CHAPTER 1

GENERAL INTRODUCTION AND LITERATURE REVIEW

1.1 GENERAL INTRODUCTION

The South African vision for the water services sector is stipulated as follows (DWAF, 2002):

(*i)* *All people living in South Africa should have access to adequate, safe and affordable supply of potable water, live in a healthy environment with safe and acceptable sanitation, be able to engage in sustainable livelihoods, be economically empowered and be able to participate actively in a vigorous and healthy civil society.*

(ii). *All people should be knowledgeable about healthy living practices and use water wisely.*

(iii). *There should be adequate water available for economic development.*

(iv). *Water supply and sanitation services should be sustainable and be provided by efficient and effective service providers who are accountable and responsive to the customers they serve.*

The above are expected to give the outcomes of a healthy population, a healthy environment, economic growth that improves the quality of life and livelihoods of the whole population, especially the poorest (DWAF, 2002). The 1994 white paper (DWAF, 1994) also made commitments to the effective monitoring of the sector performance to ensure that universal access to basic services is progressively achieved, financial resources are used efficiently and effectively and that water service institutions are accountable to local communities and standards are maintained.

Safe drinking water as defined by the Guidelines (WHO, 2004) does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages. This means that safe water can be defined as water that does not contain harmful chemical substances or microorganisms in concentrations that could cause illness in any form. Safe drinking water is still a dream in many rural and peri-urban communities as small water treatments plants are still failing to apply standard water quality control methods developed in South Africa and worldwide (Mackintosh and Colvin, 2002, Acho-chi, 2002).

Small water treatment plants are typically installed in areas which are not well serviced and which do not fall within the confines of urban areas. They are therefore mostly plants in rural and peri-urban areas and include water supplies from boreholes and springs that are chlorinated, small treatment systems for rural communities, treatment plants of small municipalities and treatment plants for establishments such as rural hospitals, schools, clinics, forestry stations, etc. Most of these applications require small plants of less than 2.5 Ml/d, although plants of up to 25 Ml/d may sometimes also fall into this category (Barkley, 2002).

Communities served by such systems are still experiencing problems of waterborne disease outbreaks. The reasons for this situation are often a combination of factors related to source water quality, treatment practices and biofilm development in the distribution systems (Geldreich, 1989). The key issues contributing to the poor performance of small potable water supply systems include: inadequate sampling and monitoring techniques; inadequate consideration of the range of factors that affect drinking water quality, and failure to provide an effective response to microbiological pathogens and contaminants.

The key to ensuring clean, safe and reliable drinking water is to implement multiple barriers, which control microbiological pathogens and chemical contaminants that may enter the water supply system. Small communities need access to systems and technologies that can support a reliable performance with realistic staffing and training requirements, including shared systems for monitoring, operation, and management. Improved record keeping and a more systematic maintenance schedule are two of the areas that have to be considered in trying to improve water quality in rural developing communities.

The study presented here was undertaken in the town of Alice, a small rural town in the Eastern Cape, one of South Africa's poorest provinces. Tested samples of drinking-water supplies in rural communities in the Eastern Cape have revealed that substandard quality drinking water is being supplied to the majority of these communities. The overall efficiency of drinking-water provision in the Eastern Cape regarding microbiological water quality is extremely poor. In some of the worst cases, the water-supply schemes are failing completely, and consumers are forced to make use of poor alternatives such as ponds (Mackintosh and Colvin, 2002, Momba and Kaleni, 2002).

The present study aimed at ensuring sustainable effective disinfection in a small rural water supply of Alice in order to improve the quality of potable water in the rural community and to make significant progress toward compliance with bacteriological quality standards at the point of consumption. The following objectives were then set:

(i) To examine the quality of drinking water supplied by the Alice Water treatment plant to its consumers and to estimate what effect the water supply might have on the health of the community it serves.

(ii) To evaluate the Alice water treatment plant from the raw water intake to the disinfection process and the distribution system, and to identify problems affecting the performance of the plant including the effectiveness of the disinfection process for the removal of indicator bacteria and to evaluate the plant operational cost.

(iii) To ensure the maintenance of an effective residual disinfectant throughout the reticulation system and consumer's tap by establishing the relationship between the performance of the plant dosing system and the water quality in the bulk distribution system.

(iv) To investigate the performance of the plant for the removal of dissolved organic carbon and to assess the impact of biodegradable dissolved organic carbon on the bacterial regrowth in the finished water.

(v) To transfer knowledge and skills to the operators and the Municipal staff in order to ensure that the improved operation of the plant can be sustained in the future.

(vi) To develop guidelines ensuring a sustainable effective disinfection that can lead to repeat the Alice case-study in other South African small municipal water treatment plants.

The study was expected to provide valuable information that could assist Local Water Authorities in rural communities to work out problems in the management of small water treatment plants.

1.2 LITERATURE REVIEW

1.2.1 Problems faced by small water treatment plants

This section refers to problems commonly encountered by small systems employing conventional water treatment. Conventional treatment consists of the following steps: coagulation, flocculation, sedimentation, filtration and disinfection.

1. 2.1.1 Coagulation processes: mixing, destabilisation and flocculation

Coagulation begins by first destabilizing the surface charge to create microflocs. This step requires the addition of a charge-neutralizing (cationic) coagulant plymer (either organic or inorganic) to destabilize the negative surface charge on most colloidal dispersions. For this to be effective in a flow-through process, the coagulant chemical, which typically converts into active form in a matter of second when added to water, must be added in the correct amount and must be dispersed quickly and evenly by rapid mixing.

The particles that are removed from drinking water range in size from one tenth to one hundred thousandth of a millimetre (100 to 0.01μm). The larger the particles the more easily they are removed. Small particles settle v`ery slowly while large particles settle faster. The small particles (colloids) usually have a negative charge in natural waters and as a result, repel one another. The efficiency of coagulation is highly sensitive to pH and alkalinity, so lime or acid is also used to maintain the pH in the optimal range. Alum (aluminium sulphate), the most widely used drinking water coagulant, reacts quickly with alkalinity (capacity of the solution to accept H^+) to produce positively charged (cationic) polymers of aluminium hydroxide. The pH (ngative logarithm of H^+ concentration) in the range of 5.8to 8.5 and sufficient alkalinity must be available for alum, otherwise it will not react and no effective coagulation will be achieved (Hrudey and Hrudey, 2004).

Other coagulants often used in water treatment include ferric chloride, polyaluminium chloride and sodium aluminae. Coagulant aids are added to enhance the treatment process by improving coagulation, promoting more resilient, denser or larger floc, reducing temperature sensitivity, reducing he rimary coagulant dose and reduring the quantities of sludge requiring disposal. Coagulant aids include activated silica, wighing agents (bentonite clay, powdered limestone or powdered silica and cationic polyelectrolytes (organic polymers). Polyelectrolytes can be used alone as coagulant, but they will achieve more effective and consistent turbidity removal when used with a primary coagulant (Hrudey andHrudey, 2004).

If alkalinity-demanding coagulants like alum are used and the natural alkalinity of the raw waer is insufficient, it may be necessary to increase alkalinity to achieve effective coagulation. Chemicals suitable for raising alkalinity include lime, soda ash, caustic soda and sodium bicarobonate. Accurate dosing of these water treatment chemicals requires effective chemical handling facilites to ensure that quantities are accurately controlled. These facilities require regular maintenance because the chemicals may be corrosive or sticky, making it challenging to keep process equipment operating effectively (Hrudey and Hrudey, 2004)

In small water treatment systems, the coagulation process is often not as efficient as it should be due to the use of incorrect chemical doses. This is typically caused by limited operational skills and poorly maintained equipment. The result is inadequate turbidity removal and/or waste of chemicals and excessive sludge production. Recent studies done to determine the upgrading of small and rural surface water treatment plants in South Africa and the subsequent process of drawing guidelines on how to address these needs unveiled a number of potential research areas (Swartz, 2000). One of these research areas is the development of the simple, effective and reliable chemical dosing systems for controlling chemical dosages. It was found that chemical dosing was problematic. Some of the plants do not have dosing facilities. For the plants that have them, the facilities either malfunction or are not in use at all. In most cases they are out of operation and waiting for spare parts (Swartz, 2000, Mwiinga *et al*., 2002).

Strategies can be applied to optimize coagulant dosages, including jar testing, a pilot plant to mimic the full scale plant, a pilot filter to receive coagulated water after rapid mixing and prior plant scale experience under comparable conditions (Bellamy *et al*., 1993).

Control of pH after coagulant addition is another important parameter. To adjust the pH, some plants add base or acid independently of the coagulant. The pH of cold water in the winter should be higher than for warm water in the summer (Cleasby *et al.,* 1989).

Flocculation is the next stage after coagulation where the size of the floc particles are increased, making it easier to be removed by filtration or settling. The flocculation process is frequently aided by slow stirring of the water using large paddles or using baffled channels to induce gentle mixing, which increase the number of collisions between particles. These measures promote gentle turbulence while minimizing short-circuiting and ensuring adequate residence time. If the water is agitated too hard the larger flocs will be ripped apart.

Process problems that commonly arise in coagulation and flocculation include low water temperature, weak floc and slow floc formation (AWWA, 2003). Cold water interferes with coagulation and flocculation by increasing the settling rate of the floc, leading to excess floc carry-over from sedimentation to filtration process. Weak floc leads to overloading of the filters, as well as reducing filter turbidity removal.This problem often occurs if the rapid mixing in the flocculation basins is inadequate. Slow floc formation often occurs with low-turbidity waters and indicates insufficient particle matter to combine with the coagulant to yield an effective, settleable floc blanket. Response may include recycling the settled floc in order to build up more material for the added coagulant to combine with or adding a weighing agent such a bentonite to increase the turbidity available for capture (Hrudey and Hudrey, 2004). If slow floc formation is caused byinsufficient alkalinity, the alkalinity will need to be increased by adding lime or soda ash.

1. 2.1.2 Sedimentation

Sedimentation is one of the many solid-liquid processes predominantly employed in water treatment to reduce the solids concentrations in a process fluid, thus lowering the load on other associated units downstream, such as filters. Sedimentation processes promote gravity settling of solid particles to the bottom of the water column where accumulated solids are removed (Thompson *et al*., 2004). For water treatment applications, the settling rate is normally determined experimentally. This is due to the non-uniform and flocculent nature of the particles.

The primary function of the sedimentation process is to prepare the water for filtration. The clarification process must be effective to ensure optimum filtration. In addition to the reduction of suspended material, an effective sedimentation process also removes significant amounts of organic material that cause colour and may also be precursors for the formation of disinfection by-products.

The preceding steps of coagulation and flocculation determine the efficiency of sedimentation (Thompson *et al*., 2004).

The primary test to indicate efficient sedimentation is turbidity. Turbidity of the samples taken from the raw water and the outlet of the basin should be tested at least three times a day. More frequent testing may be necessary if the water quality is changing rapidly. If the difference between raw water turbidity and effluent turbidity is small, it means very little turbidity is being removed. This indicates that better coagulation or flocculation is needed or that short-circuiting is occurring. A minimum of two sedimentation tanks should be provided so that one can be taken out of service without disrupting the plant. The operator must ensure that the flows are divided evenly and any changes in the flow are effected smoothly. The flow rates over the wells should be evenly distributed over the length of the weir. After sedimentation, water should have turbidity of less than 2 NTU (USEPA, 1998).

Operating problems with clarification include short-circuiting, wind-induced turbulence, density currents and algae or slime growth (Hrudey and Hrudey, 2004). Short-circuiting involves water traveling through the clarifier much faster than the nominal average detention time Iestimated as the clarifier volume divided by the average flow rate). If short-circuiting occus, it can reduce detention time so much that particle removal by sedimentation is inadequate. Wind can also contribute to short-circuiting in open settling basins. Problems with short-circuiting, usually a result of poor clarifer design, can be revealed by tracer studies. Density current arise he water with higher solids content or lower temperature is added, making it denser than the surrounding water in the clarifer. In this case, the denser flow sinks to the bottom of the clarifer, where it may disrupt the sludge blanket and displac currents of sludge upwards, leading to carry-over of solids into the clarifer effluents. This condition is is usually a result of a clarifer design unsuited to local operating condtions. Algae or slime often grow I open basins exposed to sunlight. This growth may cause taste or odour problems, as well as contributing to solids laoding on the filters when cells grow or biofilms detach (Hrudey and Hrudey, 2004).

1. 2.1.3 Filtration

Filtration processes are used primarily to remove suspended particulate materials from water and are one of the unit operations used in the production of potable water. Particulates removed may be those in the source water or those generated in treatment processes. Examples of particulates include clay and silt particles, microorganisms, colloidal and precipitated humic substances and other organic particulates from the decay of vegetation, precipitates of aluminium or iron used in coagulation, calcium carbonate and magnesium hydroxide precipitates from lime softening, and iron and manganese precipitates (Geldreich, 1989). For disinfection purposes, the desirability of the lowest turbidity possible – less than 1 NTU – is very important. This concern arises because substantial turbidity may allow individual pathogens to be shield from the disinfectant within turbidity particles and because the chemical reaction of disinfectant with turbidtity particles consumes disinfectant and thereby increases the disinfectant demand (WHO, 1993).

Turbidity levels of 5 NTU could be achieved routinely by coagulation-flocculation-clarification-filtration. With the emergency of *Giardia*, and more recently *Cryptosporidium*, as serious problems for drining water safety, turbidity targets have dropped from 0.5 to 0.3 NTU and are commonly below 0.1 NTU. It is possible to consistently achieve these targets with conventional water filtration, but the performance of the filter must be optimized (Hrudey and Hrudey, 2004). Excessive turbity can also be correlated with taste and odour problems or with promoting biofilm growth in the water distribution system.

The filtration stage is one of the more challenging stages in small water treatment plants especially in rural or peri-urban areas. The most important factor that affects the performance of the filters is the use of optimal coagulant dosages in pre-treatment processes. Without optimal coagulation, even the best rapid filtration facilities and the best operational procedures cannot ensure good filter performance. If the best filtrate quality is desired, no attempt should be made to scrimp on coagulant dosages to save operating costs. The proof of the treatment's adequacy is the quality of filtered water under all source water conditions, especially worst-case source water quality (Bellamy *et al*., 1993). The performance of the filtration stage needs to be optimised to reduce the potential for the passage of cysts and other pathogenic microorganisms. In some cases, turbidity and particle counting can be used to surrogate parameters for the removal of indicator microorganisms (Bellamy *et al*., 1993). Plants that treat water potentially contaminated with *Cryptosporidium* and *Giardia* cysts must pay special attention to filter operation to obtain best possible filtrate quality. The turbidity of each filter should be monitored continuously. The turbidity data for the first 2 - 3 hours after backwashing should be carefully observed. Normally there is a short period of poor water quality at the beginning of the cycle. If this is evident, the water should be filtered to waste until the turbidity drops to near the normal production turbidity for the remainder of the filter cycle. Similarly, the turbidity should be scrutinised before the end of the cycle (before filter backwash) to see if terminal breakthrough (rising turbidity) has occurred. If it has, the filter cycle should be terminated before the onset of the terminal breakthrough (Bellamy *et al*., 1993).

The continuous monitoring of turbidity can also reveal the detrimental effect of other bad operational practises, such as the on-off operation and sudden increases in filtration rates on dirty filters. Such practices should be eliminated or if elimination is not possible reduced to an absolute minimum. The frequency of the on-off operation should be reduced by taking full advantage of treated water storage (Bellamy *et al*., 1993). The performance of the treatment plant can be best evaluated by comparing the source water with filtered water. For source water turbidities consistently above 5 NTU, the reduction in turbidity from source water to filtered water can give a reasonably good indication of removal of microorganisms and cyst sized particles (Cleasby, 1989).

The performance of the rapid filter depends on the following parameters: filtration rates, influent characteristics and filter medium characteristics which control the removal of the particles and their release upon backwashing. Generally, it is true that the effect of the treatment can be improved by reducing filtration rates (not less than $2.5 m.h^{-1}$), smaller granulation size of the filter medium, and increasing the depth of the filter bed, increasing the size of the flocs and decreasing the concentration of the particles to be retained. The range of the filter bed is between 1 and 2m. The operating head is between 1.5 and 2.5m. The required filter surface can be determined according to the following relationship:

$$A = Q/ (a*v)$$

Where A= surface area (m^2), v = filtration rate [$m^3/ (m^2*h)$]; Q = throughput of water per hour; a = operating hours per day (Heber, 1985).

Recent investigations have shown that the end of a filter cycle (just before initiation of the next backwash) can also be very vulnerable. Even if the effluent turbidity shows only a slight increase, severe impirement of a filter's ability to remove pathogens such as *Cryptosporidium* occysts can occurs (Huck *et al*., 2002).Operators must not extend filter run until complete turbidity breakthrough despite the economic incentive to mximize the length of filter runs (Hrudey and Hrudey, 2004).

Filter operating problems can be diverse, but three are particularly common: ineffective coagulation/flocculation, flow-rate control and filter backwashing (Hrudey and Hrudey, 2004). Flow-rate fluctuations can drive trapped contaminants deeper into the filter bed, increasing the chance of breakthrough. Ineffective backwashing is a major source of problems in conventional filtration. Several problems can be created, including mudball formation, filter be shrinkage and gravel displacement. These problems accumulate over time and ultimately impir the reliability of the filter bed to provide a effective barrier to turbidity breakthrough. Inadequate cleansing of the filter media can also allow the coated grains to compress unevenly as head loss builds up in a filter run. This uneven compession may open cracks in the filter bed, allowing short-circuiting downward through the filter bed withouth adequate filtration and turbidity removal.

Overall, the operation of water treatment filters requires skill and experience on the part of the operator. Besides the fact that these filters are effective in removing suspended solids and require minimal land for construction, they are not well suited to small water supply systems because of the following disadvantages: high capital and operational costs, the use of energy for pumping, the need for a high degree of training for operators for monitoring, operation and maintenance (Heber, 1985).

1. 2.1.4 Disinfection: Chlorination

All the water treatment processes described above contribute to lowering the number of microorganisms that appear in the raw intake water before treatment. These processes, therefore, will remove protozoa, bacteria and viruses to some extent. However to achieve a high degree of assurance that pathogenic microorganisms do not reach comsummers in numbers and in a condition capable of causing disease, disinfection process must be applied.

Water is usually disinfected before it enters the distribution system to ensure that dangerous microbes are killed. Further, if the water travels a distance to the customer or is stored for a period of time in system reservoirs, the disinfectant must remain effective long enough to prevent disease. For the purpose of this investigation, disinfection will be discussed in terms of chlorination, because it remains the most widely used in small rural water supplies in developing cuntries.

Chlorine may be added to water as a gas (Cl_2) or as a solution made from either sodium hypochorite (NaOCl) or calcium hypochlorite (Ca $[OCl]_2$). Once dissolved in water chlorine gas forms a combination of hypochlorous acid (HOCl) and hydrochloric acid (HCl). Hypochlorous acid partially dissociates in water to release hydrogen ion (H^+) and hypochlorite ion (OCl^-). All of the disinfectant capability of the chlorine gas resides with either the undissociated HOCl or the OCl^-. If either sodium or calcium hypochlorite is used as thr source of chlorine, each will yield OCl^- upon dissociation in water. The distribution between HOCl and $OCl^{-\,i}$s determined by the pH of the water. A low pH will drive the distribution towards HOCl and a high pH will do the opposite. This distinction is important because HOCl is estimated to be about 100-fold more effective as a disinfectant than is OCl^- , making chlorine disinfectant more effective at low pH (Hrudey and Hrudey, 2004).

The success of chlorination is determined by several factors, which include the residual concentration (chlorine remaining after initial rapid reactions in water), contact time with water that contains microbes, temperature of the water, pH of the water, presence of particles and presence of oxidable matter which determines chlorine demand (AWWA, 2003). The most critical factors for achieving effective disinfection are the residual concentration and the contact time. The combination of these two factors is expresses as the CT value (concentration of disinfectant x contact time with disinfectant) in units of mg-min/L. For surface water treatment, greater than 99% pathogen removal is required, and levels as high as 99.9%, 99.99% or higher may be required in specific circumstances. These high removal rate targets are typically expressed in lerms of log (base 10) removal, wherby 1 log removal is a factor of 10 reduction from 2 log (99%) to 4 log (99.99) removal (Hudrey and Hudrey, 2004).

Disinfection requirements are expressed in terms of the chlorine residual, not the chlorine dose. The chlorine residual requirement at treatment will reflect the effect of the initial chlorine demand. The level of chlorine demand in the water to be disinfected is a critical factor because if the demand consumes too much of the chlorine dose, the residual chlorine may be insufficient to achieve the required level of disinfection. This concept is expressed as:

Chlorine residual = chlorine dose – chlorine demand

Chlorine residual provides a vital important real time measure of wheter adequate conditions for disinfection are being maintained. Any sudden change in chlorine demand that reduce the chlorine residual normally needed to cope with the potential challenge of pathogens effectively signals, in real-time, exposure to possible dangerous contamination (Hrudey and Hrudey, 2004).

Drinking water should be disinfected in emergengy situations, and an adequate disinfectant residual should be maintained in the system. Turbid water should be clarified whenever possible to enable disinfection to be effective. Minimum target concentrations for chlorine at the point of delivery are 0,2 mg/l in normal circumstances and 0.5 mg/l in high-risk circumstances (WHO, 2004).

Although great strides have been made in the effort to provide safe water to previously disadvantaged communities in South Africa, studies have shown that rural communities with small water systems are still facing inadequate disinfection (Pearson and Idema, 1998, Muyima and Ngcakani, 1998, Momba and Kaleni, 2002). This is true for some small rural towns with relatively good infrastructure as well as small remote villages.

Previous studies have indicated a need for more reliable and cost-effective disinfection systems for small water supply schemes (Swartz, 2000) whilst at the same time indicating that chlorine dosing systems and slow-sand filter treatment systems are less reliable and ineffective for these small treatment systems. The inadequate disinfection of water in the small water treatment systems is placing many small communities at risk of disease outbreaks during times of disease epidemics (Pearson and Idema, 1998, Muyima and Ngcakani, 1998, Momba and Kaleni, 2002).

1. 2.1.5 Operational problems and institutional problems

Other key operational problems and institutional problems contributing to poor performance of water supply facilities can be identified as follows: Inadequate data on operation and maintenance, Insufficient and inefficient use of funds, Poor management of water supply facilities, Inappropriate system design and Low operation and maintenance profile DWAF, 2002).

a. Inadequate data

There is an overall lack of data regarding operation and maintenance in small water treatment systems. Precise, accurate data on the number of small water systems is not always available together with information on the main reasons why some failures are experienced. Detailed figures are also necessary to determine how much it costs to undertake an adequate operation and maintenance programme for different types of facilities (DWAF, 2002).

Data are also required on the rates of breakdown of different system elements such as pumping stations, distribution networks, and treatment plants in rural developing systems. Until this information is forthcoming it will be impossible to assess accurately the performance of operation and maintenance and compute the financial losses due to poor operation and maintenance. These exact financial data are urgently needed to demonstrate to decision makers the advisability of implementing a good operation (DWAF, 2002).

b. Lack of operator attention and skill and the inefficient use of funds

Because treatment plant and distribution system operators have a significant degree of control over the quality of a community's drinking water, and thus over public health, appropriate and up-to-date training is essential. This training must include basic education about the need for disinfection to ensure public health goals are met. In a number of small water works the operators are not trained and as a result the plants are not operated the way they should be (Hueb, 2001).

Sometimes it is the inefficient use of funds rather than a lack of money that contributes to poor operation and maintenance. The poor management of facilities results in the squandering of resources, which then reduces the viability of the water supply system. Those responsible for managing water supply facilities need to look carefully at their operations to ensure that they are efficient. Common problems are too often related to many unskilled staff and poor logistical and organizational structures (Hueb, 2001).

c. Lack of effective maintenance and operation of the water treatment plants

The inadequate operation and the ineffective maintenance of water and sanitation systems continue to be a major problem within the water sector in developing areas. Due to the fact that operation and maintenance of water supplies and sanitation in developing municipal areas is highly neglected, official data on the numbers of people served by these services often are overly optimistic because, in reality, many of these facilities are broken or operating at a reduced capacity. In most cases the management systems have failed to provide the necessary guidance and structure for effective operation and maintenance of the water supply and sanitation facilities. The deterioration of the valuable physical assets is a major loss to national economies, which can and should be avoided (Hueb, 2001).

1.2.2 Strategies to ensure safe drinking water in small potable water supply systems

The assessment of the drinking water supply forms the basis of all activities related to providing the cleanest, safest, most reliable drinking water to the public. Assessments identify the characteristics of the water source; potential hazards, how these hazards create risks and how these risks can best be managed. The drinking water supply includes everything from the collection of the raw water to the point where the water reaches the consumer.

A comprehensive multi-barrier drinking water program includes:

- Source water protection
- Watershed or well-head protection plans
- Routine maintenance of the distribution system
- Operator training and certification

1.2.2.1 Protection of the water sources

Source water quality management is the first step in ensuring an adequate supply of safe drinking water and should be an integral element in every water utility operation. Drinking water comes mainly from two types of sources: ground water (e.g. wells and springs) and surface water (e.g. lakes, rivers and reservoirs).

The control of source water quality both facilitates the economical production of safe drinking water and enhances its value. Source water quality management provides a means of determining the impacts on drinking water sources resulting from both natural factors and human activities, of estimating the immediate and long-term effects of such impacts and of preventing the occurrence of public water supply system problems that are difficult or expensive to correct (Geldereich *et al*., 1993).

Drinking water, which may be produced from ground water, surface water, or both, is vulnerable to contamination. If the drinking water source is not protected, contamination can cause a community significant expense as well as put people's health in danger. Cleaning up contamination or finding a new source of drinking water is complicated, costly, and sometimes impossible (USEPA, 1998).

Source water contamination prevention is the first barrier to the outbreak of waterborne illnesses. Keeping contaminants out of the source water helps keep them out of the drinking water supply (USEPA, 1998). Source water can be protected by a variety of strategies including the following:

- The effective treatment of the effluent waste waters before discharging them to rivers or lakes.
- Preventing the animals from reaching the water source.
- Preventing human activities like washing and swimming in the water sources.
- Setting out programs to protect the water resource and partly address recreational issues in the catchments and water bodies.

1.2.2.2 Operational procedures

The proper maintenance and operation of water supply, treatment and distribution systems are essential parts of any effort to ensure the on-going production and delivery of the highest quality drinking water possible. Operational procedures vary among treatment plants but, generally speaking, operational-related monitoring requirements should be in place and be clear; plants should be supervised by trained and certified operators; operator training programs should be available; facilities should be inspected on a regular basis; and administrative support should be available (Federal-Provincial-Territorial Committee on Environmental and Occupational Health, 2001).

1.2.2.3 Monitoring, reporting and record-keeping

In order to protect health, we need to know the quality of water consumed/used, which may be very different from both that supplied at the point of consumption and that supplied at the point of treatment. Measures of water quality have historically been considered under three main categories – biological, chemical and physical to refelect the primary characteristics of each measure. Water quality can also be classified according to the physical characteristics relevant to treatment options. Table 1.1 illustrates major water quality parameter classes (Hrudey and Hrudey, 2004). Protocols related to drinking water quality monitoring should be in place for all activities, including selection of laboratories, routine monitoring, sample analysis and public notification.

Routine monitoring entails taking samples of raw water at the intake water source, at the treatment plant or from different stages of treatment, and samples of treated water in the distribution system at predetermined intervals to verify the quality of the water. It is imperative for a monitoring system to be in place for notifying the public when test results show that drinking water presents a potentially serious health risk, or for explaining the significance of changes in aesthetic quality. It is particularly important to have protocols in place to deal with the microbiological quality of the drinking water. This will be discussed in section 1.2.3.

Table 1.1 Major water quality parameter classes (Hrudey and Hrudey, 2004)

	Physical	Chemical	Biological
Major Charateristics	• can be measured by strictly physical means • treat by physical or chemical means	• detection may require chemical reaction,pocess • treat by physical, chemical or biological means	• organim that may be alive (viable)or dead • treat by physical, chemical orl biological means
Parameters Relevant to Infectious Disease Outbreaks	• turbidity • temperature • colour	• pH • alkalinity • chlorine demand	• viruses • bacteria • protozoa

Other types of monitoring include on-going assessment of the location of sampling sites. Because samples are taken from such a small fraction of the water in any given system, the analysis should be done as much as possible to ensure the water in the samples is representative of the quality of the water throughout the plant and distribution system. In order to quickly remedy situations where water flow appears to be restricted, it is imperative that up-to-date drawings of the distribution system be kept in an accessible location.

a. Timelines

Many parameters such as temperature, turbidity and flow rates can be measured instantaneously (in "real time"). The results can be flashed from the points of measurement to central control points, where operators can adjust processes to maintain high quality. However, measuring other critically important parameters (notably those dealing with the presence of pathogens, but also including many chemical pollutants) require that samples be sent to laboratories for analysis. All laboratory tests take time during which people will consume the potentially contaminated water unless a substantial amount of stored, treated water is available. But storage may degrade water quality in other ways. This distinction between real-time and lagging (or trailing) measurements leads to two observations:

- Since it is currently impossible to measure microbial contamination in real-time, the engineers who design systems and the operators who run them must rely on the treatment process to safeguard the water. Measuring the presence or absence of microbes can be used only as an after-the-fact method of auditing the integrity of treatment
- As long as direct, real-time measurements are not possible, there are significant advantages to the development of indirect or surrogate real-time measures for microbial contaminants. (Krewski *et al*., 2002).

b. Real-time measurement

Many critical measurements can be carried out in real time in the field. These continuous measures (known as in-line measures) can be sent to remote locations, used for process control, archived for regulatory compliance and troubleshooting purposes, and summarized for regulatory and public use. Among the parameters that can be measured accurately and economically in-line are the following: pH, temperature, flow rates, turbidity, colour and chlorine residual.

All municipal water providers should have, as a minimum, continuous inline monitoring of turbidity, disinfectant residual, and flow rate at the treatment plant. The disinfectant residual should be continuously or frequently measured in the distribution system. In treatment processes like disinfection, coagulation, and filtration, flow rates affect process efficiency, because they affect how much time is available for chemical reactions to take place. If the flow rate is too low, the process will not be efficient; if the flow rate is too hight, the process will not be effective. Rapid changes in flow or rates outside design parameters are undesirable; flow must therefore be monitored to track such changes (Krewski *et al*., 2002).

c. Lagging or trailing measures

It is still impossible at present to measure some contaminant parameters in real time. This is especially true for various pathogens but also for most chemical, physical, and radiological parameters. These delays occur for various reasons, including the time it takes to transport and prepare samples, the time it takes to grow cultures, and the need for sophisticated equipment that makes in-line monitoring impractical.

(i) *Microbial Parameters*

The most significant problems associated with pathogen measurement are the lag time involved in testing and, especially for protozoa, the large number of false results. Few direct detection techniques have been developed. Those that have been developed tend to be difficult, expensive, and still not fast enough to assist in process control. Most rely on the growth of cultures in the laboratory before identification tests can be carried out. Furthermore, identification is often a tedious process of elimination based on the known characteristics of each species. DNA analysis offers promise for the future as techniques are refined, but the methods available at present are too expensive and time-consuming for routine monitoring. Many of the tests require highly qualified analysts, and small variations in method can produce significant differences in results.

(ii) Chronic Threats

Chemical and physical contaminants are almost always measured in a laboratory. Gas chromatography and mass spectrometry are the most frequently used methods for measuring organic contaminants. When properly done, these tests can offer great quantitative precision.

d. Sampling

A test can only be as good as the sample on which it is performed. The location and procedures under which the sample is taken and the conditions under which it is transported to the laboratory, affect the quality and usefulness of the result. Those who collect the samples must have proper skills and training. In this context, producing representative results requires going beyond taking a few samples at source, in the treatment plant, and in the distribution system. It must also entail taking measurements under conditions that challenge the system (e.g., after heavy rainfall, and at the farthest or most sluggish ends of the distribution system). It means gathering enough data to have confidence about water quality for each regulated parameter throughout the distribution system. Finally, it should include the data necessary for sustainable asset management (Hargesheimer, 2001).

Problems with laboratory tests are exacerbated by sampling problems associated with pathogens. Microorganisms are not uniformly distributed through a water column: when present, they are generally present intermittently and in low numbers. Samples taken from one location may or may not indicate the presence of microorganisms in other locations. These sampling problems limit the confidence one can have in any statistical interpretation of the tests.

1.2.3.4 Response to adverse results

This component of the multi-barrier approach involves appropriate responses to failing process measures or adverse water quality. For example, the failure to detect a disinfectant residual indicates that the disinfectant dose is insufficient to meet the disinfectant demand. Specific notification and operational procedures should exist for adverse quality measures such as microbiological results. These procedures include further sampling to confirm the adverse results, flushing water mains, and increasing the disinfectant dose (Hueb, 2001).

1.2.3.5 Certification and training

Because treatment plant and distribution system operators have a significant degree of control over the quality of a community's drinking water, and thus over public health, appropriate and up-to-date training is essential. This training must include basic education about the need for disinfection to ensure that public health goals are met. Operator certification programs should be available to ensure that treatment plant operators have appropriate levels of education, experience and knowledge to allow them to competently operate the type of plant they are working in (Federal-Provincial-Territorial Committee on Environmental and Occupational Health, 2001). It is imperative that operators and other staff have on-going access to opportunities for maintaining and upgrading their skills and knowledge (Federal-Provincial-Territorial Committee on Environmental and Occupational Health, 2001).

1.2.3.6 Research and development

Drinking water officials must respond to on-going research into emerging issues, with an emphasis on the microbiological quality of drinking water from source to tap.

Water and public health officials can play an important role in research by collecting data on their water systems and the health of the community; they should be encouraged to participate in research activities. Comparing these data to local hospital admittance records, medical billing records or sales of over-the-counter pharmaceuticals, can sometimes monitor health effects. Data collected help to identify whether the contaminants or pathogens in question are entering the system or are a concern in small drinking water supplies. These data may form the basis of new or revised public health policies (Federal-Provincial-Territorial Committee on Environmental and Occupational Health, 2001).

1.2.4 Microbial safety of drinking water and the use of indicator organisms

This section only focuses on main tests that can be used in rural small water treatments to ensure the safety of drinking water taking into account the laboratory facilities they can afford. These tests include the tests for coliform group and heterotrophic bacterial count.

1.2.4.1 Coliform group tests

To ensure the absence of bacterial pathogens, the drinking water should be free of faecal organisms. The primary bacterial indicator recommended for this purpose is the coliform group of organisms. Total and faecal coliforms are used much more than any other indicator group for monitoring drinking water quality because they addresses both health and treatment efficiency objectives. Although as a group they are not exclusively of faecal origin, they are universally present in large numbers in the faeces of human and other warm blooded animals. A subgroup of these coliform organisms, the faecal (thermo-tolerant) coliforms, or in particular *Escherichia coli,* provides definitive evidence of faecal pollution by warm blooded animals. Faecal coliforms are primarily used to indicate the presence of bacterial pathogens *Salmonella* spp. *Shigella* spp., *Vibrio cholerae, Campylobacter jejuni, Campylobacter coli, Yersinia enterocolitica* and pathogenic *E, coli* (DWAF, 1996). The presence of faecal coliforms in treated water indicates poor or inadequate treatment of drinking water. Higher concentrations of faecal coliforms in treated water indicate a high risk of contracting waterborne disease, even if small amounts of the water are consumed (DWAF, 1996).

There is an important asymmetry regarding *E. coli* as an indicator for faecal pathogens. The presence of *E. coli* is a reliable indicator of the likelihood of faecal contamination, meaning that faecal pathogens may be present. Likewise, because *E. coli* is very sensitive to chlorine disinfection, the presence of *E. coli* is a clear indication of inadequate disinfection. On the other hand, some pathogens, particularly protozoan parasites such as *Giardia* and *Cryptosporidium,* may be much more resistant than *E. coli* is to chlorine disinfection. The absence of *E. coli* therefore does not assure the absence of these more resistant fecal pathogens (Duranceau *et al*, 1999).

The objective of zero *E. coli* per 100 ml of water is the goal for all water supplies and should be the target even in mergencies; however, it may be difficult to achiee in the immediate post-disater period. An indication of a certain level of faecal indicator bacteria alone is not a reliable guide to microbial water safety. Some faecal pathogens, including many varuses and protozoal cysts and oocysts, may be resistant to chlorine than common faecal contamination, then even a very low level of faecal contamination may be considered to present a risk, especially during outbreak of a potentially waterborne disease, such as cholera (WHO, 2004).

1.2.4.2 Heterotrophic plate count tests

The use of Heterotrophic plate count (HPC) bacteria, also known as colony counts and previously known as standard plate count bacteria, as an indicator for drinking water quality dates back to as early as 1800s (Bartram *et al.*, (2003). Even at that time, it was known that enteric bacteria were the cause of many significant illnesses, but HPC bacteria as surrogate indicators because of a lack of specific detection for enteric organisms. With resent advancement in specific methodologies such as defined-substrate media for *Escherichia coli*, measuring HPC bacteria in water during treatment and immediately upon leaving the treatment plant can be used by plant operators as one of several routine tests to monitor plant operation. Although, HPC measurement can take as long as seven days before they become available, their measurement can play an important role in validation and verification of treatment plant procedures. Validation is used to ensure that any novel or existing treatment process or disinfection practice is operating effectivey. Verification, however, measures the overall performance of the system and provides information about the quality of the drinking water. Neither validation nor verification is suitable for continous control of drinking water quality; hence, the lag time involved in testing is acceptable (Bartram *et al.,* 2003). Water utilties can generally achieve heterotrophic bacteria concentrations of 0-100cfu/ml in finished drinking water (DWAF, 1996). Low and consistent levels of HPC bacteria in the finished drinking water add assurance that the treatment process is working properly. Other indicator bacteria, such as *E. coli,* thermotorela coliforms or total coliforms, should not found when HPC are low, since they are more susceptible than heterotrophic bacteria to disinfection.

When high HPC levels are found in the water leaving the treatment plant, the HPC levels in the distribution system are usually also high. When the water leaving the treatment plant contains acceptable levels of HPC bacteria but levels in distribution system water are above the recommended limit, this usually indicates bacterial regrowth occurring in the distribution system. The density of HPC bacteria reached in the distribution system can be influenced by numerous parameters, including the bacterial quality of the finished water entering the system, temperature, residence time, presence or absence of disinfectant residual, piping materials and the availability of nutrients for growth (Momba *et al.,* 2000; Momba *et al*, 2002; Momba and Makala, 2004).

Most of the heterophic bacteria in drinking water are not human pathogens. However, HPC bacteria in drinking water may include isolated from the following genera that may be potential pathogenic microorganisms: *Pseudomonas* spp, *Acinetobacter* spp., *Moraxella* spp., *Xanthomonas* spp. and different fungi (Bartram *et al.,* 2003).

1.2.4.3 Parameters commonly measured to assess microbial safety of drinking water

This section gives a summary of the parameters most commonly measured to assess microbial safety of drinking water according to World Health Organisation recent guidelines for drinking-water quality (WHO, 2004):

- *E. coli*: Thermotolerant coliforms may provide a simpler surogate.
- *Residual chlorine*: Taste does not give a reliable indication of chlorine concentration. Chlorine content should be tested in the field with, for example, a colour comparator, generally used in the range of 0.2-1mg/l.
- *pH*: It is necessary to know the pH of water, because more alkaline water requires a longer contact time or a higher free residual chlorine level at the end of the contact time for

adequate disinfection (04.-0.5 mg/l at pH 6-8, rising to 0.6 mg/l at pH 8-9; chlorination may be ineffective above pH 9).

- *Turbidity:* Turbidity adversely affects the efficiency of disinfection. Turbidity is also measured to determine what type and level of treatment are needed. It can be carried out with a simple turbidity tube that allows a direct reading in nephelometric turbidity units (NTU).

1.2.5 Roles and responsibilities relating to water services provision in South Africa

Water is a scare resource and therefore water quality management becomes increasingly important in order to conserve the existing resources. The policy and functions of the Department of Water Affairs and Forestry prior to the 1994 elections were restricted exclusively to water resource management. This included the management of the larger catchments; the administration of government water control areas, the supply of bulk untreated water to water boards (bulk treated water supply utilities) and water quality management. There were no guidelines or common policy and as a result both the public sector and the private sector lacked direction as to how to begin meeting the vast needs of the people (DWAF, 1994; Abrams, 1996). Consequently, this resulted in the absence of formal services of known capacity and reliability, and the lack of responsible and capable authorities, rural communities being left to fend for themselves.

For the above mentioned reasons, the new government of South Africa and particularly the Department of Water Affairs and Forestry, together with their policy advisors, recognized that there was an urgent need for a new policy in the country (Abrams, 1996). The policy has since been developed and has been proved very effective and has been heralded throughout the country and abroad for its clarity and insight into the problems facing the country and how they should be addressed. The specific areas which have been most helpful have been clarity on service levels and the definition of the minimum standards (Abrams, 1996).

1.2.5.1 National legal framework relating to drinking water services

Since 1994 various pieces of legislation concerning the water and local government sectors have been finalised. The following are the most important (Mackintosh *et al.,* 2004):

- ***The constitution of South Africa, 1996***, assigns responsibility of ensuring access to water services to logal government. The role of the national and provincial spheres of government is to support, monitor and regulate local government.
- ***The Water Service Act, 1997,*** defines the municipal functios of ensuring water services.

- ***The National Water Act, 1998,*** defines a new way of managing South Africa'scarse water resources. This act states that water is an invisible national resource for which national government is the custodian.
- ***The Local Government: Municipal Demarcation Act, 1998***, provides a legal framework for defining and implementing a post-transitional system of local government.
- ***The local Government: Municipal Strctures Act, 1998,*** defines types and structures of municipalities. Three categories of municipalities exist in South Africa after demarcation: Category A (Metropolitain), Category B (Local) and Category C (District).
- ***The Local Government: Municipal Systems Act,*** 2000, defines how local government should operate ad allows for various types of partnership arrangement a municipality may enter into to ensure delivery of services for example water.
- ***The local Government: Municipal Structure Amendement Act, 2000*** places the function of ensuring access to water services (as well as Health and Electricity) at a district level, unless a local municipality is authorized to perform this function.

1.2.5.2 Clarifying roles of the service providers

To assure that effective performance is achieved, responsibility and accountability must be established at all levels within the organisation of a water provider. According to the 1994 and 2002 White Paper, it is the function of the local government to ensure that adequate water supply and sanitation services are provided to the people, particularly to the poor and the vulnerable. This mandate cannot be delegated, outsourced or privatized (DWAF, 1994; DWAF, 2002). It is important to note that whilst local government has the responsibility of supplying water to consumers, it is the central government's function to ensure that this happens in terms of the norms and standards described in the government's policy. Where local government fails to perform its function, the Department of Water Affairs and Forestry is empowered to take direct action to strengthen local government and temporarily perform the functions of local government. To achieve this mandate, a number of tools may be employed. One option is that of public-public partnerships, in which, for example, a public utility water board can be contracted by local government to provide water services. This is an option that brings a range of skills, expertise and access to funding, while still retaining a high degree of public accountability. Another option is the use of the private sector to provide these skills and resources (DWAF, 2002).

A water management institution must, at its own expense, make information at its disposal available to the public in an appropriate manner, in respect of the waterworks which might fail or have failed, any risk posed by the quality of water to life, health or property; and any matter connected with water or water resources, which the public needs to know (South African National Water Act, 1998).

It is the responsibility of every water services authority to monitor the performance of water service providers and water service intermediaries within its area of jurisdiction to ensure that the standards and norms set by the water services authority are complied with (Water Services Act, 1997).

1.2.6 Legislation relating to drinking water quality in South Africa

For any public service as vital to community health as the provision of safe drinking water, dishonesty or repeat of violation of required operating procedure is absolutely intolerable. In South Africa, all Water Services Authorities are legally required to monitor drinking water quality on a monthly basis. The Water Service Act introduced a compulsory national standard for drinking water quality. The *Compulsory National Standards for the Quality of Potable Water,* as published in Government Gazette No 22355 of 8 June 2001, reads as follows:

Quality of potable water

5. *(1) Within two years of the promulgation of these Regulations, a water services authority must include a suitable programme for sampling the quality of potable water provided by it to consumers in its water services development plan.*

(2) The water quality sampling programme contemplated in subregulation (1) must specify the points at which potable water provided to consumers will be samples, the frequency of sampling and for which substances and determinants the water will be tested.

(3) A water services institution must compare the results obtained from the testing of the samples with SABS 241: Specification for Drinking Water, or the South African Water Quality Guidelines published by the Department of Water Affairs and Forestry.

(4) Should the comparison of the esults as contemplated in subregulation (3) indicate that the water supplied poses a health risk, the water services institution must inform the Director-General of Department of Water Affairs and Forestry and the head of the relevant Provincial Department of Health and it must take steps to inform its consumers -

(a) that the quality of the water that it supplies poses a health risk;

(b) of the reasons for the health risk;

(c) of any precautions to be taken by the consumers; and

(d) of the time frame, if any, within which it my be expected that water of a safe quality will be provided.

It is the responsibility of Local Government to monitor drinking water quality, and for both Provincial and National Government to ensure that is taking place. Where Local Government lacks resources to carry out such monitoring, a co-operation government requirement would require Provincial and/or National Government to ensure that monitoring takes places (Mackintosch *et al.,* 2004).

Much has been achieved in the water service sector in the past 10 years. Prior to the change of government in 1994, an estimated 30 - 40% of South Africa's population (14 -18 million people) was without adequate water supply services and some 21 million people were without adequate sanitation (Van der Merwe, 2003). As of 2004 some 10 million additional people have been supplied with drinking water, thereby reducing the backlog in 2003 to some 4 million (Kasrils, 2004). Although great strides have been made in the effort to provide safe and clean water to all South Africans, studies have shown that in small rural towns and small remote villages with adequate water supply services, the drinking water quality is generally poor and often not fit for human consumption at the point of use (Pearson and Idema, 1998, Swartz, 2000; Momba and Kaleni, 2002, Momba *et al.*, 2004). The drinking water supplied by the small rural water supplies is substandard and is therefore adding to the number of deaths caused by waterborne diseases.

The following chapter of the present investigation reports the quality of drinking water supplied by water the Alice water treatment plant to its consumers.

CHAPTER 2

WATER QUALITY AND TREATMENT PLANT OPERATING PROBLEMS IN ALICE DURING THE FIRST PHASE OF THE PROJECT

2.1. PLANT DESCRIPTION

The Alice plant is a conventional water treatment plant, which includes coagulation, flocculation, sedimentation, rapid sand filtration and chlorination. Water drawn from the Binfield Dam on the Tyume River (approximately 12 km from Alice) is fed under gravity to the head of the works. The design capacity of the plant is 7 Ml/d, however it is currently operating between 3 and4 Ml/d. A number of surrounding villages currently without water services are to be connected to the Alice system in the near future.

At the beginning of the investigation (June 2002) until November 2002, lime and alum were used for the pre-treatment of the raw water. The coagulants are dosed at the same point just ahead of a 90^{o} V-notch weir and hydraulic jump. Powdered hydrated lime and granular alum were mixed with domestic water in separate dissolving/slurry tanks and then fed under gravity to the dosing point. Flash mixing of the chemicals with the raw water results from the turbulence generated over the hydraulic jump. Granular alum and hydrated lime were replaced by Ultrafloc (a poly-aluminium chloride and polyamide mix supplied by Südchemie) at the beginning of December 2002. At the foot of the jump, the water enters a relatively short hydraulic flocculator before flowing under gravity to a three-way flow splitter via an underground pipe. From the splitter the water flows through short intermediate channels into each of the three-clarifier inlet channels. From the influent channels, the water flows into the clarifier inlet chambers via pipes passing through clarifier walls (9 per clarifier). The discharge into the inlet chambers induces gentle hydraulic mixing which promotes the formation of large settlable floc. The water passes over a vertical baffle wall into the main body of each of the three rectangular horizontal clarifiers. Settled water overflows into a common channel, which feeds into the filter influent pipe. The filter influent is split between three 4.3 m diameter self-backwashing valve less sand filters. Chlorine gas is added to the combined filtrate just before the on-site reservoir from where it is fed into the bulk distribution system.

2.2 ASSESSMENT OF THE OPERATING CONDITIONS AND PROBLEMS AT THE ALICE WATER TREATMENT PLANT

2.2.1 Assessment of the operation of the Alice water treatment plant using alum and lime coagulation

The following activities were undertaken from June 2002 to January 2003:

- A tour of the plant and a visual inspection of the various unit processes
- Interview of the operators and plant superintendent about operating practices and monitoring programme
- Measurement of the raw water flow rate using the V-notch weir
- Assessment of adequacy of the lime and alum doses
- Determination of the optimum doses of alum and lime using the Jar tests
- Use of the Cascade tests to investigate the effect of velocity gradients and retention times for flocculation on clarifier performance
- Measurement of the dimensions of the various unit processes and calculation of the corresponding design and operating parameters
- Measurement and interpretation of the turbidity, pH and the temperature at each step in the treatment process
- Measurement of the initial chlorine dose, free and total chlorine residual concentration in the on-site reservoirs
- Investigation of the formation of floc between the hydraulic flocculator and the clarifiers
- Opening and inspecting one of the valveless filters.

In the next section details of the investigation and findings with regard to the operating practices and performance of the Alice Water Treatment Plant during the first phase are explained.

2.2.1.1 Flow rate measurement and control

A manually adjusted valve at the head of the works controls the plant flowrate. The operating staffs increase the plant flow rate when the water level in the clear-wells drops too low and throttles it back when the reservoir is close to overflowing.

The plant was equipped with a flow meter however this was located in a sump, which is currently flooded and the meter had not been read for several years. The flow could also be measured at the V-notch weir at the hydraulic jump; however, the plant operating personnel were unaware of this prior to the project team's visit. Accurate measurement of the flow at this point was difficult because there was a substantial amount of surging and pulsing due to the inlet arrangement. However, when it was later possible to compare the V-notch measurement with a flow meter reading, the two measurements agreed within 6 % at a flow of ~ 5 Ml/d. During this part of the evaluation, the flow of the raw water was calculated using the existing 90° V notch weir according to Kawamura (1991).

For a 90° V-notch weir, the total flow rate, *Q*, is related to the height of the crest over the weir, *H* as follows:

$$(m^3/s) = 1.40\ H^{2.5}$$

→ Where H (m) is the height of water above the weir crest.

Table 2.1 below shows H values with corresponding flows as calculated using the hydraulic equation given above.

TABLE 2.1
SOME EXAMPLES OF FLOW RATE MEASUREMENT CONSIDERING HEIGHT (H) OF WATER

H (m) =	0.20	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.30
Q (m3/s) =>1.40$H^{2.5}$ =	0.025	0.028	0.032	0.034	0.040	0.044	0.048	0.053	0.058	0.063	0.069
Q (Ml/d)=>121$H^{2.5}$ =	2.16	2.45	2.75	3.07	3.41	3.78	4.17	4.58	5.02	5.48	5.96

The height of the crest over the weir (distance from the bottom of the notch to the water surface above the weir) can be measured using a stick and a measuring tape; however, the weir plate should ideally be calibrated with the actual flow rates. From June to July 2002, the flow rate ranged between 2.75 Ml/d and 3.97 Ml/d while in September 2002 the flow ranged between 2.75 Ml/d and 3.4 Ml/d.

2.2.1.2 Lime and alum dosing and control

a. Dosing system

Lime and alum were manually loaded into dry chemical feeders and dosed at a constant rate into the mixing tanks below (Fig.2.1). Each chemical feeder had a hopper, which fed the dry chemical onto a rotating plate. The powdered chemicals are scraped into the mixing tanks by a "*knife*". Increasing or decreasing the clearance between the bottom of the feed hopper and the plate would adjust the rate of chemical addition.

Fig. 2.1 Photo showing dry chemical feeders for alum and lime (from left to right, *the green conical units lying on the floor were bought but never used because they were inappropriate*).

Lime and alum were dosed at the same point just before the weir. Water samples collected at the bottom of the hydraulic jump were found to contain small amounts of undissolved lime. Furthermore, the water pH was found to increase from the beginning of the flocculator to the clarifiers suggesting that further lime dissolution probably occurred.

Kawamura (1991) recommends that alum be added before lime to lower the pH and promote the formation of positively charged species. Lime should be added to decrease the solubility of aluminium and promote precipitation. Theoretically, lime addition should only be necessary if there is insufficient alkalinity in the raw water to prevent the pH dropping below about 6 or the colloidal particles becoming re-stabilised. If the coagulated water pH is above 6 then the addition of lime increases the solubility of aluminium and the amount of alum required.

Adding lime may also be necessary to reduce the corrosivity of the finished water to the distribution system. However, in this case, lime should only be added after filtration to prevent resolubilisation of the alum floc. This issue was not investigated any further.

b. Dosing rate and control

Staff at the water works had never measured the actual alum and lime doses. The superintendent determined whether the dose of alum and lime should be increased based on the taste and appearance of the finished water and whether adequate floc formation was occurring ahead of the clarifiers. If the finished water appeared dirty then the doses were increased. If the finished water began to have a strong taste of alum or lime then the doses were decreased. This is not an accepted technique in the treatment of drinking water.

Moreover, it was noted that coagulant doses were not automatically adjusted when the plant flow-rate was changed. There was a substantial amount of alum sludge deposition throughout the plant, including ahead of the hydraulic jump and in the on-site reservoirs. Furthermore, the evidence of post-precipitation of alum in the filters was detected. These observations suggested that the plant was generally overdosing with alum and lime.

The operators reported that a 50 kg bag of alum was apparently consumed in approximately 7 h while a 25 kg bag of lime lasted approximately 24 h. The dosing rate could also be determined directly by measuring the amount of dry chemical dropping into the mixing tanks over a fixed amount of time.

The average alum and lime doses were estimated to be 57 and 12 mg/l respectively while Jar tests conducted using raw water from the plant indicated that an alum dose of 30 mg/L with no lime addition should have given adequate performance. It is however quite possible that lime addition was necessary to achieve good flocculation at other times of the year. The calculations are summarized below.

c. Estimating alum and lime consumption and Costs

Alum and lime consumption according to the operators

The operators reported that about 4 x 50 kg bags of alum and 3 x 25 kg bag lime were used per day.

Cost estimates:

- 1 x 50 kg alum bag costs about R 96.00
- 1 x 25 kg lime bag costs about R 30.00

Table 2.2 illustrates the cost estimates of alum and lime according to the operator's information.

Average alum and lime consumption and costs according to the measurements done onsite

During the evaluation period, the consumption of alum and lime were estimated by timing (using a stop watch) the time it took to collect certain amounts of the chemicals and weighing these amounts. Table 2.3 below presents the results obtained during evaluation. Using the flow rate estimated on each day, the corresponding dosages in mg/l and the costs were estimated.

TABLE 2.2 ALUM AND LIME COST ESTIMATES ACCORDING TO OPERATORS'S INFORMATION					
Item No	**Description**	**Unit**	**Unit cost (Rand)**	**Consumption (bags/ year)**	**Total Cost (Rand/year)**
1	Aluminium Sulphate (alum)	50 kg bag	96	4 x 365 = 1 460	140 160
2	Lime	25 kg bag	30	3 x 365 = 1 095	32 850

<u>Alum demand and costs based on the Jar test results</u>

All Jar Test results revealed that 15 mg/l was the optimum dosage compared to the average value of 61 mg/l. With an average flow of 3.27 Ml/d, the cost of alum per year at a dosage rate of 15mg/l was: [{3.17 $*10^6$ *(l/d)* * 15 * 10^{-6} (kg/*l*)}/50 (kg)]* 365 (d) * R96 = **R 33 323.00 per year** *(This cost is for 50kg bags per year).* Fig. 2.2 shows an example of the clarity of the settled water and the lowest turbity at a dosage of 15 mg/l.

TABLE 2.3 ESTIMATING ALUM AND LIME CONSUMPTION AND COSTS				
Flow (Ml/d)	**Alum**		**Lime**	
	Consumption (kg/d)	**Dosage (mg/l)**	**Consumption (kg/d)**	**Dosage (mg/l)**
2.75	172	63	42	15
2.75	224	82	27	10
3.41	184	54	42	12
4.17	192	46	45	11
Average				
3.27	193	61	39	12
Average Cost per year (R)	**Alum**		**Lime**	
	135 255		17 082	

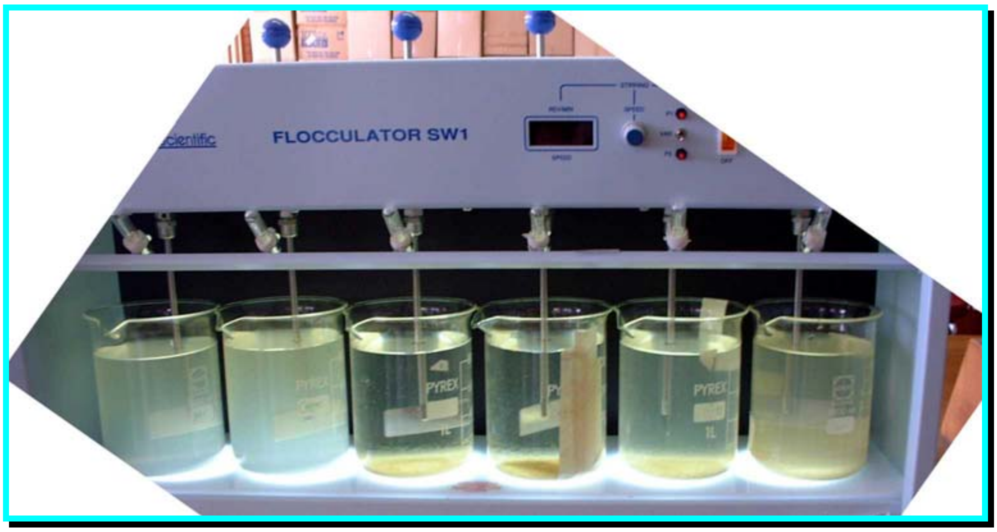

Fig. 2.2 Photo 2 showing clarity of settled water during Jar testing (*beaker No 3 from left showed lowest turbidity at a dosage of 15 mg/l)*

Cost estimates above indicate that if Jar test results were implemented, cost savings in the order of R100 000 per year could have been achieved.

2.2.1.3 Flash mixing

Flash mixing of the coagulant chemicals results from the turbulence generated over a hydraulic jump. The jump is broken into four steps as shown below (Fig.2.3). Angled baffles on each of the steps appear to further promote mixing. The overall head-loss over the jump is 1.1 m; compared to a recommended minimum of 0.6 m it should be quite adequate for flash mixing. However, the alum and lime were added a few seconds before the jump. Theoretically, alum hydrolysis species form within few distances and should be dispersed as quickly as possible for maximum coagulating effect. Therefore the position of the dosing point may have resulted in a small decrease in the efficiency in coagulant use. However, this would have been a second order effect as compared to the consequences of massive overdosing.

