table 4.2 for an example).

Table 4-2: Example of a spreadsheet for the calculation of dosing rates

	A	B	C
1	**Parameter**	**value**	**unit**
2	❖ Q ➔ flow rate (Q) of the water to be treated =	800	m^3/d
3	❖ C_1 ➔ concentration of chemical solution given as 10 (changed to mg/l by multiplying by 10000).	100000	mg/l
4	❖ C_2 ➔ the dosage in milligrams per litre (mg/*l*)	30	mg/l
5	❖ C_o ➔ initial concentration of the chemical to be dosed in water being treated (mg/l)	0	mg/l
6	**$q = (1000/24) * Q*C_2 / (C_1 - C_2) =$**	6.7	l/h
	The formula in cell B6 is (1000/24) * B2*B4 / (B3 - B4)		

4.3.6 Calibration of the chemical dosing system

Before application, the gravity chemical dosing system must be calibrated to ensure that the setting and adjustment of dosing rates is easier and reliable for operators. This must be done by skilled personnel.

The objective of the calibration is to establish and provide a graphical or tabular relationship between the dosing rate and orifice-head (see Figure 3.4 for the definition of orifice-head).

This relationship would then be used to adjust dosing rates by simply adjusting the orifice-head, without the trouble of volumetric analysis

In practice, dosing rates are not adjusted regularly in small water treatment plants. It only becomes necessary to adjust dosing under the following conductions:

(1) When there are prolonged or seasonal changes in water quality.

(2) When changes in daily water flow are in excess of ± 10% .

Therefore, under each of the above conditions, the chemical dosing systems must be able provide the adjusted dosing rate. The new dosing rate can be calculated from a spreadsheet presented in Table 4.2. Historical data on the water quality and water demand can be used to estimate probable changes and anticipated dosing rates.

The chemical dosing system must therefore be designed to accommodate the entire range of dosing rates expected due to water quality and flow changes

The hard dosing tube must be graduated using permanent marks whose positions relative to its guide should represent a specific orifice-head (see Figure 3.4). Each graduation mark on the hard dosing tube must represent a dosing rate 5 -10 % bigger than the lower mark.

The calculation of a dosing rate for each orifice-head (h) should only be done by volumetric analysis and timing. A minimum of 3 measurements must be done for each orifice-head and resulting dosing rates must not vary by more than 1% from the average.

A plot or table of the orifice-head (h) against dosing rate (q) would produce the calibration curve or table for the chemical dosing system.

4.4 Operation and monitoring aspects

The following are guidelines for operation and monitoring:

(1) The chemical solution concentration must be maintained constant as much as possible during operation

(2) The position of the float (that ensures a constant head orifice) must always be at 180^o from the outlet point to minimise the bending of the flexible dosing tube (see Figures 3.4 and 4.1).

(3) The chemical solution level must be checked at least once a day depending on the capacity of the stock solution tanks.

(4) The stock of chemicals available must be equivalent to a month's supply and orders must be placed in good time to avoid running out of chemicals

(5) Visual inspection of the dosing rates must be done at least once a day. If there are any indications of the rate being different, then it must be checked manually using volumetric measurements.

> Use of a graduated cylinder and stop-watch can be used to check accuracy applied dosing rates. A calibration chart for such checks can be developed in which operators can be trained to check the accuracy by collecting specific volumes over specific durations, e.g. if 250 ml is collected in 30 seconds, then the dosing rate is acceptable.

(6) Sludge build up must be observed on a weekly basis in conical bottom of the chemical dosing systems.

(7) The supply of clean water for the preparation of the solution can either be achieved by manual labour or conventional pumping where affordable.

4.5 Maintenance aspects

The following are the maintenance guidelines:

(1) Regular removal of sludge build-up, both in the chemical dosing systems' solution tank and stock solution preparation tank,

> It is recommended that the chemical dosing system be drained once every week

(2) Weekly cleaning of the orifice to remove any fouling due to foreign objects or chemical precipitates.

→ A piece of wire can be attached to the chemical dosing system and be used to remove any fouling materials on the orifice.

(3) Repairing of any leaks as soon as possible.

(4) The flexible and hard dosing tubes must be inspected frequently for any holes or cracks or leaks.

→ This should be done carefully not to damage the dosing tubes when disconnecting the flexible tubing from the hard dosing tube or shut-off valve.

5 Conclusions

From the literature review conducted and innovation, a chemical dosing system which works by gravity using a constant-head orifice system was developed, fabricated and evaluated both under laboratory and field conditions. The chemical dosing system was locally fabricated from locally available construction materials.

The knowledge gathered from literature and the visitations made to various water treatment plants regarding the challenges with chemical dosing, confirmed that the chemical dosing system developed has good potential for full-scale application, both as the only dosing equipment and/or as a standby chemical dosing unit. It can be used to dose ALUM and HTH solutions.

The chemical dosing system developed is comparatively simpler due to the following factors:

- It does not require electrification to operate since it uses gravity;
- It does not employ moving parts susceptible to wear and tear; and
- It does not need skilled labour to operate (dosing rate control and adjustment) and maintain.

These advantages make the system more appropriate in small and rural plants, as an alternative to electronic dosing equipment or a stand-by dosing system where electronic pumps are in use. Plants of capacities up to 5 Ml/d can use the chemical dosing system developed.

6 Recommendations for further studies

The principle of chemical dosing by a constant–head orifice is well documented. What is needed is to develop full-scale designs and applications that satisfy local water treatment plant conditions and document the performance of the dosing systems. In order to learn more about practical challenges, the chemical dosing system need to be applied and studied further on full-scale water treatment plants, either new or existing.

Specific aspects that will have to be dealt with and studied in each fabricated chemical dosing system are as follows:

(1) Determining the range of dosing rates possible,

(2) Development of calibration tables, charts or graphs:

→ calibration must never be based on theoretical calculations of dosing rates,

(3) The performance of the inlet's constant level float systems,

(4) The stability and reproductivity of the dosing rates,

(5) The ability to easily adjust the rates when necessary,

(6) The performance of construction materials,

(7) The fouling of the orifice if possible,

(8) How the dosing rates are influenced by the type of fluid to be dosed and even concentrations.

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Appendices

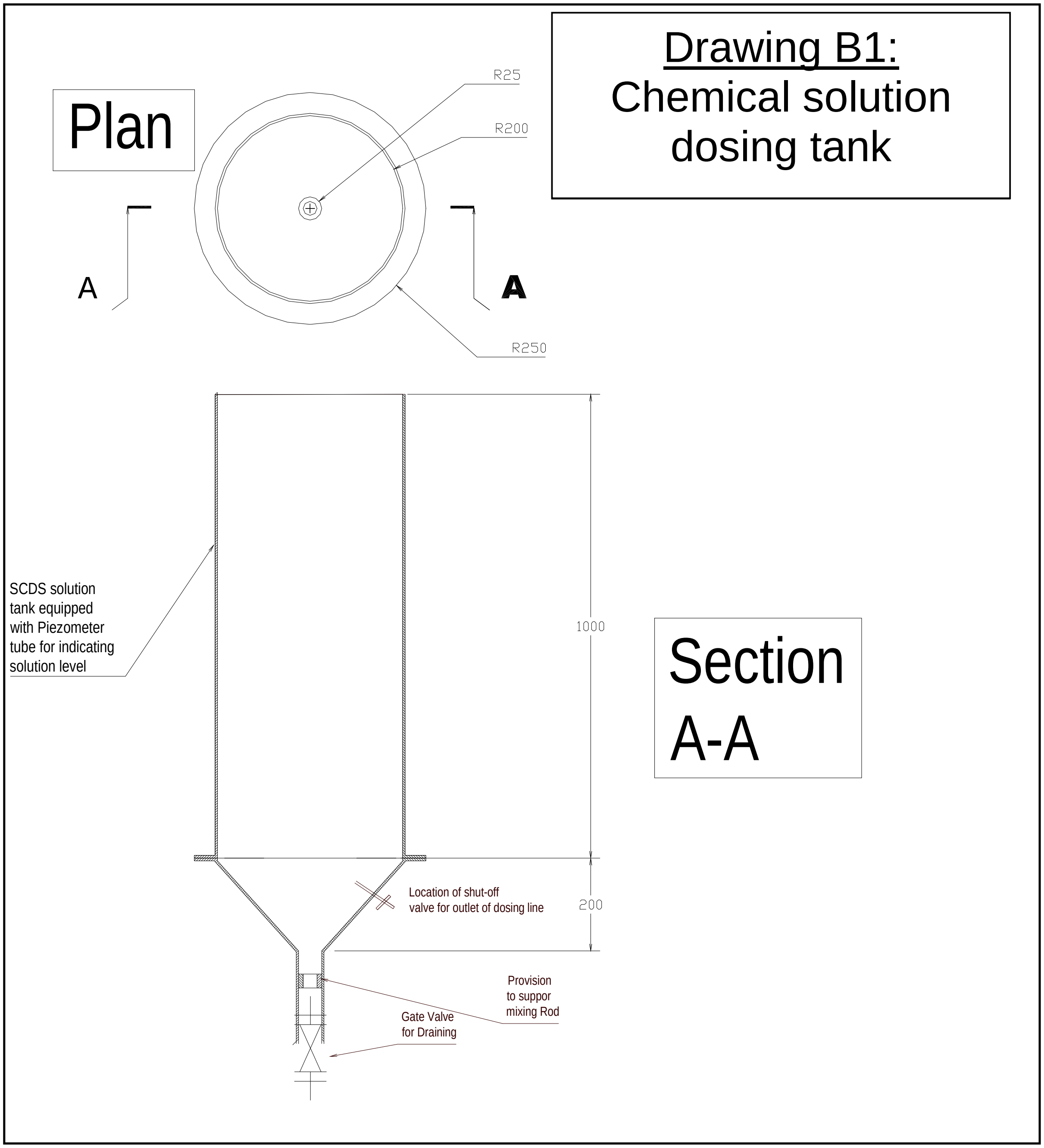
Appendix A: Details of 20 small water treatment plants surveyed by Swartz (2000)

❑ Plant Name ❑ Location ❑ Treatment scheme	❑ Plant Capacity (m³/d) ❑ Raw Water Source; Turbidity (NTU) ❑ Final Water Turbidity (NTU)	Status of Chemical Dosing facilities	Status of Sand Filtration Process
1. Moganya ▪ Northern Province ▪ Hydraulic Coagulation/Flocculation; Up-flow sedimentation; Slow sand filtration; Gas chlorination	▪ 800 (design); 1200 (operation) ▪ River; 3.6 – 13 ▪ 0.3 – 1.2	▪ Electrical disruptions and poor electrical connections ▪ Lime feeder not working and not repaired ▪ lack of spare parts for dosing equipment ▪ Lack of chemicals since chemical suppliers reluctant to deliver due to bad road condition	▪ High filtration rates ▪ Turbidity break through ▪ Rapid clogging, hence frequent cleaning ▪ Process by-passed
2. Tompi Seleka ▪ Northern Province ▪ Hydraulic Coagulation/flocculation; Up-flow sedimentation; Pressure filtration; Liquid chlorination	▪ 220 ▪ Lolamontes Dam next to Oifants River; 10 – 40 ▪ 0.7 – 7.5	▪ No chemical dosing equipment available ▪ Uncontrollable drip dosing used to dose chemical solutions ▪ Overdosing of coagulants	▪ Sand never inspected and probably never replaced
3. Vandermerweskraal ▪ Northern Province ▪ Liquid Chlorination	▪ 100 ▪ Oifants River Sandbed; Low – Value not available ▪ 3.8	▪ Drip dosing used to dose Calcium Hypochlorite (HTH) ▪ There is no control over the dosing rate	▪ Data Not available
4. Hlogotlou ▪ Northern Province ▪ Hydraulic Coagulation / flocculation; Horizontal flow sedimentation; Rapid sand filtration; Gas chlorination	▪ 2500 ▪ Mhlangu Dam; 4.0 – 4.5 ▪ 0.4 – 3.2	▪ Dosing of pre-treatment chemicals not reported ▪ Chlorine gas dosing equipment lack adequate safety measurement in place	▪ Faulty control valves
5. Vergelegen ▪ Northern Province ▪ Hydraulic Coagulation / flocculation; Horizontal flow sedimentation; Rapid sand filtration; Liquid chlorination	▪ 2400 ▪ Lehlagare Matlala Dam; 24 – 233 ▪ 0.3 – 16	▪ Electricity interruptions ▪ Coagulation chemical dosing not reported ▪ Available chlorine gas chlorinators not in use due to insufficient pressure in water supply line to activate gas injection ▪ Lime feeder not in use	▪ Runs intermittently due unbalanced flow problems which cause plant to switch on and off
6. Pit Gouws ▪ Northern Province ▪ Hydraulic (pipe) Coagulation/flocculation; Horizontal flow sedimentation; Rapid sand filtration; Liquid chlorination	▪ 1500 ▪ Piet Gouws Dam; 12 – 540 ▪ 1.8 – 34	▪ Coagulation/flocculation not giving good results ▪ Available chlorine gas chlorinators broken ▪ No Spare parts ▪ Drip dosing used to with control over the dosing rates	▪ Nozzle problems ▪ Depleted filter media
7. Boschkloof ▪ Northern Province ▪ Hydraulic Coagulation / flocculation; horizontal flow sedimentation; Slow sand filtration; Liquid chlorination	▪ not known ▪ Steelpoort River; 4.5 – 4.6 ▪ 0.5 – 1.0	▪ mixing not effective ▪ Dosing methods not reported	▪ Filtration by-passed due to operational problems
8. Bethesda Hospital ▪ Kwa Zulu Natal ▪ Hydraulic (pipe) Coagulation/flocculation; up- flow sedimentation; Pressure filtration; Liquid chlorination	▪ 500 ▪ Mkuze River; 0.3 – 465 ▪ 0.2	▪ Optimisation difficult due to varying raw water quality ▪ Coagulation / flocculation not effective	▪ Data not available
9. Jozini ▪ Kwa Zulu Natal ▪ Hydraulic (pipe) Coagulation/flocculation; Horizontal & up flow sedimentation; Pressure filtration; liquid chlorination	▪ 800 – 1200 ▪ Jozini Dam; 1.3 – 120 ▪ 0.2 – 0.7	▪ Available chlorine cas chlorinators broken ▪ No spare parts ▪ HTH is now used but dosing method is not known	▪ Operational problems

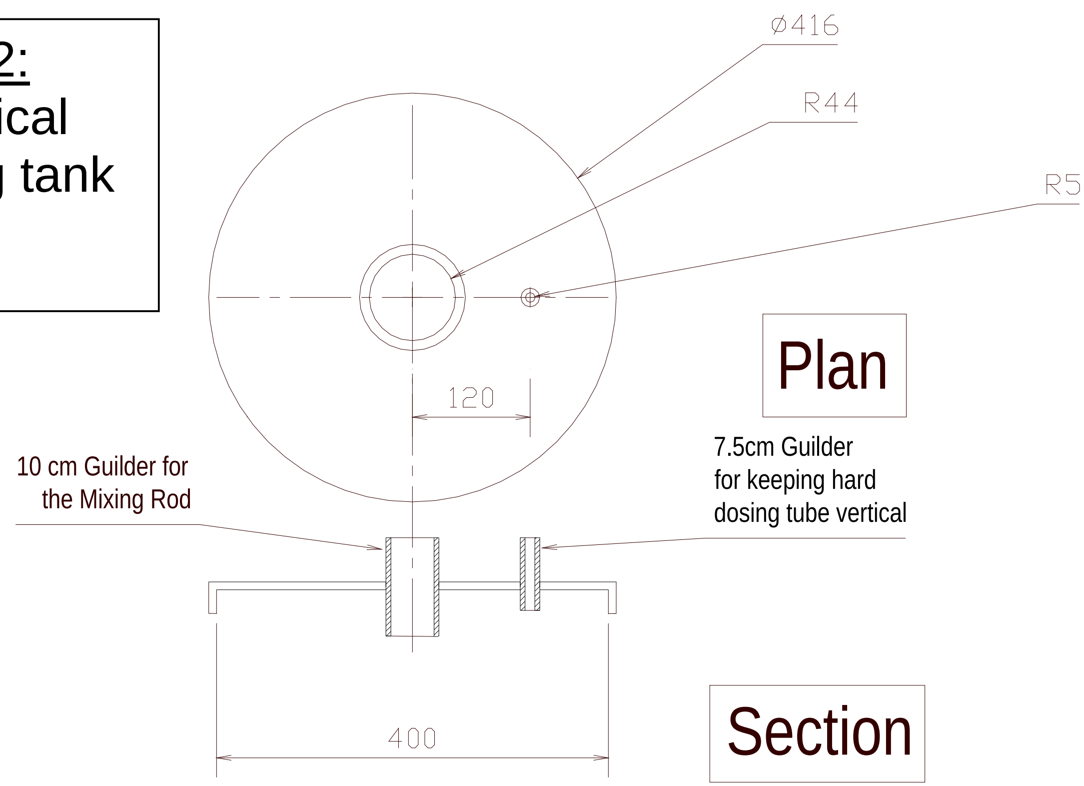
Appendix A continued:

10. Mosvold hospital ▪ Kwa Zulu Natal ▪ Hydraulic (pipe) Coagulation/flocculation; up-flow sedimentation; Slow sand filtration; Liquid chlorination	▪ 300 ▪ Dam; 3.6 ▪ 3.8	▪ Both coagulant and chlorine added by drip method but there is no control over rates	▪ Low sand-bed depth (6 cm!) ▪ High filtration rate
11. Manguzi Hospital ▪ Kwa Zulu Natal ▪ Hydraulic Coagulation/flocculation; Direct rapid sand filtration; Liquid chlorination	▪ 550 ▪ Lake Shengeza / Maputo River; 4.4 ▪ 3.9	▪ Available chlorine gas chlorinators broken ▪ No spare parts ▪ HTH is drip fed with dosing rate control and monitoring	▪ Sand filters overloaded ▪ No air scour for back-washing filters ▪ No operator
12. Frischgewaagd ▪ Kwa Zulu Natal ▪ Hydraulic Coagulation/flocculation; up-flow sedimentation; Slow sand filtration; Liquid chlorination	▪ 680 ▪ Dam & Spring; 43 ▪ 0.4	▪ No control over dosage and HTH quantities not known ▪ Lime dosing out of order ▪ Inadequate coagulation resulting in poor coagulation/flocculation	▪ Low sand-bed depth (1/2 of design value) ▪ Poor operation
13. Upper Mnyameni ▪ Eastern Cape ▪ Direct pressure filtration (polyelectrolyte used); liquid chlorination	▪ 260 ▪ Mnyameni Dam; Low-value not available ▪ 3.5 – 15	▪ Dosing pumps broken down and there are no spare parts ▪ Waiting for electrification to commission the electric pumps	▪ Data not available
14. Pleasant View ▪ Eastern Cape ▪ Coagulation/flocculation (in-line mix and pipe Coagulation/flocculation); Circular sedimentation; Pressure filtration	▪ 650 (design); 75 (operating); ▪ Pleasant View Dam; Low - value not available ▪ 1.4 – 15	▪ Dosing pumps broken down and there are no spare parts	▪ Data not available
15. St. Thomas ▪ Eastern Cape ▪ Coagulation/flocculation; sedimentation; pressure filtration; tablet chlorination	▪ 200 ▪ River; Medium-value not available ▪ 0.2 – 19	▪ Inadequate dosing equipment for both chemical pre-treatment and disinfection	▪ Short circuits in Sedimentation , hence filtration is overloaded
16. Dordrecht ▪ Eastern Cape ▪ Coagulation/flocculation; sedimentation; rapid sand filtration; gas chlorination	▪ 1632 (design); 1689 (operating) ▪ Anderson Dam; Low-value not available ▪ Data not available	▪ Data not available	▪ Data not available
17. Clocolan ▪ Free State ▪ Coagulation/flocculation; sedimentation; Rapid sand filtration; liquid chlorination	▪ 1968 (design) ▪ Mopedi dam; low-value not available ▪ 0.1 – 8.7	▪ Inadequate performance of chlorination equipment and too expensive to replace ▪ Sodium hypochlorite used	▪ Data not available
18. Syferfontein → Free State → Coagulation/flocculation; sedimentation; Rapid sand filtration; liquid chlorination	▪ 3264 (design); 2160 (operating) ▪ sand river; Medium – value not available ▪ 0.2 – 8.5	▪ Data Not Available	▪ Data Not Available
19. Calitzdorp ▪ Western Cape ▪ Coagulation/flocculation; circular sedimentation; Slow sand filtration; gas chlorination; lime stabilisation	▪ 850	▪ No control over dosing rate hence inaccurate-under or over dosing common ▪ Gas chlorinators used	▪ Rapid clogging (2 weeks filter run) as poor chemical dosing and floc carry over
20. Builsplaas ▪ Western Cape ▪ Aeration (iron removal); pH adjustment (Na_3CO_3); sedimentation (in aeration tank); upflow contact filtration; pressure filtration; Gas chlorination	▪ 120 ▪ Groundwater; iron – value not available ▪ Data not available	▪ Mechanical problems with soda ash dosing ▪ Gas chlorinators not consistent due to low pressures	▪ Rapid clogging

