Guidelines for the Improved Disinfection of Small Water Treatment Plants

MNB Momba, P Thompson & CL Obi

TT 355/08

Water Research Commission

GUIDELINES FOR THE IMPROVED DISINFECTION OF SMALL WATER TREATMENT PLANTS

Report to the

Water Research Commission

by

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Foreword

In South Africa the supply of drinking water to rural communities by small drinking water treatment plants has been plagued by several operational and management problems. These problems have previously been documented and proved to impinge on water quality, but efforts to address them have been fragmented or conducted in a piecemeal manner. The comprehensive guidelines contained in this report describe methods and processes for tackling the litany of problems associated with the drinking water supplied by small water treatment plants. This is critical, as the supply of safe drinking water is a fundamental human right and *sine qua non* for life.

The guidelines provide an overview of the problems and proffer practical solutions and precautions that maximize the efficacy of disinfection for safe drinking water supplies to rural communities for improved public health care delivery.

In compiling the guidelines, emphasis was placed on the multiple barrier approach to optimizing disinfection, which highlights the importance of source selection and protection as the primary barrier for the prevention of the contamination of the raw water. Appropriate planning, design and unit process selection are reviewed, highlighting critical design parameters that should be strictly implemented to ensure the optimum functioning of such water treatment plants. The criteria for the selection of disinfectants and details for the design and maintenance of gaseous chlorine systems are highlighted to ensure that proper maintenance practices are implemented because chlorination is the primary disinfection protocol practised in South Africa.

The various chlorination techniques such as gaseous chlorination, liquid and granular hypochlorination, including their advantages and disadvantages, are presented. Capital and operating costs for typical small water treatment plants are highlighted to assist in budgeting and planning. The description of a commercially available typical gravity dosing system in South Africa is included as an option for use where frequent power failures are experienced.

Due to the importance of process and water quality monitoring, the guidelines include details on critical process parameters that should be monitored as well as the frequency of monitoring that will ensure the efficiency of the disinfection process. Contact details for accredited laboratories in South Africa are included to assist management in appropriate budgeting.

This guide is intended for use by plant supervisors, plant operators, plants owners, consultants, technical managers, design engineers and Municipal Water Local Authorities for ultimate service efficiency and improved welfare.

Executive Summary

A number of recent studies and surveys (Swartz, 2000; Mackintosh and Colvin, 2002; Momba *et al*., 2004a; 2004b; Momba and Brouckaert, 2005; Obi *et al.*, 2007) conducted in South Africa have confirmed that about 50% of small treatment plants are not producing the desired water quantity or quality. The primary reasons for the failure of these plants have been well documented and include inappropriate technology, poor operation, lack of training, municipal financial constraints, lack of motivation of operators and lack of knowledge of basic water treatment operations.

Seventy eight percent (78%) of the operators lacked the ability to calculate chlorine dosages, determine flow rate, estimate the free chlorine residual concentrations, undertake readings of turbidity and pH values, or repair basic process equipment. In addition, there appears to be a lack of understanding of process selection, design, techniques of chlorination, process quality monitoring and evaluation. Poor working conditions, depletion of chemicals, the lack of a maintenance culture, the lack of emergency preparedness and poor communication were also found to be major contributors to the failure of these systems. The remoteness of many of the sites results in limited technical support and this often leads to total/absence of disinfection or dysfunctional disinfection systems.

These guidelines have been formulated to serve as a reference document on ways and means of addressing the array of problems facing small water treatment plants in order to mitigate the disastrous effects of unsafe water supplies. Application of the recommendations in these guidelines will ensure that appropriate disinfection systems are selected and installed.

The guidelines include the multiple barrier approach to optimizing disinfection, which highlights the importance of source selection and protection as the primary barrier for the prevention of contamination of the raw water. The importance of appropriate planning and design and unit process selection is highlighted. The technical properties of the various disinfection practices employed in South Africa are reviewed and criteria for the selection of disinfectants are included in the guidelines.

In compiling the guide document, emphasis was placed on chlorination as the primary disinfection protocol practiced in South Africa. Various chlorination techniques include gaseous chlorination, liquid hypochlorination and granular hypochlorination. The advantages and disadvantages of the various disinfectants are discussed in detail. Details for the design and maintenance of gaseous chlorine systems are highlighted to ensure that proper maintenance practices are implemented. Capital and operating costs for a typical plant sized at 2.5 Ml/d are included as a guide to assist in budgeting and planning.

A description of a typical gravity dosing system available commercially in South Africa is included as an option for use where frequent power failure is experienced. The minimum requirements for operator training and development are included. A summary of roles and responsibilities of the various role players involved in the management and operation of this system. The guidelines also emphasize the need for regular water quality and process monitoring and provide a contact list of various reference laboratories that can assist in this area.

These guidelines outline practical steps for improving the efficiency of disinfection at small rural water treatment plants and are intended to be used by plant supervisors, plant operators, plants technical managers, design engineers, plant owners, consultants and Local Authorities for ultimate service efficiency and improved welfare.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

In South Africa, water infrastructure is well developed in urban areas as opposed to rural areas where the infrastructure is either poorly developed or non-existent. The supply of water to rural communities is usually undertaken through small water treatment plants. Small water treatment plants are defined as water treatment systems that are installed in areas which are not well serviced and which do not normally fall within the boundaries of urban areas. They include water supplies from boreholes and springs which are then chlorinated, treatment plants of small municipalities and establishments such as rural hospitals, schools, clinics and forestry stations. However, the efficacy of small water treatment plants is plagued by several technical and management problems, which include: the inability of plant operators to calculate chlorine dosages, determine flow rate, estimate free chlorine residual concentrations, undertake readings of turbidity and pH values, or effect repair of basic equipment. In addition, there appears to be lack of understanding of process selection, design, techniques of chlorination, process quality monitoring and evaluation. Others include poor working conditions, the frequent depletion of chemical stock, the lack of a maintenance culture, the lack of emergency preparedness and poor communication (Swartz, 2000; Mackintosh and Colvin, 2002; Momba *et al.*, 2004a; 2004b; Momba and Brouckaert, 2005; Obi *et al.*, 2007). The remoteness of many of the sites results in limited technical support and this often leads to a total absence of disinfection or a dysfunctional disinfection system. This is corroborated by the extensive documentation on the supply of water of poor microbiological quality, which is unsafe for human consumption, in different provinces of South Africa. Contaminated water is a vehicle for several waterborne diseases such as cholera, typhoid fever, shigellosis, salmonellosis, campylobacteriosis, giardiosis, cryptosporidiosis and Hepatitis A viral infections. Such infections cause great debilitation including a substantial degree of morbidity and mortality in different age groups in both males and females, with ripple effects on socio-economic and health care systems.

Consequently, these guidelines have been formulated to serve a reference document on ways and means of addressing the array of problems facing small water treatment plants in order to mitigate the disastrous effects of unsafe water supplies. These guidelines have been derived from the findings of a survey of 181 small water treatment plants in South Africa (WRC Report 1531/1/08: Improving disinfection efficiency of small drinking water treatment plants) which is available at the Water Research Commission of South Africa.

The document is presented in three major parts and highlights the results of the survey of disinfection efficiency of small drinking water treatment plants. It provides guidance on good practice for technical as well as management issues concerning small water treatment plants for the purpose of effective implementation of the disinfection process.

The installation and operating costs for the different disinfection systems and chemicals, the cost of disinfecting drinking water to the required standard using the required equipment instrumentation and manpower, and the estimated costs of maintenance as well as human development needs are also included in the document.

Chapter 2 covers the results of the detailed surveys that were undertaken. Technical and non-technical issues that are responsible for the poor disinfection of small treatment plants were identified and summarized.

CHAPTER 2

SURVEY OF DISINFECTION EFFICIENCY OF SMALL DRINKING WATER TREATMENT PLANTS: CHALLENGES FACING SMALL WATER TREATMENT PLANTS IN SOUTH AFRICA

2.1 Introduction

In order to unravel the intricacies around the operational and management parameters impinging on the efficiency of small water treatment plants and to ensure sustainability of a potable water supply to rural communities, a study involving 181 small water treatment plants across seven provinces of South Africa was undertaken (WRC Report 1531/1/08). The focus was to determine the nature and full extent of the problems and provide practical and user-friendly guidelines for intervention. Specific objectives addressed in this survey include the following:

- To identify and characterize the various types of disinfection equipment currently employed at small water treatment systems, as well as systems that could potentially be used.
- To identify the means of disinfection (i.e. the physical and/or chemical processes) employed at these systems, as well as the performance, chemical and electrical inputs, and ongoing maintenance requirements of each type.
- To identify or determine the current quality of treated water, procedures followed to monitor and control the disinfection processes and the adequacy and consistency of the levels of disinfectant added.
- To identify the frequency and adequacy of microbiological tests performed on the final treated water.
- To identify the main reasons for disinfection problems experienced at small water systems – both technical and non-technical.
- To estimate the cost of drinking water disinfection appropriate for the required standards using the required equipment, instrumentation and manpower.
- To identify major problems resulting in water quality changes in a distribution system.

2.2 Summary of the major findings and conclusions reached

Small water treatment plant ownership – Four categories of the plant ownership were identified viz Local/District Municipality, Department of Water Affairs and Forestry (DWAF), Department of Health (DOH) and Water Board (private company). Overall 81% of the small water treatment plants surveyed in South Africa were owned by Local/District Municipality.

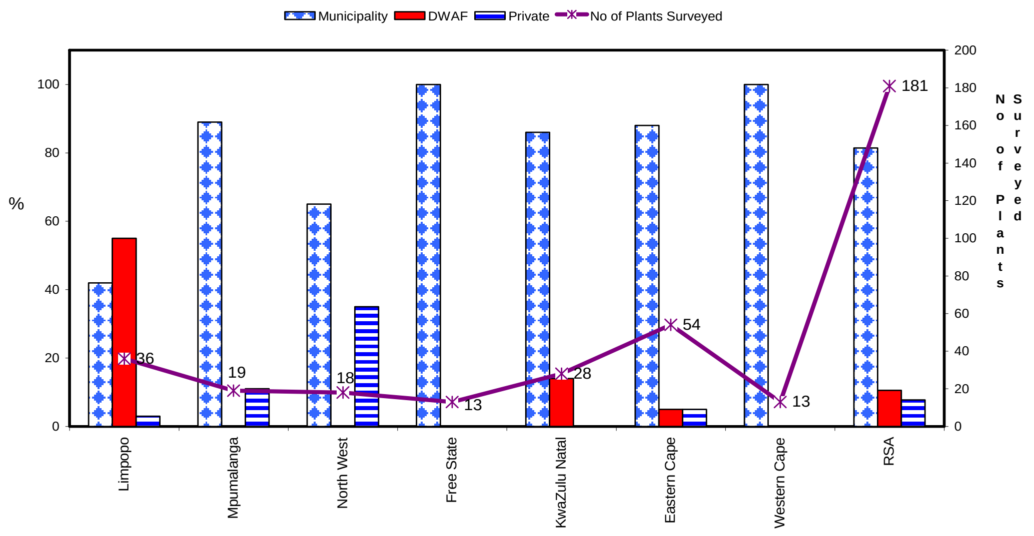

Figure 2.1 Category of Ownership of Small Treatment Plants surveyed in South Africa

Design capacity of small water treatment plants – The capacity of the plants surveyed during the investigation varied between 0.3 ML/d and 120 ML/d. Most of the plants were operating below the design capacity.

Type of raw water sources – Overall 86% of the small water treatment plants surveyed abstracted their raw water from surface sources, 10% used groundwater and 4% a combination of both sources.

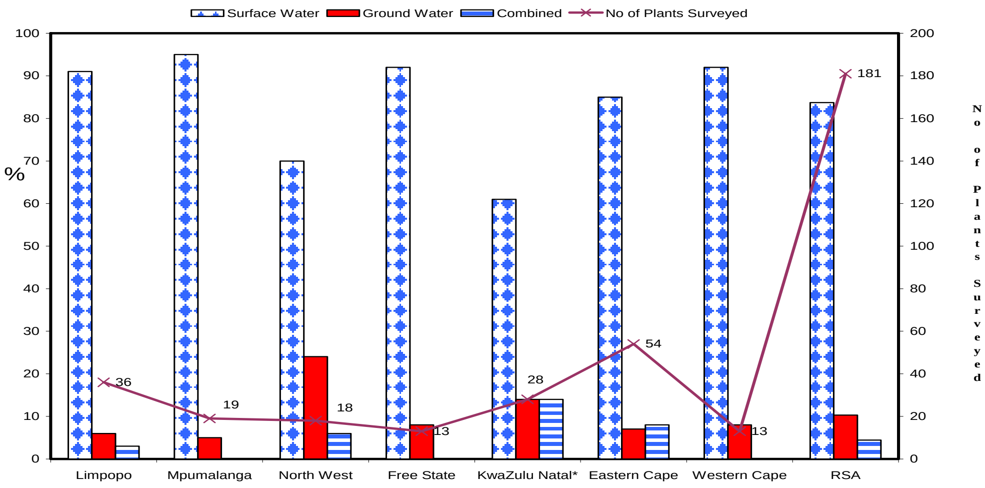

Figure 2.2 Types of Water Sources in Small Treatment Plants surveyed in South Africa

***Water treatment practices* –** Conventional water treatment processes were generally used in the majority of the plants surveyed. In terms of coagulation, it was noted that polyelectrolyte (66%) was commonly used, followed by alum (18%) and ferric chloride (6%). Sixty percent of the small water treatment plants used the rapid gravity filtration system while a further 24%, 9% and 2% of the plants made use of pressure filters, slow sand filtration and diatomaceous earth filters respectively. Chlorine gas was found to be the most popular disinfectant (69%), followed by sodium hypochlorite (15%) and calcium hypochlorite (HTH) (14%), among others.