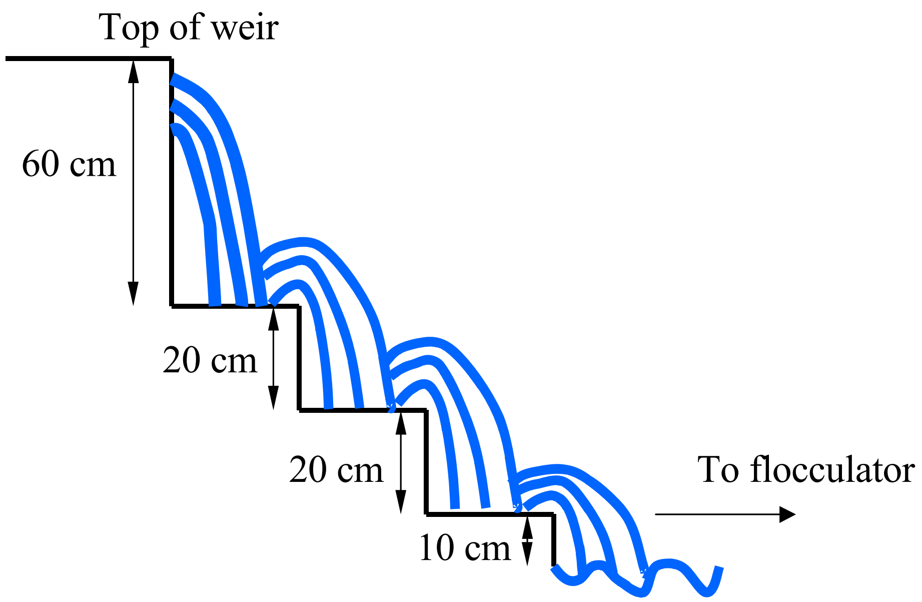

Fig.2.3 Diagram showing the hydraulic jump in the Alice water treatment plant

It was noted that a layer of sludge had formed on the bottom of the channel just ahead of the jump. This could have been either raw water particles, which had settled out, alum floc and/or undissolved lime.

2.2.1.**4 Flocculation**

Hydraulic mixing for flocculation occurs in a number of stages:

- After flash mixing, coagulated water flows through the 23 m long baffled channel (hydraulic flocculator or race)
- The water then flows under gravity through a 36 cm diameter pipe between the baffled channel and the flow splitter ahead of the clarifiers
- From the splitter the water flows via interconnecting channels to the influent channels for clarifiers 1 and 2 and via a 28 cm diameter pipe to clarifier 3. Flow into the influent channels for 1 and 2 is regulated by sluice gates (one for clarifier 1 and two for clarifier 2).
- Clarifier inlet channels
- Pipes between the clarifier inlet channels and the hydraulically mixed inlet chambers
- Hydraulically mixed chambers at the clarifier inlets (before the intermediate baffle wall) where a combination of flocculation and settling occurs.

Turbulence in all the above-mentioned sections contributes to floc formation. According to the operating staff, floc formation was usually visible from the baffled channel onwards during summer while in winter it only occurred later in the process. During the plant evaluation, no floc formation was observed up to the splitter, very small pin-point floc were observed in the clarifier influent channels and large settlable floc were observed only in the hydraulically mixed inlet chambers.

Estimates of the retention times and mixing intensities (G values) for the stages listed above indicate the following:

- The lag time between flash mixing and the hydraulically mixed inlet chambers is approximately 4 to 8 minutes depending on the plant flowrate. Between these two points, the estimated mixing intensities are relatively high (> 25/s at the lowest flow-rate measured) which would tend to promote the formation of small floc. High local mixing intensities at certain points including the flow splitter, sluice gates and pipes through the clarifier walls will tend to break up any large floc formed.
- Retention times in the hydraulically mixed influent chambers were estimated at 16 – 38 minutes depending on flow-rate while the G-values were estimated approximately between 10 and 20/s.

There is therefore an overall decrease in mixing intensity between flash mixing and sedimentation, which provides some degree of tapered flocculation with a total retention time of greater than 20 minutes. The flocculation facilities appear to be adequate but not optimized at the present operating conditions.

2.2.1.5 Flow splitting

The flow splitter was designed with three identical broad crested rectangular weirs in a triangular pattern to achieve an equal three way flow split. However, gates downstream of the weirs control the flow into the clarifiers. During the plant visits in June and July, it was observed that the flow split was not even and the weir to the middle clarifier was submerged. The operators were advised to open the sluice gates in the clarifier inlet channels wide enough to allow the water level downstream of each weir to drop just below the crest. The gates can be propped open by jamming blocks of wood underneath them.

2.2.1.6 Sedimentation

The general performance goal of a settling tank preceded by chemical coagulation is that its effluent (settled water) must have a turbidity of less than 5 NTU (WHO, 1993). Stricter limits exist in most large urban plants in which the overflow from sedimentation tanks need to have a turbidity of less than 2 NTU. The aim in setting such performance goals is to protect subsequent sand filtration processes against high loads of suspended solids and thus ensure their effectiveness in producing filtered water suitable for disinfection by chlorination (< 1 NTU). Low turbidity in settled water also means less accumulation of suspended solids in sand filters and hence less frequent cleaning. This reduces operation and maintenance costs.

Currently there are 3 settling tanks (1 new and 2 old) similar capacity. During the plant evaluation exercise, the combined effluent turbidity of the settling tanks was found to vary between 8.5 and 17.9 NTU. Visual observation indicated that the new east tank was receiving more coagulated water and therefore could be overloaded. The measured turbidities of the individual settling tank effluent are shown in Table 2.4.

TABLE 2.4

AVERAGE EFFLUENT TURBIDITY VALUES OF THE SETTLING TANKS

Clarifier No	Clarifier 1	Clarifier 2	Clarifier 3
Average turbidity (NTU)	10.6	8.5	17.9

The above results confirmed the suspicion of the unequal flow distribution to the settling tanks. Besides the unequal flow distribution, collection of the settled water seems unequal. The settled water-collecting troughs (No 2) at about 3 m apart in each settling tank seem to be inadequate as well. Generally, these troughs should be 1 m apart to ensure uniform and adequate collection of settled water. This is important to prevent turbulent flow, which would disturb the settling floc.

No procedures and records existed regarding the cleaning of the settling tanks. According to the operating staff, the clarifiers were usually manually desludged twice a week. The sludge valves were left open until the water being discharged was relatively clean. The time required depends on the amount of solids coming into the plant. The superintendent estimated that approximately 5 % of the clarifier volume was drained out during desludging. The greatest amount of sludge was drawn from the hydraulically mixed inlet chambers. The sludge was discharged into settling ponds at the bottom of the plant along with the filter backwash wastewater. Supernatant from the ponds could be pumped back to the head of the works.

At the time of the plant visits, the wastewater recycle pump was not working and as a result, flooding or leaking from the settling ponds was apparently causing problems for the community down gradient from the treatment plant. The clarifiers were therefore only being desludged once a week. The superintendent was also unable to drain a clarifier for the project team to inspect.

2.2.1.7 Filtration

Rapid sand filtration (RSF) is used at Alice water works. The combined clarified water is split between three 4.3 m diameter (Area = 14.5 m^2) autonomous valveless sand filters as indicated in Fig. 2.4, each containing a 0.6 m bed of 0.7 mm effective size sand. It was assumed that the flow split was even. Filtration rates were estimated at ~ 2 to 4 m/h during the evaluation of the plant.

These rates are quite low and could lead to long filtration runs, which could potentially lead to mud-balling problems. The filtration flow rate at the plant design capacity (7 Ml/day) was estimated at 6.7m/h which is typical for this type of filter and application.

Recommended filtration rates for RSF are generally between 5 and 20 $m^3/h/m^2$ filter area. The main operational activity of RSF is cleaning the filter media by reversing flow (backwashing) using clean water and draining the wash water to waste as shown in Fig. 2.5. Modern filtration systems typically employ air high pressure water jets to improve the dislodging of dirt from the sand grains before sending in the backwash water. The recommended frequency of backwashing is any period when maximum head-loss is reached, but not more than 36 h when auxiliary backwash is used.

Valveless rapid sand filters are designed to clean themselves automatically once terminal headloss is reached without the use of manual or electronic controls. Valveless filters do not have any facility for auxiliary wash and therefore a run time of no more than 24 h is recommended (WRC Report K5-919) .This means if the headloss is not reached within 24 h, the filters must be back-washed, manually or automatically. The operator interviewed said that each filter was backwashing automatically approximately every 17 h and that he could hear a backwash taking place from anywhere on the plant.

Fig. 2.4 The three valveless of the rapid sand filters at the Alice water treatment plant

However, it appears that individual filters were often running for several days at a time without backwashing. This may initially have been due to low filtration rates and slow headloss development. (Note: The air lock in the backwash pipe is part of the filter design. It gradually gets sucked out by the self-priming system)

WHO guidelines for potable water production state that water meant for disinfection by chlorination must have turbidity < 1 NTU for effective disinfection (WHO, 1993**)**. Higher turbidity water will exert greater disinfectant demand. Filtrate turbidities at the Alice water treatment plant frequently exceeded 1 NTU.

Fig. 2.5 Wash water immediately after starting the backwashing

Post-precipitation of alum floc contributed to poor filter performance. Alum floc consists primarily of amorphous aluminium hydroxide (Al $(OH)_3$(am) which has a minimum solubility at pH ~ 6. The pH of the settled water at the Alice water treatment plant was typically greater than 7. Consequently, a small drop in pH across the filters would in a decrease in aluminium solubility making precipitation possible. This is typically a problem when lime and alum are being overdosed, which was certainly the case at the Alice water treatment plant.

The plant was shut down and the filter 3 opened for inspection once during the study period (11 July 2002). The filter media was found to be in a fairly good state, except at the edges of the filter, where it had built up against the filter walls and where a number of mud-balls were found. This indicated poor flow distribution adjacent to the walls. The media away from the walls appeared to be quite clean except for a few millimeter of sludge on the top surface of the bed (typical of filters backwashed without auxiliary backwash). Numerous lumps of mud containing filaments of algae had accumulated on the surface of the filter.

An analysis of filter effluent turbidity immediately after back washing revealed very high values (>20 NTU), which indicated the ineffectiveness of the back-washing process. Kawamura (1991), for example, recommends that backwashing be terminated once a wash water turbidity of 10 to 15 NTU is achieved. Fortunately, the water produced right after backwashing flows to the backwash tank and not to the in-plant reservoir. However, 4 h later, the filtered water turbidity was still well above 1 NTU (Table 2.5).

TABLE 2.5
AVERAGE TURBIDITY AFTER BACKWASHING (NTU)

Filter 1	Filter 2	Filter 3
Turbidity immediately after back-washing (BW)		
ND	39.0	27.5
Filtered Water Turbidity 4h after BW		
2.3	3.4	2.5
Filtered water turbidity 6h after back-washing		
2.0	2.0	2.0

2.2.1.8 Disinfection

a. Chlorination

The disinfection of the filtrate effluent is achieved by injecting chlorine gas into it and ensuring an adequate contact time before the water flows out to service. An ALLDOS chlorinator with a capacity of 50 to1000 g/h is used. There were two chlorinators on site but at the time of evaluation one was out of operation. Chlorine gas is dissolved in a small side stream which is then added to the combined filtrate at the entrance to the new 100 kl contact tank (also referred to as the on-site reservoir). The old 45 kl contact tank is connected to the new on site reservoir as a side branch. There is no through flow in the old tank but the reservoir level indicators appear to be connected to the old tank. There is negligible flow resistance between the old and new tanks so their levels are always identical.

The chlorine dose rate is manually controlled and set using a rotameter housed in the chlorination room. The dosing rate was set at 100 g/h Cl_2 (up to June 2002) and was not ratioed to the plant flow rate. This translated into applied chlorine doses of 0.6 to 1.3 mg/l (Examples of the calculation of the chlorine dose are given in section 2.1.1.8b). Measurements made at a community stand pipe in Ntselamanzi village (a sampling site which generally showed a relatively small decrease in chlorine residual compared to in plant measurements) indicated that there was little or no free chlorine residual in the water reaching consumers. On 25th June 2002, the chlorine gas dose was increased to 400 g/h but the chlorine flow was still not ratioed to the plant flow-rate. This resulted in applied dose rates of 2.4 to 5.0 mg/l at the flow-rates recorded in June to July 2002. For emergency situations (lack of chlorine gas or dosing equipment failure), a drum of granular HTH (High Test Hypochlorite) was stored on site. When necessary, 500g of HTH was added to the reservoir every 6 h, substantially less than the 400 g/hactive chlorine employed when using chlorine gas. There were no records of chlorine consumption or monitoring of chlorine residual.

In July 2002, the free chlorine measured at the outlet of the on site reservoir was only 0.2 mg/l. Increasing the rate of application to 400 g/h only produced a 0.2 mg/l increase in the residual. In general, the chlorine residual leaving the plant should be at least 0.5 mg/l with at least 0.2 mg/l in tap water at the end of the distribution system. The applied doses were therefore still inadequate, although improvements in turbidity removal might have decreased the chlorine demand of the filtrate.

It was also noted that a substantial amount of floc had settled in the contact chambers, possibly as a result of post precipitation. The sludge probably increased the overall chlorine demand in the reservoir.

NOTE!!! The old reservoir does not really contribute significantly to the contact time because the water only flows in or out if the level is changing. It creates a dead zone or stagnant region rather than additional contact time]

For the flowrates measured during this period (3.75 to 4.2 Ml/d), the on site chlorine contact time would have been 34 to 38 min. This would drop to 21 min at the design flowrate.

b. Estimation of chlorine dosage

The average plant flow was estimated at 3.27 Ml/d. Assuming there were no losses within the plant, this flow would then be equal to the amount of water to be disinfected. 400 g/h dosing rate of the gaseous chlorine would translate to:

$$(400 \text{ x } 1\,000 \text{ x } 24) / (327 \text{ x } 10^{6)} = 3.03 \text{ mg/l.}$$

When the gas system was out of operation the HTH was used and 500g of the HTH was added every 6 h giving a total of 2 kg per day. With an average plant flow of 3.27 Ml/d and the fact that the HTH used is 68% active chlorine, the effective dose was:

$$0.68 * 2 * 10^6 / (3.27 * 10^6) = 0.42 \text{ mg/l}$$

c. Effect of turbidity on the performance of the chlorination process

After dosing chlorine, there should be a residual of between 0.3 and 0.5 mg/l free chlorine at the furthest consumer's tape in the distribution systems to combat any possible contamination in the network and to protect public health. Residual chlorine also prevents bacteria re-growth in the pipe system, which may impair the taste and general quality of the water. Generally the recommended residual chlorine in the water leaving the plant is between 1and 1.5 mg/l.

High filtrate turbidity increases the chlorine demand of the water and makes it more difficult to maintain an adequate residual. Fig, 2.6 illustrates the performance of the Alice water treatment plant in terms of the removal of turbidity between October 2002 and January 2003. The determination of the level of the turbidity and the concentration of the free chlorine residual in treated water samples were done twice a week.

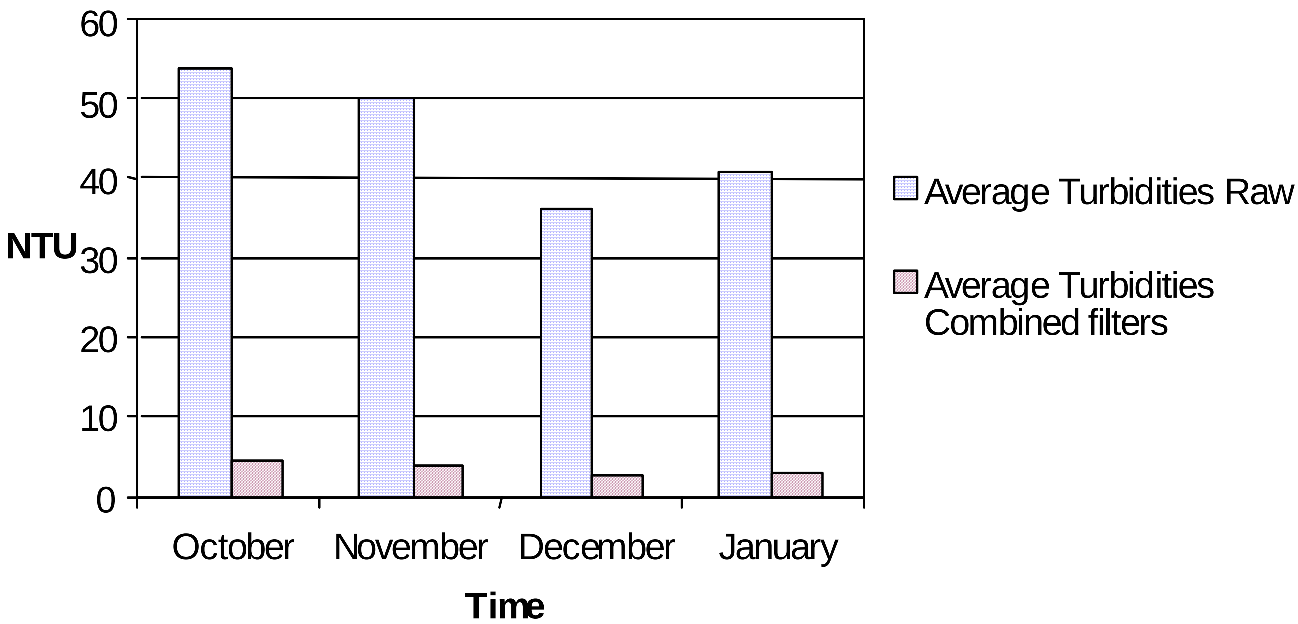

Fig. 2.6 Performance of the Alice water treatment plant for the removal of the Turbidity (from October 2002 to January 2003)

Although there was a decrease in raw water turbidity from September to November 2002, the average turbidity values from all three filters remained above 1 NTU. This automatically had a negative effect on the disinfection process as shown in Figs. 2.7 and 2.8. The higher the average filtrate turbidity, the lower the average chlorine residual recorded.

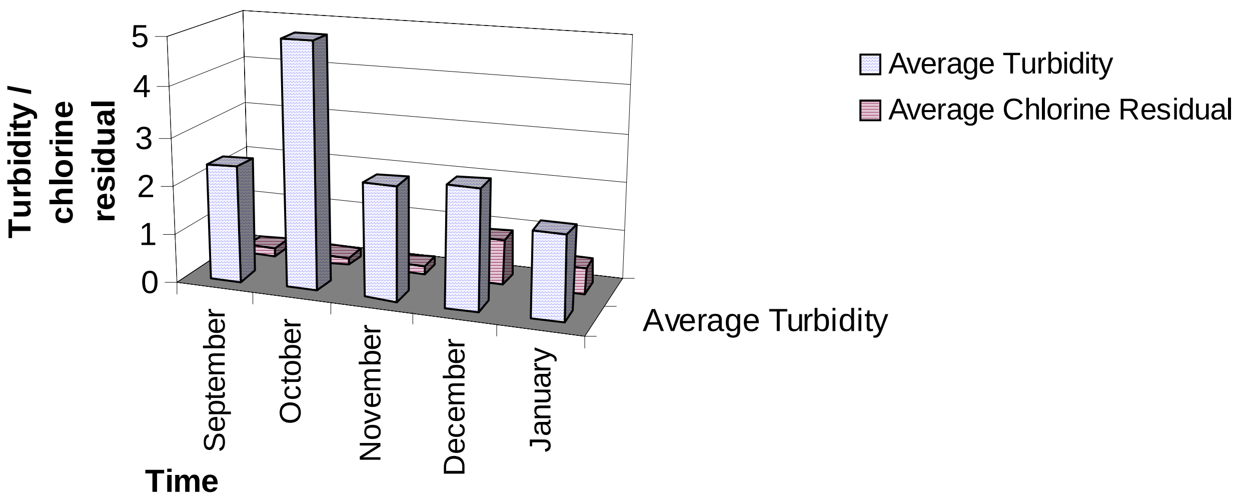

Fig .2.7 Average turbidity values (NTU) versus average chlorine residual concentrations (mg/l) in the in-plant reservoir (from September 2002 to January 2003)

2.2.2 Assessment of the operation of the Alice water treatment plant using Ultrafloc.

In December 2002, the Alice water treatment plant switched from using alum and lime to Ultrafloc (supplied by Sudchemie) for coagulation. The reasons for the change were never discussed with the research team; however, they appear to have included the following:

- Ultrafloc produces less sludge than alum and lime

- The liquid coagulant is easier and safer to handle than the powdered alum and lime

The performance of the Alice water treatment plant with Ultrafloc pretreatment was monitored from December 2002 to March 2003. Although a slight decrease in the filtrate effluent turbidities were recorded in December 2002 and January 2003, this appeared to be due to a decrease in the raw water turbidity. Figure 2.8 shows that the final water turbidity was not within acceptable limits and the chlorine residual was also inadequate. Little or no chlorine residual was recorded at various sampling points in the distribution system (Fig. 2.8).

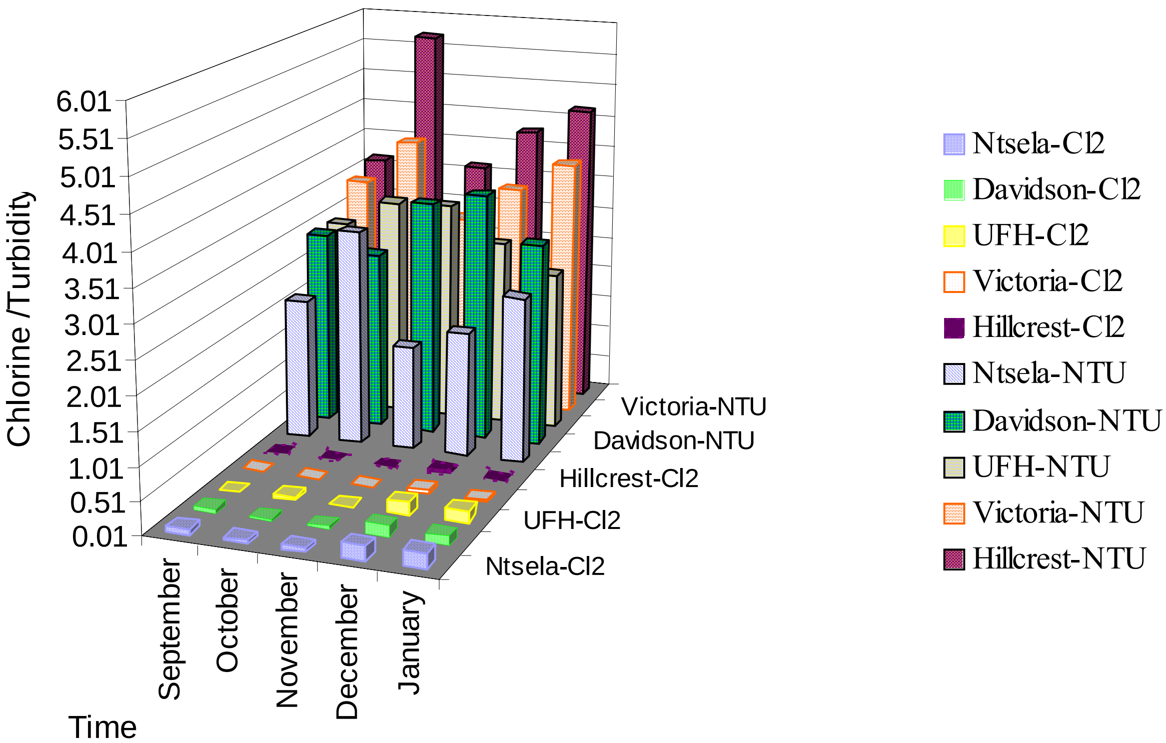

Fig. 2.8 Average turbidity values (limits for no risk: 0 to 1NTU) versus chlorine residual concentration (mg/l-average values) in the distribution system (from September 2002 to January 2003).

The month of March 2003 was characterized by an increase in the applied chlorine at the point of treatment which resulted in high levels of chlorine residuals in the distribution system with the exception of Hillcrest and Victoria East clinic, which showed the absence of chlorine residual (Fig. 2.9). Chlorine residual levels in the point of treatment exceeded by far the limits recommended by water authorities worldwide, (which ranged between 1 and 1.5mg/l for the water leaving the plant and between 0.3 and 0.5 mg/l at the furthest consumer's tape in the distribution system). This could have a negative impact on the health of the consumer, as high chlorine residuals might react with organic matter on the distribution system. It has been reported that high chlorine residuals form organo- halogenated compounds that have been identified as partial mutagenic or even carcinogenic chlorinated organics (Dore, 1989; Gibbs *et al*, 1990; Meyer *et al*, 1993).

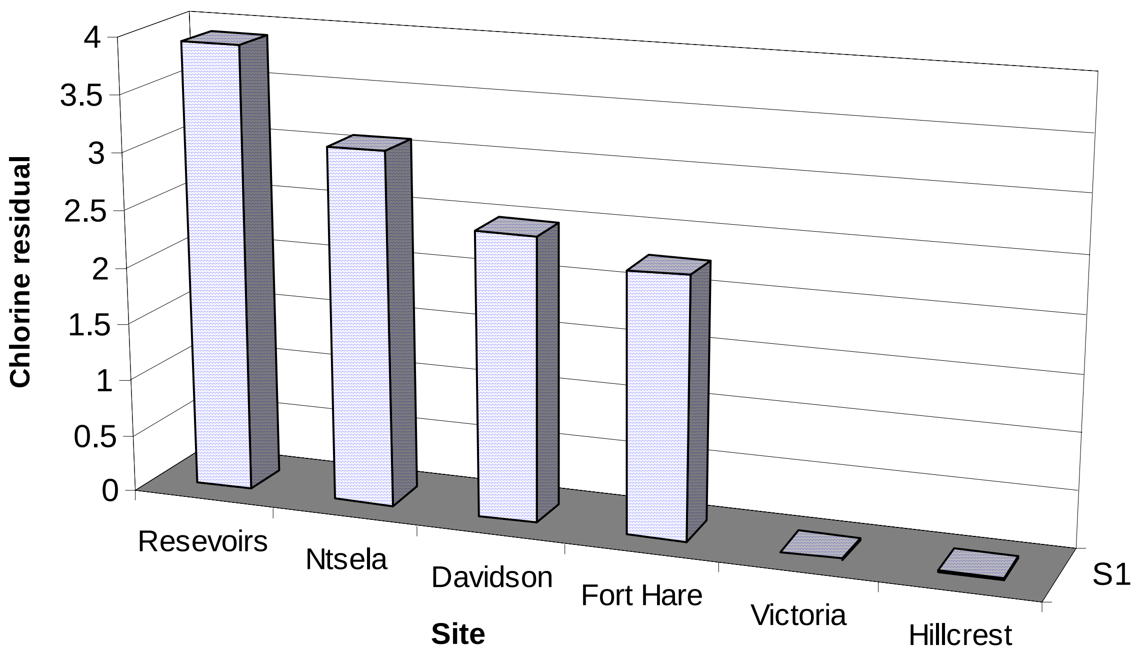

Fig. 2.9 Average chlorine residuals (mg/l) measured at the point of treatment (main reservoir) and in the distribution system during the month of March 2003.

2.3 ASSESSMENT OF PHYSICO-CHEMICAL CHARACTERISTICS OF THE ALICE DRINKING WATER

Chlorine residual concentration, pH, temperature and turbidity were measured on site using a multi-parameter ion specific meter (Hanna-BDH laboratory supplies), thermometer and microprocessor turbidity meter (Hanna instruments) respectively. The concentrations of chromates, fluorides, nitrates, phosphates, chemical oxygen demand (COD), sulphate, total hardness, cadmium, zinc and copper were determined according to the spectroquant NOVA 60 manual (1998), using photometric test kits (Merck). Water samples for these chemical quality analyses were collected twice a week in thoroughly cleaned non-sterile bottles and transported to the base laboratory at the University of Fort Hare, Faculty of Science and Technology. Analyses were performed within 2 to 4h after the collection.

TABLE 2.6

PHYSICAL AND CHEMICAL QUALITY (RANGE VALUES) OF THE WATER SAMPLES COLLECTED FROM RAW WATER AND IN-PLANT RESERVOIRS – SEPTEMBER 2002 - JANUARY 2003

Variable	Limit for No risk	Raw water	New reservoir	Old reservoir
Fluoride (mg/l)	0-1*	0.06 – 0.19	< 0.01	< 0.01
Phosphate (mg/l)	NS	0.06 – 0.24	< 0.5	< 0.5
Chromate (mg/l)	0.05-1*	0.05 – 0.18	<0.05	<0.05
Sulfate (mg/l)	0-200	28 – 37	22 – 29	22 – 30
Total Nitrogen (mg/l)	0-6*	4.1 – 5.1	< 0.5	< 0.5
Total Hardness (mg/l)	0-50*	8 – 17	6 – 10	5 – 11
Copper (mg/l)	1-3*	0.18 – 0.34	0.04 – 0.1	0.03 – 0.09
Cadmium (mg/l)	5-10*	0.03	<0.025	<0.025
Zinc (mg/l)	0-3*	1.8 – 2.35	0.6 – 1.05	0.6 – 1.0
COD (mg/l)	NS	5.8 – 7.2	< 4 – 4	< 4 – 4.1
Ph	6-9*	6.0 – 6.4	6.3 – 7.1	6.2 – 7.1
Temperature ° C	< 25 #	16 – 19	16 – 19	16 – 19

#: DWAF, 1993; *: DWAF 1996; NS: not specified.

TABLE 2.7

PHYSICAL AND CHEMICAL QUALITY (RANGE VALUES) OF THE WATER SAMPLES COLLECTED FROM THE DISTRIBUTION SYSTEM-

SEPTEMBER 2002 - JANUARY 2003

Variable	**Limit for no risk**	**Ntsela**	**Davidson**	**Victoria**	**Hillcrest**	**Fort Hare**
Fluoride (mg/l)	0-1*	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Phosphate (mg/l)	NS	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Chromate (mg/l)	0.05-1*	<0.05	<0.05	<0.05	<0.05	<0.05
Sulfate (mg/l)	0-200	28-38	27-38	23-40	23-28	24-26
Total Nitrogen (mg/l)	0-6*	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Total Hardness (mg/l)	0-50*	3-16	3-17	4-16	4-19	5-17
Copper (mg/l)	1-3*	0.01-0.1	0.02-0.1	0.02-0.1	0.01-0.1	0.01-0.07
Cadmium (mg/l)	5-10*	<0.03	<0.03	<0.03	<0.03	<0.03
Zinc (mg/l)	0-3*	0.5-1.5	0.5-1.2	0.6-2.1	0.8-1.9	0.9-1.6
COD (mg/l)	NS	<4-4.3	<4-4.2	<4-4.5	<4-4.1	<4-4.8
pH	6-9*	6.1-7.2	6.1-7.1	6.1-7.0	6.0-6.8	6.0-6.3
Temperature °C	<25 #	16-18	16-18	16-18	18-21	18-21

#: DWAF, 1993; *: DWAF 1996; NS: not specified.

The values for all the physico-chemical parameters of the water samples collected from both reservoirs from September 2002 to January 2003 were found to be within the recommended limits for potable water (Table 2.6) and lower than those found in raw water (with the exception of the pH values) . These results suggested that all the water quality parameters had no adverse health effect on the consumer according the *South African Water Quality Guidelines for Domestic Use* (DWAF, 1996).

The values for all the physico-chemical parameters of the water samples collected from both reservoirs from September 2002 to January 2003 were found to be within the recommended limits for potable water (Table 2.6) and lower than those found in raw water (with the exception of the pH values) . These results suggested that all the water quality parameters had no adverse health effect on the consumer according the *South African Water Quality Guidelines for Domestic Use* (DWAF, 1996).

Table 2.7 illustrates the general characteristic of the quality of drinking water in 5 different sites of the distribution in terms of fluoride, phosphate, chromate, sulphate, total nitrogen (nitrate and nitrite), total hardness, zinc, COD, copper, cadmium, pH and temperature. The values obtained for all these physico-chemical parameters were within the recommended limited for no risk. The results suggest that all these water quality parameters had no adverse health effects on the consumers according to the *South African Water Quality Guidelines for Domestic Use* (DWAF, 1993, 1996).

2.4 ASSESSMENT OF THE PERFORMANCE OF THE ALICE WATER TREATMENT PLANT FOR THE REMOVAL OF INDICATOR MICROORGANISMS

Basic monitoring of the raw water intake and treated water was particularly significant in the determination of the overall performance of the disinfection process from the point of treatment to the distribution system. Heterotrophic plate count (HPC) bacteria and coliforms were used as the parameters with reference to the *South African Water Quality Guidelines for Domestic Use* (DWAF, 1996). Heterotrophic plate count and coliform bacteria are currently used as bacterial indicators to define general microbial quality of drinking water and to assess general hygienic quality of water respectively (DWAF, 1996).

Faecal coliforms are used to evaluate the quality of raw water for drinking water supply. The presence of *E.coli* is used to confirm the presence of faecal pollution by warm-blooded animals (often interpreted as human faecal pollution) (DWAF, 1996).

2.4.1. Sample collection

The performance of the Alice water treatment plant for the removal of indicator microorganisms was assessed from raw water to the reservoirs (new and the old) and further in the distribution system (Ntselamanzi village, Davidson primary school, Victoria East clinic, Hillcrest primary school, and Fort Hare University). Treated water is supplied to the above five end-users by the public standpipe system. Test waters were collected twice a week from each pipe according to the standard procedures for microbiological analysis using sterile bottles, which contained sodium thiosulphate *(ca* 17.5 mg/l). Water samples were placed in ice bags and transported to the University of Fort Hare laboratory and analysis were undertaken within 2 to 4h after collection.

2.4.2. Analysis of the indicator microorganisms

The heterotrophic plate count bacteria were enumerated by standard plate procedure using R2A agar (Oxoid), incubated at 28° C for 7days (APHA, 1998). Analyses of each water sample from September 2002 to January 2003 were carried out in duplicates to confirm the results. Heterotrophic plate count bacteria were expressed in cfu/ml.

Total coliform and faecal coliform bacteria were analysed by membrane filtration technique using filters with 0.45 µm pore size and 47 mm diameter (Millipore). Different volumes ranging from 1 to 100 ml were filtered depending on the type of water used. Volumes of 1 ml and 10 ml filtered for raw (untreated) water due to observations of bacterial growth, which were *too numerous* to count when larger volumes were filtered while treated water was filtered on the volume of 100 ml. Sterile saline water was used as a diluent for the 1 ml and 10 ml volumes to spread the bacteria evenly over the filter membrane.

The membranes were placed on Chromocult coliform agar (Merck) plates and incubated for 24 h at 37° C (APHA, 1998). Analysis of each water sample was carried out in triplicates. Coliform bacteria were expressed in cfu/100 ml.

2.4.3. Test for identification of bacterial isolates

After bacterial colonies had been counted, plates were selected for the identification of different bacterial isolates. Bacterial colonies differing in size, shape and colour were randomly selected from the different plates and further isolated on MacConkey (Biolab) by the streak plate technique and incubated at 37° C for 24 h. These were further purified by the same method at least three times using nutrient agar (biolab) before Gram staining was done. Oxidase tests were then done on those colonies that were Gram-negative. The API 20E kit was used for the oxidase-negative colonies and the strips were incubated at 35° C for 24 h. The strips were then read and the final identification was done using API LABPLUS computer software (BioMérieux SA).

2.4.4. Microbiological quality of the Alice drinking water from September 2002 to January 2003

2.4.4.1 In-plant reservoirs

a. Heterotrophic plate count bacteria

The HPC bacterial counts for the raw water ranged between 9.8×10^4 cfu/ml and 1.8×10^6 cfu/ml and these counts were found throughout the study period. Although there was a decrease in HPC after disinfection as indicated by the average range counts of 2.6×10^3 cfu/ml – 3.2×10^3 cfu/ml recorded during the first five months of the study in new and old reservoirs respectively, these counts exceeded by far the limits (0 to100 cfu/ml) allowed by the *South African Water Quality Guidelines for Domestic Use* (DWAF, 1996). The month of January was marked by lower HPC bacteria in both reservoirs compared to the first four months of the study; however these counts were still higher than the limits recommended by the *South African Water Quality Guidelines* (Fig. 2.10).

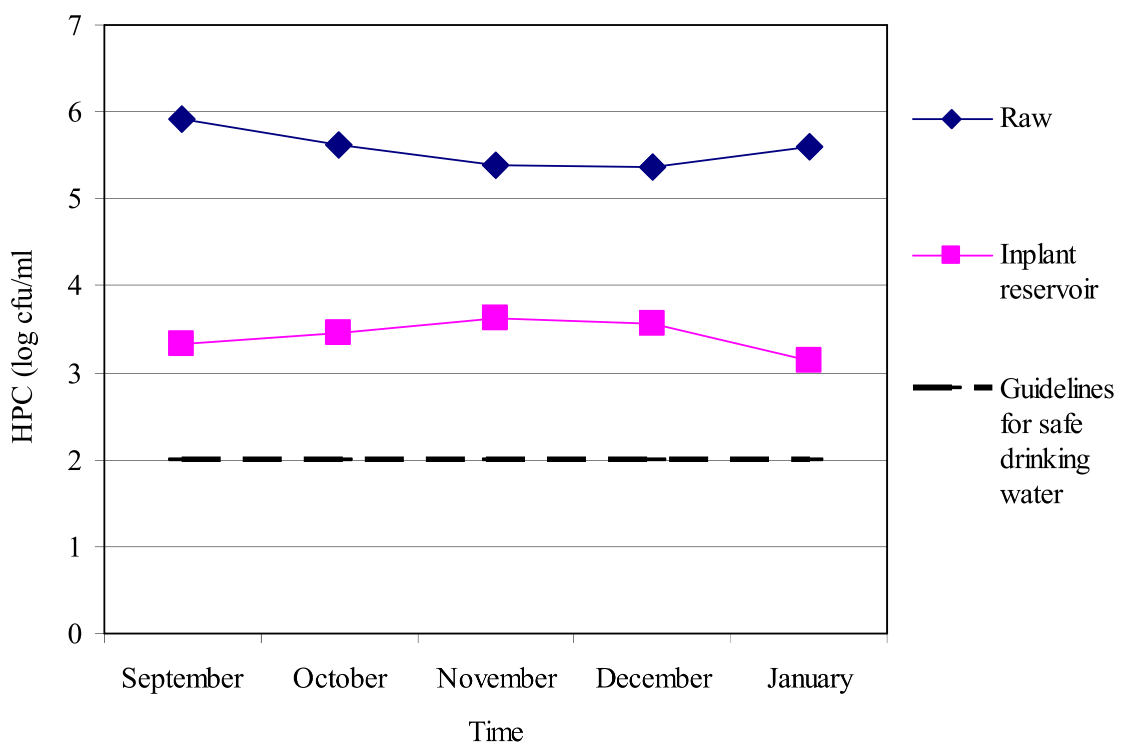

Fig. 2.10 Average counts of heterotrophic bacteria in raw water and in the in-plant reservoir (from September 2002- January 2003).

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b. Total coliforms

Total coliform bacterial counts in both reservoirs were found to be lower than those recorded in raw water. The average range values of 10 to 38 cfu/100 ml and 10 to 39 cfu/100ml were comparatively higher than the recommended limits (0-100 cfu/100 ml) of the *South African Water Quality Guidelines*. Although there was a slight improvement in the decrease of total coliform bacteria in January for both reservoirs, all these counts were above the limits (0 to 5 cfu/100ml) allowed by water industries in South Africa (Fig. 2.11).

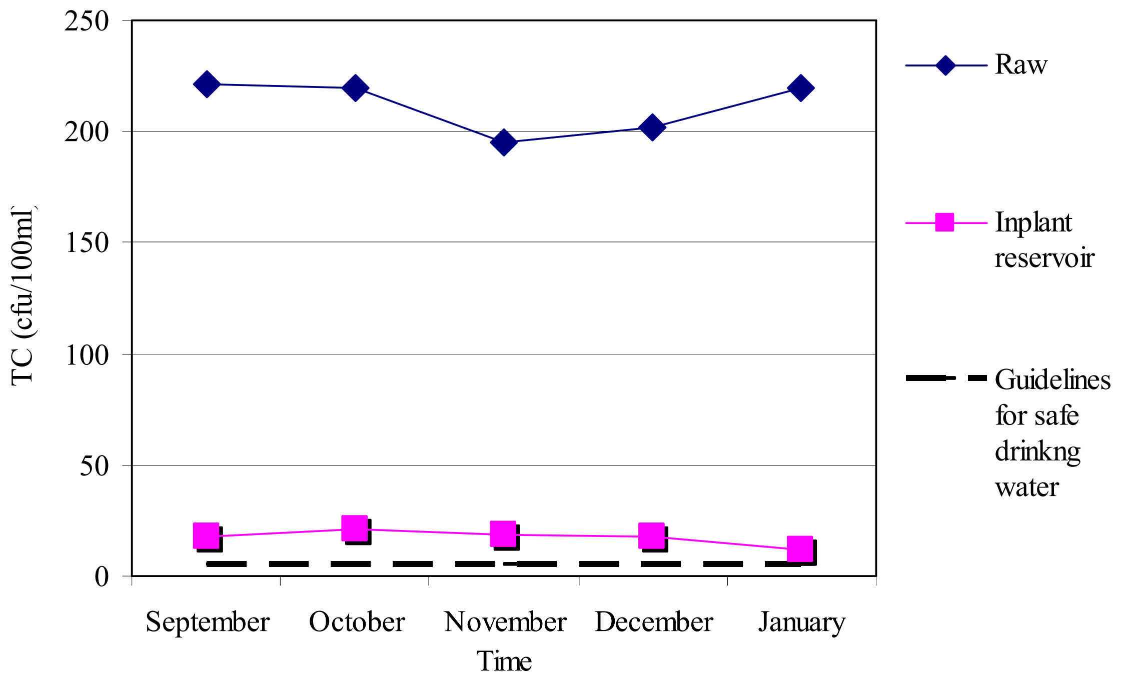

Fig. 2.11 Average total coliform (TC) bacterial counts in the raw water and in the in-plant reservoir (from September 2002- January 2003).

c. Faecal coliforms and presumptive *Salmonella*

High faecal coliform bacterial counts with a minimum of 3 cfu/100 ml and a maximum of 22 cfu/100 ml were recorded during the first five months of the study. However, the *South African Water Quality Guidelines for Domestic Use* state that there should be no faecal coliforms in treated water that is meant for drinking. This was not the case with the Alice water treatment plant; the highest coliform counts were recorded in October and November 2002 (Fig. 2.12).

The months of September, October, November and January gave evidence that both reservoirs were highly contaminated with *Salmonella* species. This was proved by the presence of presumptive *Salmonella* in average values ranging between 3 cfu/100 ml and 17 cfu/100ml. Lower coliform bacterial counts, which were between 0 and 1 cfu/100 ml, were recorded in December 2002 (Fig. 2 12).

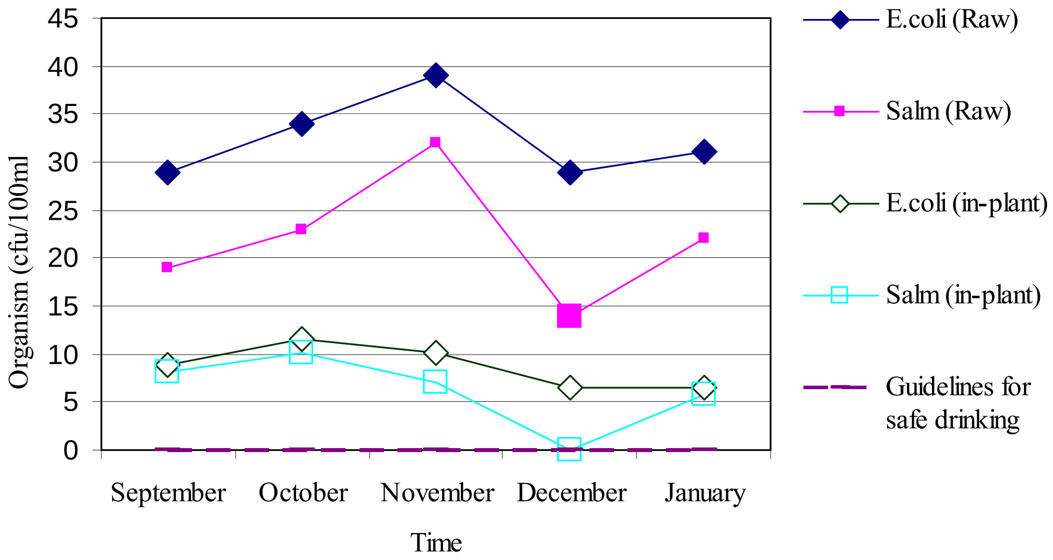

Fig. 2.12 Average counts of *E.coli* and S*almonella* spp. (cfu.100m/l) in the raw water and in the in-plant reservoir (from September 2002- January 2003).

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2.4.4.2 Distribution system

a. Heterotrophic plate count bacteria

From September 2002 to January 2003 at all sites in the distribution system (Ntselamanzi village, Davidson primary school, Victoria East clinic, Fort Hare University) high HPC bacterial counts exceeded by far the limits allowed by the *South African Water Quality Guidelines for Domestic Use*. These counts ranged between 2.2 x 10^3 and 9.6 x 10^4 cfu/ml. Throughout the study period, the furthest sites in the distribution system (Hillcrest primary school and Victoria East clinic) had the highest HPC bacterial counts compared to other sites. This was particularly evident in the month of November 2002 (Fig. 2.13).

b. Total coliforms

Total coliform counts recorded in the distribution system were much higher than the recommended limits of the *South African Water Quality Guidelines for domestic Use*. Hillcrest primary school, followed by Victoria East clinic showed the highest total coliform bacterial counts compared to other sites throughout the study period. When taking the factor time into account, the first three months (September, October and November) of the study period were marked by the highest total coliforms especially in Hillcrest primary school (Fig. 14).

c. Faecal coliforms and presumptive *Salmonella*

Average values of 3 to 41 cfu//100ml and 3 to 29 cfu/100ml were recorded for faecal coliforms and presumptive Salmonella respectively in the distribution system. Although both faecal coliforms and presumptive *Salmonella* were relatively lower in the month of December 2002, the average counts recorded (Faecal coliforms: 6 to 14 cfu/100ml, Presumptive salmonella 2-7 cfu/100ml) were still higher than the limits recommended by the *South African Water Quality Guidelines* (Figs. 2.15 and 2.16).

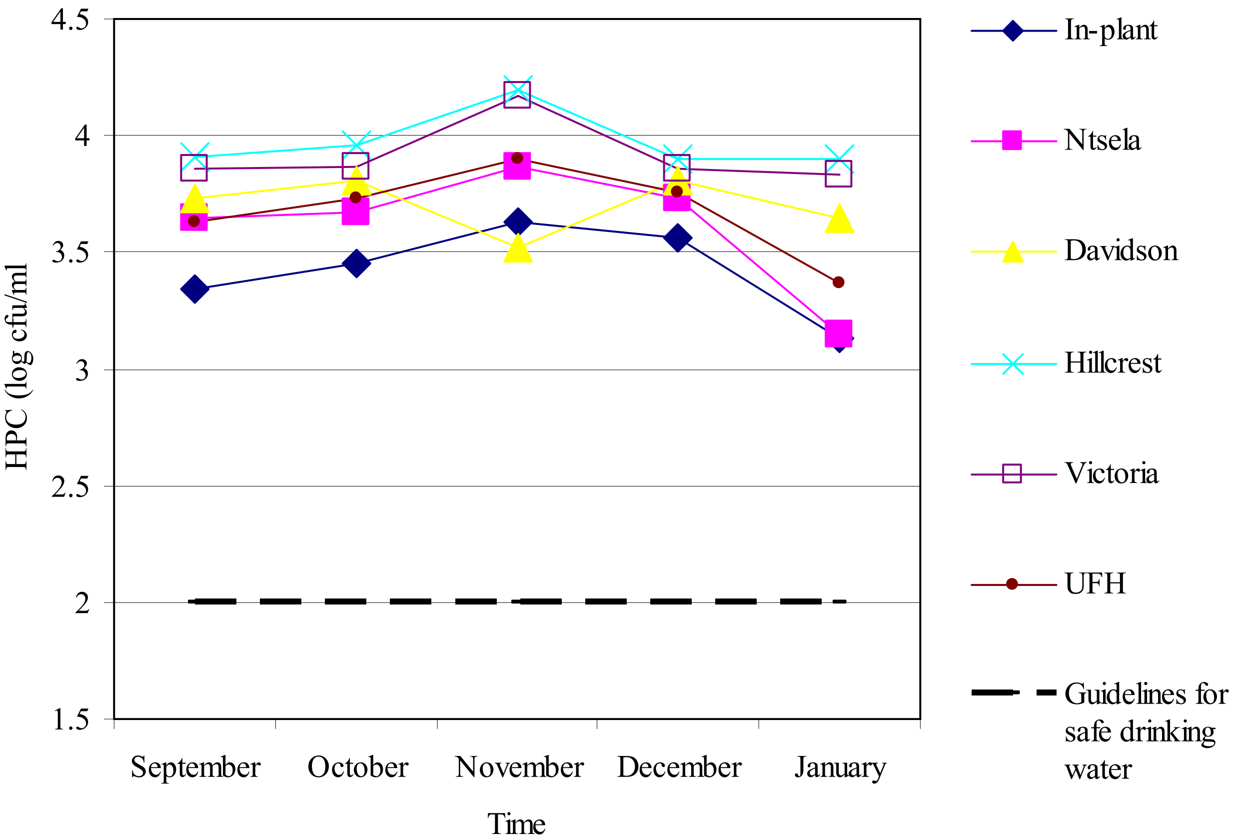


Fig. 2.13 Average counts of heterotrophic bacteria in the distribution system versus HPC in the in-plant reservoir (from September 2002 toJanuary 2003).

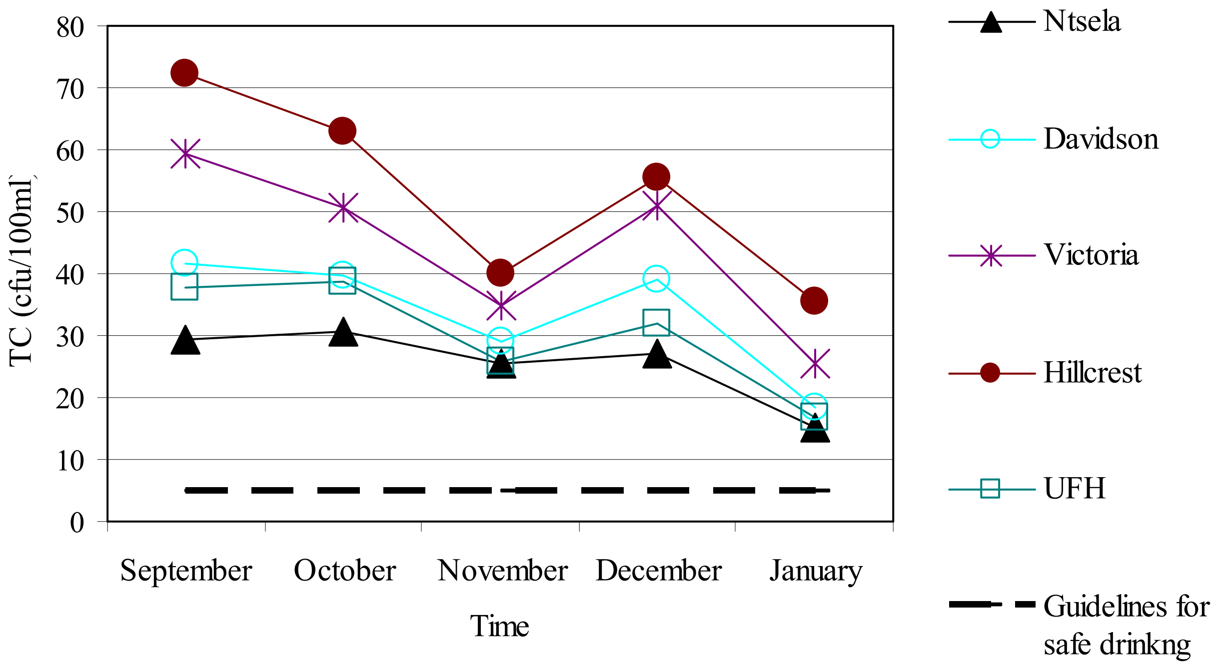


Fig. 2.14 Average total coliform (TC) bacterial counts in the distribution system (from September 2002 to January 2003).

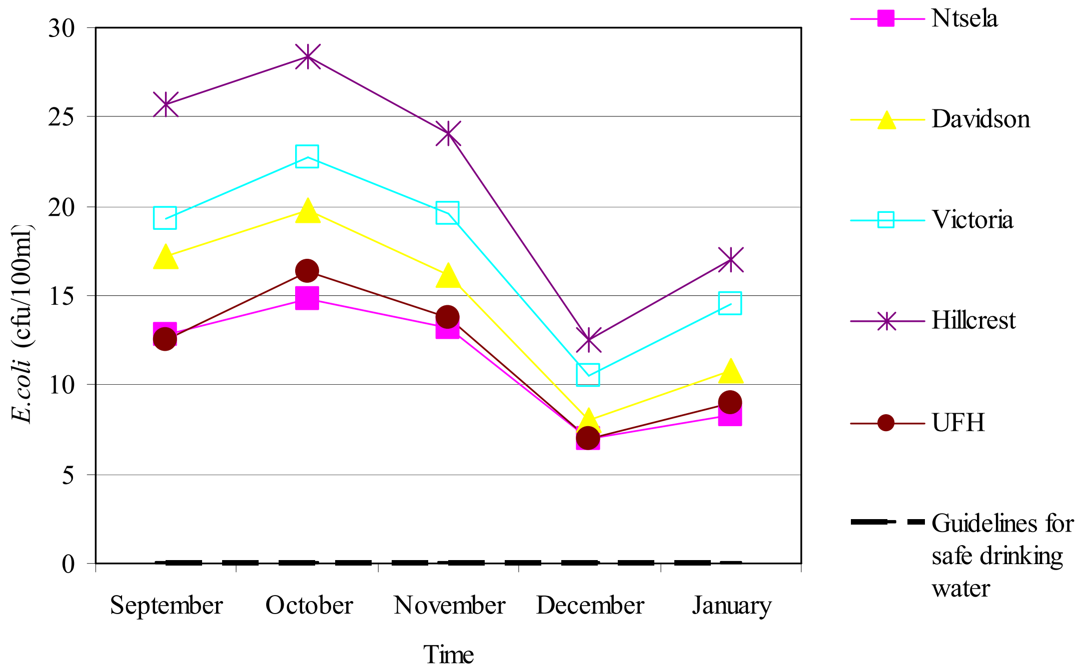
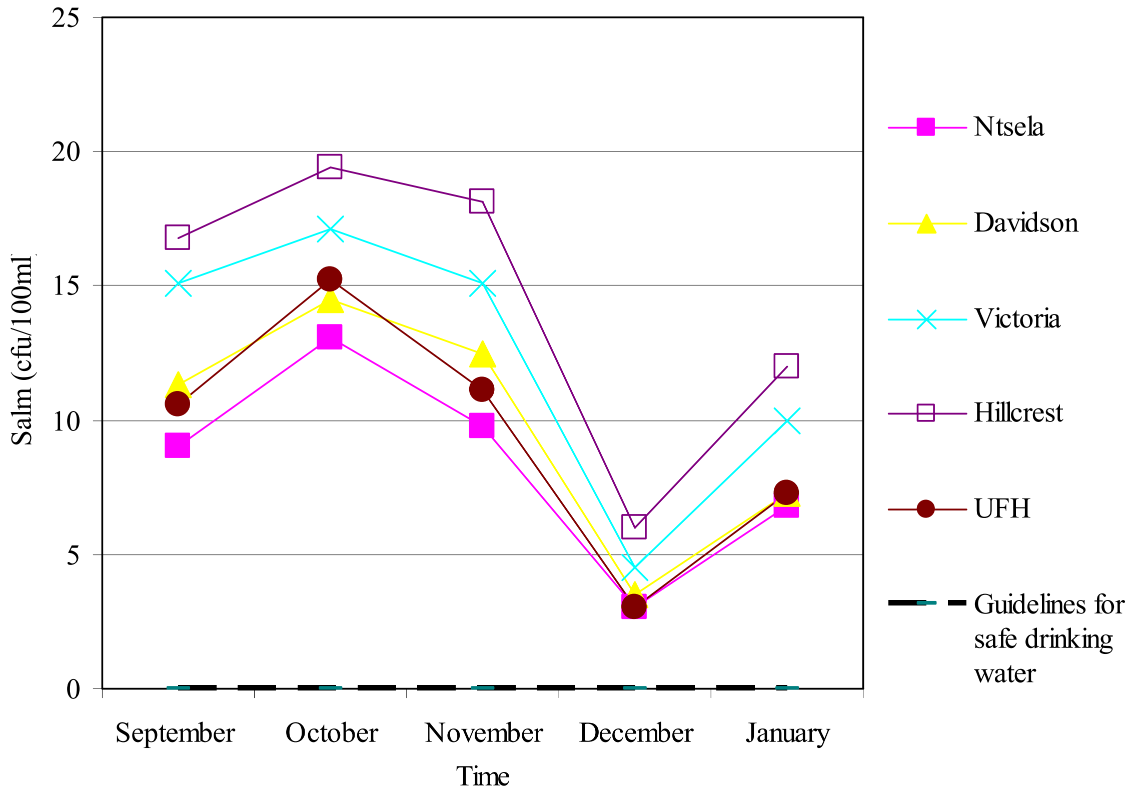


Fig. 2.15 Average *E.coli* counts (cfu.100/ml) in the distribution system (from September 2002 to January 2003).



Fig, 2.16 Average counts of *Salmonella* spp. in the distribution system (from September 2002 to January 2004)

2.4.5. Microbiological quality of the Alice drinking water in March 2003

With the exception of Hillcrest primary school and Victoria East clinic, all indicator microorganisms (HPC: 28 to 53 cfu/ml; TC: 0 to 2 cfu/ml; FC: 0 cfu/ml; 0 cfu/ml) recorded in the distribution system were within the recommended limits, however this water could not be considered safe for drinking as it was overdosed with chlorine. HPC average bacterial counts (2.4 x 10^2 to 3.5 x 10^2 cfu/100ml), TC (7 to 14 cfu/.100ml), FC (1 to 2 cfu/100ml) recorded in Hillcrest primary school and Victoria East clinic were higher than the standard limits recommended in South Africa. These can be attributed to little or absence of chlorine at these sites (Figs. 2. 17 and 2.18).

