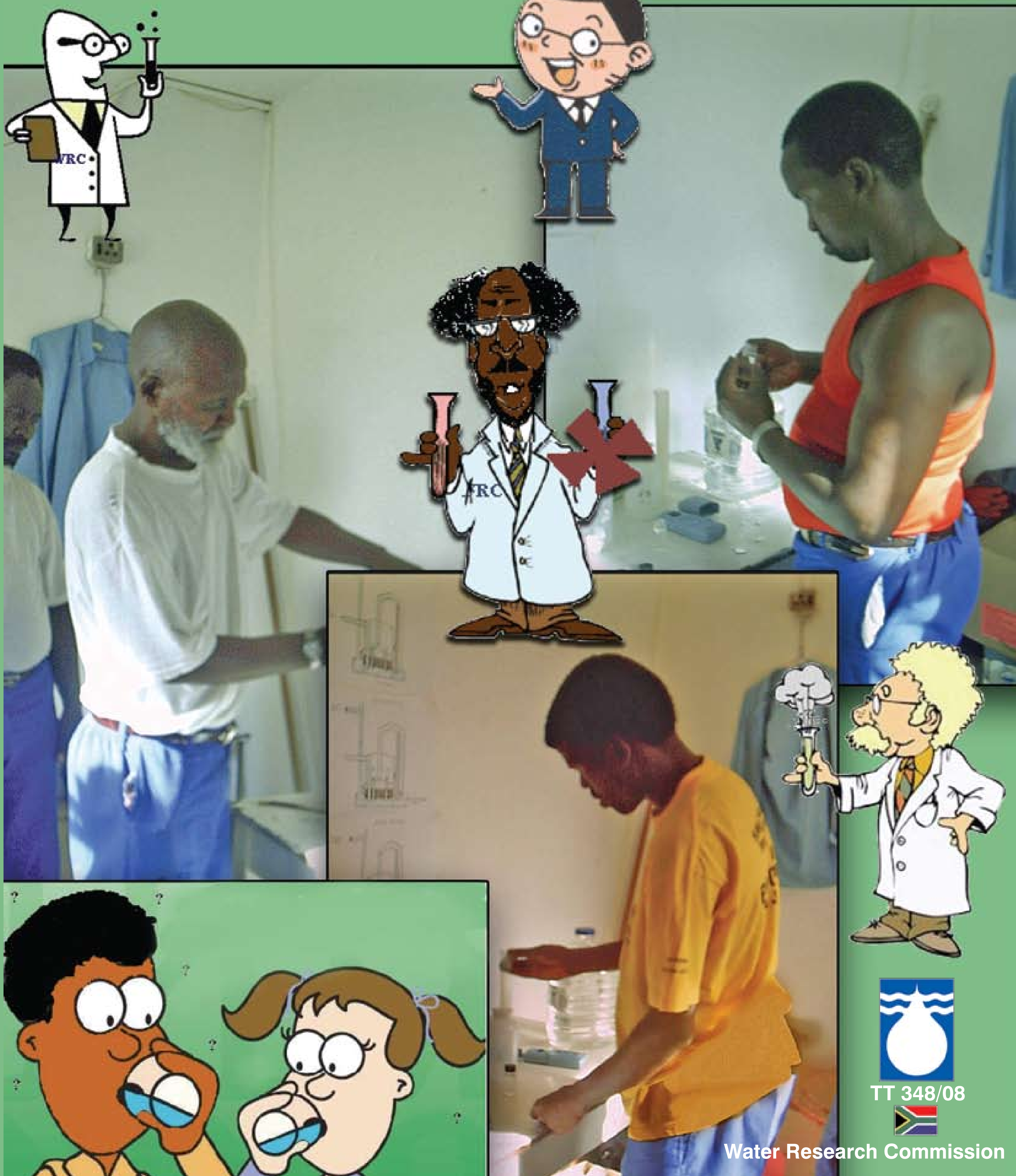
On-Site Mobile Training of Operators in Small Rural Water Supplies: An Illustrative Kit

MNB Momba, N Makala & M Dungeni



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Water Research Commission

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MNB Momba, N Makala and M Dungeni

Report to the

Water Research Commission

by

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Preface

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 7 provinces of South Africa, 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.

In rural water treatment plants, there is a need for most operators 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. Moreover, they may not understand how to implement certain procedures in their own plants if they do not correspond exactly to the example studied in class.

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. This illustrative kit is an end-product of a series of on-site mobile training of 26 operators from 7 different small water treatment plants in the Eastern Cape Province. It emphasises 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. The kit was developed in colour format and can be translated in local languages in order to be useful to operators with a wide range of education levels.