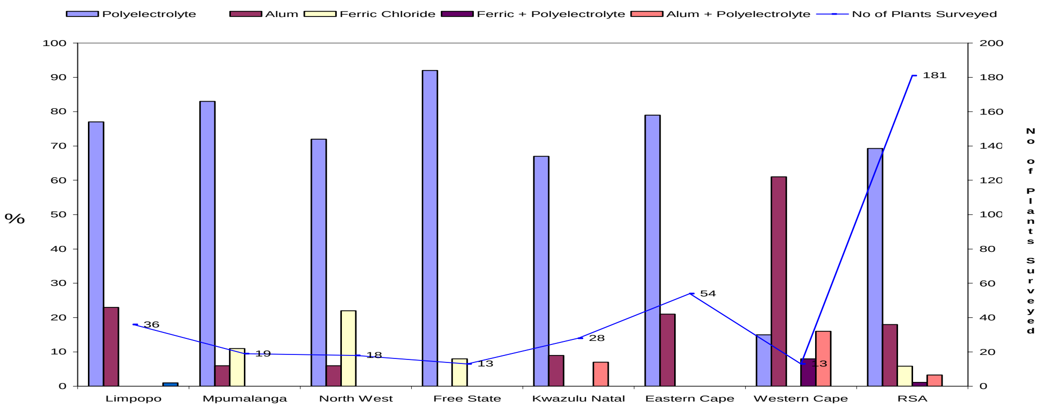

Figure 2.3 Types of Coagulants used in Small Treatment Plants Surveyed in South Africa

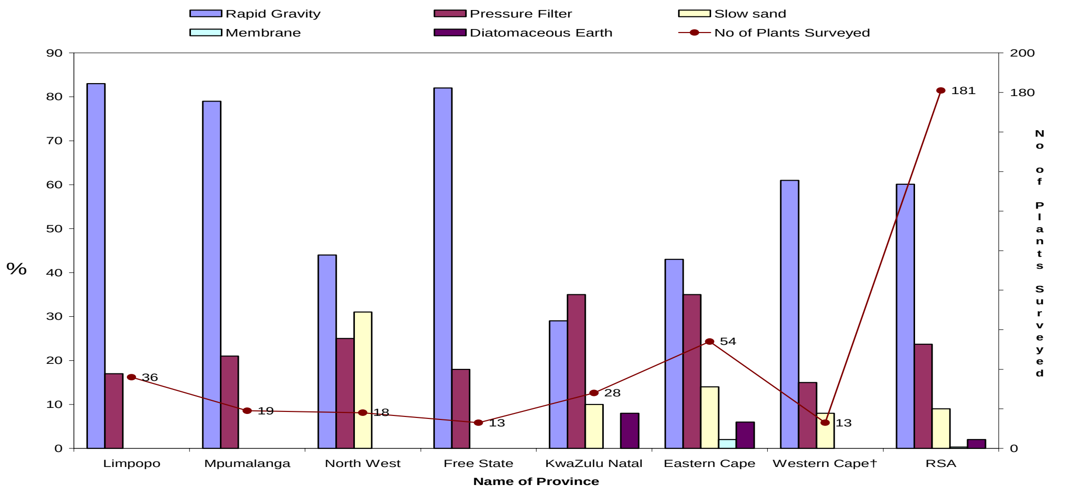

Figure 2.4 Types of Filters used in Small Treatment Plants surveyed in South Africa

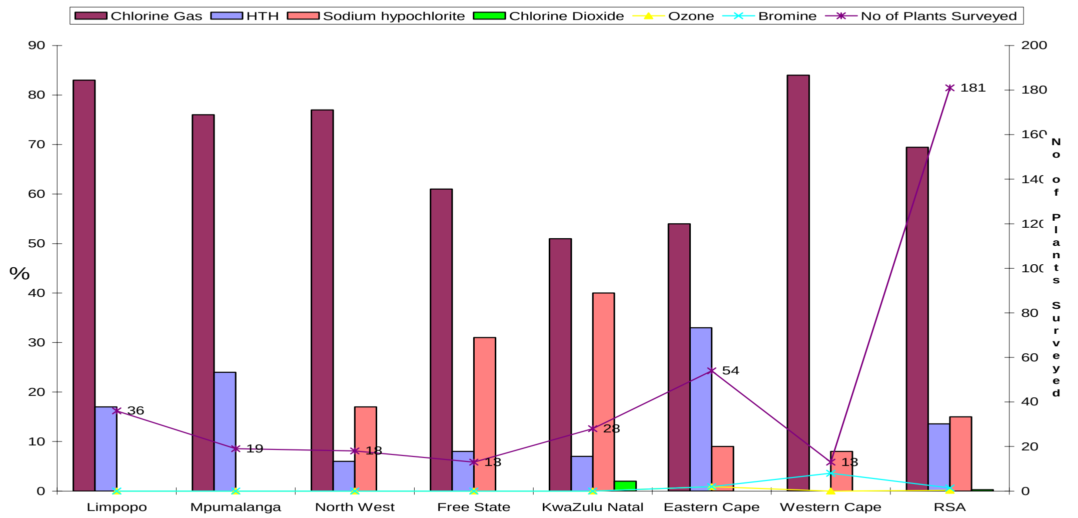

Figure 2.5 Types of Disinfectants used in Small Treatment Plants in South Africa

Physicochemical quality compliance – All water samples collected at various plants fell within SANS 241:2005 Class I in terms of pH (5 to 9.5) and conductivity (< 150 mS/m).

Turbidity – At the point of treatment, 44% and 38% of the small water treatments surveyed in South Africa fell within SANS turbidity Class I (<1 NTU) and Class II (1-5 NTU), respectively. At the point of consumption, 46% and 41% of the plants fell within Class I and Class II, respectively. The highest turbidity compliance (Class I: 69-73%, Class II: 27-31%) was noted in the Free State and the lowest turbidity compliance (Class I: 27-33%, Class II: 24-45%) was recorded in the Eastern Cape Province.

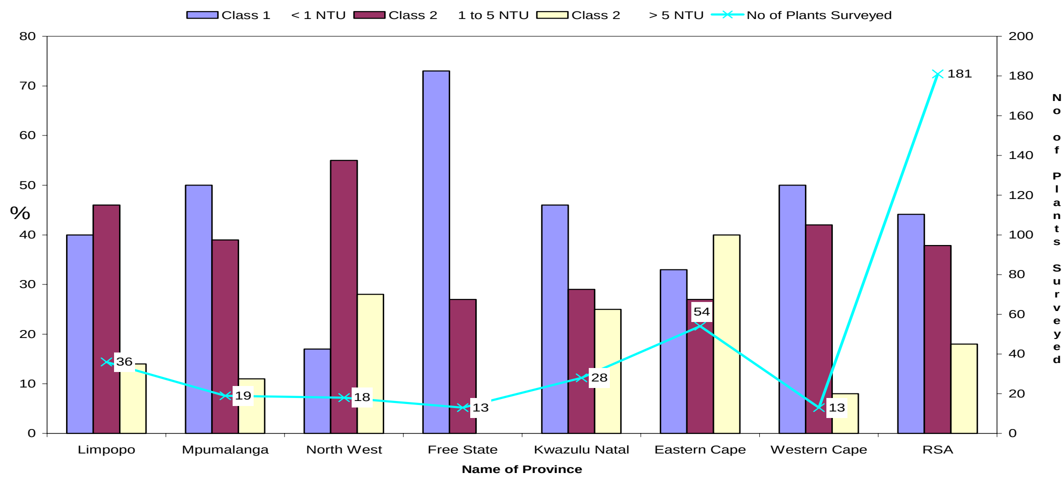

Figure 2.6 Turbidity Compliance of Small Treatment Plants at the Point of Treatment

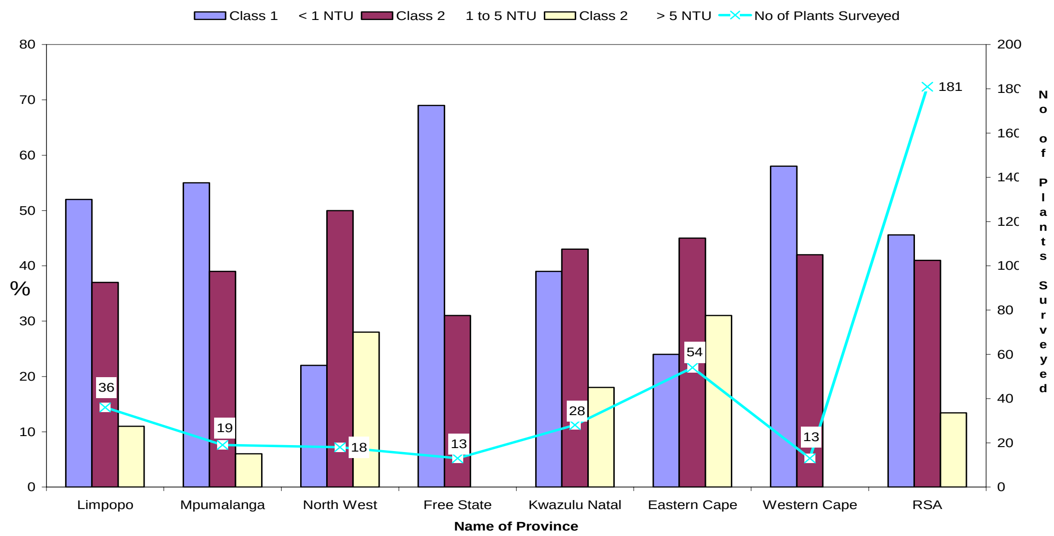

Figure 2.7 Turbidity Compliance of Small Treatment Plants in Distribution system

Chlorine residual **–** Overall, the small water treatment plants surveyed had drinking water with free chlorine residual concentrations ranging between ≤ 0.1 and ≤ 0.5 mg/L. Forty percent of the plants visited during the survey did not comply with the ideal target range of 0.3-0.6 mg/L free chlorine residual in the consumer's tap water. In most cases, the flow rate of the water and the initial chlorine dose were not known, resulting in under chlorinated drinking water.

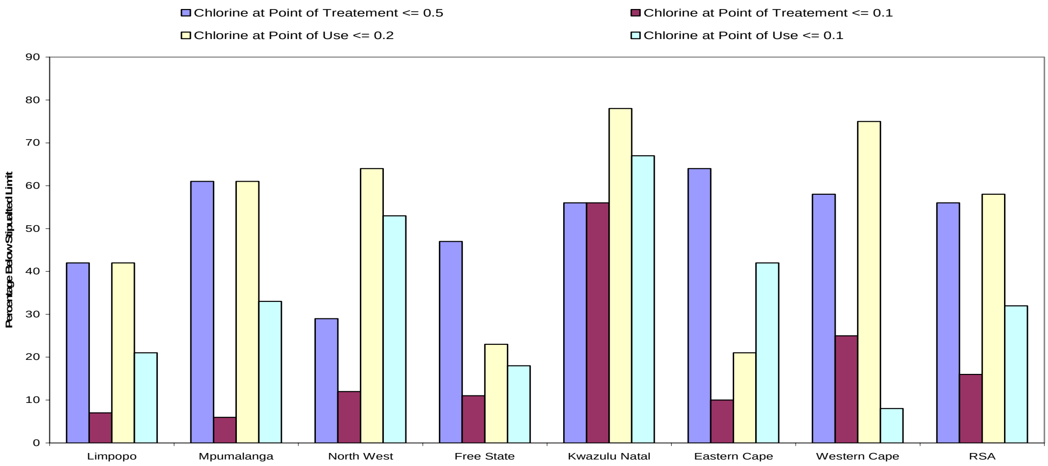

Figure 2.8 Free Chlorine per Province at Point of Use and Point of Treatment

During the on-site evaluation of the operating conditions at Fort Beaufort, Seymour and Alice water treatment plants, the following major problems were found to impact on the effectiveness of the disinfection process in the distributions: i) the distribution systems of the pipe network did not show acceptable levels of residual chlorine while the plant chlorination systems gave adequate dosage at the dosing points; ii) a high chlorine demand in the reservoirs and bulk pipelines resulted in low chlorine concentrations in the distribution system.