2.4.6 Coliform bacteria identified from the drinking water produced by the Alice water treatment plant

According to the API system, oxidase test and Gram staining, 14 different species (*Aeromonas hydrophila, Aeromonas caviae, Aeromonas sobria, Escherichia coli, Serratia odorifera, Serratia* *liquefaciens, Serratia marcescens, Salmonella arizonae, Pseudomonas aeruginosa*, *Pseudomonas fluorescens, Vibrio fluvialis, Chryseomonas luteola, Enterobacter aerogenus, and Enterobacter*

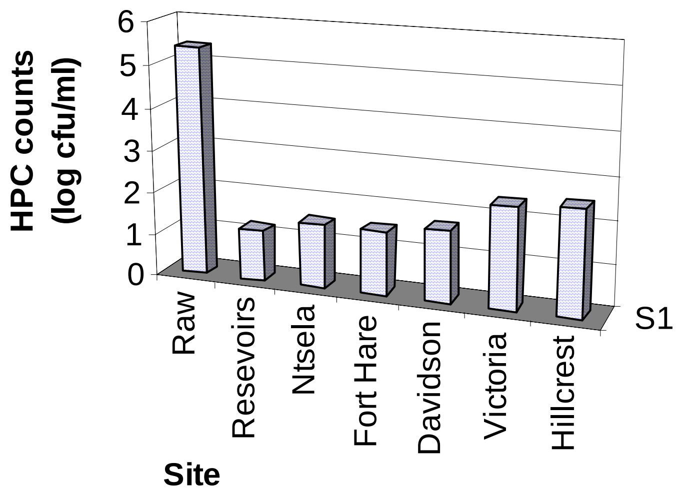


Fig.2.17 Average HPC (log cfu/ml) in the raw water, in-plant reservoirs and in the distribution System during the month of March 2003

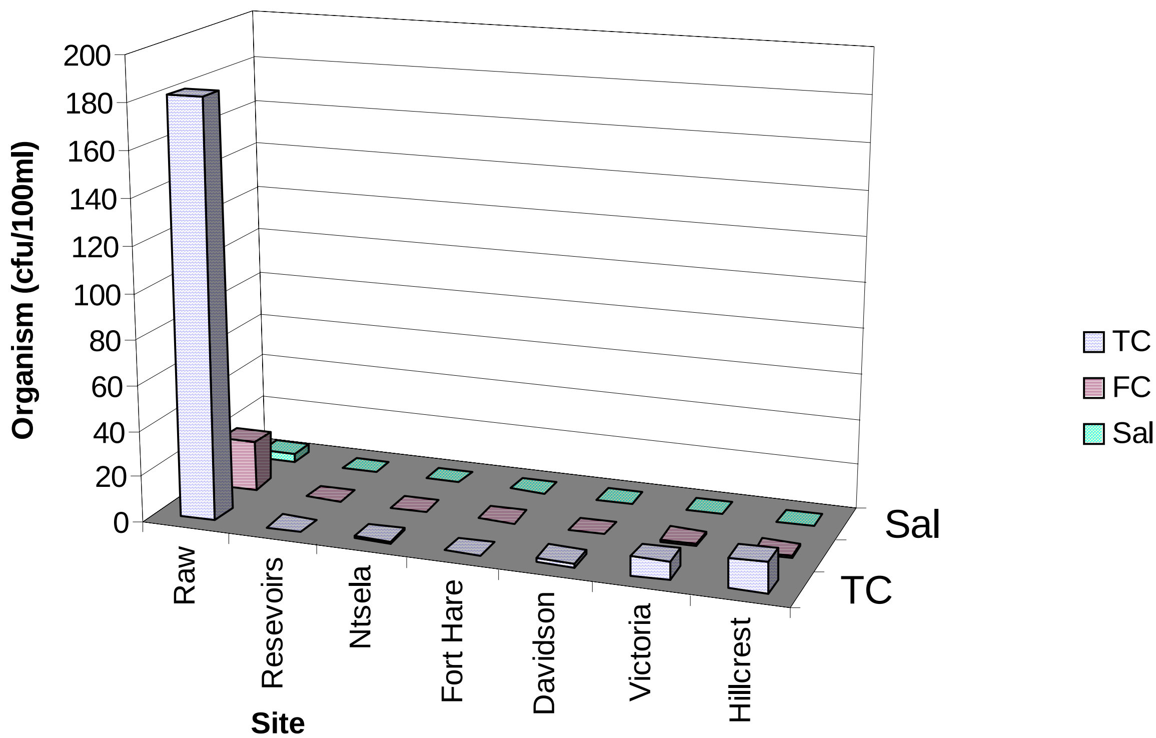


Fig. 2.18 Average total coliforms, faecal coliforms and presumptive Salmonella (cfu/100ml) species in the raw water, in-plant reservoirs and in the distribution system during the month of March 2003.

TABLE 2.8

COLIFORM ISOLATES IDENTIFIED FROM THE WATER SAMPLES ANALYSED – From September 2002 to January 2003

Site	Bacterial isolates identified
A	*Aeromonas hydrophila, Aeromonas caviae, Aeromonas sobria, Escherichia coli, Serratia odorifera, Serratia liquefaciens, Serratia marcescens, Salmonella arizonae, Pseudomonas aeruginosa*, *Pseudomonas fluorescens, Vibrio fluvialis, Chryseomonas luteola, Enterobacter aerogenus, Enterobacter sakazakii,*
B	*Aeromonas hydrophila, Escherichia coli, Serratia odorifera, Serratia liquefaciens, Serratia marcescens,, Pseudomonas aeruginosa*, *Pseudomonas fluorescens, Salmonella arizonae*
C	*Aeromonas hydrophila, Escherichia coli, Serratia odorifera, Salmonella arizonae Serratia liquefaciens, Serratia marcescens, Peseudomonas aeruginosa*, *Pseudomonas fluorescens*
D	*Aeromonas hydrophila, Escherichia coli, Serratia odorifera, Serratia liquefaciens, Serratia marcescens, Salmonella arizonae, Pseudomonas aeruginosa*, *Pseudomonas fluorescens, Salmonella arizonae*
E	*Aeromonas hydrophila, Escherichia coli, Enterobacter cloacae Serratia odorifera, Serratia liquefaciens, Serratia marcescens, Salmonella arizonae, Pseudomonas aeruginosa*, *Pseudomonas fluorescens*
F	*Aeromonas hydrophila, Escherichia coli, Serratia odorifera, Serratia liquefaciens, Serratia marcescens, Salmonella arizonae, Pseudomonas aeruginosa*, *Pseudomonas fluorescens*
G	*Aeromonas hydrophila, Escherichia coli, Serratia odorifera, Serratia liquefaciens, Serratia marcescens, Salmonella arizonae, Pseudomonas aeruginosa*, *Pseudomonas Fluorescens, Vibrio fluvialis*
H	*Aeromonas hydrophila, Escherichia coli, Serratia odorifera, Serratia liquefaciens, Serratia marcescens, Salmonella arizonae, Pseudomonas aeruginosa*, *Pseudomonas fluorescens*

A: Raw water **B:** New Reservoir **C:** Old Reservoir **D:** Ntselamanzi tap **E:** Davidson tap **F:** Hillcrest tap **G:** Victoria East Clinic tap **H:** Fort Hare tap *sakazakii)* were found in the raw water. Among them, 8 species (*Aeromonas hydrophila, Escherichia coli, Serratia odorifera, Serratia liquefaciens, Serratia marcescens, Salmonella arizonae, Pseudomonas aeruginosa*, *Pseudomonas fluorescens*), were still prevalent in the reservoirs and in all the end user stand pipes (Table 2.8). It is also important to note that *Vibrio* species, which are enteric pathogens in humans, were found in Hillcrest primary school and Victoria East clinic standpipes. These enteric bacteria are reportedly causative agents of various diseases and their complications (Bourne and Coetzee, 1996).

2.5 CONCLUSIONS FROM PHASE I AND RECOMMENDATIONS TO NKONKOBE MUNICIPALITY

The first phase of the investigation revealed that the Alice water treatment plant's major operating problems include: 1) no flow measurement, 2) no turbidity or pH measurement and no record of chlorine residual, 3) poor coagulant dosing control resulting in inadequate turbidity removal in the clarifiers and filters; and 4) the lack of a proper chlorine dosing procedure or monitoring programme. Due to inadequate pre-treatment and insufficient chlorine residuals, Alice treated water did not meet the minimum limits for potable water. The conclusions and recommendations arising from the first phase of the study were presented to the Nkonkobe Local Municipal Water Authority. The Nkonkobe Municipality was informed that although the AWTP was not operating effectively, it had great potential for improvement. This could be achieved easily with minimum cost if the plant had better trained personnel. The following was strongly recommended:

(i) Training of the plant operators

(ii) Plant flow rate - The existing non-functional raw water flow meter should be repaired or replaced and the flow rate measurement be done without fail,

(iii) Coagulant dose rate - The treatment plant should acquire jar stirrer apparatus to determine the optimum alum and lime doses. The doses should be adjusted appropriately when the raw water flow was changed. This would reduce their coagulant costs by up to 75 %.

(iv) pH measurement - The operators should monitor pH at various points in the plant for coagulation control .

(v) Turbidity measurement - The turbidity of the raw, settled, filtered and final water should be monitored

(vi) Filtration - The operators should aim for filtrate turbidity of < 1NTU since high turbidities exert high disinfectant demand, and particles may shield microorganisms from disinfectants. Times of filter backwashes should be recorded to ensure the filters were functioning correctly.

(vii) Chlorine measurement - The chlorine dose has to be applied proportionally to the plant flow rate. To ensure effective disinfection, measurement of the chlorine demand of water was highly recommended.

(viii) Monitoring programme -A programme for monitoring the bacterial quality of water at the point of treatment and various sites of the distribution systems should be established.

Detailed guidelines on implementing these recommendations are presented in chapter 4 while chapter 3 focuses on the strategies to ensure safe drinking water from the point of treatment to the point of comsumption.

CHAPTER 3
PHASE 2: ANALYSIS OF THE ALICE WATER DISTRIBUTION SYSTEM AND OPERATOR TRAINING

The second phase of the project (April 2003-February 2004) concentrated on three issues/activities:

i) Firstly establishing the relationship between the performance of the plant chlorine dosing system and the water quality in the bulk distribution system. Booster chlorination and lowering the operating levels of the treated water reservoirs were considered to ensure adequate chlorine residual is maintained throughout the distribution system.

ii) Secondly investigating the performance of the plant for the removal of dissolved organic carbon and assessing the impact of biodegradable dissolved organic carbon on the bacterial regrowth in the finished water.

iii) Thirdly transferring knowledge and skills to the operators and the Municipality staff to ensure that the improvement in the operation of the plant can be sustained in the future.

3. 1 OPERATION PHASE 2

3.1.1 Establishing the relationship between the plant dosing system and the water quality in the distribution system

The quality of water reaching consumers depends not only on operating conditions at the treatment plant but also on changes in the distribution system. Water of the highest quality may be leaving the plant but its condition deteriorates to some extent before it reaches the consumer. In particular, the chlorine residual always decays. Given sufficient time, the chlorine residual will decrease to zero. Factors, which accelerate decay, include high finished water turbidity, old pipes, biofilm growth and sludge accumulation in the storage reservoirs. In extreme cases, dangerous re-contamination of the finished water can occur.

3.1.1.1 Description of the Alice distribution system

Figure 1 shows a schematic diagram of the Alice distribution system developed by the research team with assistance from the municipality's plumbing superintendent.

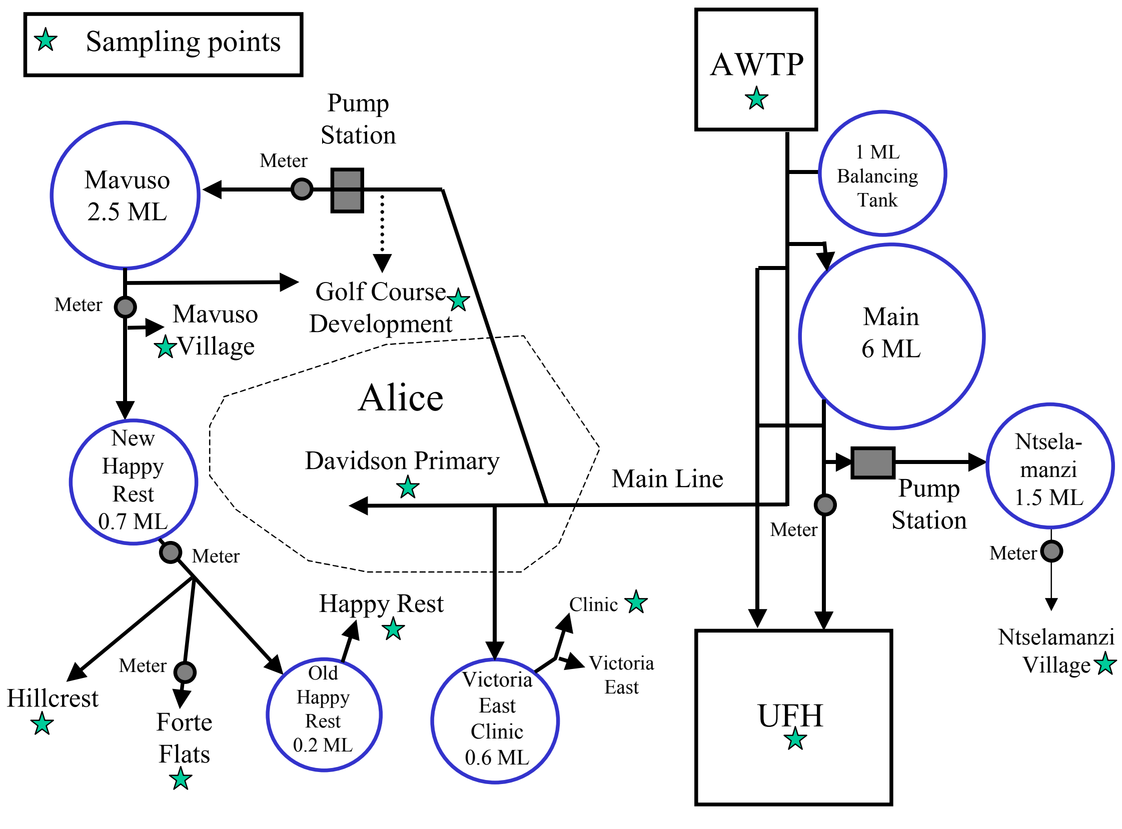


Fig.3.1. Schematic diagram of the Alice distribution system

Five of the town's seven reservoirs, including the main reservoir fill under gravity. Float valves regulate the flows into the reservoirs and they operate at essentially 100 % capacity under normal conditions. Flow to Ntselamanzi and Mavuso reservoir is augmented by pumping which is initiated automatically based on the signals from level sensors in their reservoirs. Before October 2003, the Golf Course housing development was supplied from the line to the Mavuso pumping station. From October, it was supplied from the Mavuso Reservoir itself, resulting in a large increase in flow through the reservoir and a reduction in its hydraulic retention time.

3.1.1.2 Calculation of the flow rates and retention times in different reservoirs

The hydraulic retention time of a reservoir is by definition

$$\theta = \frac{V}{Q}$$

Where, θ is the average hydraulic retention time (d),

Q is the flow through the reservoir (m^3/d) and

V is the reservoir volume (m^3).

In a real reservoir, there is always a certain amount of mixing of the influent with water that has been there for some time. As result, some of the flow remains in the reservoir for both longer and shorter times than the average retention time. Consequently, there is a gradual response to any change in influent concentrations, which in this case, is a gradual response to a change in dose at the treatment plant.

a. Metered flow rates

Table 3.1 illustrates the metered flow rates measured during the study. The measured flows during the chlorine step test in June are compared with the average flow determined for June to November 2003. The average flow rates for June to September and October to November were calculated separately for the Mavuso Pump Station, Mavuso Reservoir and New Happy Rest Reservoir meters, because it was evident that there was a substantial increase in flow pumped to Mavuso from the beginning of October 2003.

Ntselamanzi Reservoir Outlet

The calculated average flow rates for the chlorine step test in June and for June to November agreed within 10 %. The higher flow for June to November was consistent with an increase in demand in the warmer months.

Metered Fort Hare Line

The value given in Table 3.1 was an instantaneous flow rate measured in June 2003. In November, the total volume recorded on the meter was less than in June suggesting that the meter had been changed.

Mavuso Pump Station

Three average flow rates are shown in Table 3.1. During the chlorine step test, the Mavuso pumps were not operated for at least 7 of the 12 days of the test and the reservoir drained down by an estimated 700 m^3. Therefore, the figure of 0.235 ML/d calculated for 23 June to 23 September provided a better estimate of the average flow into the reservoir before the Golf Course Line was opened. There was a more than four fold increase in flow pumped to the reservoir between the 23 September and 16 October and it was assumed that the Golf Course Line was opened during this period.

<table>
<tr><th colspan="3">TABLE 3.1
ESTIMATED METERED FLOW RATES MEASURED DURING
THE CHLORINE STEP TEST IN 2003</th></tr>
<tr><th>Metered Line</th><th>Period</th><th>Average flow, Ml/d</th></tr>
<tr><td>Raw water</td><td>6 – 17 November</td><td>3.928</td></tr>
<tr><td rowspan="2">Ntselamanzi Reservoir Outlet</td><td>12 - 16 June
(Chlorine step test)</td><td>0.601</td></tr>
<tr><td>12 June – 21 November</td><td>0.660</td></tr>
<tr><td>Metered Fort Hare Line</td><td>16 June</td><td>1.763</td></tr>
<tr><td rowspan="3">Mavuso Pump Station</td><td>12 - 23 June
(Chlorine step test)</td><td>0.149</td></tr>
<tr><td>23 June – 23 September</td><td>0.235</td></tr>
<tr><td>16 October - 21 November</td><td>1.056</td></tr>
<tr><td rowspan="3">Mavuso Reservoir Meter - outflow to New Happy Rest, Mavuso Village and Sheshugu Village</td><td>12 - 23 June
(Chlorine step test)</td><td>0.196</td></tr>
<tr><td>23 June – 23 September</td><td>0.202</td></tr>
<tr><td>16 October - 21 November</td><td>0.230</td></tr>
<tr><td rowspan="3">New Happy Rest Outlet - Happy Rest, Fort Hare Flats and Hillcrest</td><td>12 - 23 June
(chlorine step test)</td><td>0.111</td></tr>
<tr><td>23 June – 23 September</td><td>0.117</td></tr>
<tr><td>16 October – 21 November</td><td>0.160</td></tr>
<tr><td rowspan="2">Fort Hare Flats</td><td>17 - 23 June
(Chlorine step test)</td><td>0.0039</td></tr>
<tr><td>23 June – 21 November</td><td>0.0046</td></tr>
<tr><td rowspan="2">Victoria Clinic Meter</td><td>14 - 23 June
(Chlorine step test)</td><td>0.0009</td></tr>
<tr><td>23 June – 21 November</td><td>0.0131</td></tr>
</table>

b. Calculation of the retention times

Main Reservoir

Table 3.2 illustrates the calculation of the estimated retention time of the Main Reservoir. The only available measurement of the flow in the metered Fort Hare line was the instantaneous measurement made on 16 June and this value was used for both the estimates presented. The estimated retention time was the same for the chlorine step test and during the period June to November 2003. This was not unexpected since the flow in the Fort Hare line was the largest part of the estimated flow. The estimated retention time based on flow was consistent with the response to the chlorine step, allowing for some dispersion.

Ntselamanzi Reservoir

The operating level and volume of Ntselamanzi Reservoir appeared to vary substantially, therefore average retention times in Table 3.3 were calculated for the reservoir 50, 75 and 100 % full based on the Ntselamnazi meter flowrates listed in Table 3.1

Mavuso Reservoir

Table 3.4 shows the results for Mavuso Reservoir. The retention times during the step test were based on the outflow measured at the Mavuso Reservoir meter since there were several days of no pumping during this period. However, the results for June to September and October to November were calculated based on the meter at the pump station.

The chlorine step test results were difficult to extrapolate because there had been no pumping for several days when the test started and then suddenly a large amount of chlorinated water was added to the partially emptied reservoir in a short period of time. The estimated retention times before October 2003 were extremely large (> 14 d at 100 % capacity).

Once the Golf Course Line was opened, the retention time dropped to less than that for Main Reservoir. Since Mavuso pump station draws water from the main Alice line, which bypasses the Main Reservoir, this means that the response time for a change in chlorine dose in areas drawing directly from Mavuso reservoir should now be less than Ntselamanzi Reservoir.

New Happy Rest reservoir

New Happy Rest Reservoir operates at 100 % full at all times and the total outlet flow was metered so the retention time was simply calculated as the measured capacity divided by the metered outflow.

The retention time was quite large (Table 3.5). When added to the retention time of the Mavuso Reservoir, the total retention added up to around 10 days. However, the chlorine and microbial data for October suggest that an adequate residual could still be maintained. Lowering the reservoir level would help.

TABLE 3.2
ESTIMATED RETENTION TIMES FOR THE IN-PLANT MAIN RESERVOIR IN 2003

Period	Assumptions	Retention time, d	Response to Step Test
12 - 16 June 2003 (chlorine step test)	Outflow = flow pumped to Ntselamanzi + Fort Hare Line	2.5	First appearance < 20h ,based on Fort Hare residence. Levelling off : ~45 h
16 June – 21 November 2003		2.5	

TABLE 3.3
ESTIMATED RETENTION TIMES FOR NTSELAMANZI RESERVOIR IN 2003

Period	Assumptions	Retention time, d	Response to Step Test
12 - 16 June 2003 (chlorine step test)	50 % full, based on outflow	1.3	First appearance < 23 h, based on SW standpipe. Leveling off > 72 h. Reservoir was operating between 53 and 78 % full
	75 % full, based on outflow	2.0	
	100 % full, based on outflow	2.5	
16 June – 21 November 2003	50 % full, based on outflow	1.1	
	75 % full, based on outflow	2.0	
	100 % full, based on outflow	2.3	

TABLE 3.4

ESTIMATED RETENTION TIMES FOR MAVUSO RESERVOIR IN 2003

Period	Assumptions	Retention time, d	Response to Step Test
12 – 23 June 2003 (chlorine step test)	50 % full, based on outflow	6.4	First response 19 h after pumping resumed, but no pumping for at least 100 h before that
	75 % full, based on outflow	9.6	
	100 % full, based on outflow	13.0	
23 June – 23 September 2003	50 % full, based on inflow	5.3	
	75 % full, based on inflow	8.0	
	100 % full, based on inflow	10.6	
16 October – 21 November 2003	50 % full, based on inflow	1.2	
	75 % full, based on inflow	2	
	100 % full, based on inflow	2.4	

TABLE 3.5

ESTIMATED RETENTION TIMES FOR NEW HAPPY REST RESERVOIR IN 2003

Period	Assumptions	Retention time, d	Response to Step Test
12 - 23 June 2003 (chlorine step test)	100 % full, based on outflow	6.3	Response about the same time as Mavuso Village, but all residuals after Mavuso < 0.1 mg/l
23 June – 23 September 2003		6.3	
16 October – 21 November 2003		6.0	

Flow split between Hillcrest and Happy Rest

To estimate the retention time of Old Happy Rest Reservoir, it was important to know the flow to this reservoir. The flow to Fort Hare Flats, therefore, could be subtracted from that of the New Happy Rest meter. Unfortunately, there were no meters to indicate the flow split between the Hillcrest Reservoir and the Old Happy Rest Reservoir.

Based on the predicted demands in various parts of the Alice Dstribution System presented in a 1998 report by Hawkins, Hawkins and Osborn, it was estimated that 85 % of the flow excluding Fort Hare Flats should be going to Happy Rest. This was based on 1991 census figures and DWAF guidelines, which assumed a higher per capita demand in the more affluent neighbourhoods Happy Rest. Given that the census data was at least 12 y old, the figure obtained should be considered a very rough estimate (Fig. 3.6). The calculations of the flow through Old Happy Rest Reservoir are summarised in Table 3.7.

TABLE 3.6
CALCULATED FLOW SPLIT BETWEEN HAPPY REST AND HILLCREST RESERVOIR IN 2003

Calculated flow	Period	Average flow, ML/d
New Happy Rest – Forte Flats	12 - 23 June 2003 (chlorine step test)	0.107
	23 June – 23 September 2003	0.112
	16 October - 21 November 2003	0.159
Flow to Old Happy Rest = 85 % of (New Happy Rest – Forte Flats)	12 - 23 June 2003 (chlorine step test)	0.091
	23 June – 23 September 2003	0.095
	16 October – 21 November 2003	0.135

Old Happy Rest Reservoir

Old Happy Rest operates 100 % full. The average retention time was calculated based on the reservoir capacity and the estimated flow rates from Table 3.6. If the estimated flow was correct then Old Happy Rest Reservoir was not adding an excessive amount of retention time to the water delivered to Happy Rest consumers. This was consistent with Fig.e 3.6 which shows very similar residuals at Fort Hare Flats, Happy Rest and Hillcrest consumers.

TABLE3.7
ESTIMATED RETENTION TIMES FOR OLD HAPPY REST RESERVOIR IN 2003

Period	Assumptions	Retention time, d	Response to Step Test
12 – 23 June 2003 (chlorine step test)	100% full, based on estimated flow to Happy Rest	2.2	Response about the same time as Mavuso Village
23 June – 23 September 2003		2.1	
16 October – 21 November 2003		1.5	

Victoria East Clinic Reservoir

The Victoria East Reservoir supplies Victoria East Clinic and its vicinity. The flow to the clinic is metered but as far as the project team was aware, neither the inflow nor the total outflow of the reservoir was metered. During June 2003, the inlet of the reservoir was shut off for a week before the chlorine step test and the project team was able to estimate the flow out of the reservoir during that week from the drop in level. An average flow of 0.032 Ml/d was estimated corresponding to a retention time of 22 days. This was by far the highest retention time in the system and was consistent with the very low residual chlorine concentration s observed at the clinic. However, this is probably also one of the oldest parts of the system and old pipes may also be contributing to low residual chlorine concentrations. It was also not clear that the calculated flow was typical of normal operation of the reservoir since during the investigations, it appeared that the clinic used substantially less water than usual (Table 3.8). The reservoir should probably be operated at half or less of its current capacity, but before making changes, it would be advisable to obtain more data on its operation under normal circumstances. The average flow could be obtained by requesting that the plumbers shut off the reservoir inlet for a few days and measuring the drop in level each day. It would also be helpful to obtain chlorine residual data for a period of at least 2 weeks but preferably 3 weeks when there has been no interruption in chlorine dose. Table 3.8 summarizes the estimated retention times in different reservoirs from the point of treatment to the distribution system.

TABLE 3.8
ESTIMATED AVERAGE RETENTION TIMES IN DIFFERENT RESERVOIRS IN THE ALICE DISTRIBUTION SYSTEM

Reservoir	Estimated Retention time (d)	Assumption
Main reservoir	1.9	Outflow = flow pumped to Ntselamanzi + Fort Hare Line
Ntselamanzi	2.5	100 % full, based on outflow
Mavuso – before October 2003	12.8	100 % full, based on outflow
Mavuso – after October 2003	2.5	100 % full, based on outflow
New Happy Rest	6.3	100 % full, based on outflow
Old Happy Rest reservoir	2.2	100% full, based on estimated flow to Happy Rest
Victoria East clinic	22	Based on drop in level in one week when influent shut off

The system of storage reservoirs in Alice was obviously designed with future demand in mind and provides much more storage capacity than is currently required. This has a negative impact on the water quality particularly in those areas supplied by the New Happy Rest Reservoirs, the Old Happy Rest Reservoir and for the Victoria East Reservoir. Preliminary water quality monitoring results indicated that these areas always had low to negligible chlorine residuals and poor bacteriological quality whereas the water quality supplied to consumers at Fort Hare, Ntselamanzi village and Davidson Primary School (drawing from the Main Alice supply line) was more dependent on the performance of the plant.

Two possible options for improving the situation were considered: i) temporarily lowering the reservoir operating levels to reduce the retention time; ii) installing booster chlorination in the reservoirs with the lowest chlorine residuals.

3.1.1.3 Chlorine tracer experiment

In order to determine the optimum strategy for improving the chlorine residuals, a chlorine tracer experiment was carried out in June 2003. This led to a determination of the response at various points in the distribution system to a step increase in the chlorine dose at the plant. The rationale behind this experiment was that low chlorine residuals and poor microbial quality found in treated water samples in Alice could be partly due to long retention times in some parts of the system. Since no other tracer was readily available, it was decided to step up the chlorine dose for a finite period and monitor the impact of the dose increase at various points in the distribution system. The sampling points are indicated on Fig. 3.1.

The chlorine dose at the point of treatment was stepped from 800 to 900 g/h chlorine at midday on Friday 13th June and stepped down to 550 g/h. The start of the experiment coincided with the restoration of chlorine dosing at the plant after several days during which the chlorination system had been non-functional. Consequently, chlorine residuals were low or absent throughout the distribution system. The residual in the in-plant reservoir was maintained at between 1 and 2 mg/L free chlorine, depending on the plant flowrate for the first four days.

Figure 3.2 shows the concentrations of free chlorine residual in water samples taken at the plant by the operators from the end of March 2003. The concentrations of the free chlorine residual in water samples taken from the new reservoir by the project team are also shown. The results revealed that there were evidently problems with the chlorine dosing around the 10th June with the dosing pump working sporadically. The operators had been adding HTH to the New Reservoir to compensate, but the doses were apparently inadequate.

Sampling was carried out from 13th to 23rd June. However, the bulk of the sampling was undertaken from 13th to 18th June, which included a long weekend (14th to 16th June). This may have had some impact on the results. For example, no water was pumped to Mavuso Reservoir between 12th and 17th June. Demand may also have dropped over the weekend. As a result of decreases in plant flowrates, the step down in chlorine flow on Saturday 14th June did not have a dramatic effect on the actual chlorine dose. This is shown in Figure 3.3.

The experiment was carried out in June 2003 before the line from Mavuso Reservoir to Golf Course housing development was opened (Fig. 3.4). Residuals of greater than 1 mg/l were recorded at University of Fort Hare, Davidson Primary School and Golf Course within 24 h of the resumption of chlorine dosing. This confirms that treatment plant performance is the primary factor determining water quality in these areas. A more gradual increase in chlorine residual was recorded between 20 and 72 h at Ntselamanzi with a residual of greater than 1 mg/L being achieved at the end of the period (Fig.3.4). This is consistent with the combined average retention times estimated for the Main and Ntselamanzi Reservoirs (Table. 3.1). It was also evident that the impact of storage time on water quality in this area was small and that the poor quality must be directly related to the performance of the plant.

The results for areas supplied by Victoria East Reservoir (Fig. 3.5) and Mavuso Reservoirs (Fig. 3.6) were less conclusive because there had been no flow into the former for a week before the test started and no pumping into the latter for the first four days of the experiment. This resulted in a sudden influx of a large volume of chlorinated water when the flow into the reservoirs resumed. However, the chlorine dosing failed again before the effect of the higher chlorine dose on water quality at Happy Rest, Hillcrest and Fort Hare Flats could be determined (Fig. 3.6). Consequently the concentrations of the chlorine residuals measured from these sites of the distribution system were always less than 0.1 mg/l. It is probably not possible to detect any significant trends at this level but there appeared to be some correlation between concentrations measured at Hillcrest Reservoir, Happy Rest Reservoir and Mavuso dispensing point No. 3.

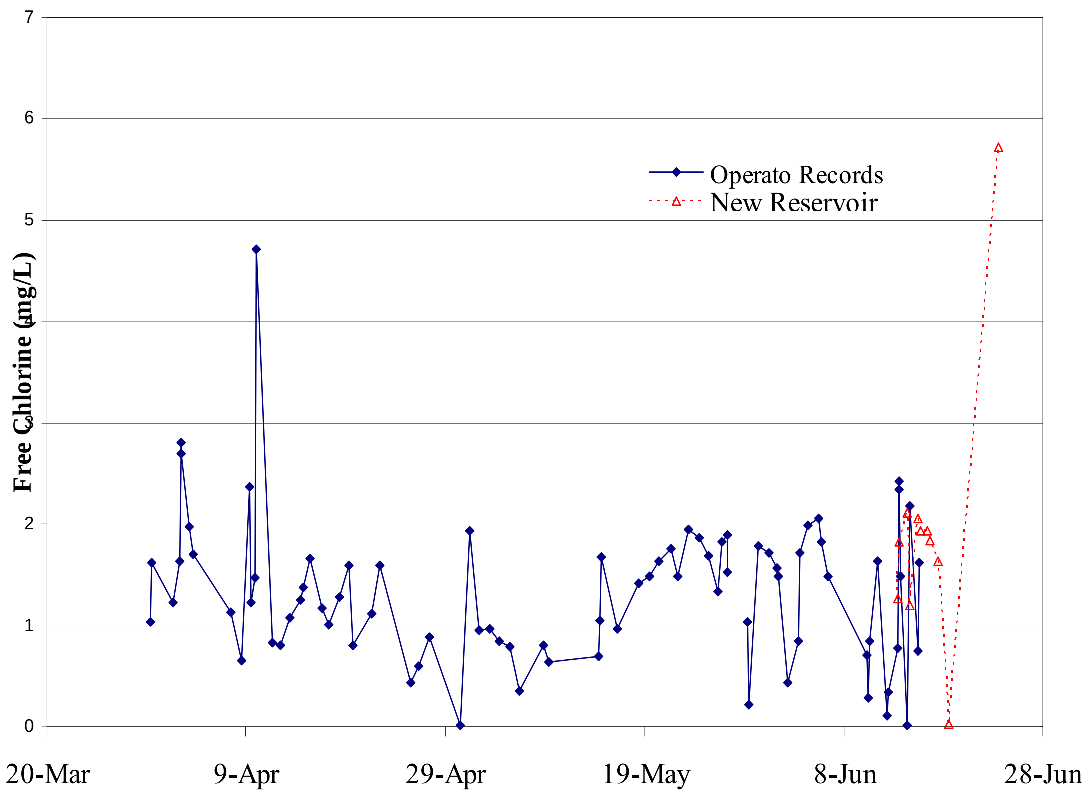


Fig. 3.2 Chlorine residuals measured at Alice water treatment plant in 2003

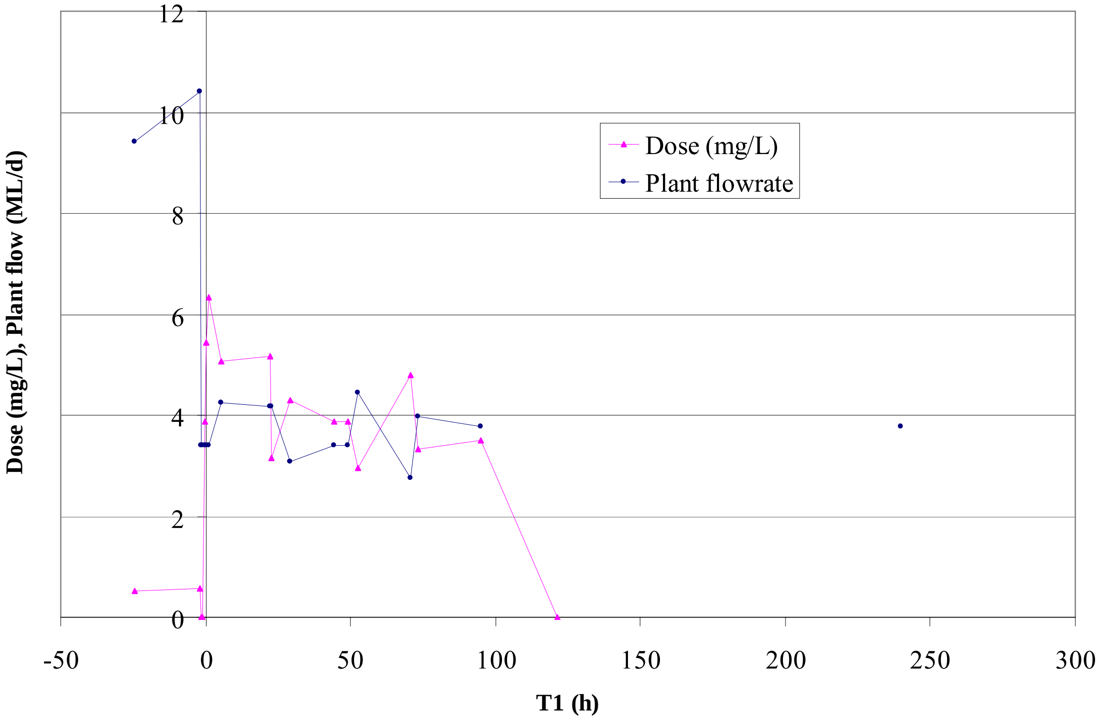


Fig. 3.3 Plant flow rate and chlorine dose (T1 is the time elapsed from the start of the experiment).

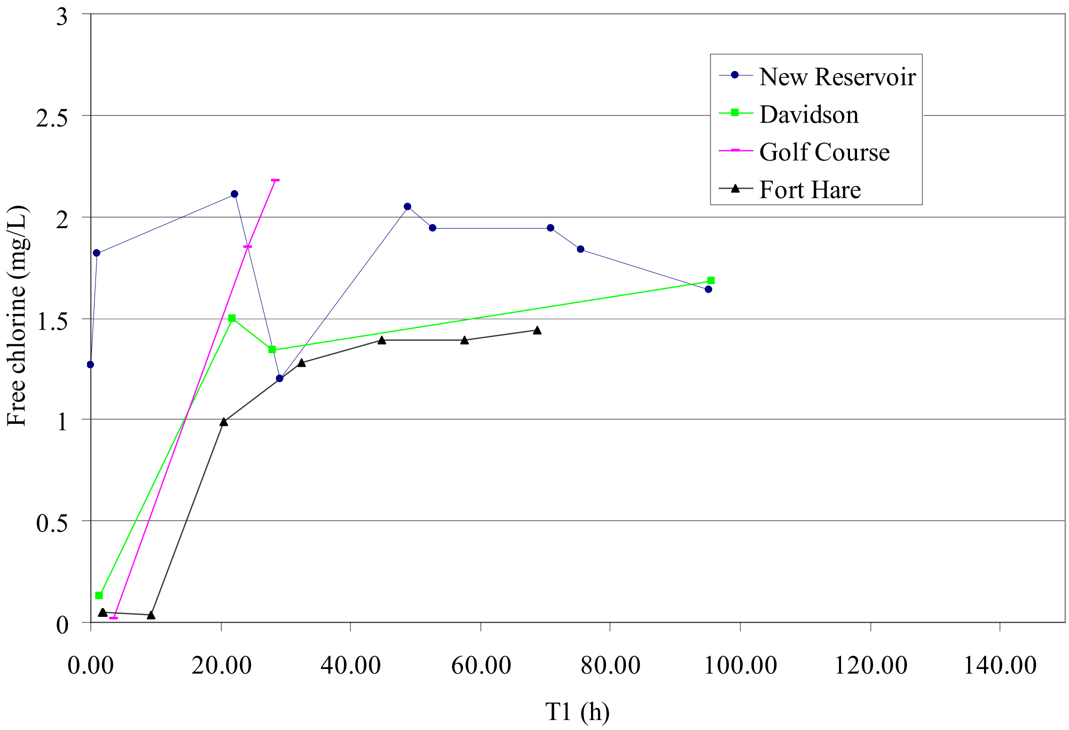


Fig. 3.4 Chlorine residuals measured at Davidson, Golf Course and Fort Hare during the tracer experiment.

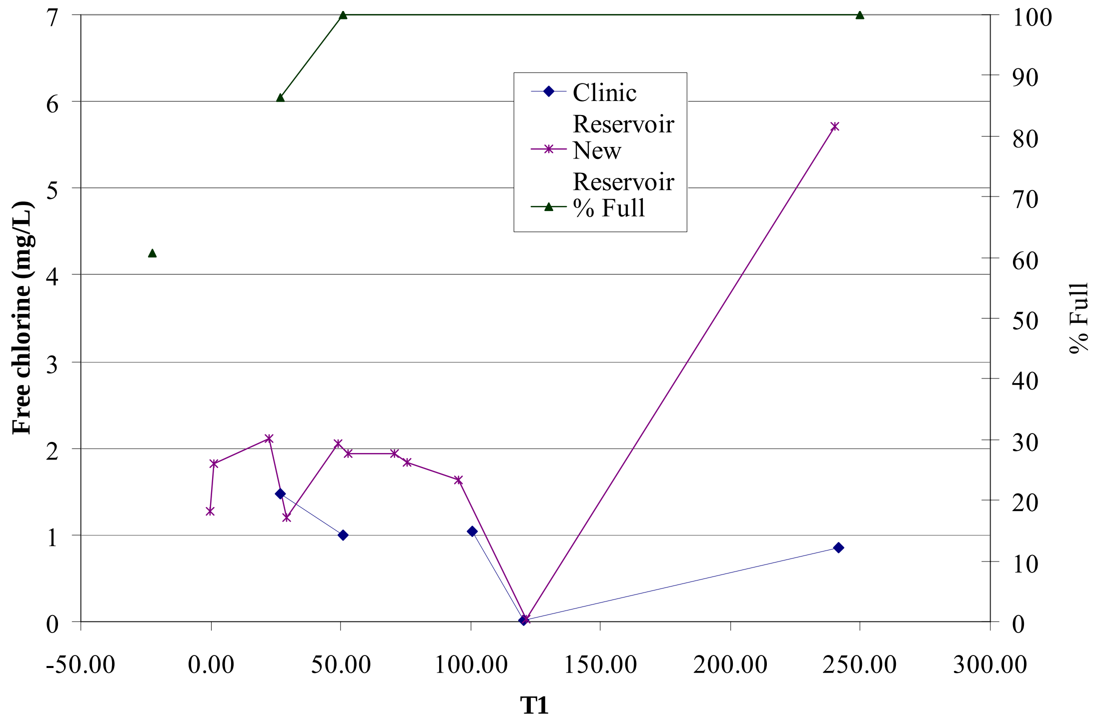


Fig. 3.5 Chlorine residuals measured at Victoria East Clinic during the tracer experiment

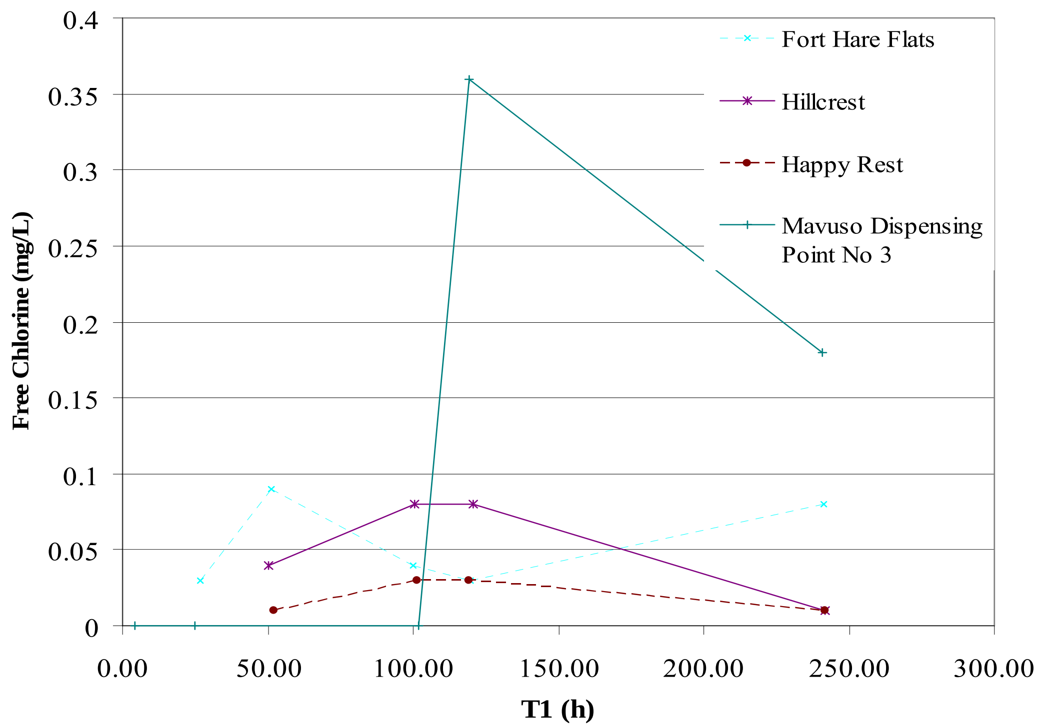


Fig. 3.6 Chlorine residuals measured at Mavuso, Happy Rest, Fort Hare Flat and Hillcrest during the tracer experiment

3.1.1.4 Assessing the need for booster chlorination

Regular samplings for the determination of the free chlorine residual, turbidity and the microbiological quality of the Alice drinking water were continued at the AWTP, and at the various sites of the distribution system (Mavuso Village, Hillcrest, Happy Rest and Fort Hare Flats) from July to November 2003. The aim of the experiment was to check the consistency of the chlorine dosing, the microbiological quality and the possibility of maintaining adequate free chlorine residual throughout the distribution system without overdosing. It was also important to investigate the overall dissolved organic carbon (DOC) removal at the point of treatment.

3.1.1.5 Consistency of chlorine dosing at the Alice water treatment plant

Figure 3.7 shows the chlorine residual at the plant (in-plant or New Reservoir) and the sampling points beyond Mavuso Reservoir. From the in-plant reservoir results, it is evident that there was no chlorine dosing for over a month from July to August. The chlorine-dosing pump was also non-functional for part of the previous visit in June and the entire visit in November and December 2003. These results clearly showed that the Municipality was still struggling to achieve continuous dosing and this is the major factor determining whether or not there is a residual in the distribution system. From Fig. 3.7, it is apparent that once chlorine dosing was restored at the plant, there was a detectable residual at all sampling point downstream of Mavuso within a few days. This was true even before the new Golf Course Line opened in October 2003.

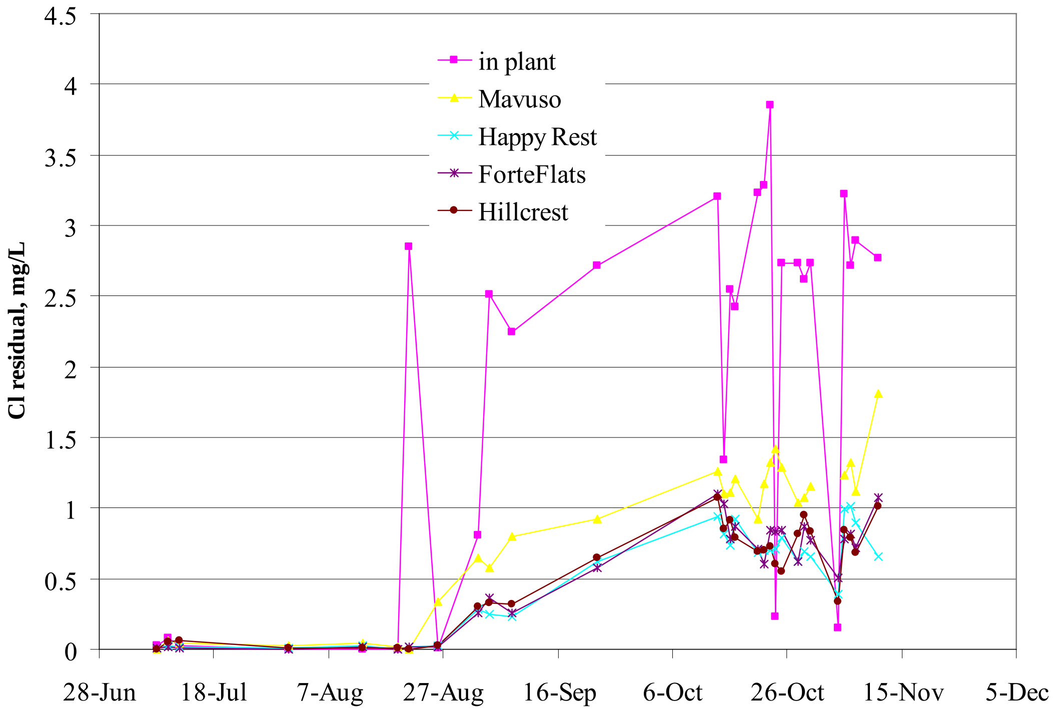


Fig.3.7 Chlorine residual at various points from July to November 2003

The chlorine dosing history was generally not known for previous sampling trips and this influenced the interpretation of the results. When dosing was restored in August, the operators apparently had difficulty controlling the dose properly and in-plant free chlorine residuals of greater than 2.5 mg/L were typical. The operators knew that the residual should be kept around 1 ppm and apparently tried to reduce the dose but this was unsuccessful**.**

3.1.1.6 Microbiological quality of thedrinking water samples collected from July to November 2003

The values for the microbial quality of the drinking water at the various sampling points were plotted against those of the chlorine residual.

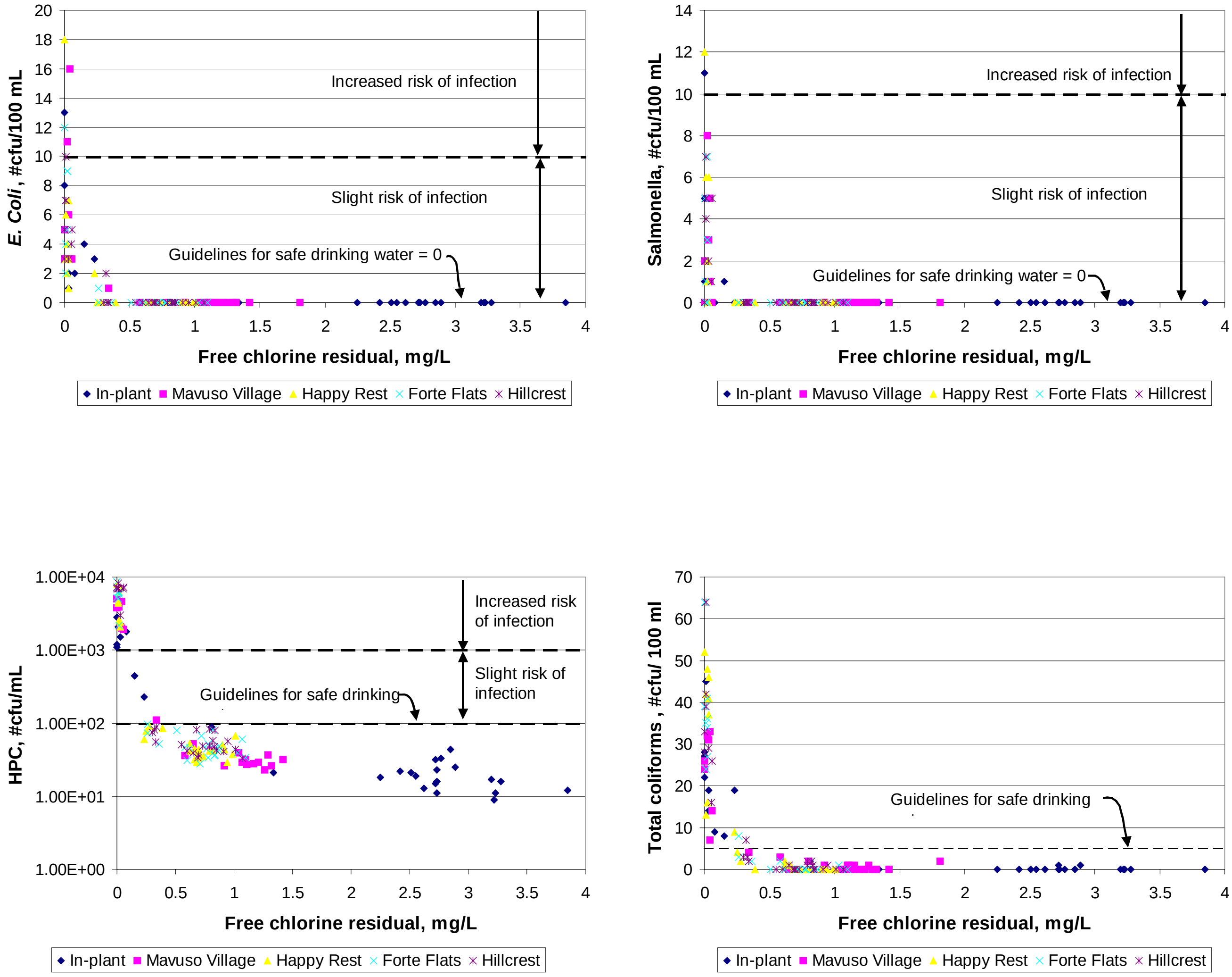


Fig. 3.8 Microbiological characteristics of water samples collected from the in-plant reservoirs and from various sites of the distribution system from July to November 2003

The results were compared with the limits recommended by the South African Water Quality Guidelines for Domestic Use to establish the minimum residual, which should be maintained. Figure 3.8 indicates that the water quality guidelines for microbial safety could generally be met if a residual of at least 0.3 mg/l was maintained at all points in the distribution system. This is somewhat higher than the usual recommendation of 0.1 mg/l. However, chlorine residuals of around ~ 0.3 mg/l mostly occurred in the period 2 to 8 September (Fig 3.7). This meant that the reservoirs contained a mixture of water, which was adequately disinfected to begin with, and water, which had not been disinfected at all.

3.1.1.7 Turbidity of the Alice drinking water from July to November 2003

Overall turbidity removal at the plant appears to have been poor for the entire monitoring period, as shown in Figure 3.9. This was probably due to a combination of filter problems, non-optimal coagulation and periods of no coagulant addition. High final water turbidity would have decreased the efficiency of disinfection and may have increased the free chlorine residual required to meet the microbial quality guidelines.

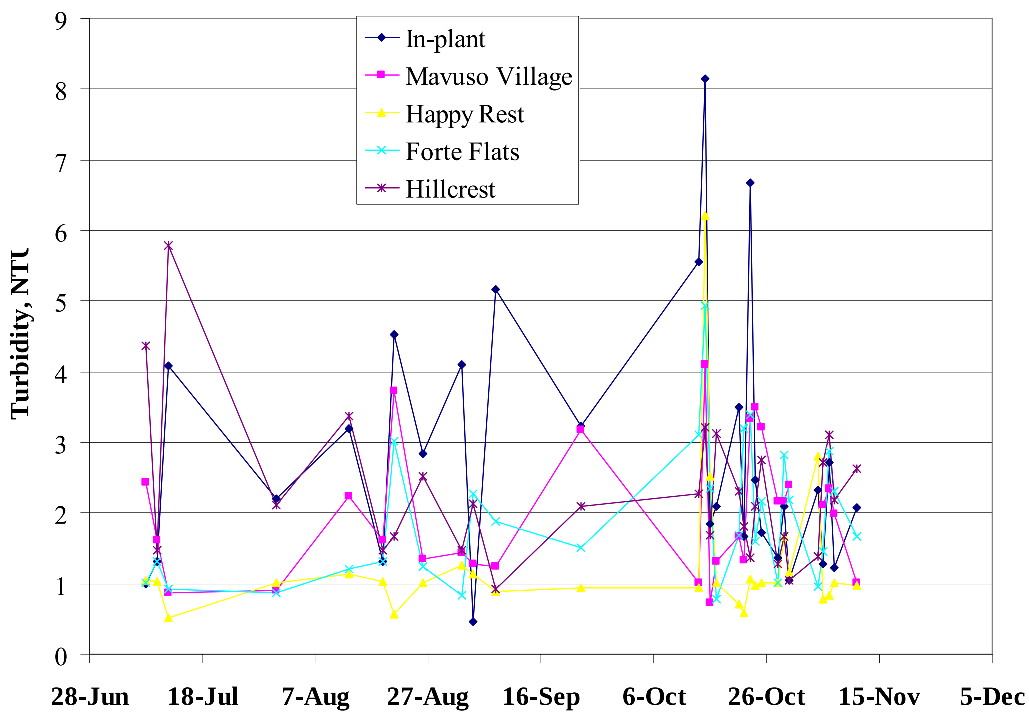


Fig. 3.9 Turbidity values at sampling points from June to November 2003

3.1.1.8 Maintaining an adequate chlorine residual

Considering the trends in the data over the long term (Figs. 3.9 - 3.10), it became evident that good chlorine residuals and microbial quality could be established and maintained even at the three most distant points of the distribution system in terms of retention time (Hillcrest, Happy Rest and Forte

Flats) as long as chlorine was dosed consistently at the plant for a sufficiently long period. This is shown in Fig. 3.7. The problem with these results was that when the chlorination system was functioning, chlorine was generally being overdosed. Therefore it was not immediately clear that Happy Rest consumers, for example, could enjoy good microbial quality without central Alice, the University and Ntselamanzi Village experiencing excessive chlorine levels. In order to resolve this issue, it was first necessary to establish the minimum residual required ensuring an acceptable microbial quality. Taking into account the microbial quality results plotted against chlorine residual and compared with the guidelines for drinking water quality (Figs. 3.8), it appears that the guidelines for microbiological safety can generally be met if a residual of at least 0.3 mg/l is maintained at all points in the distribution system. It was found that if all the results in Fig.3.7 were scaled down by a factor of 2.2, then most of the in-plant residuals fell within the range of 1 to 1.5 mg/l while the residuals at the sampling points remained above 0.3 mg/l. If the decay of the chlorine is assumed to be approximately first order, then the chlorine concentration in the water at any point in the distribution should be proportional to the free chlorine concentration when it left the plant. Therefore it appears that the chlorine residual can be maintained at a reasonable level in all sites without booster chlorination. Figure 3.10 shows the effect of scaling all the results (from Fig. 3.7) down by a factor of 2.2. According to Figure 3.8, it should be generally possible to maintain a residual of at least 0.3 mg/l at Mavuso Village, Happy Rest, Hillcrest consumer's taps and Fort Hare Flats consumer's taps provided that the in-plant residual is maintained in the range 1 to 1.5 mg/l.

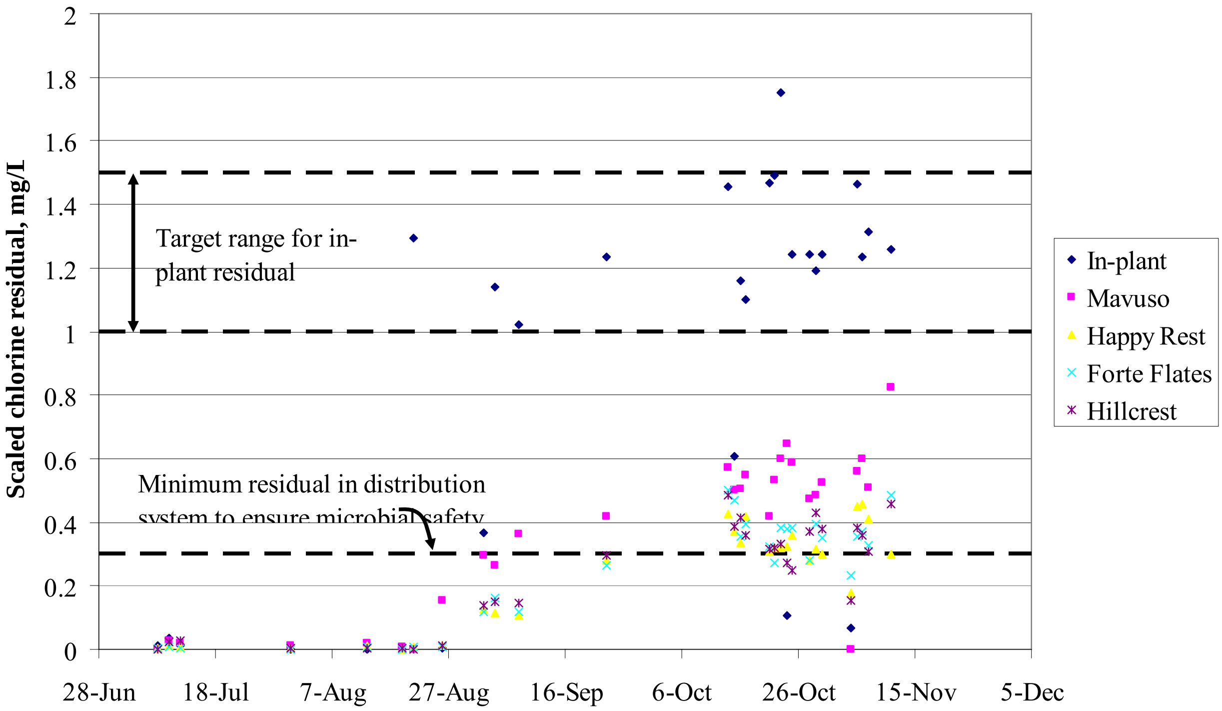


Fig.3.10 Measured chlorine residuals scaled down by a factor of 2.2

Based on the above results, it appears that not only is booster chlorination not required but also it is inadvisable. This is because it is clear that the water quality problems are primarily a result of failures in the AWTP chlorination system and it is unlikely that the Municipality would be able to manage a booster system any better than they manage the plant system. Consequently, their efforts and resources should rather be directed at fixing the system they already have.

The one outstanding issue however is the reservoir supplying Victoria East clinic. This reservoir also used to supply the Old Happy Rest reservoir and it probably had a substantially lower retention time in the past. The best solution in this case would be to lower the reservoir level. This could be achieved easily and cheaply simply by lowering the float which closes the inlet valve.

3.1.2 Assessing the performance of the plant for the removal of the Dissolved Organic Carbon and its impact on bacterial regrowth at the point of treatment

Water samples (raw water, water after filtration and water after chlorination) for the dissolved organic carbon (DOC), biodegradable dissolved organic carbon and growth factor were collected weekly using sterile glass bottles (brown sterile bottles for raw water and water after filtration). Prior to use, all the glassware (except the filter frit) was pre-treated according to Servais and co-workers's methods, which were modified by Grundlingh *et al.* (1999) in order to make sure that there were no traces of organic matter left in the glassware as this might lead to false results. Water samples for DOC analysis were prepared according to Mathieu *et al.*(1993). The DOC concentrations were determined using an AQUADOC^{TM} TOC Analyzer.