The authors sincerely thank the Water Research Commission for the financial support and also all the Eastern Cape supervisors and operators who contributed to the development and the success of this training manual.

Table of Contents

Definitions, Terminology and Acronyms

Assessment Guide	Refers to the Assessment Guide for South Africa.
Coagulant	A chemical added to raw water to give floc. Sometimes it is also referred to as a flocculant.
Distribution System	This refers to the network of pipes, storage reservoirs and pumps between the treatment plant and the consumer's tap.
DPD1 Tablets	*N.N* diethyl-*p*-phenylenediamine sulphate
DWAF	Department of Water Affairs and Forestry.
Faecal Coliforms	Faecal coliforms are bacteria which normally inhabit the digestive system of all warm-blooded animals, including humans. These are the most commonly used bacterial indicator of faecal pollution.
Free Chlorine	The sum of hypochlorous acid and hypochlorite ions in water (in mg/L).
Free Chlorine Residual	The amount of free chlorine remaining in the water after a 30 minute contact time.
NTU	Nephelometric turbidity units.
Pathogens	Microorganisms which cause disease.
Raw Water	Untreated water.
SANS-241	South African National Standard 241. Can be purchased from Standards South African (Pretoria South Africa)
Solubility	The tendency of a chemical to dissolve in water.
TDS	Total dissolved solids, measured in mg/L.
WSA	Water Services 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).
WSP	Water Services Provider.

Introduction

The proper maintenance and operation of water supply, treatment and distribution systems is an essential part of any effort to ensure the on-going production and delivery of high quality drinking water. If a community fails to recognize the need for the training of operators in specific treatment processes, professional guidance and technical assistance in system selection, and adequate funding for operation and maintenance, system operation and water quality will suffer (USEPA, 2003).

Many small rural water treatment plants in South Africa do not produce the quality or quantity of water that they were meant to (Swartz, 2000; Mackintosh and Colvin, 2002; Momba *et al.*, 2004). Both technical and human factors have been reported to be the major causes of the failure of small rural water treatment plants to provide potable water to their consumers. Inadequate water treatment systems are therefore placing rural communities at risk of diseases.

It has been found that most of the operators who operate rural small water treatments lack the knowledge of plant operational processes (Swartz, 2000; Mackintosh and Colvin; 2002, Momba *et al.*, 2004). Even when an attempt has been made to offer training, the level of the material used is well beyond the educational level of the operators. Moreover, each plant is different and has different problems. Improving the theoretical knowledge of the operators in a class-room will have limited benefits if they do not understand how to apply that knowledge to their own plant. It is therefore important to customize the training for each plant. Furthermore, the trainees must have seen the conditions at the plant for them to be effective.

In a recent survey of small rural water treatment plants, Momba and co-workers (2006) have often found that when questioned about the operation of their plants, the operators gave inaccurate or misleading answers simply because they do not understand the question related to the practical aspect of their own plant. Furthermore, smaller water treatment plants have typically one operator. When the permanent operator is on leave, someone with little or no experience in the operation of the plant is left in charge. In these circumstances, it would be particularly advantageous to have a simple, preferably illustrative set of instructions available. Consequently there is a need for the training to be adapted to their capability as well as to be done on-site.

This illustrative training manual is intended for use by trainers of supervisors and operators in small rural water treatment plants and it aims:

1. To provide operators involved in conducting routine maintenance tasks and checks on water purification works with a better general understanding of both the theory and practice of water purification.
2. To make sure that theoretical knowledge of water treatment operations goes together with direct implementation of that knowledge according to the condition of each plant.
3. To ensure that the operators are given hands-on training using equipment that they are familiar with.
4. To allow the municipalities to keep the operators in the plants while they are attending the training course as most of the municipalities are not in a position to send the operators away for 4-5 day workshops that are normally held in the large cities.

Although this exercise currently seems to be costly because of traveling expenses, the end product will be beneficial not only to the operators, but also to the communities as it will result in the sustainable production and delivery of safe water.

The training manual is divided into two main parts. The first part gives an overview of drinking water treatment with emphasis on the legal requirements for the safety of drinking water in terms of the Constitution and the 1997 Water Service Act. The second part focuses on-site training of the water treatment operators.

PART 1

OVERVIEW OF DRINKING WATER TREATMENT

Section I

Provision of Safe Drinking Water: Legal Aspects

South African Regulation

1.1

Provision of Safe Drinking Water: Legal Aspects

South African Regulation

The Water Services Act of 1997 and Strategic Framework for Water Services (DWAF, 2003) defines 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 of 1998 or the ministerial authorisations made in terms of this Act (DWAF, 2003). According to the Municipal Structures Amendment Act of 2000, the role of WSA is usually assigned to District Municipalities.