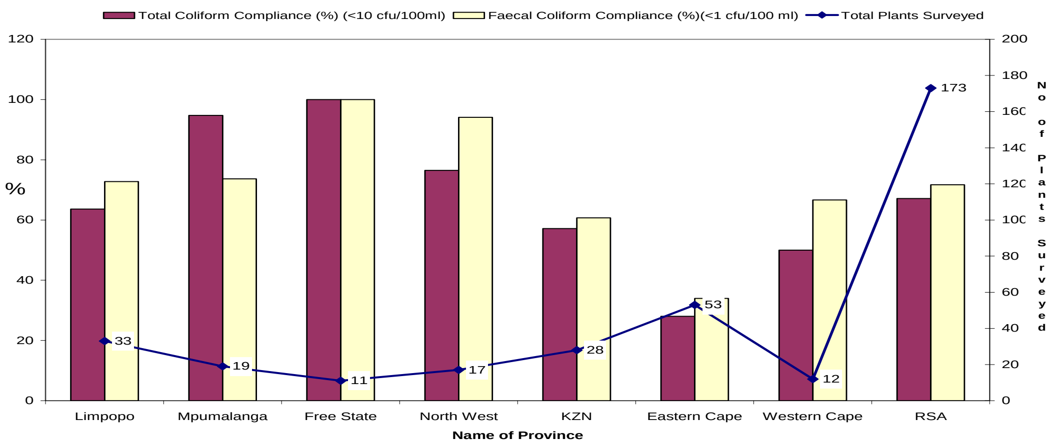

Figure 2.9 Bacteriological Compliance at the Point of Treatment

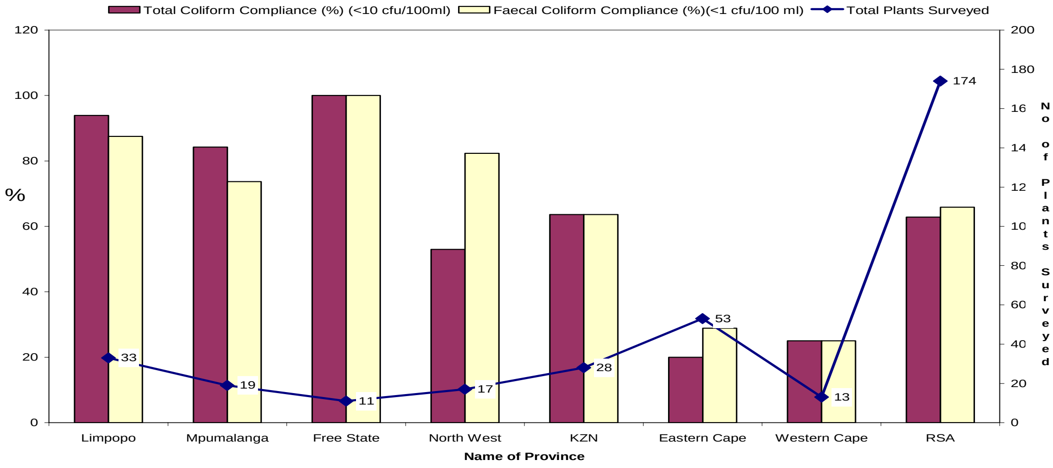

Figure 2.10 Bacteriological Compliance in Distribution System

Microbiological compliance – For coliforms, 67% and 72% of the plants complied with the South African drinking water recommended limits for total coliforms and faecal coliforms at the point of treatment, respectively. The Eastern Cape Province produced the lowest drinking water quality in terms of both total (28% of the plants) and faecal (34% of the plants) coliforms while the Free State produced the best water quality (100% compliance).

Control and monitoring – Generally, 50% of the operators and supervisors interviewed did not display the knowledge of the flow-rates at which their plants operated and more than 78% were unaware of the chemical doses used or how to correlate the required dose to the flow rate. In terms of instrumentation, only 46% of plants surveyed had the instruments to measure turbidity, pH and chlorine residual. Ninety-five percent of the plants reported that an external monitoring group visited the plants approximately once a month; however most plants complained about a lack of feedback.

Non technical (management) aspects – Non technical issues affecting the efficiency of water supply by small water treatment plants included: inadequate manpower training, poor maintenance practices, poor working conditions, insufficient financial capacity, poor recording, documentation and communication of data and information, as well as inadequate community involvement.

Chapter 3 provides a detailed guideline on the technical issues that need to be taken into consideration when selecting a disinfection system.

CHAPTER 3

TECHNICAL GUIDELINES FOR EFFECTIVE IMPLEMENTATION OF DISINFECTION IN SMALL WATER TREATMENT PLANTS

3.1 Introduction

This chapter provides the reader with a summary of the technical issues that need to be considered when implementing disinfection. Issues that are covered include the emphasis on the application of an appropriate source and unit process selection as the first step in applying the principles of "barriers" to reduce the risk of microbiological failures when disinfecting water. Selecting appropriate design parameters is critical in minimising risk. It also covered the practical issues involved in selecting disinfectants, the basic chemistry that needs to be taken into consideration as well as the advantages and disadvantages of the various types of disinfectants that are applicable to small treatment plants. Capital and operating costs of the various options available to managers are evaluated. The practical aspects involved in maintaining chlorinators have been highlighted.

3.2 Process Selection

3.2.1 Source Selection

It is important to apply a multiple barrier approach when treating waters for human consumption, the greater the number of barriers, the less the likelihood of infection.

> It is important to emphasise that the first barrier should be source selection and protection.

Source protection minimizes the risk of pathogens entering a water treatment plant and selection is thus a critical aspect of the design of a waterworks. Typical barriers are sedimentation, filtration and disinfection.

Wells and boreholes can get contaminated by users due to poor abstraction methods. Users should be educated on the use of hygienic methods of abstraction such as using clean buckets and where possible ensuring that the well or spring is protected. A pump should be fitted to a borehole to minimize the possibility of contamination.

Groundwater would typically be the first choice as this requires minimal treatment and in many cases only needs to be disinfected. Do keep in mind that many South African boreholes contain soluble iron and manganese that will require treatment

In South Africa a large proportion of the groundwater sources tend to be contaminated with iron, manganese fluoride and nitrate. Removal of these contaminants requires sophisticated chemical processes that are difficult to operate in the rural environment.

Often this contaminated underground water is the only source available and process engineers have no choice but to implement these sophisticated chemical treatment processes.

Schoeman and Steyn (2002) have recently made considerable progress in the use of membranes for the removal of nitrates in rural schemes. This has been made possible by ensuring that a well-trained technical team is readily available to assist the local community. Selection of the correct water treatment system is the first step in ensuring sustainable potable water to small communities. These aspects are covered in the following sections.

3.2.2 Design parameters

Design engineers often concentrate on getting the maximum flow out of the limited funds available for small water treatment plants, resulting in the neglect of the disinfection unit process, which can be considered to be the main and final barrier in ensuring safe production of potable water. It is necessary to ensure that reservoirs are designed in a modular fashion to ensure ease upgrade. In many of the small rural schemes, population statistics and growth rate data are often not available. Formerly, the estimation of population density, growth rates and water consumption figures for design purposes was poor. However, this has improved markedly over the last five years and has resulted in changes to the design standards.

A second parameter that has been improved is the design period for construction. Earlier design engineers used the traditional design periods of 20-30 years. These figures resulted in major water quality failures in the primary distribution systems due to long retention times. They have been downgraded and designs are now undertaken for periods of 5 to 10 years, and structures such as reservoirs are designed in a modular fashion to ensure ease of upgrade.

In rural areas, water is often transported over long distances, firstly by pipeline, frequently followed by transport in buckets, drums and vehicles, increasing the possibility of cross contamination.

3.2.3 Unit Process Selection

In rural schemes of South Africa, surface water is the primary source available (86% of the plants surveyed abstracted water from surface sources) and this has necessitated the use of traditional treatment processes of chemical coagulation, flocculation sedimentation, filtration and disinfection.

> Ensure Proper Unit Process selection by undertaking detailed Raw Water quality analysis for at least 12 months before design of the plant

During water quality assessment, it is also necessary to ensure that sufficient samples are taken for laboratory jar tests to determine optimum pH, coagulant type and dosage rates. If this information is not available, the design engineer should investigate whether other water treatment plants abstract water from the same river or catchment as this would provide appropriate performance data for existing unit processes.

Primary reasons for failure of disinfection systems in small treatment plants are as follows:

- Poor design
- Poor maintenance
- Lack of appreciation by operators and management of the importance of disinfection
- Lack of communication between technical officials and political decision makers
- Lack of training
- Selection of inappropriate technology
- Lack of spares
- Misdirection of funds from water treatment to other areas
- Lack of water quality information and absence of water quality monitoring programmes
- Poor pre-treatment of upstream unit processes. Table 3.1 summarizes the recommended design criteria for small water treatment plants.

TABLE 3.1

RECOMMENDED DESIGN CRITERIA FOR SMALL WATER TREATMENT PLANTS

Design Parameters	**Minimum**	**Maximum**
Slow sand filtration rate	0.1 $m^3/m^2.h$	0.3 $m^3/m^2.h$
Rapid gravity filtration rate	5 $m^3/m^2.h$	7 $m^3/m^2.h$
Pressure filtration rate	5 $m^3/m^2.h$	15 $m^3/m^2.h$
Horizontal sedimentation	0.5 $m^3/m^2.h$	1 $m^3/m^2.h$
Upflow Sludge Blanket Clarifiers	1 $m^3/m^2.h$	2 $m^3/m^2.h$

Slow sand filters remove *Cryptosporidium* more effectively than pressure or rapid gravity filters. Design problems experienced with pressure filters tend to be the incorrect sizing of the filters due to budget constraints. In poorly planned systems, the cost of the treatment plant is often under-estimated and thus there is a limited budget for project implementation. This results in high filtration rates of 20 to 30 m/h, resulting in short filter runs and high energy costs due to the need for frequent backwashing. Many pressure filters have inefficient backwashing systems due to poor design. This inefficient backwashing system, coupled with the fact that none of the typical pressure filters has a combined air/water backwashing system, leads to mudballing with subsequent deterioration in filtered water quality. Chemical dosing systems required for pressure filtration are frequently oversized resulting in overdosing. The modern trend is to replace conventional ferric sulphate and aluminium sulphate salts with polyelectrolytes. These polyelectrolytes are very sensitive to dose and minor deviations from the optimum dose will cause a re-stabilization of the particles and a failure of the system. In small treatment systems, alum and ferric salts are still the preferred choice as they are less sensitive to over or under-dosage.

Do not exceed a filtration rate of 0.3 $m^3/m^2.h$ for slow sand filters

Keep pressure filtration to a maximum of 10 $m^3/m^2.h$

Use alum or ferric chloride whenever is possible

Use slow sand filters whenever possible provided the source water quality limits tabulated in Table 3.1 are complied with, Other typical design problems include the lack of facilities for the measurement of raw water flow rate, filtration velocity and headloss development. One of the major advantages of slow sand filtration is that there is often no need for chemical dosing.

3.3 Chlorine Disinfection

Disinfection is the physico-chemical addition of a chemical designed to inactivate microorganisms and pathogens that are harmful to human health. There are a wide variety of disinfectants available for application in the water industry. This presents a dilemma for water works managers and municipal managers in South Africa. This section provides an overview of the important considerations when selecting a disinfectant for application in small treatment plants.

The most common chemical used for disinfection is chlorine and it can be applied in different forms, viz, either as a gas, liquid (sodium hypochlorite) or a solid form (calcium hypochlorite either as a tablet or a powder)

3.3.1 Terminology

Chlorine dose required - The amount of chlorine required to satisfy the chlorine demand and also to achieve the required chlorine residual.

When chlorine is added to water the following reaction takes place:

$$Cl_2 + H_2O = HOCl + HCl$$

Chlorine Dose = Chlorine Demand + Chlorine Residual

Chlorine residual: The amount of chlorine remaining in the water after a minimum contact period of usually 20 minutes after the disinfection.

Chlorine gas Cl_2 dissolves in water to form hypochlorous (HOCl) and hydrochloric acid (HCl). The actual disinfecting agent is hypochlorous acid which dissociates as below.

$$HOCl \leftrightarrow H^+ + OCl^-$$

Hypochlorous acid has excellent microbiocidal properties and penetrates the microorganism's cell walls by disrupting its metabolic activities. The chlorine species in the form of hypochlorous acid, HOCl, plus the hypochlorite ion, OCl^-, are termed free available chlorine. Chlorine in the form of monochloramine (together with other chloramine species) is termed combined available chlorine.

As indicated in Figure 3.2, the above reaction is highly pH dependent – higher hydrogen (H^+) ion concentrations will drive the reaction to the left thus increasing the concentration of hypochlorous acid.

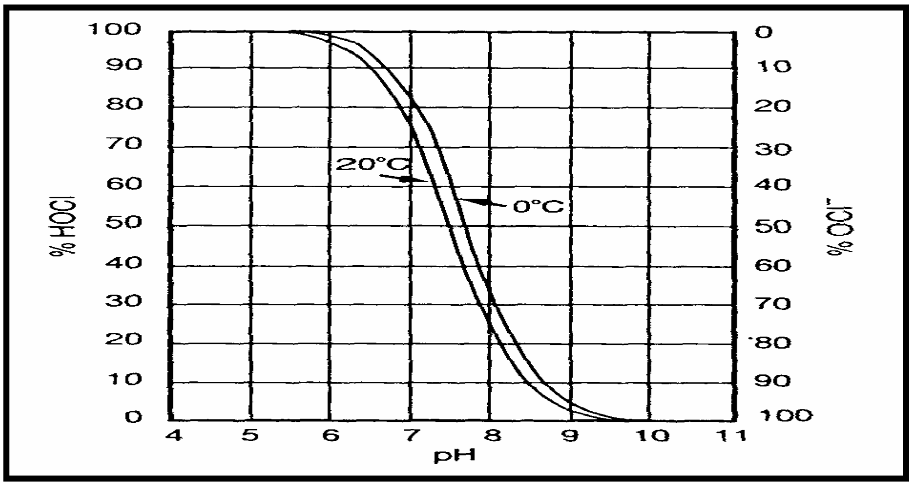

Figure 3.1 Chlorine Concentrations as a function of pH (AWWA, 2001)

3.3.2 Techniques of chlorination

The principal chlorination practices of relevance to small water supplies are:

Free residual chlorination: where the available residual chlorine (the chlorine in the water after a specific period of time) is either in the form of HOCl or OCl^-.