The preparation of the inoculums was performed according to Grundlingh *et al*., (1999). A 50 ml raw water sample was filtered through a 2.0 μm nucleopore polycarbonate membrane, 47mm diameter (Merck, Cat. No. 111111) and was stored in a sealed glass bottle. This water sample was used for the analysis of BDOC and for the growth factor. The BDOC was determined according to the method previously used by Servais and co-workers (1987) modified by Grundlingh and co-workers (1999). Briefly, a water sample was vacuum filtered through a 0.2 μm nucleopore polycarbonate membrane, 47mm diameter (Merck, Cat. No. 111106) and 200 ml of this water sample was measured using a glass measuring cylinder into a brown bottle. Two millilitres of the innoculum was added. The water sample was then incubated for 28 days in a dark cupboard to prevent the breakdown of DOC by sunlight. After every 7 days, 20 ml was removed and prepared for the DOC analysis. The concentration of BDOC was calculated as the difference in the DOC concentration before incubation and on the last day of incubation. Bacterial regrowth was then determined using total coliforms (TC), faecal coliforms (FC) and heterotrophic plate count (HPC) as main parameters, which were enumerated as described for the monitoring of the bacterial quality of the finished water using standard methods (*Standard Methods for the Examination Water and Wastewater*, 1998).

The growth factor was analyzed according to Page and co-workers (2002) to evaluate the potential of the water to support the regrowth of bacteria. Each water sample was allowed to warm to room temperature after collection and was then vacuum-filtered through a 2.0 µm nucleopore polycarbonate membrane, 47mm diameter (Merck, Cat. No. 111111) and 200ml of this water sample were measured into a brown bottle, 20 ml of sterile nutrient broth were added to the sample. This water sample was then vacuum filtered using a 0.2 µm nucleopore polycarbonate membrane, 47mm diameter (Merck, Cat. No. 111106) and then poured into 3 sterile turbidity cuvettes. A microprocessor turbidity meter (HACH Co., model 2100P) was zeroed using this sample. The inoculum (bacteria from raw water) was added until the turbidity readings were between 0.2 and 0.4 NTU. The turbidity meter was zeroed again to ensure that only the growth of new bacteria was enumerated. Turbidity readings were taken after every 30 minutes until a plateau was reached. The growth factor was calculated as follows:

$$\frac{\text{Turbidity at the plateau}}{\text{Turbidity at the lag phase}}$$

Sand filtration processes are performed in order to decrease the DOC concentration from the raw water to the filtered water. Overall DOC removal at the AWTP appeared to have been very poor for the entire monitoring period as indicated in Table 3.9. The Alice water treatment plant's filtration system did not decrease the DOC concentration to the level recommended by the water industries, which ranges between 0 and 5 mg/L (DWAF, 1996). The DOC concentrations in the filtered water samples were above these limits (Table 3.9). The highest DOC concentration in raw water was found in October and the removal was at 59.57%, while the lowest concentration of the DOC in raw water was recorded in August. No removal of the DOC was noted in August and in September, in contrast there was an increase in DOC concentration at rates of 13.64 and 35.34 % respectively. The inefficiency of the filtration process could be attributed to the lack of backwashing of the sand filters in the Alice water treatment plant. It was noted that the filters went for days without backwashing. This impacted on the quality of the filtrate in terms of the DOC removal.

The concentration of the DOC in the filtered water accounted for the presence of that in the finished water samples at the point of chlorination. Although no free chlorine residual was noted in August and during the first week of September (Table 3.9), the DOC concentrations increased by 24 % and by 46.5 % respectively during the monitoring period. In October, the free chlorine residual concentrations exceeded the limits recommended for potable water, which are in ranges of

0.3-0.6 mg/l as ideal free chlorine residual concentration and 0.6-0.8 mg/l as good free chlorine residual concentration for insignificant risk of health effects (DWAF *et al.*, 1998). During this

TABLE 3.9

CHARACTERISTICS OF THE ALICE WATER TREATMENT PLANT IN TERMS OF DOC (MG/L) AND BDOC (MG/L) CONCENTRATIONS AND GROWTH FACTOR AND CHLORINE RESIDUAL CONCENTRATION.

MONTH		**DOC**		**BDOC**	**GF**	**CR**
		FW	CW	CW	CW	CW
AUGUST	MIN	12.00	15.00	1.00	2.90	0.00
	MAX	13.00	16.00	6.70	3.04	0.00
	$\bar{x}$	12.50	15.50	3.85	2.97	0.00
	Sx	0.71	0.71	4.03	2.05	0.00
SEPTEMBER	MIN	13.00	13.00	4.20	3.29	0.00
	MAX	18.00	33.00	14.80	6.54	2.77
	$\bar{x}$	15.70	23.00	14.00	5.76	1.19
	Sx	2.52	10.00	9.43	0.74	1.42
OCTOBER	MIN	9.00	27.00	4.00	4.41	2.52
	MAX	133.00	50.00	40.00	7.12	3.58
	$\bar{x}$	37.20	31.00	18.80	6.86	2.82
	Sx	57.30	15.79	16.45	1.34	0.44

DOC: Dissolved organic carbon, BDOC: Biodegradable dissolved organic carbon, GF

month, the DOC concentration decreased by 16.67 %. As indicated in Table 3.9, high concentrations of the DOC in the Alice finished water contributed to the biodegradability of the organic matter in the drinking water. This followed the trend of chlorine residual as it increased each month.

The concentration of BDOC and the growth factor revealed that water distributed by the Alice water treatment plant was biologically unstable. Water with growth factors below 5 is considered biologically stable (Page *et al*., 2002). In the Alice water treatment plant, the average values of growth factors were found to be high in September (7.72), followed by October (5.97), exceeding the above limit. The lowest values of the growth factor were found in August (4.37).

Removal of BDOC to the level that limits microbial regrowth provides not only a direct control of bacterial population but also an indirect control of protozoan population through a trophic food web (Servais *et al*., 1989). A high BDOC concentration in finished water indicates poor quality and a potential for microorganisms to multiply in the water (LeChevallier *et al*., 1988). It has been reported that treated water containing a BDOC concentration of less than 1 mg/l is not prone to regrowth (Benhardt and Wilhems, 1985). However, treated water supplied by the Alice water treatment plant had very high concentrations of BDOC, up to 40 mg/l (Table 3.6). This resulted in high bacterial regrowth during the study period (Fig.3.8). The increase of the bacterial counts was parallel to the increase in the BDOC concentration from August to September but bacterial regrowth decreased in October contrary to the increase in the BDOC concentration. This decrease in bacterial regrowth could be related to high concentration of free chlorine residual, which was up to 3.58mg/l (Table3.9). The variation of the free chlorine residual concentration was associated with the fact that the operators in the Alice water treatment have little understanding of the chlorination process in the purification system.

3. 2 TRAINING OF THE OPERATORS

3.2.1 Operator training by the Municipal Mentoring Programme

When the water quality and treatment plant operating problems were presented to the Nkonkobe Local Municipal Water Authority and Councilors, action was taken immediately. By the end of November 2002, the Municipal Mentoring Programme (MMP), an agency working with local municipalities, began working with the operators and training them in the basic concepts of water treatment. A turbidity meter and a chlorine meter were provided, performance goals were set and the operators began monitoring turbidity removal and the chlorine residual. They were also taught to initiate manual backwashing of the filters if turbidity breakthrough was observed. However, the training did not include flow measurement or quantitative procedures for setting the chlorine or coagulant doses, even after a new raw water flowmeter was installed.

3.2.2 Operator training by the project team

The project team conducted a three-day operator-training course in November 2003. At this time, the operators already had a reasonable qualitative understanding of the treatment course so the course focused on quantitative issues. The training included the following:

i) Overview of water treatment and its importance in preventing disease (Appendix I)

ii) Flow rate measurement using the V-notch weir, and its importance for setting correct chemical dosing rates (Appendix II).

iii) Jar tests for determining the optimum coagulant dose and methodology for setting the correct dosing rates (Appendix III).

iv) Chlorine demand and methodology for setting the correct chlorine dosing rate (Appendices IV and V).

v) Operation of the valveless filters and inspection of the filter media in Filter 3.

Notes in English and isiXhosa were provided for each session. The project team also worked out detailed procedures for the optimum coagulant dose and setting the correct dosing rates using the Jar test and for chlorine demand tests which would be easy for the operators to follow with the resources available to them and a few additional articles which the municipality should be able to buy fairly cheaply. The complete bilingual course notes are provided in Appendixes I -V. The operators requested that the test procedures be presented in pictorial form.

The operators did not appear to have confidence in using a calculator. Tables were developed to assist the operators in finding the raw water flowrate from the height over the V-notch weir, chlorine contact time and correct chlorine and coagulant dosing rates. The calculations involved are presented in Appendix III. The project team provided the operators with a simple electronic calculator which they were taught how to use in the follow up sessions. Up to March 2004, the project team were still doing the follow up by checking once a week the progress on the implementation of Jar test, chlorine demand, flow rate measurement, turbidity and chlorine residual measurement as well as and the operation of the filters.

3.3 CONTINUOUS PROBLEMS IN THE ALICE WATER TREATMENT PLANT

3.3.1 November- December 2003

Despite the improvement in operator skills, the treatment plant continued to experience severe problems in the second phase of the project. Upon further investigation, it was found that these problems were mainly related to malfunctioning equipment and to stocks of treatment chemicals not being replenished in time. Contributing factors were insufficient maintenance personnel and technical expertise, and poor planning in the purchase and delivery of treatment chemicals. The continued lack of flow measurement was also a major problem.

Flow measurement

Although a functioning raw water meter was installed at the plant, it was not easily accessible and the operators had not been trained to read it. The operators change the plant flowrate as often as once a day to maintain the level in the on-site reservoir within a certain range. In order to adjust the chemical doses in proportion to the flow, they need to know what the initial and final raw water flows are.

Coagulant dosing

Two major problems affecting coagulant dosing were identified. Firstly, there are no procedures pertaining the ordering and delivery of chemicals in the AWTP. It takes several days or weeks for the chemicals to be delivered to the plant when they are exhausted. Throughout the waiting period the plant is run without any coagulant. Secondly, the dosing pump had apparently been struck by lighting and the fine control no longer worked. Consequently, the dosing rate could not be adjusted and Ultrafloc was being overdosed. The operators were partially aware of the problem but nothing had been done about it. A Jar test conducted on 19 November indicated that the optimum dose was around 6 mg/l with acceptable turbidity removal of up to 11.5 mg/l. The measured dosing rate was 39,5 kg/d. Raw water flowrates for the week ranged between 3.6 and 4.8 ML/day. At a 4.8 Ml/d flowrate, 39.5 kg/d of coagulant corresponds to a dose of 8.3 mg/l while at 3.6 Ml/d the dose increases to 11 mg/l. This means that 30 to 45 % of the Ultrafloc was being wasted.

Filtration

The Alice water treatment plant has been experiencing problems with its filters since at least June 2002. Throughout the second phase, the filtrate turbidities were very poor, often between 4 and 5 NTU and often worse than the settled water turbidity. The filters rarely backwashed autonomously, and the operators had resorted to backwashing them manually once a day. However, the initiation of manual backwash had become very slow on one filter and in November, had ceased to work at all for another. The filters had been operating for about three years.

Many small treatment plants have installed valveless filters believing that they will operate without any maintenance for many years. Although it is true that these types of filters typically require less maintenance than other types, research carried out by Umgeni Water has indicated that problems can be expected to develop within as a little as a year depending on the operating conditions (Brouckaert *et al.,* 2002). The major weakness of valveless filters is that while backwash is regular when the filters are functioning properly, it is relatively inefficient. This means that over time, mud and floc will build up in the filters, eventually causing performance problems. Long delays between backwashes, overdosing coagulant and the use of organic coagulants (Ultrafloc has an organic component) would tend to accelerate the deterioration (Brouckaert *et al.,* 2002). The accumulated mud tends to shrink, causing cracks to form between the bed and the filter walls. As a result, influent can bypass the media resulting in poor filtrate turbidity.

Chlorination

Chlorine dosing was a major on-going problem at the Alice water treatment plant. Delivery of chlorine gas to the plant was often delayed and the chlorinator was frequently shut down due to gas leaking from the regulator. When this happened, the Nkonkobe maintenance team was informed but it was often days or weeks before the problem was attended to. In the meantime, the plant either ran with no chlorine at all or the operators would add four HTH tablets once a day to the on-site reservoir. The amount of chlorine added amounted to approximately 5 % of the total chlorine demand. When the chlorinator was functioning, problems with regulating the dose continued and overdosing was common. As a result, the recommended residual of 1 and1.5mg/l in the on-site reservoir was never maintained for any extended period of time during the study period.

3.3.2 January - February 2004

Improvements have been made in the Alice water treatment plant; however there was a lot of rooms for improvement in monitoring, maintenance and enforcement to protect the AWTP water quality.

Flow measurement

The operators have stopped measuring the flow from the V-votch well. The technician from Onduka Compagny told them that measuring from the well was not accurate and advised the Nkonbe Municipality to buy a scale that can be installed ahead of the weir, which, according to him is cheaper in Queenstown.

Coagulant dosing

Operators are still experiencing problems in getting the exact Ultrafloc dose. The operator who was on duty on the 26th February 2004 reported that since the new dosing pump was installed and the Ultrafloc delivered, they were hardly getting settled water turbidities of < 5 NTU and they could not see the flocs in the inlet chambers. They even thought that the Ultrafloc may be mixed with water or the dosing pump was not functioning well. However it was proved that the dosing pump was functioning well.

Settling tanks

Higher turbidities were recorded in the over flow from the settling tanks as compared to the previous year. This was thought to be caused by inaccurate coagulant dosing. The ranges of 2.1 to 10.7 NTU, 1.8 to 16.5 NTU, and 2.4 to 15.6 NTU were obtained from settling tanks 1, 2, and 3 respectively during the month of February 2004.

Filters

The three filters are still being backwashed manually. Filtrate turbidity ranges of 1.1 to 9.6 NTU, 0.9 to 5.7 NTU, and 0.1 to 4.5 NTU have been recorded from filter 1, 2 and 3 respectively during February 2004.

Disinfection

Since the 5th of February 2004, the chlorine residual ranged between 0.41and 2.44 mg/l in the in-plant reservoir and the final water turbidity ranged between 0.5 and 6.7 NTU.

Microbiological monitoring programme

The microbiological monitoring programme was not been established until February 2004.

3.4 OVERALL CONCLUSIONS ON THE OPERATING CONDITIONS OF THE ALICE WATER TREATMENT PLANT DURING THE SECOND PHASE (APRIL 2003 TO FEBRUARY 2004)

(I) The main cause of inadequate disinfection in Alice is frequent and prolonged disruptions of chlorine dosing. The Nkonkobe management should deal with this issue urgently.

(II) Booster chlorination was **not recommended**. Firstly, it is not really necessarily when the in-plant chlorine dose is adequate and secondly, it would be unlikely to function properly if the Municipality is already struggling with the in-plant dosing system. (In this case it proved to be unnecessary – but the operation of the distribution system and its effect on water quality should always be considered

(III) Cleaning and disinfecting the reservoirs should be considered, especially since there has been no chlorine dosing from July to August 2003.

(IV) The opening of the Golf Course Line from Mavuso Reservoir has greatly reduced the retention time in this reservoir, which should have a positive effect on water quality for all areas it supplies.

(V) It is probably necessary to lower the operating level of Victoria East Clinic Reservoir, however, a better estimate of the typical outflow and water quality should be obtained.

(VI) Solving the turbidity removal problems at the Alice water treatment plant would improve disinfection efficiency while at the same time saving money by applying the chlorine demand test.

3.5 PERFORMANCE OF THE ALICE WATER TREATMENT PLANT AFTER THE INTERVENTION (AFTER JUNE 2004)

The follow up session was conducted from June to August 2004 to evaluate the performance of the Alice water treatment plant after the intervention. Various parameters such as turbidity in all the stages of water treatment and chlorine residual in the in-plant reservoir and end-user taps were measured by the Fort Hare research group during the visit of the plant.

3.5.1 Turbidity Removal

Figure 3.11 illustrates the performance of Alice water treatment plant for the removal of turbidity between 30 June and 4 August 2004 when the sand bed was replaced in the filters.

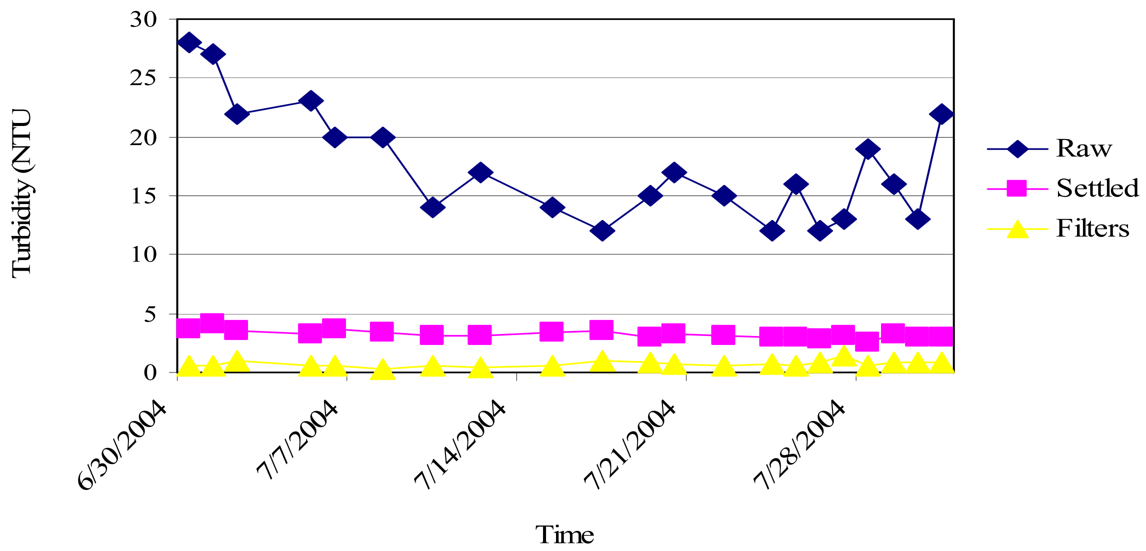


Fig 3.11 Performance of Alice water treatment plant for the removal of turbidity after intervention (from June 2004)

The turbidity values that ranged between 12 NTU and 28 NTU were recorded in Alice raw water from the 30th of June to the 4th of August 2004 (Fig. 3.11). A decrease in turbidity that reached the minimum of 2.9 NTU and the maximum of 4.1 NTU was noted after clarification. The turbidity values further decreased after the filtration stage and these values ranged between 0.3 NTU and 0.9 NTU. All the turbidity values recorded in the clarifiers and in the filters were within the limits recommended by the World Health Organization (WHO, 1993) and the South African Bureau of Standards (SABS, 1984), respectively.

3.5.2 Characteristics of the Alice treated water after the intervention

Figure 3.12 illustrates the quality of the Alice treated water after the intervention (during June and July 2004). The quality of the Alice treated water in the in-plant reservoir and in the end user taps was acceptable based on the recommended limits.

The turbidity values in the in-plant reservoir ranged between 0.2 NTU and 1 NTU, while the chlorine residuals ranged between 0.5 mg/l and 2.5mg/l. The chlorine residuals of 0.3 mg/l and 0.8 mg/l recorded in the end user tap were sufficient to ensure safe drinking water in Alice.

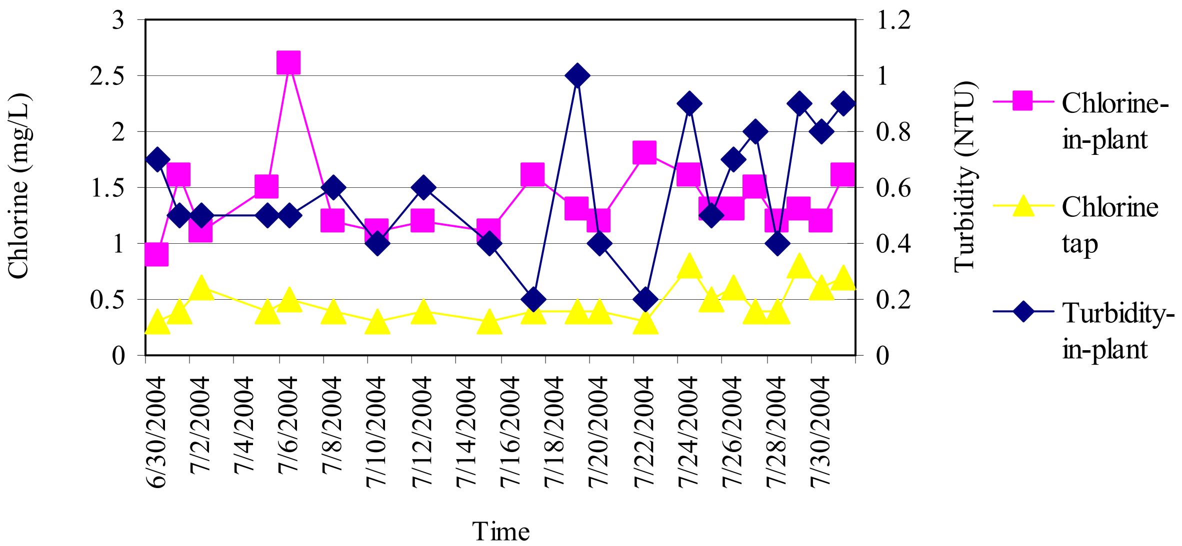


Fig 3.12 Characteristic of Alice treated water in terms of turbidity and chlorine residual after intervention (from June 2004)

3.6 LESSONS LEARNED FROM THE ALICE WATER TREATMENT PLANT CASE STUDY

This section briefly outlines the major lessons learned from the Alice experience. While the situation at each treatment plant is slightly different, the problems faced by the Alice water treatment plant are fairly typical of rural water services providers.

3.6.1 Dosing failures

During, the study period one of the major reasons for poor water quality in Alice was found to be faulty dosing equipment and lack of functioning stand-by equipment. Furthermore, it typically tooks days to months to get faulty equipment repaired or replaced. A second major cause of dosing failures was that treatment chemicals often ran out before new supplies were delivered. As result, the plant sometimes operated for days without coagulant and/or chlorine. Researchers had to assist municipal staff in finding companies who could make the necessary repairs to their equipment. At the time of the study, municipal officials did not regard dosing failures as an emergency and made no attempt to warn the community that the safety of their drinking water was at risk.

In order to avoid these sorts of problems, the following must be taken into account:

- First it is important for both operators and municipal officials to realise that **disruptions in chemical dosing are unacceptable**.
- Treatment plants need to have **standby dosing systems** for both coagulants and disinfectants and they need to be kept in good working order.
- **Maintenance** of critical equipment such as dosing systems must be considered a top priority. If the skills to repair specialised equipment do not exist in-house, then municipalities need to have plans for getting repairs or replacements as quickly as possible when required. These plans should be developed before a problem occurs to avoid unnecessary delays.
- Municipalities must pay greater attention to getting treatment chemicals to all of their treatment plants before they run out.

3.6.2 Filter problems

The Alice water treatment plant had installed three valveless filters to replace the existing conventional filters. The operators and municipal officials were initially unaware of how these filters worked or that the backwash design is inherently limited in its effectiveness. After 2 to 3 years of operation, the filters were no longer able to backwash properly and the state of the filter beds had deteriorated. Consequently, overall turbidity removal at the plant was poor and disinfection also suffered. After the filter media was replaced and the backwash pipes cleaned out, filter performance was restored and the plant was able to produce filtered water turbidities of less than 1 NTU.

Municipalities need to realise that the **filter media in rapid filters tends to deteriorate over time** and backwash flow rates can also decline as a result of blocked pipes. Filter media will generally have to be replaced every 1 to 2 years and all pipes and valves should be inspected and cleaned at the same time. Only companies with experience in filter maintenance and refurbishment should be used.

3.6.3 Coagulant dosing

The Alice water treatment plant could make substantial savings on chemical costs if coagulant **dose optimisation** was conducted. The cost savings would easily cover the purchase of the **jar test equipment** required for dose optimisation. Coagulant dose optimisation could also lower the **chlorine demand** of the filtered water and hence the cost of disinfection. This is probably also true for many other small treatment plants.

3.6.4 Flow measurement

It is critically important that operators are able to measure the plant flow rate in order to make appropriate dose adjustments. This was particularly true at the Alice water treatment plant where a lack of balancing capacity meant that operators had to make frequent adjustments to the flow rate. The plant's only flow meter was located in a 2 m deep sump and was submerged in water. Consequently, it was difficult and dangerous for the operators to read. A **V notch weir** was located close to the raw water inlet; however, this was also difficult to read due to the turbulence of the flow at that point.

It is very important that flow meters are installed in such a way that operators can easily access and read them at least once a day. Operators should also be trained to measure flow using V-notch weirs at plants which have them.

3.6.5 Clarifying roles and responsibilities

There appeared to be a lack of clarity about who was responsible for the management and some aspects of the operation of the plant. This included a number of critical activities such as ensuring chemicals were delivered on time, adjusting coagulant doses and repairing equipment. As a result many evident problems were left unattended to for long periods of time. Furthermore, municipal management did not act when plant performance data collected by the operators clearly indicated the plant had major problems.

There needs to be a **clear framework clarifying roles and responsibilities** for all municipal workers and officials who are involved in ensuring the safety of drinking water in small water treatment systems. Equally important is the need for the municipal management structures at all levels to support this framework by providing adequate resources to fulfil these various roles.

3.6.6 Operator training

During the course of the investigation in the Alice water treatment plant, the operators received on-site training from both the Municipal Mentoring Programme (MMP) and the University of Fort Hare research team. The operators responded very positively to the training and made significant advances in both skills and confidence over the study period. Some of the key lessons emerging from the interaction with the operators were as follows:

- The operators wanted their relationship with the research team to be one of **mutual co-operation and support**. While the project team had a superior theoretical knowledge about water treatment in general, the operators had years of practical experience of the plant and its problems.
- The operators were able to grasp the conceptual aspects of the water treatment process fairly easily but struggled with the **quantitative aspects**. Follow up training sessions on **dose adjustment and optimisation** were critical and special attention was paid to the concept of **chlorine demand**.
- The operators wanted training materials, instructions and safety information translated into their own languages. They also preferred training materials and procedures to be illustrated.

3.6.7 Communication between operating staff and management

Operators complained about a lack communication with the municipal management. They felt that their concerns were ignored and they were usually blamed for poor plant performance even if it resulted from factors they had no control over. Operators play a critical role in protecting a community's drinking water supply, but they generally occupy a very lowly position in the municipal hierarchy. It is important that municipal managements understand that they (and not the operators) ultimately held responsible for the quality of the drinking water. Consequently, it is most important that management works to establish a more co-operative and supportive relationship with operating staff.

3.6.8 Need for public education on water quality issues

During the course of the Alice case study, the project team came to appreciate that **the level of awareness about water quality issues among the local population is very low**. This included the relatively educated University of Fort Hare community. In this context, the lack of priority placed on water quality issues by the local municipality was quite understandable. The municipality, like the local community, was simply more interested in increased access to water services and low cost housing. The connection between the prevalence of enteric diseases and water quality was not appreciated. **Education of both the public and municipal officials** on health issues related to water quality is essential if municipalities are to see merit in expending resources to improve the microbial safety of their water supplies.

3.6.9 Role of partnerships

The difficulties experienced in training and retaining adequately skilled personnel to run water treatment plants in impoverished rural municipalities have been among the major hurdles in providing acceptable water services in these areas. Sending skilled technicians from urban centres to operate plants in outlying areas is also usually prohibitively expensive.

Over the course of the study, interaction between the operating staff and both the Municipal Mentoring Programme and the University of Fort Hare research team resulted first in a substantial improvement in operator skills and finally an improvement in treated water quality after the many equipment problems were resolved. In the process, an ongoing relationship between the Alice water treatment plant operating staff and the Research Group at the University of Fort Hare has been established. This experience has shown that partnerships between municipalities, capacity building organisations and local tertiary organisations can yield results but a **long-term commitment** is required to ensure improvements can be sustained.

If the partnership can be shown to be a cost-effective option for improving service delivery and reducing the risks and health costs associated with water borne diseases, then the programme should ultimately be adopted and funded by local or central government. However, the public health benefits of an improved water supply are likely to be small if they are not accompanied by improvements in sanitation and hygiene practices.

It must be emphasized that the responsibility for running the treatment plant and achieving acceptable water quality remains solely with the municipality. The role of the local and non-local expert support is to provide the municipality with assistance in meeting its objectives and to review its progress. A possible model for co-operation is presented below.

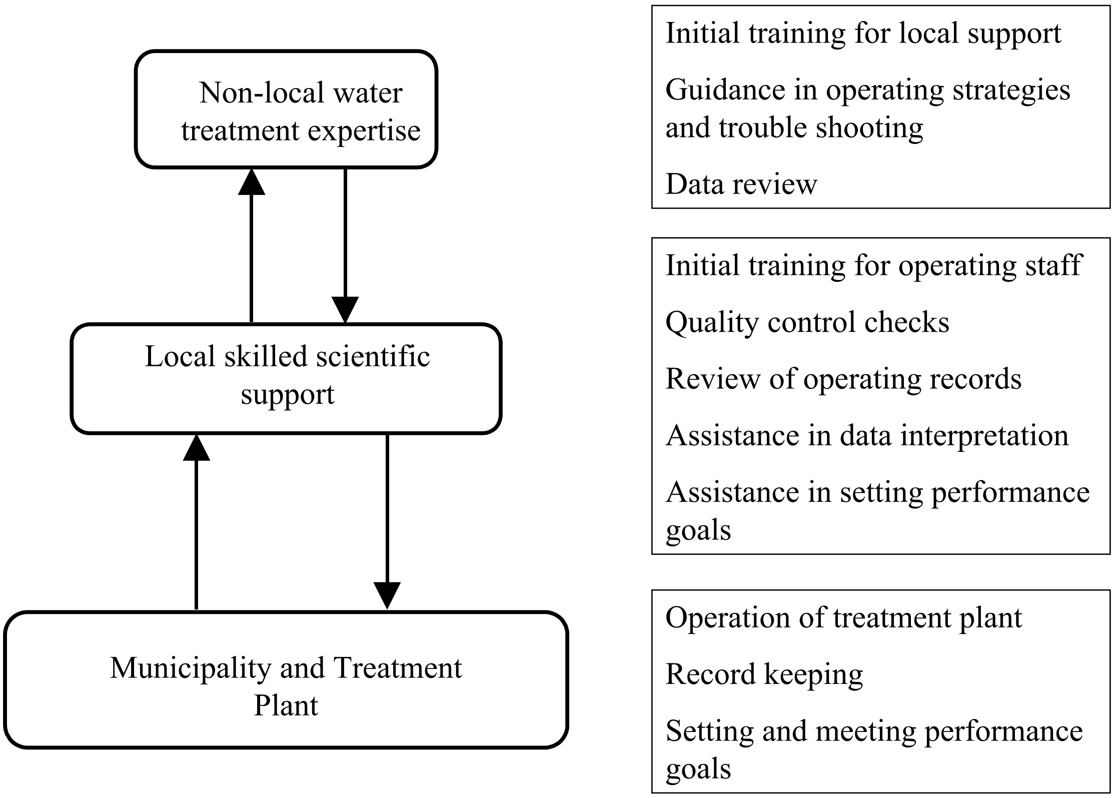


Fig. 3.13 Diagram showing possible model of co-operation between Municipal water treatment plant in rural areas and non- and local experts.

Detailed guidelines outlining practical steps for ensuring the efficiency and sustainability of disinfection at small rural water treatment plants are presented in chapter 4.

CHAPTER 4

GUIDELINES ENSURING SUSTAINABLE EFFECTIVE DISINFECTION IN SMALL WATER SUPPLY SYSTEMS

4.1 GENERAL CONSIDERATIONS

Of all the advances made possible through science and technology, the treatment and distribution of safe drinking water is truly one of the greatest. Abundant, clean water is essential for good public health. It has been increasingly recognized by world leaders that safe drinking water is a critical building block of sustainable development. **Disinfection**, a chemical process whose objective is to control disease-causing microorganisms by killing or inactivating them, is critically important in drinking water treatment.

The purpose of a water supply is to deliver to each consumer safe drinking water that is adequate in quantity and acceptable in terms of taste, odour and appearance. Safe water can be defined as water that does not contain harmful chemical substances or microorganisms in concentrations that could cause illness in any form. Safe drinking water is yet to be achieved in many rural and peri-urban communities including many of those which have a treated water supply.

Small water treatment plants are generally installed in areas which are not well serviced and typically fall outside the confines of urban areas. They include systems which chlorinate borehole and spring water, small treatment systems for rural communities, treatment plants operated by small municipalities and treatment plants for establishments such as rural hospitals, schools, clinics, forestry stations, etc. Most of these applications treat less than 2.5 Ml/d, although plants of up to 25 Ml/d may sometimes also fall into this category (Barkley, 2002).

The South African vision for the water services sector in 2002 was stipulated as follows (DWAF, 2002a):

i) All people living in South Africa should have access to an **adequate, safe and affordable supply of potable water**, live in a healthy environment with safe and acceptable sanitation, be able to engage in sustainable livelihoods, be economically empowered and be able to participate actively in a vigorous and healthy civil society.

ii) All people should be **knowledgeable** about healthy living practices and use water wisely.

iii) There should be adequate water available for economic development.

iv) Water supply and sanitation services should be **sustainable** and be provided by **efficient and effective service providers** who are **accountable and responsive** to the customers they serve

The above are expected to give the outcome of a healthy population, a healthy environment and economic growth that improves the quality of life and livelihoods of the whole population, especially of the poorest (DWAF, 2002a). The 1994 White Paper (DWAF, 1994) also made commitments to the effective monitoring of the sector performance to ensure that universal access to basic services is progressively achieved, financial resources are used efficiently and effectively and that water service institutions are accountable to local communities and standards are maintained.

The provision of adequate water services was one of the more difficult and pressing challenges inherited by the new South Africa. Prior to the change of government in 1994, an estimated 30 - 40% of South Africa's population (14 -18 million people) was without adequate water supply services and some 21 million people were without adequate sanitation (Van der Merwe, 2003). As of 2004, some 10 million additional people have been supplied with drinking water, thereby reducing the backlog in 2004 to some 4 million (Kasrils, 2004). Although great strides have been made in the effort to provide safe and clean water to all South Africans, studies have shown that in small rural towns and small remote villages with adequate water supply services, the drinking water quality is generally poor and often not fit for human consumption at the point of use (Pearson and Idema, 1998; Swartz, 2000; Momba and Kaleni, 2002; Momba *et al.*, 2004). Therefore water supplied by these plants is adding to the number of deaths caused by waterborne diseases.

> Diseases related to contamination of drinking water constitute a major burden on human health. Interventions to improve the quality of drinking water provide significant benefit to health (WHO, 2004).

The key issues contributing to poor performance of small potable water supply systems include the installation of inappropriate treatment systems, a lack of knowledge of basic treatment principles, the inadequate maintenance of equipment, financial constraints and a lack of community involvement during the conception of the plants (Swartz, 2000, Momba *et al.,* 2004). Other contributing factors include:

- Some Water Service Authorities are not familiar with the minimum requirements for the quality of potable water as defined under South African law (Mackintosh *et al*., 2004a)
- There is **inadequate monitoring** of water quality and inadequate intervention when monitoring indicates poor water quality
- There is a **lack of technical and managerial** capacity in many of the newly established municipalities
- The focus of development activities in the water sector has understandably been on improving **access** to water with insufficient attention on the **quality** of water produced.
- There is a **lack of public awareness** about water quality, health and hygiene issues in rural communities. Consequently these communities usually do not exert pressure on municipalities to improve the quality of their potable water

The key to ensuring clean, safe and reliable drinking water is to implement **multiple barriers**, which control microbiological pathogens, and chemical contaminants that may enter the water supply system. This includes adopting sound management practices and continuously reviewing both the state of the water treatment and distribution infrastructure and the quality of the water produced. Application of a disinfection barrier is a critical component of primary treatment of drinking water (LeChevallier, 1998). Disinfection is important because the turbidity removal by sedimentation and filtration does not remove all microbial pathogens from water. The **disinfectant residual** in the drinking water distribution system is also one of the key factors controlling the microbial quality of water, preventing bacterial proliferation in the water phase (regrowth) and limiting viability of bacteria released from pipe wall biofilms. The disinfection of small water supplies in South African rural areas is almost universally accomplished by the use of chlorine. The ability of chlorine to kill pathogenic microorganisms and to maintain a residual in the distribution system, as well as its availability at moderate cost, make it well suited for small water supplies (LeChevallier *et al*., 1987).

It has been observed that the chlorine decay is influenced by the **chlorine demand** of the water and the reactions with deposits such as organic and inorganic sediments. It is therefore important for operators to understand and compensate for the way disinfectant decreases in the distribution system. Although chlorine is used to reduce bacterial numbers, the mere use of chlorine does not guarantee the removal microbiological pathogens; it is essential to apply the correct dose at the correct frequency.

The present guidelines have been developed as an end product of the lessons learned from the Alice Water treatment plant case study. While the situation at each treatment plant is slightly different, the problems faced by the Alice water treatment plant are fairly typical of rural water services providers.

4.1.1 Target audience, objectives and scope of the guidelines

4.1.1.1 Target Audience

These guidelines are primary directed at municipal officials, water treatment plant supervisors and operators outside the major urban centres, as well as groups and institutions trying to assist them in improving their drinking water quality.

4.1.1.2 Objectives

The objectives of the guidelines are first to help municipalities to understand their legal obligations with regard to the quality of water that they are supplying to consumers and then to explain how specifically the microbial quality of the water can be improved.

4.1.1.3 Scope

The focus of these guidelines is on improving the **microbial quality** of potable water in rural municipalities since this has the most immediate impact on consumers' health. Several technical and management issues relating to the **treatment** and **distribution** of water are discussed as well as the role of surveillance and co-operative partnerships in improving water quality. The discussion of technical issues is limited to **conventional treatment** (coagulation, flocculation, sedimentation, filtration, disinfection and stabilisation) only. Community education in water related health and hygiene matters is not discussed but the importance of two-way **communication between consumers and water services institutions** is emphasized.

The guidelines specify a minimum set of practices that water service authorities and providers need to put in place to ensure water supplied to consumers meets the compulsory national standards as soon as possible. However, they should be seen only the first step and water service institutions need to continue to work towards all of the goals articulated in the *National Framework* (DWAF, 2003), particularly the integrated sustainable management of water resources, in order to ensure an adequate quantity and quality of potable water.

4.1.2 Structure of the guidelines

Section4.2 discusses the **legal aspects** of the provision of safe drinking water. Both the **regulations** relating to drinking water quality and the **responsibilities of the various role-players** in the water sector are discussed.

Section 4.3 discusses **technical aspects** of the production of safe drinking water including the operation of treatment plants and distribution systems and the need for adequate process control measures. The focus is on specific problems and deficiencies which typically plague the operation of small treatment plants in rural areas.

Getting the technical issues right requires **effective management**. **Section 4.4** describes several management issues which require attention in small municipalities providing water services. These include defining responsibilities, improving communication, developing effective partnerships and capacity building, surveillance and quality control.

Section 4.5 provides a summary and overview of **strategies** for ensuring the sustainable production of microbiologically safe drinking water.

4.1.3 Important sources of free information

These guidelines make frequent reference to several other documents and guidelines published by the Department of Water Affairs and Forestry (DWAF) and the South African Water Research Commission (WRC). These include

- *Quality of Domestic Water Supplies*
    - *Volume 1: Assessment Guide*
    - *Volume 2: Sampling Guide*
    - *Volume 3: Analysis Guide*
    - *Volume 4: Treatment Guide*
    - *Volume 5: Management Guide*
- *The South African Water Quality Guidelines*

The above publications can be downloaded at http://www.dwaf.gov.za/IWQS/report.htm. Several important documents on water services regulation and policy can also be downloaded from http://www.dwaf.gov.za/Documents/ from the **Government Notices: Related to Water Services**, **Other: Water Services** and **Water-Related Legislation** sections. These include:

- *Water Services Act - 1997 (No. 108 of 1997)*
- *Regulations Relating to Compulsory National Standards and Measures to Conserve Water*
- *Strategic Framework for Water Services* (Previously called Draft White Paper on Water Services)
- *Guidelines for Compulsory National Standards and Norms and Standards for Water Services Tariffs*

The internet addresses of all these publications are given in the References section. In addition, anyone in South Africa can request free copies of most Water Research Commission publications. These include research reports on many of the technologies currently used in rural treatment plants including many not discussed in these guidelines. Unfortunately, many of the municipal personnel involved in water supply are not aware that these resources exist or do not know how to access them. A list of WRC publications can be found on the WRC web page: http://www.wrc.org.za. Click on the **publications** link. Information for ordering publications is also provided on the website or can be obtained by calling 012-330-0340 or faxing 012-331-2565.

4.1.4 Definitions, terminology and acronyms

Calcium carbonate precipitation potentional (CCPP): the amount of calcium carbonate which can be precipitated from water (in mg/L).

Coagulant: a chemical added to raw water to produce floc. Sometimes also referred to as a flocculant.

DWAF: Department of Water Affairs and Forestry.

Distribution system: this refers to the network of pipes, storage reservoirs and pumps between the treatment plant and the consumer's tap.

Filter media: sand or other granular material used in filters.

Point of delivery: this refers to the tap at which water is collected. It may be a tap in a building or private residence, a yard tap or a public stand pipe. It may not be the same as the **point of use**. For example, consumers or water vendors may collect water at public standpipe and then use it somewhere else. The water service provider is responsible for the quality of the water up to the point of delivery only.

Finished water: finished water refers to the water leaving the on-site storage reservoir or chlorine contact chamber and entering the distribution system.

Pathogens: micro-rganisms which cause diseases.

Surface water: water resources which flow above the ground (rivers, lakes, dams) as opposed to below the ground (groundwater).

Solubility: the tendency of a chemical to dissolve in water.

Water services institutions: institutions involved in the provision of water services.

Water treatment: in this document, water treatment refers to the treatment of raw water to produce drinking water.

WSA: Water Services Authority.

WSP: Water Services Provider.

WHO: World Health Organisation.

4.2 REGULATORY ISSUES

This section discusses the legal requirements for the safety of drinking water in terms of the Constitution and the 1997 Water Service Act. Section 2.1 discusses the responsibility of the water service and authorities to provide consumers with an adequate **quality** of water while Sections 2.2 and 2.3 discuss the **specifications** for drinking water quality, which have to be met (Compulsory National Standards). Section 2.4 discusses the responsibility of Provincial and National government to monitor the performance of Water Service Authorities with respect to drinking water quality and to support efforts to comply with the compulsory national standards.

4.2.1 Responsibility for the provision of safe drinking water

The Constitution of South Africa (1996) defines access to safe drinking water as a basic human right. The responsibility for providing access to water services (water and sanitation) is assigned to local government while national and provincial government are tasked with supporting, monitoring and regulating local government in the performance of its constitutionally mandated functions (Mackintosh et al., *2004).*

The Water Services Act (1997) and *Strategic Framework for Water Services* (2003) define various types of institutions which are responsible for providing water services:

- **A Water Service Authority** (WSA) is a municipality which has executive authority to supply water services to its area of jurisdiction in terms of the *Municipal Structures Act* (1998) or the ministerial authorisations made in terms of this Act (DWAF, 2003). According to the *Municipal Structures Amendment Act* (2000), the role of WSA is usually assigned to **District Municipalities**. The responsibilities of WSAs include:
    - Progressively ensuring access to basic water services to all people living under their jurisdiction.
    - Making and regulating contracts for the provision of water services with water service providers (WSPs) in their areas of jurisdiction. Regulating WSPs **includes** monitoring their performance in terms of producing water of a **quality** which conforms to **compulsory national standards** (discussed in Section 2.2).

- o Ensuring adequate investments are made in water services infrastructure, including maintenance, repair and replacement of equipment when necessary (Section 4.2 in *Strategic Framework for Water Services*, DWAF, 2003)

District Municipalities, whether they are WSAs or not, have primary responsibility for health and hygiene education related to water and sanitation services (Section 3.6.4 in *Strategic Framework for Water Services*, DWAF, 2003).

- **A Water Service Provider** (WSP) is an organisation which assumes **operational responsibility** for the provision of water services to consumers or other water service providers. The role of water service provider is typically assigned to **local municipalities** but in some areas, this function is performed by **Water Boards**. In some cases, Water Service Authorities may also act as Water Service Providers. Specifically, the Engineering or Water Services Department of the WSA is assigned the role of WSP. However, since WSAs are required to regulate WSPs it is preferable for them to be separate institutions in order to avoid conflicts of interest. When a WSA is also a WSP, the Engineering Services Department usually assumes the role of WSP (DWAF, 2003).

Responsibility for the safety of water supplied to consumers is therefore shared by both the WSAs and the WSPs: the WSPs are required to provide water of a safe quality while the WSAs must ensure that they do so through monitoring and regulation (by-laws). Section 2.2 discusses the legal requirements for monitoring the safety of drinking water while Section 3 provides guidance on operational issues which affect the microbial quality of the water. Both types of water institutions must work together to ensure that water treatment works, storage reservoirs and distribution networks are properly maintained and have adequate resources and appropriately trained personnel to ensure the efficient provision of safe drinking water.

Water Service Providers are responsible for the provision of safe drinking water while **Water Service Authorities** are responsible for monitoring and regulating the performance of the Water Service Providers.

4.2.2 Compulsory National Standards for potable water

According to Section 9 (l) of the 1997 Water Services Act, the Minister of Water Affairs and Forestry may introduce compulsory national standards for various aspects of water services delivery. Regulations relating to compulsory national standards for **potable water quality** were published in the *Government Gazette, Vol. 432 No. 22355, 8 June 2001*. Guidance on the interpretation and implementation of these regulations is provided in *Guidelines for Compulsory National Standards and Norms and Standards for Water Services Tariffs* (DWAF, 2002b). The regulations require that water supplied by water service providers which is intended for drinking or domestic purposes must be of a quality consistent with **SABS 241** (Specifications for Drinking Water, South African Bureau of Standards), as may be amended from time to time. In order to ensure that these standards are met, the regulations also specifically require WSAs to **monitor** and **report** on the quality of water produced. Furthermore, the regulations specify the **steps which must be taken** if quality of water does not meet the required standards. The relevant regulations state the following:

Sub-regulation 5.(1)

Within two years of the promulgation of these regulations (i.e. by June 2003) every WSA must have developed a programme for sampling the quality of potable water provided to consumers in its area of jurisdiction.

Sub-regulation 5.(2)

The sampling programme must specify the sampling points, frequency of sampling and for which substances and determinants the samples will be tested.

Sub-regulation 5.(3)

Water services institutions must compare results from the sampling programme with ***SABS 241: Specifications for Drinking Water*** or the ***South African Water Quality Guidelines*** published by DWAF.

Sub-regulation 5.(4)

Should the comparison of the results as contemplated in sub-regulation (3) indicate that the water supplied poses a health risk to consumers, the water services institution must inform the Director-General of the Department of Water Affairs and Forestry and the head of the relevant Provincial Department of Health and **it must take steps to inform its consumers** –

a) that the quality of the water that it supplies **poses a health risk;**
b) of the reasons for the health risk;
c) of any **precautions to be taken by the consumers**; and
d) of the time frame, if any, within which it may be expected that water of a safe quality will be provided.

With respect to sub-regulation 5.(3), *SABS 241* (SABS, 2001) provides specific allowed ranges of values for regulated contaminants while the *South African Water Quality Guidelines* (DWAF, only discuss the health affects associated with different levels of contaminants. The revised definition of potable water (Annexure 3 of the *Strategic Framework for Water Services*, DWAF, 2003) refers only to *SABS 241*, i.e. water quality samples are required to be compared to these standards only. However, the *Water Quality Guidelines* provide the rationale behind the standards so personnel involved in treatment and water quality issues should be familiar with its contents.

SABS-241 can be purchased from the South African Bureau of Standards (Pretoria South Africa) while the *Water Quality Guidelines* (DWAF, 1996) can be downloaded free of charge from the DWAF website. Another DWAF publication *Quality of Domestic Water Supplies Volume 1: Assessment Guide* (DWAF, 1998) provides water quality guidelines which closely correspond to *SABS -241* (See Section 4.1.3 for information on how to obtain these publications). Note that all three of these publications will be updated from time to time and Water Service Institutions need to keep up to date with any changes introduced.

Where local government structures lack the resources to carry out the required monitoring, co-operative government requirements specify that Provincial and National Government must ensure that monitoring takes place (Mackintosh, 2004).

- Each Water Service Authority must implement a programme for monitoring the quality of drinking water provided to consumers.
- Compulsory national standards for the quality of the water provided are defined in **SABS-241**.
- If water testing indicates that the quality of water poses a health risk to consumers then **both** the authorities listed in Sub-regulation 5.(4) and the affected consumers must be informed immediately

If the new regulations relating to the compulsory national standards are contravened, the Water Services Authority (District or Local Municipal council) will be held accountable (Mackintosh *et al.*, 2004b). If the responsibility for water services has been delegated to a specific official such as a Chief Executive Officer or City Engineer/Town Engineer/Technical Director, the latter becomes co-responsible. If the responsibility is delegated, and the designated technical officer/Town Engineer cannot perform his duties in accordance with the regulation, he is obliged to inform the Water Services Authority of the situation and the possible repercussions. If he neglects to inform council, he becomes liable. If he does notify council, the onus is on council to make available sufficient resources to enable the technical officer to implement the necessary, to conform to the regulation.

The *Water Services Act* in its current form does **<u>not</u>** criminalise non-compliance with national standards (Mackintosh et al., 2004a)., however, it does make it an offense for any person to "fail or refuse to give information or to give false and misleading information when required to give information in terms of this Act". Therefore, as long as Water Service Authorities comply with their obligations under Sub-Regulation 5.(4) they minimise their risk of incurring penalties under the this Act.

4.2.3 Potable water quality and monitoring requirements as defined by SABS-241

In all, ***SABS 241-2001*** specifies compulsory standards for 36 physical, chemical and organoleptic parameters and 8 microbial contaminants. However, it is accepted that routine analysis for the full range of contaminants specified will often be prohibitively expensive, especially for smaller municipalities. Therefore, the following minimum list of parameters for monitoring of ongoing operation efficiency must be considered: **conductivity or dissolved solids, pH, turbidity, faecal coliforms or *E. coli*** and **residuals of treatment chemicals and disinfectants** (for example, if the coagulant used contains aluminium, the aluminium content of the finished water should be measured).

In addition, the following 6 contaminants should be monitored in the **raw water** to determine its continued acceptability as a raw water source: **fluoride as F^-, nitrate and nitrite as N, heterotrophic plate count, iron as Fe, manganese as Mn** and **arsenic as As**. The acceptability of the raw water source is assessed in terms of being able to meet at least the minimum allowable standards (maximum contaminant levels) in the treated water. For guidance on assessing the suitability of raw water sources, see *Quality of Domestic Water Supplies Volume 1: Assessment Guide* (DWAF *et al.*, 1998). Some water treatment plants have the option of switching between multiple raw water sources depending on water quality. Others may need to consider developing alternate raw water sources and/or implementing environmental control measures to improve the quality of their current source.

Note that all water treatment plants and all water service providers should at the very minimum have their own equipment to monitor **turbidity, pH** and **free chlorine residual** as part as their

Minimum set of water quality parameters to be monitored:

Finished Water

- Conductivity or TDS
- pH
- turbidity
- faecal coliforms or *E.Coli*
- treatment chemical residuals (Al or Fe and free chlorine)

Raw Water

In addition to the above

- fluoride
- nitrate and nitrite
- heterotrophic plate counts
- iron

routine operation (See Section 4.3.4). The other determinants will often be measured at off-site laboratories usually by external organisations.

SABS-241- 2001 specifies three different classes of water in terms of physical, microbial and chemical quality:

- Class 0: an ideal standard largely based on first world standards (pertaining to the European Union and United States of America).
- Class I: water that is known to be acceptable for a whole lifetime of consumption.
- Class II: water that is considered to be the minimum allowable quality for short-term consumption (usual and continuous daily consumption for periods not exceeding one year).

South African water service institutions are required to aim to consistently achieve at least Class I quality drinking water with respect to **physical**, **chemical** and **organoleptic** parameters. The inclusion of the Class II category in the standards is an acknowledgement that at present and for the foreseeable future many WSPs will not be able to consistently produce and distribute Class I quality water and that labelling municipal piped water as "unfit for human consumption" if it only marginally fails to meet Class I standards may drive consumers to potentially worse quality and possibly illegal sources of drinking water (Mackintosh *et al.*, 2004a). The standards specify the maximum allowable time periods for Class II levels of each contaminant. Table 4.1 lists the standards for the minimum suggested set of physical and chemical parameters.

SABS 241 – 2001 does not specify upper or lower limits for the **free chlorine residual**, however, with the exception of plants which do not use chlorine disinfectants; this is a parameter which **must** be monitored on a daily basis. Guidelines for free chlorine residuals are discussed in Section 4.3.2.2.

The requirements regarding the **microbial** quality of the water are more complicated. The microbial standards are reproduced in Table 4.2. For any given year, at least 95 % of samples must not exceed the value given in Column 3 (Class 0), no more than 4 % may be greater than Column 3 but less than Column 4 (Class I), and no more than 1 % may be greater than Column 4 but less than Column 5 (Class II). If any sample exceeds the value in Column 5 then immediate re-sampling and appropriate remedial reaction is required until the water quality complies at least with Column 5.

The requirements for compliance with the microbial standards are stricter than for the chemical and physical requirements because the chemical contaminants typically found in drinking water generally only have significant adverse affects after long-term exposure, whereas poor microbial quality poses an immediate health risk to consumers.

Water services providers which are unable to meet Class I standards are required to take action to improve the quality of their treated water. Water that fails to meet Class II standards, in particular with regard to bacteriological standards is considered unfit for human consumption and urgent action is required including notification of the authorities and consumers as specified Sub-Regulation 5.(4) discussed previously.

TABLE 4.1

***SABS 241 – 2001*: PHYSICAL, ORGANOLEPTIC AND CHEMICAL REQUIREMENTS**

Determinant	**Units**	**Upper limit and Ranges**			**Max. allowable period for consumption of Class II water**
		Class 0 (Ideal)	**Class I (Acceptable)**	**Class II (Max. allowable)**	
Conductivity at 25 ^{0}C	mS/m	< 70	70 - 150	150 - 370	7 years
pH at 25 ^{0}C	pH units	6.0-9.0	5.0 - 9.5	4.0 - 10.0	No primary health effect – extreme pH's can cause structural problems in the distribution system
Turbidity	NTU	< 0.1	0.1 – 1	1 - 10	No limit but high turbidities indicate treatment inefficiencies and risks associated with pathogens
Fluoride as F^-	mg/L	< 0.7	0.7 - 1.0	1.0 - 1.5	1 year
Nitrites and nitrates as N*	mg/L	< 6.0	6.0 - 10.0	10.0 - 20.0	7 years
Iron as Fe^-	µg/L **	< 10	10 - 200	200 - 2000	7 years based on aesthetic rather than health effects
Manganese as Mn	µg/L **	< 50	50 - 100	100 - 1000	7 years
Arsenic as As	µg/L **	< 10	10 – 50	50 - 200	3 months
Aluminium as Al	µg/L **	< 150	150 – 300	300 - 500	1 year

* Note that nitrates are a component of commercial fertilisers and therefore may be a problem in agricultural areas

** 1 µg/L = 0,001 mg/L and 1000 □g/L = 1 mg/L

TABLE 4.2

***SABS 241 – 2001*: MICROBIAL REQUIREMENTS**

(1)	**(2)**	**(3)**	**(4)**	**(5)**
Determinant	Units	Allowable compliance contribution		
		95 % min.	4 % max.	1 % max.
		Upper Limits		
Heterotrophic Plate Count	Counts/mL	100	1000	10000
Total Coliform	Counts/100 mL	Not detected	10	100
Faecal coliform	Counts/100 mL	Not detected	1	10
Somatic coliphages	Counts/10 L	Not detected	1	10
Enteric viruses	Counts/100 L	Not detected	1	10
Protozoan parasites	Counts/100 L	Not detected	1	10

It is important that all samplings and analysis for regulatory compliance be carried out by properly trained personnel using approved techniques Guidance on sampling techniques and the design of sampling programmes that are provided in *SABS ISO 5667* and in *Water Quality of Domestic Water Supplies Volume 2: Sampling Guide* (DWAF *et al.*, 2002a). Guidance on sample analysis can be found in *Quality of Domestic Water Supplies Volume 3: Analysis Guide* (DWAF *et al.*, 2002b). Both DWAF publications can be downloaded free from the DWAF website or ordered from the Water Research Commission (See Section 1.5).

The number of samples that should be collected for monitoring purposes depends on a wide range of factors including climatic (weather) conditions, human and industrial activities,

> Sampling and analysis for regulatory compliance must be carried out by properly trained personnel using approved techniques Guidance on sampling and analysis techniques are provided *SABS ISO 5667* and Voluems 2 and 3 of *Quality of Domestic Water Supplies* (DWAF *et al.*, 2002a and b).

volume of water treated and distributed, area covered by the reticulation system and the capabilities of the analytical facility (SABS, 2001). These all need to be taken into consideration in drawing up an appropriate sampling plan. The minimum suggested frequency of sampling based on population served is given in Table 4.3.

TABLE 4.3 **MINIMUM SUGGESTED SAMPLING FREQUENCY (*SABS 241-2001*)**	
Population served	Minimum number of samples per month*
More than 100 000	10 per 100 0000
25 001 – 100 000	10
10 001 – 25 000	3
2 500 – 10 000	2
Less than 2 500	1

* Sampling should be more frequent during rainy season

EXAMPLES

1) A WSA collects 36 samples from consumers taps in a given supply area over the course of one year. The results of the faecal coliforms analysis are as follows:
    - Number of samples with 0 Faecal Colifoms = 35 samples = 97 %
    - Number of samples with 1 Faecal Coliform/100 mL = 1 sample = 3 %
    - Number of samples with > 1 Faecal Colifomr/100 mL = 0

Based on these results, the water in this supply area complies with the compulsory national standards for microbial quality of potable water.

2) A different WSA collects 36 samples from a similar town as in example 1). This time, the results are as follows:
    - Number of samples with 0 Faecal Colifoms = 34 samples = 94 %
    - Number of samples with 1 Faecal Coliform/100 mL = 1 sample = 3 %
    - Number of samples with > 1 Faecal Colifomr/100 mL = 1 sample = 3 % (actual result is 3 Faecal Coliforms/100 mL

According to these results, the water in this supply zone technically fails to meet the Compulsory National Standards. However, the failure is marginal. Part of the problem is that if so few samples collected, if even one falls in column 5, then the results overall fail to comply with the standards. One solution may be to increase the number of samples collected to at least 100 per year. The WSA and WSP should also look for possible reasons for the one bad sample e.g. heavy rainfalls a few days earlier, temporary disruption in dosing, a pipeline leak close to where the sample was taken.

3) In a different municipality, 50 samples are collected over a one year period. The results are as follows:
   - Number of samples with 0 Faecal Colifoms = 5 samples = 10 %
   - Number of samples with 1 Faecal Coliform/100 mL = 3 sample s= 6 %
   - Number of samples with > 1 Faecal Colifomr/100 mL = 42 samples = 84 %

   In this supply zone, the water fails to meet microbial standards by a wide margin and poses a significant risk to consumers' health. Urgent action is required to determine the cause of the failure and to correct the problem.