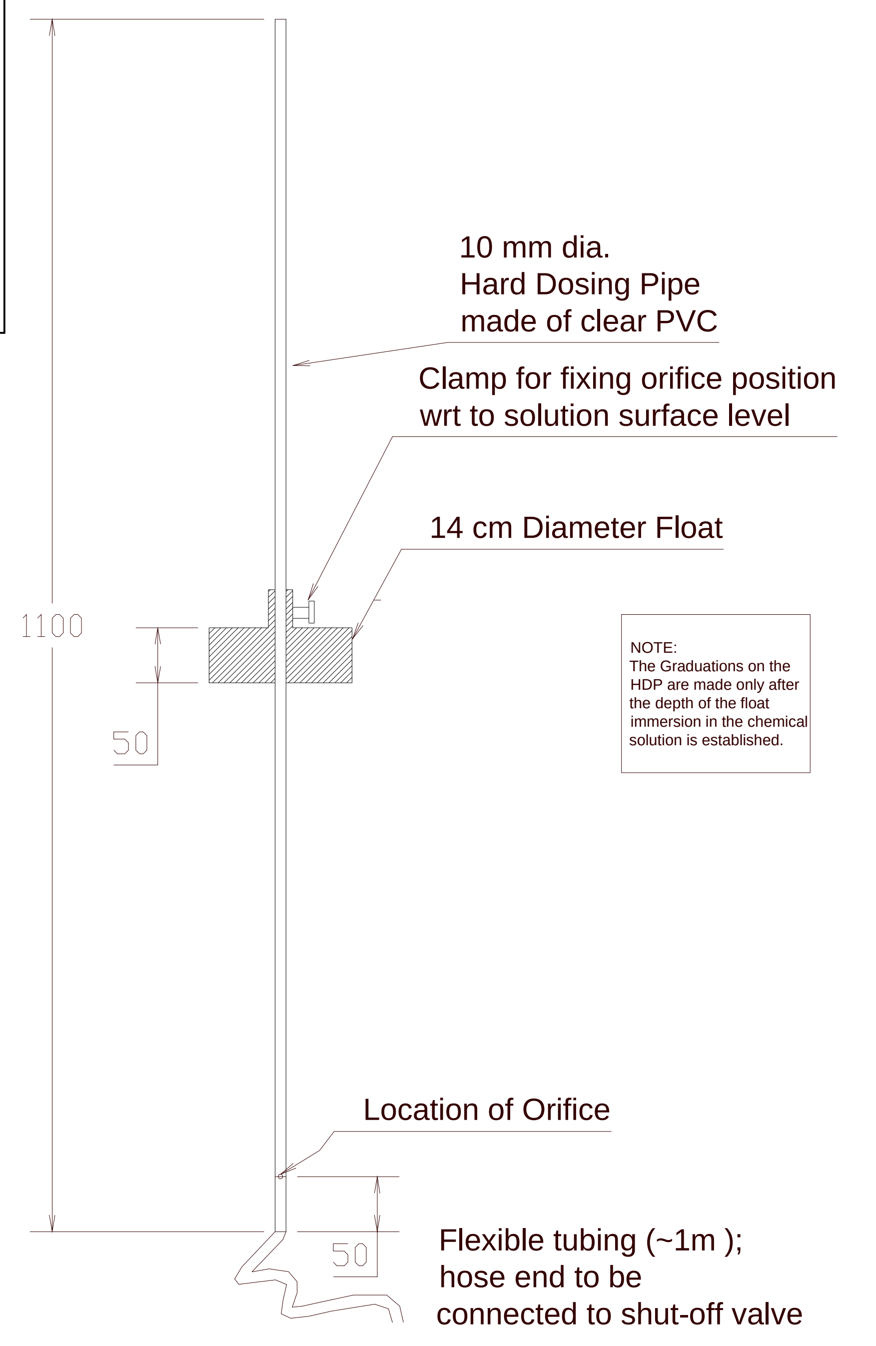
Appendix B: Detailed design drawings of the chemical dosing system

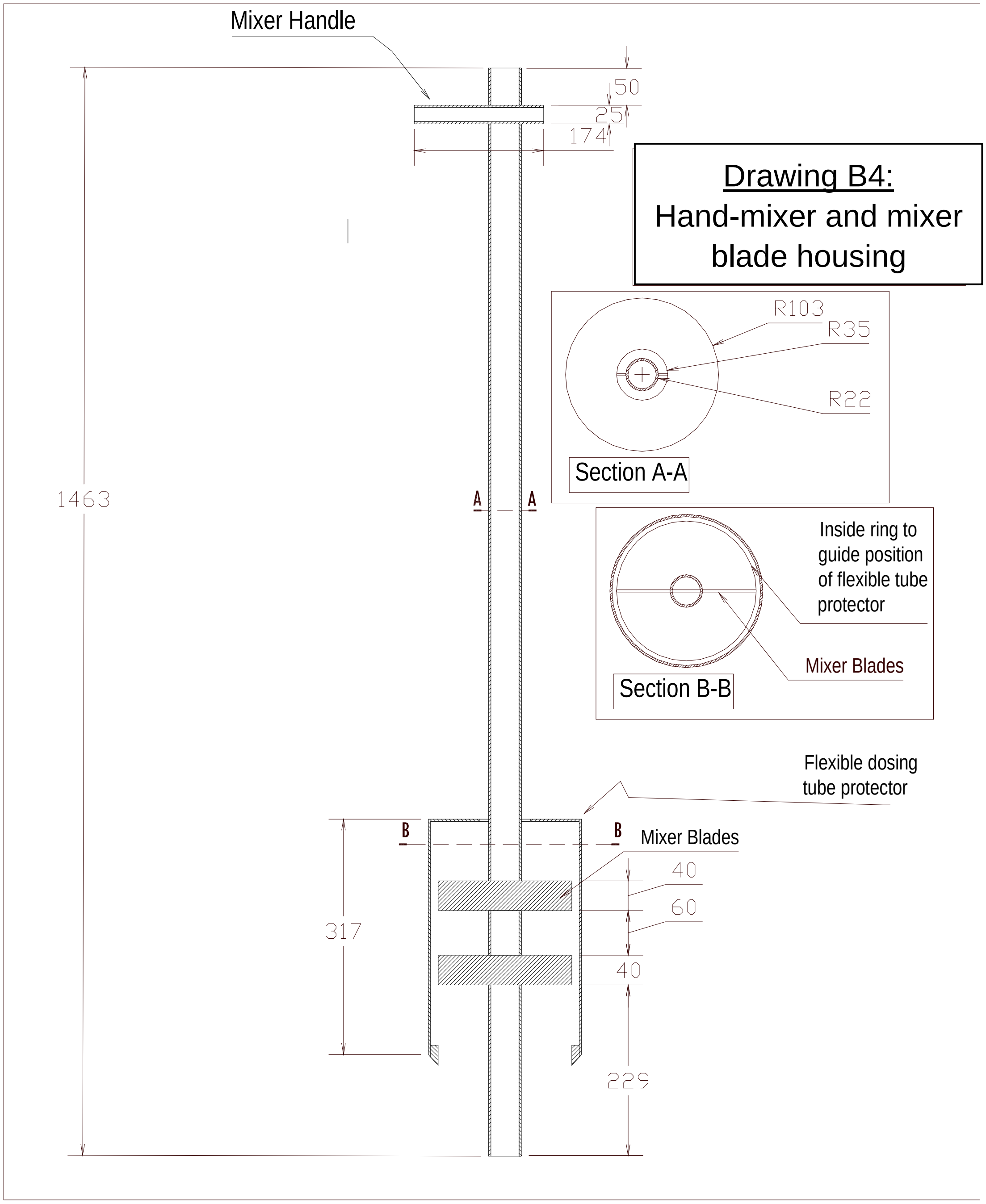


Drawing B2:
Lid for chemical solution dosing tank

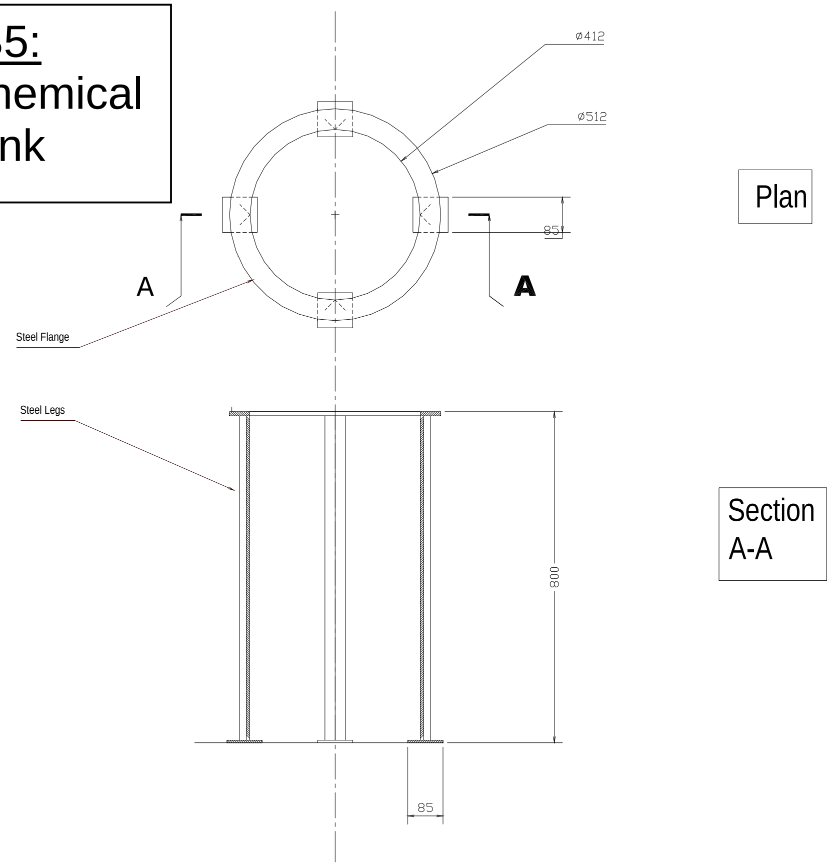


Drawing B3: Orifice's constant - head float and dosing tubes




Mixer Handle
50
25
174
Drawing B4:
Hand-mixer and mixer blade housing
R103
R35
R22
Section A-A
1463
A
A
Inside ring to guide position of flexible tube protector
Mixer Blades
Section B-B
Flexible dosing tube protector
B
B
Mixer Blades
40
60
317
40
229

Drawing B5:
Stand for the chemical solution tank



Appendix C: Chemical dosing systems flow/dosing ate analysis results

Table C (i) Actual measurement of tap water flow through 2 mm orifice

h (cm)	Trial	V(ml)	t (s)	Q (l/h)		h (cm)	Trial	V(ml)	t (s)	Q (l/h)
3	1	940	1014	3.337		12	1	470	230	7.357
	2	840	928	3.259			2	320	146	7.890
	3	920	1016	3.260			3	225	112	7.232
	4	750	811	3.329			4	260	124	7.548
	5	800	822	3.504			5	210	107	7.065
4	1	1100	953	4.155		13	1	220	106	7.472
	2	570	508	4.039			2	200	102	7.059
	3	700	630	4.000			3	220	106	7.472
	4	410	341	4.328			4	245	115	7.670
	5	820	735	4.016			5	300	132	8.182
5	1	750	608	4.441		14	1	210	101	7.485
	2	920	732	4.525			2	195	54	13.000
	3	570	440	4.664			3	195	55	12.764
	4	570	441	4.653			4	210	102	7.412
	5	490	401	4.399			5	194	54	12.933
6	1	680	455	5.380		15	1	220	102	7.765
	2	650	446	5.247			2	250	111	8.108
	3	520	355	5.273			3	220	103	7.689
	4	610	434	5.060			4	190	53	12.906
	5	820	600	4.920			5	190	54	12.667
7	1	300	201	5.373		16	1	195	51	13.765
	2	1190	835	5.131			2	195	51	13.765
	3	600	520	4.154			3	330	130	9.138
	4	270	203	4.788			4	220	100	7.920
	5	260	202	4.634			5	200	54	13.333
8	1	350	216	5.833		17	1	200	52	13.846
	2	280	150	6.720			2	240	104	8.308
	3	300	202	5.347			3	200	52	13.846
	4	240	139	6.216			4	200	51	14.118
	5	260	151	6.199			5	230	59	14.034
9	1	300	209	5.167		18	1	290	114	9.158
	2	250	156	5.769			2	180	44	14.727
	3	260	202	4.634			3	180	46	14.087
	4	370	221	6.027			4	200	51	14.118
	5	500	320	5.625			5	200	51	14.118
10	1	420	229	6.603		19	1	260	101	9.267
	2	300	143	7.552			2	210	50	15.120
	3	230	119	6.958			3	210	50	15.120
	4	260	130	7.200			4	210	51	14.824
	5	420	227	6.661			5	230	56	14.786
11	1	470	237	7.139		20	1	180	42	15.429
	2	220	113	7.009			2	130	31	15.097
	3	240	120	7.200			3	140	33	15.273
	4	250	125	7.200			4	140	34	14.824
	5	245	124	7.113			5	330	119	9.983

Table C (ii) Actual measurement of 5 % ALUM solution flow through 2 mm orifice

Orifice -head (cm)	Trial No.	Volume (ml)	Time (s)	flow rate (l/h)	Orifice -head (cm)	Trial No.	Volume (ml)	Time (s)	flow rate (l/h)
3	1	45	24.31	6.66	17	1	84	16.47	18.36
	2	40	21.47	6.71		2	106	20.72	18.42
	3	21	11.1	6.81		3	144	28.95	17.91
	4	39	21.47	6.54		4	138	26.93	18.45
	5	32	17.81	6.47		5	140	28.12	17.92
4	1	39	18.62	7.54	18	1	112	21.19	19.03
	2	45	22.06	7.34		2	93	18.21	18.39
	3	33	16.12	7.37		3	144	28.75	18.03
	4	46	23.19	7.14		4	146	28.53	18.42
	5	31	15.6	7.15		5	86	16.03	19.31
5	1	28	11.88	8.48	19	1	104	19.34	19.36
	2	38	16.88	8.10		2	122	23.15	18.97
	3	29	13.03	8.01		3	130	24.97	18.74
	4	35	15.34	8.21		4	142	27.22	18.78
	5	25	10.94	8.23		5	80	15.43	18.66
6	1	32	12.78	9.01	20	1	110	19.85	19.95
	2	42	16.97	8.91		2	102	18.6	19.74
	3	26	10.94	8.56		3	126	22.87	19.83
	4	34	14.12	8.67		4	142	26.37	19.39
	5	33	14.09	8.43		5	112	20.47	19.70
7	1	47	17.6	9.61	21	1	84	14.41	20.99
	2	32	12.03	9.58		2	104	18.47	20.27
	3	41	15.53	9.50		3	75	13.12	20.58
	4	45	16.82	9.63		4	128	23	20.03
	5	31	11.62	9.60		5	79	14.19	20.04
8	1	42	14.78	10.23	22	1	101	17.16	21.19
	2	41	14.41	10.24		2	60	10.25	21.07
	3	41	16.06	9.19		3	106	18.22	20.94
	4	38	14.65	9.34		4	134	23.31	20.69
	5	36	11.6	11.17		5	96	16.56	20.87
9	1	96	30.25	11.42	23	1	102	16.9	21.73
	2	40	11.71	12.30		2	96	16.28	21.23
	3	46	13.84	11.97		3	102	17.59	20.88
	4	46	13.81	11.99		4	124	20.59	21.68
	5	56	16.81	11.99		5	86	14.75	20.99

Table C (ii) Continued

10	1	70	20.35	12.38	24	1	116	18.91	22.08
	2	48	13.78	12.54		2	62	9.97	22.39
	3	46	13.16	12.58		3	125	21	21.43
	4	72	20.53	12.63		4	168	28.63	21.12
	5	62	18.16	12.29		5	86	14.53	21.31
11	1	50	13.78	13.06	25	1	50	7.28	24.73
	2	62	17	13.13		2	40	6.59	21.85
	3	58	15.59	13.39		3	36	5.78	22.42
	4	56	15.06	13.39		4	72	11.5	22.54
	5	36	9.84	13.17		5	62	10	22.32
12	1	92	25.15	13.17	26	1	84	12.97	23.32
	2	68	17.5	13.99		2	80	12.22	23.57
	3	60	15.62	13.83		3	82	12.92	22.85
	4	80	20.88	13.79		4	90	14.15	22.90
	5	68	18.03	13.58		5	162	25.31	23.04
13	1	58	14.03	14.88	27	1	109	16.87	23.26
	2	62	15.25	14.64		2	118	18.53	22.92
	3	50	12.28	14.66		3	94	14.57	23.23
	4	64	16.12	14.29		4	100	15.37	23.42
	5	56	13.69	14.73		5	122	18.5	23.74
14	1	116	28.03	14.90	28	1	66	10.12	23.48
	2	58	13.94	14.98		2	62	9.44	23.64
	3	66	15.75	15.09		3	92	13.94	23.76
	4	60	14	15.43		4	82	12.53	23.56
	5	63	15.03	15.09		5	60	9.13	23.66
15	1	49	11.06	15.95	29	1	68	10.02	24.43
	2	71	16.47	15.52		2	76	11.18	24.47
	3	47	10.81	15.65		3	94	13.97	24.22
	4	66	15.16	15.67		4	104	15.75	23.77
	5	85	19.72	15.52		5	50	7.34	24.52
16	1	96	22.88	15.10	30	1	74	10.82	24.62
	2	110	22.1	17.92		2	54	7.75	25.08
	3	96	19.53	17.70		3	94	14.37	23.55
	4	102	20.82	17.64		4	126	18.12	25.03
	5	122	24.78	17.72		5	78	11.43	24.57

Table C (iii) Actual measurement of 5 % ALUM solution flow through 5 mm orifice

For each orifice depth, 5 measurements were carried out.

Orifice-head (cm)	Trial No.	Volume (ml)	Time (s)	flow rate (l/h)		Orifice-head (cm)	Trial No.	Volume (ml)	Time (s)	flow rate (l/h)
3	1	200	19.47	36.98		17	1	140	6.12	82.35
	2	170	16.59	36.89			2	176	7.91	80.10
	3	234	22.44	37.54			3	244	10.87	80.81
	4	190	19.22	35.59			4	198	8.91	80.00
	5	234	23.19	36.33			5	230	10.25	80.78
4	1	174	14.87	42.13		18	1	180	7.88	82.23
	2	192	16.37	42.22			2	150	6.43	83.98
	3	230	19.28	42.95			3	178	7.75	82.68
	4	160	13.19	43.67			4	212	9.12	83.68
	5	158	13.37	42.54			5	176	7.75	81.75
5	1	204	15.69	46.81		19	1	162	6.65	87.70
	2	180	13.85	46.79			2	168	7	86.40
	3	248	18.84	47.39			3	196	8.25	85.53
	4	148	11.47	46.45			4	170	7.09	86.32
	5	186	14	47.83			5	232	9.72	85.93
6	1	202	14.31	50.82		20	1	172	7.03	88.08
	2	186	13.2	50.73			2	140	5.71	88.27
	3	188	13.25	51.08			3	188	7.78	86.99
	4	190	13.47	50.78			4	200	8.15	88.34
	5	220	15.62	50.70			5	196	8.12	86.90
7	1	196	12.97	54.40		21	1	186	7.54	88.81
	2	152	10.28	53.23			2	188	7.5	90.24
	3	218	14.82	52.96			3	246	9.78	90.55
	4	170	11.47	53.36			4	130	5.25	89.14
	5	142	9.68	52.81			5	212	8.5	89.79
8	1	188	11.69	57.90		22	1	162	6.19	94.22
	2	162	10.06	57.97			2	172	6.72	92.14
	3	178	11.19	57.27			3	198	7.81	91.27
	4	188	11.69	57.90			4	168	6.57	92.05
	5	152	9.63	56.82			5	238	9.34	91.73
9	1	162	9.69	60.19		23	1	146	5.63	93.36
	2	190	11.41	59.95			2	172	6.97	88.84
	3	182	10.66	61.46			3	194	7.32	95.41
	4	132	7.78	61.08			4	188	7.31	92.59
	5	162	9.94	58.67			5	216	8.46	91.91
10	1	176	10	63.36		24	1	160	6.13	93.96
	2	172	9.71	63.77			2	162	6.28	92.87
	3	132	7.53	63.11			3	232	8.84	94.48
	4	228	12.72	64.53			4	182	6.72	97.50
	5	126	7.16	63.35			5	144	5.47	94.77
11	1	150	8.57	63.01		25	1	228	8.63	95.11
	2	122	6.69	65.65			2	186	7.03	95.25
	3	180	9.94	65.19			3	180	6.63	97.74
	4	158	8.34	68.20			4	174	6.4	97.88
	5	176	9.66	65.59			5	152	5.72	95.66