Breakpoint chlorination: In breakpoint chlorination, sufficient chlorine is added to react with ammonia and organics in the water leaving a free residual concentration for the protection of the distribution system. This ensures that the distribution system is protected against secondary contamination (Figure. 3.2).

Chloramination or combined residual chlorination: Ammonia is deliberately added to the water in conjunction with chlorine. This system is practised where there are long distribution systems. Table 3.2 summarizes the advantages and disadvantages of chorine disinfection.

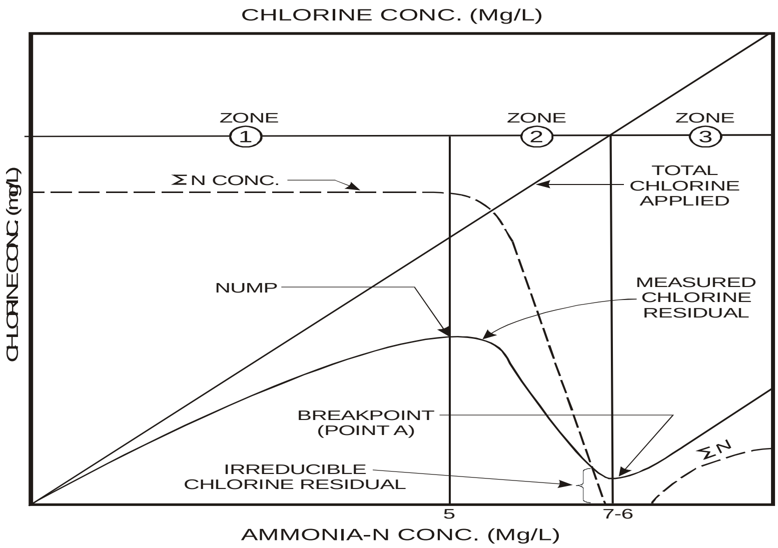

Figure 3.2. Breakpoint Chlorination Curves (Source - White, 1999)

TABLE 3.2 ADVANTAGES AND DISADVANTAGES OF CHLORINE		
Disinfectant	**Advantages**	**Disadvantages**
Chlorine	Cost effective, well established process, effective against a wide spectrum of pathogens and can be dosed in a number of different forms. Flexibility in its application to suit various circumstances provides a lasting residual that can easily be measured in the distribution system using very simple apparatus.	Highly corrosive, limits the materials of use. Shipping and handling and application thus have to be carefully controlled and managed on a water works. Forms a number of disinfection by-products which can be harmful to human health, however its advantages far outweigh these disadvantages.

3.3.3 Selecting a Suitable Disinfection System

The following factors must be taken into consideration when choosing a suitable disinfectant:

- Ease of handling,
- Safety,
- Ability to destroy harmful bacteria and pathogens,
- Storage,
- Capital and operating costs,

- Toxicity and disinfection by-products,
- Size of water treatment plant,
- Remoteness of site,
- Size of plant and suitability of disinfection system

Tables 3.3 and 3.4 summarise various methods of chlorine additions and important considerations for the use of chlorine as a disinfectant, respectively.

TABLE 3.3 METHODS OF CHLORINE ADDITION			
Method	**Description**	**Safety precautions**	**Costs**
Gaseous chlorine	Chlorine is delivered as a gas in 70 kg or 1 ton cylinders. In small treatment plants the typical size used is the 70 kg cylinder. A chlorinator is required to feed the gas into the water stream. The gas is fed into the stream by creating a vacuum using a pump and ejector. The gas feed rate is controlled by a metered orifice.	Gaseous chlorine is a strong oxidizing agent. It is highly toxic and required stringent safety precautions. Minimum safety equipment required for the installation includes breathing apparatus and shower. Training is critical.	This is the most economical method of disinfection. Typical costs are 14c/kl for a 2.5 Ml/d plant.
Sodium hypochlorite	Sodium hypochlorite is supplied as liquid ranging in concentration 8% to 16%. Delivery is either in 20 litre, 200 litre or larger bulk tanks. The solution can be diluted before addition to the process stream or in larger plants; it can be fed directly as a concentrate.	Sodium hypochlorite solution is strongly oxidizing, toxic and classified as a hazardous chemical. Safety precautions in handling include gloves, eye protection and a bund wall large enough to contain the full volume under storage.	Costs are approximately 35c/kl for a 2.5 Ml/d plant.
Calcium hypochlorite	Calcium hypochlorite is supplied in granular of tablet form. Available chlorine concentration is 65%. The granules have to be dissolved in water to prepare 5% m/v solution before addition to the process stream	Calcium hypochlorite is a strongly oxidizing, toxic chemical. When added to water it produces heat and will react with any oxidizing material. Preparation tanks must either be Glass Re-enforced Plastic or PVC type compounds.	Cost is approximately 36c/kl for a new installation for a 2.5 Ml/d plant

TABLE 3.4 IMPORTANT CONSIDERATIONS FOR USE OF CHLORINE AS DISINFECTANT	
Consideration	**Description**
Generation	Chlorine, a chlorine gas, sodium hypochlorite or calcium hypochlorite is manufacture off-site by specialist manufacturers. There has been a move to on-site generation; however this involves high maintenance and technical support.
Primary uses	The primary use of chlorination is disinfection. Chlorine also serves as an oxidizing agent for taste and odor control, the prevention of algal growths, maintaining clear filter media, the removal of iron and manganese, the destruction of hydrogen sulfide, color removal, maintaining the water quality at the distribution systems, and improving coagulation.
Inactivation efficiency	The general order of increasing chlorine disinfection difficulty is bacteria, viruses, and then protozoa. Chlorine is an extremely effective disinfectant for inactivating bacteria and highly effective viricide. However, chlorine is less effective against *Giardia* cysts. *Cryptosporidium* oocysts are highly resistant to chlorine.
Byproduct formation	When added to the water, free chlorine reacts with natural organic matter (NOM) and bromide to form disinfection by-products (DBPs), primarily trihalomethanes (THM)'s, some haloacetic acids (HAAs), and others.
Point of application	Raw water storage, coagulation/post-raw water storage, pre-sedimentation/ post coagulation, post-sedimentation or pre-filtration, post filtration (disinfection), or in the distribution system.
Special considerations	Because chlorine is such a strong oxidant and extremely corrosive, special storage and handling considerations should be considered in the planning of a water treatment plant. Additionally, health concerns associated with the handling and use of chlorine is an important consideration.

3.3.4 Process Monitoring

It is essential to monitor the treatment process, especially the final water disinfection doses and residual chlorine concentrations. Ideally, a plant should be maintained in a steady state with minimal flow rate or raw water quality changes or interruptions. However this is seldom the case and flow rate changes will be experienced.

All flow rate changes must be accompanied by a process change where the chlorine dose is either increased or decreased to compensate for the flow rate variation. Similarly when the raw water quality changes, there is a need to change the coagulant dose and the chlorine dose. These changes must be effected after the necessary calculations are done and the information must be recorded in a log sheet. A list of SANAS approved laboratories is attached as Appendix 1.

Process Water Quality must be monitored every two hours. Turbidity, chlorine and pH should be measured at the raw water inlet, clarifier overflow, individual filters and reservoirs. A typical process control log sheet is attached as Appendix 2.

All water treatment plants must have a jar stirrer on site to determine the optimum coagulant dose. Table 3.5 lists the basic process laboratory equipment required for a waterworks.

TABLE 3.5

COSTS OF PROCESS MONITORING EQUIPMENT

Equipment	Budget Cost
Ph meter	R6 000
Turbidity Meter	R20 000
Chlorine Comparator	R5 000
Lab Bench	R10 000
Deionised water still	R5 000
Jar Stirrer	R30 000
Consumables and reagents	R10 000 per annum
Glassware	R5 000

3.3.5 Distribution quality monitoring

Sampling Frequency in Distribution System

In a piped water supply, the probability of contamination of the distribution system increases with the length of the pipe network and the plumbing systems attached to it. It is desirable to take samples at least weekly; however in small systems, this may not be possible due to human resource and financial resource constraints. The Sampling frequency recommended by the World Health Organisation (WHO, 1993) is tabulated in Table 3.6. It is important that the sampling frequency be spaced out evenly throughout the month. It is thus best to cluster a number of water works and employ a dedicated sampling officer to sample the raw water storage dams, final water reservoirs and distribution reservoirs.

Budget approximately R10 000 per month for sampling

TABLE 3.6a

SAMPLING FREQUENCY AT A WATERWORKS

Determinand	**Frequency**	
	Raw Water	Final Water
Free Chlorine	NA	Two-hourly
Total Chlorine	NA	Two-hourly
Turbidity	Two-hourly	Two-hourly
pH	Two-hourly	Two-hourly
Total Coliforms	Weekly	Daily
Faecal Coliforms	Weekly	Daily
Faecal Streptococci	Weekly	Daily
Colony Counts	Weekly	Daily
Suspended Solids	Weekly	NA

TABLE 3.6b SAMPLING FREQUENCY AT A WATER WORKS – RAW AND FINAL	
Population Served	**Minimum Number of Samples**
Less than 5 000	1 sample per month
5 000 – 100 000	1 sample per 5 000 population per month
More than 100 000	1 sample per 10 000 per month

3.4 Capital and Operating Costs

Capital and operating costs are highly dependent on the plant size, the environment in which the product is being used and the form in which it is applied. Generally, gaseous chlorine has the lowest total operating costs in comparison to calcium and sodium hypochlorite. The total costs should include the capital costs, the operation and maintenance costs, equipment replacement and repairs and personnel costs. The following sections provide a summary of the design of typical chlorination systems as well as the respective capital and operating costs. The designs are based on an average plant size of 2.5 Ml//d. Costs are based on 2007 values. A typical Process and Instrumentation Diagram (P&ID) for a Gas Chlorination system is illustrated in Figure 3.3. The costs have been estimated on the basis of the aforementioned design with the duty and standby system as shown in Figure 3.4.

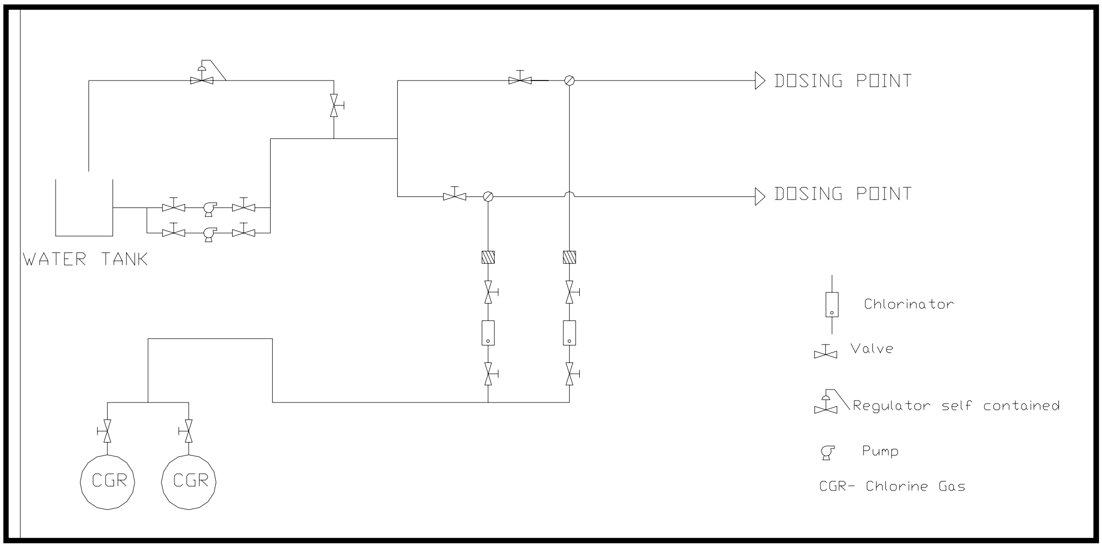

Figure 3.3 Gas Chlorination P&ID

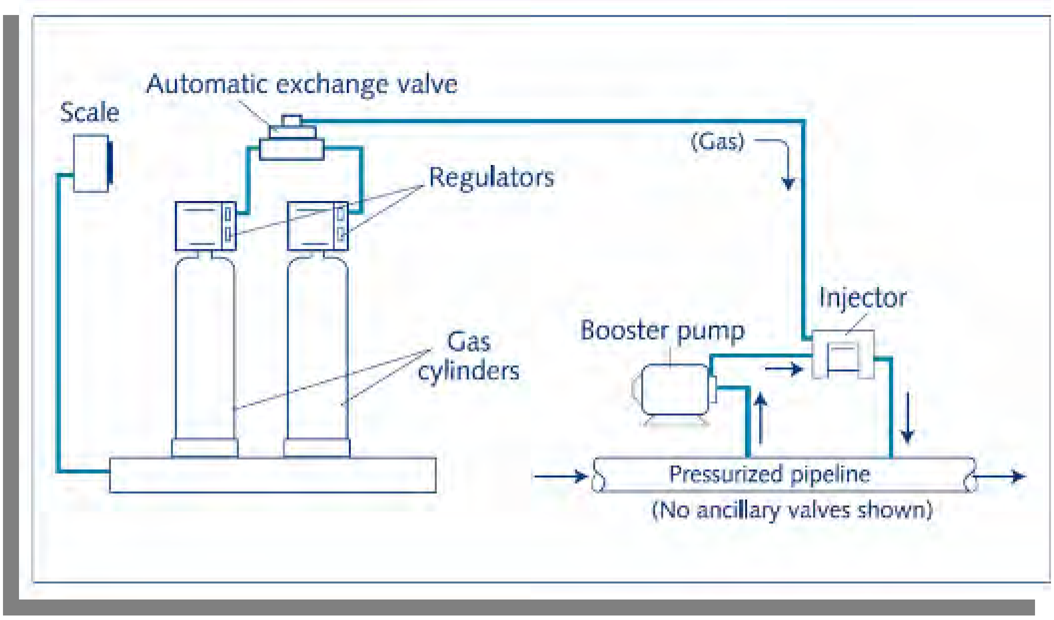

Figure 3.4 Typical Setup for 70 kg Gas Chlorine System (AWWA, 2001)

Calcium hypochlorite is added to a perforated basket and diluted with water to the required concentration. Allowance is made for mechanical agitation using an axial type mixer. Baffles are used to optimize mixing and minimise vortexing which can lead to the settling of the calcium. Calcium hypochlorite solutions are highly corrosive to many of the steel alloys available. A typical setup of this gravity based dosing system is illustrated in Figure 3.5. In this application Glass Re-enforced Plastic (GRP) materials are used wherever possible. Where steel has to be used, it has to be encapsulated in GRP to minimise exposure to the hypochlorite solution. Mixer shafts and impellers have to be coated with a fluoroploymer for optimum protection.