4) If any one sample contains more than 10 Faecal Coliforms/100 mL then sub-regulation 5.(4) applies.

4.2.4 Requirements for National and Provincial Government to monitor and support Local Government

As the national **regulatory** authority, DWAF has the responsibility of ensuring that water services institutions producing water for drinking and domestic purposes comply with the Compulsory National Standards. However, co-operative governance principles as well as the realities of the South African situation require both national and provincial government to play a **supportive** role (capacity building) in assisting local governments to achieve progressive improvements in their performance. Therefore an appropriate balance has to be struck between the regulatory and supportive functions in order to best serve the interests of the public in the long term. Key issues are the **openness** of municipalities in admitting and reporting problems, their **willingness** to make necessary corrections to their operations and their **capacity** to do so.

Section 62 of the **Water Services Act** requires the Minister of Water Affairs to monitor **every water services institution** in order to ensure compliance with prescribed national standards. This is primarily done through a **water services audit** which each Water Services Authority is required to submit as part of its annual report on the implementation of its water services development plan (Sub-regulation 10 under *Regulations Relating to Compulsory National Standards and Measures to Conserve Water, Government Gazette No. 22355, June 2001*). The water services audit must include the **water quality sampling programme** contemplated in regulation 5(1), the results of the comparison set out in regulation 5(3) and any occurrence reported in compliance with regulation 5(4). In addition, each WSA must report on the number of households (and % of total households supplied by formal piped system) which **do not** receive water of an adequate quality as defined by *SABS-241* (Annexure 2: Key Performance Indicators for Water Service Authorities in *Strategic Framework for Water Services, DWAF*, 2003).

If a WSA fails to comply with legislative requirements, including those for the quality of water supplied, then DWAF must take the following steps (Section 7 in *Strategic Framework for Water Services*, DWAF, 2003):

1) First DWAF must **request compliance**.

2) If the WSA expresses a sincere **willingness** to comply but has **genuine constraints** which make it unable to comply then DWAF and provincial must provide **support** to correct the problems through one or more of the following mechanisms (For details, see *Strategic Framework for Water Services*, Section 8, DWAF 2003):
   (a) Capacity building grants
   (b) Establishing knowledge networks
   (c) Providing advisory services
   (d) Development of guidelines and tools (this document is an example)
   (e) Strategic support including technical assistance
   (f) Training and skills development

3) However, if a WSA **refuses to comply** or is **negligent in complying** and has the capacity to do so, then DWAF and provincial government may attempt to secure compliance through any of the following mechanisms:
   (a) **Publicize the failure** so that the public will exert pressure on the WSA to comply
   (b) Together with the National Treasury, Department of Provincial and Local Government (DPLG) and relevant provincial departments, DWAF can exert **financial pressure** by withholding capital funds.
   (c) If options (a) and (b) fail to secure compliance then **direct intervention** may be considered. This may include taking over the running of the water services for a limited period of time.
   (d) As a final resort, DWAF may take **legal action** against the WSA.

4.3 ACHIEVING EFFECTIVE DISINFECTION - TECHNICAL ISSUES

Ensuring that the water that consumers receive is safe to drink from a microbial point of view involves four steps:

1. Protecting the source water from contamination e.g. from pollution from human and animal faeces, rubbish and litter, sludge and inadequately treated effluent from municipal wastewater treatment plants and from industry
2. Adequate purification and disinfection of the water in the water treatment plant.
3. Maintaining the integrity of the distribution system and ensuring an adequate chlorine residual throughout the system
4. Safe handling and storage of water by consumers.

It is envisioned that the **source water protection** (Step 1) will be the joint responsibility of **Catchment Management Agencies**, Water Service Authorities and Water Services Providers. This is discussed briefly in **Section 4.3.1**.The second two steps are primarily the responsibility of the Water Service Providers with the Water Services Authorities closely monitoring their performance. These two steps are the main focus of these guidelines. **Water treatment** for pathogen control is discussed in **Section 4.3.2** while the **operation of distribution systems** is discussed in **Section 4.3.3**. **Safe handling and storage of water** is the responsibility of **consumers**, however, **District Municipalities** are responsible for **public education** on matters of health and hygiene related to water and sanitation. (For more information on step 4, see Jagals *et al.* (1997); Momba and Kaleni (2002), Momba and Nosthe (2003) and Nala *et al.* (2003) and for more details on the responsibilities of various spheres of government as well as consumers, see DWAF's *Quality of Domestic Water Supplies Volume 5: Management Guide* (DWAF *et al.*, 2002d)). A critical part of the efficient operation of both the treatment plant and the distribution system is the introduction of appropriate **process control measures**. These are discussed in **Section 4.3.4**.

4.3.1 Source water protection

4.3.1.1 Sources of contamination

Pathogens in the raw water generally come from a variety of sources with **faecal matter** from humans, livestock and wild animals being the primary concern. Major sources of faecal contamination include inadequate sanitation facilities, leaking pit latrines, overflowing sewers, livestock farming and inadequately treated sludges and effluents from water and wastewater treatment plants. Chemicals which are harmful to water quality and human health may wash into rivers and dams from cultivated lands (fertilizers and pesticides), off roads and parking lots (petrol and oil products), and from rubbish and litter including abandoned cars dumped closed to the water source. Industrial wastewater discharges and leaking chemical storage tanks are also a concern in some areas. High levels of nitrate and phosphate (usually from agriculture and industrial and wastewater effluent discharges) promote the growth of algae in surface waters. Algae cause problems with the settling and filtration steps of treatment and may also release toxic substances into the water. Soil erosion during heavy rainfall and as a result of poor land management practices increases both the turbidity and number of pathogens in the raw water.

In general, **groundwater** (from boreholes) has less microbial contamination than **surface water** (from rivers, lakes and dams) because soil tends to filter microbes out. However, groundwater can still be contaminated by pit latrines and leaking septic tanks. Furthermore, the closer a borehole is to a body of surface water, the more likely the groundwater is to be contaminated with the same chemicals and microorganisms as the surface water. For more details on the types of and sources of contaminants expected in South African raw water supplies, see DWAF's *Quality of Domestic Water Supplies Volume 5: Management Guide* (DWAF *et al.*, 2002d).

4.3.1.2 Need for source water protection

The quality of the raw water being used for drinking water production is of concern because the lower the levels of contaminants in the raw water, the less likely they are to survive purification and disinfection to find their way into the finished water. Conversely, if pathogen levels in the raw water become very high, it becomes increasingly difficult for treatment plants to consistently meet the compulsory national standards, even if the efficiency of pathogen removal (total % removed) is high. For example, if there is an average of 10 faecal coliforms/100 mL in the raw water, a 99 % removal efficiency (easily achievable even in plants not performing optimally) will result in an average of 0.05 faecal coliform/ 100 mL or an average of one faecal coliform detected in 5 % of samples. This would comply with *SABS-241* (See Table 2 in Section 4.2.3).

> The higher the quality of the source water, the less likely microbial contaminants will be present in the finished water.

However, if the raw water contained 100 faecal coliforms/100 mL then 99 % removal would mean an average of 1 faecal coliform/100 mL for all samples, which would not comply with *SABS-241*. Consequently, source water protection should be considered an integral part of water treatment for domestic use.

4.3.1.3 Strategies for source water protection

Source water protection is a major topic on its own and will only be discussed briefly here. Source water protection varies widely from country to country. In some developed countries all discharges into watersheds are strictly regulated and in some cases no swimming or other recreational activities are allowed in lakes and dams used as raw water sources. In other countries, raw sewage and toxic industrial wastes are routinely dumped into rivers and lakes irrespective if they are used for drinking water, presenting a major health hazard to consumers.

In South Africa, the *National Water Act* (1998) requires that the management and protection of all water resources in a given catchment area is to be taken over by **Catchment Management Agencies**, which are currently in the process of being established. These agencies will play a major role in the protection of the raw water sources used in to producing drinking water. However, water services institutions also have a number of specific responsibilities.

Under current South African regulations, water service institutions must take measures to prevent any substance other than uncontaminated storm water from entering any storm water drain; or any watercourse, except in accordance with the provisions of the *National Water Act* (1998). This requires that every institution that discharges effluent into a water body (river, stream, lake, and reservoir) must have an authorisation to do so from the Department of Water Affairs and Forestry. The authorisation would specify the types and maximum levels of contaminants that the effluent is allowed to contain.

The progressive provision of basic sanitation facilities for poor communities as required by the *Water Services Act* (1997) should also go a long way towards reducing microbial contamination of water resources. Municipalities should also discourage the development of informal settlements on riverbanks as this is hazardous both to the residents when flooding occurs and to water quality in the river. Furthermore, while there are currently no regulations requiring it, it is in the interest of Water Services Authorities and Water Services Providers to take steps to protect their source water close to the point of abstraction. At present, it is common to find livestock grazing on river banks and people swimming and washing clothes in rivers and dams close to the abstraction point. These all contribute to the microbial contamination of the raw water. Restricting access by humans and animals to dams and sections of the river is likely to be a controversial issue. However, water service providers should at a bare minimum attempt to do the following:

- Fence off small raw water holding dams to prevent access by livestock and unauthorised personnel
- Fence off sections of larger dams close to the abstraction point
- Fence off sections of rivers upstream of river abstraction points
- Where possible, locate boreholes away from human settlements and livestock

Education about water quality issues and source water protection is essential if the local community is to accept restrictions on land use and access to raw water sources.

- Locate new housing developments away from or downstream of abstraction points wherever possible.

Communities have to be educated about source water protection if they are to accept and support these measures and alternate ways for accessing water should be considered. For example, water for livestock might be transferred (gravity or pumping) to an alternate point downstream and/or well away from the abstraction point to prevent large quantities of faecal matter getting into the raw water.

In addition, regular inspections of the raw water source, abstraction point, in-take structure and transmission line should be carried out (e.g. once a week). Any rubbish or debris should be promptly cleared away and any problems such as algae blooms or evidence of contamination should be noted.

Strategies for source water protection

- Establishment of Catchment Management Agencies and implementation of integrated water resource management (led by DWAF)
- Delivery of basic sanitation
- Effective treatment of wastewater before discharge into water bodies
- Restricting access to raw water sources close to abstraction
- Public education
- Regular inspection and maintenance of intake facilities
- Regular monitoring of raw water quality
- Development of alternate raw water sources

Ongoing monitoring of the quality of the raw water is also a regulatory requirement (See Section 4.2.2). This should be used to monitor the success of water source protection measures as well as assess the acceptability of the raw water source. Some water treatment plants have the option of switching between multiple raw water sources depending on water quality and treatability (may vary seasonally). If there is a serious and irreversible deterioration of raw water quality which makes effective treatment too expensive or too difficult, WSAs and WSPs have to seek alternative raw water sources.

4.3.2 Water treatment operations

4.3.2.1 Overview

Water treatment plants have two important and complementary functions:

- First to remove contaminants from the water
- Second to add sufficient disinfectant (usually chlorine) to the water to kill any remaining microbes and ensure an adequate disinfectant residual at the consumer's tap.

Contaminants in water can be in the form of small particles (including dirt and microbes) or in dissolved form (e.g. colour, iron and manganese). **Turbidity** is a parameter which should be measured at all treatment plants and provides an indication of the concentration of particles in water. Turbidity in the raw water is usually removed by a combination of **chemical coagulation**, **flocculation**, **settling** and **granular media filtration**. Up to **99.99 %** of microbes in the raw water can be removed by these processes before any disinfectant is added to the water (LeChevallier and Au, 2004). Furthermore, the cleaner water is (the lower the turbidity and colour) when the disinfectant is added, the more efficient the disinfection process. Consequently the more effectively particulate and dissolved contaminants are removed prior to disinfection; the less disinfectant has to be used. Therefore effective turbidity removal is very important for efficient disinfection.

The number of treatment steps required to produce good quality water from different raw water sources depends on the type and quantity of contaminants in the source water. Most municipal water treatment plants include some or all of the steps listed in Table 4.4. Figure 4.1 is a schematic representation of a typical conventional treatment plant. Raw water is pumped or flows under gravity from the abstraction point to the treatment works. Some water treatment plants have a small **holding dam** or **raw water tank on-site**. **Coagulant** is added to the raw water just before **flash** or **rapid mixing**. Many plants also add a **pH adjustment chemical** at this stage and a few add an **oxidant chemical** such as chlorine.

> Efficient disinfection quires effective turbidity removal

Floc starts to form in the **flocculation** stage, which usually consists of a baffled channel. Most small treatment plants have at least two settling tanks and two filters operating in parallel (In the Fig. 4. 1, there are 3 of each).

The flow is usually split just before or just after the flocculation channel(s). Most of the floc formed should be removed in the **settling tanks** (clarifiers) with a small amount of remaining floc being removed by the **filters**. Some treatment plants have balancing tanks between the settling tanks and filters (not shown).

TABLE 4.4

TYPICAL TREATMENT STEPS IN POTABLE WATER PRODUCTION

Step	**Description**	**Purpose**
Pre-chlorination	Addition of chlorine to the raw water.	Remove of colour, iron and/or manganese. Prevent biofilm growth in channels, settling tanks and filters.
pH adjustment/ Stabilisation	Addition of chemicals such as lime, soda ash or carbon dioxide which change the pH.	Adjust the pH to fall in a required range for good floc formation and/or to prevent corrosion or excessive scaling in the distribution system.
Coagulation	Addition and flash mixing of coagulants (also called flocculants) such as alum and/or polymer solutions to raw water	Add chemicals which produce floc. Floc contains many of the contaminants present in the original raw water.
Flocculation	Formation of floc in channels or pipes between coagulant addition and the settling tanks.	Form floc which is easily removed in the settling tanks.
Settling	Floc sinks to the bottom of the settling tank while settled water flows over the top into the settled water channels.	Removal of floc formed in coagulation and flocculation steps.
Filtration	Water is filtered through a granular media (sand and/or anthracite).	Removal of floc or particles not removed in the settling tanks.
Disinfection/ post-chlorination	Addition of chlorine to the filtered water or final water storage reservoir.	Kill off any microbes in the filter water and provide a chlorine residual to prevent later re-infection.
Finished water storage	After disinfection, the treated water flows to a storage reservoir on or near the plant.	Allow sufficient time for the chlorine to act and ensure an adequate supply of water during periods of high demand or disruptions to the operation of the plant.
Sludge settling and washwater recovery	Dirty backwash and or sludge from the settling tanks is held in settling ponds where the sludge settles to the bottom of the ponds and the supernatant is recycled to the top of the plant.	Reduces water losses on the plant and avoids discharging sludge and spent backwash water to either natural water bodies (which is illegal) or to the sewer (which requires a permit).

The filtered water is then **disinfected**, usually by the addition of some form of **chlorine**. Some plants also add a pH adjustment chemical to the filtered water for **corrosion control** (Section 4.3.2.7). However, post-pH adjustment is not common in small treatment plants in South Africa because of the additional equipment and expense involved. After chlorine addition, the treated water usually flows to an **on-site storage reservoir** before entering the **distribution system.**

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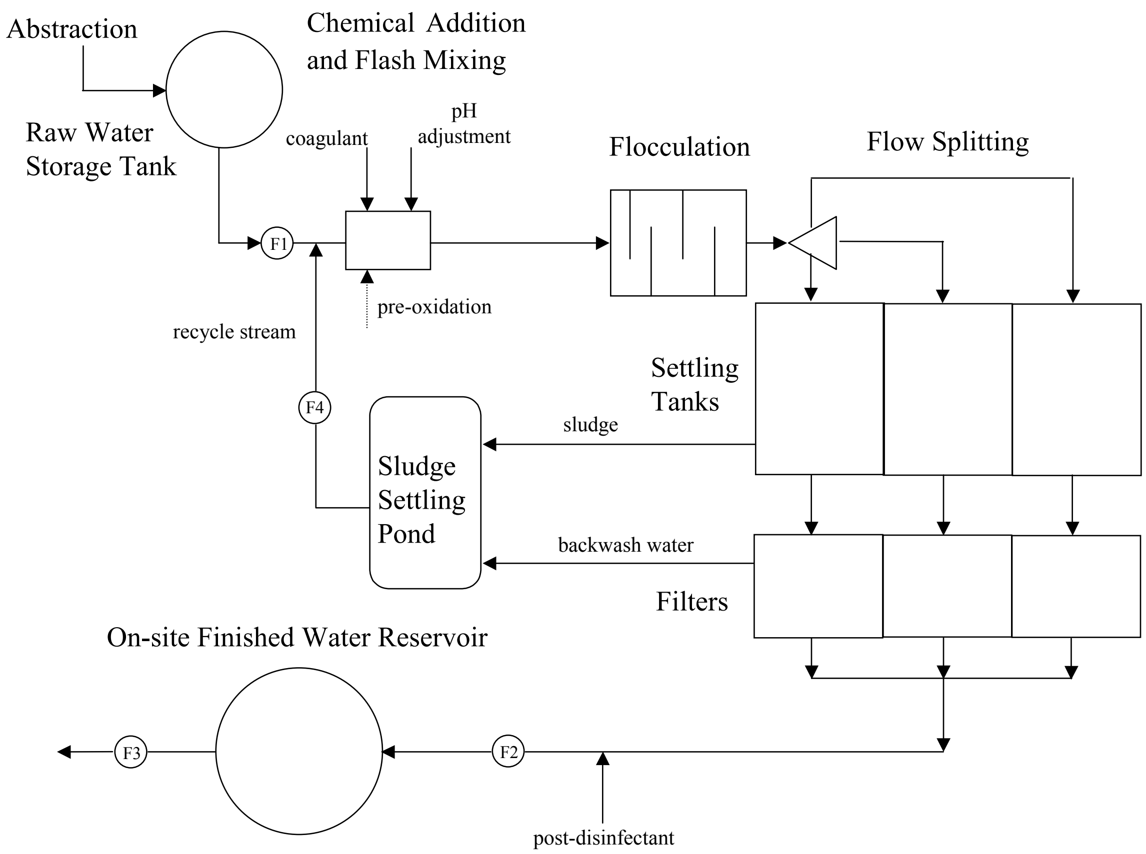


Fig. 4.1 Schematic of a conventional water treatment plant

Settling tanks have to be "**desludged**" periodically to remove settled floc. This involves opening a valve at the bottom of the settling tank to drain out the sludge that forms there. Filters clog up over time and have to be cleaned either by **backwashing** (for rapid filters) or scraping off the clogged surface layer (slow sand filters). Figure 1 also includes a system to recover water from the spent backwash and settled sludge. Sludge and dirty filter backwash water are sent to a **sludge pond** and allowed to settle out. The **supernatant** (clear upper layer formed after settling) is then pumped back to the head of the works before coagulant addition. The recovered water could also be returned to the raw water storage reservoir.

Many small treatment systems do not currently have a washwater and sludge recovery system and instead discharge sludge and spent backwash water into a nearby river, dam or onto land downhill from the plant. However, discharges of untreated sludge or backwash water tend to negatively impact the quality of the receiving water body. Under the 1998 *National Water Act*, every institution that discharges effluent into a water body (river, stream, lake, and reservoir) must have an authorisation to do so from the Department of Water Affairs and Forestry. The authorisation would specify the types and maximum levels of contaminants that the effluent is allowed to contain (DWAF, 2002b). Furthermore, DWAF is currently working on a **Waste Discharge Tariff System** which will require all institutions including water service providers to pay tariffs for all effluents discharged with the size of the tariff depending on the quantity and quality of waste. Consequently, water treatment works will face increasing pressure to install wash water and sludge treatment systems. For more information on sludge handing and disposal see Section 6.E in *Quality of Domestic Water Supplies Volume 4: Treatment Guide* (DWAF *et al.*, 2002c).

The following sections discuss each of the treatment steps in greater detail with emphasis on the **importance of each step in ensuring the microbial safety of the water**. For additional information on various treatment processes see DWAF *Treatment Guide* (DWAF *et al.*, 2002c).

4.3.2.2 Disinfection

The most critical step determining the microbial safety of water is **disinfection**. Although disinfection is usually the last step in conventional treatment it will be discussed first, because the requirements for efficient disinfection affect all the treatment processes which come before it. Water which has not first been purified (removal of particulate and dissolved contaminants) can still be disinfected, however, the disinfection process will be less efficient and the overall quality of the water will be poorer.

4.3.2.2.1 Disinfectants used

Several different types of disinfectant are in use today including various chlorine compounds, bromine, ozone and UV radiation. Chlorine compounds are by far the most commonly used disinfectants worldwide and the discussion here will be limited to the three types of chlorine most commonly used in small treatment plants: **chlorine gas**, **sodium hypochlorite** (supplied as a liquid or generated on site by electrolysis of a salt solution) and **calcium hypochlorite** (usually supplied as granular HTH). During emergency situations, for example the cholera outbreaks in KwaZulu-Natal, households may be advised to disinfect their own drinking water using household bleach (Jik) which is a sodium hypochlorite solution. Chlorine based disinfectants **<u>not</u>** discussed here include chlorine dioxide and chloramines.

Using chlorine gas is usually the cheapest option; however, there are significant safety issues involved. Consequently, many smaller plants opt for granular HTH ($Ca(OCl)_2$) which is much safer and easier to transport, handle and store and which does not require specialized dosing equipment. A few small plants as well as some major urban plants use sodium hypochlorite (NaOCl) solution generated on site.

Chlorine gas is supplied in pressurised gas bottles or tanks. The gas is dissolved in a small side stream of water in a device known as the **chlorinator** and then dosed into the main flow. The gas flow from the tank is controlled by a **regulator** on the gas bottle and is typically measured by a device known as a rotameter. A control knob on the rotameter is usually used to set the gas flow rate.

Fig. 4.2 shows a gas chlorination system at a small treatment plant. Note that there are two problems with the set up in the photograph. Firstly, although there is a spare gas bottle, there is no back up dosing system. Since chlorination is critical to the production of safe drinking water, all plants need to have a back up dosing system. Secondly, for safety reasons, the gas bottles including the bottle in service should be kept in a separate room to the chlorinator and the gas rotameter (Kawamura, 1991; Thompson, 2003).

Solutions of sodium hypochlorite and HTH dissolved in water are usually dosed using **dosing pumps**. Dosing pumps for liquid solutions are discussed further in Section **4.2.4.2**.

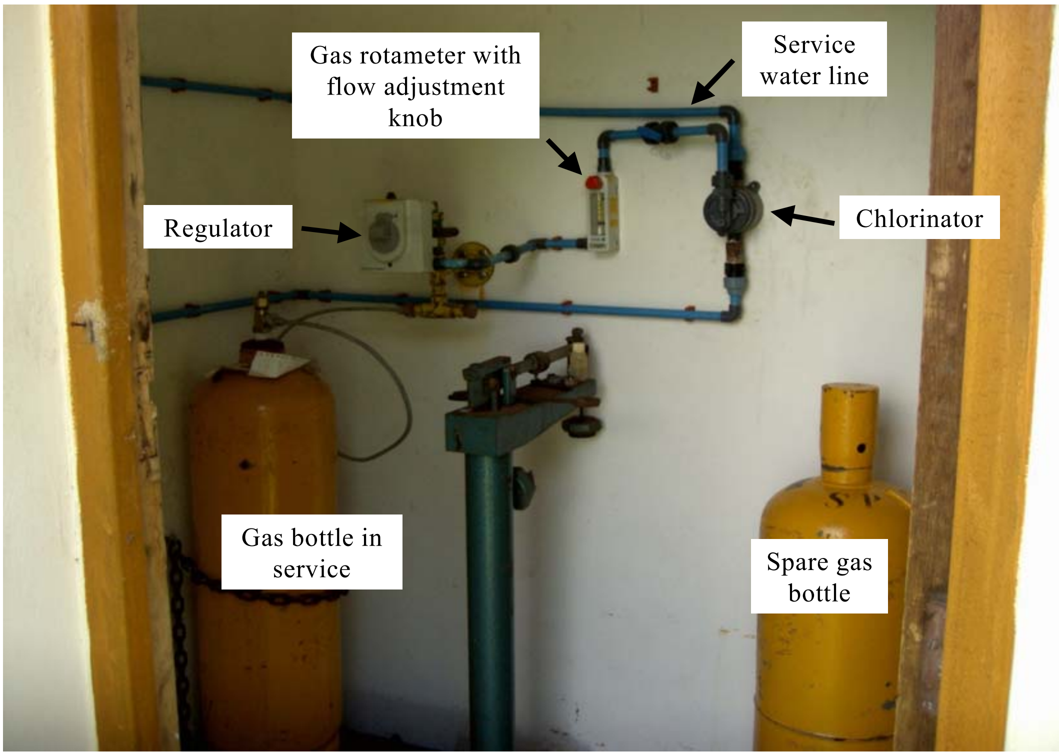


Fig. 4.2 Gas chlorination system at a small water treatment plant

4.3.2.2.2 Chlorine chemistry and disinfection efficiency

In order to use chlorine disinfectants most effectively, it is important to understand something about their chemistry and disinfectant (microbe killing) power. When chlorine gas ($Cl_{2(g)}$) dissolves in water (H_2O), it forms one molecule of **hypochlorous acid** (HOCl) plus one chloride ion (Cl^-) for each molecule of $Cl_{2(g)}$ dissolved (For an explanation of molecules and ions see Note Box 2 page 12 of *Quality of Domestic Water Volume 3: Analysis Guide* (DWAF *et al.*, 1998))

$$Cl_{2(g)} + H_2O \rightarrow HOCl + H^+ + Cl^-$$

Hypochlorous acid dissociates (splits up) to form hydrogen and **hydrochlorite ions** (OCl^-)

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

All of the disinfectant capability of the chlorine gas resides with either the undissociated HOCl or the OCl^- ion – the chloride ion (Cl^-) has no ability to kill microbes at the concentrations which occur in drinking water. If either sodium or calcium hypochlorite is used as the source of chlorine, each will yield OCl^- upon dissociation in water. Sodium hypochlorite will release one hypochlorite ion per molecule sodium hypochlorite while calcium chlorite will release two hypochlorite ions per molecule:

$$NaOCl \rightarrow Na^+ + OCl^-$$

$$Ca(OCl)_2 \rightarrow Ca^{2+} + 2OCl^-$$

The hypochlorite ions can recombine with hydrogen ions water to form hypochlorous acid in the reverse of the dissociation reaction above (The double arrow shows that the reaction can go both ways). The distribution between HOCl and OCl^- (relative amounts of each formed) depends on the pH of the water. HOCl and OCl^- are present in approximately equal amounts at pH 7.4. At lower pH's, more HOCl will be formed while at higher pH's more OCl^- will be formed. This is important because HOCl is estimated to be about 100 times more effective as a disinfectant than is OCl^-, making chlorine disinfection more effective at low pH (Hrudey and Hrudey, 2004). Table 4.5 shows the relative amounts of hypochlorite ion and hypochlorous acid at pH's between 7.0 and 10.0.

TABLE 4.5 DISSOCIATION OF HYPOCHLOROUS ACID AS A FUNCTION OF pH (SNOEYINK AND JENKINS, 1980)		
pH	**% HOCl**	**%OCl^-**
7	78	22
8	28	72
9	4	96
10	0	100

The optimum pH of the finished water typically falls in the range **6.5 – 8.0** depending on the characteristics of the water and the materials used in the distribution. This is a compromise between maximizing disinfection efficiency and minimizing the potential for corrosion.

Disinfection is most efficient in the pH range 5 to 7. However the lower the pH of the finished water, the more **corrosive** it tends to be to materials used in the distribution system. pH and corrosion control are discussed further in Section 3.2.7. The optimum pH for each treatment system depends on the characteristics of both the water and the materials in the distribution system. However, as a general rule, it tends to fall in the pH range 6.5 – 8.0 (Chapter 10 in WHO, 2004). The WHO guideline for effective disinfection is based on a finished water pH not greater than 8.0 (WHO, 2004).

Note that dissolving **chlorine gas** in water tends to **decrease** the pH of the water due to the formation of hydrochloric acid whereas the addition of either **sodium** or **calcium hypochlorite** tends to **raise** the pH. Adding calcium hypochlorite also tends to increase the calcium concentration of the water which can be beneficial for corrosion control (See Section 3.2.7).

The sum of the concentrations of HOCl and OCl^- in a water sample is known as the **free chlorine** concentration (usually given in units of mg/L Cl).

$$\text{Free chlorine} = HOCl + OCl^-$$

Since these two forms of chlorine are available for killing microbes, free chlorine is sometimes also referred to as **free available chlorine**. In addition to destroying microbes, free chlorine also tends to react with other compounds and particles in the water, especially organics (chemical compounds of plant, animal or bacterial origin) to form a range of chlorinated compounds. Compounds formed from the reaction of chlorine with ammonia or organic amino compounds are collectively termed **combined chlorine**. The sum of the free and the combined chlorine is known as the **total chlorine**.

Total chlorine = Free chlorine + Combined chlorine

Chlorinated organics generally have a negligible ability to kill germs at the concentrations involved, consequently, only the free chlorine component of the total chlorine is relevant to disinfection. An exception occurs when ammonia is deliberated added to water along with chlorine to form inorganic chloramines in a process known as chloramination. However, chloramination is seldom used in small treatment works because of safety issues. Therefore it is not discussed here.

The **free chlorine residual** (usually referred to simply as the chlorine residual) is the free chlorine concentration measured in a water sample after the chlorine has had some specified time (referred to as the **contact time**) to react with various chlorine consuming compounds in the water.

Plant supervisors must ensure that they are measuring the free chlorine residual in their finished water. The tablets or powders used should be labelled "**DPD 1**" or "**Free chlorine**".

It is important for plant supervisors to make sure that they are measuring **free chlorine** (**DPD 1** tablets or equivalent) and not one of the other forms of chlorine (DPD greater than 1). During a recent survey of treatment plants, the authors found some plants were using DPD 3 tablets instead of DPD 1 which means that they were actually measuring total chlorine rather than free chlorine. Consequently, they may have been overestimating the chlorine residual actually available for disinfection.

One of the main advantages of using chlorine compounds as disinfectants is their ability to produce **free chlorine residuals** which may persist for days during storage and distribution of the treated water. This offers some protection against re-infection of the water and helps to prevent the growth of biofilms (coatings of living bacteria) on the pipe walls. The chlorine residual remaining in a sample after a given **contact time** depends on the initial dose and the concentrations of all compounds which will react with the free chlorine. The **chlorine demand** is defined as the difference between the free chlorine dose and the chlorine residual (all expressed in units of mg/L Cl).

Chlorine demand = Free chlorine dose – Chlorine residual

Note that half of the chlorine added as chlorine gas will initially form free chlorine whereas all of the chlorine in sodium or calcium hypochlorite will initially form free chlorine. The chlorine demand varies with the turbidity and dissolved organic content of the water. If the chlorine demand increases, e.g. as a result of an increase in turbidity of the water, then the chlorine dose must be increased by the same amount to achieve the same chlorine residual.

Adequate disinfection requires a free chlorine residual of at least 0.5 mg/L, an effective contact time of at least 30 minutes and pH of not greater than 8.0.

4.3.2.2.3 Factors affecting disinfection efficiency

The success of chlorination is determined by several factors. The effects of pH and turbidity on disinfection efficiency have already been discussed. The turbidity should be reduced to less than 1 NTU and preferably less than 0.5 NTU prior to disinfection (DWAF *et al.*, 2002c). In addition, the efficiency of disinfection increases with increasing free chlorine concentration, temperature and contact time and decreasing chlorine demand. For routine operational monitoring, the adequacy of the chlorination step is assessed based on the free chlorine residual leaving the plant and the contact time, rather than on the chlorine dose.

For efficient disinfection, the turbidity should be less than 1 NTU and preferably less than 0.5 NTU.

The **contact time** can be defined as the time between the addition of the disinfectant and the time that the disinfected water reaches the closest consumer's tap. This includes the time that it takes for the water to pass through the on-site storage reservoir, the distribution lines and any off-site reservoirs between the treatment plant and the closest consumer.

The *WHO Guidelines for Drinking-water Quality* (Annexure 4, WHO, 2004) state that effective disinfection requires a residual of at least 0.5 mg/L free chlorine after a contact time of at least 30 minutes at pH less than 8. To ensure adequate contact time, the on-site reservoir is often designed to have a hydraulic retention time of at least 30 minutes. The hydraulic retention time is defined to be the ratio of the volume of water in the reservoir to the flow through the reservoir.

$$\theta = \frac{V}{Q}$$

Q	Hydraulic retention time, min
V	Volume of water in the reservoir, kL
Q	Flow through reservoir, kL/min

However, because of **mixing effects**, some of the water remains in the reservoir for less than the full hydraulic retention time. This means that it may not be adequately disinfected by the time it leaves the reservoir. The best way to overcome this problem is to design the reservoir to minimize mixing and short-circuiting. This can be achieved by constructing **baffles** to force all of the flow to follow the same path through the reservoir. The effect of baffling on the flow is illustrated in Fig. 4.3. Note that this only applies to reservoirs where disinfectant is being added at or close to the inlet. For storage reservoirs with no disinfect addition, mixing tends to improve water quality (Ainsworth, 2004). Table 5 shows effective contact times for various reservoir designs (USEPA, 2003).

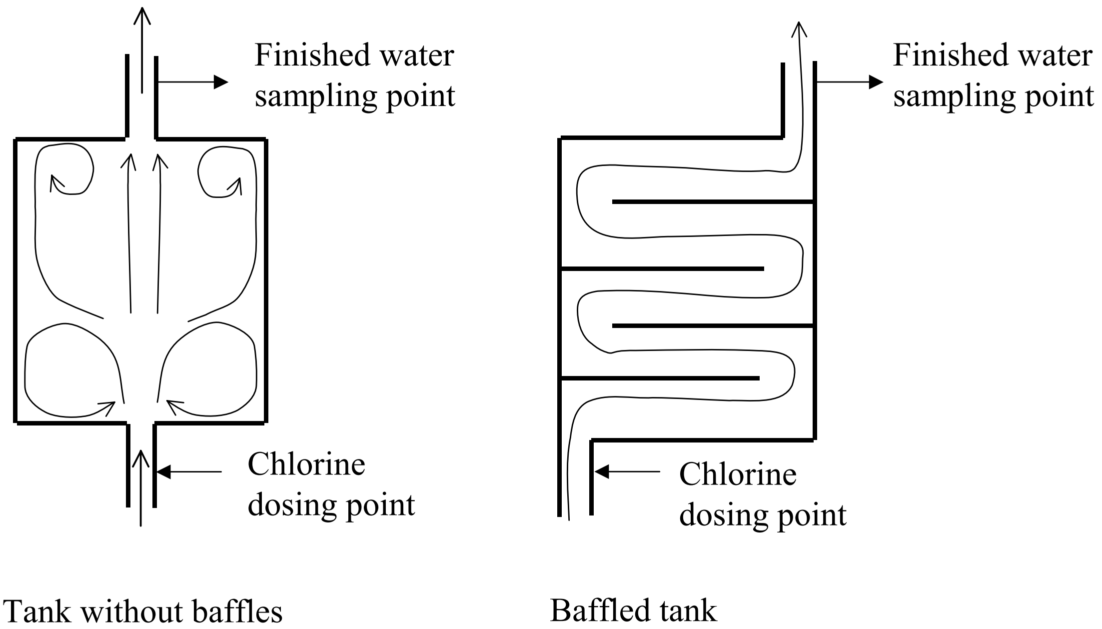


Fig. 4.3 Effect of baffles on flow patterns in tanks and reservoirs

In order to determine whether disinfection is effective, the effective contact time for the **shortest hydraulic retention time** (highest flow and lowest typical reservoir volume) should be calculated. The effective contact time can also be **determined directly** by conducting the following experiment:

The chlorine dose should be temporarily increased by at least 1 mg/L. Samples of water leaving the on-site reservoir (finished water sampling point in Fig. 4.3) should be collected every 5 minutes and immediately analysed for free chlorine residual. The time at which the free chlorine residual measured at the outlet increases by 10 % of the total increase is the effective contact time.

TABLE 4. 6 APPROXIMATE EFFECTIVE CONTACT TIMES FOR DIFFERENT TANK/ RESERVOIR DESIGNS (USEPA, 2003)		
Baffling	**Effective contact time**	**Description**
None (mixed flow)	10 % of *q*	No baffles, low length to width area (e.g. circular tanks), high inlet and outlet flows. Typical of most clearwells where the inlet and outlet are submerged pipes.
Poor	30 % of *q*	Single or multiple inlets and outlets without baffles. A few **intra –basin** (in the main body of the tank) baffles. Many **conventional clarifiers** and storage tanks with two or three baffles fit this description.
Average	50 % of *q*	Baffled inlet and outlet with some intra-basin baffles in the main body of the tank. A few clarifiers and highly baffled storage tanks fit this description.
Superior	70 % of *q*	Perforated inlet baffles (walls with evenly distributed holes that the water passes through). Serpentine or perforated intra-basin. Serpentine baffled contact tank (similar to the baffled tank example in Fig. 3). **Filters** have approximately the same effective contact time.
Perfect plug flow (pipe flow)	100 % of *q*	Very high length to width ratio. Perforated inlet, outlet and intra-basin baffles. Sections of pipe with lengths at least 10 times their diameter have this effective contact time.

Example

Suppose the free chlorine residual leaving the on-plant storage reservoir/chlorine contact chamber is 0.53 mg/L. If the chlorine dose at the inlet is increased by 2 mg/L then the effective contact time will be the time taken for the chlorine residual at the outlet to increase by 10 % of 2 mg/L i.e. by 0.2 mg/L. In other words the effective contact time corresponds to the time taken for the outlet chlorine free residual to increase to 0.73 mg/L. Sampling should continue for at least 15 minutes after the effective contact time is reached in order to confirm the result.

Assume the results of the sampling are as follows:

Time	Free chlorine residual in the outlet
0 min	0.53 mg/L
5 min	0.52 mg/L
10 min	0.58 mg/L
15 min	0.62 mg/L
20 min	0.63 mg/L
25 min	0.65 mg/L
30 min	0.70mg/L
35 min	0.79 mg/L
40 min	0.90 mg/L
45 min	1.21 mg/L

In this case, the effective contact time is between 30 and 35 minutes. This means that as long the free chlorine residual is at least 0.5 mg/L and the pH is not greater than 8.0, then disinfection may be considered adequate (provided microbial analysis does not indicate otherwise).

Note that the effective retention time should be determined when **the flow through the plant is at its highest and the reservoir is at it its lowest typical operating level**. If the effective contact time is too short, then the following steps can be taken:

1. Repeat the experiment but this time collect samples at the closest consumer's tap (closest in terms of length of pipeline). If the effective contact time, chlorine residual and pH are at least 30 min, 0.5 mg/L and not greater than 8.0 respectively, then disinfection may be considered adequate unless microbial analysis indicates otherwise.
2. Increase the chlorine dose. Table 4.7 lists required chlorine residuals as a function of effective contact time for pH less than or equal to 8.0. For example, if the effective contact time is 15 minutes then the chlorine residual should be approximately 1.2 mg/L for pH 8.0 and temperature greater than 10 ^{o}C.
3. Install baffling to increase the effective contact time.

TABLE 4.7
REQUIRED CHLORINE RESIDUAL AS A FUNCTION OF CONTACT TIMES WATER TEMPERATURE AND pH (MANCL, 1989)

Contact time (minutes)	Necessary chlorine residual (mg/L)		
	pH 7	**pH 7.5**	**pH 8**
Water temperature not less than 10 ^{o}C			
40	0.2	0.3	0.4
30	0.3	0.4	0.5
20	0.4	0.6	0.8
10	0.8	1.2	1.6
5	1.6	2.4	3.2
2	4.0	6.0	8.0
1	8.0	12.0	16.0
Water temperature 0 - 10 ^{o}C			
40	0.3	0.5	0.6
30	0.4	0.6	0.8
20	0.6	0.9	1.2
10	1.2	1.8	2.4
5	2.4	3.6	4.8
2	6.0	9.0	12.0
1	12.0	18.0	24.0

4.3.2.2.4 Chlorine dosing point

The optimum point for disinfectant addition is the filtered water (**post-disinfection**, see Fig. 1). This is because clean filtered water has the lowest chlorine demand. Consequently less chlorine needs to be added to achieve the required chlorine residual. Furthermore, chlorine can react with organic matter in water to produce what are known as **disinfection by-products**. These are suspected of being harmful to human health. The filtered water should have the lowest level of all kinds of contaminants and therefore the lowest potential to form disinfection by-products.

However, there are valid reasons why a plant may need to dose chlorine into the raw water at or before coagulant addition (**pre-oxidation** in Fig. 1). One reason may be to remove colour and/or dissolved iron and manganese. The addition of chlorine to the raw water oxidises these compounds causing them to precipitate (go from a dissolved to a particulate form) so that they can then be removed by coagulation, flocculation, settling and filtration. While there are other **oxidant chemicals** which can be used such as ozone or permanganate, chlorine is usually the most practical option for small treatment plants.

> To prevent disruptions in chlorine dosing
> - Have backup dosing systems
> - Conduct preventative maintenance
> - Maintain adequate stocks

> The optimum chlorine dosing point for disinfection is the filtered water. Pre-chlorination may be used for removal of colour, iron and manganese and for controlling algae and bacteria slimes in the clarifiers and filters.

The other reason to use pre-chlorine is to prevent the growth of algae and biological slimes in the settling tanks and filters. Note that chlorine should **never** be added to the raw or settled water ahead of **slow sand filters** as it will interfere with the biological removal mechanisms in the filters. Slow sand filtration is discussed in Section 4.3.2.6.2).

Depending on the raw water source, pre-chlorination may only be required at certain times of the year. Because of the high chlorine demand of raw water, plants using pre-chlorination should also have post-chlorination to ensure an adequate disinfectant residual without having to use excessive amounts of chlorine in the raw water. Unfortunately, some small treatment plants only apply pre-chlorination because they do not have the facilities for post-chlorination. This is an unacceptable situation and requires the upgrading of the facilities. Some plants using pressure filters find that the pressure in the filtered water line is too high for the chlorine dosing equipment. This is an issue which has to be addressed in the design phase. Since the floc which accumulates in the filters exerts a high chlorine demand it is not desirable to have continuous chlorine dosing in the filter influent. (Sometimes chlorine may be added to filter influent to control the build up of bacteria in filters).

4.3.2.2.5 Manual dosing of chlorine

In the event of a failure of the chlorine dosing system, small treatment plants typically resort to manual dosing of HTH directly into the final water storage reservoir. Plants should avoid this situation in the first place by:

1. Having a standby dosing system which is maintained in working order,
2. Conducting regular preventative maintenance,

3. Maintaining an adequate stock of disinfectant on site and ensuring regular delivery of chemicals.

However, if it becomes necessary to resort to manual dosing, the following guidelines need to be strictly adhered to:

1. The amount of HTH added must be sufficient to ensure a residual of at least 0.5 mg/L and preferably higher in the finished water (leaving the on-site reservoir).

On one occasion when the chlorine dosing system at Alice water treatment plant failed, the authors found that the amount of HTH the operators were adding amounted to less than 5 % of the actual chlorine demand of the filtered water and therefore was insufficient to maintain an adequate residual. Each treatment plant needs to draw up clear guidelines on manual dosing of HTH when the chlorine system fails.

2. Continuous dosing is better than batch dosing (dosing a large amount all at once).

It is **no**t acceptable to dose chlorine once or twice a day while treated water is flowing into the distribution system. Dosing once or twice a day would result in some water having a very high concentration of chlorine while some will not have enough to effectively kill bacteria. This is also true of treatment plants which currently have no chlorine dosing equipment. It is acceptable to batch dose HTH into on-site storage reservoirs while the outlet is closed. The HTH should be dosed at least 30 minutes before the outlet is opened to ensure sufficient contact time.

Batch dosing is also acceptable for **booster dosing**. For example, some plants which shut down overnight may add HTH to their finished water reservoir before starting up, even though they have continuous dosing of the filtered water while the plant is running. Booster HTH should be added as close to the reservoir inlet and as far from the outlet as possible.

To achieve continuous dosing without dosing pumps, HTH should be mixed with water in a 100 – 200 L drum fitted with a tap at its base. The tank should be set up so that solution drips into the filtered water channel or into the clearwell or finished water reservoir close to the inlet. Some plants are already using this system for routine operation because they do not have dosing pumps. It is **not** an acceptable alternative to a proper metered dosing system because it does not maintain a constant dose, however, it can be used in emergencies. (Therefore, plants which are replacing this inferior system with dosing pumps should keep their old dosing tanks for emergencies).

> If HTH is being dosed by hand only, HTH must be dosed at least every **2 hours**. The chlorine residual at any time **must not be more than 5 mg/L or less than 0.5 mg/L**. The plant should be shutdown when there is no operator to continue the chlorine dosing.

If there are no drums available for continuous dosing and the operator has to dose by hand, then HTH must be dosed at least every 2 h. For example, if the plant is operating 12 h a day, then one sixth of the total daily dosing requirement should be dosed in the finished water reservoir close to the inlet every two hours. The operator should initially check the residual in the finished water (reservoir outlet) every 30 minutes to make sure that it does not drop below 0.5 mg/L. If it does, she should either increase the dosing frequency or the dose. The chlorine residual at the reservoir outlet should never exceed 5 mg/L (base on the maximum chlorine limit recommended by WHO, 2004). If HTH is being dosed by hand only, then **the plant should be shut down when there is no operator on duty.**

4.3.2.2.6 Ensuring an adequate chlorine residual at the point of use

In addition to ensuring the finished water meets the WHO Guidelines for adequate disinfection, it is also necessary to maintain a disinfectant residual in the distribution system to prevent re-infection of the treated water and to prevent the growth of biological coatings (biofilms) on the pipe walls. The WHO Guideline (WHO, 2004) for the minimum chlorine concentrations at the point of delivery is 0.2 mg/L in normal circumstances and 0.5 mg/l in high-risk circumstances (discussed next). An increasing number of people are likely to object to the taste between 0.6 mg/L and 1 mg/L (WHO, 2004). DWAF *et al*. (1998) (Section B2 in Part 2) provides more detailed guidelines on the safety an acceptability of various levels chlorine at the point of use. These are partially reproduced in Table 4.8 below.

> The chlorine residual at the point of delivery should be at least 0.2 mg/L under normal circumstances and 0.5 mg/L during periods of high risk of microbial concentration. Lower concentrations will not provide adequate protection against microbial contamination.

An acceptable maximum chlorine limit will depend on what consumers are used to. Water Services Providers must monitor the chlorine residual at consumers' taps at various points in the distribution system, including the closest and farthest points from treatment, in order to ensure the residual remains in an acceptable range throughout the system. The operation of distribution systems is discussed further in Section 4.3.3.

Some Water Service Providers unfortunately believe that a free chlorine residual of only 0.1 mg/L is acceptable at the point of use and even in the finished water (before distribution). This is not the case, particularly for the majority of South African municipalities, where there is a high risk of faecal contamination of the raw water. Since increasing the chlorine dose can have an adverse effect on the taste, the WSP needs to inform consumers of the reason for the change in taste and assure them that it makes the water safer to drink. Consumers can reduce the chlorine taste in the water by allowing it to stand for half in hour in a **clean** cup or jug before drinking it.

TABLE 4.8
SAFETY AND ACCEPTABILITY OF THE CHLORINE RESIDUAL IN DRINKING WATER (ADAPTED FROM DWAF *et al.*, 1998)

Free Chlorine Residual (mg/L)	**Health Effects**	**Taste**
Less than 0.05	Serious risk of infection if raw water source is microbiologically contaminated.	Acceptable to consumers.
0.05 – 0.1	Disinfection may not be effective.	Acceptable to consumers
0.1 – 0.2	Slight risk of infection.	Acceptable to consumers
0.2 – 0.3	Disinfection adequate.	Slight small of chlorine.
0.3 – 0.6	Disinfection good.	Slight smell and taste of chlorine.
0.6 – 0.8	Disinfection good. Insignificant risk of health effects due to chlorine.	Distinct smell and disinfectant taste.
0.8 – 1.0	Slight risk of mucous membrane irritation.	Unpleasant smell and taste.
1.0 – 1.5	May cause nausea and mucous membrane irritation.	Unpleasant smell and taste.
More than 1.5	Danger of toxic effects, nausea and vomiting.	Repulsive odour and taste.

4.3.2.2.7 Chlorine dosing for adverse conditions

Operators and supervisors need to be aware that pathogens can break through into the finished water even when a treatment plant appears to be operating normally and especially when any disruption in treatment (planned or unplanned) occurs. Whenever there is reason to suspect an increased risk of microbial contamination or pathogen breakthrough, the chlorine dose should be increased to increase the efficiency of disinfection (% of microbes killed by chlorine). Raising the finished water residual by 0.3 to 0.5 mg/L is recommended. Typical high-risk situations include the following:

- Heavy rainfall in the catchment area for the raw water source (some treatment plants already automatically increase their chlorine dose when heavy rains occur).
- Other events leading to a sudden increase in raw water turbidity.
- Other evidence of contamination of the raw water source e.g. a herd of cows breaks into the enclosure around a raw water holding dam.
- When a failure of any of the chemical dosing equipment occurs.
- When switching from one type of coagulant to another.
- When the filtered water turbidity increases for any reason.
- When there is a sudden increase in flow for any reason.
- When a filter or settling tank is taken off-line for maintenance resulting in an increase in flow through other units.
- When the plant is started up after being shut-down for a period of time (and for all plants which do not operate continuously i.e. 24 h/d).
- Whenever there is any construction going on at the plant.
- Whenever a new plant is commissioned.
- Whenever a new storage reservoir (on- or off-site) is commissioned or a new section of distribution system is opened.
- Whenever sampling from the distribution system indicates problems with water quality at point of use, whether microbial, physical or chemical (turbidity and chlorine residual). The chlorine dose should be temporarily increased while the cause of the problem is investigated and fixed.
- Whenever there is an outbreak of a waterborne disease in the local community e.g. cholera or shigellosis, whether or not the source of disease is drinking water and regardless of whether the part of the population receiving treated water is affected. In other words, even if it appears that only people drinking untreated water are at risk, the WSP should still take precautions with its treated water supply.

> During high risk situations, the chlorine residual in the finished water should be increased by at least 0.3 - 0.5 mg/L. Microbial analysis should be increased to at least twice a week to ensure the response is effective.

Whenever possible, the frequency of sampling for microbial contaminants (raw, finished water and point-of-use samples) should be increased to at least twice a week during high risk situations in order to determine the effectiveness of the increased chlorine dose and how long it needs to be applied. This information all needs to be carefully documented to assist the WSP in responding effectively to future adverse conditions.

4.3.2.3 Flow measurement and control

4.3.2.3.1 Flow measurement and dose calculations

It is not possible to run a water treatment plant efficiently without flow measurement. Flow measurement is required for:

1. Adding the correct amount of treatment chemicals to the water.
2. Estimation of contact times as described in Section 4.3.2.2.3.
3. Calculation of water losses both on the plant and between the point of treatment and the point of delivery.

The amount of chemical which has to be added to the water being treated to achieve a certain **dose** (in mg/L) depends on the amount of flow. The required chemical **dosing rate** is given by the following formula:

$$dose\,rate(mg\,chemical/time) = dose(mg/L) \times flow(L/time)$$

Flow rate measurements are required for dosing rate calculations and are therefore critical for effective water treatment. At a bare minimum, both the raw water and final water flow rate must be metered.

The details of the calculation depend on the dosing system and will therefore vary from plant to plant. If the operators and supervisors do not have experience in dosing calculations, they should seek assistance from the various organizations involved in mentoring and capacity building in the water services sector (See Section 4.4.5). Dosing calculations should also be an integral part of on-site training.

The dose rate equation should be used when trying to adjust the chlorine residual in the final water and when applying the results of the jar test to coagulant dosing (described in Section 3.2.4). It is also very important that dosing rates are adjusted to maintain constant doses of coagulant whenever the raw water flow rate is changed.

Many small treatment plants still do not have flowmeters, or their flowmeters are broken, or the operators do not know how to read them. Water services institutions are already required to install water meters to measure the quantity of water provided to each supply zone (Section 11 of regulations promulgated under Section 9 of the *Water Services Act*, *Government Gazette, Vol. 432*

No. 22355, 8 June 2001). They should at the same time have meters installed (or repaired) at the treatment works itself.

At a bare minimum, there should be one meter for the raw water (F1 in Fig. 4.1) and one for the finished water (F3 in Fig.4. 1). Ideally, the filtered water and recycle flow should also be metered (F2 and F4). The contract for installing the meters **must** include **training** the operators and supervisors to use the meters to measure and calculate the **instantaneous** and **daily average flows**. In addition, flowmeter must be checked and re-calibrated at least once a year. (Some types of meter may need more frequent recalibration). Meters must also be easy to access and read if they are to be useful for process control.

Companies which install flow meters must also train the plant supervisors and operators to read the meters. Requirements for calibration must also be specified at the time of installation. Meters must be easy to access and read.

4.3.2.3.2 Flow control and balancing capacity

As a general rule, treatment plants should avoid sudden changes of flow rate as far as possible. Sudden increases in flow tend to have a negative impact on settled water and particularly on filtered water quality. Furthermore, changes in flow rate require changes in chemical dose rates, which most small treatment plants struggle to get right. This is why Section 4.3.2.2.7 recommends increasing the chlorine dose when the flow rate changes.

Ideally, treatment plants should be operated 24 h/d at the daily average flow rate. This requires adequate balancing capacity in the finished water reservoirs.

Ideally, a treatment plant should be operated continuously (24 h/d) at a constant flow rate. The problem is that water demand varies continuously throughout the day. To avoid adjusting the flow every day or every few days, it should be set the daily average flow rate (total volume of water over a 24 h period). However, for this to be feasible, the plant must have sufficient **balancing capacity** in its finished water storage reservoirs. The balancing capacity is the amount by which the volume of water in the reservoirs can change without overflowing and while still providing adequate **chlorine contact time**.

Providing adequate balancing capacity is a design issue and has to take into account future increases in demand. Some of the better designed and managed small treatment plants already operate in this mode. Plants which currently make daily

Plants which turn on and off automatically based on reservoir levels require fewer dosing adjustments but there is generally a period of poor filtered water quality after start up. Nonetheless, this arrangement is a practical option for plants which are not manned 24 h/d and/or have very large seasonal variations in demand.

adjustments to flow rate should also look into whether they have sufficient capacity to operate at constant rate. The calculations required are site specific and small water suppliers will probably require assistance to perform them (See Section 4.4.5).

Alternatively, many small plants are set up such that the whole plant including all chemical dosing equipment shuts off automatically when the finished water reservoir level reaches a specified maximum level and starts up again when the level drops to its minimum limit. While the plant is running, the flow remains constant. The main advantage of this arrangement is it minimizes the number of dosing adjustments which have to be made. Chemical doses only have to be changed when the raw water quality changes. The disadvantage of this stop-start system is that it is not an ideal way to operate filters and settling tanks because of the sharp increase in flow at start up. (This is also true of plants which operate for fixed number hours per day because they are not manned at night). However, in the current South African situation, the advantages of more reliable chemical dosing probably outweigh the disadvantages. It also may be the most practical option for plants which have very large seasonal variations in demand, e.g. those serving holiday resorts. Nonetheless, these plants should consider reducing their flow rate to the average daily demand in order to operate continuously.

Whenever it is necessary to change the flow rate manually, the rate change should be made **slowly** rather than abruptly e.g. over 5 to 10 minutes depending on the size of the required change. This will reduce the impact on settling and filtration. If the flow is to be increased, the chlorine dose rate should be increased to its new required value before starting to change the raw flow. However, if the raw flow is to be decreased, then the chlorine dose rate should only be changed afterwards. The coagulant dose rates need to be adjusted continuously in proportion to the flow.

> Manual flow adjustments should be gradual rather than abrupt. Appropriate adjustments to chemical dosing rates need to be made at the same time.

4.3.2.4 Coagulation and Flocculation

4.3.2.4.1 Types of coagulant and dose optimisation

The most commonly used coagulants in South Africa are alum (aluminium sulphate) and various commercially available polymeric coagulants/flocculants. Some plants, especially those treating coloured waters, use ferric chloride. Adding alum or ferric chloride reduces the pH of water so when these coagulants are used, lime or soda ash is usually used as well. For alum, the pH after chemical addition should be kept between 6.0 and 7.4 to ensure good coagulation and acceptable levels of dissolved

> Both overdosing and under-dosing coagulants/flocculants result in treatment problems. Therefore it is important to get the dose right.

aluminium in the finished water. For ferric chloride, the acceptable pH range for coagulation is 5.0 to 8.0 (DWAF *et al.,* 2002c). By contrast, most polymers do not change the pH of the water significantly. Alum tends to be effective over a relatively wide range of doses; however overdosing can lead to poor filtered water turbidity as a result of excess alum precipitating in the filter (post-precipitation). Furthermore, larger doses of alum compared to polymer are usually required to achieve the same final water quality, resulting in the production of greater volumes of sludge. Polymers tend to work well in a smaller range of conditions than alum. Both under-dosing and overdosing lead to poor floc formation and turbidity removal so proper control of the dose is especially important when polymers are used.

The coagulant dose required to achieve the optimum level of turbidity removal is known as the **coagulant demand** (expressed in units of milligrams of coagulant per litre of water treated). The coagulant demand is function of several factors including the type of raw water, type of coagulant, raw water turbidity, pH and temperature. In general, higher raw water turbidities and lower temperatures require higher coagulant doses.

The coagulant demand varies with the raw water quality and in some cases, it may be necessary to adjust the coagulant dose several times a day. The optimum coagulant dose for a given water sample can be determined using the **jar test** (also sometimes referred to as the beaker test). This involves adding a range of doses of coagulant and pH adjustment chemical to 1 or 2 L samples of raw water and mixing them using the standard jar test apparatus. Floc is allowed to form and settle in each of the samples and the turbidity of the settled water is then measured. The optimum dose is the one which produces the lowest settled water turbidity.

The general procedure for the jar test is described on page 23 of *Quality of Domestic Water Supplies Volume 4: Treatment Guide* (DWAF *et al*., 2002c). Note: jar stirrers may be supplied with cylindrical or square beakers. Square beakers provide better mixing and should be used whenever possible. An example of a standard jar test apparatus is shown in Fig. 4.4.

In order to apply the results of the jar test, the **raw water flowrate** and **chemical dose rates** (supplied by the dosing pumps, manual or dry feeders) must be known. Ideally, the jar test should be carried out at least once a day to achieve the most effective coagulation and whenever there is a change in the raw water quality. If the coagulant demand does not vary much, then the frequency of testing may be reduced accordingly.

However, operators must be aware that the coagulant demand will always vary when the raw water turbidity varies. If a significant increase in raw water occurs e.g. after heavy rains, operators need to be aware that the coagulant demand will also increase. If the raw water turbidity is increasing rapidly, then the operators should not wait to perform the jar test before increasing the dose. They should keep adjusting the dose up based on experience while continuing to check the raw, settled and filtered water turbidities **at least once an hour**. Once the raw water turbidity has stabilised, the jar test should be conducted in order to determine the optimum dose.

Fig.4 .4 Jar test apparatus

Most small treatment plants do not currently own jar test apparatuses. Operators determine whether coagulant doses are adequate from the appearance of the floc formed before the sedimentation tanks and sometimes from the taste of the water (especially when alum and lime are used). However, **these methods do not guarantee the efficient use of chemicals or optimum turbidity removal efficiency**. For example, in the Alice water treatment plant case study, it was determined that the plant could have saved in the order of R 100 000 per year on the cost of alum and lime by implementing dose optimisation using the jar test. This would easily cover the cost of purchasing the jar test apparatus (~ R 20 000).

> Using the jar test to obtain the optimum dose improves treatment and may save chemical costs.