Table C (iii) Continued

12	1	160	8.44	68.25	26	1	152	5.4	101.33
	2	150	7.81	69.14		2	160	5.75	100.17
	3	226	11.79	69.01		3	172	6.25	99.07
	4	158	8.06	70.57		4	182	6.63	98.82
	5	126	6.68	67.90		5	156	5.66	99.22
13	1	132	6.71	70.82	27	1	180	6.31	102.69
	2	196	9.84	71.71		2	180	6.44	100.62
	3	148	7.44	71.61		3	168	6.09	99.31
	4	154	7.68	72.19		4	172	6.03	102.69
	5	138	6.91	71.90		5	180	6.44	100.62
14	1	230	11.28	73.40	28	1	160	5.56	103.60
	2	132	6.46	73.56		2	202	7.09	102.57
	3	184	8.75	75.70		3	246	8.93	99.17
	4	154	7.26	76.36		4	196	7.31	96.53
	5	136	6.59	74.29		5	104	3.71	100.92
15	1	166	7.84	76.22	29	1	138	4.75	104.59
	2	218	10.31	76.12		2	170	6	102.00
	3	158	7.56	75.24		3	222	7.78	102.72
	4	130	6	78.00		4	152	5.28	103.64
	5	148	7.03	75.79		5	196	6.97	101.23
16	1	190	8.66	78.98	30	1	140	4.88	103.28
	2	172	7.19	86.12		2	148	5.12	104.06
	3	178	8.25	77.67		3	182	6.28	104.33
	4	144	6.53	79.39		4	202	7.1	102.42
	5	172	7.88	78.58		5	172	5.94	104.24

Table C (iv) Actual dosing rates during testing of chemical dosing system for a 2 mm orifice

Orifice-head of 3 cm : 16th September to 15th October			
Sample No	Volume (ml)	Time (s)	Dosing rate (l/h)
1	114.0	72.00	5.70
2	113.0	71.00	5.73
3	112.0	71.00	5.68
4	102.0	60.00	6.12
5	100.0	60.00	6.00
6	98.0	60.00	5.88
7	70.0	44.68	5.64
8	34.0	20.94	5.85
9	44.5	27.78	5.77
10	100.0	60.00	6.00
11	100.0	60.00	6.00
12	99.0	60.00	5.94
13	100.0	62.10	5.80
14	29.0	17.44	5.99
15	42.0	25.40	5.95
16	100.0	60.00	6.00
17	99.0	60.00	5.94
18	99.0	60.00	5.94
19	99.0	60.00	5.94
20	100.0	61.00	5.90
21	100.0	60.00	6.00
22	100.0	60.00	6.00
23	101.0	60.00	6.06
24	100.0	60.00	6.00
25	100.0	60.00	6.00
26	98.0	60.00	5.88
27	100.0	60.00	6.00
28	99.0	60.00	5.94
29	99.0	60.00	5.94
30	100.0	60.00	6.00
31	99.0	60.00	5.94
32	100.0	60.00	6.00
33	100.0	60.00	6.00
34	100.0	60.00	6.00
35	100.0	60.00	6.00
36	100.0	60.00	6.00
37	100.0	60.00	6.00
38	100.0	60.00	6.00
39	100.0	60.00	6.00
40	101.0	60.00	6.06
41	100.0	60.00	6.00
42	98.0	60.00	5.88

Orifice-head of 1.5 cm : 19th to 28th October 01			
Sample No	Volume (ml)	Time (s)	Dosing rate (l/h)
1	54	60	3.24
2	53	60	3.18
3	54	60	3.24
4	53	60	3.18
5	52	60	3.12
6	53	60	3.18
7	50	60	3.00
8	53	60	3.18
9	54	60	3.24
10	53	60	3.18
11	54	60	3.24
12	54	60	3.24
13	51	60	3.06
14	52	60	3.12
15	51	60	3.06

Part B – Evaluation of roughing – slow sand filtration system combined with coagulation achieved by the gravity chemical dosing system developed in Part A

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1 Introduction

1.1 General

This chapter presents the introduction of Part B of the WRC Project K5/1396. Part A presented the development and evaluation of a chemical dosing system and Part B reports on the work done on the testing of the chemical dosing system developed on pilot water treatment plants, which consisted of a combination of coagulation, upflow roughing filtration in layers (URFL) and slow sand filtration (SSF).

The link with Part A is that the dosing of the chemical solution used for the coagulation process was achieved by the chemical dosing system reported in Part A.

Hence, the testing and practical application of the chemical dosing system developed is also reported in this Part.

The next section presents brief background information on small water treatment plants and upflow roughing filtration in layers and slow sand filtration processes, the emphasis of the work done. Thereafter, the aims, scope and limitations, and outline of the rest of the report are presented.

1.2 Background

Most water treatment plants employ chemical pre-treatment in combination with rapid sand filtration (RSF) or slow sand filtration (SSF). Rapid sand filtration is generally not recommended for application in small water treatment plants because of its costly and advanced mechanical operation and maintenance requirements. Slow sand filtration is simpler in design, operation and maintenance and therefore recommended in small water treatment plants.

The application of slow sand filtration alone is effective when treating raw water characterised by low turbidity (< 10 NTU) as it is able to produce potable water even without disinfection.

Although slow sand filtration is capable of producing potable water, it is highly recommended to disinfect water prior safeguard against incidental contamination through out the transportation and supply channels.

Slow sand filtration uses fine sand, hence it is susceptible to clogging if the turbidity of the raw water turbidity is greater than 10 NTU.

It is reported that inappropriate pre-treatment of raw water prior to slow sand filtration is a reason for the failure of most applications of slow sand filtration (Wegelin 1996).

Because of the simplicity of the process of slow sand filtration and the fact that it is generally recommended for small and/or rural communities, it is generally recommended that any pre-treatment process combined with slow sand filtration must as well be simple. This ensure that a treatment system is sustainable and the processes are compatible.

Roughing (or gravel) filtration is one of simple pre-treatment processes recommended prior to SSF. Roughing filtration has the ability to protect SSF against high and fluctuating turbidity raw water (Wegelin, 1996). However, roughing filtration is not effective in treating medium to high turbidity (> 50 - 100 NTU) raw waters largely characterised by colloidal particles. However, coagulation has been reported to improve the performance of roughing filtration in this regard (Van Wals, 1997).

Of the types of roughing filtration systems, Up-flow Roughing Filtration in Layers (URFL) is more economical in terms of construction materials and performs better. URFL is also much lower in operation and maintenance requirements, especially with the filter media cleaning process. For these reasons, URFL was selected in this project.

The strategic plans of the Water Research Commission for research on water treatment emphasises the need for research programmes in small and rural water treatment plants to concentrate on understanding the processes in these plants, overcoming unaffordable over-designs and introducing simpler technologies to encourage more community involvement (WRC 1999).

1.3 Aims of the project

The aims of the work reported in this Part B were:

1) To test the application of the chemical dosing system developed in Part A on a combination of up-flow roughing filtration layers (URFL) and slow sand filtration (SSF) in treating coagulated turbid raw water and evaluate the performance of URFL-SSF system as well.

NOTE: The dosing of the coagulant solution used in the coagulation process was achieved by the chemical dosing system developed and reported in Part A of the report.

2) To develop guidelines for practical applications of a combination of coagulation, up-flow roughing filtration layers, and slow sand filtration in small water treatment plants.

1.4 Scope and limitations

The scope and limitations of the project were as follows:

1) The evaluation was performed on two pilot plants: one located in the laboratory using simulated turbidity (kaolin clay) and the other located on an existing full-scale plant using natural river water.
2) Coagulation was achieved by using aluminium sulphate solution (Trade name ALUM),
3) The dosing of the coagulant chemical was achieved by a gravity chemical dosing system reported in part A of the report.
4) The evaluation did not look at the performance of the filtration processes at various filtration rates, but was limited to conventional filtration rates.
5) Plant monitoring and data collection was limited to day time only.
6) Specific interest in the evaluation included:
    - The impact of continuous and intermittent coagulation on URFL under both stable and varying raw water quality.
    - The Impact of sudden subjection of URFL to high raw water turbidity without adjusting chemical dosages.

1.5 Outline of the report

The following are the brief outlines of each of the remaining chapters of the report:

- ❖ **Chapter 2**: present the literature review, which focuses on a combination of upflow roughing filtration in layers and slow sand filtration and the influence of coagulation.
- ❖ **Chapter 3**: presents the methodology used with emphasis on the pilot water treatment plant plants used.
- ❖ **Chapter 4:** presents the results and discussion thereof, focussing on the water quality aspects
- ❖ **Chapter 5:** presents the guidelines that have been developed for the practical applications of coagulation, upflow roughing filtration in layers and slow sand filtration in small water treatment plants.
- ❖ **Chapter 6**: Presents the conclusions and recommendations.

2 Literature review

2.1 General

The focus in this part of the project was to study slow sand filtration preceded by roughing filtration and coagulation. Therefore, the literature review conducted was limited to slow sand filtration, roughing filtration and application of coagulation in roughing filtration.

The purpose of the literature review presented in this chapter is to give practical overviews of slow sand filtration, roughing filtration and coagulation processes so that the reader will have a good understanding of these processes and the linkage with the chemical dosing system reported in Part A.

2.2 Slow sand filtration

Slow sand filtration (SSF) is one of the oldest water purification processes. The word 'slow' was used because of the significantly much lower filtration rates (0.10 – 0.30 m/h) compared to conventional sand filtration called rapid sand filtration (RSF) (5 – 15 m/h).

In SSF, the force of gravity drives the water through the sand. As a result, for its filtration rates to be slower, the sand must be comparatively fine, i.e. effective diameter (d_e) ranges from 0.15 to 0.35 mm compared to 0.50 to 1.00 mm in RSF (*Holfkes*, 1988; *Schulz & Okun*, 1984)

Because of the low filtration rates and fine filter media (sand) used, SSF is capable of producing potable water. These parameters permit effective physical and biological mechanisms, which are responsible for the purification of water in SSF processes (see Table 2.1). Therefore, the maintenance and control of filtration rates in SSF is important. The filtration rate can be controlled either from the inlet or outlet side of the filter unit (see Figure 2.1).

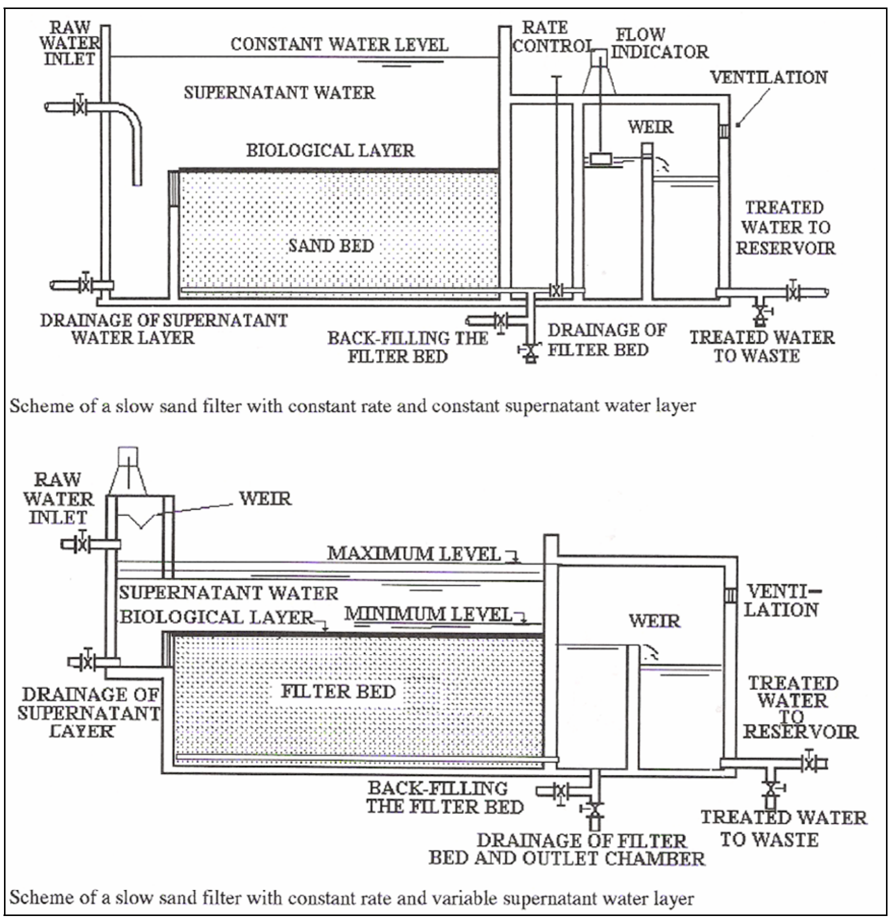

Figure 2-1: Cross section of views of an outlet (top) & inlet (bottom) controlled slow sand filter

Table 2-1: Typical treatment efficiencies of Slow Sand Filtration (Wegelin 1996)

Parameter	Typical SSF filtrate values
Coliforms Organisms (#/100 ml)	Less than 1
Turbidity	Less than 1 NTU
Total Suspended solids (mg/*l*)	Complete removal
Colour	30-90 % removal
Iron and Manganese	Considerable removal
Protozoan Cysts	99 to 99.99% removal

Although slow sand filtration is very effective in retaining suspended particles, its fine sand is susceptible to rapid clogging depending on the level and fluctuation of the turbidity of the water being treated. Nevertheless, it is not effective in colour removal. Hence, the key recommended raw water quality parameters to be treated by slow sand filtration include (Galvis et al. 1998):

- turbidity ➔ 10 NTU
- True colour ➔ 15 -25 TCU
- Total iron ➔ < 1 mg/l
- Algae ➔ < 200000 units/l

Therefore, if natural raw water is not suitable for direct SSF, then it must be pre-treated. Conventional pre-treatment processes include coagulation, flocculation and sedimentation. These processes, especially coagulation, are usually not sustainable in most small plants. Inappropriate coagulation often leads to flocs overflowing to the filter. Today, research and development regarding pre-treatment processes for SSF is still on-going as reported over a decade ago (See Figure 2.2).

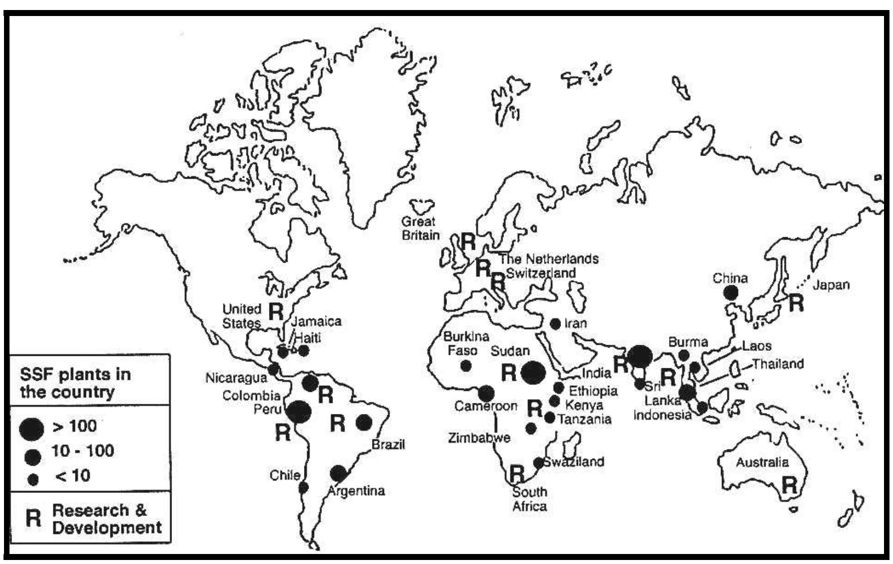

Figure 2-2: Reported locations where pre-treatment prior to SSF is required (*Collins et al., 1994*)

Since SSF is generally recommended in rural/small areas characterised by unskilled labour, it is important that any pre-treatment processes selected prior to SSF applied in such areas are compatible as far as the simplicity in design, construction, operation and maintenance of SSF is concerned.

Roughing or gravel filtration is generally a non-conventional pre-treatment process reported to be compatible with SSF and hence recommended as a pre-treatment process in rural/small SSF plants. The next section presents a review of this technology since it was the focus in this project.

2.3 Roughing (gravel) filtration

Roughing filtration (RF) (or gravel filtration) is reported to have the ability of protecting SSF against high and fluctuating turbidity, with or without coagulation. It uses various layers of gravel media (2 to 25 mm) which can be arranged in different configurations (see Figure 3.3).

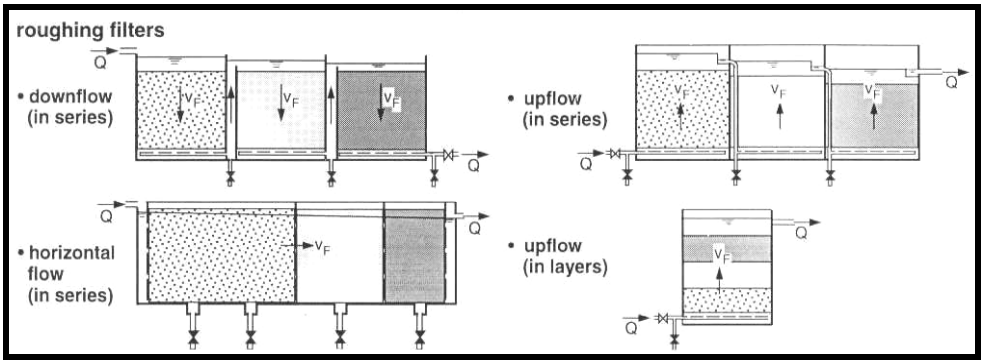

Figure 2-3: Types of Roughing Filters [*Wegelin, 1996*]

Because of the course filter media used in roughing filters, the process is not effective in treating water which is largely characterised by colloidal particles and colour causing organic contamination.

If coagulation is applied to such waters, then the performance of RF can be improved. The use of coagulation in roughing filtration has been reported so far, including a study done in Mozambique (Berry 1997).

Roughing filters are considered compatible with slow sand filters since they are both technically simple, as a result would be easier to operate and maintain if combined even at rural level management.

Of the different types of roughing filters (Figure 2.3), up-flow roughing filtration in layers (URFL) is reported to be characterised by lower capital costs. It also needs less land space, since one filter unit accommodates all filter media layers, making it relatively more compatible and cost effective, and less demanding with respect to operation and maintenance. In URFL, the different layers of the filter media can be cleaned by a single drainage of the filter unit, unlike in the other filters which use separate compartments for each filter media. In addition, URFL can easily be integrated into existing sedimentation/flocculation tanks or slow sand filters. (see Figure 2.4). This has been demonstrated in some applications done in Cameroon (*Wegelin* et al. 1996).

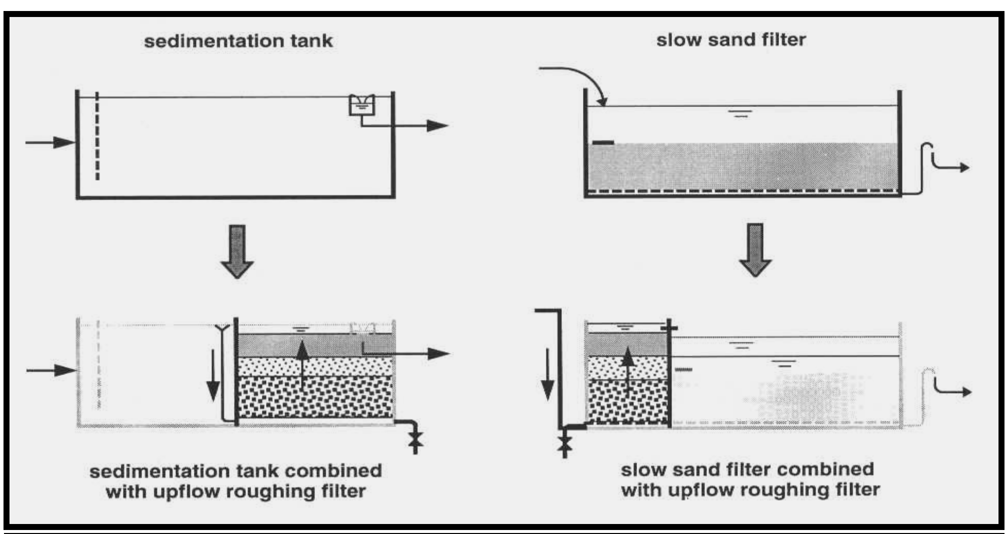

Figure 2-4: Possible integration of URFL into existing sedimentation or SSF tanks (Wegelin 1996)

URFL is comparatively less effective in treating very high turbidity raw water, being limited to levels ranging from 10-70 NTU at filtration rates less than 1.0 m/h (*Wegelin 1996; Galvis et al. 1993).* This is because of the comparatively shortened filter media depth, which offers less detention times for effective sedimentation.

Nevertheless, URFL is capable of reducing turbidity to less than 10 NTU as long as the feed water turbidity is not highly turbid (> 70 NTU)

Mwiinga (1998) studied URFL on a pilot plant and the results indicate that URFL is also capable of removing faecal coliforms and the potential of URFL in treating raw water with turbidity values greater than those recommended elsewhere.

This finding indicate the need pilot testing prior to applying any water treatment processes.