Installation and operating costs of disinfection Systems are summarized in Tables 3.8 and 3.9 below.

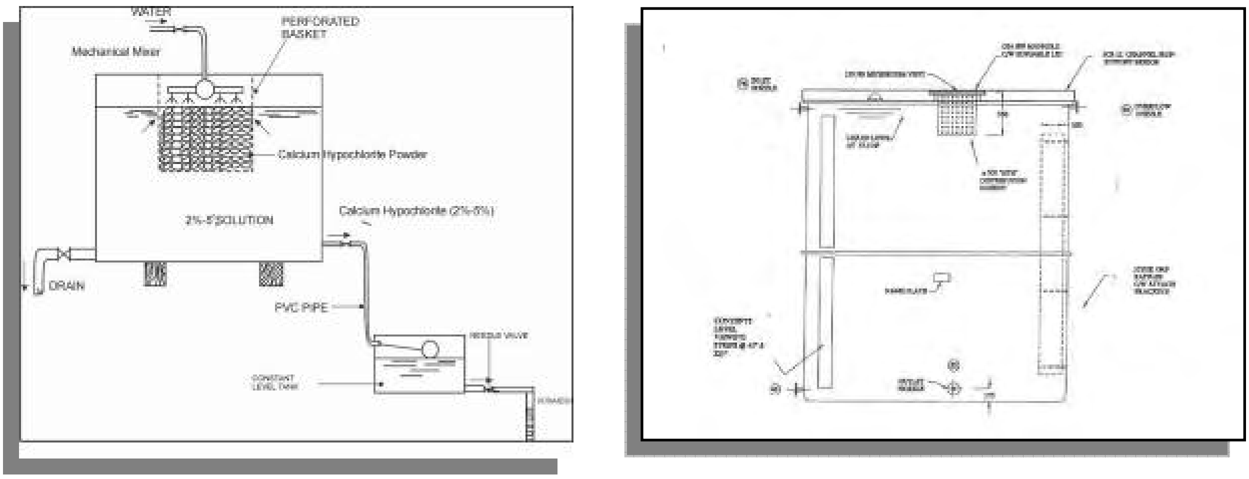

Figure 3.5 Typical Setup for Gravity Dosing System

TABLE 3.7 DESIGN OF SODIUM HYPOCHLORITE DOSING SYSTEM				
Average daily inflow	Ml/day	2.5		
Average inflow	Ml/year	913		
Chlorine dose	mg/l	7		
Chlorine dose	kg/Ml	7		
Chlorine consumption	Tons/year	6.39		
Mass Balance		**Min**	**Average**	**Max**
Inflow	Ml/day	1.50	2.50	3.00
Chlorine dosage	mg/l	7.00	7.00	7.00
Chlorine dosage rate required	kg/day Cl_2	10.50	17.50	21.00
NaOCl specific gravity	kg/litre	1.05	1.05	1.05
Sodium hypochlorite 10% m/v	% (m/v)	10.00	10.00	10.00
Sodium hypochlorite dosage required	l/day	105.00	175.00	210.00
Sodium hypochlorite dosage required	l/hr	4.38	7.29	8.75
Storage capacity		**Min**	**Average**	**Max**
NaOCl consumption	l/day	105.00	175.00	210.00
NaOCl consumption	m3/day	0.11	0.18	0.21
Maximum supplier off-line time	Days	15.00	15.00	15.00
Min storage required cap. required	m3	1.58	2.63	3.15
Minimum bulk tank size				
Tanker load (10% m/v)	**m3**	**2**		
Safety factor		**0.25**		
Tank size for accepting delivery	**m3**	**2.50**		
Equivalent chlorine delivered	kg Cl2	200.0		

TABLE 3.8 OPERATING COSTS OF SODIUM HYPOCHLORITE DOSING SYSTEM		
Container size as sold	**Litres**	25
Cost as delivered	R/litre NaOCl	R2,40
Sodium hypochlorite	R/kg NaOCl	R2,29
Sodium hypochlorite empty container price	R/container	R57,00
Contribution of cost of container to overall price	R/litre container	2.28
Sodium hypochlorite total price as delivered	R/litre NaOCl	R4,68
Chlorine total price as delivered	R/kg Cl_2	R46,80
Chlorine cost (delivered)	R/ton Cl_2	R46 800
Chlorine cost per annum	R/yr	R298 935
Total inflow (based on average inflow)	Ml/yr	912.50
Chemical costs R/annum		R298 935
Direct annual operating costs		R308 935
Total annual operating costs		**R317 455**

TABLE 3.9 CAPITAL & OPERATING COSTS OF SODIUM HYPOCHLORITE DOSING SYSTEM				
Item Description	**No**	**Unit Cost**	**Total**	
Purchased equipment (installed)				R15 800
Bulk storage tanks, 2 m^3 GRP	2	R3 000	R6 000	
Day tank, 0.1 m^3, GRP	1	R800	R800	
Dosing pumps	2	R4 000	R8 000	
Piping & fittings (PVC, C16)			R1 000	
Electrical & instrumentation				R6 800
Level transmitter	2	R3 000	R6 000	
Installation	1	R800	R800	
Civil & structural				R20 000
Bund & plinth	1	R4 000	R4 000	
Total fixed capital investment				R42 600
Annual Operating Costs		**R/yr**	**cents/kl**	
Chemical cost – avail chlorine		R298 935	32.76	
Maintenance		R10 000	1.10	
Direct operating costs		R308 935	33.86	
Fixed charges Depreciation (20% pa)		R8 520	0.93	
Total operating costs		**R317 455**	**34.79**	

TABLE 3.10 **GAS CHLORINATION DESIGN**		
Gas Chlorination Operating Costs		
Gas Chlorination Design Parameters	**Quantity**	**Units**
Unit cost (R/kg)	12.00	R/kg
Treated water flow rate	2.50	Ml/day
Purity (% Cl_2)	100.00	%(m/m)
Dose (mg/l $Cl_{2)}$	7	mg/l Cl_2
Dose (kg/Ml)	7	kg/Ml
Daily chlorine gas consumption	17.50	kg/day
No. of days per year	365	days/yr
Annual consumption	6 387.50	kg/year Cl_2
Annual cost	R76 650	R/yr
Cost per kl	8.40	cents/kl
Size of chlorinator	0.7	kg/h

TABLE 3.11 CAPITAL COSTS FOR GAS CHLORINATION SYSTEM			
Description	Quantity	Unit Rate	Amount
Cylinder manifold	2	R5 000	R10 000
Chlorinators, one duty and one standby.	2	R15 000	R30 000
Chlorine leak detector and alarm system dual sensor	1	R20 000	R20 000
Duty/standby operating water booster pumps for chlorinator including connections	2	R4 000	R8 000
Heating & lagging	1	R5 000	R5 000
Valves, fittings, chlorine injection sets	1	R10 000	R10 000
Breathing apparatus (gas respirators)	1	R20 000	R20 000
Chlorine cylinders, 65 kg each filled	2	R8 400	R16 800
Scales	2	R10 000	R20 000
Exhaust fan,	1	R15 000	R15 000
Emergency shower, eyewash	1	R4 000	R4 000
First aid kit	1	R1 000	R1 000
Warning and instruction signboards	1	R1 000	R1 000
Filter cartridges for breathing apparatus.	4	R600	R2 400
Chlorine gas injector.	2	R2 600	R5 200
O' rings for vacuum and dosing unit.	4	R4 100	R16 400
TOTAL			**R184 800**

TABLE 3.12 TOTAL OPERATING COSTS FOR GAS CHLORINATION			
Fixed Capital Costs			
Item description	**Total**		
Purchased equipment (installed)	R184 800		
Civil & structural	R10 000		
Total fixed capital investment	R194 800		
Operating costs	R/yr	cents/kl	
Chemical cost	R76 650	8.40	
Maintenance	R10 000	1.10	
Direct operating costs	R86 650	9.50	
Fixed charges: depreciation (20%)	R38 960	4.27	
Total operating costs	R125 610	13.77	

TABLE 3.13 CALCIUM HYPOCHLORITE DESIGN AND CAPITAL COSTS				
Typical Calcium Hypochlorite (HTH) Dosing System				
Basis for design		**Size**	**No.**	**Cost (R)**
Process flow rate	**2.50**	Ml/day		
Chlorine dose required	**7**	mg/l Cl_2		
No. of days per year	**365**			
Daily consumption	**17.50**	kg/day Cl_2		
Solution strength	**5**	% (m/v)		
No. batches prepared per day	**1**			
Volume solution required per day	**0.35**	m^3		
Tank diameter (assume 1 m)	**1**	m		
Area of tank	**0.79**	m^2		
Height of tank	**0.45**	m		
Allow free board of 0.3 m	**0.30**	m		
Total height of tank	**0.75**	m		
Estimated Cost on 1 m^3 Tank				
CAPITAL COSTING	**Unit Cost**		**No**	**Cost**
Preparation tank size	1	m^3		
Cost of preparation tank	R5 000		2	R10 000
Baffles for make up tank	R2 000		2	R4 000
Constant head tank size	0.02	m^3		
Cost of constant head tank	R5 000		2	R10 000
Axial flow mixers	R15 000		2	R30 000
20 mm PVC pipework	1 000		1	R1 000
Electrical	10 000		1	R10 000
Fitting and installation	20 000		1	R20 000
Total capital costs				R85 000

The calculations for the design and costing of the dosing system are based on the preparation of 5% (m/v) calcium hypochlorite solution.

TABLE 3.14 CALCIUM HYPOCHLORITE OPERATING COSTS$_{(a)}$		
Process flow	**Design flow (Ml/d)**	**Units**
Calcium hypochlorite unit of supply	50	kg drums
Unit cost (R/kg) calcium hypochlorite	16.00	R/kg
Purity % Cl_2	68%	%(m/m)
Unit cost (R/kg) as chlorine (Cl_2)	23.53	R/kg Cl_2
Dose	7	mg/l Cl_2
No. of days per year	365	
Daily consumption	17.5	kg/day
Annual consumption as chlorine (Cl_2)	6 387	kg/year
Annual consumption as chlorine (Cl_2)	6.39	Tons/ year
Annual cost Rands per year	150 294	R/Year
Cost per kilolitre	16.47	Cents/kl

TABLE 3.15 CALCIUM HYPOCHLORITE OPERATING COSTS$_{(b)}$		
Fixed Capital Costs		
Item Description	**Total**	
Purchased equipment (installed)	R85 000	
Civil & structural	R5 000	
Total fixed capital investment	R90 000	
Operating Costs		
Item description	R/yr	cents/kl
Direct chemical cost	R150 294	16.47
Maintenance	R5 000	0.55
Direct operating costs	R155 294	17.02
Depreciation	20%	
Fixed charges: depreciation (20%)	R18 000	1.97
Total Annual Operating costs	R328 588	36.01

TABLE 3.16 COMPARISON OF COSTS OF DISINFECTION ALTERNATIVES			
	Gas/liquid Chlorination	**Sodium Hypochlorite**	**Calcium Hypochlorite**
Capital cost	R194 800	R317 455	R90 000
Direct operating cost c/kl	9.50	33.86	17.02
Maintenance c/kl	1.10	1.10	0.55
Total Operating Cost c/kl	13.77	34.79	36.01

3.5 Guidelines for Design of Chlorine Gas Facilities

Chlorine gas is very toxic and the primary consideration when selecting this unit process is public safety, plant reliability and operation. All chlorine gas installations should be designed to ensure that a leak can be contained in the chlorine room thus minimizing plant personnel and the public exposure. Doors and windows should be gas-tight to minimize escape of gaseous chlorine to the exterior atmosphere or building interior.

- Chlorinators should be housed in a room separate from but adjacent to the chlorine storage room. This is to minimize the need to enter the storage room to adjust feed rates and to minimize the potential for equipment damage caused by chlorine leaks. A gas-tight shatter resistant window shall be present for viewing the storage and chlorinator rooms from an interior wall of the plant.

Works managers must consider the following design guidelines extracted from the Ten State Standards (2004), when selecting this unit process:

- All chlorine cylinders must be contained in the chlorine storage room. Vacuum regulators should be located on individual chlorine cylinders in service. The use of pressurized chlorine gas lines and manifolds is strongly discouraged and, if utilized, must be contained in the chlorine storage room.
- All chlorine cylinders should be adequately restrained.
- Chlorinators should be housed in a room separate from but adjacent to the chlorine storage room. This is to minimize the need for entering the storage room to adjust feed rates and to minimize the potential for equipment damage caused by chlorine leaks. A gas-tight shatter resistant window should be present for viewing the storage and chlorinator rooms from an interior wall of the plant.