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.

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 next Section).

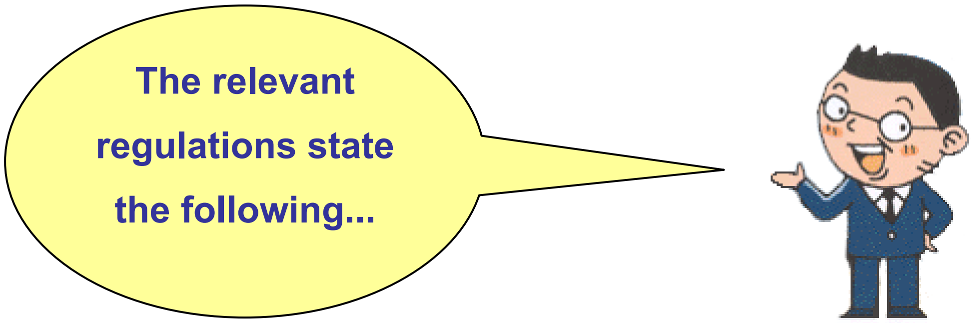
- Ensuring adequate investments are made in water services infrastructure, including maintenance, repair and replacement of equipment when necessary (Section 4.2 in *Strategic Framework for Water Services*, DWAF, 2003).

1.2
Compulsory National Standards for Potable Water:
Government Gazette, Vol. 432 No. 22355, 8 June 2001

Regulations relating to compulsory national standards for potable water quality were published in the Government Gazette, Vol. 432 No. 22355, 8 June 2001.

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 SANS 241(2005) (Specifications for Drinking Water, South African National of Standards).

The regulations specify the steps which must be taken if quality of water does not meet the required standards.



Sub-regulation 5(1)

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 **SANS 241 (2005)**: Specifications for Drinking Water or the South African Water Quality Guidelines published by DWAF.

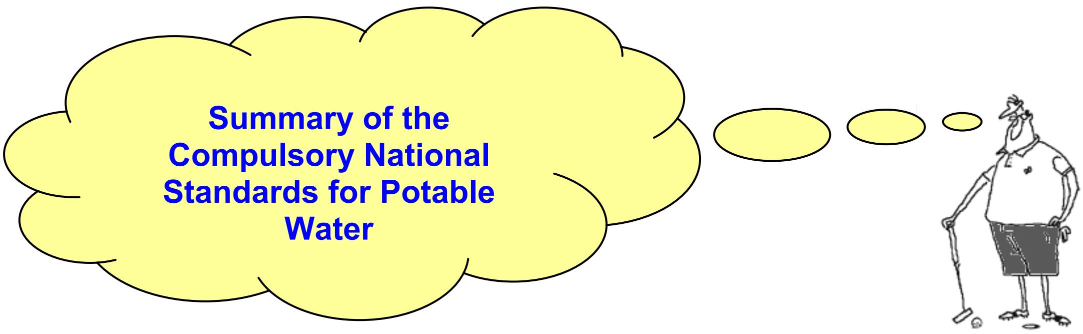
Sub-regulation 5(4)

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 of the following:

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

(b)The reasons for the health risk;

(c)Precautions, if any, to be taken by the consumers; and the time frame, if any, within which it may be expected that water of a safe quality will be provided.



- 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 SANS-241 (2005).

- 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

1.3
Potable Water Quality and Monitoring Requirements as defined by SANS-241 (2005)

Minimum Set of Water Quality Parameters to be Monitored:

a. Finished Water

- Conductivity or TDS
- pH
- Turbidity
- Faecal coliforms or *E.coli*
- Treatment chemical residuals (Al or Fe and free chlorine)

b. Raw Water

In addition to the above:

- Fluoride
- Nitrate and nitrite
- Heterotrophic plate counts
- Iron
- Manganese
- Arsenic

Different Classes of Water as Defined by SANS-241 (2005)

The South African National Standards-241 (2005) 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 more than one year).

The minimum suggested frequency of sampling based on population served is given in Table 1, and the microbial requirements in Table 2. Table 3 indicates the physical, organoleptic and chemical requirements.

TABLE 1: Suggested Minimum Sampling Frequency (SANS 241-2005)	
Population served	**Minimum number of samples per month***
More than 100 000	10 every month per 100 0000 of population served
25 001 – 100 000	10 every month
10 001 – 25 000	3 every month
2 500 – 10 000	2 every month
Less than 2 500	1 every month
* During the rainy season, Sampling should be carried out more frequently.	