2.4 Combination of roughing and slow sand filtration

The potential application of the combination of roughing filtration and slow sand filtration systems is enormous in most small and/or rural areas of developed and developing countries. Figure 2.5 shows geographical locations were roughing filtration research and development was reported in 1996.

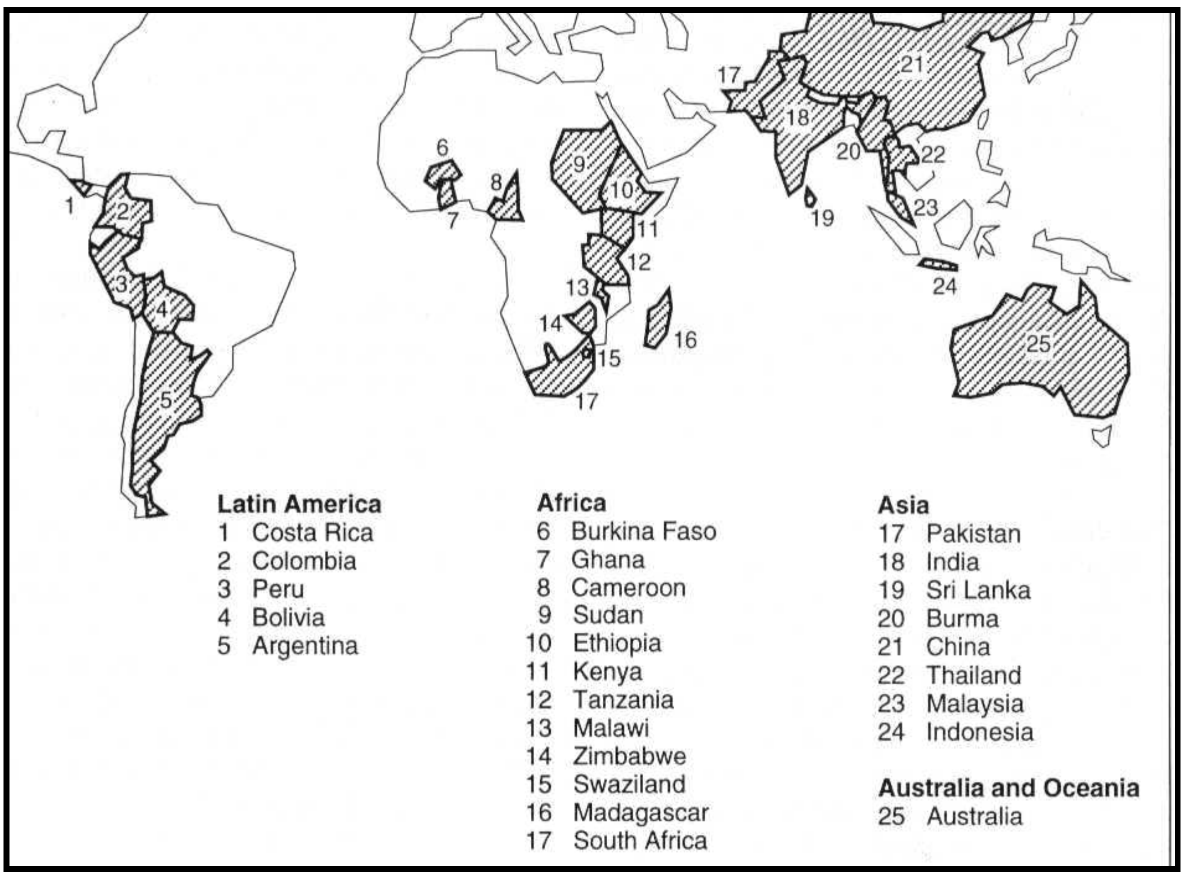

Figure 2-5: Geographical Locations where RF R & D have been reported (Wegelin 1996)

Not shown in this figure 2.5 are many more developing countries where similar studies have been conducted and are on-going. At the time of this reporting, the author was conducting pilot studies on the treatment of coloured water by the combination of URFL and SSF in the Western Cape Province, South Africa. A great need to purify coloured water was identified in many farm communities which use coloured raw water for domestic purposes without any treatment.

2.5 Coagulation and its application roughing filtration

Coagulation is the process of adding coagulant chemicals to turbid raw water so that stable suspended particles, that cannot be removed effectively by plain sedimentation, are destabilised to be able to coagulate or come together. Flocculation on the other hand is the process that permits the coagulated particles to come together and form larger and easily settled flocs. This is achieved by slow mixing of coagulated water. Since most of the particles to be removed from raw water are negatively charged, the coagulants used in water treatment normally introduce positively charged ions into the water to attract and neutralise the charges, hence prevent repulsion between particles.

The coagulation process takes place within seconds. Hence coagulants must be added to the water at a point where there is rapid mixing in the absence of mechanical mixers. In roughing filtration, the appropriate dosing point would be at the inlet weir.

Since a number of factors affect coagulation/flocculation, coagulant dose selected must be based on tests called Jar Tests**.** These tests evaluate the actual performance of the coagulant at various concentrations (see Appendix D for the procedure)

Widely used coagulant chemicals are hydrated aluminium sulphate ($Al_2(SO_4).18H_2O$, trade name ALUM), ferric sulphate ($Fe_2(SO_4)$. $7H_2O$), and ferric chloride ($Fe2Cl_3$). These chemicals introduce trivalent ions of aluminium or iron (Al^{+3} and Fe^{+3}) when they dissolve and ionise in water.

Typical dosage ranges for ALUM and iron salts are 10 – 100 mg/*l* and 10 - 50 mg/*l* respectively. Optimum pH range fall within 4.5 - 8.5 for ALUM and 3.5 – 9.0 for iron salts [AWWA].

Both are affected by the alkalinity of the water. Ferric sulphate is very corrosive and requires special handling and storage facilities.

ALUM is the most used and is also highly recommended in small and/or rural water treatment plants. It is available in ivory coloured granules, powder, lumps or liquid. The granular form, usually dosed in solution form is the most commonly used and was used in this project. In solutions of less than 1 % (10g/*l*) strength, the chemical is hydrolysed (i.e. form agglomerates with the chemical feed water) before it is dosed into the water. These agglomerates will render the coagulation process ineffective and can be prevented if the ALUM solution is prepared to a strength greater than 1.5% (15g/*l*).

Coagulation is likely to increase the performance of up-flow roughing filtration in layers (URFL) in treating both low to high turbidity raw waters. The rapid mixing required can be achieved by dosing the chemical solution at the inlet weir where there is high turbulence.

The up-flow movement of the coagulated water through the coarser support and lower gravel media layers of URFL provide the necessary flocculation environment.

Retained flocs in these layers subsequently ensure that finer flocs are retained by adsorption. It is generally considered that this theory is responsible for the efficacy of coagulation in URFL. It is likely that even fluctuating turbidity levels in the raw water would have less affect the effectiveness of URFL.

Because of the up-flow direction, low filtration rates (<1.0 m/h) and the fact that flocs are removed largely by gravitational settling in URFL, most of the flocs would be returned near the bottom of the filter unit. The lower half of URFL houses the coarse gravel layers which provide large storage capacity for the flocs and hence ensure longer filter runs. The subsequent cleaning by rapid draining therefore becomes much easier. The top-half finer gravel layers are therefore left with a polishing duty. In this way, URFL would guarantee the protection of SSF from high turbidity.

The risk that goes with coagulation prior to SSF is that flocs can overflow and rapidly clog the sand when the coagulation/flocculation is not operated properly. This could be possible in URFL if the filtration rates are high to an extent of preventing gravitational settling of the flocs. Inadequate dosing and mixing can also influence the floc formation. Chemical dosing systems to be used has to be as simple in design, operation and maintenance as URFL-SSF systems to ensure compatibility.

3 Methodology

3.1 General

This chapter presents the methodology of the project. The study was conducted on pilot water treatment plants. The location of the pilot plants, design details, construction, operation and maintenance aspects, and the monitoring and data collection are presented separately in the following sections.

3.2 Location and design of the pilot plants

The project team was based in the City of Bellville, about 30 km from Cape Town City Centre. The laboratory plant was based in Bellville while the field plant was located in Ashton within a full scale water treatment plant that supplies water to the community of Ashton (See Map in Figure 3.1).

Figure 3-1: Location map for the pilot water treatment plants

The selection of locating the field plant in Ashton was based on the availability of appropriate raw water quality in terms of turbidity levels, required for the study (> 10 NTU). The design parameters for both the Bellville and Ashton pilot plants were identical and are summarised in Table 3.1 and 3.2.

Table 3-1: Design parameters for up-flow roughing filtration in layers units

Parameter	Design value	
(a) Operation (hours/day)	24	
(b) Number of filter units	2	
(c) Diameter of each filter Unit (mm)	300	
(d) Filtration rate (m/h)	0.3 – 1.0	
(a) Inflow to each filter unit (*l*/h)	25.0 – 70.0	
(e) Filtration media [UC=2]	Size (mm)	Depth (cm)
• Top layer	1 – 5	20
• Middle layer	5 – 10	40
• Bottom layer	10 – 20	60
• Support/Drainage layer	25 – 35	20
(f) Supernatant depth, filled with 25-50 mm gravel to provide shading	10	
(g) Free board depth (cm)	10	
(h) Total Height (m)	1.60	

Table 3-2: Design parameters for slow sand filtration units

Parameter	Design value
(b) Operation (hours/day)	24
(c) Number of filter units	2
(d) Diameter of each filter unit (mm)	400
(e) Filtration rate (m/h)	0.1 - 0.3
(f) Inflow to each filter unit (*l*/h)	12.5 – 38.0
(g) Filtration media	
• Initial depth (cm)	0.80
• Effective size -d_e (mm)	0.15 -.35
• Uniformity coefficient (UC)	2 - 5
(e) Graded support gravel:	
• Bottom layer	size = 20-40 mm, thickness = 10 cm
• Middle layer	size = 5-15 mm, thickness = 10 cm
• Top layer	size = 1-5 mm, thickness = 10 cm
(f) Maximum supernatant water depth (m)	0.80
(g) Free board (cm)	10
(h) Total Height of filter unit	2 m

3.3 Pilot plant construction and layouts

The cylindrical filter units and pipe systems were made of PVC (see Figure 3.2). In each plant, there were two identical production lines. Schematic layouts for the Bellville plant are presented in Appendix A and the ASHTON plant had the same schematic layout. .

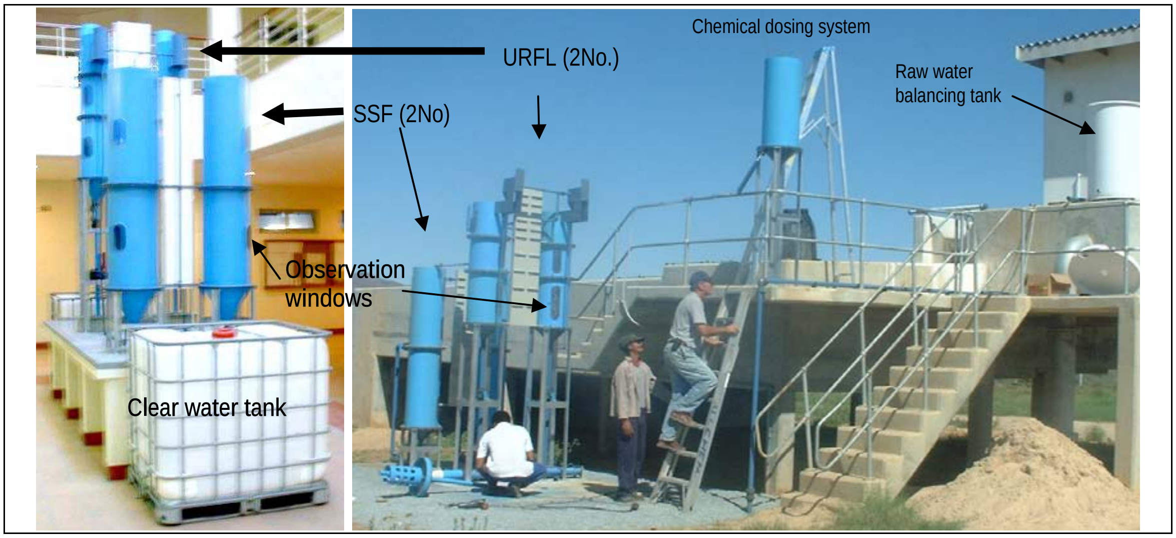

Figure 3-2: Bellville (L) and Ashton (R) pilot plant pictures

Figures 3.3 and 3.4 present the hydraulic profiles for the PENTECH and Ashton plants, respectively.

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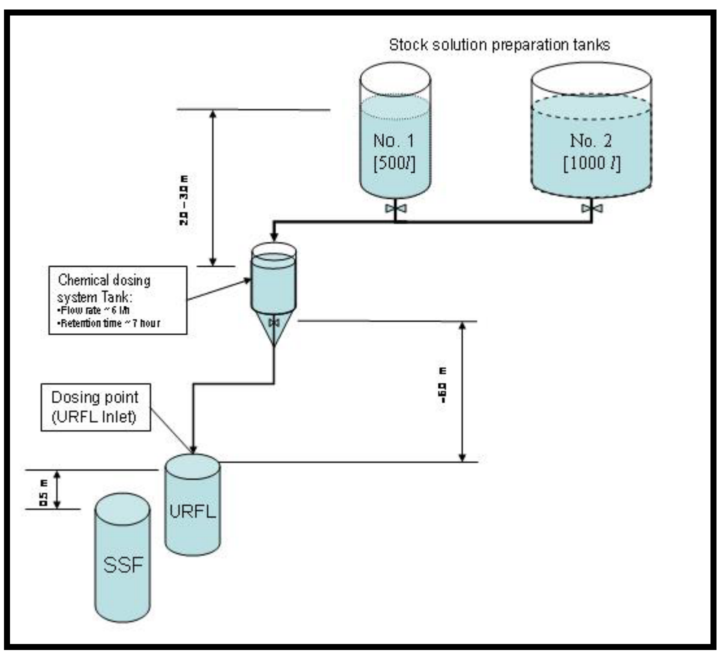

Figure 3-3: Hydraulic profile of the plant at Bellville plant

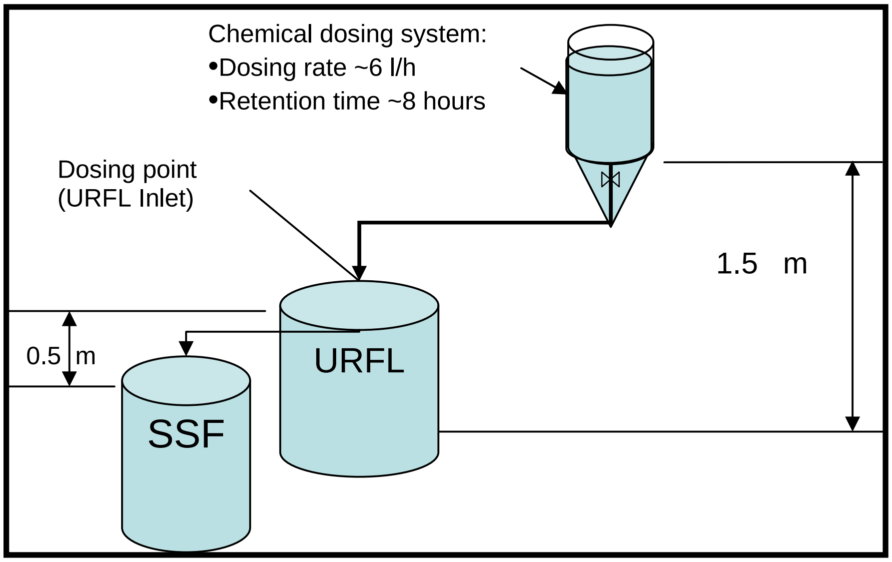

Figure 3-4: Hydraulic profile of the plant at Ashton plant

3.4 Operation, monitoring and maintenance aspects

When the plants were in operation, they were run for 24 hrs per day. The operation tasks included:

1) Controlling flow/filtration rates,
2) preparation of ALUM solutions
3) Controlling chemical dosing rates: the optimum dosage was determined from Jar Tests. Therefore the strength of the ALUM solution was such that a dosing rate of 6 l/h achieved the optimum dosage (see Chapter 4.3.5 in Part A)
4) controlling the raw water turbidity simulation,

The monitoring tasks included:

1) influent and effluent water quality,
2) SSF filter media clogging through head-losses observation,
3) Settleable solids/floc accumulation in URFL gravels through the observation windows (see Figure 3.2).
4) simulation of raw water for the PENTECH plant,
5) dosing rates monitoring,

Maintenance was performed as the need arose. Main tasks included filter media cleaning and clearing the pipes by regularly flushing of sediments in pipes.

The plants were both monitored during day-time. A number of research assistants were engaged. Generally, the PENTECH plant was monitored more frequently since it was closer to the project team's offices. A local operator and research assistants (students) from PENTECH were stationed at the Ashton Plant for regular monitoring of the plant.

The main water quality parameter analysed was turbidity. For each grab sample, turbidity was analysed three times and the final values were reported as daily averages. During water sampling, URFL and SSF head-losses were also recorded.

The capability of both plants to handle variations in raw water turbidity and also sudden peaks of turbidity which are expected to occur during winter/rainy seasons was tested. This was done by subjecting the plants to sudden increases in turbidity over a few hours and intensively monitoring the quality of the effluents as well.

4 Results and discussions

4.1 General

The investigation of the combination of up-flow roughing filtration in layers (URFL) and slow sand filtration (SSF), preceded by coagulation, focussed on the water quality improvement and the influence of coagulation thereof considering the fact it was dosed by a simple gravity chemical dosing system presented in Part A. Although turbidity was the main water quality parameter that was monitored in all samples, occasional measurements of total suspended solids and colour was done.

Coagulation was applied to one production line of each of the plants at PENTECH and in Ashton. URFL were operated at average filtration rates of 0.30 - 0.50 m/h and SSF rates varied between 0.1 and 0.20 m/h.

The water quality analysis results for the PENTECH and Ashton plants are presented in Appendix B and C respectively.

Turbidity was the main water quality parameter analysed in all samples: raw water, effluents or filtrates from URFL and SSF. Nevertheless, for the characterisation of the raw water, additional water quality parameters measured included pH, conductivity and temperature.

- ❖ Sections 4.2 and 4.3 present discussions of the results at the PENTECH and Ashton plants, respectively.
- ❖ Section 4.4 presents a summary of the results from both plants.

4.2 URFL – SSF plant at PENTECH

The sample turbidity reduction results presented in Appendix B for the PENTECH plant are summarised in Table 4.1. Other parameters analysed in the raw water are also included.

Table 4-1: Sample turbidity analysis results over 38 days - PENTECH plant

Raw water turbidity (NTU)		**Average removal (%) (Effluent turbidity values – NTU)**			
URFL-1	**URFL-2**	**URFL-1 (SSF-1 Influent)**	**URFL-2 SSF-2 Influent)**	**SSF-1**	**SSF-2**
10.3 - 142	6.78 - 120	88 - 95 (0.77 – 13.6)	80 - 87 (1.54 – 23.7)	87 - 89 (0.17 – 1.10)	84 - 96 (0.35 – 1.85)

NOTE:

- ❖ URFL – 1 treated coagulated raw water; SSF-1 1 treated effluents from URFL -1
- ❖ URFL – 2 treated raw water without coagulation, SSF-2 treated effluents from URFL -2
- ❖ Other raw water quality parameters (average) included:
  - o pH
  - o True Colour
  - o Temperature
  - o Conductivity

❖ <u>Performance of Up-flow roughing filtration in layers:</u>

The performance of URFL-1 was better than URFL-2 at all times. This is attributed to the addition of coagulants to water that was treated by URFL-1.

❖ At the beginning of the first test run (See Appendix B: day 1 up to day 14), URFL-1 produced effluents with turbidity less than 2. 5 NTU while the turbidity of URFL-2 effluents for the same period ranged from 5.4 to 25.3 NTU (see Appendix B).

- Interestingly, the turbidity of the effluents for both URFL units was high on the first day. This is attributed to self-cleansing effect of the new filter media before maturing.

- The turbidity of URFL -1 effluent improved from day 1 and was less than 1 NTU up to day 8 regardless of the fluctuations of the raw water turbidity. Afterwards it was slightly above 1.00 NTU on days 9 and 10, but sharply increased to 5.94 on day 11 after which it never dropped to less than 1 NTU and the filter was cleaned on day 14.

    - It is clear that as the filtration process progresses, the storage capacity of the filter media is reduced due to floc/turbidity retention which eventually leads to floc/turbidity break-through.

> When the turbidity breaks through (i.e. increases to undesirable levels), then the filter media need cleaning

    - The retention and accumulation of flocs in URFL-1 were visible through the clear PVC windows (see Figure 4.1).

Figure 4-1: Pictures showing floc retention in URFL- 1, PENTECH Plant.

- The turbidity of URFL-2 effluent was however never less than 5 NTU during the fist test run but was averaging 10 NTU during the first 10 days. When turbidity broke-through on day 11 (same day as URFL-1), the effluent turbidity doubled to an average of about 20 NTU for the remaining 4 days up to day 14. (see Appendix B).