- The chlorine storage room should only be accessible from the outside. The exterior access door for the chlorine storage area must open outward, being equipped with panic bar hardware on the interior. A small viewing window should be present in the door or adjacent to the door in the exterior wall to allow operator examination of the room before entry. Loading dock doors shall also open outward and be equipped with the appropriate moldings, gaskets, and weather stripping to minimize gas leakage to the exterior. Inside access to the chlorinator room shall be acceptable if chlorine gas is supplied under vacuum.
- All access doors should be properly labeled with appropriate warning signs.
- A pressure relief valve should be located on the chlorine vacuum line within the vacuum regulator to prevent gas pressurization of the chlorinator. This valve should be vented to the chlorine storage room or to the outside if appropriate.
- All openings between the chlorine storage room and other parts of the building should be sealed such that chlorine leaks can be contained within the storage room.
- There should be no exterior windows to chlorine storage rooms other than the small viewing window at the entrance. (This is to minimize the potential for heat build-up from the sun and to minimize vandalism.)
- Scales should be constructed of durable material to withstand the aggressive environment and situated such that they can be easily and accurately read through a viewing window or use of a remote readout. This type of design will minimize the need to enter the chlorine storage area to take readings.
- Separate light and ventilation switches should be located outside of the chlorine storage room near the entrance door and interior viewing window. Lighting fixtures within the chlorine storage area should be suitable for use in an aggressive environment and, if possible, designed to operate even during a chlorine gas release.

- Electrical components should be minimized within the chlorine storage area. Motors for louvers, cylinder cranes, and ventilation equipment shall be suitable for use in an aggressive environment. Convenience electrical components, such as outlets, should be avoided. All electrical systems for the chlorine storage area should be on dedicated circuits.

- The chlorine storage room should be equipped with ventilation equipment capable of one complete air exchange per minute. This equipment should be located such that it will draw suction near the floor as far away as practical from the entrance door and air inlet. Exhaust shall be located away from the door and other air intakes. Exhaust discharge should be located so as not to contaminate other air inlets to any rooms or structures. Air intakes should be through louvers near the ceiling. Louvers for intakes and exhaust should facilitate airtight closure.
- All ventilation and duct work within a chlorine storage room should be separated from domestic building ventilation systems. All chlorine room duct work should be gas tight and not pass through other rooms or areas of the building.
- The self contained breathing apparatus (SCBA) should not be located within the chlorine storage room. It is preferable that this equipment be placed in a convenient location where personnel can easily access it in the event of an emergency.
- Service water to operator injectors/eductors should be of adequate supply and pressure to operate feed equipment within the needed chlorine dosage range for the proposed system. All service water should be properly protected by the appropriate cross connection control device.

- The placement of injectors/eductors should be carefully evaluated. Current system operation and chlorination practices should also be reviewed before design. In some cases, it may be appropriate to locate the injector/eductor in the chlorinator room with distribution of highly chlorinated water to the point of application. In other situations, it may be best to locate the eductor/injector can at the point of application with distribution of chlorine gas through plastic tubing under vacuum to the point of application.
- A chlorine cylinder repair kit with a leak detection bottle should be supplied within each chlorine storage room.
- Floor drains should not be designed within the chlorine storage area.
- Combustible materials should not be stored in chlorine rooms.
- Fire sprinkling systems should not be installed in chlorine rooms.
- The location of the chlorine room should be on the prevailing downwind side of the building, away from entrances, windows, louvers, walkways, etc.
- When using chloramination, the ammonia room must be separate from the chlorine storage room.

3.6 Operation of Small Water Treatment Systems

Schultz and Okun (1984) quote the following statement by George D Woods, former president of the World Bank (1965): “Neither general programs nor even generous supplies of capital will accomplish much until the right technology, competent management, and manpower with the proper blend of skills are brought together and focused effectively on well conceived projects.” They rightly conclude that this statement “summarizes the dilemma that is faced in the provision of water in the developing world.”

Many of the schemes implemented are sold as fully automated package plants and there is often the perception that there would either be no operators required or minimal operational input. We have found that irrespective of the degree of automation, a minimum operator input of two hours per day is required to ensure continual production of acceptable quality water. The operator needs to undertake the following measurements on a daily basis: chlorine, pH, turbidity, flow rates, reservoir levels and chemical dosages.

Intervention by the operator would depend on their level of training. However, it is expected that they would have been trained to make decisions such as optimising the chemical doses.

All systems that have treatment plants will need some technical backup from management, artisans, technicians, laboratory personnel, scientists and process engineers. Small stand-alone treatment systems cannot afford this level of institutional backup and this is one of the primary reasons for the failure of the entire system. Fortunately, in large institutions, such as Water Boards and the larger Metropolitan Municipalities, these services are readily available as the overhead costs can be shared across a large number of small treatment systems.

3.7 Selection, Operation and Maintenance of Chlorinators

In a detailed review of gravity and water powered chlorinators, Skinner (2001) lists the following criteria that should be used in selecting chlorinators. The following sections are abstracted from the review.

3.7.1 Nature of the flow of the water to be treated

"Is the water stagnant or flowing – Water driven chlorinators will require flowing water.

Is the flow constant or variable? Some dosers can automatically compensate for changes in flow rate but many can not.

Is the flowrate continuous or intermittent? Continuous, constant flow is usually the easiest situation to cope with, other than if the chlorinator has to discontinue operation when it is being refilled or maintained. Having a standby unit that can be brought into operation whilst the first is being maintained is a good idea if the flow of water can definitely not be stopped during the maintenance period, although this situation is rare. If flow is continuous and the dosing is interrupted then obviously some of the water will not receive the correct dose of chlorine. However, it may be possible to divert this water to waste. If flow periodically ceases, some chlorinators will automatically stop, others will have to be turned off manually, while some units' valves are needed to stop siphoning taking place when flow stops.

Does all of the water have to pass through the unit or should a bypass be used? With high flowrates it may be necessary to divert only part of the flow through the chlorinator. This water is then dosed with a high concentration of chlorine before it is diverted back, to be thoroughly mixed with the remainder of the water. Care needs to be taken when using a bypass, to ensure that the proportion of flow diverted through the unit remains constant, particularly if the flowrate is variable.

What dosing rate per hour is required? Some chlorinators can only dispense small doses of solution, which makes them only suitable for disinfecting water with low flowrates. This problem is compounded if only low strength solutions are available for dosing. Although the use of more than one chlorinator in parallel will increase the total rate of dosing, the use of a different type of chlorinator may be the better alternative.

Does the flow need to remain in a pipe or can it be open to the atmosphere? In some situations the dose needs to be added to flow in a pressurized pipe. Only a few types of chlorinators are suitable for this.

Is the chlorine demand of the water constant? None of the chlorinators described in this report can automatically adjust for changes in the dosing rate to cope with changes in the chlorine demand of the water. It is therefore important that a chlorinator operator test the concentration of free residual chlorine (in the water leaving the contact tank) whenever s/he suspects there is a change in the quality of the raw water. Adjustments to the dose should then be made if necessary".

3.7.2 Origin of the doser and its operation/maintenance requirements

Is the doser produced locally or is it imported?

If an imported chlorinator is to be used it is important that a reliable supply of affordable, essential spares be readily available. Because small chlorinators are not widely used it may be hard to find in-country agents able to supply such a service. If this is the case enough spares for several years operation, or even for the whole life of the chlorinator, may need to be purchased when it is initially imported.

What are the operational and maintenance requirements of the doser?

The level of skills of both the operators of the chlorinator and the technical staff who may support them should be matched to the complexity of the operation and maintenance tasks. Training and monitoring of performance will often be necessary to ensure that operators carry out effective chlorination.

3.7.3 Types of chlorine compound available

What form of chlorine is available?

Different forms of chlorine, sodium hypochlorite, chlorinated lime, calcium hypochlorite, liquid, powder, tablets, etc. may determine what types of chlorinator are feasible.

Is the supply of the chlorine compound reliable?

In view of the potential, fast deterioration of some chlorine compounds, effective chlorination will often require a regular and reliable supply of chlorine compounds. If it is properly stored calcium hypochlorite has the longest shelf-life of the compounds discussed in this report, but for many chlorinators it will first have to be dissolved to prepare a solution ready for dosing. The calcium content of chloride of lime and calcium hypochlorite may cause problems unless regular maintenance takes place.

3.8 Chlorinator options for different sources of water

The most appropriate choice of chlorinator will be partly dependent on the source of the water and the way in which it is collected or distributed. These aspects are discussed in the following sub-sections.

3.8.1 Open wells

Successful chlorination of water from open wells is problematic. Unless the water is pumped from the well the usual choice is a diffusion device such as a pot chlorinator, but this may not be effective. Another option is to use a constant-rate dosing device to drip-feed chlorine solution into the well at a suitable rate to match the average rate at which the water is being collected from the well. This is also unlikely to provide a very reliable dose, since it will tend to provide too little chlorine during periods of peak demand and too much during periods when the well is not in use. There also needs to be a way in which the device can be turned off overnight or at other times of low water demand from the well.

The fact that the water in open wells is not flowing practically rules out the use of most of the other chlorination devices. However, if the water is raised from the well using a suction hand pump then a direct suction doser, fitted to the suction side of the hand pump may be used. If it is feasible, household-level treatment will be another option, which will require less chlorine solution because the householder can choose to only treat drinking water which seems more logical.

Any organic matter introduced into an open well will consume some of the chlorine meant for disinfecting the water. It is therefore important to keep the well water as clean as possible.

3.8.2 Boreholes

Water in a properly constructed and maintained borehole that is equipped with a hand pump or a mechanically powered pump is not prone to contamination by users. Chlorination is therefore only necessary if for some reason the groundwater is already polluted or to give some level of protection from contamination in a piped distribution system. If a motorised pump is raising the water, then a number of different types of chlorinator may be appropriate. In fact the situation is identical to that discussed below when treating pumped surface water except that other treatment processes to deal with turbidity, etc., will not be necessary.

Unfortunately the variable and intermittent nature of the discharge from hand pumps usually means that any chlorinator positioned after the pump is unlikely to perform well. However, the suction device already described may be appropriate if users allow sufficient contact time before they consume the water. This system is not appropriate for deepwell hand pumps because the suction side of the cylinder in these pumps will be below the container from which the solution will be drawn. This means that the solution will continue to siphon into the well even after pumping stops. Household-level treatment is probably the only reliable method of chlorination where deepwell hand pumps are used.

A constant rate drip-feed dosing device is not suitable for a hand pump supply because of the intermittent use of the borehole. Potentially such a device could be used with a powered pumping system that pumps for a long period at a fairly constant rate, as long as the chlorinator can be turned off as soon as the pump stops. However, to be effective the chlorine solution needs be delivered close to the intake to the pump, which is usually some distance below the water level. Delivery at this point may be achieved if the solution is dripped into an open pipe that runs down the inside of the borehole to a point near to where the water is entering it from the aquifer.

Some groundwater may contain chemicals such as iron that initially react with chlorine making less of the dose available for disinfection. The chlorine demand of the chemicals in groundwater should therefore be established before designing a chlorination system.

3.8.3 Springs

The water from a well-protected spring should all originate from groundwater. Often this will be safe and will not need any disinfection other than what may be desirable to protect it in a distribution system. Once the spring water has been channeled into a pipe a number of chlorination systems may be appropriate. These will be similar to those used for treating surface water for piped systems.

The discharge of springs may be fairly constant although there may be some gradual seasonal

variations that may require periodic changes in the dosing rate. If the discharge changes rapidly after rain it may indicate a probable pollution by surface water.

3.9 Chlorine dose

To determine the appropriate amount of chlorine solution (the ‘dose’) needed to disinfect water from a particular source it is first necessary to find the chlorine demand of the water. This can be established by following these steps:

i) Divide a sample into say six 100 ml sub-samples and put each in different vessel

ii) Add different measured amounts of 100 ppm chlorine solution (i.e. 100 mg of chlorine per litre of water) to each vessel. For example one could use incremental steps of 0.5 ml with this amount being added to the first, 1.0 ml to the second etc. After adding the chlorine solution each sample should be well stirred.

iii) Leave the sample for the required contact period in a cool place and out of direct sunlight.

iv) After the contact period has expired, take a sample of water from the first vessel and test it for the presence of residual chlorine. If there is no residual chlorine then test the water in the next vessel, and so on, until residual chlorine is first detected. This indicates that in that particular vessel the chlorine demand has been met. If for example it is first detected in the vessel to which 2.0 ml of the solution was added but is not found in the previous vessel (to which 1.5 ml was added) then the chlorine demand is at least 1.5 ppm but less than 2 ppm (2 mg/litre).

The chlorine demand of water sources will not necessarily remain constant. It will almost certainly vary for surface water sources, depending on the recent pattern of rainfall run-off contributing to the source.

If the water to be treated contains a high level of suspended solids (i.e. it is turbid) there are two likely results. Firstly, much of the chlorine dose can be wasted because of chemical reactions with the suspended solids (particularly organic substances) and secondly micro-organisms in cavities inside some of the suspended particles may not be fully exposed to the full germicidal effects of the chlorine. This is why some form of treatment prior to disinfection is always advisable where unprotected surface water is to be chlorinated. Some micro-organisms that are fairly resistant to chlorination may be found in unprotected surface water sources so in any case, at least filtration and possibly other forms of treatment prior to chlorination may need to be provided to remove these.