TABLE 2a: 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

[+] DWAF,1996; DWAF *et al.*, 1998; SABS 241-2001; SANS-241, 2005.

TABLE 2b: Microbiological Safety Requirements (SANS-241 – 2005)				
1	2	3	4	5
Determinant	**Units**	**Allowable compliance contribution** [a]		
		95% of samples, min.	**4% of samples, max.**	**1% of samples, max.**
		Upper Limits		
Escherichia coli [b] or	counts/100 mL	Not detected	Not detected	1
thermotolerant (faecal) coliform bacteria [c]	counts/100 mL	Not detected	1	10

[a] The allowable compliance contribution shall be at least 95% to limits indicated in column 3, with a maximum of 4% and 1%, respectively, to the limits indicated in column 4 and column 5. The objective of the disinfection should, nevertheless, be to attain 100% compliance to the limits indicated in column 3.

[b] Definitive, preferred indicator of faecal pollution.

[c] Indicator of acceptable microbial water quality, could be tested instead of *E.coli* but is not the preferred indicator of faecal pollution. Also provides information on treatment efficiency and aftergrowth in distribution networks.

TABLE 3: Physical, Organoleptic and Chemical Requirements[+]				
1	**2**	**3**	**4**	**5**
Determinand	**Unit**	**Class I (Recommended operational limit)**	**Class II (max. allowable for limited duration)**	**Class II water consumption period,[a] max.**
Physical and organoleptic requirements				
Conductivity at 25°C (aesthetic)	mS/m	<150	**150 – 370**	7 years
Dissolved solids (aesthetic)	mg/L	<1000	**1 000 - 2 400**	7 years
pH at 25°C (aesthetic)	pH units	5.0-9.5	**4.0 – 10.0**	No-limit [b]
Turbidity (aesthetic/operational/ Indirect health)	NTU	<1	**1 – 5**	No-limit [c]
Chemical requirements macro-determinand				
Ammonia as N (operational)	mg/L	<1.0	**1.0 – 2.0**	No limit [c]
Chloride as Cl^- (aesthetic)	mg/L	<200	**200 - 600**	7 years
Fluoride as F^- (aesthetic)	mg/L	<0.7	**0.7 – 1.0**	1.0 – 1.5
(Nitrites and nitrates) as N (health)	mg/L	<10	**10 – 20**	7 years
Chemical requirements micro-determinand				
Aluminium as Al (health)	µg/L	<300	**300 – 500**	1 year
Arsenic as As (health)	µg/L	<10	**10 – 50**	1 year
Iron as Fe (aesthetic/operational)	µg/L	<200	**200 – 2 000**	7 years
Manganese as Mn (aesthetic)	µg/L	<100	**100 – 1 000**	7 years

[+] DWAF 1996; DWAF *et al.*,1998; SABS-241,2001; SANS-241,2005.[a] The limits for the consumption of class II water are based on the consumption of 2L of water per day by a person of mass 70 years. Columns 4 and 5 shall be applied together.[b] No primary health effect – low pH values can result in structural problems in the distribution system.

[c] These values can indicate process efficiency and risks associated with pathogens.

1.4
What Are The Factors that need to be taken into consideration In Drawing an Appropriate Sampling Plan – SANS-241, 2005?

Example 1:

Compliance with the Compulsory National Standard for the microbial quality of potable water

36 samples collected 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 coliforms = 35 samples = 97%**
- **Number of samples with 1 faecal coliform/100 mL = 1 sample = 3%**
- **Number of samples with > 1 faecal coliform/100 mL = 0**

Example 2:

Non Compliance with the Compulsory National Standard for the microbial quality of potable water

36 water samples collected from a similar town as in example 1. This time, the results are as follows:

- **Number of samples with 0 faecal coliforms = 34 samples = 94%**
- **Number of samples with 1 faecal coliform/100 mL = 1 sample = 3%**
- **Number of samples with > 1 faecal coliform/100 mL = 1 sample = 3% (actual result is 3 Faecal Coliforms/100 mL)**

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.

Example 3:

Non Compliance with significant risk to consumers' health

50 water samples collected over a one year period. The results are as follows:

- Number of samples with 0 faecal coliforms = 5 samples = 10%
- Number of samples with 1 faecal coliform/100 mL = 3 sample s= 6%
- Number of samples with > 1 faecal coliform/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…

… What then should be done?

Urgent action is required to determine the cause of the failure and to correct the problem!

Example 4:

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

Action should be taken!!