> Turbidity break-through in URFL-2 was much higher than URFL 1 and it can generally be said that in the absence of coagulation, turbidity break-through are much higher and can have a much more adverse effect on subsequent slow sand filtration processes.

- However, prolonged URFL operation without cleaning URFL results in turbidity break-through (> 10 NTU) and must be avoided as it impacts on SSF performance in terms of filter runs and effluent quality.

> It is recommended that URFL are drained at least once every week regardless of the effluent quality in order ensure sufficient protection of slow sand filtration.

❖ **<u>Performance of slow sand filtration:</u>**

The performance of the slow sand filter (SSF-1) that received effluent from URFL-1, which treated coagulated raw water, was by far better than the one (SSF 2) in the production line that did not include coagulation during the first 3 weeks. After about 3 weeks, the performance of SSF-2 significantly improved signifying the maturation of the slow sand filtration process.

The following observations can thus be made:

- ❖ Coagulation enhances maturation of slow sand filtration with respect to turbidity removal
- ❖ Where there is no coagulation, slow sand filters must be allowed to mature before good performance is expected.

The average turbidity for SSF-1 and SSF-2 effluents in the data in Appendix B were 0.69 and 2.13 NTU, respectively.

It is evident that if slow sand filtration is supplied with well pre-treated raw water, its performance can be guaranteed as long as all operational parameters are satisfied and that it is allowed to mature.

A mature slow sand filter is able to reduce turbidity to less than 1 NTU, a quality recommended for effective disinfection

However, both URFL units indicated that their performance decreases with increased raw water turbidity levels. URFL was required to produce less than 10 NTU turbidity effluents, but higher values were recorded with increased raw water turbidity and prolonged operation. Because of the coagulation URFL-1 and SSF-1 comparatively performed better.

4.3 URFL – SSF plant located Ashton

Table 4.2 presents a summary of the sample turbidity reduction results presented in Appendix C for the plant that was located in Ashton.

Table 4-2: Sample turbidity results over 126 days –Ashton Plant

Raw water turbidity to both URFLs (NTU)	Average removal (%) (Effluent turbidity values - NTU)			
	URFL-1 (SSF-1 Influent)	**URFL-2 SSF-2 Influent)**	**SSF-1**	**SSF-2**
1.47 - 172	41 - 71%	35 – 71%	78 - 80	69 - 77
	(1.46 – 57.8)	(1.46 – 58.0)	(0.17 – 14.8)	(0.22- 12.63)

NOTE:

- ❖ URFL – 1 treated coagulated raw water; SSF-1 1 treated effluents from URFL -1
- ❖ URFL – 2 treated raw water without coagulation, SSF-2 treated effluents from URFL -2
- ❖ Other raw water quality parameters (average) included:
  - ❖ pH = 5.5 – 7.5
  - ❖ True Colour = 5 – 40 TCU
  - ❖ Temperature = 11 – 20 ^{o} C
  - ❖ Conductivity = 105 – 1600 us/ms
  - ❖

Analysis and discussion of data in Table C 1:

During for which the data in Table C1 appendix C is presented, the filtration rates for both URFL and SSF were analysed by volumetric analysis (see table 4.3 for sample results)

Table 4-3: Sample results of volumetric analysis for filtration rates

			URFL-1 inflow				SSF-1 inflow				SSF-1 outflow			
Date	Time	No	V (ml)	t (s)	Flow (l/h)	V_f (m/h)	V (ml)	t (s)	Flow (l/h)	Vf (m/h)	V (ml)	t (s)	Flow (l/h)	Vf (m/h)
06/09/2003	13:00	1	295	19.82	53.582	0.462	205	49.22	14.994	0.129	145	32.4	16.111	0.139
		2	215	13.66	56.662	0.488	200	46.81	15.381	0.133	155	34.47	16.188	0.139
		3	175	11.37	55.409	0.477	220	52.22	15.167	0.131	100	22.72	15.845	0.137
				Avg	55.218	0.476		Avg	15.181	0.131		Avg	16.048	0.138
			URFL-2 inflow				SSF-2 inflow				SSF-2 outflow			
Date	Time	No	V (ml)	t (s)	Flow (l/h)	Vf (m/h)	V (ml)	t (s)	Flow (l/h)	Vf (m/h)	V (ml)	t (s)	Flow (l/h)	Vf (m/h)
11/09/2003	09:30	1	215	12.96	59.722	0.515	175	51.62	12.205	0.105	135	42.97	11.310	0.097
		2	225	13.62	59.471	0.512	195	56.53	12.418	0.107	135	42.94	11.318	0.098
		3	235	14.4	58.750	0.506	185	53.78	12.384	0.107	150	46.46	11.623	0.100
				Avg	59.315	0.511		Avg	12.336	0.106		Avg	11.417	0.098

❖ **Performance of up-flow roughing filtration in layers:**

The performance of URFL-1 was better than URFL-2 when coagulation was applied to raw water supplied to URFL- 1 on day 1.

Preceded by coagulation, URFL- 1 improved the reduction of turbidity by 50 to 70% when compared to URFL

Without coagulation, the performance of both URFLs was basically the same. For the raw water turbidity that was less than 30 NTU most of the time, both URFLs managed to reduce turbidity to less than 10 NTU.

Generally, the turbidity removal by URFL with or without coagulation, improved when raw water turbidity reduced. For instance, for the days when raw water turbidity was less than 10 NTU, URFL effluents consistently had turbidity less than 5 NTU.

Hence, if raw water has low turbidity (<30 NTU), URFLs can manage to adequately pre-treat the water without the aid of coagulation.

❖ **Performance of slow sand filtration:**

From the date the plant was commissioned, the turbidity of the effluent from SSFs was greater than 1 NTU and at few occasions greater than 5 NTU. At times the turbidity of SSF effluents was greater than the inflow turbidity!

With respect to turbidity reduction, a well designed slow sand filtration plant is expected to reduce turbidity less than 1 NTU.

Experience to date has indicated that when prolonged high turbidity in slow sand filtration effluents are recorded (say over a period in excess of 1 week), it can only be attributed to the use of unclean sand, i.e. inadequately washed sand.

However, short period (<1 week) high turbidity are only expected from newly commissioned slow sand filters due to the self cleansing of the filter media.

Generally, slow sand filtration is expected to produce effluent with turbidity less 1 NTU within a few days of being commissioned.

Due to the inability of SSF to produce effluent less than 1 NTU for the period reported in Table C1, It was therefore concluded that the filter media was not adequately clean. In order to ascertain this conclusion, the plant was operated further in August and September 2003 (see Appendix C Table C2).

Analysis and discussion of data in Table C 2:

In this period, the turbidity of the SSF effluent did not improve to less than 1 NTU as desired. Due to the higher average turbidity of the raw water (> 60 NTU) , the turbidity of the URFL effluents was also on average higher than 10 NTU.

The inability of URFL to handle higher turbidity loads reconfirms the need for inclusion of coagulation to enhance turbidity removal in roughing filtration.

Consequently, the turbidity of the SSF effluents also increased to an average of 5 NTU. However the turbidity of the SSF effluents started decreasing after 2 weeks, but still above 1 NTU (see Table C2 6th to 12th September 2003). This was seen as an indication for the maturation of the slow sand filtration process. Nevertheless, it was still suspected that the filter media was highly contaminated and was never going to produce better effluents.

→ The filter sand was then removed and washed and the plant was run for another period whose results are reported in Appendix C Table C3 and discussed in the following paragraphs.

Analysis and discussion of data in Table C3

URFL showed better performance for raw water turbidity levels less than 10 – 20 NTU, having produced effluents with turbidity consistently less than 5 NTU.

Nevertheless, URFL performances deteriorated with increasing raw water turbidity levels. For instance:

→ For raw water turbidity levels between 20 and 172 NTU, URFL effluent turbidity levels increased to between 14 and 60 NTU, without the aid of coagulation (see 27th July to 14th September 20004 in Table C3) .

Slow sand filtration performed well for the first month producing effluents with turbidity averaging 1 NTU. This was an indication of the fact that the cleanness of the filter media could have previously been affecting the filtrate quality of slow sand filtration. However, performance started to deteriorate with time.

In Tables C1 and C2, the ineffectiveness of the SSF based in ASHTON was attributed to the inadequate cleanness of the filter sand and possibly non-maturation of the filter media's ***schmutzdecke***. Unclean sand is expected to clean itself as filtration progresses during which the ***schmutzdecke*** is expected to mature as well. The results indicated the ability of SSF to produce effluents with turbidity less than 1 NTU for a period of about 4 weeks. However, turbidity break-through (above 1 NTU) were noted after this time although the inflow quality remained the same.

Deterioration of SSF effluent quality is not expected with time of operation; the turbidity of the effluent is actually supposed to improve with time**.** The raw water quality could have colloidal particles, especially colour causing, which would not easily be removed even with SSF. It seems even with a fully developed schumtzdecke, this particulate matter still breaks through.

The challenges experienced by slow sand filtration in producing good effluent quality are largely dependent on the quality of raw water. Although SSF is conventionally known not to experience turbidity break-through, it is actually likely to occur depending on the raw water quality.

4.4 Operation and monitoring

Both plants required close operation and monitoring.

> The most crucial operational parameters that demanded close monitoring were chemical dosing rates, filtration rates (flow rates) and raw water quality (turbidity).

The other parameters that were monitored were the head-loss and accumulation of sludge in URFL units. The filter columns for both URFL and SSF units were equipped with small windows made of clear PVC for visual observation of the filter media.

The monitoring of all parameters was achieved by trained operators (student research assistants) who were visiting the plants almost daily.

> The methods used for monitoring included visual observations, on-site measurements of flows and water quality.

It was found that if the quality of raw water is generally less variable, the frequency of monitoring could be much less. But filtration rates were checked daily.

4.5 Maintenance

The maintenance of both plants was essential to ensure that they operated within the desired operational parameters and produced the expected results. Maintenance tasks included the following:

- Regular flushing of the pipe systems to remove sediments that could have impacted on the flow rates
- Flushing of the roughing filtration system remove excessive accumulation of suspended solids prevent: this was done when effluent quality or head-loss reached terminal values.
- Filter media cleaning in slow sand filtration by the scraping process when terminal head-loss was reached.

The maintenance of both plants was relatively easier as the maintenance procedures did not entail use of mechanical equipment.

5 Guidelines for URFL-SSF systems

5.1 General

The guidelines presented in this chapter were drawn from the experience gained on the pilot upflow roughing filtration in layers (URFL)-slow sand filtration (SSF) plants used in the project, in addition to literature review. Roughing filtration is conventionally recommended for application without the aid of chemical coagulation, but this project also looked at the use coagulation to enhance the performance of roughing filtration. Hence, the guidelines also include the use coagulation in roughing filtration.

They are presented as a general check list and are divided into the following aspects:

- ❖ General guidelines for application
- ❖ Guidelines for design and construction
- ❖ Guidelines for operation and maintaining
- ❖ Guidelines for maintenance

The consultation of a publication by Wegelin M (1996) is highly recommended.

5.2 Guidelines for application

The guidelines for the practical application of URFL-SSF systems are:

(1) URFL-SSF systems are generally recommended for small and rural applications because of their simplicity in design, operation and maintenance.

- ❖ The capacity of full-scale URFL-SSF plants should generally be less than 1 Ml/d, but plants of up to 2 Ml/d are reported to exist.

(2) Depending on the raw water, URFL-SSF systems can be employed with or without coagulation in treating surface waters highly characterised by turbidity.

- ❖ The incorporation of Coagulation in URFL-SSF systems, either continuous or intermittently, greatly improves the reduction of turbidity

(3) If URFL are to be used without coagulation to reduced suspended matter, then the turbidity of the source water is recommended to be less than 30 NTU

(4) Where raw water seasonally exhibit high turbidity, intake pre-treatment options such as plain sedimentation, intake or dynamic roughing filters should be considered.

- ❖ Plain sedimentation is achieved by storing water in some reservoir for at least 4 hrs
- ❖ **Appendix E** presents descriptions and design of Intake and dynamic roughing filtration

(5) For the treatment of raw waters with colour, continuous coagulation is recommended. However, intermittent coagulation is possible and must only be applied if pilot testing has proved that the plant will work effectively.

- ❖ Aluminium sulphate is the recommended coagulant for URFL-SSF systems because it demands less stringent controls and dosing requirements compared to other coagulants and it is readily available and affordable for small plants.

- ❖ Optimum coagulant dosages should be estimated using Jar tests experiments (**see Appendix D for the procedure**)

(6) Since URFL-SSF systems are generally simple technologies, to ensure compatibility the addition of coagulant chemicals must also be achieved by simpler technologies especially those that dose by gravity (see PART A of the report).

(7) Although URFL-SSF systems are considered simpler technologies adequate training must be provided to operators to ensure sustainability. Areas of training include:

- ❖ Flow measurements and basic water quality analysis for parameters such as turbidity, colour, pH and suspended solids.
- ❖ Preparation of chemical solutions and dosing
- ❖ Process performance evaluation and trouble shooting

5.3 Guidelines for design and construction

It is recommended that the design of upflow roughing filtration in layers (URFL) and slow sand filtration (SSF) systems be undertaken by persons skilled in the field of water treatment. It is also important that the designers are involved in supervising the construction.

It is important that the design considers local conditions as much as possible and that the construction makes use of local resources

In addition to the information given in the literature review chapter and design values presented in Tables 3.1 and 3.2, the following are the guidelines for the design and construction of URFL-SSF systems

(1) A minimum of two filter units for both URFL and SSF processes is recommended.

(2) The layout of filters and location gate valves must ensure reliability and uninterrupted operation during maintenance.

- ❖ See Figure 3.1 for a typical cross section view of a slow sand filter unit.
- ❖ It must be possible to isolate each filter without interrupting operation of other filters (see Appendix A for the layout of filters)

(3) The flow through plant must preferably be by gravity.

(4) In case of rehabilitation projects, the use of existing structures is recommended as much as possible (see Figure 3.4).

(5) Preference must be given to rectangular shapes for the filters so that common walls can be taken advantage of.

(6) Filter media (sand) for slow sand filtration must be carefully selected and thoroughly cleaned prior to use; use of unclean sand can result in long initial maturation periods.

(7) Design of filter units must allow for sampling points and flow measuring points.

- ❖ It is recommended that sampling points and flow measuring be done at the inlet works and effluents of each filter (see fig 5.1)

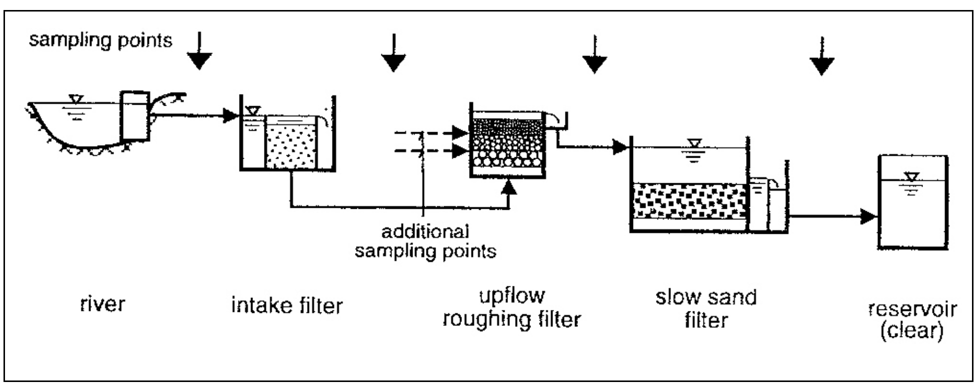

Figure 5-1: Location of water sampling points (Wegelin 1996)

(8) Filter media cleaning facilities for both URFL and SSF units must be provided.

5.4 Operation, monitoring and maintenance

Without effective operation, monitoring and maintenance, any well designed and constructed facility can not be effective.

Although, upflow roughing filtration in layers (URFL) and slow sand filtration (SSF) systems, combined with gravity chemical dosing system (Part A), are considered simple technologies it is important that adequate attention is given to operation, monitoring and maintenance aspects to ensure sustainability.

The guidelines for operation, monitoring and maintenance of URFL-SSF systems can be obtained from referenced literature. The following are key aspects as learnt from the project:

(i) <u>When commissioning new URFL, the effluent turbidity on the first day or two may not be acceptable (<10 NTU) for SSF due to the self-cleansing of the filter media.</u>

- ❖ If turbidity of newly commissioned URFL is not less than 10 NTU, it is recommended that URFL be filtered to waste until the turbidity is less than 10 NTU.

(ii) <u>Similarly, the turbidity of SSF effluents for new filters may not be acceptable due to the self-cleansing of the filter media.</u>

(iii) <u>Flow rates to each filter unit must be known whenever the filtration process is in operation.</u>

- ❖ A calibration table/chart must be developed which should show the relationship between flow (m^3/h) and filtration rates ($m^3/h/m^2$) for easy check of filtration rates of each filter.
- ❖ URFL filtration rates must preferably be kept at an average 0.50 $m^3/h/m^2$ so that one UFRL unit can supply at least 2 SSF units.
- ❖ The SSF process must operate at an average filtration rate of less than 0.20 $m^3/h/m^2$.

(iv) <u>Basic water quality parameters that must be monitored must include turbidity.</u>

- ❖ Turbidity of effluents from URFL must be less than 10 NTU.
  - ❖ If the turbidity of URFL effluents is greater than 10 NTU during operation, then the filter is due for cleaning:
    - o Cleaning of URFL is simply achieved by draining the filter.
    - o It is recommended that URFL are cleaned at least once every week even if the terminal turbidity is not reached.
- ❖ Turbidity of effluents from matured SSF must be less than 1 NTU.
  - ❖ If the turbidity of effluents from newly commissioned SSF is greater than 1 NTU for prolonged periods greater than 4 weeks, then it implies that the quality of the filter media is not adequate and must be replaced

(v) <u>Head losses must be recorded daily for both URFL and SSF processes.</u>

- ❖ URFL head loss must be kept below 30 cm, while that of SSF must never exceed the depth of the supernatant water.
- ❖ Head loss is the main indicator parameter for the filter-run of SSF, which are capable of operating for at least a month before cleaning is required.

Typical head losses of SSF in South Africa are reported to be between 4 to 6 weeks.

(vi) <u>Maturation period of newly commissioned SSF must be considered where there is no disinfection.</u>

- ❖ A SSF is considered mature when its filtrate has no microbiological contamination
- ❖ A SSF would typically mature within 3 to 4 weeks where there is no coagulation prior to URFL; with coagulation (using ALUM), this period is reduced to less than 3 weeks.

6 Conclusions and recommendations

6.1 Conclusions

Although URFL-SSF systems have conventionally been in application for the treatment of turbid raw water without the aid of coagulation, the incorporation of coagulation (using a simple gravity chemical dosing system developed in Part A) prior to URFL have indicated enhanced performance of both URFL and SSF processes:

- the incorporation of coagulation increases the capability of URFL to handle sudden peaks of turbidity in raw waters and also the variation of raw water turbidity.
- Maturation of SSF is speeded up where the combination of coagulation and URFL is used prior to the SSF process.
- URFL filter media cleaning is more effective where coagulation is applied.
- It was also observed that intermittent coagulation can still return good performance of URFL. This is envisaged to result in cost-saving with respect to coagulant chemicals.

Without coagulation, URFL is not capable of effectively treating raw water with turbidity generally greater than 30 NTU. This inability for URFL to handle higher turbidity loads reconfirms the need for inclusion of coagulation to enhance turbidity removal or for inclusion of addition pre-treatment processes.

The project developed some key guidelines for the design and application of the combination of coagulation and URFL-SSF systems.

6.2 Recommendations

The following are the recommendations for the application and further research:

(1) Because of their simplicity in design, operation and maintenance, URFL-SSF systems are recommended for small water treatment plants. Therefore, if coagulation is incorporated in URFL-SSF, it must be compatible in simplicity, design, operation and maintenance as well. Gravity chemical dosing systems as reported in Part A of this report are highly recommended.

- ❖ Where coagulation is used in URFL, the use of Aluminium Sulphate (ALUM) is recommended because of easier and economical application.

(2) Adding coagulation prior to URFL means more effective removal of suspended solids, hence more sludge production. This means URFL would need more sludge storage space. It is therefore likely that the smaller gravel fractions (< 5 mm) may not be necessary in URFL if coagulation is used. Although Wegelin (1996) recommends that the optimum number of filter gravel layers in URFL should be three, adding coagulation would mean more sludge production. Hence, replacement of the smaller gravel layers with large size gravel when coagulation is used is a question that needs research.

(3) The impact of coagulation on the efficiency of slow sand filtration to remove faecal coliforms (indicators of the presence of pathogens organisms) and other contaminants and pollutants is another area that needs further investigation. Slow sand filtration is well known for its ability to remove pathogens even without coagulation because of the dirty layer (*Schmutzdecke*) that forms on top of the sand. But it is known to be not very effective in treating coloured waters.

(4) It is recommended that further treatment be applied prior to URFL if raw water turbidity is higher than 30 NTU. The use of dynamic and/or intake roughing filtration is recommended for protection of URFL-SSF systems (see Appendix E).