Two of the important variables that control the effectiveness of chlorination are: i) the concentration of the chlorine and ii) the time during which the organisms are exposed to it. Therefore usually both a time of contact with the chlorine and a residual concentration are specified to ensure effective chlorination.

3.10 Contact Time and CT Value

The product of the concentration of chlorine in mg/l and the contact time in minutes is called the ‘CT value’ or ‘exposure value’.

The CT value is sometimes used to specify the exposure time and amount of chlorine needed to inactivate a particular micro-organism under specified conditions (such as temperature and pH).

Terminal disinfection must produce a residual concentration of free chlorine of ≥ 0.5 mg/litre after at least 30 minutes of contact in water at pH<8.0. The World Health Organisation (1993) indicates that this recommendation is expected to result in ‘negligible virus risk’ and normally will ensure that the water has negligible risk of transmitting parasites. *Escherichia. coli* bacteria, which are indicators of faecal pollution from humans or animals, are also expected be absent (WHO, 1993) if the water has been properly chlorinated. The number of these organisms present in a 100 ml sample of a source of water is often used to gauge its bacteriological quality.

Effective chlorination is not usually straightforward because there are a large number of variables that can affect the success of the disinfection. Some of these have already been mentioned. Others will be discussed in the following section in relation to potential operation and maintenance problems generally associated with chlorinators.

Ensuring effective contact time - The importance of contact time has already been discussed. The important feature is that there should be 'plug flow' through the tank so that there are no areas of static or near-static water. Hence flow in a long straight pipe or narrow channel is ideal. Square or circular tanks are not very good shapes for contact tanks unless they are divided up with vertical walls that ensure that the incoming water can not cross directly from the inlet to the outlet. These dividing walls should ensure that all of the water slowly follows a longer winding path before it leaves the tank. A weir or high level outlet should be provided to maintain a fixed volume of water in the contact tank. Otherwise, at low water levels, the contact period will be insufficient. The high level of the outlet means that the tank can not be used as a storage reservoir.

A storage tank can be used as a contact tank if the outlet is closed whilst it is being filled with well mixed chlorinated water. When the tank is full the contents should be left undisturbed for the contact time, after which water can be withdrawn for supply. If two storage tanks are provided they can be used alternately.

Sometimes, sufficient contact time can be provided while the water is flowing in the water supply pipework between the dosing point and the start of the distribution system. This is possible if the first position at which water can be drawn from the pipe is sufficiently far away from the chlorinator that the flow time exceeds the required contact time. However, this point may be some distance from the point of treatment. With such an arrangement it is necessary to take samples from the first water collection point on the distribution system to monitor the achievement of the required residual.

A shorter length of large diameter pipe at the start of the distribution system, positioned straight after the dosing point is an alternative. However, flow at the inlet to this larger diameter pipe must be effectively distributed across the whole of its cross sectional area.

3.11 Problems with Chlorinators

3.11.1 Problems with precipitation and scaling

The use of calcium hypochlorite and chlorinated lime can lead to problems, particularly with hard water. The formation of calcium carbonate is possible which can over time block orifices, so these need to be regularly inspected and cleaned. The formation of deposits can also occur at drip feed nozzles where the calcium in the solution can also react with carbon dioxide in the atmosphere to form calcium carbonate. Evaporation can also form deposits.

One way of reducing the build-up of deposits at drip feed nozzles is to totally enclose them in a small transparent chamber (through which the correct operation of the nozzle can be seen). A small vent hole should be provided at the top of the chamber, and at the bottom of the chamber there should be a pipe to carry away the dripped liquid. This pipe should terminate below the level of the water that is being dosed.

When making a chlorine solution from solids or powders such as calcium hypochlorite and chlorinated lime, sufficient time must be allowed for the non-soluble solids to precipitate. Then the clear solution should be carefully decanted to be used for dosing. This prevents problems that may otherwise arise from the solids being carried into the chlorinator. As an additional precaution one can use a simple filter on the outlet from the tank which stores the dosing solution. This filter can be made from cotton wool inside a perforated container (Solsona, 1990). Small petrol filters, as used on automobiles, have also worked well (Solsona, 1981).

As sodium hypochlorite is already a liquid, it is more convenient to dose than calcium hypochlorite or chlorinated lime. When used undiluted it does not usually cause problems with dosing equipment. However, when it is diluted with tap water the sodium hypochlorite can react with hardness salts to form precipitates and scales. Crystallisation of sodium hypochlorite solution can also occur over a period of time if it comes into contact with air.

3.11.2 Corrosion

Chlorine is corrosive and the atmosphere around chlorinators is often damp so only corrosion resistant components should be used for chlorinators and associated pipework. Solutions of chlorine are extremely corrosive. For this reason glass, PVC, fibreglass, polyethylene, and certain other types of plastic or special rubbers are commonly used for chlorinators and their associated pipework.

3.12 Availability and stability of chlorine compounds, and risks from additives

Wherever chlorination is being considered, it is important that sufficient amounts of a suitable source of chlorine be available. In view of the fact that the chlorine content of some compounds reduces rather quickly, it is best to avoid bulk deliveries that would cover many months of use. Where large deliveries are to be made, the size of the container should be carefully chosen to make handling safe and easy. The size chosen should also be such that the number of times that the container needs to be opened before it is emptied, and this opening and removal of the contents does not have a major adverse effect on the remaining material. The type of container and the way in which it is stored has a major effect on chlorine compounds.

Sodium hypochlorite at normal solution strength (10-14%) can be unstable, decomposition being particularly accelerated by heat and exposure to light. Chlorinated lime is also unstable. Exposure to light and moisture make the chlorine content fall rapidly. Calcium hypochlorite is more stable than either sodium hypochlorite or chlorinated lime. Powders are usually pure. Tablets are made almost entirely of calcium hypochlorite but have trace additions of materials to prevent powdering and to stop moisture being absorbed too readily. However, like the other compounds, they should still be stored in airtight containers in a cool, dry place.

Tablets that are designed for chlorination of swimming pools may have additives (such as cyanurate compounds) that make them unsuitable for chlorinating drinking water, particularly in the long-term (Williams, 1983). In view of the deterioration of these compounds with time it is important that all stock is used in order of the date of manufacture.

3.13 Handling precautions and transportation

Chlorine gas – Chlorine gas is a strong oxidizer and must be considered during the design and operation of chlorination facilities at a water treatment plant.

Sodium Hypochlorite – Sodium hypochlorite solution is a corrosive liquid with an approximate pH of 12. Therefore, typical precautions for handling corrosive materials such as avoiding contact with metals, including stainless steel, should be used. Sodium hypochlorite solutions may contain chlorate. Chlorate is formed during the both the manufacturing and storage of sodium hypochlorite (due to degradation of the product). Chlorate formation can be minimized by reducing the degradation of sodium hypochlorite (Gilbert *et al*., 1995) through limiting storage time, avoiding high temperatures and reducing light exposure.

Spill containment must be provided for the sodium hypochlorite storage tanks. Typical spill containment structures include containment for the entire contents of the largest tank (plus freeboard for rainfall or fire sprinklers), no uncontrolled floor drains, and separate containment areas for each incompatible chemical.

Calcium hypochlorite: Calcium hypochlorite is an oxidant and as such should be stored separately from organic materials that can be readily oxidized. It should also be stored away from sources of heat. Improperly stored calcium hypochlorite has caused spontaneous combustion fires (White, 1992).

Since chlorine compounds are corrosive they can burn skin. Hence gloves and sometimes other waterproof or dustproof clothing and eye protection will be necessary when handling them to avoid all accidental contact with the skin. Inhalation of concentrated gas or dust from these compounds should also be avoided. This means that the compounds should wherever possible be handled in a well-ventilated area. Care should be taken not to raise dust from powdered compounds, and as a precaution, a dust mask and goggles should be worn by an operative when s/he is handling powders.

In view of the risks that arise from handling it is preferable to choose chlorination systems that require a minimal amount of handling and diluting procedures. Manufacturers' instructions should of course, always be followed.

Transportation of the compounds also needs to be arranged carefully to ensure safety so that the material is protected from unnecessary deterioration. Low-concentration solutions and powders will of course mean that larger and heavier volumes need to be transported.

3.14 Accuracy of preparation of solutions for dosing

Care needs to be taken when preparing solutions for dosing and regular testing of the chlorine content of these solutions should be carried out. Adjustments can then be made to ensure that the chlorine concentration remains constant. (Variation in the strength of the solution may be acceptable if the rate at which it is dosed to the water being treated is adjusted to compensate, but it is easier for operatives to deal with dosing a constant-strength solution.)

If only periodic testing of the solution is possible the timing of the tests should take into account the following:

- The chlorine content of the compound used is likely to reduce over time. Hence, to obtain the same strength of solution, increased amounts of the compound need to be added to any fixed volume of water used for dilution. Alternatively the volume of dilution water will have to be reduced.
- The volume (or mass) of the compound, and the volume of water it is added to, both need to be carefully measured each time a solution is prepared. Scales are rarely used to weigh out powders. Instead the powders are normally measured by volume which is related to a known mass.
- The chlorine demand of the water used to make the solution may need to be checked to see if it has any major effect on the level of available chlorine, particularly if the quality of this water changes.

• Adjusting dilutions to produce a consistent strength of solution may cause operatives problems if they are not sufficiently numerate to carry out the necessary calculations. The use of numerical tables and charts may overcome this problem. To make adjustments the operative also needs to have appropriate equipment to accurately measure out a varying quantity of the compound, or a varying volume of dilution water.

3.15 Calculations

Assuming that the concentration of chlorine in a compound as a percentage (C1%) by mass is reliably known, then the necessary mass (M1 grams) of it that should be added to a known volume of water (V2 litres) to produce a desired concentration of solution (C2%) can be readily calculated from the equation:

$$M_1 = (C_2 \times (1000 \text{ x } V_2)/C_1 = (1000 \text{ x } V_2 \times C_2/C_1)$$

For example to determine the mass of bleaching powder, with the strength of 20% chlorine by mass (C_1 = 20) that needs to be added to 50 litres of water (V_2 = 50) to produce a 0.5% solution (C_2 = 0.5), the equation is:

$$M_1 = (1000 \times 50 \text{ x } 0.5/20) = 1250 \text{ g}$$

So 1250 grams of the powder has to be added to the 50 litres of dilution water to produce a 0.5% solution

Note that a 0.5% solution contains 5 g of chlorine per litre of water = 5000 mg/l

The volume (V2 litres) of a solution of known strength (C2%) which needs to be added to each litre of water to be treated, to give a required dose (C3%) can be calculated from the equation:

$$V_2 = C_3/C_2$$

So if a dose of 5 mg/l (C3 = 0.0005%)) is required, and the 0.5% solution (C2 =0.5) is being dosed, the required volume (V2) per litre will be given by:

V2 = 0.0005/0.5 = 0.001 litre (= 1 ml) of 0.5% solution needs to be added to each litre of water to be treated to apply a dose of 5 mg/l.

3.16 Measurement of Treated Water Flow Rates

The amount of solution that needs to be dosed will depend on the quantity of water to be treated. Chlorinators that dose in proportion to the flowrate need to be used if the flowrate is variable.

• If the water to be treated is stationary as in the batch treatment system (i.e. when the contents of a whole tank of water are treated) the volume of water to be treated can be found by calculating the amount of water in the tank.

• Where the water is flowing it will be necessary to know its flowrate. This could be based on a water meter reading but the meter will need to be well maintained to ensure accuracy.

• One method of calculating the flowrate in a pumped system is to observe the rate at which a tank fills or empties because of the flow of water. The flowrate in m^3/h can then be calculated from multiplying the rate of fall or rise in the water level (in m/h) and the plan area of the tank (in m^2).

• Where flow is exposed to the atmosphere sharp-edged triangular or rectangular notches can also be used. The depth of flow through such notches can be used to calculate the flow using formulae, graphs or numerical tables.

3.17 Mixing of the dose with the water to be treated

For chlorination to be successful, all of the water to be treated must come into contact with the disinfectant for at least the required contact time. It is therefore important that at the start of the contact period the dose is already fully mixed with the raw water.

With constantly flowing water the dose can be added at a constant rate directly into the water flowing in a pipe or channel, or just as it enters the contact tank. It will then be well mixed throughout the water.

Where the dose is being added to a large volume of relatively stationary water it is more difficult. In such a case, the dose should be added at a number of different points, and then the contents of the tank or well should be agitated to ensure full mixing of the dose. In an open well, raising and lowering a bucket through the whole depth of the water many times is a good way to agitate the water.

3.18 Testing for chlorine concentration

The first objective of effective chlorination is to ensure that an acceptable chlorine residual (usually a free chlorine residual) exists after the contact time. The physical arrangement of the system should be designed to prevent water being consumed before this period has elapsed.

A second objective is often that the chlorine residual is sufficient to protect the water from any minor sources of contamination it may encounter as it flows through the distribution system. It should also prevent the growth of nuisance bacteria and other organisms in the pipework. Monitoring the achievement of this second objective means that in addition to any testing directly after the contact tank, the water needs to be periodically tested at other points in the distribution system, particularly those that are far from the point at which the chlorinated water enters the system.

It is important that testing for residual chlorine in drinking water is carried out with sufficient frequency to ensure that chlorination is being successfully accomplished.