4.3.2.4.2 Coagulant dosing systems

Coagulants and flocculants are usually added to the raw water as liquids, solutions or slurries (a slurry is a suspension of a granular or powdered chemical carried by the water). In very small treatment plants (< 2 ML/d), chemicals such as alum which are supplied in dry form are usually first dissolved in water in **dosing tanks** (dosing solution prepared in batches). The chemical supplier or contractor who installs the dosing equipment usually provides instructions on how to make the dosing solution up (for example, 10 kg of alum in 100 L of water). The water used to make up all dosing solutions should be as clean as possible (filtered or tap water) to prevent dirt or floc particles reacting with the coagulant before it is dosed into the raw water. Dry chemicals should always be stored in a dry area at moderate and fairly uniform temperature. Most chemicals will harden and cake if exposed to moisture, so bags should be stored on pallets to allow air circulation beneath them (Thompson *et al.*, 2004).

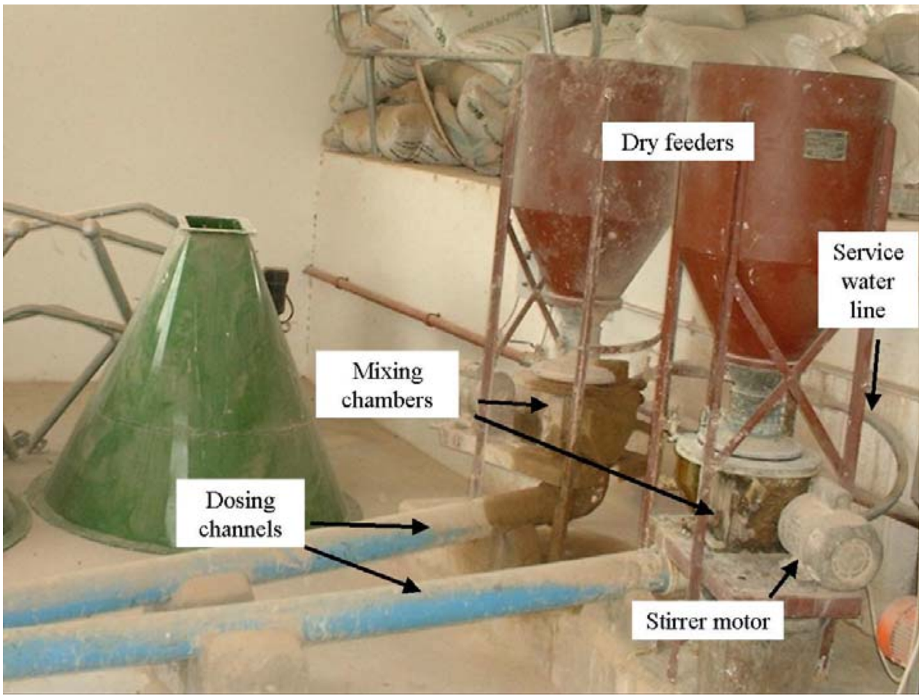
In larger plants (> 2 Ml/d) powdered chemicals are often dosed using **dry feeders** as in Fig. 4.5(a). The dry feeder drops powdered chemical into a small mixing chamber at a controlled rate. A continuous stream of water carries the chemical from the mixing chamber to the dosing point. The actual flow of water through the dosing system is not important provided that it is much smaller than the raw water flow but large enough to prevent the dry chemical depositing in the chamber and dosing channel. Raw water can usually be used here as it does not spend much time in the mixing chamber before being combined with the main flow. Polymers (supplied as liquids) are sometimes also diluted in water before being dosed into the raw water channel.

When dry feeders are used, the rate of chemical addition is controlled by increasing or decreasing the gap through which the dry chemical is fed. The dosing rate can be measured by collecting and weighing the amount of chemical dropping into the mixing chamber in a fixed time period e.g. 30 s. The weight of dry chemical can be measured using a simple **kitchen scale** or balance purchased from most supermarkets. As discussed in Section 4.3.2.3.1, the details of dosing rate calculations for both solutions and dry chemicals are site and equipment specific and should be developed with expert help.

For coagulants in liquid or solution form, the dosing rate is usually controlled by an electrically powered **dosing pump** as in Fig.4.5 (b). However some plants use hydraulic or mechanical devices such as constant header tanks which do not require electricity. Figure 4.5(c) shows an example of constant header tanks. Whatever device is used, it is important that: a) the operator can **easily** and **accurately** adjust the dosing rate when required and (b) the dosing rate remains **constant** as the dosing tank empties, unless the operator adjusts it.

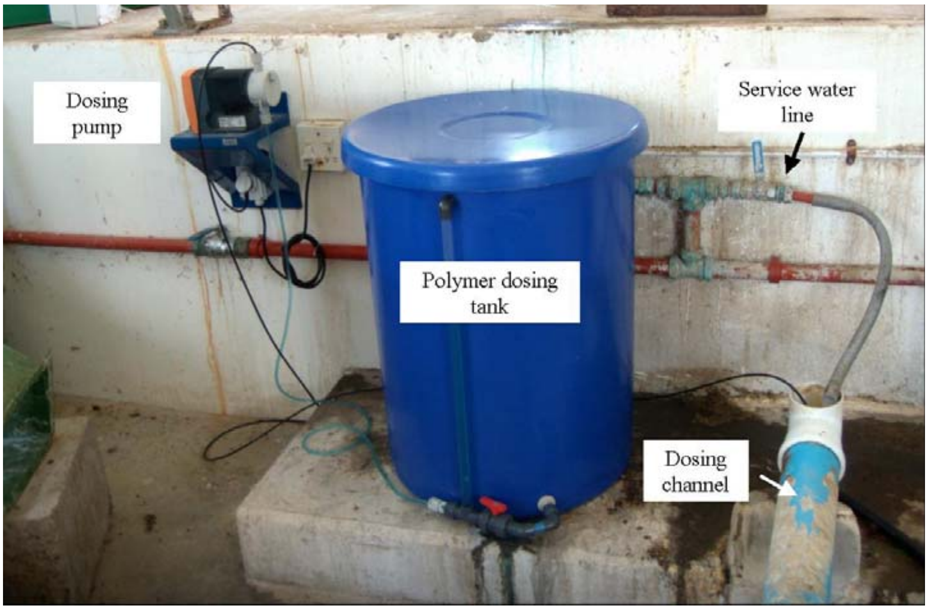
> Liquid dosing systems must be able to deliver a **constant dose rate**. The operator must also be able to **easily** and **accurately** adjust the dose rate when required.

In some small treatment plants which currently do not have proper or functioning dosing equipment, the dosing solution is made up in a small tank or large bucket and then allowed to drip into the raw water channel via an outlet tap (This is the same system that was described in Section 4.3.2.2.5). The problem with this arrangement is that the dosing rate decreases as the level in the tank decreases so it is not possible to maintain the dosing rate constant unless the variation in the level in the dosing tank is kept to a minimum. Consequently, plants relying on such a system should have properly designed dosing equipment installed as soon as possible.



(a) Dry feeders for alum and lime.

(b) Polymer dosing system with dosing pump.



(c) Constant header dosing tanks. These tanks are designed to maintain a constant dosing rate without dosing pumps.

Fig. 4.5 Coagulant dosing systems

In addition to having a dosing system which can maintain a constant dosing rate, the operators need to know how to **set and measure the dosing rate**. The equipment supplier or consultant should demonstrate the calibration of the equipment to the operators when it is installed. The **calibration** is the relationship between the settings on the equipment and the actual dose rate delivered in litres/hour. For example, the rate setting on most dosing pumps is marked off in percentage. If the pump is set at 50 %, it should deliver approximately 50 % of its maximum flow. The maximum flow is given in the operating manual and may also be engraved on the pump itself, usually in units of litres/hour (L/h).

However, the operators and their supervisors must be aware that **the calibration of dosing pumps does not always remain constant**. Over time, as the pump becomes worn, the maximum dose rate is likely to drop. In the short term, clogging and/or the development of air bubbles in the dosing lines may also cause variations in the dosing rate. The operators should check the dosing lines to make sure they have not become clogged at least once a day and whenever there is an unexplained increase in settled water turbidity. The operators or supervisor should also check the calibration of the dosing pump or other dosing device once a month. If the measured flow at a given setting is more than 5 % different than it should be based on the calibration data, the operator should first check that there is no clogging in the line and then redo the calibration if necessary.

> The calibration of dosing pumps for all chemicals dosed should be checked at once per month and the calibration redone if it is more than 5 % in error.

Checking the dosing rate and calibrating the dosing device is greatly facilitated if a clear plastic **sight glass** is installed on the dosing tank as shown in Fig. 4.6. A rigid tube should preferably used but a flexible tube is also acceptable provided that it is clamped firmly in a vertical position. When the valve between the sight glass and the tank is open, the level should be the same in both. (This also gives the operator a quick check on the dosing tank level). When the valve is shut off, the level in the sight glass will start to drop rapidly. The operator can measure the time taken for the level to drop between calibration marks on the sight glass in order to determine the dosing rate.

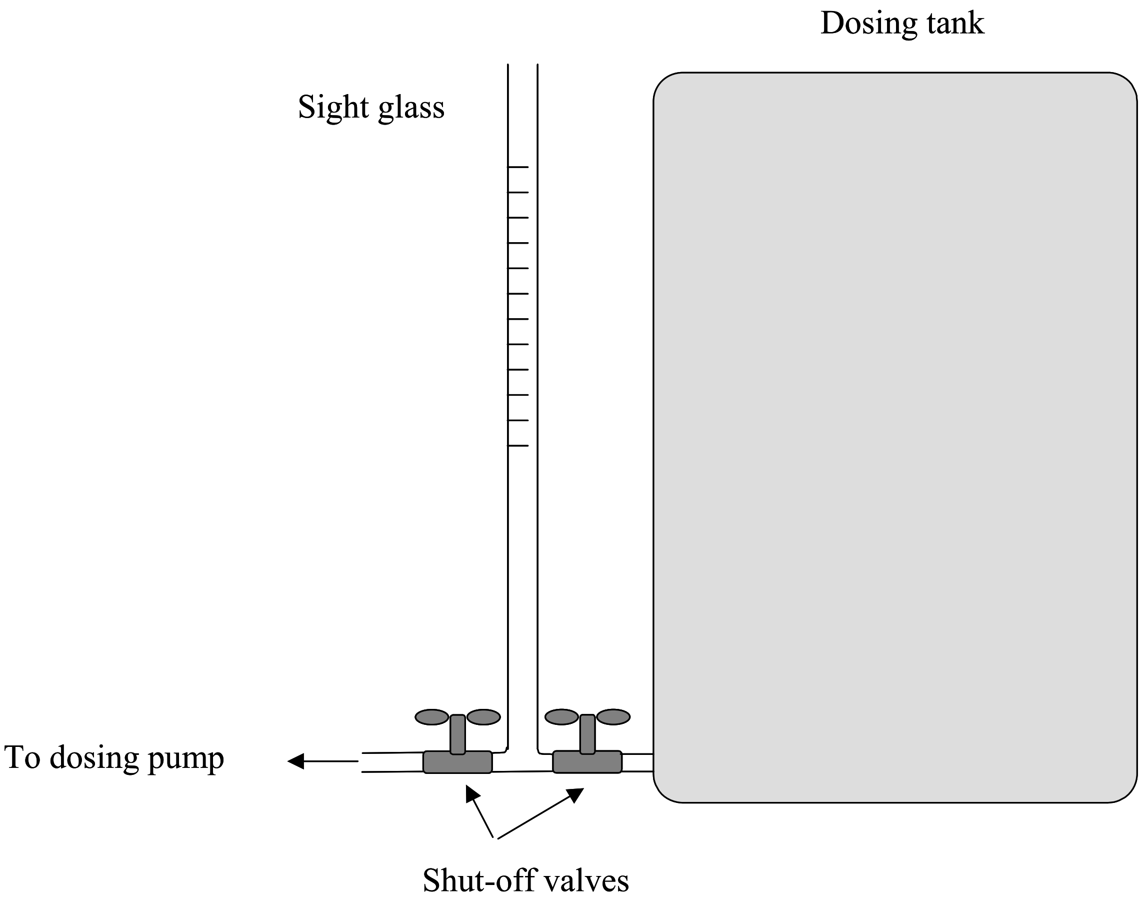
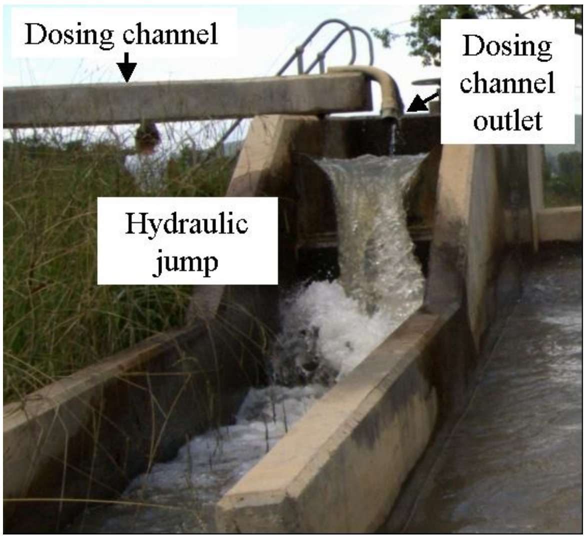


Fig. 4. 6 Dosing tank with sight glass.

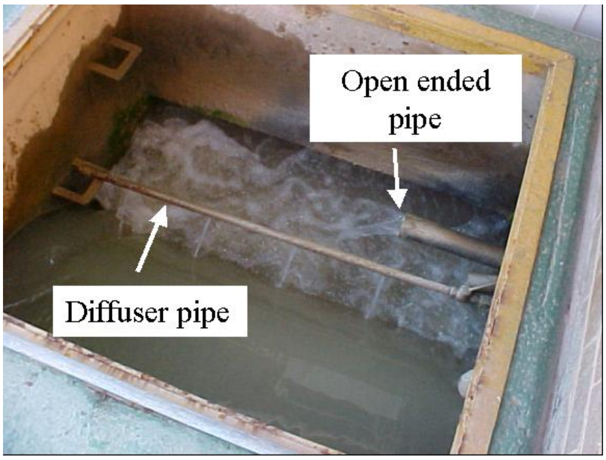
4.3.2.4.3 Mixing for coagulation and flocculation

Mixing plays an extremely important role in the efficient use of coagulant and the growth of settlable floc. Failure to provide adequate mixing can result in poor turbidity removal and/or waste of coagulant. First, the coagulant must be rapidly and evenly mixed with the raw water (rapid or flash mixing) and then a period of gentle mixing is required to promote the growth of large, rapidly settling floc.

Rapid or flash mixing for small conventional treatment plants is usually accomplished with hydraulic jumps. These are steep drops of at least 60 cm over which the raw water flows. The coagulant and pH adjustment chemical are usually added either at the top of the jump or just below it where maximum mixing occurs. Examples of chemical dosing at hydraulic jumps are shown in Fig. 4.7. Chemical diffusers consisting of pipes with small holes through the coagulant flows are often used to ensure a more even distribution of chemical in the raw water, especially when dosing into wider channels. An example of a diffuser pipe is shown in Fig. 4.6(b). Diffusers can be constructed cheaply and easily from short lengths of PVC pipe. However, the required size of the diffuser holes depends on the type, strength and flow rate of the chemical solution and expert assistance may be required to determine the correct size. Diffuser holes are prone to clogging and operators should inspect and clean them on a regular basis.



(a) Hydraulic jump



(b) Diffuser pipe above hydraulic jump

Fig. 4.7 Coagulant dosing at hydraulic jumps

Some larger plants use mechanical mixers (stirrers) to provide flash mixing but this option is not commonly used in small treatment plants because of the additional maintenance requirements. In package plants, treatment chemicals are generally injected directly into the raw water pipe. Rapid mixing is typically provided by a static mixer (an immobile mixing device built into the pipe) or chemicals may be injected before a raw water pump so that mixing is provided by the pump itself.

> Inadequate mixing for coagulation and flocculation may result in poor floc formation and settling performance. However, several other factors also affect floc formation. Assessing the adequacy of mixing requires some background in design.

Most small treatments also use hydraulic mixing for flocculation. Fig. 4.8 shows a typical baffled flocculation channel. Gently local mixing is achieved by forcing the water to flow around the turn at the end of each section of the channel. In package plants, the same effect is achieved using sections of pipes.

Flocculation channels and pipes are not required in all treatment plants. Some settling tanks, such as floc blanket clarifiers are designed so that most flocculation occurs in the settling tank itself. However, some small treatment plants do not have adequate flocculation in either the flocculation channels or settling tanks and settling performance suffers as a result. Assessing the adequacy of both rapid mixing for flash mixing and slow mixing for flocculation generally has to be carried out by personnel with some background in **water treatment design**.

Fig.4.8 Flocculation channels

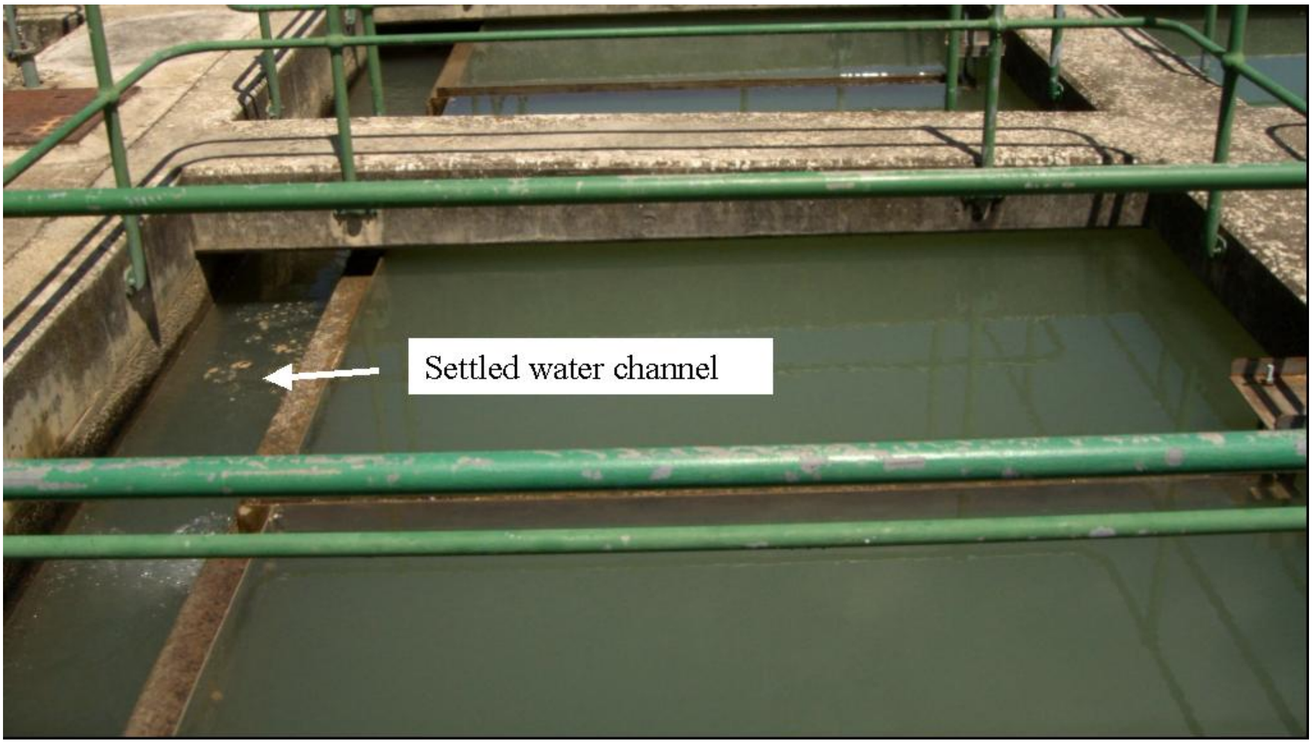
4.3.2.5 Sedimentation

In conventional treatment, sedimentation is the process in which most of the original contaminants that were in the raw water are removed. Sedimentation occurs in tanks or basins known as **settling tanks**, **settlers** or **clarifiers**. Floc formed in the coagulation and flocculation stages sink to the bottom of these tanks while the settled water overflows into the **settled water launders**. The settled floc forms a sludge layer at the bottom of the tank which is periodically removed by **desludging.**

4.3.2.5.1 Types of settling tanks

There are many different designs of settling tanks or clarifiers but they can generally be classified as either horizontal flow, radial flow or up flow (sludge blanket). Figure 4.9 shows examples of horizontal and radial flow clarifiers.

Horizontal floc clarifiers are usually large rectangular concrete basins (Figs. 4.9(a) and (b)). Flow enters at one end and overflows into the clarified water launders at the other. Well designed horizontal settlers usually have launders extending back into the body the tank to increase the length of the weir over which the settled water flows.



(a) Small horizontal settling tank

(b) Horizontal settling tank with collection launders extending into the main body of the tank

(c) Radial flow clarifier with travelling bridge.

Fig.4. 9 Horizontal and radial flow clarifiers

In radial flow clarifiers, the flocculated water is introduced through a central feedwell and flows outwards to clarified water launders around the edges of the tank. This kind of clarifier is usually circular but can also be square. Radial flow clarifiers may be large concrete tanks but smaller package plant type units are increasingly used for upgrading existing plants. The larger radial flow clarifiers often have rotating travelling bridge systems which either scrape sludge into sludge hoppers in the floor of the tank or suction it up. Fig.9(c) shows a radial flow clarifier with a travelling bridge.

In upflow or sludge blanket clarifiers, the flocculated water is introduced at the bottom of the tank and flows upwards through the sludge layer which in this case is called a **sludge blanket**. Passing the feed through the sludge blanket increases the efficiency of floc removal. However, the problem with this type of clarifier is that the sludge blanket is easily lost if it is not operated and desludged carefully and this leads to a reduction in performance. Sludge blanket clarifiers are not commonly used in rural treatment plants.

4.3.2.5.2 Factors affecting the efficiency of sedimentation

The most important factor affecting sedimentation is **coagulation** efficiency. If the wrong coagulant dose is applied or rapid mixing of the chemicals is inadequate then the floc formed will not settle well. The **flocculation** stage is also very important: the larger the floc formed, the better they will settle. It is therefore important to ensure that the floc is not broken up between the flocculation channels and settling tanks. **It is never acceptable to pump water from the flocculation channels to the clarifiers** as this will destroy the floc. Consequently, settling tanks must always be situated below the flocculation channels and not above them. Where flocculation takes place inside a pressurised pipe, the clarifiers may be located above the section where flocculation occurs provided that there is sufficient pressure to lift the flocculated water to the clarifier inlet without further pumping.

> Flocculation **channels** should always be located above the settling tanks so the flocculated water can flow under gravity. Passing flocculated water through a pump will break up the floc.

The efficiency of sedimentation is also strongly influenced by both the flow rate and the degree of mixing in the clarifiers. The slower the flow through the clarifier, the easier it is for floc to settle out. Conventional clarifiers are generally designed to a handle a maximum **surface loading rate** of 1 m/h. The surface loading rate is the flow through the tank in m^3/h (cubic metres per hour) divided by the surface area of the tank in m^2. Operators need to ensure that the flow is split evenly between equally sized clarifiers.

Mixing and short-circuiting (some water travels through the clarifier much faster than the rest of the flow) results in floc carrying over into the clarified water and therefore needs to be minimized. Some degree of mixing and short-circuiting occurs in all basins but it can be made worse as result of windy conditions and density currents. Density currents can occur at high raw water turbidities and when the temperature of the flocculated water is different to that of the water in the clarifier (Thompson *et al*, 2004). Reducing mixing and short-circuiting is primarily a design issue. The clarifier inlet and clarified water collection system must be designed to ensure the flow distribution is as even as possible. Baffles are also typically used to reduce short-circuiting. In addition, the operators need to check the flow into the settled water launders is evenly distributed along their length and that the weirs are kept clear of debris and floc deposits.

The growth of bacterial slimes and algae (furry green coatings) on clarifier walls is a common problem, especially in summer. Algae and bacteria cause taste and odour problems and may clog the weirs or the filters if they detach. Pre-chlorination may help to prevent biological activities and the walls can also be treated to with mixture of copper sulphate and lime (10 g of each per litre of water) painted onto the walls (Thompson *et al*, 2004).

Efficient operation of the settling tanks requires regular **desludging**. Excessive build up of sludge will reduce the volume in which settling can occur and the sludge may become more difficult to remove the longer it is left in the tank. The sludge can also become biologically active which can lead to taste and odour problems and in some cases, the release of iron and manganese back into the water.

Some clarifiers have automatic desludging systems but most clarifiers in small rural treatment plants have to be desludged manually. More frequent desludging is required when the raw water turbidity increases. Even with regular desludging, sludge deposits tend to accumulate on the sides of clarifiers without mechanical scraping systems. These clarifiers have to be periodically drained and cleaned out. Every treatment plant should therefore have at least settling tanks so that one can keep operating when the other is taken off-line for maintenance.

4.3.2.6 Filtration

Filtration is the final step in turbidity removal in conventional treatment. Water is passed through a layer of sand or other granular material such as anthracite and dirt or floc particles are removed by sticking to the grains. Filtration is the most difficult step for operators to get right and it is nearly impossible to meet turbidity standards when filters are not working properly. Consequently, filter problems are a common cause of poor treated water quality in rural water supplies. There are many different filter designs currently been used in small treatment plants and all have limitations of which operators and supervisors are often not aware. Filters can be classified as rapid filters (filters which have to be backwashed), slow sand filters (filters which have to be scraped) and pre-coat filters (filtration occurs through a thin layer of e.g. diatomaceous earth coated onto collector tubes). Pre-coat filters are not commonly used and will not be discussed here. This section discusses the most common types of filters in use and some important operating issues which impact their long-term performance. For more information on both rapid and slow sand filters see Section 2B of *Quality of Domestic Water Supplies Volume 4: Treatment Guide* (DWAF *et al*., 2004).

4.3.2.6.1 Rapid filtration

Typical examples of rapid filters used in small treatment plants include conventional filters, pressure filters and valveless or self-backwashing filters. The common characteristic of rapid filters is that once they have clogged up, they are cleaned by backwashing. Backwashing involves sending a flow of water and sometime also air up through the clogged media to dislodge the deposited floc. Filters should be backwashed as soon as any of the following occur:

(a) The filter reaches its maximum headloss (maximum pressure or degree of clogging. If the filter is not backwashed, the filtration rate will start to decrease).

(b) The filtered water turbidity starts to increase, even though coagulation, flocculation and sedimentation seem to be working well (discussed in Section 4.3.2.6.2).

(c) The maximum filter run time is exceeded (discussed in Section 4.3.2.6.1).

The most common types of rapid filters used in rural treatment plants are conventional filters, pressure filters and valveless filters. Examples of each type of filter are shown in Fig. 4.10.

Conventional gravity filters consist of a sand bed in a concrete tank with nozzles or orifices in the floor which allow the filtered water to pass through. These filters are expensive to construct and tend to be used mainly in larger treatment works while pressure filters and valveless filters are popular in smaller plants. The sand bed in a pressure filter is located inside a pressurised tank. Clarified water is pumped into the filter by the filter pump. The filter pump usually provides sufficient pressure to also pump the filtered water into an elevated finished water storage reservoir. The filter pump is also used for backwashing. Valveless filters are designed to operate under gravity and to be able to backwash themselves automatically when a certain headloss (degree of clogging of the filter sand) is reached. They are called "valveless" filters because no valves have to be opened or closed for the filter to backwash.

Rapid filters have a number of limitations which need to be understood if they are to be used effectively and if appropriate actions are to be taken when they develop problems. Various factors which affect filter performance are discussed next.

(a) Conventional rapid filters.

(b) Pressure filters.

(c) Valveless filter.

Fig. 4,10 Common types of rapid filters

4.3.2.6.2 Factors affecting the efficiency of filtration.

As in the case of clarifiers, the efficiency of turbidity removal in filters depends very strongly on the effectiveness of coagulation. It also depends on the flow through the filter and on there being an even flow distribution. Scouring of the surface of the filter bed by the filter influent must be avoided.

4.3.2.6.3 Variations in filtrate turbidity during the filter run

During normal filter operation, the filtrate turbidity does not remain constant but varies with time. At the beginning of the run, there are usually two to three hours of relatively poor filtrate turbidity. While this is normal, the operator should try to ensure that the filtered water turbidity remains less than 1 NTU. High filtrate turbidities after backwashing can indicate:

(a) Coagulation is inadequate
(b) Backwash was stopped to soon. Backwash should be continued until the turbidity of the dirty backwash water drops to 10 NTU.
(c) The filter bed was not adequately cleaned because backwash is inadequate (discussed further in the next section).

After the first few hours, if the filter is working properly, the filtrate turbidity should improve. However, if the filter is run for too long, the filtrate turbidity may start to get worse again. This is known as **terminal filter breakthrough**. The filter should be backwashed as soon as terminal breakthrough is observed and preferably before.

4.3.2.6.4 Adequacy of backwash

The most challenging part of the operation of rapid filters is ensuring that the filter media (sand or other granular material) is adequately cleaned during backwashing. Floc which remains attached to the filter grains after backwashing tends to accumulate and form solid masses known as mudballs. Inadequately cleaned areas of filters also tend to shrink during filtration resulting in cracks n the filter bed through which dirty water can pass without being properly filtered. The deterioration of the filter media can go unnoticed for some time, especially in valveless and pressure filters where the operator cannot see the filter bed. However, filter performance will eventually be affected. Typical signs of filter media problems include:

- The filter clogs up very quickly even though the settled water turbidity is low
- The filtered water turbidity is poor throughout the filter run even though coagulation, flocculation and sedimentation appear to be adequate.

Once filter has developed these problems, the filter media usually has to be replaced. It is now widely accepted that it is not possible to clean filters properly with water backwash alone. Some kind of auxiliary backwash system is required to prevent dirty filter problems developing. In South Africa, the most common form of auxiliary backwash involves blowing compressed air through the filter (air scour). However, this is not necessarily a suitable option for small rural treatment plants. There is a danger of seriously damaging the filter floor or blowing the sand out in the washwater if the air is not applied correctly. Furthermore, air scour systems not only add a significant cost the plant but also need regular maintenance to f unction properly.

Consequently, many filters in small treatment plants are installed without auxiliary backwash facilities. This includes all valveless filters and some pressure filters. These filters will typically develop problems within one to two years of clean filter media being installed. Consequently, municipalities must be prepared to change or chemically clean the filter media at least every two years and probably every year.

> Plants with rapid filters without auxiliary backwash will have to replace or chemically clean the filter media every 1 to 2 years.

Other factors which negatively affect backwash efficiency include overdosing coagulant/flocculant, allowing filters to run for too long without backwashing and uneven and/or inadequate backwash flow. The longer filters run without backwashing, the more difficult it is to remove the floc deposits (Brouckaert, 2004).

Filters which have air scour backwash should be backwashed after 48 hours at most while filters without air scour should be backwashed at least once a day. Backwashing in conventional and pressure filters is usually initiated by the operator. Backwash in valveless filters is initiated by the filter clogging up, but can also be manually initiated. Operators should to be trained to initiate backwash manually if necessary when the filters are installed. Operators need to keep track of when the filters are backwashing automatically and make sure that backwash occurs at least once a day.

> Filters with auxiliary backwash should be backwashed at least once every 48 hours. Filters without auxiliary backwash should be backwashed at least once a day.

Filters should be designed to ensure that the backwash flow is appropriate for the size and weight of the filter grains and is evenly distributed across the filter floor. Poor backwash design will lead to poor backwash efficiency. However, backwash flow problems can also develop over time. Filter nozzles and backwash pipes can become clogged causing the backwash flow in some or all areas of the filter to drop. The development of large mudballs and clogged regions also contribute to uneven backwash flow. In conventional filters, the operator can easily see evidence of poor flow distribution during backwash (including air distribution) however, he will not be able to see what is going on inside a pressure or valveless filter. He should, however, always report any apparent drop in the overall backwash flow observed at the point where the dirty water is discharged.

Whenever the filter media is replaced, the filter nozzles and pipes should be inspected for signs of damage or blockage. Any work done on filters which involves removing the sand and exposing the filter floor should only be done by experts in filter refurbishment because of the risk of damaging the nozzles.

4.3.2.6.5 Filter media size and depth

The performance of filters is also strongly dependent on both the depth of the filter bed and the size of the filter media. If the sand is replaced, the replacement sand must be exactly the same size as the original sand and the filter must be filled to the original design depth. Note that the bed depth can change during operation as a result of number of factors including mudablling which tends to cause the bed height to increase (Brouckaert *et al*, 2003) and media losses which tends to cause it to decrease). The design media size and depth should be given in the plant operating manual or may be obtained from the company which installed or upgraded the filter.

If the bed height is too short, poor filtered water turbidities may result. If too much sand is added, it may be washed out during backwashing. It may also result in air binding of the filters if there is insufficient water level above the top of the bed. Air binding involves the formation of air bubbles in the filter which cause it to clog up more quickly than it should. It is more likely to occur if the water level above the filter is too low. For filters fed by gravity, the water depth above the bed should not be less than 0.5 m. Air binding does not happen in pressure filters because high pressure causes dissolved gases which form air bubbles to stay in solution.

4.3.2.6.6 Slow sand filtration

a. Principle of operation

Slow sand filters differ from rapid filters in several key respects: The filtration rate is much lower in slow sand filters (0.1 m/h compared to 5 to 10 m/h) and the sand is smaller (0.3 mm in size compared to 0.5 to 1 mm in size for rapid filters. In rapid filters, floc penetrates deep into the filter bed and consequently the whole bed has to be backwashed. In slow sand filters, floc, micro-organisms and dirt particles are mainly removed in a thin layer which forms at the top of the filter. When the filter clogs up, this layer can simply be scraped off. Note this layer, known as the *schmutzedecke* is biologically active, and plays an important role in the removal of pathogens by slow sand filters. Consequently, there should be not be any chlorine in the influent to slow sand filters. Filters typically operate for several weeks or months between cleanings, depending on the characteristics of the water being filtered. The sand removed during scraping may be cleaned and replaced or discarded and replaced with fresh sand.

b. Advantages and disadvantages of slow sand filters

Slow sand filters have a number of advantages which make them attractive for use in small treatment plants:

- The filters are simply to operate. They can be operated successfully by workers or community members with minimal training.
- The design of slow sand filters is very simple. They have no backwash pumps and there are few things which can go wrong with them. They are therefore cheaper to operate and maintain than rapid filters.
- They can be effective in removing pathogens even without the use of coagulant. By contrast, the removal of pathogens in rapid filters is strongly dependent on effective coagulation.

Slow sand filters have traditionally been operated without any chemical pre-treatment. However, this option is only suitable for very high quality raw waters because turbidity removal is generally poor when coagulant is not used. In South Africa, a number of small treatment plants use slow sand filtration instead of rapid filtration following conventional coagulation, flocculation and sedimentation. Disadvantages of slow sand filters include the following:

- As a result of much lower filtration rates, slow sand filters have to be much bigger than rapid filters to treat the same amount of water. Consequently, the initial cost of slow sand filters tends to be higher than rapid filters
- When slow sand filters are used on their own (without coagulation, flocculation and sedimentation), they cannot achieve the same turbidity removal as conventional treatment and can clog up too quickly when the raw water turbidity increases.
- Operators do not like cleaning the filters and the dirty filter sand manually.

Municipalities currently using slow sand filters should consider their options carefully before replacing them with rapid filters. Some may be tempted by the convenience of having filters which can be backwashed as opposed to the tedious manual process of cleaning slow sand filters. However, they are often not aware of the many operating and maintenance problems which they are likely to encounter with rapid filters.

Major advantages of slow sand filtration for small treatment plants:

- Simplicity of operation.
- Low operating costs.

4.3.2.7 Stabilisation

Chemical stabilisation is an important part of conventional treatment but it is unfortunately neglected in many small treatment plants in South Africa. The negative effects of not providing chemical stabilisation may not be observed immediately and some municipalities appear to believe that they can cut costs by leaving it out of their treatment process (Hinsch, 2003). This section explains what chemical stabilisation is and why it is necessary both to reduce operating costs and improve the quality of the water provided to consumers.

4.3.2.7.1 Why chemical stabilisation is important?

The chemical stability of water refers to its tendency to either form chemical scales on surfaces in water pipelines and fixtures or to corrode materials used in the construction of the distribution system (DWAF *et al.*, 2002c). Both excessive scale formation and corrosion have serious economic consequences for water service providers and consumers. Excessive scaling reduces the capacity of pipes and can damage kettles and geysers. Associated costs include:

- Increased pumping costs.
- Cost of cleaning or replacing pipes.
- Cost of replacing equipment and appliances.

> Corrosive waters can seriously damage metallic and asbestos-cement pipes, pumps, valves and flow meters, metallic plumbing fixtures and concrete. Failure to stabilise finished water will lead to increased pumping and maintenance costs and may lead to catastrophic system failures. No Water Services Provider can afford to ignore the need for adequate corrosion control.

Corrosion can damage metal and asbestos-cement pipes, fittings and even concrete structures such as reservoirs (Schock, 1990; Kawamura, 1991). This leads to leaks, significantly increased water losses and increased maintenance requirements. Corrosion also has a negative impact on the microbial quality of the water. Corrosion products (chemicals released into the water or deposits formed on the pipes as a result of corrosion) consume chlorine and therefore make it difficult to maintain adequate chlorine residual. Biofilms (bacteria growing on the pipe walls) find it easier to grow on corroded surfaces than on clean smooth surfaces. Biofilms consume chlorine, can cause taste and odour problems, may harbour dangerous pathogens, increase the number of bacteria in the water at the point of delivery and can even increase the rate of corrosion. Increased costs associated with corrosion include:

- Increased pumping costs due to corrosion products.
- Water losses and lost water pressure due to leaks.

- Replacing corroded pipes.
- Repairing damage to concrete structures.
- Water damage to dwellings and businesses and the necessity of replacing corroded fittings and water heaters.
- Dealing with consumer complaints about “coloured water” (due to corrosion products), stained laundry and plumbing fixtures as well as unpleasant tasting water.
- Increased chlorine dosing requirements.

Polyvinyl chloride (PVC) piping, which is widely used in the distribution systems of small treatment plants in South Africa, is fortunately resistant to corrosion. However, since every distribution system includes concrete and metallic elements, it is imperative that **all** Water Services Providers take steps to minimize corrosion in their systems.

4.3.2.7.2 Calculating and adjusting the chemical stability of water

The chemistry of both corrosion and scale formation are quite complicated but the tendency of the water to form scale increases with increasing pH and hardness (calcium and magnesium concentrations) while the corrosiveness of the water tends to increase with decreasing pH and decreasing hardness. Waters with total hardness (sum of calcium and magnesium ions) less than 75 mg/L as $CaCO_3$ are classified as soft whereas waters with total hardness greater than 75 mg/L are classified as hard (Benefield and Morgan, 1990).

Chemical stabilisation involves adding certain chemicals to water to prevent both excessive amounts of scale formation and corrosion. This is usually achieved by adjusting the pH to ensure that the finished water is slightly over-saturated with calcium carbonate. Water which is over-saturated with calcium carbonate tends to form a small amount of calcium carbonate scale on the surfaces of pipes and fixtures. While a large amount of scale is undesirable, a thin film of calcium carbonate tends to protect metal pipes and fixtures from corrosion. Ensuring that the water is over-saturated with calcium carbonate also prevents corrosion of cement –asbestos pipes and concrete structures such as storage reservoirs.

The tendency of water to form calcium carbonate scale can be expressed as its calcium **carbonate precipitation potential** (**CCPP**). A **finished water** calcium carbonate precipitation potential of at least 4 mg/L is recommended while the total **total hardness** should remain in the range of 50 – 100 mg/L as $CaCO_3$ (Thompson *et al*, 2004). Water with a negative potential to form calcium carbonate scale (i.e. water which tends to dissolve calcium carbonate) is treated with a chemical which tends to **increase pH**. The most commonly used chemical for increasing pH is **lime**. However, many plants are switching to **soda ash** (Na_2CO_3) because it is easier to handle. If on the other hand the CCPP value of the water is too high, then **carbon dioxide gas** is added to the water to reduce the pH.

The following information is required to calculate the CCPP of water and determine its potential to corrode various materials (Murphy, 2002):

- On-site pH
- On-site temperature
- Electrical conductivity (EC)
- Alkalinity
- Magnesium concentration
- Calcium concentration
- Calcium hardness
- Chloride concentration
- Sulphate concentration

Most small treatment plants and municipalities do not have the facilities to measure all of these parameters in-house and consequently the analysis for water stability would probably be done by an external laboratory on a weekly or monthly basis **(Note: it is important that pH and temperature are measured on site)**. The calculation of CCPP is also quite complicated and is usually performed using spreadsheet or computer software, such as **STASOFT** (Loewnthal, Ekama and Marais, 1988). STASOFT can be purchased from the South African Water Research Commission (WRC). Some background in chemistry and familiarity with computers is helpful.

In practice, the calculations would be used to determine an acceptable range of **final water** pHs and expected doses of the pH adjustment chemical(s). The operators would then adjust the chemical doses to get the final water pH in the target range. Note that if alum or ferric chloride is used for coagulation, the amount of lime or soda ash required will generally increase with increasing coagulant dose.

An alternate and widely used indicator of the corrosive tendency of finished water is the **Langelier Index** (LI). The LI of water is the actual pH of the water minus the pH of the same water at which CCPP would be 0. Since the solubility (amount which can dissolve in water) of calcium carbonate tends to decrease with increasing pH, a positive value of LI usually corresponds to a positive value of CCPP while a negative value of LI corresponds to a negative value of CCPP. A value of LI ~ 0.2 is generally recommended (Kawamura, 1991). LI has several limitations including that it does not always correctly predict whether CaCO3 will precipitate or not and it also does not predict how much will precipitate (Schlock, 1990). Therefore it is preferable to use CCPP rather than LI.

4.3.3 Operation of piped water distribution systems

Once treated water leaves the chlorine contact tank or finished water reservoir, it typically spends several hours to several days in the distribution system. The distribution system consists of all the pipes, storage reservoirs and pumping stations between the treatment plant and the taps or community standpipes where consumers obtain their water (point of delivery). Depending on the quality of the finished water, the state of the distribution system and the length time that water remains in the distribution, the quality of the water at the point of delivery may be substantially worse than the quality of the finished water at the treatment plant.

Chlorine residual is one of the primary indicators used to assess the microbial quality of water and the adequacy of treatment. The chlorine residual in the treated water helps to prevent the growth and proliferation of microorganisms and provides some protection against re-contamination. However, free chlorine disappears over time and will eventually disappear completely if the water is not used quickly enough. Factors which cause the chlorine to disappear more quickly include high finished water turbidities, high dissolved organics concentrations (including colour), corrosion, the presence of biofilms and other organic or inorganic deposits in pipes and the contamination of treated water with untreated water as a result of leaks, backflow and cross-connections.

This section discusses the impact of various aspects of the operation of the distribution system on water quality. For a comprehensive review on managing distribution systems, see *Safe Piped Water* (Ainsworth, 2004) published by the World Health Organisation (WHO, 2004).

4.3.3.1 Preventing the development of biofilms in the distribution network

Biofilms are coatings of living bacteria, which become established on the walls of pipes and reservoirs in the distribution system. Biofilms negatively impact water quality in several ways:

- They may cause taste and odour problems.
- They may harbour dangerous pathogens.
- Individual cells or clumps of bacteria break off from the walls and increase bacterial counts (specifically heterotrophic plate counts) in the water at the point of delivery.
- Biofilms consume chlorine, reducing the chlorine residual.
- They may increase the rate of corrosion of the surfaces they are attached to.

One of the main reasons for trying to maintain chlorine residual in the distribution system is to prevent biofilm growth in the first place. However, biofilms may still develop if:

- **Chlorine is not consistently applied**. For example, if there is no chlorine or inadequate chlorine for several weeks, then biofilms will become established. Once they are established, restoring the chlorine dose to recommended levels usually will not get rid of the biofilms.

- **If there are significant levels of turbidity and biodegradable organic material in the finished water**. Turbidity shields bacteria from chlorine and bacteria feed on biodegradable material. The presence of both turbidity and organics will also reduce the chlorine residual.
- **Pipes are corroded or coated with organic or inorganic deposits**. Biofilms establish themselves more easily on rough corroded surfaces than smooth clean surfaces.

In order to prevent biofilm development it is important to:

- **Reduce turbidity, organic matter and bacteria in the finished water** to the lowest levels possible.
- **Maintain consistent and adequate chlorine residual** in the finished water and throughout the distribution system.
- **Minimise corrosion** in the distribution system by ensuring that the finished water is adequately stabilised.
- **Minimise the potential for untreated water to seep into the reticulation system** (discussed further in Section 4.3.3.3).
- **Monitor heterotrophic plate counts** in both the finished water and at various points in the distribution to determine where biofilms may be developing.

Once biofilms have become established they usually have to be removed by shock dosing of disinfectant and/or high velocity flushing or swabbing of the pipes. Methods and strategies for cleaning pipe networks are discussed in Chapter 4 of *Safe Piped Water* (Ainsworth, 2004).

4.3.3.2 Storage reservoir design and operation

Most towns have several domestic water storage reservoirs which serve different zones in the supply area. Water is pumped to reservoirs located above the treatment works while reservoirs located below the plant may be fed by gravity. Reservoirs may be operated with either variable or constant level. **Level indicators** are usually used to determine when the flow to the reservoir needs to be either increased or decreased. In many cases, automatic level control systems are used: the level sensor on a reservoir sends signals to the pumps feeding the reservoir to turn them on or off. When the reservoir level drops to the minimum allowed value, the pumps are turned on and when the level reaches the allowed maximum, the pumps are turned off.

Reservoirs which are fed under gravity (water flowing downhill with no pumping required) from other reservoirs are often operated at constant level. A **float valve** on the inlet opens when the reservoir level starts to drop and closes when the reservoir level starts to rise. This simple scheme prevents the lower reservoir overflowing when the flow at the outlet drops.

Off-site storage reservoirs provide additional storage capacity for:

- **Meeting peak flow requirements (balancing capacity).** They allow the treatment works to operate at a relatively constant rate even though the water demand in the supply area varies from hour to hour.
- **Having a sufficient supply of water on hand for fighting fires.**
- **Providing residents with an uninterrupted supply of water** during both scheduled (for maintenance or construction) and unscheduled (emergencies and system failures) down time at the treatment works.
- **Providing additional chlorine contact time** if the contact time at the treatment works is insufficient.

Elevated reservoirs are used to increase the pressure in the distribution system so that consumers are able to getting a sufficiently strong flow at the point of delivery. Unfortunately, storage reservoirs also significantly increase the amount of time that water remains in the distribution system and this can negatively affect water quality. The chlorine residual even in very clean water gradually disappears and will eventually drop to zero. The longer the water remains in storage reservoirs or stagnant areas of the pipe network, the more time bacteria have to recover from the disinfection process and start increasing in numbers again.

Particular attention needs to be paid to storage reservoirs and areas of the distribution system where demand is low. Some towns and villages have only a few days total storage capacity at most while others have storage tanks designed with future demand in mind. These tanks may be much larger than the area's current need and can have very long **retention times** if operated closed to 100 % full (See Section 4. 3.2.2.3 for the calculation of retention time). As a result the chlorine residual in the water may disappear before the water reaches consumers and there is an increased chance of bacterial regrowth. Problems may also arise when there is a chain of reservoirs with one feeding into another as shown in Fig. 11 It may be difficult to maintain an adequate residual in supply zone 4 without having unpleasantly high levels of chlorine in zones 1 and 2.

Other factors which affect the quality of water stored in reservoirs include the degree of mixing in the reservoirs and their general sanitary state. Section 4.3.2.2.3 discussed the importance of minimising the amount of mixing in tanks and reservoirs used for providing chlorine contact time. The opposite is true for reservoirs which are used only for storage i.e. those reservoirs which do not have chlorine addition at the inlet. In this case, the greater the degree of mixing and the shorter the effective contact time, the better the water quality. Small lengths to width ratios are preferred and baffles are generally not recommended (Ainsworth, 2004).

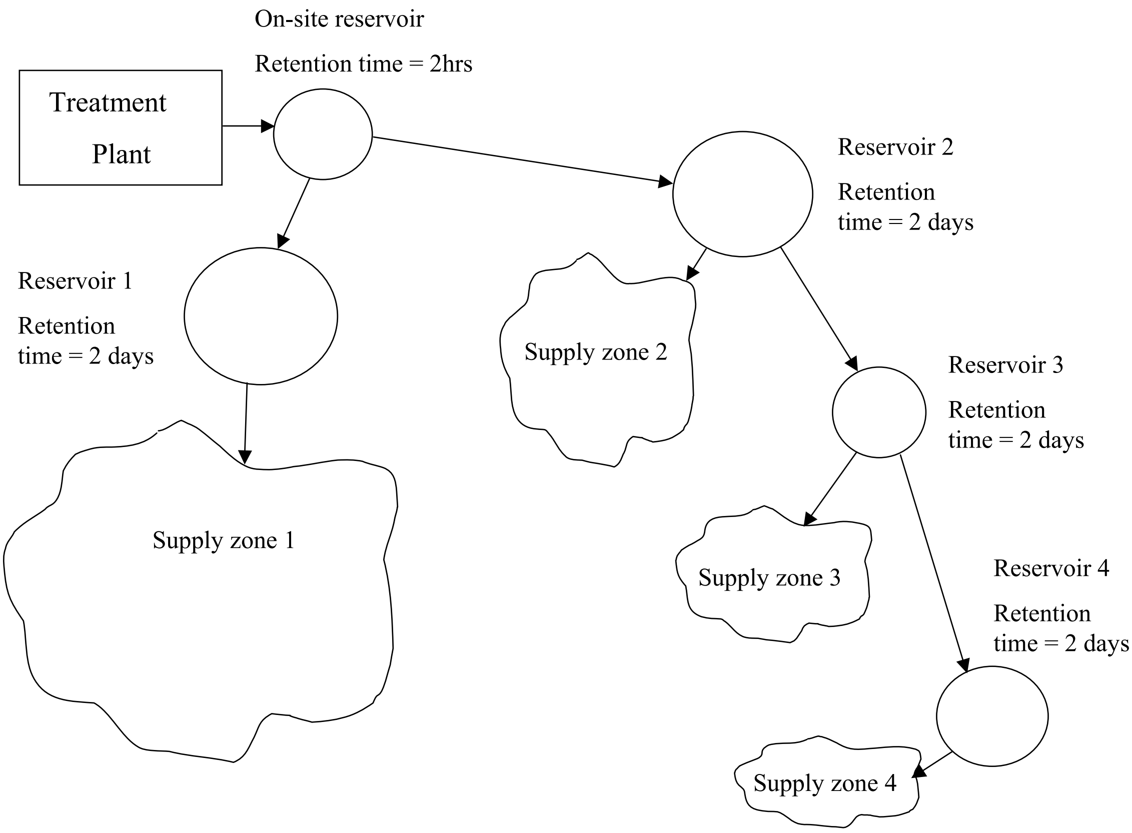


Fig. 4 11 Example of a distribution system with several off-site storage reservoirs

> Treated water storage reservoirs must be covered and secured to prevent contamination of the stored water. Reservoirs should be drained and cleaned every 1 to 5 years depending on the rate of accumulation of sediment in the reservoirs.

Maintaining the sanitary condition of reservoirs is extremely important (Ainsworth, 2004). All reservoirs holding treated water need to be covered and secured to prevent contamination by humans, animals and litter. All access hatches should be kept locked except for inspections or sampling and reservoirs should be fenced off. Vents should be designed to prevent animals and foreign objects entering the reservoir. A suitable design is a U-shaped pipe or duct with a mesh covered opening facing downwards. In addition, reservoirs should be drained and cleaned out with pressure hoses or approved chemical treatments every 1 to 5 years. This is because sediments which tend to settle out in the reservoir will tend to consume chlorine, making it difficult to maintain an adequate residual. The required frequency of cleaning will depend on the efficiency of turbidity removal at the treatment works, water quality at points downstream of the reservoir and visual evidence of damage or contamination of the reservoir. It is extremely important that personnel tasked in cleaning reservoirs are properly trained in sanitary procedures. Details are given in Tarbet *etal.* (1993).

If it is not possible to maintain chlorine residuals within acceptable levels in all parts of the supply area then the following options may be considered:

1. **Reducing the operating level.** Reducing the operating levels of reservoirs reduces the average retention time and therefore the loss of chlorine residual. For reservoirs operated with varying level, this means lowering the minimum level to provide no more than two days average retention time at average daily flow. The average daily flow is the average volume of water flowing out of the reservoir in one day. This number may vary seasonally. For reservoirs operated at constant level, the operating level must be lowered. Where the inlet valve is operated by a float, the float arm can simply be lengthened so that the valve closes at a lower operating level. Whatever arrangement is made, it must be easy to change back if the average demand increases and the average operating level needs to be increased again.

2. **Introducing booster chlorination.** Booster chlorination involves dosing additional chlorine at points in the distribution where long retention times are a problem. This makes it possible to maintain adequate chlorine residuals at the farthest points in the distribution system without excessively high chlorine levels in the water delivered to consumers closer to the plant. The most convenient point to deliver booster chlorination is the inlet of storage reservoirs. HTH will usually be the most practical option for off-site chlorination. If a dosing pump is to be used, there must a suitable power source and the dosing system must be protected from the weather. Other options including floating swimming pool chlorinators and manual dosing by municipal workers. Manual dosing should be at least once a day. Both manual dosing and floating chlorinators should be kept as close to the reservoir inlet as possible to ensure that the chlorine is mixed with as much of the flow as possible. When booster chlorination is used, it is important to ensure that workers can visit the reservoir regularly to replenish the chemicals. Furthermore, the chlorine residual needs to be measured at various points below the reservoir to ensure the system is working as intended.

3. **Introduce chloramination.** Chloramination produces a longer lasting disinfectant residual than chlorination and therefore is a potential option for distribution systems

with long retention times. However, there is a risk of nitrites formation in stagnant areas (LeChevallier and Au, 2004). Furthermore, the successful application of chloramination requires a high level of operator skills and the maintenance of high safety standards (Thompson, 2003). Consequently, it is not suitable for use in most small treatment plants under South African present conditions.

4.3.3.3 Minimising the risk of contamination in pipe networks

Apart from inadequate disinfection at the treatment plant or contamination of reservoirs, there are several other ways that microbes can enter pipes in the distributions system. These include contaminated water seeping into leaky pipes when the pressure in the distribution system drops, cross-connections, backflow and failure to maintain hygienic conditions during construction and repair of pipe networks (Ainsworth, 2004). The chlorine residual in the treated water will generally be insufficient to kill off microbes entering the pipe network via any of the above routes, but the sudden disappearance of the residual may be an indication that contamination has occurred. Therefore routine monitoring of chlorine residual and microbial quality at various points in the distribution system is important for detecting possible contamination.

Leaking pipes and intermittent (not continuous) water supply pose a major risk to the microbial safety of water. While the pressure in the distribution system is high, water tends to leak out of the pipes. Although this is wasteful, there is little risk of contaminants entering the pipes against the flow. However, if the water supply is shut off for any reason then the pressure in the pipes will drop. Consequently, dirty water from outside the pipes may seep in through the leaky pipe walls. In order to avoid contamination by this route, it is important to:

- Minimise disruptions in pressure and water supply.
- Minimise leaks.

Water services providers should any case seek to minimise leaks because the wasted water represents an increase in operating costs without an increase in revenues. Strategies for reducing leakage include:

1. Installing meters at various points of the distribution system to determine where significant water losses are occurring.
2. Repairing leaks promptly when they occur.
3. Maintain the operating pressure throughout the distribution system below 900 kPa or if feasible, below 600 kPa to reduce the risk of pipe bursts.
4. Using appropriate materials and construction methods in the pipe network.
5. Stabilising the treated water to minimize corrosion.

Current regulations already specifically require Water Services Authorities and Providers to implement the first three points (DWAF, 2002b). The last four points also apply to sewers and wastewater lines because leaking wastewater poses a threat to any drinking water lines it comes in contact with. The risk can be reduced by locating water pipes a safe distance from sewer lines wherever possible. For, example regions in the United States recommend that water and sewer mains should be separated by at least 3 m horizontally and 45.7 cm vertically (Great Lakes, 1997). It is also undesirable to have water lines passing through stagnant pools of water e.g. in flooded drains (Ainsworth, 2004).

A **cross-connection** is any connection between the piped domestic water supply and any potential source of contamination. Cross-connections are most likely to occur on private property (residential and commercial) where the Water Services Provider has less control over the plumbing arrangements (Ainsworth, 2004). However, since they may affect the safety of water supply supplied to other consumers in the vicinity, they are very much the Water Services Provider's concern.

The most dangerous type of cross-connection is **accidental connections between potable water and wastewater pipes**. In order to prevent this from occurring:

- The Water Services Provider and Water Services Authority must keep up to date maps of all domestic water, sewer and industrial wastewater lines.
- Potable water and wastewater lines should be easy to tell apart e.g. different colour pipes could be used.
- Connections should be made only by properly trained, authorised personnel.
- All illegal connections should be removed as soon as they are discovered.

Other types of cross-connections can potentially contaminate the piped water supply as a result of **backflow**. Backflow may occur if the pressure in the distribution system drops or if a high back pressure is applied at the point of delivery. Backflow events have been identified as the most common cause of waterborne disease outbreaks in the United States (Dyksen, 1997; Craun, 1981). Examples of potential sources of cross-connection due to backflow include beverage dispensers, hose pipe sprayers, water jetting equipment and fire sprinkling systems (Ainsworth, 2004). Strategies for preventing backflow include:

- Installing backflow prevention devices where hazards are identified.
- Minimising disruptions to the water supply.
- Educating consumers about the dangers of cross-connections.
- Implementing a cross-connection management programme.

Strategies to prevent contamination of pipe networks:

- Minimise flow disruptions.
- Minimise leaks and pipe bursts.
- Locate water pipes away from sewer mains and areas where stagnant pools of water collect.
- Prevent cross-connections and backflow.
- Adopt hygienic work practices and disinfect lines after installation or repair.
- Monitor chlorine residual and microbial quality at point of delivery to identify potential problem areas.

For more information on cross-connection control see Chapter 3 of *Safe Piped Water* (Ainsworth, 2004). For detailed guidelines see the *Australian and New Zealand Standard AS/NZS 3500.1.2:1 National plumbing and drainage code. Part 1.2: water supply — acceptable solutions.* AS/NZS (1998) or *Manual M14: Recommended practice for backflow protection and cross connection control* (AWWA, 1990). South Africa does not currently have national guidelines on cross-connection control. However, backflow prevention is discussed in Annex F of SANS 10252-1 (SABS 0252-1), *Water supply and drainage for buildings: Part 1: Water supply installations for buildings* (SABS, 2004). South African regulations (*Government Gazette, Vol. 432 No. 22355, 8 June 2001*) do however require that all consumer installations other than meters comply SANS 10252/SABS 0252 (SABS, 2004a) and SANS 10254/SABS 254 (SABSb).

There is also a significant risk of contamination of pipes during construction and maintenance. While every precaution should be taken to minimise contamination of pipework (see Chapter 5 of *Safe Piped Water* (Ainsworth, 2004) for details), it is inevitable that some dirt will get into the lines. Therefore lines should be disinfected and thoroughly flushed until all the dirt has been washed out. Pipes can be disinfected by placing powdered HTH in the lines before sealing them (Ainsworth, 2004). Local users should be warned that the disinfectant may cause taste and odour problems and discolouration of the water for a period of time (DWAF *et al.*, 2002d).