(5) The use URFL-SSF systems in combination with coagulation to treat coloured waters in South Africa requires further treatment.

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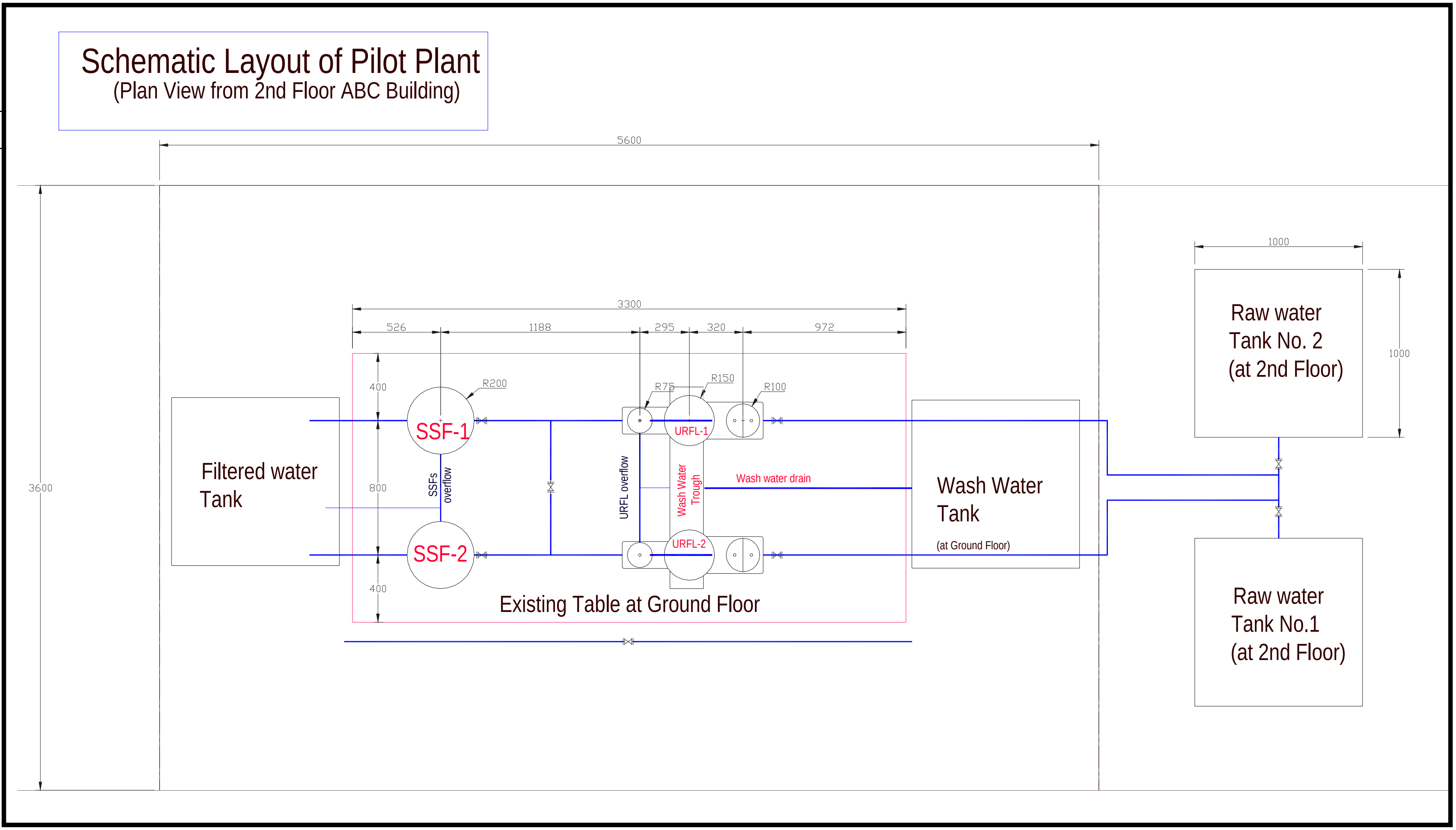
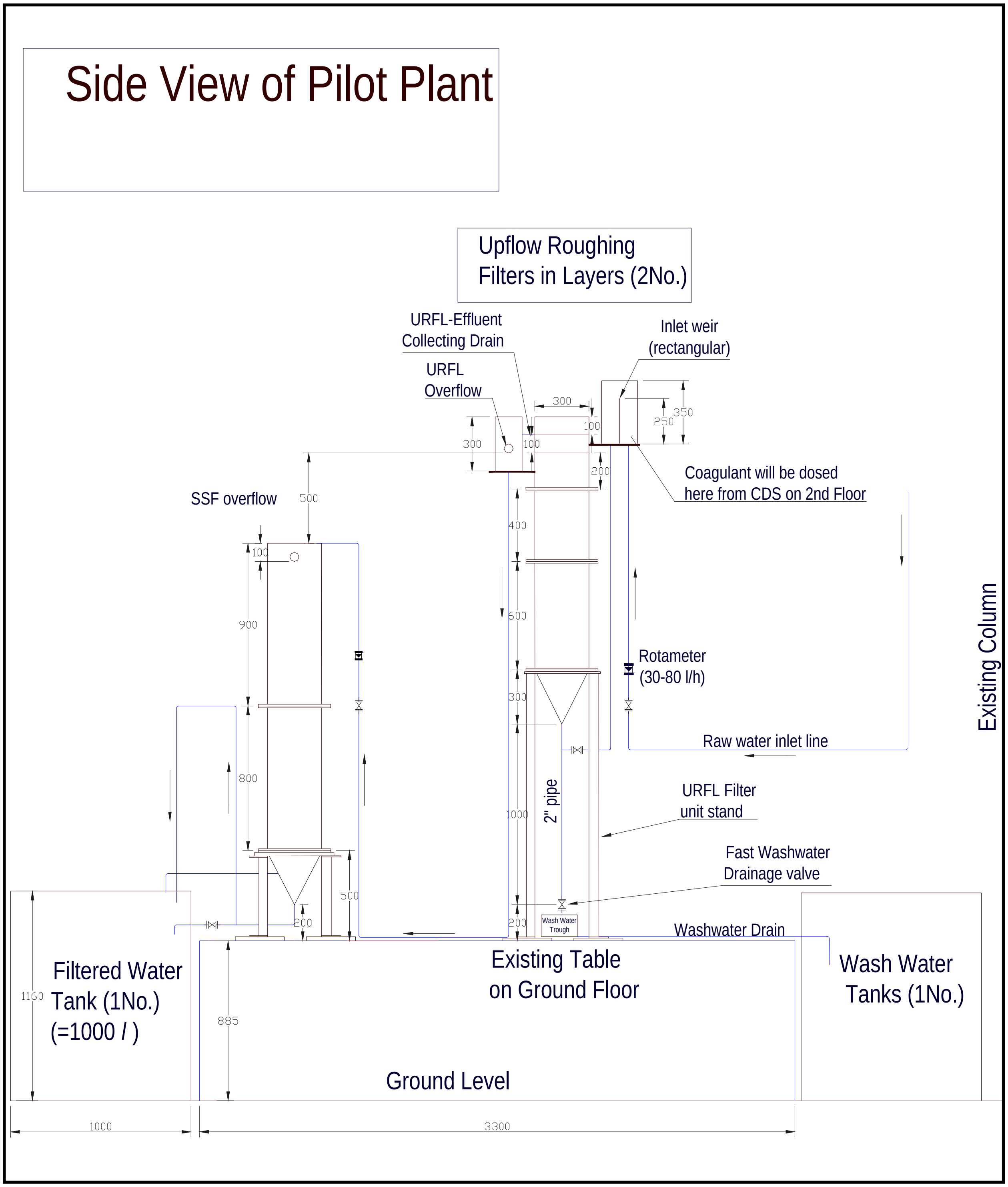
Appendices

Appendix D: Schematic layout of the PENTECH plant – Plan view



Schematic layout of the PENTECH plant – Section view



Appendix E: Turbidity analysis results PENTECH Plant

Day	Average turbidity levels													
	URFL-1			URFL-2				SSF-1				SSF-2		
	Influent	Effluent	% Removal	Influent	Effluent	% Removal		Influent	Effluent	% Removal		Influent	Effluent	% Removal
1	110.80	2.34	97.9%	107	12.70	88.1%		2.34	-	-		12.70	-	-
2	86.55	1.00	98.9%	114	5.90	94.8%		1.00	0.91	8.5%		5.90	3.04	48.4%
3	61.30	0.60	99.0%	65.7	12.5	80.9%		0.60	0.55	8.0%		12.53	3.34	73.3%
4	45.20	0.92	98.0%	81.3	12.7	84.3%		0.92	0.77	16.6%		12.73	4.05	68.2%
5	59.47	1.01	98.3%	54.5	9.05	83.4%		1.01	0.61	39.1%		9.05	3.37	62.7%
6	40.35	1.40	96.5%	41.82	8.97	78.5%		1.40	0.56	59.7%		8.97	2.92	67.4%
7	81.80	0.68	99.2%	100.10	16.10	83.9%		0.68	0.92	-34.6%		16.10	4.70	70.8%
8	99.00	0.58	99.4%	98.00	5.40	94.5%		0.58	0.32	44.8%		5.40	2.06	61.8%
9	84.57	1.20	98.6%	81.97	15.60	81.0%		1.20	0.37	69.1%		15.60	2.69	82.8%
10	146.33	1.04	99.3%	97.03	10.68	89.0%		1.04	0.75	28.2%		10.68	2.18	79.6%
11	134.52	5.94	95.6%	119.25	25.30	78.8%		5.94	0.91	84.7%		25.30	2.52	90.0%
12	133.33	3.37	97.5%	75.87	17.77	76.6%		3.37	0.76	77.5%		17.77	2.40	86.5%
13	151.67	3.01	98.0%	105.33	21.80	79.3%		3.01	0.87	71.1%		21.80	2.24	89.7%
14	135.00	4.00	97.0%	105.67	17.67	83.3%		4.00	1.00	75.0%		17.67	2.00	88.7%
15	-	-	-	-	-	-	-	-	-	-	-	-	-	-
16	-	-	-	-	-	-	-	-	-	-	-	-	-	-
17	250.00	-	-	161.00	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	-	-	-	-	-	-	-	-	-	-
19	68.00	2.00	97.1%	125.67	13.67	89.1%		2.00	1.00	50.0%		13.67	2.00	85.4%
20	105.88	1.03	99.0%	97.17	4.80	95.1%		1.03	1.05	-1.6%		4.80	1.70	64.6%
21	128.00	1.00	99.2%	193.67	8.00	95.9%		1.00	1.00	0.0%		8.00	1.50	81.3%
22	34.33	3.33	90.3%	91.33	15.00	83.6%		3.33	1.00	70.0%		15.00	2.00	86.7%
23	199.33			115.82	-	-		-	-	-		-	-	-
24	133.48	1.44	98.9%	130.48	27.37	79.0%		1.44	2.00	-38.6%		27.37	-	-
25	149.58	1.67	98.9%	93.62	25.00	73.3%		1.67	1.00	40.0%		25.00	2.00	92.0%
26	143.08	0.47	99.7%	46.07	-	-		0.47	0.38	20.2%		-	-	-
27	62.67	0.33	99.5%	-	-	-		0.33	0.25	25.0%		-	-	-
28	175.00	0.50	99.7%	-	-	-		0.50	0.33	34.4%		-	-	-
29	-	-	-	-	-	-		-	-	-		-	-	-
30	156.00	-	-	128.33	1.18	99.1%			0.37			1.18	0.80	32.6%
31	324.83	0.89	99.7%	72.30	9.40	87.0%		0.89	0.32	63.9%		9.40	1.47	84.4%
32	26.72	0.30	98.9%	46.00	4.89	89.4%		0.30	0.34	-12.9%		4.89	1.20	75.4%
33	51.27	-	-	52.23	-	-		-	-	-		-	-	-
34	170.25	1.15	99.3%	126.08	1.14	99.1%		1.15	0.27	76.6%		1.14	0.81	28.7%
35	300.33	1.70	99.4%	100.33	14.10	85.9%		1.70	0.60	64.7%		14.10	0.70	95.0%
36			0.0%	-	-	-		-	-	-		-	-	-
37	170.33	0.60	99.6%	103.50	10.13	90.2%		0.60	0.45	25.0%		10.13	0.70	93.1%
38	192.17	1.52	99.2%	188.17	20.17	89.3%		1.52	0.45	70.3%		20.17	0.85	95.8%
39	227.00	-	-	87.67	-	-		-	-	-	-	-	-	-
Min	*26.72*	*0.30*	*0.00%*	*41.82*	*1.14*	*73.30%*		*0.30*	*0.25*	*-38.57%*		*1.14*	*0.70*	*28.74%*
Max	*324.83*	*5.94*	*99.73%*	*193.67*	*27.37*	*99.10%*		*5.94*	*2.00*	*84.69%*		*27.37*	*4.70*	*95.79%*
Ave	*130.53*	*1.55*	*95.05%*	*100.21*	*12.85*	*86.39%*		*1.55*	*0.69*	*36.96%*		*12.85*	*2.13*	*75.40%*

Appendix F: Turbidity analysis results – Ashton Plant

Table C 1: Sample Turbidity analysis results for period 14th – 21st June 2003

Turbidity (NTU)			Sample No					Turbidity (NTU)			Sample No			
Time	Date	Filters	1	2	3	Average		Time	Date	Filters	1	2	3	Average
08:00	14-Jun-03	SSF1 eff	3.62	3.68	3.73	3.68		08:00	15-Jun-03	SSF1 eff	4.19	4.5	4.05	4.25
No chemical dosed		SSF2 eff	2.59	2.7	2.56	2.62				SSF2 eff	3.29	3.01	3	3.1
		URFL1 eff	6.01	5.95	5.83	5.93				URFL1 eff	5.46	5.96	5.84	5.75
		URFL2 eff	5.94	5.77	5.84	5.85				URFL2 eff	4.72	4.55	4.65	4.64
		URFL1 in	22.9	22.9	22	22.6				URFL1 in	42	42.2	42.8	42.33
		URFL2 in	16.1	16.4	16.8	16.43				URFL2 in	34.9	34.6	34.3	34.6
10:00	14-Jun-03	SSF1 eff	3.42	3.71	3.64	3.59		09:30	15-Jun-03	SSF1 eff	3.46	3.44	3.18	3.36
No chemical dosed		SSF2 eff	2.63	2.76	2.77	2.72				SSF2 eff	2.68	2.96	2.86	2.83
		URFL1 eff	6.22	6.31	6.16	6.23				URFL1 eff	5.33	5.52	5.47	5.44
		URFL2 eff	6.17	6.32	6.51	6.33				URFL2 eff	3.68	3.26	3.6	3.51
		URFL1 in	35	35.2	35.7	35.3				URFL1 in	46.4	46.9	45.9	46.4
		URFL2 in	41.1	39.9	40	40.33				URFL2 in	37.1	37	37.7	37.27
11:00	14-Jun-03	SSF1 eff	3.29	3.09	3.06	3.15		11:00	15-Jun-03	SSF1 eff	3.88	3.8	3.65	3.78
Chemical dosed till the following day		SSF2 eff	3.59	3.57	3.49	3.55				SSF2 eff	3.47	3.37	3.36	3.4
		URFL1 eff	5.92	5.72	5.4	5.68				URFL1 eff	6.98	6.77	6.78	6.84
		URFL2 eff	5.55	5.36	5.14	5.35				URFL2 eff	3.5	3.21	3.6	3.44
		URFL1 in	27.5	27.6	27.8	27.63				URFL1 in	59.6	60.7	60.7	60.33
		URFL2 in	19.3	20.7	20.3	20.1				URFL2 in	49.8	49.8	50.1	49.9
12:00	14-Jun-03	SSF1 eff	3.63	3.52	3.38	3.51		12:00	15-Jun-03	SSF1 eff	3.49	3.4	3.4	3.43
		SSF2 eff	4.27	4.21	4.18	4.22				SSF2 eff	3.25	3.01	3.21	3.16
		URFL1 eff	6.03	6.17	6.19	6.13				URFL1 eff	6.66	6.51	6.98	6.72
		URFL2 eff	3.08	2.94	2.95	2.99				URFL2 eff	2.7	2.72	2.7	2.71
		URFL1 in	19.6	20.3	20.5	20.13				URFL1 in	44.2	43.9	44.6	44.23
		URFL2 in	17	16.5	16.6	16.7				URFL2 in	35.4	35.7	36.1	35.73
13:00	14-Jun-03	SSF1 eff	3.77	3.63	3.82	3.74		13:00	15-Jun-03	SSF1 eff	3.53	3.58	3.6	3.57
		SSF2 eff	3.67	3.36	3.58	3.54				SSF2 eff	3.51	3.34	3.32	3.39
		URFL1 eff	5.2	5.46	5.7	5.45				URFL1 eff	5.98	5.97	5.99	5.98
		URFL2 eff	3.36	3.59	3.37	3.44				URFL2 eff	2.21	2.17	2.08	2.15
		URFL1 in	97.5	96.9	92.9	95.77				URFL1 in	36.9	35.9	35.8	36.2
		URFL2 in	99	98.5	99.5	99				URFL2 in	32.2	32.3	32.5	32.33
14:30	14-Jun-03	SSF1 eff	4.88	4.64	4.49	4.67		14:15	15-Jun-03	SSF1 eff	3.78	3.63	3.62	3.68
		SSF2 eff	3.86	3.92	3.74	3.84				SSF2 eff	3.97	3.85	3.79	3.87
		URFL1 eff	5.27	5.3	3.72	4.76				URFL1 eff	6.88	6.18	6.86	6.64
		URFL2 eff	2.53	2.59	2.46	2.53				URFL2 eff	3.44	3.58	3.49	3.5
		URFL1 in	49.6	50	48	49.2				URFL1 in	35.3	34.4	35.3	35
		URFL2 in	46.6	46.5	47	46.7				URFL2 in	25.1	26.9	27.2	26.4
16:00	14-Jun-03	SSF1 eff	4.91	4.94	4.84	4.9		15:15	15-Jun-03	SSF1 eff	3.84	3.95	3.68	3.82
		SSF2 eff	3.91	3.94	3.85	3.9				SSF2 eff	3.95	3.78	3.98	3.9
		URFL1 eff	7.06	7.02	7.54	7.21				URFL1 eff	4.86	4.97	4.72	4.85
		URFL2 eff	2.36	2.28	2.46	2.37				URFL2 eff	4.56	4.3	4.53	4.46
		URFL1 in	31.4	32	30.2	31.2				URFL1 in	19.9	20.6	20.8	20.43
		URFL2 in	28.9	28.6	28	28.5				URFL2 in	16.7	16.2	16.7	16.53
								16:15	15-Jun-03	SSF1 eff	3.65	3.95	3.93	3.84
										SSF2 eff	3.59	3.56	3.49	3.55
										URFL1 eff	5.74	5.88	5.77	5.8
										URFL2 eff	4.44	4.38	4.45	4.42
										URFL1 in	12.4	12.6	13.2	12.73
										URFL2 in	11.9	11.5	11.5	11.63

Table C 1 Continued

Turbidity (NTU)			Sample No			
Time	Date	Filters	1	2	3	Average
08:00	16-Jun-03	SSF1 eff	2.90	2.90	2.99	2.93
		SSF2 eff	3.43	3.40	3.36	3.40
		URFL1 eff	4.18	4.27	4.54	4.33
		URFL2 eff	5.13	5.22	5.06	5.14
		URFL1 in	15.90	15.50	15.00	15.47
		URFL2 in	16.50	16.10	15.90	16.17
09:30	16-Jun-03	SSF1 eff	3.10	2.80	2.70	2.87
		SSF2 eff	3.40	3.10	3.50	3.33
		URFL1 eff	4.48	4.78	4.72	4.66
		URFL2 eff	5.26	5.30	5.42	5.33
		URFL1 in	23.70	23.80	23.70	23.73
		URFL2 in	21.50	22.00	22.10	21.87
11:00	16-Jun-03	SSF1 eff	2.94	2.79	2.60	2.78
		SSF2 eff	3.80	3.48	3.76	3.68
		URFL1 eff	4.02	4.10	4.60	4.24
		URFL2 eff	5.37	5.32	5.17	5.29
		URFL1 in	24.30	24.50	24.70	24.50
		URFL2 in	24.90	24.10	22.00	23.67
12:00	16-Jun-03	SSF1 eff	3.48	3.49	3.27	3.41
		SSF2 eff	3.90	3.97	4.08	3.98
		URFL1 eff	5.70	5.53	5.86	5.70
		URFL2 eff	6.18	6.04	6.03	6.08
		URFL1 in	25.80	25.90	32.40	28.03
		URFL2 in	21.40	20.70	21.90	21.33
13:00	16-Jun-03	SSF1 eff	4.86	4.78	4.99	4.88
		SSF2 eff	4.85	5.01	4.94	4.93
		URFL1 eff	5.52	5.42	5.21	5.38
		URFL2 eff	6.08	6.24	6.08	6.13
		URFL1 in	16.70	17.40	17.40	17.17
		URFL2 in	16.70	16.60	16.10	16.47
15:15	16-Jun-03	SSF1 eff	5.85	5.78	5.87	5.83
		SSF2 eff	5.21	5.17	5.20	5.19
		URFL1 eff	5.05	5.40	5.30	5.25
		URFL2 eff	5.81	5.77	5.83	5.80
		URFL1 in	16.90	17.20	17.20	17.10
		URFL2 in	14.90	14.90	15.10	14.97
16:15	16-Jun-03	SSF1 eff	5.81	3.69	3.79	4.43
		SSF2 eff	5.04	5.08	5.02	5.05
		URFL1 eff	4.82	4.86	4.82	4.83
		URFL2 eff	5.05	5.21	5.11	5.12
		URFL1 in	19.50	19.90	18.50	19.30
		URFL2 in	20.10	20.20	19.70	20.00