For measuring high strength concentrations, such as sodium hypochlorite, it may be necessary to first carefully dilute the sample with demineralised water. This complicates the testing procedure and can be a source of error unless the operatives of small-scale systems are well trained.

The standard methods of field-testing for chlorine concentrations are based on the following principle:

The most convenient method for measuring ‘residual chlorine’ is the colorimetric method that uses DPD (diethyl paraphenylene diamine) tablets that are dissolved in a measured sample of the water. The extent of the red colour change resulting in the sample is judged visually in comparison to a scale of standard colours that relate to specific concentrations. It is important that the test is completed as rapidly as possible (less than 20 seconds after dissolving the tablets) to prevent the reagent acting on the combined chlorine. Small, cheap, simple ‘comparators’ accurate to within about 0.1 ppm are available. Different tablets are available either to measure the ‘free residual chlorine’ or the ‘combined residual chlorine’.

The following chapter highlights the soft issues that need to be considered in order to ensure that disinfection systems used at small treatment plants are sustainable.

CHAPTER 4

MANAGEMENT GUIDELINES FOR EFFECTIVE IMPLEMENTATION OF DISINFECTION IN SMALL WATER TREATMENT PLANTS

The capacity of any water treatment plant to provide acceptable drinking water quality depends on the performance of each functional unit in the plant including coagulation-flocculation, sedimentation, filtration and disinfection. Management and administration of water treatment plants play an important role in determining the quality of the final water. The major hurdles to providing safe and clean drinking water in rural areas are: i) poor definition of the roles and responsibilities of key players in the municipality, ii) lack of training and inability to retain skilled staff to run water treatment plants, iii) poor financial management, iv) inexperienced managers, v) lack of maintenance of infrastructures, vi) loss of institutional and intellectual knowledge and vii) poor working conditions. This chapter therefore outlines practical steps that can be implemented by management to improve and sustain water quality in rural and peri-urban areas.

4.1 Roles and Responsibilities

There are a number of institutions and role players involved in the management of water works in South Africa. Table 4.1 lists the various role players and their primary functions. The role players include staff working directly on the water works such as Operators, Senior Operators, and Works Managers. Their role is one of water service provision. Other institutions involved in water supply include Water Service Authorities (WSA) such as local and district municipalities, the Department of Water Affairs and Forestry (DWAF) and the Department of Health (DoH). There are also non governmental organisations that represent the interest of the community. It is imperative that the various role players understand their roles and responsibilities in order to minimise the possibility of overlooking certain functions to the detriment of the consumer. There is also the possibility of duplication of activities/functions which can make the system dysfunctional.

TABLE 4.1 ROLES & RESPONSIBILITIES	
Role Player	**Responsibility**
Operator	Primarily responsible for day to day operation of the plant, ensuring that all processes are optimised
Senior Operator	Responsible for process control & implementing major changes to process
Works Manager/Superintendent	Overall responsible for safety and operation of plant
Water Service Provider	A Water Services Provider is any institution that has a contract with a WSA to sell water to that authority. A WSP can also be any institution which has a contract with a WSA to assume operational responsibility for providing water services to one or more consumers (end users) within a specific geographic area.
Water Service Authority (WSA)	Responsible for planning, ensuring access to, and regulating provision of water services to all constituents within their area of jurisdiction.
Department of Water Affairs and Forestry (DWAF)	Responsible for the formulation and implementation of policy and regulations governing the water sector. To provide support and strengthen the capacity of local government, and to regulate local government to ensure effective performance of its duties. As sector leader, DWAF has ultimate responsibility for water services provided by local government and manages information to be used for support, monitoring, regulation and planning.
Department of Health (DoH)	The Department of Health (DoH) is responsible for health strategy, policies and practices as well as the development and drafting of legislation and associated regulations. District municipalities have the primary responsibility for health and hygiene education related to water and sanitation services. National and provincial departments will assist in the training of staff to do this work, and in the training and support of community-based hygiene educators and health promoters on water and sanitation projects.

4.2 Training and Development

Ongoing training and development is a prerequisite for the sustainability of small treatment systems. Local operators become highly marketable when they have been trained in the operation of treatment plants and tend to migrate towards the larger towns where they can earn better salaries. . It is thus necessary to have a continuous operator-training programme that provides technical and operational skills in the sector. It is highly recommended that municipalities gear themselves to provide internship programmes for graduates from universities of technology. This is a win-win situation as it provides the trainee with practical experience while the employer has a continuous feed of new blood into the organization.

> Municipalities must ensure that they are registered as institutions that can provide training and learner-ships for students in civil and chemical engineering as well as analytical chemistry and microbiology.

Examples of relevant areas to address include general water quality, and specific training to optimise system performance such as: coagulant control testing; proper filter operation; disinfection system operation; reticulation management; sampling, monitoring and analysis; interpretation and recording of results, and maintenance of equipment.

> Identify local people during the planning stage of the project, employ them during the construction stage and train them to operate the plant.

There are limited numbers of locally based staff trained in the operation of water treatment plants. It can take anything from 18 months to two years to get a local resident trained to the level required. It is thus best to identify suitable staff during the planning stage of the project and employ them during the construction stage. This ensures that they receive ongoing training during the life cycle of the project whilst gaining an excellent understanding of the integration of the various unit processes.

4.3 Operator Salaries & Motivation

One of the key findings has been the low salaries paid to operators. It is strongly recommended that a minimum salary of R5 000 be paid to the lowest level of operator. The overall package and incentives that are offered to operators and managers working in small water treatment plants in rural areas needs to be urgently reviewed by the local and district municipalities.

> Management must urgently review remuneration packages and incentives for operators and technical supervisors working in small treatment plants

This will improve their motivation and pride in the job they are doing. Coupled with this is the urgent need to implement legislation on the health, hygiene and safety standards at water treatment plants. This must include general landscaping and industrial safety measures such as hand rails. It should also be noted that a chlorine gas installation is regarded as a Major Hazard Installation and is governed by the MHI Act which has very stringent regulations on the safety and management of such facilities.

4.4 Community Involvement and Awareness

Community consultation, involvement and awareness can have a major impact on public confidence in the water supply and the organisation's reputation. A communication programme including both consultation and education should be designed to provide active, two-way exchange of information to ensure that the consumers' needs and expectations are understood and are being satisfied.

4.5 Maintenance

Maintenance is one of the most important elements and if this is neglected, the situation is bound to fail. Detailed assessments of maintenance should be undertaken where the following information is recorded as part of normal operation.

Quality of Installed facilities	Water Consumption
Acceptable number of breakdowns	Quality of spare parts and repairs
Level of preventative maintenance	Cost of maintenance

4.6 Independent Water Quality and Process Audits

As part of the routine operation of small treatment systems, an independent water quality audit needs to be undertaken to ensure that the water complies with the guidelines or standards that have been agreed to by the consumers and the water service authority. Independent process audits need to be undertaken to ensure that the treatment process is optimized and to assist with any major technical problems that have been identified. The frequency of these audits depends on the number of consumers being served and the volume of water supplied.

Undertake regular independent Process Audits and Evaluations of the Water Treatment Plants

The audit will identify potential problems with the water works equipment, operating procedures and maintenance that would impact on disinfection.

A summary of the areas covered as well as the information that needs to be gathered is discussed in the following paragraphs.

- Individual unit process
- Condition of mechanical equipment
- Competence of operators
- Design capacity
- Piping
- Controls and instrumentation
- Turbidity results across unit processes
- Chemicals used and dosages
- Capacity of chlorinators
- Estimation of the contact time, CT
- Housekeeping and cleanliness
- Metering
- Reliability
- Record keeping
- Evaluation of the condition of intake including sitting and physical condition
- Documentation of size of pumps and their condition
- Condition and functionality of intake pump house
- Evaluation of the condition of well head if supplied from a borehole

- Inspection of maintenance records that apply to raw water intake system.
- Water treatment and disinfection system
- Storage reservoirs
- Distribution system water quality
- Measurement of disinfectant concentrations at terminal points

CONCLUSION

There are a number of different types of disinfection processes that are currently practiced in South Africa, including chlorination, UV, chlorine dioxide, bromination and ozone. The research and surveys undertaken have indicated that disinfection with chlorine is still one of the most effective and practical forms of disinfection for small treatment plants. This guideline will assist water works managers and municipal mangers in selecting the correct type of disinfection system and will highlight the need to increase the practice of disinfection in many areas where it is currently neglected and poorly managed. This should contribute to a reduction in water-borne diseases and lead to an overall improvement in the health of the communities that are serviced with water from small treatment plants.

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APPENDICES

APPENDIX 1

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Bemlab (Pty) Ltd	021 851 6401	021 851 4379	akotze@bemlab.co.za	P.O. Box 12457, Die Boord, Stellenbosch, 7613
BioCrop Laboratories	012 305 6004	012 305 6003	lizettec@necsa.co.za	P.O. Box 582, Pretoria, 0001
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Distell Central Laboratory	**021 809 7460**	**021 886 5414**	**jcerasmus@distell.co.za**	**P.O. Box 184, Stellenbosch, 7599**
East rand Water Care Company (ERWAT)	**011 929 7014**	**011 929 7065**	**alisonc@erwat.co.za**	**P.O. Box 13106, Norkem Park, 1631**
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ESKOM Enterprises, Technology Services International	**011 629 5728**	**011 629 5528**	**jenny.reeves@eskom.co.za**	**Private Bag 40175, Cleveland, 2022**
Food Consulting Services	**011 315 5007/8**	**011 315 5029**	**elri@fcs-labs.co.za**	**P.O. Box 1461, Halfway House, 1685**
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Hearshaw and Kinnes Analytical Laboratory	**021 650 3533**	**021 650 2860**	**phirsch@science.uct.ac.za**	**P.O. Box 34143, Rhodes Gift, 7707**
Highveld Environmental Control Services cc	**017 647 3296**	**017 647 3296**	**hecscc@mweb.co.za**	**P.O. Box 2174, Bethal, 2310**
Inno Venton Analytical	**041 504 3497**	**041 504 9497**	**cecisaun@nmmu.ac.za**	**P.O. Box 77000, NMMU, Port Elizabeth, 6000**
Inspectorate M & L	**011 496 2228**	**011 496 2239**	**Alban.Boyle@inspml.co.za**	**P.O. Box 82124, Southdale, 2135**
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Interfruit Microbiology Laboratory	**011 918 3951**	**011 894 1163**	**yolandie@interfruit.co.za**	**P.O. Box 26331, East Rand, 1462**
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Johannesburg Water (Pty) Ltd-CYDNA, Northern Works & Goudkoppies Laboratory	**011 728 7373**	**011 728 5444**	**tngodela@jwater.co.za, rrimmer@jwater.co.za**	**P.O. Box 61542, Marshalltown, 2107**
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Mintek Analytical Services	**011 709 4053/4046**	**011 792-6650**	**nqobileg@mintek.co.za**	**Private Bag 3015, Randburg, 2125**

Mpumalanga Analytical Services CC	**017 799 3144**	**017 799 3462**	**semaja@ripplesoft.co.za**	**P.O. Box 155, Volksrust, 2470**
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Namakwa Sands Smelter Laboratory	**022 701 3911**	**022 701 3075**	**escholtz@namakwa.co.za**	**P.O. Box 435, Vredenburg, 7380**
Natref Laboratory	**016 940 2167**	**016 940 2045**	**anita.mcclintock@natref.com**	**P.O. Box 234, Sasolburg, 1947**
NECSA Pelindaba Analytical Laboratories	**012 305 4535**	**012 305 4725**	**mbritton@necsa.co.za**	**P.O. Box 582, Pretoria, 0001**
Rand Water	**016 4215150**	**016 455 2055**	**mmthemb@randwater.co.za**	**P.O. Box 3526, Vereeniging, 1930**
Regen Waters cc	**013 690 1487**	**013 656 5050**	**regenlab@mweb.co.za**	**P.O. Box 8328, Witbank, 1035**
Resource Quality Services (Previously IWQS)	**012 808 9621**	**012 808 0338**	**PortwigE@dwaf.gov.za**	**Private Bag X313, Pretoria, 0001**
Rhodes Food Group	**021 870 4194**	**021 874 1370**	**thomasl@rfffoods.com**	**Private Bag X3040, Paarl, 7680**
SABS Commercial (Pty) Ltd Water Laboratory Western Cape		**086 618 0903**	**santerj@sabs.co.za**	**P.O. Box 615, Rondebosch, 7701**
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Sediba Laboratory	**032 944 8020/6821**	**032 944 7695**	**bishs@millenniumwaste.co.za**	**P.O. Box 1852, Tongaat, 4400**
Sedibeng Water - Quality Control Laboratory	**056 515 0318**	**056 515 0381**	**lsaunderson@sedibeng.co.za**	**P.O. Box 500, Bothaville, 9660**
Set Point Laboratories	**011 923 7020**	**011 923 7029**	**cor@sethold.com**	**P.O. Box 856, Isando, 1600**
SGS Emoyeni Qualitest	**031 466 2713**	**031 466 2727**	**Rajen_perumal@sgs.com**	**P.O. Box 21831, Bluff, 4036**
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APPENDIX 2

EXAMPLE OF A PROCESS CONTROL SHIFT LOG SHEET

Date	**Plant Name:**			**Operator Name:**				
Time	***Raw water Turbidity***	***Raw water pH***	***Coagulant Dose***	***Clarifier turbidity***	***Chlorine dose***	***Final water chlorine***	***Lime dose***	***Final water pH***
06:00								
08:00								
10:00								
12:00								
14:00								
16:00								
18:00								
20:00								
22:00								
00:00								
02:00								
04:00								