4.3.4 Process control

Water treatment plant operators are all aware that the characteristics of the raw water they are treating changes from time to time. The quality of **borehole water** tends to change the least while the quality water extracted directly from **rivers** tends to change the most. The raw water can be more or less dirty and it may be more or less difficult to form a floc which settles easily. Even the change in temperature from winter to summer can affect how difficult it is to treat the water. (It is harder to form floc in cold water). Furthermore, there are variations in water demand which may require changes in raw water flow rate. Consequently, operators need to make adjustments to the operation of the plant from time to time in order to meet changing treatment requirements. They also need to check that the adjustments that they are making are having the desired effect

The efficient production of safe drinking water requires the implementation of proper **process control procedures**. Process control involves **measuring** the performance of the various treatment processes (including storage and distribution) and **adjusting** the operation of these processes to achieve the desired performance. The most important process control measures involve the dosing of treatment chemicals. For process control to be effective, an appropriate system for measuring treatment effectiveness needs to be in place. Such a system will have three key components:

i) What parameters (turbidity, pH, etc.) need to be monitored and what procedures and equipment are required for sampling and analysis (measurement).

ii) At which stages of the treatment will samples be collected/measurements be made.

iii) What is the **frequency** of sampling (how often are samples collected and analysed).

Process control requires that a further two components be specified:

i) Acceptable **ranges of values** for the measurements made must be defined

ii) **Procedures** for adjusting the treatment processes to meet required performance standards must be established.

The number of different operational parameters monitored for process control will depend on the size and complexity of the plant, the treatment objectives and the skill of the operators. Every treatment plant should be equipped to measure at least **turbidity**, **pH**, **free chlorine, filter run time, flow rate** (See Section 4.3.2.3) and/or **hours of operation**. These are all easy to measure if the right equipment is available and all have an impact on the efficiency of treatment. In addition, operators need to be able to carry out the **jar test** to select the **optimum coagulant dose** and should record all dosing rates. The **operating levels**, **flows** into and out of and **hours of pumping** for all storage tanks and reservoirs in the distribution system should also be recorded.

A vital part of monitoring and process control is **record keeping**. All measurements must be recorded on **logsheets** along with the time and date they were measured and any comments. All **process control decisions** and adjustments (including time and date) should also be recorded. This is vital for correctly interpreting the results and for improving process control procedures in the future.

Monitoring for process control should be carried out both at the treatment plant and at various points in the distribution system. Monitoring on the plant should be undertaken by the operators as part of their daily routine. Monitoring and process control in the distribution system is more complicated because there are many more possible sampling points, there are few operating variables which can be adjusted and it is difficult to tell what is going on in the pipes and at the bottom of reservoirs. Process control actions also take much longer to have a measurable effect therefore past experience is important in making the correct decisions.

The Water Service Provider should set up a system for monitoring at least **pH**, **turbidity** and **chlorine residual** in tap water from around the distribution system. The area supplied by the treatment plant should be divided into different zones based on an **up to date map of the distribution system** and **at least one** sampling site should be selected in each zone. There should be at least on site for each **storage reservoir** and **main line** and one for **each type delivery point** in a given zone (inside tap, yard tap or public standpipe). Sampling should be carried out all sites **monthly** but not necessarily all on the same day. Monitoring data collected by the WSP should be compared with data collected by any external monitoring groups (for example data collected on behalf of the Water Service Authority as required by national regulations) however, it is not necessary for all the same sampling sites to be used in both cases.

The following sections describe how the process control monitoring data will be used to make process control decisions.

4.3.4.1 Turbidity

Turbidity is used to assess the efficiency of the **coagulation**, **flocculation**, **sedimentation** and **filtration** processes. It is also required to access the quality of water at the point of delivery and can provide an indication of various processes in the distribution system which can negatively impact water quality. These include sedimentation in the reservoirs and pipelines, biofilm development and corrosion. Turbidity should be measured at the following points: raw water, settled water, filtered water, finished water, point-of-use. It is **not** necessary to measure the turbidity of the flocculated water. If there are more than one settling tank and/or filter, the settled or filtered water from each individual unit should be measured if possible. This is particularly important in the case of filters since they perform differently at different times in their cycle (See Section 4.3.2.6). Both slow and rapid filters tend to produce higher than average turbidities just after backwashing/scraping while the filtered turbidity from a rapid filter may also start to get worse towards the end of its cycle. In this case, the filter should be backwashed as soon as the worsening quality is observed.

Table 4.9(a) lists the points in the treatment plant where turbidity should be measured, the frequency of sampling and the recommended control limits. Raw water here refers to the raw water

TABLE 4.9(a)

TURBIDITY MONITORING

Sampling point	**Frequency**	**Person**	**Target Ranges (NTU)**		
			Ideal	**Good**	**Acceptable**
Raw water	At least once per shift, preferably once every two hours. More often when raw water turbidity high or turbidity removal targets not met	Operator/ supervisor	-	-	-
Settled water*			< 2	< 5	< 10
Filtered water			< 0.1	< 0.5	< 1.0
Finished water (after on-site reservoir)**			< 0.1	< 0.5	< 1.0
Distribution system *** At least one sample per zone and for each type of delivery point.	Monthly or whenver a complaint is received from the area.	Supervisor	< 0.1	< 1	< 10

* In addition to meeting the target turbidity values, the settled water turbidity must be significantly less than the raw water turbidity. For example, if the raw water turbidity is 2.5 NTU and the settled water turbidity is 1.9 NTU then there is clearly a problem with coagulant dosing and/or the sedimentation process.

** The filtered and finished water indicates that sediment is settling out in the finished water reservoir. This is a problem because the layer of sludge which develops in the reservoir will exert a high chlorine demand.

*** The turbidity of tap water samples is often higher than that of filtered and finished water. This is not necessarily a problem, but a sudden and excessive increase in turbidity in tap water samples not related to treatment plant performance should be investigated further. A significant decrease in turbidity between the treatment plant and consumers' taps suggest that excess turbidity is settling out in storage reservoirs. See previous comment.

TABLE 4.9(b)

PROBABLE CAUSES OF TURBIDITY PROBLEMS AND CORRECTIVE ACTIONS *

Sample	**Possible cause**	**Control action**
Raw	Heavy rains.	Usually operators have no direct control over raw water quality but some plants have the option of switching between sources. For river abstraction, stopping abstraction for short periods during storms and floods may be considered in order to avoid the worst quality raw water (DWAF *et al*, 2002d). When significant changes in raw water turbidity are observed, the operator must be prepared to make appropriate adjustments to chemical doses. See Sections 3.2.2.7 and 3.2.4.2.
Settled water	The most likely cause is incorrect coagulant dose.	The jar test should be used to find the correct dose.
	Very high raw water turbidity.	See comments for raw water.
	Plant flow rate is too high.	Adjust down if possible and extend hours operation if necessary. The settling tanks may be operating above their design capacity and may require upgrading.
	Settling tank requires desludging.	Desludge.
	Excessive mixing in settling tanks due to wind or thermal currents.	See Section 3.2.5. Design modifications may be required. Increase filter backwash frequency and chlorine dose while problem persists
	Sludge blanket has been lost due to excessive desludging or other reasons.	Dose bentonite if facilities available. Increase filter backwashing and chlorine dose until new sludge blanket develops.

* If there are problems with the settled water turbidity, then problems with filtered water and finished water should also be expected. First the probable causes of poor settling should be addressed, and then if the problems with filtered water turbidity persist, these should be addressed separately.

TABLE 9(b) CONT. PROBABLE CAUSES OF TURBIDITY PROBLEMS AND CORRECTIVE ACTIONS		
Filtered water	Post-precipitation. This can occur when alum, lime or ferric chloride is overdosed.	Conduct the jar test to determine the optimum dose.
	A filter has been taken off-line for backwashing or has just returned to service after backwashing.	Keep monitoring filtered water turbidity and temporarily increase chlorine dose until turbidity improves. Also check whether backwashing is being stopped too quickly. The turbidity of the dirty backwash water should drop to 10 NTU before backwash is stopped.
	Mudballing and filter cracking	Replace or chemically clean filter media as soon as possible. Investigate whether filter backwash is too weak (See Section 3.2.6). In the mean time increase the chlorine dose until the problem is fixed.
	A slow sand filter has been returned to service after being scraped.	Raise the chlorine dose in the filtered water until the turbidity is within an acceptable limit.
Finished water or off-site storage reservoir	Scouring of sludge accumulated in storage/contact tank.	Drain and scour reservoir to remove sludge.
	Dirty water leaking in from an external source.	Repair leak. Clean and disinfect tank/reservoir.

inlet before coagulation. Note that in the case of turbidity, operators should try to keep improving the turbidity of the filtered and finished water, even if it is already good. This is because the lower the turbidity, the more efficient disinfection becomes and the smaller the chance that any pathogens will get into the final water. Table 4.9(b) provides a list of possible causes of poor turbidities at each stage of the treatment process and corrective actions.

4.3.4.2 pH

pH is a critical control parameter because it impacts the efficiency of three key processes, namely coagulation, disinfection and stabilisation. The pH control strategy has to take into account the requirements of all three processes. Many small treatment plants are not setting sufficiently tight control limits for pH. Supervisors should note that the ideal pH range of 6.0 – 9.0 specified in SABS-241 does not correspond to appropriate control limits for conventional treatment plants. For example, pH 6 water may be corrosive while disinfection efficiency will be deceased at pH 9.

The pH of the flocculated water has to fall in the acceptable range for the coagulant used (see section 4.3.2.4). The optimum pH for coagulation can be determined from the jar test (see 4.3.2.4.1). If there are no further chemical additions between flocculation and filtration then the pH should not vary much between the flocculated and filtered water. An increase in pH between the flocculated and settled water when lime is used for pH adjustment suggests that the lime was not completely dissolved at the flocculated water dosing point. When alum is used, a drop in pH between the settled and filtered water combined with poor filtered water turbidity indicates overdosing of alum and **post-precipitation**. Other factors which could cause variations in measured pH include instrument problems (instrument drift), disruptions in dosing and biological activity in the treatment units. The optimum pH range for stabilisation has to be determined from the calculation of calcium carbonate precipitation (Section 4.3.2.7). As a general rule, the pH of the finished water should be not more than 8.0 for disinfection to be adequate but not so low that the water is corrosive. A lower limit of pH 6.5 is recommended. The Table 4.10 illustrates some factors to consider for the pH monitoring.

4.3.4.3 Free chlorine residual

Free chlorine residual is the primary indicator of **microbial safety** used in process control. Although it is extremely important to monitor the actual microbial quality of the water microbial analysis takes hours or days to yield results, by which time it is too late to prevent poor quality water reaching consumers. By contrast, chlorine can be measured almost instantaneously and any necessary adjustments to operation can be made within minutes.

One of the most important steps in water treatment is ensuring there is adequate chlorine residual in the finished water. However, the Water Services Provider must also ensure that sufficient free chlorine remains in the water at the point of delivery. Establishing **control limits** for chlorine residual is more difficult than for turbidity or pH because it depends on the size of the distribution system, the state of the pipes and reservoirs and the length of time that water is being

<table>
<tr><th colspan="6">TABLE 4.10
pH MONITORING</th></tr>
<tr><th rowspan="2">Sampling point</th><th rowspan="2">Frequency</th><th rowspan="2">Person</th><th colspan="3">Target Ranges (NTU)</th></tr>
<tr><th>Ideal</th><th>Good</th><th>Acceptable</th></tr>
<tr><td>Raw water</td><td rowspan="4">At least once per shift, preferably once every two hours. Flocculated water pH should be checked more often when coagulant and lime/soda ash doses being adjusted.</td><td rowspan="5">Operator/ supervisor.</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>Flocculated water</td><td rowspan="3">Determined from jar test.</td><td colspan="2" rowspan="3">6.0 – 7.4 (alum*)
5.0 – 8.0 (ferric)
For other coagulants, check with manufacturer/supplier.</td></tr>
<tr><td>Settled water</td></tr>
<tr><td>Filtered water</td></tr>
<tr><td>Finished water</td><td>At least once per shift, preferably once every two hours.</td><td>Based on disinfection efficiency and corrosion control requirements for specific system .</td><td colspan="2">6.5 – 8.0 **</td></tr>
<tr><td>Point of use (distribution system) ***</td><td>Monthly. Daily if problem detected or reported by public.</td><td>Supervisor and/or monitoring agency.</td><td>6.0-9.0</td><td>5.0 – 9.5</td><td>4.0 – 10.0</td></tr>
</table>

* This pH range is required both to ensure good coagulation and to prevent high aluminium residuals in the finished water (DWAF *et a*l., 2002c)

** This pH range is recommended for ensuring adequate disinfection efficiency and for reducing the risk of corrosion in the distribution system

***The control limits for pH at the point of use are those specified by SABS-241. A large change in pH between the finished water and point of use indicates possible problems with corrosion, scaling and/or biological activity in the distribution system.

stored at various points. This is why routine monitoring of chlorine residual throughout the system is required to determine the effect of the chlorine dose at the plant on the quality of the water received by consumers in various areas of the supply zone. In addition to ensuring that all the requirements for adequate disinfection are met in the finished water (See Section 4.3.2.2.4) the **supervisor** needs to ensure that the chlorine residual is between 0.1 mg/L and 1 mg/L at all points in the distribution system. It may be quite difficult to meet these requirements at all points simultaneously. Slightly higher chlorine residuals may be permitted at public standpipes. This is because:

- These delivery points are always contaminated with microbes from the people collecting water there and from the animals usually roaming free in the vicinity.
- The containers used to collected the water are usually not properly cleaned and disinfected
- The water is generally stored in the containers for a period of time before being used.

Sampling points and required ranges of chlorine residual are summarised in Table 4.11(a). Monitoring chlorine residual at the point of delivery is an important way of detecting a variety of problems within the distribution system. The most common reason for an insufficient chlorine residual at the tap is inadequate chlorine dose at the plant. However, there are a number of reasons why the chlorine residual may be absent at the tap in certain parts of the supply area even when chlorine dosing appears to be adequate. Possible causes of inadequate chlorine residuals and corrective actions are summarised in Table 4.11(b).

Every time an inadequate chlorine residual is detected in a tap water sample, the cause needs to be investigated and the situation in that particular area needs to be **monitored on a daily basis** until the chlorine residual is restored. In the mean time, **local residents and businesses should be warned** of the potential threat to the safety of their water and advised to take precautions.

4.3.4.4 Other control parameters

In addition to turbdity, pH and free chlorine residual, several other operating parameters need to be **monitored**, **recorded** and **adjusted** when required. These are listed in Table 12.

TABLE 4.11(a)
MONITORING FOR CHLORINE RESIDUAL

Sampling point	**Frequency**	**Person**	**Target Ranges (mg/L)**		
			Ideal	**Good**	**Acceptable**
Finished water (after on-site reservoir)	At least once per shift, preferably once every two hours. More often when raw water turbidity high or turbidity removal targets not met	Operator/ supervisor	At least 0.5 mg/L at pH less than 8.0 and turbidity less than 1 NTU after at least 30 minutes effective contact time (See Sections 3.2.2.3 and 3.2.2.7)		
Distribution system*. At least one sampling point in each zone and for each type of delivery point.	Monthly. Daily if problem detected or reported by public.		0.3 – 0.6	0.2 – 0.3 or 0.6 – 0.8	0.1 – 0.2 or 0.8 – 1.0**

* Reference: *Quality of Domestic Water Supplies Volume 1: Assessment Guide* (DWAF *et al.*, 1998)

** A slightly higher limit is acceptable if the water is not used immediately.

TABLE 4.11(b)
PROBABLE CAUSES OF CHLORINE RESIDUAL PROBLEMS AND CORRECTIVE ACTIONS *

Sample	Possible cause	Control action
Finished water	Chlorine dose inadequate	Increase dose
	Filtered water turbidity too high	See Table 9(b)
	Accumulated sediment in finished water reservoir consumes chlorine. Another clue would be a drop in turbidity between the filtered and finished water.	Clean reservoir. Improve turbidity removal
Point of delivery	Chlorine dose at plant inadequate	Check plant chlorine dose. Note that it takes several hours or days for water to travel from the treatment works to point of delivery in certain areas of the distribution system. There may have been a dosing disruption a few days earlier although the current dose is correct. **Check the plant operating records** and keep monitoring the situation.
	High turbidity in the filtered and finished water results in rapid disappearance of the chlorine residual	See Table 9(b)
	Sediment deposited in storage reservoirs exerts a high chlorine demand. (Another clue would be a decrease in turbidity after the reservoir).	Clean reservoir. Ensure reservoir properly covered and secured and to prevent small animals, leaves, debris and rubbish getting in. Improve turbidity removal at plant (Table9(b))

TABLE 4.11(b) CONT.
PROBABLE CAUSES OF CHLORINE RESIDUAL PROBLEMS AND CORRECTIVE ACTIONS

Sample	Possible cause	Control action
Point of delivery	**The growth of biofilms in pipes and slimes in reservoirs**. This may be accompanied by taste and odour problems at the point of delivery. This is usually the result of inadequate chlorine dosing, corrosion and aging the pipes.	Maintain effective chlorine dosing. Implement corrosion control. Some sections of pipe may need to be replaced in severe cases. Once biofilms are established, shock dosing with chlorine or chloramines, high pressure flushing or mechanical cleaning should be considered.
	Consumption of chlorine by corrosion products. This may be accompanied by other evidence of corrosion such as rusty water at the point of delivery	Implement corrosion control. Some sections of pipe may need to be replaced in severe cases. High pressure flushing or mechanical cleaning can be considered.
	Contamination of the piped water due to leaks or cross-connections with sewage and wastewater lines	Repair all leaks promptly (water or wastewater). Be particularly careful with water lines passing through flooded areas. Keep up to date maps of all water and sewer lines and records of all repairs to lines. Implement a cross-connection prevention programme. Removal all illegal connections and educate public about the danger of cross-connections.
	Contamination of the storage reservoirs due to leaks or small animals or birds or rubbish getting into them.	Cover and secure all reservoirs to prevent any foreign materials entering them. All access hatches should be sealed and locked.
	Stagnant areas within the distribution system, especially storage reservoirs with much more capacity than required	Possible solutions include operating reservoirs at lower levels (no more than 1 week average retention time). Booster chlorination may be considered. (See Section 3.3.2).

TABLE 4.12
OTHER PROCESS CONTROL PARAMETERS

Operating Parameter	Frequency	Comments
Flow rate (raw, filtered, finished, recycle)	At least once per shift and every time the flow rate is changed.	**Flows should be changed gradually** rather than abruptly. Both the **instantaneous flow** and **daily average flow** must be recorded. The instantaneous flow is used to calculate required dose rates. The average daily flows are used to calculate water losses and balancing requirements,
Hours of operation	Daily	If the plant or any part of it does not operate continuously, then the hours of operation must be recorded. If the plant is shut down and started up manually, then the operator must record the **shutdown** and **start up times**. If shutdown and start up is automatic then the operator should record the number of hours on the **pump hour meters**.
Reservoir levels	Daily and whenever the flow rate is changed manually.	Reservoir levels are required to calculate the chlorine contact time and flow balancing requirements (Section 2.3.3).
Desludging of settling tanks	Depends on plant design and raw water characteristics.	If settling tanks are desludged manually then the operator must record **which tank is desludged, the time and date, the number of minutes the sludge valve is open and any comments about the quality and appearance of the sludge**. This information can be used to determine whether the desludging procedure needs to be adjusted.

TABLE 4.12 CONT. OTHER PROCESS CONTROL PARAMETERS		
Operating Parameter	**Frequency**	**Comments**
Filter run time (rapid filters) and filter backwash	At least once a day if no auxiliary backwash (air) otherwise at least once every 48 hours. These time limits apply whether the plant operates continuously or not.	Filters should be backwashed if the turbidity breakthrough occurs, the maximum pressure drop /headloss is achieved or if the maximum run time is reached. The **time of each backwash for each filter** should be recorded. This is to assist in the interpretation of filtered water turbidity data. The **duration of backwash** (number of minutes) should also be recorded along with any comments about the appearance of the washwater. If possible the operator should take a sample of the washwater **at the end of backwash** and check that the turbidity has dropped to about 10 NTU. If the turbidity is much higher the length of backwash should be increased. If the turbidity is lower than 10 NTU, the length of backwash may be decreased.
Jar test	Once a day or when the raw water turbidity changes..	Records of all jar test results should be kept along with the **time** and **date** of each test. This will assist in the analysis of trends in coagulant demand and consumption.
Chemical dose rates	Once per shift and whenever adjusted.	The **times** and **dates** of all dose rates adjustments must be recorded. All **calibration checks** should also be recorded.
Calcium carbonate preciptiation potential (CCPP)	Monthly	The calculation of CCPP is required to determine the optimum pH range for stabilisation. Since the raw water characteristics change over time, the stabilisation requirements must be continuously reviewed.
Off-site storage reservoir levels and pumping hours.	Weekly	These should be recorded weekly by the supervisor or the plumbing department in order to monitor reservoir retention times.

In addition, plants which have problems with **iron, manganese** and/or **colour** will have to introduce process control strategies for these parameters. Iron and manganese are common problems in borehole water and may also occur in dam water at certain times of year. Colour here refers to dissolved organic compounds in the water which give it a brownish appearance even when all particles have been removed. This is a common problem in the Western Cape. It is **not** the same as the muddy colour resulting from ordinary dirt particles in most other raw waters. Colour is an important consideration in disnfection efficiency because it consumes chlorine. Colour has to be removed before a stable chlorine residual can be established.

Iron, manganese and colour can all be measured using simple colorimetric methods similar to that used for chlorine. However, the actual removal of colour, iron and manganese are considered advanced treatment methods and are beyond the scope of these guidelines. Expert help is required for modifying or adding treatment processes to remove these contaminants and for establishing process control measures. For basic information on colour, iron and manganese removal, see *Quality of Domestic Water Supplies Volume 4: Treatment Guide* (DWAF *et al.*, 2002c).

4.3.4.5 Equipment required for process control

In order to implement process control measures, operators need to have the right equipment and instruments. The minimum requirements for equipment and instrumentation are listed below.

Equipment required for process control

- Turbidity meter.
- pH meter.
- Chlorine meter or chlorine comparator.
- Flow meters.
- Standard jar test apparatus.
- Stop watch.
- Measuring cylinders or dosing tanks with calibrated sight glasses to measure dosing rates for dosing pumps.
- Kitchen scale to measure dry chemical dose rates if dry feeders are used.
- Chlorine gas flow meter if chlorine gas is used.
- Clip board.
- Log sheets.
- Documented process control procedures.

4.4 ACHIEVING EFFECTIVE DISINFECTION – MANAGEMENT ISSUES

The sustainable production of safe drinking water requires **supportive** and **pro-active** (acting before rather than after problems arise) management strategies. This section discusses various management strategies for improving the quality of drinking water and areas in which management in Water Services Institutions needs to improve. **Section 4.4.1** discusses the implementation of drinking-water quality management plans which have had some success in improving water quality in the Free State and Western Cape (Mackintosh et al, 2004a,b).

Sections 4.4.2 discusses the responsibilities of the operating staff and various levels of municipal management in ensuring that the water supplied to consumers is of an acceptable quality or consumers are warned if the water is not safe to drink. Within the Water Services Provider, the treatment plant operators and their supervisors make daily decisions which affect the quality of the water produced and supplied to consumers. They are also generally the first to notice problems with equipment which could jeopardise operations. However, **ultimate responsibility** for the safety of the water supply lies with the top levels of municipal management (Mackintosh *et al.,* 2004b). In order to ensure that the Water Service Provider is able to comply with all Compulsory National Standards (Section 4.2.2), management must ensure that the operating staff (operators and supervisors) have adequate training and resources to run the treatment plants, effective process control measures are in place, facilities and infrastructure are adequately maintained and operating and maintenance costs are budgeted for. Management must also constantly review performance data to ensure standards are being met. A critical part of effective management is insisting that detailed and accurate records of performance data, operational procedures and both routine and non-routine maintenance are kept.

Section 4.4.3 deals with strategies maintaining the safety of water supply in rural municipalities: treatment chemicals not being replenished in time and equipment not being adequately maintained. **Section 4.4.4** discusses the importance of good communications between management and the operating staff while **Section 4.4.5** discusses the importance of communication between the municipality and the local community on water quality issues. Many Municipalities (District and Local) currently lack technical capacity in several key areas, in particular those relating to water quality monitoring and treatment plant and distribution system optimisation. In the short term, partnerships with various governmental and non-governmental organisations can assist municipalities in both monitoring and improving the quality of water produced. However, the majority of these partnerships should be seen as capacity building exercises rather than permanent arrangments. Training of both operators and managers is crucial to ensuring that municipalities become more independent and self-sufficient in the near future. It is also important that municipal management takes an active part in both determining what its specific training needs are and co-ordinating the efforts are the various organisations trying to assist them.

Section 4.6 discusses the role of partnerships, training and capacity building in helping municipalities to achieve sustainable improvements in the quality of drinking water supply. Finally **Section 4.7** discusses the importance of **external monitoring** for **protecting** and **regulating** the quality of water supplied to consumers.

4.4.1 Drinking water quality management plans

The sustainable, efficient and effective production of safe drinking water which complies with all relevant national standards requires a holistic and pro-active approach to the entire process of water treatment and distribution. Under current regulations Water Services Authorities are required to monitor and report on the quality of drinking water supplied to all consumers in the area under their jurisdiction. However, monitoring alone will not result in any improvements in water quality. The causes of poor drinking water quality need to be determined and appropriate actions taken to resolve the problems. Mackintosh *et al.* (1999; 2004) describe a simple methodology for achieving progressive and sustainable improvements in rural water treatment schemes which they refer to as Drinking-water Quality Management (DWQM) procedures. The methodology is appropriate for both water treatment schemes operated by municipalities and community operated schemes. The development and implementation of DWQM involves four main steps:

1. **Initial data collection on a water scheme**. This includes relevant information on water sources, vulnerability of sources, water treatment requirements and existing treatment procedures, the drinking-water distribution network, drinking-water quality records and present drinking-water quality management procedures.

2. **Collection of additional water quality data to fill in gaps in existing data**. Special attention is given to sampling raw water sources, post-water treatment works, network dead-ends, high occupancy buildings, hospitals and schools, areas perceived to be problematic and any regions using untreated water.

3. **Defining roles and responsibilities for operators, managers and community members.** Emphasis is placed on skills training, capacity building, technical support, planning and facilitation of project implementation and increasing community participation.

4. **Design and implementation of a monthly drinking water quality monitoring programme** based on the findings of steps one and two, and considering the outcome of step three. This includes training operators and local community members to collect the required samples according to standard techniques, the review and dissemination of water quality data to all stakeholders and taking appropriate action when the water quality fails to comply with required standards. This includes issuing "boil order" alerts to the community if the water quality is determined to pose a significant health risk.

Water Services Authorities which have sufficient experienced and qualified personnel can work with Water Services Providers under their jurisdiction to develop appropriate Drinking-water Quality Management plans. Where the WSA lacks capacity to carry out the required monitoring, co-operative government requirements specify that Provincial and National Government must ensure that monitoring takes place. Assistance with training, capacity building and planning may be provided by a number of different organisations.

Mackintosh *et al.*, (2004a,b) describe a particularly successful example of co-operation between local and provincial government in setting up the Free State Water Quality Management Initiative. The Free State Department of Local Government and Housing conducts a monthly Consultative Audit of drinking water and treated wastewater across all Free State communities. The results of water quality analysis are reported back to local government. Since the inception of the programme, there has been a 45 % reduction in the number of samples collected from surface water based systems which exceed 5 total coliforms/100 mL and a 30 % reduction in the number of samples in which faecal coliforms were detected.

The following sections discuss specific management issues which need to be addressed in the operation of water treatment schemes under municipal control.

4.4.2 Clarifying roles and responsibilities

For any organisation to function effectively and efficiently there needs to be a clear framework clarifying roles and responsibilities for all the aspects of its operation. Equally important is the need for the municipal management structures at all levels to support this framework by providing adequate resources to fulfil these various roles. This is particularly critical in the case of water services providers because failure to follow proper procedures or to deal with operational problems as quickly as possible can result in treatment failures which endanger public health. A common reason for poor water quality in rural municipalities is that serious operational and maintenance problems are not dealt with in a timely fashion. This is often due to misunderstandings about who is responsible for dealing with various situations, and in many cases, how serious these situations are. Management must ensure that:

- First, it understands what is required to produce safe water efficiently;
- All employees know what their own particular responsibilities are and are able to perform them;
- All employees also understand what the roles and the responsibilities of the people working above and below them are;
- All employees, including managers, know who to report problems to and where they can ask for help;
- All employees know what constitutes an emergency situation (a treatment failure which poses a serious risk to public health).
- All employees know what they are required to do in an emergency situation.
- No critical tasks, such as routine maintenance, have been overlooked.

In addition, management should make every effort to hire and retain competent and motivated staff. Figure 4.13 shows a typical organogram for a local municipality acting as a Water Services Provider.

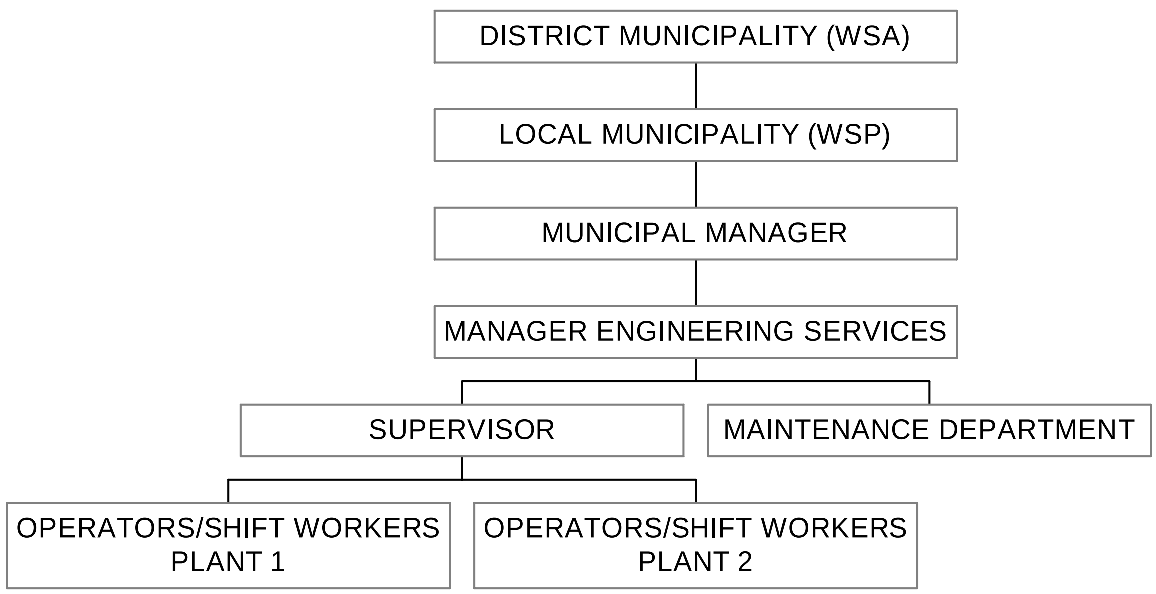


Fig. 4.13 Typical organogram for a Water Services Provider

The actual titles of positions will vary from municipality to municipality depending on the size and structure of the organization, the size of the treatment plants and number of people required to run them, and the skills levels of the operators and their supervisors. In particular there is a large overlap in the functions typically assigned to operators and supervisors. What is important however is that employees at each level understand clearly what their responsibilities are. The following sections outline the typical responsibilities of operators, supervisors and municipal management.

4.4.2.1 Operators

For the purposes of these guidelines, **operators** are employees who remain at the treatment plant most or all of the time and are responsible for most or all of the tasks required for routine operation (e.g.making up chemical stocks and backwashing filters). Operator skill and training levels vary widely as do their responsibilities. Some simply take instructions from the supervisor or overseer or from a senior operator whereas others mostly work independently. In some cases, a single operator may be responsible for running more than one treatment plant, usually with the assistance of one or more shift worker. Education and training levels vary from on-the-job training only, to some formal training to some post-matric education and technical certification.

4.4.2.2 Supervisors

Operators report to **supervisors** who are usually responsible for overseeing the operation of more than one plant and are also responsible for the procurement of chemical supplies, new equipment and repairs to existing. Supervisors are usually based at the municipal offices and spend a few hours a week at most at any given plant. In some cases, monitoring and process control (Section 4.3.4) is the sole responsibility of the supervisor. However, this is not an ideal situation. Since process control measurements should be made as frequently as is practical, both the measurements and the process control adjustments should be the responsibility of the operators since they spend more time at the plant. The supervisor should review their data and check the plant performance herself daily for inexperienced operators and weekly for experienced operators.

The importance of good co-operation between the maintenance or plumbing and water treatment departments cannot be overstated. The water treatment supervisor must work closely with the maintenance department to ensure that all maintenance issues relating to water treatment and distribution are promptly dealt with. The supervisor should also make sure that the maintenance department is always involved when any new equipment is installed.

4.4.2.3 Water or engineering services manager

The water treatment supervisor or supervisors usually report to the water services manager if there is one, or more usually to the engineering services manager or town engineer. Water treatment is usually not the top priority of the engineering department; nonetheless the engineering services manager is responsible for ensuring that:

:

- water treatment has sufficient, appropriately trained, motivated staff;
- the staff have the resources they need to properly execute their duties;
- proposed plant upgrades are appropriate and meet all treatment needs;
- all requirements to provide training are met by suppliers and contractors;
- systems are in place for process control and routine maintenance;
- compulsory national standards are being met in the water supplied to consumers;
- consumer complaints and queries are efficiently dealt with;
- monitoring data collected by external agencies, particularly microbial data is shared with the supervisors and operators;

4.4.2.4 Municipal manager

Ultimate responsibility for the safety of the treated water supply lies with the municipal manager. In addition to ensuring that water services are functioning properly, the municipal manager must set up a system whereby the public can be rapidly informed if the drinking water supply is determined to pose a threat to health and of what measures consumers need to take to avoid potential exposure to water born diseases. Communicating with the public is discussed further in Section 4.4.6. Options for emergency home treatment of water are discussed in Section 3B of *Quality of Domestic Water Supplies Volume 4: Treatment* (DWAF *et al.*, 2002c).

4.4.3 Important strategies for maintaining the safety of the treated water supply in rural areas

In rural municipal water supplies of South Africa, two major causes contributing to poor water quality have been pointed out: treatment chemicals not being replenished in time **and** equipment not being adequately maintained**.** Plans should therefore be developed in maintaining the safety of water supply in terms of emergency situation, chemical stock replenishment and major equipment failure.

4.4.3.1 Developing emergency response strategies

Particular attention needs to be given to defining roles and responsibilities in emergency situations. Emergency situations include those where **the supply of water is affected** e.g. major pipelines are ruptured or pumps are damaged as well as those where only **the safety of the water is affected**. A typical example of the latter is the failure of the chlorination system. In municipalities, there seems to be an attitude that these sorts are situations that can be dealt with whenever it is convenient for the staff involved while the potentially serious threat to public can simply be ignored. In fact, the law requires that they are dealt with as a matter of extreme urgency **and** that the public also be informed (Section 4.2.2).

Water services authorities and water services suppliers must draw up emergency response plans for foreseeable events such as natural disasters, major equipment failures and human actions such as strikes and sabotage (Chapter 4, WHO, 2004). In situations with a high risk of waterborne disease outbreaks, the assistance of provincial and national government may be required. Emergency response plans must be developed with consultation with all relevant authorities and be consistent with all local and national emergency response arrangements.

Good **communication** between operators, maintenance personnel and management is especially important during emergency situations. The operators will usually be the first to pick up problems with the raw water supply or with the treatment process and must have a means of rapidly informing the relevant authorities. They must also know what immediate steps they can take, for example, temporarily shutting down the plant. Management must act quickly and decisively to resolve the problem.

Emergency response plans must always include a **communications plan** to inform the public of the situation. The municipal manager is responsible for alerting the public if the treated water is determined to be unfit for human consumption (See Section 4.2.2). Municipal management should also inform the public when scheduled activities such as plant upgrades may temporarily affect the reliability of supply and the quality of the water. Communication with the public is discussed further in Section 4.4.6. For a more detailed discussion of emergency response plans, see Chapter 4 of *Guidelines for Drinking-water Quality* (WHO, 2004).

4.4.3.2 Ensuring adequate chemical supplies

The plant supervisor or other municipal official directly responsible for overseeing the routine operation of the plant is responsible for ensuring that **the plant always has adequate stocks of water treatment chemicals** (coagulant/flocculant, pH adjustment chemical, disinfectant). The plant operators are responsible for ensuring that the superintendent is aware of the rate of consumption of the chemicals and when fresh stocks will be needed. Any disruption to coagulant or disinfectant dosing (whether due to equipment failure or chemicals running out) constitutes an emergency situation which must be dealt with as outlined in Section 4.4.2.5. In many cases it may be possible to produce at least Class II quality water without a pH adjustment chemical (lime, soda ash, carbon dioxide or acid). Therefore, one of these chemicals running out does not necessarily constitute an emergency. However, the replenishment of the chemical must be treated with utmost urgency and the plant performance must be closely monitored (sampling at least every 2 h) until dosing is restored.

Chemical stocks must be replenished at least **1 week** before they are needed. The ordering of new chemical stocks should preferably be automatic, that is, the water service provider should arrange with the supplier(s) to have the treatment chemicals delivered without fail at regular intervals. Otherwise, each order must be initiated sufficiently far in advance to ensure that the chemicals will arrive on time. The minimum frequency of delivery will depend on the rate of consumption of chemicals and the available storage space. In order to ensure regular and timely delivery, the water service provider must: (a) buy only from reputable suppliers and (b) ensure suppliers are always paid on time. Adequate funds for the purchase of treatment chemicals must be earmarked in the municipal budget, taking into account possible increases in transport costs over the budget period. All municipal employees involved in the processing of orders must be aware of the importance of having the chemicals arrive at the plant on time, must follow up on orders and must face significant penalties if they allow avoidable disruptions in chemical dosing due to their own negligence.

> All municipal employees involved in the procurement of treatment chemicals must be aware that it is critically important that chemicals **arrive at the plant** on time. Proper planning and budgeting is required to avoid disruptions.

The operators must record the daily usage of chemicals e.g. they should record the date on which each bag of alum/drum of polyelectrolyte/drum of HTH is finished. The supervisor must review these records in planning and budgeting for purchasing chemical supplies taking into account seasonal variations in coagulant and chlorine demand.

4.4.3.3 Maintenance

An acceptable quality of treated water cannot be sustained if the facilities for abstracting, treating and distributing the water are not adequately maintained. Water Service Authorities are required to submit details of their maintenance plans as part of their water development plans, however, maintenance of pumps and water treatment equipment is generally given very low priority in small treatment plants. In the authors' experience, equipment failure is one of the major contributors to poor water quality. Furthermore, there is a lack of urgency when dealing with equipment failures provided that the quantity of water which can be supplied is not affected. Consequently, vital equipment such as flowmeters, dosing pumps and chlorinators may not function correctly or at all for months or even years before action is taken. There appear to be several reasons for this problem:

- **Lack of interest** by both municipal management and the public in the quality of water provided. (By contrast, broken pipelines which result in disruption of the water supply are dealt with much more quickly).
- **Operators are not trained or do not have the tools** to perform routine maintenance and minor repairs.
- **The maintenance department may not have the skills** to repair specialised equipment.
- The maintenance department is located some distance from the treatment plant and **personnel often do not have transport.**
- There are **insufficient maintenance personnel**.
- There are **insufficient funds** budgeted for maintenance and the repair and replacement of faulty equipment.
- **The process for approving the purchase of replacement parts or paying for repairs** by external agencies is too slow.

The relationship between Water Service Authorities and local service providers can make the problem worse in some cases. In a recent survey of small treatment plants in the Eastern Cape, some plant supervisors complained that it took days or weeks to get approval for vital repairs from the Water Service Authority. They felt that WSA officials based at the District Municipality head offices were not particularly interested in the problems of Water Services Providers located several hundred kilometres away. It therefore appears that the first step to solving this problem is getting municipal and district municipality management to realise that:

- Maintenance of all parts of the treatment and distribution system is a critical part of providing effective, efficient and sustainable water services.
- Scheduling routine maintenance and addressing equipment problems as soon as they arise is cheaper in the long run than neglecting maintenance.

1) maintenance of all parts of the treatment and distribution system is a critical part of their obligation to provide effective, efficient and sustainable water services.
2) scheduling routine maintenance and addressing equipment problems as soon as they arise is cheaper in the long run than ignoring evident problems until a catastrophic failure occurs..

In addition to drawing up and implementing routine maintenance programs, water services institutions must streamline the procedures for getting faulty equipment replaced or repaired. As soon as a problem is noticed, **the operators must immediately alert the plant supervisor** who should in turn notify both the **maintenance department** and the **water or engineering services manager**. The supervisor should make a judgement on how urgent the problem is and must follow up to ensure that the problem is dealt within an appropriate time frame. Where outside assistance is required or replacement parts have to be purchased, the supervisor must be able to obtain authorisation within a matter of hours and not days.

It is also important that **records of all maintenance activities** are kept, both routine and non-routine. Copies of these records should be available at both the treatment plant and the municipal offices. This will assist in planning and scheduling routine maintenance, budgeting for both routine and non-routine maintenance and developing procedures for dealing with equipment failures. Monitoring and surveillance (Section 4.4.7) should include checking that these records are accurate, complete and up to date.

4.4.4 Communication between operating staff and management

In some municipalities, communication between operating staff and management is generally very good, however in many others, this is an area which needs to be improved. Operators complain that working condition are poor, their concerns about equipment and operating problems are ignored, they are discouraged from reporting bad results, they receive no feedback about treatment plant performance and are not informed about or involved in managements decisions which affect water treatment.

The operating staffs at water treatment plants play a vital role in protecting public health and ensuring municipality resources are used efficiently and effectively. Furthermore, the success of any attempt to improve plant operation requires the full commitment and co-operation of the operators, especially since they will usually be required to undertake additional duties. All decisions and strategies should be discussed with the operators and they should be encouraged to take a personal interest and pride in any improvements achieved. It is equally important that management demonstrates that it also committed to improving the performance of water treatment plants through both fulfilling the responsibilities listed in Section 4.4.2 and creating an institutional environment where operators feel that their work is important and valued.

> For more discussion on important management concepts for water service providers, see Section 6 of *Quality of Domestic Water Supplies Volume 5: Management Guide* (DWAF, 2002).

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4.4.5 Communication between the municipalities and the public on water quality issues

Good communication between municipalities and consumers is an essential part of providing effective water services. Municipalities are already used to interacting with the public on issues of **water supply** and **access to services**. However more attention to issues relating to **water quality** is required. Several different types of interactions are involved:

4.4.5.1 Public education

An informed public is a better partner in ensuring the sustainable delivery of water services and preventing outbreaks of waterborne diseases. Effective communication and public education helps to increase community awareness and knowledge of drinking-water quality issues and helps consumers to understand and contribute to decisions about the service provided by a drinking water supplier. An informed public is also more likely to accept land use constraints imposed in catchment areas (WHO, 2004). The revised definition of a basic water supply (Annexure 3: Definitions in the Strategic Framework for Water Services, DWAF 2003) includes the communication of good water-use, hygiene and related practices. District Municipalities, whether they are WSAs or not, have primary responsibility for health and hygiene education related to water and sanitation services (Section 3.6.4 in Strategic Framework for Water Services, DWAF, 2003). For more details on the responsibilities of various spheres of government as well as consumers regarding water supply, see DWAF's *Quality of Domestic Water Supplies Volume 5: Management Guide* (DWAF, 2002c).

4.4.5.2 Consumer complaints

While it is extremely important for municipalities to monitor the quality of water supplied to consumers, for practical and economic reasons, routine sampling will be limited to a few sites and a few samples per month. Therefore, routine sampling can easily miss problems in some areas of the distribution system and deterioration of water quality due to transient (lasting for a short time) events. Consumers however are collectively exposed to water quality at all points of the distribution system on a daily basis. Therefore, consumer complaints about the taste, smell and appearance of the water delivered are an important tool for detecting problems in the distribution system and should be encouraged rather than discouraged.

According to the *Strategic Framework for Water Services* (DWAF, 2003), it is the responsibility of Water Services Authorities to establish mechanisms for facilitating, listening to and responding to the consumer and citizen feedback on the quality for services provided. However, it is important that consumers interact directly with the **local Water Services Provider**. All consumer complaints should be logged along with the date, time and location in the distribution system and reported to the engineering services department or water treatment supervisor. Up to date maps of the distribution system should be kept at the water services provider offices. The location, type and date of the complaint can be marked on the maps to help identify problem areas (areas in which several similar complaints are reported) and focus investigations to determine the source of the problem.

4.4.5.3 Alerting consumers about poor water quality

The Constitution of South Africa defines access to safe drinking water as a basic human right. While a healthy adult population may become adapted to a certain level of microbial contamination of their drinking water, young children and babies, elderly people, the sick (particularly HIV infected individuals) and visitors to the area are always at risk. If a Water Services Provider is for any reason unable to supply water that complies with Class II standards for potable water (See Section 4.2.3), then the provisions of the Water Services Act (1997) require that it inform the Department of Water Affairs and Forestry, the relevant Provincial Department of Health and all consumers. Information supplied to consumers must include the nature of the problem, the risks associated with the problem, what the Water Services Provider and Water Services Authority are doing to resolve the problem and what consumers can do to protect themselves from waterborne diseases. Information on home treatment of water in emergency situations is provided in Section3B of *Quality of Domestic Water Supplies Volume 4: Treatment Guide* (DWAF *et al.*, 2002c).

Possible means of communication include announcements on local radio broadcasts and in local newspapers, notices posted in public places like taxi ranks, schools, clinics and municipal offices, and municipal representatives or community workers going door to door where necessary. While the public have a fundamental right to know if their drinking water is unsafe, informing consumers about potential risks to their health must be handled sensitively to avoid spreading panic, confusion and misinformation among the public and potentially driving them to even less safe sources of water. Furthermore, there are health risks associated with issuing a “boil water” alert so this option should only be exercised if the microbial quality of the water is determined to pose a significant health risk (WHO, 2004).

Broad based communication of water quality and awareness information to restore public confidence in drinking water should be a significant area of communication activity in the aftermath of a major incident.

4.4.6 Training, capacity building and partnerships

A major barrier to the production of safe drinking water in many areas of South Africa is the inadequate qualifications and training of many operators and supervisors at small treatment plants. This is particularly a problem in newly established municipalities which did not previously have water services. In a recent survey of plants in the Eastern Cape, the authors found that newly commissioned plants without properly trained operators typically performed much worse than older plants with inadequate facilities but experienced and motivated operators and/or supervisors.

The Department of Water Affairs and Forestry is currently developing regulations which specify minimum qualifications for treatment plant operators and supervisors based on the size and complexity of treatment works (Boyd, 2004). However, the reality is that attracting and retaining technically qualified personnel is a major problem in most municipalities outside of the major urban centres. Two practical ways of addressing this problem are as follows:

1) Upgrading the training of the personnel already involved in running these treatment facilities.
2) Developing partnerships between municipalities and external agencies and institutions which can provide technical support and mentorship.

To a large extent this is already happening. There are already a range of organizations involved in training and mentorship, including NGO's, consulting firms, educational and research institutions, suppliers of treatment chemicals, established water boards and various departments of national and provincial government. This section highlights a few areas in which these initiatives can be made more effective.

4.4.6.1 Specific areas in which technical assistance is often required

While many operators have a good working knowledge of their treatment works and an instinctive feeling for how to deal with various operating problems, they often struggle with record keeping and anything that requires computational skills. Also many are not fluent in English, the language in which most manuals and technical guidelines are written. Consequently, it is important that training courses and capacity building activities are tailored to their specific needs and skills levels. A substantial amount of time and effort needs to be devoted to **dosing calculations** and **process control**. To assist operators it can be helpful to generate tables which summarise dosing calculations. For example, required alum dose rates can be tabulated as a function of raw water flowrate and optimum dose determined from the jar test (Appendices II-V for examples). However, follow up training is required to ensure that these kinds of tools are being used correctly and that operators are able to obtain all of the information required to use them.

Technical aspects of treatment plant operation and management where operators and supervisors may require technical assistance are listed below. Technical assistance may take the form of training to perform specific tasks e.g. jar tests, guidance or collaboration on the development and documentation of operating procedures and co-operative arrangements e.g. the calibration of instruments is checked during routine monitoring by the Water Services Authority.

- Calibrating dosing equipment (Section 4.3.4)
- Checking dosing equipment calibration (Section 4.3.2.4.2)
- Calculating dosing rates (Section 4.3.2.31.)

- Conducting jar tests and using the results to adjust chemical doses (Section 4.3.2.4.1 and Annexure 1)
- Adjusting chlorine doses to achieve desired residual in finished water (meeting the chlorine demand) (Section 4.3.2.2.2)
- Evaluating filter backwash (Section 4.3.2.6.1.3)
- Measuring flow rate (Section 4.3.2.3.1)
- Flow rate adjustment (Section4. 3.2.3.2)
- Calculating balancing capacity (Section 4.3.2.3.2)
- Calculating reservoir detention times and effective chlorine contact times (Section 4.3.2.2.3)
- Determining dosing requirements for chemical stabilisation (Section 4.3.2.7)
- Use of instruments (pH, turbidity, chlorine) (Section 4.3.4)
- Taking care of instruments (Section 4.3.4)
- Calibrating and checking the performance of instruments (Section4.3.4)
- Sample collection and handling techniques (Section 4.4.1)
- Developing and writing up procedures for all aspects of plant operation e.g. making up dosing solutions, desludging settling tanks, cleaning filters, cleaning reservoirs, etc.
- Developing and writing up process control strategies. Tables 4.9 to 4.12 in Section 4.3.4 can be used as a starting point but they need to be adapted for individual treatment works (Section4. 3.4)
- Record keeping
- Interpretation of data
- Troubleshooting (investigating and solving problems)
- Reporting problems and failures
- Developing operating manuals for older plants
- Translation of procedures and safety materials into the local language for staff who are not fluent in English
- Gaining access to guidelines and educational materials published by DWAF and the South African Water Research Commission
- Developing log sheets and sampling programmes for specific plants
- Basic maintenance

Organisations involved in capacity building exercises must work together with the operating staff and responsible municipal officials to determine the most practical ways to ensure that none of these important aspects of treatment plant operation are neglected.

4.4.6.2 Importance of on-site training

Most operators of rural treatment plants and many of their supervisors need to upgrade their training in order to achieve the necessary improvements in performance to produce water that is consistently safe to drink. Formal training in a classroom environment does have some benefits: it is cheaper to have many learners in one location and operators will benefit from the exposure to new ideas and the opportunity of meeting their peers. However, operators with low levels of formal education may find the presentation of the course material difficult to follow. Furthermore, operators may not understand how to implement certain procedures in their own plants if they do not correspond exactly to the examples studied in class. In many cases, operators may return to plants which do not have the instruments and equipment necessary to practice their newly acquired skills and will quickly forget their training if they do not have the opportunity to use it.

For training to be effective, it is therefore very important for trainers to understand the conditions and constraints at each treatment plant and to tailor the training to the needs and skills of individual operators. This is best achieved through on-site training courses. The advantages of on-site training include:

1) Trainers have a better idea of the challenges faced by operators at particular plants and be better able to assess their competence. The authors have often found that when questioning operators about the operation of their plant, they give inaccurate or misleading answers simply because they cannot relate the question to their own practical experience of the plant.
2) Trainers can ensure that the acquisition of theoretical knowledge of water treatment operations goes together with direct implementation of that knowledge for the specific conditions at each plant.
3) Operators are given hands on training with equipment that they are familiar with.
4) The benefits of treatment plant optimisation can be demonstrated for the operating staff and municipal officials.

On-site training should always involve plant supervisors, and other municipal officials should also be encouraged to attend. On-site training must emphasise why each step in water treatment is important for the sustainable production and delivery of safe drinking water and how to check the performance at each stage. Illustrated training materials should be developed in colour format with translations in local languages in order to be useful to operators with a wide range of education levels.

4.4.6.3 Role of universities and technikons

Universities and technikons can play an important role in capacity building at small treatment plants, particularly when students team up with experienced professionals from either academia or industry. Students and academic research groups can be used to strengthen capacity building and partnerships with municipalities in a number of specific ways:

- Students can be used to
  - increase contact time with operators to reinforce skills learned in formal training programmes.
  - assist the operators with calculations and data analysis.
  - assist the operators in developing and documenting operating procedures.
  - translate training materials, manuals and safety information into local languages.
- Tertiary institutions also can provide municipalities with indirect access to a number of important resources which they may not have otherwise
  - laboratory facilities.
  - internet and other information sources.
  - extensive local and international contacts within the water sector and research community.
  - information on national and global trends.

Students and university research programmes are often funded by external agencies such as the Water Research Commission, National Research Foundation and even international funding agencies so the assistance provided to municipalities and to other agencies working with them may be free of charge.

Students also benefit tremendously from this arrangement because they get hands-on experience, hopefully under the guidance of experienced professionals. In many cases, young graduates and diplomates are being placed in positions of enormous responsibility in local and district municipalities with little prior experience. Students who have participated in the type of partnership envisaged here would bring all the advantages of appropriate academic background, relevant experience and an established network of contacts to any position in which they are employed in the water sector.

4.4.6.4 Pro-active attitude of municipal management

For a partnership or mentorship programme to be effective the municipality involved must believe this is important and relevant to its needs and obligations. In the experience of the authors, the people closest to the plant operation, that is the operators and supervisors, are usually enthusiastic about upgrading their own training and improving plant operations. However, the efficiency of treatment plants and the quality of the water supplied to consumer are typically low on the list of priorities of municipal management. Not only does management pay little attention to what is going on at the purification works, but they are often reluctant to spend money on critical equipment and repairs.

For example, during an on-site operator training course at Alice Water Treatment Plant, Momba *et al* (2004b) found that the coagulant dosing pump, filters and chlorine dosing system all had such serious problems that it was impossible to demonstrate the skills being taught at the plant-scale. During a recent survey of small treatment plants in Eastern Cape, the authors also met operators who had taken off-site training courses and were aware of the need for process monitoring and control but did not have any of the equipment needed to implement it.

It is important that municipal management not only provides the necessary resources for improving the efficiency of water treatment but that it also takes an active interest in the process. Municipalities cannot simply be passive recipients of technical assistance, but need to ensure that specific goals are being met and maximum use of available resources is being made. Areas which require particular attention include the following:

(a) **Municipalities must ensure that capacity building is actually taking place** and that employees are acquiring the skills that they need to run the plants efficiently. For example, operators need to be given the training and resources to make appropriate adjustments to chemical doses whenever required. They should not be dependent on a consultant who only visits the plant once a month.

(b) **Management must ensure that there is a training component in every contract to supply equipment or chemicals, to upgrade any part of existing treatment works or to build new ones.** Installing new equipment is more likely to have a negative than positive impact on treated water quality if no one in the municipality understands how to operate or maintain it (See also Section 4.4.4 on maintenance).

(c) **Management at both and district and local level must ensure** that all water quality monitoring data is shared with plant operators and supervisors as soon as it is available (See Section 4.4.1 and 4.4.8). This is particularly important for microbial quality data since individual treatment plants rarely have the facilities or skills to perform these analyses themselves. Many plant operators and supervisors complain that various groups are collecting monthly samples from plants, usually on behalf of the Water Services Authority, however, they never receive feedback on the results and consequently do not know if their performance is adequate or not.

4.4.7 Importance of surveillance and treatment plant audits

Surveillance by external agencies does not remove or replace the responsibility of water services providers to monitor their own operations and to ensure that the water produced meets all required standards.

In addition to routine operational monitoring, international experience has shown that it is extremely important to have an external agency periodically checking the quality of the water being provided and the performance of the Water Services Provider in general (WHO, 2004). Surveillance by an external agency contributes to the protection of public health by promoting improvement of the water quality, quantity, accessibility, coverage, affordability and continuity of water supplies (known as service indicators). Drinking-water surveillance is also used to ensure that any transgressions which occur are appropriately investigated and resolved. It is important to note, however, that surveillance by external agencies does not remove or replace the responsibility of Water Services Providers to monitor their own operations and to ensure that the water produced meets all required standards.

The surveillance agency must have, or have access to, legal expertise as well as expertise on drinking water and water quality (WHO, 2004). The surveillance agency should be independent of and have the power to penalise service providers which fail to comply with compulsory standards or to meet contractual obligations in terms of provision of services. The surveillance agency should be empowered by law to compel water suppliers to recommend the boiling of water or other preventative measures when microbial contamination which could threaten public health is detected. However, the relationship between the surveillance agency and the service provider should be primarily collaborative with the emphasis on setting realistic goals to ensure the **progressive** improvement of service provision. Punitive action should only be taken as a final resort. Surveillance has two important components:

(a) Direct assessment of the quality of the water supplied
(b) Review of all aspects of treatment and distribution of water supplied including inspection of facilties, review of operating records and procedures, process control measures and management strategies.

Direct assessment is important for providing an independent check on water quality which can be compared to the water services provider's own monitoring data. However, it provides only a indication of water quality at the particular time that samples are collected and may miss occurrences of poor water quality which the water services provider may or not report. Furthermore, water quality analysis alone does not necessarily provide any information on why a particular water quality problem has occurred and what can be done to correct it. A comprehensive review of the condition of facilities, operating procedures and records on the other hand will show whether the conditions and procedures required for the sustainable production of safe water are in place.

In the South Africa, the role of regulating and monitoring Water Service Providers is assigned to the Water Service Authorities. All WSA's should have developed and implemented programmes for sampling the quality of potable water provided to consumers in their areas of jurisdiction by 2003. Detailed guidelines on water quality sampling and analysis are provided in *Quality of Domestic Water Supplies Volume 2: Sampling Guide and Volume 3: Analysis Guide* (DWAF, 2002). Where local government structures lack the resources to carry out the required monitoring, co-operative government requirements specify that Provincial and National Government must ensure that monitoring takes place Mackintosh *et al.*, (2004a).

The performance of the Water Service Authorities is in turn monitored by provincial and national government, primarily through the annual water services audit which WSA's are required to submit (See Section 4.2.2). The water services audit must include information on the quantity of water services supplied, extension of services to the unserved, level of service provided, level of cost recovery achieved, progress with meter installations, water quality sampling and testing, progress on water conservation and demand management measures (DWAF, 2002b). While the Water Services Act places general requirements on water services institutions to operate treatment plants in an effective, efficient and sustainable manner and to make appropriate investments in infrastructure including maintenance, there is currently no regulatory requirement for WSAs to undertake comprehensive reviews of operating procedures and conditions of facilities as part of its monitoring programmes. However, this may change in the future as regulations become tighter and expectations of Water Services Providers are raised.

4.5 STRATEGIES FOR ENSURING SAFE DRINKING WATER

This section provides a summary of recommendations for water services authorities and providers to ensure the microbial safety of treated water supplied to consumers in rural municipalities. The key to ensuring clean, safe and reliable drinking water is to implement **multiple barriers**, which control microbiological pathogens, and chemical contaminants that may enter the water supply system. This includes adopting sound management practices and continuously reviewing both the state of the water treatment and distribution infrastructure and the quality of the water produced.

Source Water Protection

- Restrict access by humans and animals to raw water source close to abstraction point.
- Educate public about water quality issues and water resource management.
- Work with Catchment Management Agencies to protect water resources.

Treatment Plant Operation

- Install flowmeters on the raw water, filtered water, finished water and recycle flow.
- Avoid large or rapid variations in plant flowrate. Operate plant continuously (24 h/d) if possible.
- Use the jar test to optimise coagulation and flocculation.
- Install baffles and wind breaks if necessary to minimize mixing in settling tanks.
- Closely monitor filter and filter backwash performance. Expect to change filter media every 1-2 years if filter performance deteriorates.
- Monitor disinfectant residual, pH and effective contact time to ensure adequate disinfection.
- Implement chemical stabilisation to prevent excessive scaling or corrosion in the distribution system.
- Introduce process control measures for turbidity removal, pH adjustment and disinfection.
- Install back-up dosing systems for coagulation and disinfection.
- Attend to all maintenance issues promptly to avoid catastrophic system failures.
- Develop procedures for responding to adverse conditions and emergency situations.
- Keep up to date records of all performance data, operating decisions and maintenance activities.