Turbidity (NTU)			Sample No			
Time	Date	Filters	1	2	3	Average
08:00	17-Jun-03	SSF1 eff	3.63	3.60	3.59	3.61
		SSF2 eff	3.41	3.35	3.32	3.36
		URFL1 eff	5.01	4.97	5.03	5.00
		URFL2 eff	5.72	5.75	5.71	5.73
		URFL1 in	19.90	20.70	19.40	20.00
		URFL2 in	19.80	19.40	18.70	19.30
09:30	17-Jun-03	SSF1 eff	3.88	3.80	3.82	3.83
		SSF2 eff	3.40	3.30	3.36	3.35
		URFL1 eff	5.15	5.15	5.10	5.13
		URFL2 eff	5.83	5.88	5.85	5.85
		URFL1 in	36.60	36.90	36.90	36.80
		URFL2 in	33.40	32.90	32.70	33.00
10:30	17-Jun-03	SSF1 eff	4.39	4.45	4.46	4.43
		SSF2 eff	3.50	3.54	3.31	3.45
		URFL1 eff	5.88	5.82	5.95	5.88
		URFL2 eff	6.32	6.31	6.31	6.31
		URFL1 in	36.70	36.70	36.10	36.50
		URFL2 in	30.00	29.80	29.60	29.80
11:30	17-Jun-03	SSF1 eff	5.48	5.65	5.76	5.63
		SSF2 eff	3.85	3.78	3.72	3.78
		URFL1 eff	6.14	6.13	6.03	6.10
		URFL2 eff	7.09	7.05	7.15	7.10
		URFL1 in	25.60	24.60	24.80	25.00
		URFL2 in	22.50	22.90	21.40	22.27
12:30	17-Jun-03	SSF1 eff	4.89	4.90	4.93	4.91
		SSF2 eff	3.79	3.83	3.81	3.81
		URFL1 eff	6.23	6.18	6.11	6.17
		URFL2 eff	6.77	6.78	6.79	6.78
		URFL1 in	19.20	19.00	20.10	19.43
		URFL2 in	17.90	18.50	18.60	18.33
13:30	17-Jun-03	SSF1 eff	5.93	5.93	5.20	5.69
		SSF2 eff	4.22	4.36	4.22	4.27
		URFL1 eff	5.47	5.58	5.41	5.49
		URFL2 eff	6.11	6.11	6.12	6.11
		URFL1 in	27.90	27.70	29.60	28.40
		URFL2 in	29.90	29.20	29.10	29.40
15:00	16-Jun-03	SSF1 eff	5.37	5.21	5.21	5.26
		SSF2 eff	4.21	4.19	4.22	4.21
		URFL1 eff	5.22	5.23	5.27	5.24
		URFL2 eff	5.54	5.60	5.76	5.63
		URFL1 in	19.40	19.30	20.00	19.57
		URFL2 in	20.20	20.30	21.50	20.67
16:00	16-Jun-03	SSF1 eff	5.52	5.47	5.44	5.48
		SSF2 eff	4.28	4.39	4.34	4.34
		URFL1 eff	5.00	4.94	5.08	5.01
		URFL2 eff	5.86	5.80	5.69	5.78
		URFL1 in	29.10	30.20	29.40	29.57
		URFL2 in	27.20	27.50	26.20	26.97

Table C 1 Continued

Turbidity (NTU)			Sample No			
Time	Date	Filters	1	2	3	Average
08:00	18-Jun-03	SSF1 eff	3.29	3.18	3.14	3.20
		SSF2 eff	2.64	2.60	2.77	2.67
		URFL1 eff	4.39	4.36	4.32	4.36
		URFL2 eff	5.10	5.19	5.11	5.13
		URFL1 in	36.10	36.20	36.40	36.23
		URFL2 in	22.80	22.70	22.30	22.60
09:30	18-Jun-03	SSF1 eff	3.27	3.22	3.36	3.28
		SSF2 eff	2.70	2.70	2.77	2.72
		URFL1 eff	4.22	4.60	4.67	4.50
		URFL2 eff	5.03	5.01	5.06	5.03
		URFL1 in	16.90	17.30	16.60	16.93
		URFL2 in	15.10	15.40	16.00	15.50
10:30	18-Jun-03	SSF1 eff	3.48	3.46	3.47	3.47
		SSF2 eff	2.85	2.54	2.55	2.65
		URFL1 eff	4.56	4.51	4.67	4.58
		URFL2 eff	4.35	4.33	4.39	4.36
		URFL1 in	14.90	15.10	15.00	15.00
		URFL2 in	15.80	16.00	15.00	15.60
11:30	18-Jun-03	SSF1 eff	3.80	4.06	4.04	3.97
		SSF2 eff	2.77	2.74	3.03	2.85
		URFL1 eff	4.60	4.58	4.30	4.49
		URFL2 eff	5.01	5.00	5.06	5.02
		URFL1 in	13.50	13.70	14.20	13.80
		URFL2 in	12.90	12.80	13.30	13.00
12:30	18-Jun-03	SSF1 eff	4.34	4.31	4.16	4.27
		SSF2 eff	3.32	3.47	3.41	3.40
		URFL1 eff	4.08	4.16	3.98	4.07
		URFL2 eff	4.32	4.36	4.51	4.40
		URFL1 in	11.50	11.20	12.40	11.70
		URFL2 in	12.90	12.20	12.60	12.57
13:30	18-Jun-03	SSF1 eff	4.80	4.60	4.80	4.73
		SSF2 eff	3.50	3.52	3.50	3.51
		URFL1 eff	3.52	3.63	3.60	3.58
		URFL2 eff	4.64	4.44	4.49	4.52
		URFL1 in	36.60	35.70	35.90	36.07
		URFL2 in	36.20	35.20	35.30	35.57
15:00	16-Jun-03	SSF1 eff	5.03	5.00	4.98	5.00
		SSF2 eff	3.60	3.66	3.68	3.65
		URFL1 eff	3.76	3.75	3.67	3.73
		URFL2 eff	4.58	4.44	4.58	4.53
		URFL1 in	19.80	19.50	20.50	19.93
		URFL2 in	16.30	16.10	15.60	16.00
16:00	16-Jun-03	SSF1 eff	5.09	5.08	5.11	5.09
		SSF2 eff	3.89	3.96	3.85	3.90
		URFL1 eff	3.89	3.97	3.91	3.92
		URFL2 eff	4.57	4.56	4.54	4.56
		URFL1 in	20.80	19.70	20.00	20.17
		URFL2 in	17.20	16.90	16.30	16.80

Turbidity (NTU)			Sample No			
Time	Date	Filters	1	2	3	Average
08:00	19-Jun-03	SSF1 eff	3.29	3.06	3.09	3.15
		SSF2 eff	2.25	2.13	2.14	2.17
		URFL1 eff	2.57	2.58	2.60	2.58
		URFL2 eff	3.13	3.20	3.07	3.13
		URFL1 in	19.90	20.40	20.80	20.37
		URFL2 in	18.30	18.70	17.90	18.30
09:30	19-Jun-03	SSF1 eff	2.70	2.77	2.70	2.72
		SSF2 eff	1.99	1.98	2.01	1.99
		URFL1 eff	2.77	2.90	2.84	2.84
		URFL2 eff	3.40	3.46	3.40	3.42
		URFL1 in	14.00	14.30	14.20	14.17
		URFL2 in	16.40	16.70	16.80	16.63
10:30	19-Jun-03	SSF1 eff	2.93	2.89	2.88	2.90
		SSF2 eff	2.16	2.16	2.10	2.14
		URFL1 eff	2.63	2.86	3.70	3.06
		URFL2 eff	4.17	4.24	4.29	4.23
		URFL1 in	18.90	18.40	17.70	18.33
		URFL2 in	14.00	13.60	13.20	13.60
11:30	19-Jun-03	SSF1 eff	3.33	3.29	3.36	3.33
		SSF2 eff	2.38	2.41	2.37	2.39
		URFL1 eff	4.03	4.05	3.97	4.02
		URFL2 eff	4.16	3.96	3.90	4.01
		URFL1 in	14.30	14.40	13.70	14.13
		URFL2 in	13.30	14.50	14.20	14.00
12:30	19-Jun-03	SSF1 eff	3.45	3.61	3.63	3.56
		SSF2 eff	2.65	2.55	2.49	2.56
		URFL1 eff	3.82	3.84	3.92	3.86
		URFL2 eff	3.91	3.96	3.87	3.91
		URFL1 in	14.40	14.90	14.00	14.43
		URFL2 in	14.30	14.60	13.50	14.13
13:30	19-Jun-03	SSF1 eff	4.12	4.20	4.06	4.13
		SSF2 eff	2.64	2.67	2.74	2.68
		URFL1 eff	3.68	3.78	3.78	3.75
		URFL2 eff	3.70	3.78	3.70	3.73
		URFL1 in	38.10	37.30	37.90	37.77
		URFL2 in	32.30	33.50	33.60	33.13
15:00	19-Jun-03	SSF1 eff	4.68	4.68	4.62	4.66
		SSF2 eff	3.23	3.16	3.28	3.22
		URFL1 eff	3.96	4.03	4.02	4.00
		URFL2 eff	4.01	4.02	4.06	4.03
		URFL1 in	18.40	18.60	17.30	18.10
		URFL2 in	15.00	15.50	16.10	15.53
16:00	19-Jun-03	SSF1 eff	4.86	4.79	4.81	4.82
		SSF2 eff	3.39	3.54	3.39	3.44
		URFL1 eff	3.80	3.87	3.73	3.80
		URFL2 eff	4.06	3.93	4.00	4.00
		URFL1 in	29.80	29.90	30.40	30.03
		URFL2 in	21.00	22.30	21.60	21.63

Table C 1 Continued

Turbidity (NTU)			Sample No					Turbidity (NTU)			Sample No			
Time	Date	Filters	1	2	3	Average		Time	Date	Filters	1	2	3	Average
08:00	20-Jun-03	SSF1 eff	2.46	2.38	2.53	2.46		08:00	21-Jun-03	SSF1 eff	2.71	2.79	2.66	2.72
		SSF2 eff	1.99	2.03	2.04	2.02				SSF2 eff	2.12	2.14	2.18	2.15
		URFL1 eff	2.99	3.14	3.11	3.08				URFL1 eff	2.55	2.60	2.63	2.59
		URFL2 eff	3.21	3.29	3.06	3.19				URFL2 eff	2.73	2.75	2.68	2.72
		URFL1 in	11.60	11.10	10.70	11.13				URFL1 in	23.40	24.50	24.70	24.20
		URFL2 in	10.80	10.50	10.80	10.70				URFL2 in	21.50	20.10	21.00	20.87
09:30	20-Jun-03	SSF1 eff	2.39	2.47	2.48	2.45		09:30	21-Jun-03	SSF1 eff	2.42	2.47	2.55	2.48
		SSF2 eff	2.15	2.19	2.22	2.19				SSF2 eff	2.12	1.99	2.06	2.06
		URFL1 eff	3.05	3.15	2.92	3.04				URFL1 eff	2.51	2.56	2.07	2.38
		URFL2 eff	3.17	3.08	3.20	3.15				URFL2 eff	2.84	2.78	2.72	2.78
		URFL1 in	16.80	15.90	16.30	16.33				URFL1 in	23.30	22.30	22.00	22.53
		URFL2 in	15.80	15.50	15.40	15.57				URFL2 in	18.20	19.60	18.90	18.90
10:30	20-Jun-03	SSF1 eff	2.86	2.97	2.94	2.92		10:30	21-Jun-03	SSF1 eff	2.48	2.47	2.35	2.43
		SSF2 eff	2.19	2.12	2.07	2.13				SSF2 eff	2.07	1.91	2.29	2.09
		URFL1 eff	3.31	3.35	3.44	3.37				URFL1 eff	3.03	3.20	3.15	3.13
		URFL2 eff	2.83	2.84	2.98	2.88				URFL2 eff	3.47	3.56	3.49	3.51
		URFL1 in	12.20	13.00	11.80	12.33				URFL1 in	18.70	18.60	17.50	18.27
		URFL2 in	12.30	13.00	11.60	12.30				URFL2 in	16.30	15.60	15.70	15.87
11:30	20-Jun-03	SSF1 eff	3.37	3.32	3.40	3.36		11:30	21-Jun-03	SSF1 eff	3.45	2.55	2.49	2.83
		SSF2 eff	2.63	2.45	2.66	2.58				SSF2 eff	2.44	2.43	2.25	2.37
		URFL1 eff	3.34	3.34	3.42	3.37				URFL1 eff	3.20	3.04	3.06	3.10
		URFL2 eff	3.03	2.90	3.08	3.00				URFL2 eff	3.53	3.60	3.59	3.57
		URFL1 in	11.50	11.60	11.40	11.50				URFL1 in	13.90	13.90	13.80	13.87
		URFL2 in	10.60	10.50	11.10	10.73				URFL2 in	12.80	11.70	11.80	12.10
12:30	20-Jun-03	SSF1 eff	3.65	3.60	3.63	3.63		12:30	21-Jun-03	SSF1 eff	2.85	2.78	2.82	2.82
		SSF2 eff	2.79	2.67	2.70	2.72				SSF2 eff	2.67	2.60	2.58	2.62
		URFL1 eff	3.09	3.25	3.06	3.13				URFL1 eff	3.06	2.91	2.94	2.97
		URFL2 eff	3.15	3.29	3.31	3.25				URFL2 eff	3.12	3.24	3.22	3.19
		URFL1 in	9.80	10.60	10.70	10.37				URFL1 in	22.10	21.80	22.90	22.27
		URFL2 in	11.30	10.60	10.30	10.73				URFL2 in	19.00	18.30	19.40	18.90
13:30	20-Jun-03	SSF1 eff	3.90	3.95	4.06	3.97		13:30	21-Jun-03	SSF1 eff	2.91	2.94	2.88	2.91
		SSF2 eff	2.94	3.15	3.02	3.04				SSF2 eff	2.88	2.78	2.70	2.79
		URFL1 eff	2.51	2.55	2.50	2.52				URFL1 eff	2.72	2.78	2.74	2.75
		URFL2 eff	3.20	3.24	3.25	3.23				URFL2 eff	2.84	2.87	2.91	2.87
		URFL1 in	17.00	16.20	16.90	16.70				URFL1 in	12.30	13.00	12.60	12.63
		URFL2 in	16.60	16.50	16.40	16.50				URFL2 in	13.00	13.20	13.20	13.13
								15:00	21-Jun-03	SSF1 eff	3.24	3.21	3.18	3.21
										SSF2 eff	3.23	3.17	3.18	3.19
										URFL1 eff	2.90	2.88	2.88	2.89
										URFL2 eff	2.70	2.78	2.70	2.73
										URFL1 in	16.30	15.70	16.40	16.13
										URFL2 in	17.10	17.00	16.80	16.97
								16:00	21-Jun-03	SSF1 eff	3.38	3.36	3.30	3.35
										SSF2 eff	3.13	3.20	3.20	3.18
										URFL1 eff	2.65	2.70	2.71	2.69
										URFL2 eff	2.84	2.75	2.79	2.79
										URFL1 in	13.60	13.20	12.70	13.17
										URFL2 in	13.10	12.70	12.50	12.77

Table C 2: Turbidity analysis results: 12th August to 12th September 2003

Date	Time	URFL-1 Inflow	URFL-1 Effluent	SSF-1 Effluent	URFL-2 Inflow	URFL-2 Effluent	SSF-2 Effluent
8/12/2003	13:30	60.97	28.07				
	13:45				53.60	24.90	
	16:25	46.87	20.77				
8/13/2003	8:40	34.20	23.60	6.27	34.80	24.17	7.54
	13:10	101.00	25.07	10.27	76.33	25.40	11.67
	14:10	231.67	32.10		214.33	34.87	
	15:40	55.83	103.33	11.20	53.90	95.37	12.93
	19:00	39.80	28.97	9.61	39.57	28.67	12.13
8/14/2003	8:20	116.67	67.77	7.09	115.33	69.63	8.11
	13:15	79.83	32.27	6.64	75.50	35.67	7.46
	14:30	59.73	33.60	6.75	58.23	32.10	8.03
	16:20	54.43	29.20	9.46	51.80	29.60	12.00
8/15/2003	8:15	88.40	58.80	6.67	87.90	61.03	7.25
	13:00	112.33	57.07	7.06	114.00	57.03	8.63
	15:00	104.77	58.07	6.04	94.70	57.93	7.51
	17:00	79.20	48.57	5.37	78.57	50.23	6.96
8/16/2003	8:30	57.73	42.80	3.32	58.07	42.53	6.12
	15:40	105.33	41.70	3.36	101.77	42.23	
8/17/2003	11:30	82.03	52.00	2.68	81.17	52.77	6.26
	13:15	87.43	42.23	3.09	84.83	43.03	6.58
8/18/2003	8:30	49.30	34.63	3.24	49.60	34.20	6.00
	13:00	30.50	16.97	3.40	30.70	22.17	6.14
	15:00	26.10	29.90	5.40	26.53	31.80	7.11
8/19/2003	8:30	9.96	7.82	8.98	10.27	7.01	8.20
	13:00	11.03	8.49	6.62	10.97	7.86	6.20
	16:30	12.67	8.53	4.70	12.60	9.37	9.70
8/20/2003	8:30	21.40	8.59	6.66	20.17	8.46	4.99
	13:30	46.43	12.60	4.90	25.23	12.37	5.43
	16:00	19.57	11.60	5.18	19.23	11.80	7.75
8/21/2003	8:30	25.63	8.99	4.81	22.43	8.78	4.31
	13:30	215.00	18.63	4.83	33.80	18.17	4.83
	17:00	38.50	19.43	5.48	38.17	16.23	7.58
8/22/2003	8:30	63.73	28.87	7.96	63.47	29.67	7.97
	13:00	47.33	19.90	6.56	47.50	19.27	5.70
8/23/2003	11:00	43.33	18.60	6.41	42.83	18.20	5.90
	14:00	46.97	18.07	6.00	50.60	18.13	6.04
8/25/2003	8:30	24.60	17.93	7.26	24.70	17.90	6.32
	15:00	13.43	12.10	5.00	13.77	12.13	5.80
8/26/2003	8:30	11.50	6.85	6.27	11.90	6.38	4.51
	14:00	36.50	12.43	5.27	32.73	11.67	5.10
	16:30	29.90	12.67	5.18	29.20	12.47	6.06
8/27/2003	8:00	15.13	6.64	4.03	14.90	5.73	5.26
	12:30	26.50	8.97	5.13	24.73	11.60	5.33

Table C2 Continued:

Date	Time	URFL-1 Inflow	URFL-1 Effluent	SSF-1 Effluent	URFL-2 Inflow	URFL-2 Effluent	SSF-2 Effluent	Turbidity of Raw water at Main plant intake
9/6/2003	12:00	75.73	18.33	3.99	70.77	12.97	2.36	60.5
	14:00	42.70	19.47	4.07	42.43	13.43	2.26	59.5
	14:50	35.20	21.40	4.48	33.50	12.60	2.56	
9/8/2003	8:30	55.83	26.77	2.10	55.13	20.43	2.34	71.9
	10:30	74.57	26.27	2.16	35.03	25.73	2.34	71.6
	14:00	32.00	14.93	3.30	31.10	11.33	2.90	
	15:45	69.40	13.60	2.93	44.70	10.87	2.89	
9/9/2003	13:00	28.17	9.60	2.74	24.30	9.21	2.46	
	15:30	13.50	7.70		12.90	7.20		
9/10/2003	8:30	15.7	3.96	3.25	14.80	4.00	3.41	8.10
	11:00	8.26	3.39	3.45	7.99	3.86	3.19	7.6
	12:15	9.89	3.75		9.44	3.68		
	13:30	12.50	3.57		12.97	4.08		
9/11/2003	8:30	16.80	4.98	2.48	16.17	5.04	2.12	21.40
	11:00	18.47	5.29	2.49	18.30	5.56	2.22	20.40
	13:00	54.37	7.92	3.03	54.00	8.09	2.54	21.80
	14:00	51.07	10.00	2.93	51.57	10.50	2.40	
9/12/2003	8:30	90.43	23.00	3.37	89.50	21.47	1.63	90.50
	9:45	86.60	27.43		83.43	36.47		93.50

Table C 3: Turbidity analysis results: 22nd May to 26th September 2004

Date	Time	URFL inflow	URFL1 effluent	Removal %	URFL2 effluent	Removal %	SSF1 effluent	SSF2 effluent
22-May-04	8:00	6.51	2.26	**65.30**	2.18	**66.48**	No data	No data
22-May-04	16:00	7.88	2.62	**66.78**	2.57	**60.54**	No data	No data
23-May-04	8:00	5.26	2.44	**53.55**	2.44	**62.54**	1.06	4.11
23-May-04	18:00	2.99	1.92	**35.90**	1.95	**70.11**	1.16	4.34
24-May-04	7:30	5.68	1.94	**65.83**	1.78	**72.72**	0.97	1.04
25-May-04	8:00	2.07	1.83	**11.90**	1.87	**71.29**	0.72	1.54
26-May-04	8:00	3.88	1.48	**61.74**	1.51	**76.87**	0.63	1.40
27-May-04	8:00	3.66	1.33	**63.66**	1.36	**79.12**	0.71	1.12
28-May-04	8:00	3.36	1.39	**58.63**	1.57	**75.90**	0.58	1.02
30-May-04	8:00	5.87	1.43	**75.65**	1.37	**78.92**	0.63	1.39
31-May-04	8:00	7.58	1.87	**75.38**	1.80	**72.42**	0.50	0.99
1-Jun-04	8:00	4.83	1.54	**68.02**	1.46	**77.53**	0.63	1.22
1-Jun-04	18:00	6.66	1.26	**81.14**	1.34	**79.38**	0.59	1.14
2-Jun-04	9:00	7.50	1.59	**78.79**	1.69	**74.05**	0.50	1.08
3-Jun-04	10:00	3.51	1.40	**60.21**	1.38	**78.81**	0.35	0.62
4-Jun-04	8:00	8.75	3.11	**64.48**	3.22	**50.51**	0.53	1.32
5-Jun-04	8:00	9.09	1.67	**81.66**	1.78	**72.67**	0.60	0.98
6-Jun-04	8:00	9.95	1.89	**81.01**	1.73	**73.39**	0.35	0.63
7-Jun-04	8:00	5.30	1.54	**70.90**	1.53	**76.56**	0.50	0.79
8-Jun-04	8:00	9.74	1.30	**86.62**	1.40	**78.45**	0.54	0.80
9-Jun-04	8:00	9.99	3.16	**68.37**	1.71	**73.75**	0.27	0.49
10-Jun-04	8:00	9.21	2.12	**77.02**	1.20	**81.58**	0.28	0.50
11-Jun-04	8:00	8.43	3.00	**64.36**	1.19	**81.68**	0.27	0.47
12-Jun-04	8:00	10.93	2.98	**72.74**	1.79	**72.57**	0.60	0.95
13-Jun-04	8:00	6.34	3.69	**41.75**	3.84	**40.99**	0.67	1.62
14-Jun-04	8:00	9.99	6.62	**33.74**	6.85	**-5.12**	0.33	0.79
15-Jun-04	8:00	9.61	3.89	**59.54**	3.99	**38.74**	0.55	1.56
16-Jun-04	8:00	8.87	3.68	**58.47**	3.52	**45.96**	0.74	1.88
17-Jun-04	8:00	9.99	9.94	**0.47**	9.25	**-41.97**	0.61	1.63
18-Jun-04	8:00	9.99	8.30	**16.95**	8.52	**-30.86**	1.07	2.25
19-Jun-04	8:00	9.99	9.02	**9.68**	8.95	**-37.36**	1.10	2.17
20-Jun-04	8:00	9.99	9.99	**0.00**	9.99	**-53.38**	1.29	2.68
21-Jun-04	8:00	10.43	6.95	**33.33**	7.22	**-10.85**	1.40	2.61
22-Jun-04	8:00	8.80	6.54	**25.67**	6.68	**-2.56**	2.72	3.97
23-Jun-04	8:00	9.44	6.00	**36.38**	6.39	**1.89**	1.49	2.80
24-Jun-04	8:00	9.99	7.05	**29.40**	7.43	**-14.07**	1.89	3.03
25-Jun-04	8:00	9.37	7.06	**24.62**	7.30	**-12.03**	1.86	2.79
28-Jun-04	8:00	9.99	6.04	**39.57**	6.05	**7.06**	1.81	2.72
29-Jun-04	8:00	9.99	5.67	**43.28**	5.86	**9.98**	2.09	2.82
30-Jun-04	8:00	9.99	5.68	**43.11**	6.11	**6.19**	2.08	2.81
1-Jul-04	8:00	9.66	4.14	**57.11**	4.38	**32.80**	2.49	3.13
2-Jul-04	8:00	9.99	8.09	**18.99**	8.11	**-24.56**	2.19	2.88
3-Jul-04	8:00	9.99	7.18	**28.13**	7.41	**-13.82**	2.78	3.71
4-Jul-04	8:00	9.99	9.98	**0.07**	9.99	**-53.38**	2.07	2.68
5-Jul-04	8:00	9.99	9.99	**0.00**	9.99	**-53.38**	2.23	2.58
6-Jul-04	8:00	5.96	5.33	**10.62**	5.67	**12.95**	1.74	1.99
7-Jul-04	8:00	9.73	8.46	**13.02**	9.12	**-39.97**	2.30	2.88
8-Jul-04	8:00	9.99	9.99	**0.00**	9.99	**-53.38**	2.24	3.54
9-Jul-04	8:00	8.18	11.33	**-38.61**	11.43	**-75.54**	3.47	3.63

Table C3 Continued

Date	Time	URFL inflow	URFL1 Outflow	Removal %	URFL2 Outflow	Removal %	SSF1 Outflow	SSF2 Outflow
10-Jul-04	8:00	2.73	1.46	**46.64**	1.46	46.64	3.29	4.43
11-Jul-04	8:00	2.68	1.48	**44.90**	1.47	44.90	3.29	4.45
12-Jul-04	8:00	2.36	1.71	**27.50**	1.72	27.50	3.27	4.89
13-Jul-04	9:00	1.48	7.98	**-438.96**	7.86	-438.96	4.11	3.60
14-Jul-04	10:00	9.23	16.33	**-76.90**	15.87	-76.90	3.66	4.43
15-Jul-04	11:00	12.77	9.90	**22.45**	10.13	22.45	3.26	4.73
16-Jul-04	12:00	1.77	10.57	**-495.86**	10.60	-495.86	3.48	8.25
17-Jul-04	13:00	20.83	7.78	**62.67**	7.86	62.67	3.22	4.06
18-Jul-04	14:00		8.92		8.78		3.95	3.67
19-Jul-04	15:00	10.83	7.71	**28.86**	7.86	28.86	3.10	4.07
20-Jul-04	16:00	11.90	8.53	**28.32**	8.61	28.32	3.47	3.98
21-Jul-04	17:00	11.40	8.63	**24.27**	8.33	24.27	3.58	10.93
22-Jul-04	18:00	26.30	13.17	**49.94**	13.10	49.94	3.73	9.93
23-Jul-04	19:00	11.10	9.35	**15.74**	8.76	15.74	3.76	12.63
24-Jul-04	20:00	2.36	1.71	**27.50**	1.72	27.50	3.27	4.89
25-Jul-04	21:00	16.83	8.55	**49.23**	8.39	49.23	3.21	no flow due to clogging
26-Jul-04	22:00	29.00	10.97	**62.18**	10.73	62.18	2.87	
27-Jul-04	23:00	51.03	18.13	**64.47**	17.93	64.47	14.81	
28-Jul-04	0:00	31.43	23.57	**25.03**	89.37	25.03	5.30	
29-Jul-04	1:00	74.87	32.73	**56.28**	31.70	56.28	4.82	
30-Jul-04	2:00	48.90	21.80	**55.42**	21.50	55.42	5.22	
31-Jul-04	3:00	20.43	8.60	**57.90**	8.73	57.90	3.51	
1-Aug-04	4:00	27.57	13.37	**51.51**	14.20	51.51	4.13	6.83
2-Aug-04	5:00	60.97	45.93	**24.66**	45.27	24.66	3.52	7.02
3-Aug-04	6:00	99.47	57.80	**41.89**	58.00	41.89	3.11	10.07
4-Aug-04	7:00	74.37	27.70	**62.75**	27.30	62.75	2.52	8.29
5-Aug-04	8:00	59.20	35.50	**40.03**	35.10	40.03	2.37	4.13
6-Aug-04	9:00	56.17	23.20	**58.69**	21.87	58.69	1.81	3.09
7-Aug-04	10:00	68.57	55.97	**18.38**	55.13	18.38	1.80	3.81
8-Aug-04	11:00	23.90	15.10	**36.82**	15.20	36.82	1.69	3.93
9-Aug-04	8:00	24.07	13.97	***41.97***	13.70	***43.07***	no flow	no flow
10-Aug-04	8:00	40.60	15.97	***60.67***	15.93	***60.76***	3.55	4.49
11-Aug-04	8:00	69.73	36.70	***47.37***	37.70	***45.94***	9.72	11.53
12-Aug-04	8:00	34.87	18.81	***46.04***	18.33	***47.42***	10.07	9.09
13-Aug-04	8:00	102.43	34.60	***66.22***	35.53	***65.31***	10.13	11.43
14-Aug-04	8:00	53.57	23.13	***56.81***	22.56	***57.88***	7.38	8.17
15-Aug-04	8:00	55.60	23.83	***57.13***	23.67	***57.43***	6.91	8.49
16-Aug-04	8:00	94.90	33.53	***64.66***	33.60	***64.59***	6.15	7.96
17-Aug-04	8:00	68.30	24.53	***64.08***	24.48	***64.16***	2.82	2.61
18-Aug-04	8:00	112.33	37.50	***66.62***	37.17	***66.91***	1.24	1.89
19-Aug-04	8:00	94.23	30.57	***67.56***	30.10	***68.06***	2.00	1.29
20-Aug-04	8:00	171.67	50.67	***70.49***	49.63	***71.09***	1.71	1.36
23-Aug-04	8:00	51.27	46.23	***9.82***	48.30	***5.79***	1.11	1.10
24-Aug-04	8:00	85.27	38.70	***54.61***	39.33	***53.87***	1.59	1.47
25-Aug-04	8:00	93.67	37.30	***60.18***	37.83	***59.61***	1.73	1.89
26-Aug-04	8:00	63.10	47.33	***24.99***	46.73	***25.94***	1.75	1.52

Table C3 Continued

Date	Time	URFL inflow	URFL1 Outflow	*Removal %*	URFL2 Outflow	*Removal %*	SSF1 Outflow	SSF2 Outflow
27-Aug-04	8:00	70.33	21.30	***69.72***	21.70	***69.15***	1.16	0.90
28-Aug-04	8:00	79.23	24.43	***69.16***	25.53	***67.77***	1.05	0.82
30-Aug-04	8:00	82.90	20.73	***74.99***	21.03	***74.63***	1.22	1.04
31-Aug-04	8:00	41.73	26.73	***35.94***	27.80	***33.39***	1.41	1.41
1-Sep-04	8:00	74.33	26.07	***64.93***	26.43	***64.44***	1.58	1.87
3-Sep-04	8:00	72.17	26.73	***62.96***	26.83	***62.82***	0.55	1.06
4-Sep-04	8:00	98.17	23.53	***76.03***	22.30	***77.28***	0.75	1.05
5-Sep-04	8:00	92.30	21.30	***76.92***	20.97	***77.28***	0.49	0.66
6-Sep-04	8:00	13.00	33.80	***-160.00***	43.70	***-236.15***	0.47	0.67
7-Sep-04	8:00	64.17	41.70	***35.01***	36.97	***42.39***	0.33	0.50
8-Sep-04	8:00	44.40	12.87	***71.02***	13.23	***70.20***	0.41	0.70
9-Sep-04	8:00	15.37	24.27	***-57.92***	24.33	***-58.35***	0.27	0.39
10-Sep-04	8:00	53.47	7.88	***85.26***	8.11	***84.83***	0.34	0.35
11-Sep-04	8:00	14.20	11.90	***16.20***	9.14	***35.61***	0.29	0.33
13-Sep-04	8:00	13.77	8.57	***37.77***	9.05	***34.24***	0.27	0.44
14-Sep-04	8:00	61.33	26.23	***57.23***	27.00	***55.98***	0.59	1.07
15-Sep-04	8:00	29.40	12.83	***56.35***	12.73	***56.69***	0.60	0.71
16-Sep-04	8:00	14.90	5.59	***62.51***	5.71	***61.66***	0.44	0.55
17-Sep-04	8:00	68.20	16.03	***76.49***	15.87	***76.74***	0.49	0.48
20-Sep-04	8:00	33.30	5.87	***82.37***	6.28	***81.15***	0.44	0.22
21-Sep-04	8:00	24.10	5.24	***78.27***	6.43	***73.32***	0.19	0.22
22-Sep-04	8:00	15.67	4.80	***69.36***	4.85	***69.04***	0.30	0.25
23-Sep-04	8:00	20.67	6.27	***69.68***	5.95	***71.21***	0.23	0.48
24-Sep-04	8:00	44.17	12.27	***72.23***	9.21	***79.15***	0.26	0.26
25-Sep-04	8:00	47.63	7.13	***85.02***	6.89	***85.54***	0.17	0.31
26-Sep-04	8:00	40.43	18.43	***54.41***	19.53	***51.69***	1.13	0.74

Notes on Table C 3:

- Where there is negative % removal, it means an error in data analysis occurred and this data is considered to be outliers and statistically rejected

- Where the turbidity value is 9.99, it means that the turbidimeter was set to read values less than 10 NTU but the sample turbidity was > 10 NTU: It was later operators did not master properly the use of the equipment, and subsequently more training

Table C4: Intensive Turbidity (NTU) monitoring

Avarage results

Date	Time	URFL inflow	URFL1 Outflow	URFL2 Outflow	SSF1 Outflow	SSF2 Outflow
1-Jun-04	8:00	4.83	1.54	1.46	0.63	1.22
	18:00	6.66	1.26	1.34	0.59	1.14
2-Jun-04	9:00	7.50	1.59	1.69	0.50	1.08
	10:45	16.47	3.62	4.30	0.38	0.72
	12:15	11.13	3.92	3.86	0.44	0.85
	13:15	19.43	2.36	2.47	0.55	1.13
	14:15	12.83	3.20	3.18	0.60	1.40
	15:15	14.10	2.25	2.47	0.64	1.39
	16:15	17.20	2.05	2.07	0.56	1.24
3-Jun-04	10:00	3.51	1.40	1.38	0.35	0.62
	11:15	10.13	2.23	2.18	0.41	0.60
	12:15	27.87	2.34	2.19	0.36	0.59
	12:45	31.60	6.95	8.63	0.36	0.50
	13:15	15.90	4.51	5.24	0.44	0.66
	14:00	52.60	2.20	2.11	0.39	0.90
	15:00	12.10	3.06	3.06	0.51	0.88
	16:10	12.13	2.09	2.11	0.47	1.18
	16:40	11.87	2.25	2.24	0.52	1.05

Appendix G: Jar Test Procedure

The jar test is intended to simulate the coagulation/flocculation process in a water treatment plant. The results that it produces are used to help optimize the performance of the plant.

The procedure for a jar test is as follows:

1. Using a 1,000 mL graduated cylinder, add 1,000 mL of raw water to be coagulated to each of the jar test beakers.
2. Using a **prepared coagulant stock solution** (Alum), dose each beaker with increasing amounts of solution.

[Stock Solutions preparation]

Stock solutions are prepared by dissolving 10.0 grams of alum (or other coagulant) into 1,000 mL distilled water. Each 1.0 mL of this stock solution will equal 10 mg\L (ppm) when added to 1,000 mL of water to be tested.

Here's an example for dosing the beakers:

Jar #	mL Alum Stock added	mg\L Alum Dosage
1	0.5	5.0
2	1.0	10.0
3	1.5	15.0
4	2.0	20.0
5	2.5	25.0
6	3.0	30.0

There can be anywhere from 4 to 6 beakers for this test, the above chart should be modified to reflect the correct amount of beakers and reflect the dosages required for a specific plant.

Here's a picture of what a jar testing apparatus might look like.

3. After dosing each beaker, it is time to turn on the stirrers. This part of the procedure should reflect the actual conditions of the specific plant.

   - For example, let's say the plant has a static mixer following chemical addition, followed by 35 minutes in a flocculator, then 1.5 hours of settling time before the filters. The jar test would be performed as follows:

     - Operate the stirrers at a high RPM for 1 minute to simulate the static mixer. Then reduce the speed of the stirrers to match the conditions in the flocculator and allow them to operate for 35 minutes. Observe the floc formation periodically during the 35 minutes. At the end of the 35 minutes turn off the stirrers and allow settling.

       Most of the settling will be complete after 1 hour.

4. Next, look at the beakers and determine which one has the best results (if any).

- An underfeed will cause the sample to look cloudy with little or no floc and almost no settling.

- An overfeed will cause a dense fluffy floc to occur and will not settle well. The beaker with an appropriate dosage of coagulant will have floc that has settled to the bottom and the water above it will be clear.

- If none of the beakers appear to have good results then the procedure should be run again using different dosages until the correct dosage is determined.

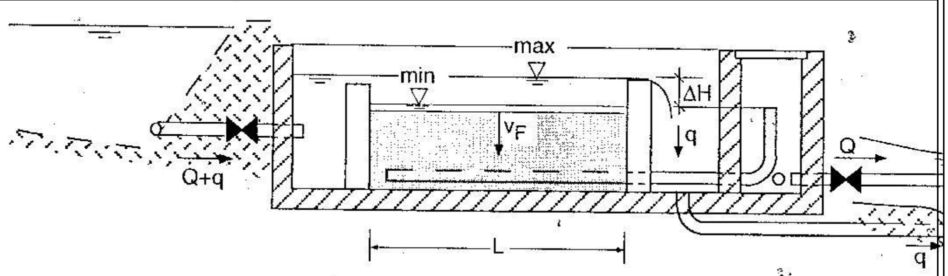
Appendix H: Description of intake and dynamic roughing filtration

<table>
<tr><td>Purpose</td><td>Intake and dynamic roughing filtration (IDyRF) are applied as first pre-treatment unit processes in a water treatment scheme to reduce suspended solids and turbidity from raw water that is characterised by medium to very high turbidity (>10-500 NTU). Suspended solids are reduced to levels acceptable in water to be treated by other filtration processes.

IDyRF are proven technologies but emerging in application in SA.</td></tr>
<tr><td>Summary of key features</td><td>Raw water flows downwards through several graded gravel media layers (decreasing in size in the direction of flow) placed in a single unit. Surplus water flows in a horizontal direction, leading to an overflow chamber.
Sedimentation and straining mechanisms retain the suspended particles within the gravel pores.
The filter unit is cleaned by fast drainage.</td></tr>
<tr><td>Description</td><td>IDyRF are gravel filtration processes in which the gravel is arranged in layers within one compartment gravity continuously drives raw water through and above the filter media at filtration rates ranging from 0.30-1.0 and 2-3 m^3/h per m^2 of filter media surface, respectively. (See Field No. 5 for design details.)

Intake roughing filtration is usually applied at the intake to remove suspended solids while dynamic roughing filters are applied within the treatment plant to protect the plant against sudden peak turbidity and suspended solids.

Physical mechanisms are responsible for the clarification of the raw water, although to some extent biological mechanisms are also active.

IDyRF are applied as a pre-treatment stage prior to up-flow or horizontal flow roughing filtration–slow sand filtration system, a combination widely known as multi-stage filtration.</td></tr>
<tr><td>Technology illustration</td><td>


list of symbols
<table>
<tr><td>d_g</td><td>(mm)</td><td>gravel size</td></tr>
<tr><td>L</td><td>(m)</td><td>filter length</td></tr>
<tr><td>W</td><td>(m)</td><td>filter width</td></tr>
<tr><td>A</td><td>(m^2)</td><td>filter area</td></tr>
<tr><td>ΔH</td><td>(cm)</td><td>headloss</td></tr>
<tr><td>Q</td><td>(m^3/h)</td><td>flow rate</td></tr>
<tr><td>v_F</td><td>(m/h)</td><td>filtration rate</td></tr>
<tr><td>q</td><td>(m^3/h)</td><td>surplus flow rate</td></tr>
</table>

design guidelines
<table>
<tr><td></td><td>intake filter</td><td>dynamic filter</td></tr>
<tr><td>filtration rate
$v_F = \frac{Q}{L \cdot W} = \frac{Q}{A}$</td><td>0.3 - 1 m/h</td><td>2 - 3 m/h</td></tr>
<tr><td>max. headloss (operation) ΔH</td><td>~20 - 40 cm</td><td>~20 - 40 cm</td></tr>
<tr><td>gravel size</td><td colspan="2">gravel layer height</td></tr>
<tr><td>d_g = 2 - 4 mm</td><td>—</td><td>20 - 30 cm</td></tr>
<tr><td>d_g = 4 - 8 mm</td><td>30 - 40 cm</td><td>10 cm</td></tr>
<tr><td>d_g = 8 - 12 mm</td><td>(10 - 20 cm)</td><td>10 cm</td></tr>
</table>
</td></tr>
</table>