Distribution system

- Avoid interruptions in supply to minimise risk of untreated water seeping into the distribution system
- Monitor disinfectant residual and microbial quality in each zone of the supply area to identify problem areas
- All service reservoirs must be covered and secured to prevent contamination of the treated water. Reservoirs must be drained and cleaned every 1 – 5 years depending on the treated water quality.

- Install flow meters on all service reservoirs in order to monitor retention time. Where excessively long retention times result in low chlorine residuals, lower operating levels or introduce booster chlorination.
- Introduce measures to prevent cross-connections between domestic water and sewer lines.

Management issues

- Become familiar with the regulatory requirements for the quality of potable water.
- Ensure that the responsibilities of all personnel are clearly defined and documented for both routine operation and emergency situations.
- Implement measures to ensure treatment chemicals are always ordered and delivered to the treatment plant on time.
- Ensure maintenance issues are always promptly attended to.
- Ensure operators have adequate training and resources to perform their duties, particularly when new equipment is installed.

The recommendations provided in this section are all measures which need to be implemented as soon as possible i.e. within the next few years. All of the recommendations are consistent with constitutional requirements for local government to provide efficient, effective, sustainable and safe water services. However, they should be only considered a first step. International experience has shown that water providers need to constantly review and improve their operating and management practices as new technologies and new threats to water quality emerge and as regulations become stricter. Once the basics are in place, Water Services Institutions need to look for new ways to improve the efficiency and effectiveness of their operations and the safety of the water supply. The World Health Organisation (WHO, 2004) advocates the development and implementation of comprehensive Water Safety Plans which go beyond the guidelines presented here. On-going professional development programmes for both operators and managers are an essential part of meeting future challenges and achieving higher standards of performance.

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APPENDIX I

BILINGUAL COURSE NOTE FOR THE TRAINING OF THE OPERATORS

OPERATOR TRAINING PROGRAMME SCHEDULE
17 –21 NOVEMBER 2003

Monday: General introduction and flowrate measurement
Tuesday: Jar testing and changing the coagulant dose
Wednesday: Chlorine demand and adjusting the chlorine dose
Thursday: Filter inspection
Friday: Revision and update on plant performance

OPERATOR TRAINING COURSE IN ENGLISH (E) AND XHOSA (X) – ALICE WATER TREATMENT PLANT – NOVEMBER 2003

Day 1: General Introduction

1.1 Purpose of water treatment

E -What is the purpose of water treatment?
X - Yintoni injongo yokucoca amanzi?
E- To remove dirt and germs from water to make it safe to drink.
X - Kukususa ubumdaka neentsholongwane emanzini.
E - Where do the dirt and germs in the raw water come from?

- Human faeces – the most dangerous source of germs in raw water
- Animal faeces – can also be very dangerous
- Pollution and litter
- People swimming and washing clothes in the river

X - Ubumdaka nentsholongwane emanzini angacocwanga zivela phi?

- Kokwangasese kwabantu- oku kokona kunobungozi
- Ubulongwe bezilwanyane- nabo bunganobungozi
- U kungcola nenkunkuma
- Abantu abadadayo nabahlamba iimpahla emlanjeni

E - What happens if people drink water which is not properly clean?
X- Kwenzeka ntoni ke xa abantu besela amanzi angacocwanga kakuhle?

E -People can get sick from the germs in the water. They usually get stomach problems and diarrhoea. Sometimes they get so sick that they can die.

X - Abantu bangagula ziintsholongwane ezisemanzini. Badla ngokuba neengxaki zesisu notyatyazo. Ngamanye amaxesha bade bagulele ukufa.

E - Sometimes nothing happens. People may be getting used to the germs in the water where they live. Some people are more likely to get sick from the water than others, especially babies, the elderly, and people who are already sick with other diseases like HIV/Aids

X - Ngamanye amaxesha akukho nto yenzekayo. Abantu bangaqhelana nentsholongwane ezisemanzini endawo abahlala kuyo. Abanye abantu ke bangagula ngaphezu kwabanye ingakumbi: Abantwana, Abantu abadala, Abantu abasebegula yintshongwane kagawulayo

E - Diarrhoea from drinking water that is not safe is a leading cause of death among babies and small children.

X - Utyatyazo olubangelwa ngamanzi lunobungozi, ngoyena nobangela wokufa ebantwaneni abancinci nabasakhulayo

E - Visitors to an area where the water is not safe often get sick because they are not used to the germs in the water.

X - Abatyeleli kwindawo enamanzi bangagula genxa yokungaqhelani neentsholongwane ezisemanzini.

E - New diseases may come into an area and then anyone can get sick. For example: **CHOLERA** has been a big problem in KwaZulu-Natal and some parts of Eastern Cape in the last few years. Thousands of people have become sick and hundreds have died. Cholera in water is easily destroyed by proper chlorine dosing.

X - Izigulo ezitsha zingafika endaweni kwaye nabani na angagula. Umzekelo: **ICHOLERA** ikhe yaba yingxaki enkulu KwaZulu Natal nakwezinye iindawo zempuma koloni kwiminyaka embalwa egqithileyo. Amawaka abantu baye bagula, amakhulu bafa. ICHOLERA ke emanzini ifa msinya xa ichlorine igalelwe ngendlela eyiyo emanzini.

E - Therefore water treatment is very important to for the community!

X - Ngoko ukucocwa kwamanzi kubaluleke gqitha ekuhlaleni!

E - Your job protects the health and lives of people in Alice!

X- Umsebenzi wenu ukhusela impilo nobomi babantu base Dikeni!

1.2 Steps of water treatment

E - Water treatment consists of two steps:

X - Ucoco lwamanzi lunezigaba ezibini

1. E - Remove as much dirt and particles from water as possible

   X - Ukususa ubumdaka nezinto ezidadayo kangangoko emanzini.

2. E - Add chlorine to kill any germs left in the water

   X - Ugalele ichlorine ukubulala iintsholongwane eziseleyo emanzini.

E - The chlorine works better when the filtered water is clean (less than1 NTU), the cleaner the filtered water the better.

X - Ichlorine isebenza ngcono xa amanzi ahluziweyo ecocekile (Iturbibidity ingaphantsi ko

E - ***Removing dirt/particles***

Many particles in water, including germs, are too small to see with our eyes. This means that even if water **LOOKS** clean, it is not necessarily safe to drink!

We use turbidity as a measure of the number of particles in water. This includes particles which are too small to see.

X - Isigaba sokuqala: Ukususa ubumdaka

Ezinye izinto ezingcolisa amanzi, kubandakanya iintsholongwane azibonakali ngeliso lenyama. Lonto ke ithetha ukuthi nokuba manzi angabonakala ecocekile awunakuwathemba uba alungele ukuselwa!

Sisebenzisa iturbidity ukujonga ubungaphi bezoingcolisi emazini. Oku kubandakanya nezo singanakuzibona ngeliso lenyama.

E - Particles are removed from water in one of two ways:

X - Izingcolisi zisuswa emanzini ngendlela ezimbini:

1. E -Settling:
2. X -Ukuzika:

E - This happens in the settlers and even in the dam where water is stored before it comes to the treatment plant.

X - Oku kwenzeka etankini elilingiselelwe oko okanye edamini apho amanzi ahlala khona phambi kokuba ayokucocwa eplantini.

E - Particles sink down to the bottom of the settling tank or the dam while the settled water flows out.

X - Izingcolisi zizika ziye ezantsi kwitanki elungiselelwe oko okanye edamini aze amanzi acocekileyo aphume.

E -Filtration

X - Ukuhluzwa

E - Particles stick to the sand in the filter and are left behind when the clean water flows out of the filter.

X - Ixzingcolisi zihlala esantini ekwi filter zize zishiyeke xa amanzi acocekileyo ephuma kwi filter leyo.

E - Both settling and filtration work better when a **coagulant** is used. A coagulant is a chemical which makes particles, even the ones that you cannot see, become more sticky when it is added to water. There are many different kinds of coagulants but they all do the same thing. When coagulant is added, particles stick together to form floc, which are big enough for us to see. Floc sink much faster than small particles so the settling tanks work much better when coagulant is used.

X - Ukungcwenga nohluzo zisebenza bhethele xa ichemical isetyenzisiwe. Le ke yichemical eyenza izingcolisi, nezo zingabonakaliyo, zibencangathi xa igalelwe emanzini. Zinintsi ke iintlobo ze chemical kodwa zenza into enye. Xa igalelwe emanzini ichemical, izingcolisi ziyadibana zenze ifloc, enkulu kangangokuba ungakwazi ukuyibona. Ifloc ke ingcwenga ngokukhwawuleza kunezingcolisi ezincinci, ngoko amatanki okuzikisa asebenza ngcono xa ichemical isetyenzisiwe.

E - The sticky floc also stick to the filter sand better.

X - Ezifloc zincangathi zincamathela ngcono nakwisanti le ikwi filter.

E - Questions

X - Imibuzo

E - Where is coagulant added to the water AWTP?

X - Igalelwa phi ichemical emanzini e AWTP?

E - How do we measure how clean the water is after the settling tanks and filters?

X - Wazi njani ukuba acoceke kangakanani na amanzi emva kokungcwenga nokuhluzwa kwezingcolisi?

E - For the coagulant to work well, we have to add the right amount.

X - Ukuze isebenze ngcono Ichemical kufuneka sisebenzise umlinganiselo ofanelekileyo.

E - If you add too little, it does not work well. You will get high turbidities in the settled water and in the filtered water.

X - Xa ugalela kancinci, ayisebenzi kakuhle. Uyakufumana i turbidity ephezulu kumanzi ahluziweyo.

E - If you add too much coagulant, you also have problems.

X - Xa ugalela kakhulu uba nengxaki kwakhona.

E - Previously, too much alum and lime was used. There was too much floc produced and it was settling everywhere including in the new reservoir (chlorine contact tank).

X - Ekuqaleni, I-alum ne lime zazisetyenziswa. Ifloc yayininzi ihlala kwindawo zonke nakwi resevoir.

E - With the new coagulant, if you add too much, the floc does not settle well.

X - Ngale intsha Ichemical, xa ugalela kakhulu, ifloc ayiziki kakuhle.

E - Using too much coagulant also wastes money and causes problems for the filters.

X - Ukusebenzisa ichemical eninzi kumosha imali yenze neengxaki kwi-filters.

E - We will teach you how to find the right amount of coagulant to add (the correct dose) using the Jar Test.

X - Sizakunibonisa ukuba ufumaneka njani owona mlinganiselo ufanelekileyo nge jar test.

E - In order to add the right amount of chemical, we also need to know how much water we are treating.

X - Ukuze ugalele umlinganiselo ofanelekileyo, kufuneka sazi ubungakanani bamanzi esiwacocayo.

E - The first lesson will be on the measurement of flow.

X - Isifundo sokuqala sakuba sekumejarisheni iflow.

E - Flow measurement

X - Ukubala umlinganiselo wokubaleka kwamanzi

E - It is important to know what the flowrate is in order to have the correct dose.

X - Kubalulekile ukwazi ubungakanani bokubaleka kwamanzi ukuze sazi owona mlinganiselo ufanelekileyo.

E - Questions

X - Imibuzo?

E - Why is the flowrate changed?

X - Sikutshintshela ntoni ukubaleka kwamanzi?

E - How do you know how much the flowrate is changed by?

X - Sazi njani ukuba sicuthe okanye senyasa kangakanani?

E - There are two ways to measure flow

X - Zimbini indlela zokufumanisa oku.

E - V-Notch Weir

E - The flow can be determined from the water level at the V-notch weir. This measurement is difficult because the water level goes up and down a lot. However, it is better to have a flow measurement, which is not very accurate than having no flow measurement at all.

X - Ukubaleka kwamanzi kungafunyaniswa ngobungakanani bamanzi ku V. Le indlela inzima ngoba amanzi ehla esenyuka. Kodwa kungcono ukuba ubenomlinganiselo noba awuthanga ncam kunoba ungabinawo kwaphela.

Flow meter

E - It is possible to get the raw water flow from the flow meter. This will be more accurate than the V-notch weir. However, the meter is not so easy to get to.

X - Ngethemba ukuba kwamsinya kuzakwenzeka ukuba ukubaleka kwamanzi kufunyaniswe kwiflow meter.

E - Changing the flowrate

X - Ukutshintshwa kobaleko lwamanzi

E - Changing the flowrate causes some problems for the plant

X - Ukutshintshwa oku kwenza ingxaki kwi plant yonke

- E - The coagulant and chlorine rates must also be changed to keep the right dose
- X - Ichemical nechlorine kufuneka nazo zitshintshwe ukuze ube nemilinganiselo ofanelekileyo
- E - The filtrate turbidity may get worse
- X - Iturbidity yamanzi ahluziweyo ingabambi kakhulu.

E - The plant works better if the flow does not have to change much.

X - Iplant ke isebenzo ngcono xa kungatshintshangwa kakhulu ukubaleka kwamanzi.

E - If it is necessary to change the flow, it is better to change it by small amounts rather than big amounts.

E - Uba kubalulekile ukutshintsha ubaleko lwamanzi, kungcono utshintshe kancinci.

E - If we know what the flow is, perhaps we can find the best flow to operate the plant at so that we do not have to change the flow much.

X - Xa usazi ukuba manzi abaleka kangakanani, mhlawumbi singafumana elona nqanaba lifanalekileyo, ze singabi nakutshintsha kwakhona.

E - This week we will try to find the best flowrate for the plant.

X - Kule veki sizakuzama ukufumana owona mlinganiselo uncomekayo apha eplantini

Day 2: Coagulant dosing

The Jar Test

E - We use the jar test to find the best dose for the plant. The **dose** is the amount of coagulant added divided by the amount of water it is added to.

X - Sisebenzisa i jar test ukuze sifumanise owona mlinganiselo ulungele iplant. Lo ngumlinganiselo wechemical udityanisiwe wohlulwe ngomlinganiselo wamanzi egalelwe kuwo.

E - In the jar test we add different numbers of ml's of coagulant solution to 1 L of raw water. The aim is to find the dose which gives the best settled water turbidity.

X - Kwi jar test ke sidibanisa inumber zechemical kwi liter yamanzi angacocwanga. Injongo ke kukufumana owona mlinganiselo unika iziphumo ezihle kwi turbidity.

E - In the plant, the dosing pump adds coagulant solution at the **dosing rate** (Litres/day) to the raw water flow (Megalitres/day).

X - Eplantini, impompo zigalela ichemical ngomyinge welitha ngemini kumanzi angumyinge wezigidi zeelitha ngemini.

1 megalitre (ML) = 1 000 000 litres.

E - The dosing rate is controlled by the dosing pump setting.

X - Umyinge wechemical ulawulwa yimpompo leyo.

E - The jar test consists of a

X - I jar test ke ingoluhlobo

E - rapid mixing step

X - ukuxutywa kukhawuleziswa

E - a slow mixing step

X - Uhlise ukukhawuleza kokuxuba

E - a settling step

X - Ukungcwenga

E - Different amounts of coagulant solution are added to different jars of raw water at the beginning of the rapid mixing step. The rapid mixing step corresponds to the raw water mixing with the coagulant as it goes over the jump.

X - Imilinganiselo eyahlukeneyo yechemical igalelwa kwi jug ezahlukileyo zamanzi, xa kanye kusaqala ukuxutywa ngokukhawuleza. Eli ke inqanaba liye lifaniswe nokuxutywa ngokukhawuleza kwamanzi angacocwanga nechemical isaya kwi jump.

E - The slow mixing step corresponds to the channels between the jump and the settlers. This is where the floc grows.

X - Oku ke kucothayo ukuxuba kufaniswa nalendawo iphakathi kwe jump nalamatanki okungcwengisa.

E - The settling step corresponds to the settling tanks.

X - Ukungcwengisa ke oku kufaniswa namatanki la okungcwenga

E - Jar Test Procedure

X - Indlela yokwenza i jar test

E - Equipment required

X - Izinto ezifunakayo

E - Jar stirrer
Two 5 L containers for collecting raw water
1 L plastic measuring cylinder
1 L flask
DI water
Five 1 L beakers, all the same size and shape
Syringes
Watch (preferably a digital stop watch)
Two small clean beakers
Thermometer
Turbidity meter

E - Preparing the stock solution

X - Ukwenza umxube olungele ijar test

E - A 1000 ml diluted coagulant stock solution must be prepared because the dosing solution is too strong for the jar test. A fresh stock solution must be prepared every day that the jar test is performed.

X - Sidinga ichemical engxengiweyo, futhi mayibentsha imihla yonke xa ijar test izakwenziwa

E - 1. Collect some coagulant dosing solution from the coagulant dosing tank in a small clean beaker

X - 1. X - Galela ichemical kwi beaker encinci ecocekileyo

E - 2. Fill a clean 1 L volumetric flask with DI water to halfway.

X- 2. Galela amanzi acocekileyo kwi volumetric flask enkulu abe sehafini.

E - 3. Add 1mL of dosing solution using a small (5 mL) syringe. You must add exactly 1 mL. This means that there must be no air bubbles in the syringe.

X - 3. Galela i1 ml ngqo yechemical usebenzisa isyringe. Akufuneki maqampu omoya ke kwi syringe eso.

E - 4. Fill the flask up to the 1 L mark with DI water, put the lid on and mix by shaking.

X - 4. Gcwalisa iflask ke ide ifike kwi mark ye liter

E - The raw water

X - Amanzi angacocwanga

E - 1. Collect raw water in a 5 L container just before performing the test. (that is you must not leave the water standing for a long time before you use it). Measure the temperature and the turbidity.

X -1. Yikha amanzi angacocwanga nge bhotile eyi 5liter phambi kokuba wenze I jar test (ungawahlalisi ixesha elide). Jonga umliganiselo we Temperature ne turbidity.

E – 2. Measure out exactly 1 L for each beaker using a measuring cylinder. Before pouring the raw water into the measuring cylinder, you must swirl the 5 L container gently to make sure that the same amount of sediment goes into each jar. The jars must all be labelled, for example: 1,2,3,… and before you start the experiment, you must write dowm the number of ml's of coagulant to be added to each jar.

X -2. Linganisela I 1 liter kwi beaker nganye usebenzisa I measuring Cylinder. Hlukuhla I 5l le inamanzi angacocwanga ukuze uqiniseke ukuba amanzi aya kwi beaker nganye ayafana. Zibhale ibeaker zakho, noba kungamanani(1,2,3….). Phambi kokuba uqalele ke bhala phantsi umyinge ozakuwugalela kwi beaker nganye.

E - 3. Insert the stirrers into each jar. Make sure they can turn without hitting the sides of the jar.

X - 3. Faka istirrer kwi beaker nganye. Qiniseka ukuba aziwabethi amacala ebeaker zakho.

E - The coagulant dose

X - Umlinganiselo we chemical

1. E - Put some stock solution in another clean beaker (not the same you used for the plant dosing solution.

1. X - Galela ichemical engxengiweyo kwi beaker e clean (ingenguwo lo uwusebenzisa e plantini.

2. E - Measure out the following amounts of stock solution using the syringes:

2. X - Yenza le milinganiselo ilandelayo usebenzisa isyringe

- mL (use the 2.5 mL syringe)
- mL (use the 5 mL syringe – not the one used to make the stock solution)
- 9.375 mL (use the 3rd mark on the 12.5 mL syringe)
- 12.5 mL (use the first mark after 10 mL on the 60 mL syringe)

- 17.5 mL (use the 3rd mark after 10 mL on the 60 mL syringe)

E - There must be no air bubbles in any of the syringes and they must not leak before you start the jar test.

X - Kungabikho maqampu omoya nakwesiphi na isyringe. Futhi mazingavuzi ungekayiqaleli ijar test.

Steps to perform the Jar Test

1. E - Increase the stirring speed to the maximum which does not cause the water to spill.

1. X - Yonyusa isantya sozamiso uyokufikelela kwelona nqanaba likhulu amanzi angachitheki kulo.

2. E - Add the coagulant to all beakers at exactly the same time. The smallest dose goes to jar 1 and the largest to jar 5.

2. X - Galela ichemical engxengiweyo kuzo zonke ibeaker ngexesha elinye. Owona mlinganiselo mncinci uya kwi beaker yokuqala ze owona mkhulu uye kweyesihlanu.

3. E - Exactly 1 minute after the dose is added, turn down the stirrers to 40 and stir at this speed for 20 minutes. You should see the floc start to form at least in some jars.

3. X - Emva komzuzu omnye ugalele umxube, yehlisa isantya sokuxuba uyekuma ku 40, uze ke uzamise imizuzu eyi 20. Uzakuyibona ke ifloc isenzeka kwezinye ibeaker.

4. E - After 20 minutes, stop the stirrers and pull them out of the jars.

4. X - Emva kwemizuzu eyi 20, yeka ukuzamisa uze ukhuphe izizamisi kwi beakers.

5. E - Let the floc settle for 30 minutes.

5. X - Linda ifloc icwenge imizuzu eyi 30

6. E - After 30 minutes carefully pour some water from the top of the jar into the turbidity meter cell. Be very careful not to disturb the floc settled on the bottom.

6. X - Emva kwalemizuzu, ngocoselelo yikha manzi phezulu apha kwi beaker ugalele kwibhotilana ye turbidity meter. Ungayiphazamisi ifloc le seyihleli ezantsi.

7. E - Throw the sample out and carefully add more from the same jar. Now measure the turbidity. Record the turbidity. Step 7 is to make sure the cell is clean inside before you take a measurement.

7. X - Wachithe ke lawo uze uphinda kwakwi beaker leyo, kweli lixa ke mejarisha iturbidity.

E - Repeat for all 5 jars. You must try to do this step quickly so that the settling times for the different jars are not very different.

8. X - Yenjenjalo kuzo zontlanu ezi beaker.

E - Compare the results for the different jars. Which is the best turbidity? Usually a turbidity of 5 NTU or less is good.

X - Jonga umahluko kwiziphumo zakho. Yeyiphi ene turbidity engcono. iturbidity engu 5 okanye ngaphantsi ingcono.

E - Setting the correct dose at the plant

X - Ukulinganisela ichemical ngokuthe ngqo eplantini

E - In order to set the correct dosing rate for the pump, you need to know

X - Ukuze ukwazi ukulinganisela ngokuthe ngqo, kufuneka wazi

- E - The correct dose from the jar test
- X - Umlinganiselo ofanalekileyo nge jar test
- E - The raw flowrate
- X - Ukubaleka kwamanzi angena eplantini

E - The correct plant dose rate is

X - Umlinganiselo ofanelekileyo ngulo

E - Dose rate in L/day = mL stock from jar test X raw flowrate (ML/day)

X - Umlinganiselo ngokwe ML/ngemini = mL zomxube kwi jar test uphindaphindwe ngokubaleka kwamanzi.

E - If the best dose from the jar test is 10 mL and the flowrate is 3.5 ML/d then the dosing rate is

X - Ukuba owona mlinganiselo ungcono ngokwe jar test ngu 10mL, ukubaleka kwamanzi kungu 3.5ML/d

10 X 3.5 = 35 L/day

E - You can use the calculator or the table of values we give you. It is best to use both and check you get the same result.

X - Ungasebenzisa icalculator okanye amanini owanikwe kwi table. Kubalulekile ukuqaphela ukuba ufumana iziphumo ezifanayo yini na kuzo zonke ezindlela.

Day 3: E- Coagulant dose revision and chlorine dose

X- Ukuzikhumbuza ngokulinganisela ichemical nokulinganisela ichlorine

E - When should you change the coagulant pump dose rate?

X - Uwutshintsha xa kutheni umlinganiselo we chemical

E - When you change the raw flowrate – no jar test needed

X - Xa utshintsha ukubaleka kwa manzi – awudingi kwenza jar test

E - When the raw turbidity changes – you should do the jar test

X - Xa iturbidity yamanzi la angacocwanga itshintsha – kufuneka wenze ijar test

E - When the settled water turbidity is not good – you should do the jar test

X - Xa iturbidity yalamanzi asuka kwi settling igentlanga – yenza ijar test

E - Discussion: what should you do if you see that the raw waterturbidity has change or the settled water turbidity is becoming bad?

X - Wenzantoni ke xa ubona ukuba iturbidity yamanzi angacocwanga itshintshile okanye le yalamanzi asuka kwi settling tank

E - It takes some time to do the jar test. If the raw turbidity increases and the settled and filtered water turbidity is not good, you should increase the dose rate immediately. If the raw water turbidity decreases and the settled and filtered water turbidity decreases you should decrease the dose rate immediately. You should do the jar test to test your new dose rate as soon as possible. Experience will help you to find the right dose quickly.

X - Ithatha ixesha ijar test, xa ubona ukuba iturbidity yalamanzi angacocwanga inyukile, yonyusa umlinganiselo wechemical ngokukhawuleza. Nakanjalo ke xa isehla iturbidity yamanzi angacocwanga nale yalamanzi asuka kwi settling tank kufuneka wehlise umlinganiselo wechemical. Emva koko khawulezisa wenze ijar test. Ukuqhelana noku kuyakukunceda ukuze ukhawuleze ukuwazi owona mlinganiselo ufanelekileyo.

E - Remember it also takes some time to see the effect of a dose rate change.

After changing the dose rate, you should check the last settled water turbidty (S3) every half hour and the final water turbidity every hour until you are happy that they have improved.

X - Khumbula, kuthatha ixeshana ukuze uwubone umahluko kutshintsho olu.

Jonga iturbidity yalamanzi asuka kwi-settling tank qho emva kwemizuzu eyi 30, namanzi agqityiweyo mhlawumbi kube kanye ngeyure emva kokuba utshintshile ude ubone umahluko.

E - When the new jar test equipment arrives next year, you should also do the jar test at least once a week, even if everything on the plant is fine. This will tell you the maximum and minimum doses that can be used and help improve the plant performance.

X - Xa ifika ijar test kulo nyaka uzayo, yenza ijar test kanye evekini, nokuba

kuhamba kakuhle apha eplantini. Oku ke kuyakukuxelela imilinganiselo elungele iplant ukuze iphucuke iplant le.

E - Chlorine Dosing

X - Ukulinganisela ichlorine

E - Why do we add chlorine to water

X - Siyigalelelani ichlorine emanzini

E - Chlorine is added to water to kill bacteria and other germs.

X - Siyigalela ukuze ibulale iintsholongwane

E - Some bacteria make people sick, like CHOLERA

X - ezi ke zithi zenze abantu bagule zizifo ezifana neCHOLERA.

E - Chlorine Demand Test

X - Ukuqikelela Umlinganiselo we Chlorine

E - Materials Needed

X - Izinto ezifunekayo

1% chlorine stock solution solution

6 containers (same and not metal)

5 ml syringe

Chlorine meter and DPD1 tablets

watch

E - Method

X - Omawukwenze

1. Prepare a chlorine stock solution: Add 2ml Jik to 1L Distilled water.
   Measure the concentration by diluting 1ml of the stock solution by 100ml DW
1. X - Yenza umxube olungele oku ngokudibanisa i2ml ye Jik kwi 1L yamanzi la akwi 20l
2. E - Fetch water from the filter, 1L from each filter and mix
2. X - Yikha amanzi kwi filter nganye uze uwadibanise
3. Take 4-6 non-metallic containers of known volumes

3. X - Thatha icontainers ezengenziwanga ngencence okanye ntsimbi zibe 4-6

4. E - Fill the containers with 100 ml of the filtered water
4. X - Galela 100ml yamanzi la asuka kwi filters kwi container nganye
5. E - Add to each container a progressively greater dose of the stock solution with a syringe
6. X - Ngokoluhlobo lungezantsi, galela imiyinge engalinganiyo ye stock solution kwi container zakho.

   Container 1 - 1ml

   Container 2 - 1.5ml

   Container 3 - 2 ml

   Container 4 - 2.5 ml

   Container 5 - 3ml

   Container 6 - 3.5ml
7. E - Wait for the required contact time.

6. X - Linda imizuzu ngoku ujonge ixesha lokuhlangana

8. E - Measure the free chlorine residual in each container.
7. X - khangela ichlorine kwi container nganye.
9. E - Choose the sample which shows a free residual chlorine level between 1.5 and 2 mg/L
8. X - Jonga eyona inika ichlorine ephakathi kuka 1.5 no 2mg/L
10. E - Calculate the chlorine flow rate required for the raw water flow rate.
9. X - Bala ukuba ungayigalela kangakanani na ichlorine, uqhaphela ukubaleka kwamanzi.

E - Calculating the exact flow rate of chlorine to be used in the plant

X - Nantsi ke indlela yokubala ubungakanani be chlorine oyisebenzisayo

E - CHLORINE FLOW RATE =

Concentration of the diluted chlorine stock x volume of the stock x100/24 x Raw water flow rate

X - ICHLORINE OYISEBENZISAYO =

Istock esixutyiweyo x umlinganiseIo we stock x 10/24 x ukubaleka kwamanzi

Day 4: E - Filter Inspection

X - Ukujonga isimo sefilter

E - How the filters work

X - Zisebenza njani iifilter

E - Water flows through a bed of sand. Dirt particles and germs stick to the sand. The particles that stick to the sand are left behind and clean water flows out of the filter.

X - Amanzi abaleka phezu kwesanti le iphakathi kwifIlter. Ubumdaka neentsholongwane zincamathela esantini zishiyeke amanzi acocekileyo esaphuma.

E - The water is clean, but the sand gets dirtier and dirtier until no more water can flow through. Before this happens, the filter sand must be cleaned by backwashing. The sand is cleaned by flowing water through it fast to try to wash the dirt away.

X - Amanzi acocekile, kodwa yona isanti iye isibamdaka ade amanzi angakwazi ukudlula. Ukuze akwazi ukuhamba amanzi, ifilter kufuneka ide ibackwashe. Isanti ihlanjwa ngokuhambisa amanzi apha kuyo ngokukhawuleza ukuze kusuke ubumdaka obu.

E - Question: Do you know where the water used to backwash the filters is stored?

X - Umbuzo: Uyawazi ukuba lamanzi asetyenziswa uku-backwasha ifilter ahlala phi na?

E - Answer: In a tank on top of the filter.

X - Impendulo: Kwitanki elilapha ngaphezulu kwifilter.

E - Sometimes we find that the filtered water turbidity is not good (more than 1NTU)

X - Ngamananye amaxesha siye sifumanise ukuba iturbidity yalamanzi asuka kwi filter ayikho ntle kwaphela

E - Why?

X - Kwenziwa yintoni oko?

E - The dose is not right

X - Umlinganiselo wechemical awunguwo

E - The settlers are not working well; the settled water turbidity should be < 5 NTU. < 2NTU is better

X - Isettling tank azisebenzi kakuhle.

E - The filter is too dirty

X - Ifilter imdaka

E - If the filter backwashed not long before, there is a lot of dirty water left inside.

X - Ukuba ifilter isanda kubackwasha, kusekho amanzi amaninzi amdaka.

E - Sometimes the filter gets dirty after some time even if the dose is right and the filter backwashes when it should. This is because the cleaning is not strong enough. This is a very big problem. All the sand in the filter may have to be changed.

X - Ngamanye amaxesha ifilter ibamdaka emva kwexesha, nangona umlinganiselo wechemical ufanelekile nefilter sele ibackwasha ngamaxesha afanelekileyo. Oku ke kwenzeka ngenxa ukuhlanjwa kwe filter akoneli. Le ke yingxaki enkulu. Isanti yonke ephakathi kwe filter kufuneka itshintshwe.

E - How often should the filter backwash?

X - Kufuneka ibackwashe kangaphi ifilter?

E - About once a day.

X - Kube kanye ngemini.

E - The filter may backwash less often if the flow is low.

X - Ifilter inganga backwashi qho xa amanzi ebaleka kancinci

E - The filter may backwash more often if the raw water is very dirty.

X - Kwakhona ifilter ingabackwasha qho xa amanzi angacocwanga emdaka kakhulu.

E - If the filter does not backwash every day, it becomes harder to clean. If the filter backwashes very often, and the raw water is not very dirty, then the filter may not be being cleaned.

X - Xa iifilter ingabackwashi yonke imihla, kubanzima ukuyicoca. Xa ibackwasha qho, namanzi angacocwanga engekho mdaka kakhulu, kodwa ibe isakunika iturbidity ephezulu, lonto ithetha ukuba ibackwash le ayenelanga ukucoca isanti

E - So if you notice that 1 filter has not been backwashed for 2 days, you should backwash it manually.

X - Ke xa uthe wabona ukuba enye yefilter ezi ayibackwashanga iintsuku ezimbini, Yinyanzele ngongwakho.

E - Today we are going to open the filter, after it has been manually backwashed to see how dirty the sand is.

X - Namhlanje sizakuvula ifilter emva kokuba siyinyanzele ukuba ibackwashe.

APPENDIX II

TABLE FOR THE CALCULATION OF THE RAW WATER FLOW RATES FROM THE HEIGHT OVER THE V-NOTCH WEIR

Plant flow from V-notch Ukubaleka kwamanzi ku V-notch

Height Ubude	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	cm
Flow Ukubaleka kwamanzi	0.43	0.49	0.54	0.60	0.67	0.74	0.81	0.89	0.97	1.05	ML/d

Height Ubude	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	cm
Flow Ukubaleka kwamanzi	1.14	1.24	1.34	1.44	1.55	1.66	1.78	1.90	2.03	2.16	ML/d

Height Ubude	20.5	21	21.5	22	22.5	23	23.5	24	24.5	25	cm
Flow Ukubaleka kwamanzi	2.30	2.45	2.59	2.75	2.91	3.07	3.24	3.41	3.60	3.78	ML/d

Height Ubude	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30	cm
Flow Ukubaleka kwamanzi	3.97	4.17	4.37	4.58	4.80	5.02	5.25	5.48	5.72	5.96	ML/d

Height Ubude	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	cm
Flow Ukubaleka kwamanzi	6.22	6.47	6.74	7.01	7.29	7.57	7.86	8.16	8.46	8.77	ML/d

Height Ubude	35.5	36	36.5	37	37.5	38	38.5	39	39.5	40	cm
Flow Ukubaleka kwamanzi	9.09	9.41	9.74	10.08	10.42	10.77	11.13	11.49	11.87	12.24	ML/d

Measure and record height before and after the flow is increased or decreased

Also record the time

Mejasisha ubhale phantsi Ubude pambi nasenva kokuba niliinyusile okanye niliihlisile ivili

APPENDIX III

SETTING THE COAGULANT DOSING PUMP FROM THE JAR TEST RESULTS

Setting the dosing pump (very low flow) Ukulinganisela ichemical

Dose from jar test (mL)	Raw Water Flowrate (ML/d)									
	0.43	**0.49**	**0.54**	**0.60**	**0.67**	**0.74**	**0.81**	**0.89**	**0.97**	**1.05**
2.5	1.08	1.21	1.36	1.51	1.67	1.84	2.03	2.22	2.42	2.64
3	1.30	1.46	1.63	1.81	2.01	2.21	2.43	2.66	2.91	3.16
3.5	1.51	1.70	1.90	2.11	2.34	2.58	2.84	3.11	3.39	3.69
4	1.73	1.94	2.17	2.41	2.67	2.95	3.24	3.55	3.87	4.22
4.5	1.95	2.19	2.44	2.72	3.01	3.32	3.65	3.99	4.36	4.74
5	2.16	2.43	2.71	3.02	3.34	3.69	4.05	4.44	4.84	5.27
5.5	2.38	2.67	2.98	3.32	3.68	4.06	4.46	4.88	5.33	5.80
6	2.59	2.91	3.26	3.62	4.01	4.42	4.86	5.32	5.81	6.33
6.5	2.81	3.16	3.53	3.92	4.34	4.79	5.27	5.77	6.30	6.85
7	3.03	3.40	3.80	4.23	4.68	5.16	5.67	6.21	6.78	7.38
7.5	3.24	3.64	4.07	4.53	5.01	5.53	6.08	6.66	7.27	7.91
8	3.46	3.88	4.34	4.83	5.35	5.90	6.48	7.10	7.75	8.44
8.5	3.67	4.13	4.61	5.13	5.68	6.27	6.89	7.54	8.23	8.96
9	3.89	4.37	4.88	5.43	6.02	6.64	7.29	7.99	8.72	9.49
9.5	4.11	4.61	5.16	5.73	6.35	7.00	7.70	8.43	9.20	10.02
10	4.32	4.86	5.43	6.04	6.68	7.37	8.10	8.87	9.69	10.54
10.5	4.54	5.10	5.70	6.34	7.02	7.74	8.51	9.32	10.17	11.07
11	4.76	5.34	5.97	6.64	7.35	8.11	8.91	9.76	10.66	11.60
11.5	4.97	5.58	6.24	6.94	7.69	8.48	9.32	10.20	11.14	12.13
12	5.19	5.83	6.51	7.24	8.02	8.85	9.72	10.65	11.62	12.65
12.5	5.40	6.07	6.78	7.54	8.36	9.22	10.13	11.09	12.11	13.18
13	5.62	6.31	7.05	7.85	8.69	9.58	10.53	11.54	12.59	13.71
13.5	5.84	6.56	7.33	8.15	9.02	9.95	10.94	11.98	13.08	14.23

14	6.05	6.80	7.60	8.45	9.36	10.32	11.34	12.42	13.56	14.76
14.5	6.27	7.04	7.87	8.75	9.69	10.69	11.75	12.87	14.05	15.29
15	6.48	7.28	8.14	9.05	10.03	11.06	12.15	13.31	14.53	15.82
15.5	6.70	7.53	8.41	9.36	10.36	11.43	12.56	13.75	15.02	16.34
16	6.92	7.77	8.68	9.66	10.69	11.80	12.96	14.20	15.50	16.87
16.5	7.13	8.01	8.95	9.96	11.03	12.17	13.37	14.64	15.98	17.40
17	7.35	8.25	9.23	10.26	11.36	12.53	13.77	15.09	16.47	17.93
17.5	7.56	8.50	9.50	10.56	11.70	12.90	14.18	15.53	16.95	18.45

Setting the dosing pump (low flow) Ukulinganisela ichemical

Dose from jar test (mL)	**Raw Water Flowrate (ML/d)**									
	1.14	**1.24**	**1.34**	**1.44**	**1.55**	**1.66**	**1.78**	**1.90**	**2.03**	**2.16**
2.5	2.86	3.10	3.35	3.60	3.88	4.16	4.45	4.76	5.08	5.41
3	3.43	3.72	4.01	4.33	4.65	4.99	5.34	5.71	6.10	6.49
3.5	4.01	4.34	4.68	5.05	5.43	5.82	6.23	6.66	7.11	7.58
4	4.58	4.96	5.35	5.77	6.20	6.65	7.12	7.62	8.13	8.66
4.5	5.15	5.58	6.02	6.49	6.98	7.48	8.02	8.57	9.14	9.74
5	5.72	6.20	6.69	7.21	7.75	8.32	8.91	9.52	10.16	10.82
5.5	6.29	6.81	7.36	7.93	8.53	9.15	9.80	10.47	11.17	11.90
6	6.87	7.43	8.03	8.65	9.30	9.98	10.69	11.42	12.19	12.99
6.5	7.44	8.05	8.70	9.37	10.08	10.81	11.58	12.38	13.21	14.07
7	8.01	8.67	9.37	10.09	10.85	11.64	12.47	13.33	14.22	15.15
7.5	8.58	9.29	10.04	10.81	11.63	12.47	13.36	14.28	15.24	16.23
8	9.16	9.91	10.70	11.53	12.40	13.31	14.25	15.23	16.25	17.32
8.5	9.73	10.53	11.37	12.26	13.18	14.14	15.14	16.18	17.27	18.40
9	10.30	11.15	12.04	12.98	13.95	14.97	16.03	17.14	18.29	19.48
9.5	10.87	11.77	12.71	13.70	14.73	15.80	16.92	18.09	19.30	20.56
10	11.44	12.39	13.38	14.42	15.50	16.63	17.81	19.04	20.32	21.65
10.5	12.02	13.01	14.05	15.14	16.28	17.46	18.70	19.99	21.33	22.73
11	12.59	13.63	14.72	15.86	17.05	18.30	19.59	20.94	22.35	23.81
11.5	13.16	14.25	15.39	16.58	17.83	19.13	20.48	21.90	23.37	24.89
12	13.73	14.87	16.06	17.30	18.60	19.96	21.37	22.85	24.38	25.97

12.5	14.31	15.49	16.73	18.02	19.38	20.79	22.27	23.80	25.40	27.06
13	14.88	16.11	17.40	18.74	20.15	21.62	23.16	24.75	26.41	28.14
13.5	15.45	16.73	18.06	19.46	20.93	22.45	24.05	25.70	27.43	29.22
14	16.02	17.35	18.73	20.19	21.70	23.29	24.94	26.66	28.44	30.30
14.5	16.60	17.97	19.40	20.91	22.48	24.12	25.83	27.61	29.46	31.39
15	17.17	18.59	20.07	21.63	23.25	24.95	26.72	28.56	30.48	32.47
15.5	17.74	19.21	20.74	22.35	24.03	25.78	27.61	29.51	31.49	33.55
16	18.31	19.82	21.41	23.07	24.80	26.61	28.50	30.46	32.51	34.63
16.5	18.88	20.44	22.08	23.79	25.58	27.44	29.39	31.42	33.52	35.71
17	19.46	21.06	22.75	24.51	26.35	28.28	30.28	32.37	34.54	36.80
17.5	20.03	21.68	23.42	25.23	27.13	29.11	31.17	33.32	35.56	37.88

Setting the dosing pump (average flow) Ukulinganisela ichemical

Dose from jar test (mL)	**Raw Water Flowrate (ML/d)**									
	2.30	**2.45**	**2.59**	**2.75**	**2.91**	**3.07**	**3.24**	**3.41**	**3.60**	**3.78**
2.5	5.76	6.11	6.48	6.87	7.26	7.67	8.10	8.54	8.99	9.45
3	6.91	7.34	7.78	8.24	8.72	9.21	9.72	10.24	10.79	11.34
3.5	8.06	8.56	9.08	9.61	10.17	10.74	11.34	11.95	12.58	13.23
4	9.21	9.78	10.37	10.99	11.62	12.28	12.96	13.66	14.38	15.13
4.5	10.36	11.00	11.67	12.36	13.08	13.81	14.58	15.36	16.18	17.02
5	11.51	12.23	12.97	13.73	14.53	15.35	16.20	17.07	17.98	18.91
5.5	12.66	13.45	14.26	15.11	15.98	16.88	17.82	18.78	19.77	20.80
6	13.81	14.67	15.56	16.48	17.43	18.42	19.44	20.49	21.57	22.69
6.5	14.97	15.89	16.86	17.85	18.89	19.95	21.06	22.19	23.37	24.58
7	16.12	17.12	18.15	19.23	20.34	21.49	22.68	23.90	25.17	26.47
7.5	17.27	18.34	19.45	20.60	21.79	23.02	24.29	25.61	26.96	28.36
8	18.42	19.56	20.75	21.98	23.25	24.56	25.91	27.32	28.76	30.25
8.5	19.57	20.79	22.04	23.35	24.70	26.09	27.53	29.02	30.56	32.14
9	20.72	22.01	23.34	24.72	26.15	27.63	29.15	30.73	32.36	34.03
9.5	21.87	23.23	24.64	26.10	27.60	29.16	30.77	32.44	34.15	35.92
10	23.02	24.45	25.93	27.47	29.06	30.70	32.39	34.14	35.95	37.81

10.5	24.17	25.68	27.23	28.84	30.51	32.23	34.01	35.85	37.75	39.70
11	25.33	26.90	28.53	30.22	31.96	33.77	35.63	37.56	39.55	41.59
11.5	26.48	28.12	29.82	31.59	33.41	35.30	37.25	39.27	41.34	43.48
12	27.63	29.34	31.12	32.96	34.87	36.84	38.87	40.97	43.14	45.38
12.5	28.78	30.57	32.42	34.34	36.32	38.37	40.49	42.68	44.94	47.27
13	29.93	31.79	33.72	35.71	37.77	39.91	42.11	44.39	46.74	49.16
13.5	31.08	33.01	35.01	37.08	39.23	41.44	43.73	46.09	48.53	51.05
14	32.23	34.23	36.31	38.46	40.68	42.98	45.35	47.80	50.33	52.94
14.5	33.38	35.46	37.61	39.83	42.13	44.51	46.97	49.51	52.13	54.83
15	34.54	36.68	38.90	41.20	43.58	46.05	48.59	51.22	53.93	56.72
15.5	35.69	37.90	40.20	42.58	45.04	47.58	50.21	52.92	55.72	58.61
16	36.84	39.12	41.50	43.95	46.49	49.12	51.83	54.63	57.52	60.50
16.5	37.99	40.35	42.79	45.32	47.94	50.65	53.45	56.34	59.32	62.39
17	39.14	41.57	44.09	46.70	49.40	52.19	55.07	58.04	61.12	64.28
17.5	40.29	42.79	45.39	48.07	50.85	53.72	56.69	59.75	62.91	66.17

Setting the dosing pump (high flow) Ukulinganisela ichemical

Dose from jar test (mL)	**Raw Water Flowrate (ML/d)**									
	3.97	**4.17**	**4.37**	**4.58**	**4.80**	**5.02**	**5.25**	**5.48**	**5.72**	**5.96**
2.5	9.93	10.43	10.94	11.46	12.00	12.55	13.12	13.70	14.30	14.91
3	11.92	12.51	13.12	13.75	14.40	15.06	15.74	16.44	17.16	17.89
3.5	13.91	14.60	15.31	16.04	16.80	17.57	18.36	19.18	20.02	20.88
4	15.89	16.68	17.50	18.33	19.19	20.08	20.99	21.92	22.88	23.86
4.5	17.88	18.77	19.68	20.63	21.59	22.59	23.61	24.66	25.74	26.84
5	19.87	20.85	21.87	22.92	23.99	25.10	26.23	27.40	28.60	29.82
5.5	21.85	22.94	24.06	25.21	26.39	27.61	28.86	30.14	31.46	32.81
6	23.84	25.02	26.25	27.50	28.79	30.12	31.48	32.88	34.32	35.79
6.5	25.83	27.11	28.43	29.79	31.19	32.63	34.10	35.62	37.18	38.77
7	27.81	29.20	30.62	32.08	33.59	35.14	36.73	38.36	40.03	41.75
7.5	29.80	31.28	32.81	34.38	35.99	37.65	39.35	41.10	42.89	44.74
8	31.79	33.37	34.99	36.67	38.39	40.16	41.97	43.84	45.75	47.72

8.5	33.77	35.45	37.18	38.96	40.79	42.67	44.60	46.58	48.61	50.70
9	35.76	37.54	39.37	41.25	43.19	45.18	47.22	49.32	51.47	53.68
9.5	37.74	39.62	41.56	43.54	45.59	47.69	49.84	52.06	54.33	56.66
10	39.73	41.71	43.74	45.83	47.99	50.20	52.47	54.80	57.19	59.65
10.5	41.72	43.79	45.93	48.13	50.39	52.71	55.09	57.54	60.05	62.63
11	43.70	45.88	48.12	50.42	52.78	55.22	57.72	60.28	62.91	65.61
11.5	45.69	47.96	50.30	52.71	55.18	57.73	60.34	63.02	65.77	68.59
12	47.68	50.05	52.49	55.00	57.58	60.24	62.96	65.76	68.63	71.58
12.5	49.66	52.13	54.68	57.29	59.98	62.75	65.59	68.50	71.49	74.56
13	51.65	54.22	56.86	59.59	62.38	65.26	68.21	71.24	74.35	77.54
13.5	53.64	56.31	59.05	61.88	64.78	67.77	70.83	73.98	77.21	80.52
14	55.62	58.39	61.24	64.17	67.18	70.28	73.46	76.72	80.07	83.51
14.5	57.61	60.48	63.43	66.46	69.58	72.79	76.08	79.46	82.93	86.49
15	59.60	62.56	65.61	68.75	71.98	75.30	78.70	82.20	85.79	89.47
15.5	61.58	64.65	67.80	71.04	74.38	77.81	81.33	84.94	88.65	92.45
16	63.57	66.73	69.99	73.34	76.78	80.32	83.95	87.68	91.51	95.44
16.5	65.56	68.82	72.17	75.63	79.18	82.83	86.57	90.42	94.37	98.42
17	67.54	70.90	74.36	77.92	81.58	85.34	89.20	93.16	97.23	101.40
17.5	69.53	72.99	76.55	80.21	83.98	87.85	91.82	95.90	100.09	104.38

Setting the dosing pump (very high flow) Ukulinganisela ichemical

Dose from jar test (mL)	**Raw Water Flowrate (ML/d)**									
	6.22	**6.47**	**6.74**	**7.01**	**7.29**	**7.57**	**7.86**	**8.16**	**8.46**	**8.77**
2.5	15.54	16.19	16.85	17.52	18.22	18.92	19.65	20.39	21.15	21.92
3	18.65	19.42	20.22	21.03	21.86	22.71	23.58	24.47	25.38	26.31
3.5	21.76	22.66	23.58	24.53	25.50	26.49	27.51	28.55	29.61	30.69
4	24.87	25.90	26.95	28.04	29.14	30.28	31.44	32.62	33.84	35.08
4.5	27.97	29.13	30.32	31.54	32.79	34.06	35.37	36.70	38.07	39.46
5	31.08	32.37	33.69	35.05	36.43	37.85	39.30	40.78	42.30	43.85

5.5	34.19	35.61	37.06	38.55	40.07	41.63	43.23	44.86	46.53	48.23
6	37.30	38.85	40.43	42.05	43.72	45.42	47.16	48.94	50.76	52.61
6.5	40.41	42.08	43.80	45.56	47.36	49.20	51.09	53.01	54.99	57.00
7	43.51	45.32	47.17	49.06	51.00	52.99	55.02	57.09	59.21	61.38
7.5	46.62	48.56	50.54	52.57	54.65	56.77	58.95	61.17	63.44	65.77
8	49.73	51.79	53.91	56.07	58.29	60.56	62.88	65.25	67.67	70.15
8.5	52.84	55.03	57.28	59.58	61.93	64.34	66.81	69.33	71.90	74.54
9	55.95	58.27	60.65	63.08	65.57	68.13	70.74	73.40	76.13	78.92
9.5	59.06	61.51	64.02	66.59	69.22	71.91	74.67	77.48	80.36	83.31
10	62.16	64.74	67.38	70.09	72.86	75.70	78.60	81.56	84.59	87.69
10.5	65.27	67.98	70.75	73.60	76.50	79.48	82.53	85.64	88.82	92.08
11	68.38	71.22	74.12	77.10	80.15	83.27	86.45	89.72	93.05	96.46
11.5	71.49	74.45	77.49	80.60	83.79	87.05	90.38	93.80	97.28	100.84
12	74.60	77.69	80.86	84.11	87.43	90.83	94.31	97.87	101.51	105.23
12.5	77.70	80.93	84.23	87.61	91.08	94.62	98.24	101.95	105.74	109.61
13	80.81	84.17	87.60	91.12	94.72	98.40	102.17	106.03	109.97	114.00
13.5	83.92	87.40	90.97	94.62	98.36	102.19	106.10	110.11	114.20	118.38
14	87.03	90.64	94.34	98.13	102.01	105.97	110.03	114.19	118.43	122.77
14.5	90.14	93.88	97.71	101.63	105.65	109.76	113.96	118.26	122.66	127.15
15	93.25	97.11	101.08	105.14	109.29	113.54	117.89	122.34	126.89	131.54
15.5	96.35	100.35	104.45	108.64	112.93	117.33	121.82	126.42	131.12	135.92
16	99.46	103.59	107.82	112.15	116.58	121.11	125.75	130.50	135.35	140.31
16.5	102.57	106.83	111.18	115.65	120.22	124.90	129.68	134.58	139.58	144.69
17	105.68	110.06	114.55	119.15	123.86	128.68	133.61	138.65	143.81	149.07
17.5	108.79	113.30	117.92	122.66	127.51	132.47	137.54	142.73	148.04	153.46

APPENDIX IV

ESTIMATING CONTACT TIME FROM THE RAW WATER FLOW RATE VALUES

Contact time - New Reservoir- Ixesha lokuhlangana

Flow Ukubaleka kwamanzi	0.43	0.49	0.54	0.60	0.67	0.74	0.81	0.89	0.97	1.05	ML/d
Ixesha lokuhlangana	333.12	296.55	265.36	238.57	215.43	195.31	177.72	162.28	148.65	136.57	Minutes

Flow Ukubaleka kwamanzi	1.14	1.24	1.34	1.44	1.55	1.66	1.78	1.90	2.03	2.16	ML/d
Ixesha lokuhlangana	125.82	116.22	107.61	99.87	92.89	86.58	80.84	75.63	70.87	66.53	minutes

Flow Ukubaleka kwamanzi	2.30	2.45	2.59	2.75	2.91	3.07	3.24	3.41	3.60	3.78	ML/d
Ixesha lokuhlangana	62.54	58.89	55.52	52.42	49.56	46.91	44.45	42.17	40.06	38.08	minutes

Flow Ukubaleka kwamanzi	3.97	4.17	4.37	4.58	4.80	5.02	5.25	5.48	5.72	5.96	ML/d
Ixesha lokuhlangana	36.24	34.53	32.92	31.42	30.01	28.69	27.45	26.28	25.18	24.14	minutes

Flow Ukubaleka kwamanzi	6.22	6.47	6.74	7.01	7.29	7.57	7.86	8.16	8.46	8.77	ML/d
Ixesha lokuhlangana	23.16	22.24	21.37	20.54	19.76	19.02	18.32	17.66	17.02	16.42	minutes

Flow Ukubaleka kwamanzi	9.09	9.41	9.74	10.08	10.42	10.77	11.13	11.49	11.87	12.24	ML/d
Ixesha lokuhlangana	15.85	15.30	14.79	14.29	13.82	13.37	12.94	12.53	12.14	11.76	minutes

APPENDIX V

SETTING THE CHLORINE DOSING PUMP FROM CHLORINE DEMAND RESULTS

Setting the chlorine flow (very low raw flow

Ukulinganisela ichlorine (amanzi angacocwanga ebaleka kancinci)

stock solution check 1.00

Istock solution esixutyiweyo

Dose from chlorine demand (mL)	Ukubaleka kwamanzi angacocwanga								
Umlinganiselo	**0.43**	**0.49**	**0.54**	**0.60**	**0.67**	**0.74**	**0.81**	**0.89**	**0.97**	**1.05**
1	18	20	23	25	28	31	34	37	40	44
1.5	27	30	34	38	42	46	51	55	61	66
2	36	40	45	50	56	61	68	74	81	88
2.5	45	51	57	63	70	77	84	92	101	110
3	54	61	68	75	84	92	101	111	121	132
3.5	63	71	79	88	97	108	118	129	141	154
4	72	81	90	101	111	123	135	148	161	176
4.5	81	91	102	113	125	138	152	166	182	198
5	90	101	113	126	139	154	169	185	202	220
5.5	99	111	124	138	153	169	186	203	222	242
6	108	121	136	151	167	184	203	222	242	264

Setting the chlorine rate (low raw water flow)

Ukulinganisela ichlorine (amanzi angacocwanga ebaleka kancinci)

Dose from chlorine demand (mL)	**Raw Water Flowrate (ML/d)** **Ukubaleka kwamanzi angacocwanga**									
Umlinganiselo	**1.14**	**1.24**	**1.34**	**1.44**	**1.55**	**1.66**	**1.78**	**1.90**	**2.03**	**2.16**
1	48	52	56	60	65	69	74	79	85	90
1.5	72	77	84	90	97	104	111	119	127	135
2	95	103	112	120	129	139	148	159	169	180
2.5	119	129	139	150	161	173	186	198	212	225
3	143	155	167	180	194	208	223	238	254	271
3.5	167	181	195	210	226	243	260	278	296	316
4	191	207	223	240	258	277	297	317	339	361
4.5	215	232	251	270	291	312	334	357	381	406
5	238	258	279	300	323	347	371	397	423	451
5.5	262	284	307	330	355	381	408	436	466	496
6	286	310	335	360	388	416	445	476	508	541

Setting the chlorine flow (average raw water flow)

Ukulinganisela ichlorine (amanzi angacocwanga ebaleka ngokuphakathi)

Dose from chlorine demand (mL)	Raw Water Flowrate (ML/d) Ukubaleka kwamanzi angacocwanga									
Umlinganiselo	**2.30**	**2.45**	**2.59**	**2.75**	**2.91**	**3.07**	**3.24**	**3.41**	**3.60**	**3.78**
1	96	102	108	114	121	128	135	142	150	158
1.5	144	153	162	172	182	192	202	213	225	236
2	192	204	216	229	242	256	270	285	300	315
2.5	240	255	270	286	303	320	337	356	374	394
3	288	306	324	343	363	384	405	427	449	473
3.5	336	357	378	401	424	448	472	498	524	551
4	384	408	432	458	484	512	540	569	599	630
4.5	432	458	486	515	545	576	607	640	674	709
5	480	509	540	572	605	640	675	711	749	788
5.5	528	560	594	629	666	703	742	782	824	867
6	576	611	648	687	726	767	810	854	899	945

Setting the chlorine rate (high raw flow)

Ukulinganisela ichlorine (amanzi angacocwanga ebaleka kakhulu)

Dose from chlorine demand (mL)	**Raw Water Flowrate (ML/d) Ukubaleka kwamanzi angacocwanga**									
Umlinganiselo	**3.97**	**4.17**	**4.37**	**4.58**	**4.80**	**5.02**	**5.25**	**5.48**	**5.72**	**5.96**
1	166	174	182	191	200	209	219	228	238	249
1.5	248	261	273	286	300	314	328	342	357	373
2	331	348	365	382	400	418	437	457	477	497
2.5	414	434	456	477	500	523	547	571	596	621
3	497	521	547	573	600	627	656	685	715	746
3.5	579	608	638	668	700	732	765	799	834	870
4	662	695	729	764	800	837	874	913	953	994
4.5	745	782	820	859	900	941	984	1027	1072	1118
5	828	869	911	955	1000	1046	1093	1142	1192	1243
5.5	911	956	1002	1050	1100	1150	1202	1256	1311	1367
6	993	1043	1094	1146	1200	1255	1312	1370	1430	1491

Setting the chlorine rate (very high raw flow)

Ukulinganisela ichlorine (amanzi angacocwanga ebaleka kakhulu)

Dose from chlorine demand (mL)	**Raw Water Flowrate (ML/d)**					**Ukubaleka kwamanzi angacocwanga**				
Umlinganiselo	**6.22**	**6.47**	**6.74**	**7.01**	**7.29**	**7.57**	**7.86**	**8.16**	**8.46**	**8.77**
1	259	270	281	292	304	315	327	340	352	365
1.5	389	405	421	438	455	473	491	510	529	548
2	518	540	562	584	607	631	655	680	705	731
2.5	648	674	702	730	759	788	819	850	881	913
3	777	809	842	876	911	946	982	1020	1057	1096
3.5	907	944	983	1022	1063	1104	1146	1189	1234	1279
4	1036	1079	1123	1168	1214	1262	1310	1359	1410	1462
4.5	1166	1214	1263	1314	1366	1419	1474	1529	1586	1644
5	1295	1349	1404	1460	1518	1577	1637	1699	1762	1827
5.5	1425	1484	1544	1606	1670	1735	1801	1869	1939	2010
6	1554	1619	1685	1752	1822	1892	1965	2039	2115	2192

APPENDIX VI

OPERATORS DURING THE TRAINING COURSE