The Water Services Institution must:

- Inform the Director-General of the Department of Water Affairs and Forestry
- Inform the head of the relevant Provincial Department of Health
- Take steps to inform its consumers.

Section II

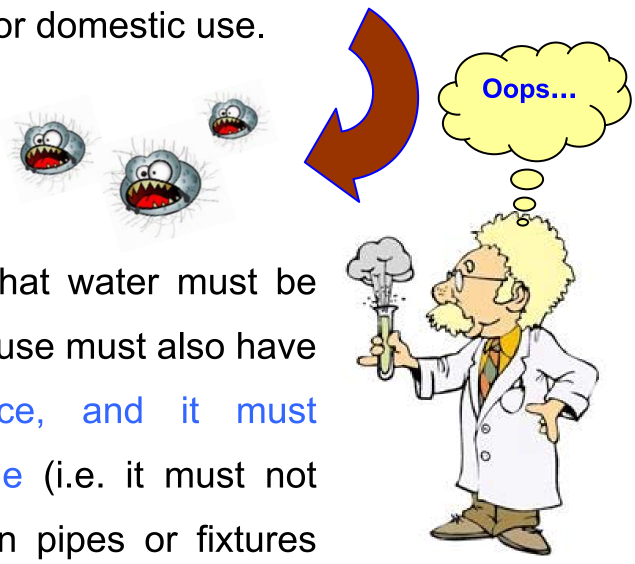
Why Water Requires Treatment?

2.1

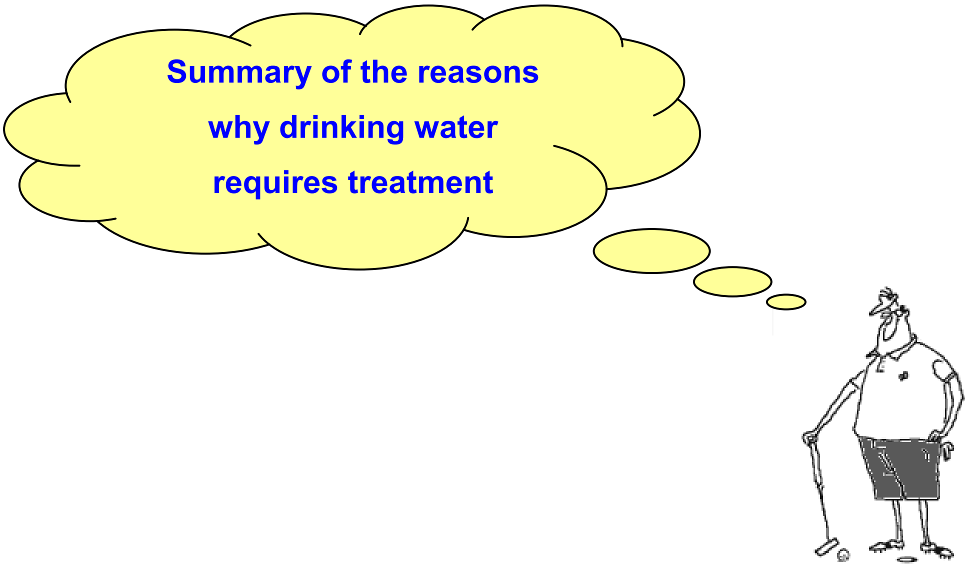
Why is it necessary to treat water for Domestic Use?

Water must meet certain basic requirements to make it fit for domestic use. The most important requirement is that it must be safe to drink.

Many water sources contain harmful micro-organisms or other substances in concentrations that make the water unsafe to drink or in other ways unfit for domestic use. These organisms and substances must therefore be removed from the water by means of treatment processes to make the water fit for domestic use.



In addition to the requirement that water must be safe to drink, water for domestic use must also have a pleasing (clean) appearance, and it must furthermore be chemically stable (i.e. it must not cause **corrosion** or **deposits** in pipes or fixtures such as geysers).



- Water must not pose a health risk due to microbiological contaminants.
- Water must not pose a health risk due to chemical contaminants.
- Water should be aesthetically acceptable.
- Water should not have an economically detrimental effect on either the distribution system nor on consumers' equipment in term of corrosivity, scaling and hardness or sediments.

!!! Note !!!

Consuming water without treatment is a dangerous practice that may result in the user contracting diseases such as cholera or dysentery if the water source is contaminated by pathogens (disease-causing organisms).

2.2
How and where does Water Treatment fit into a Water Supply System?

Water treatment is an essential element in any water supply system in order to make the water fit for domestic use. In a conventional treatment system, raw water is abstracted from the source (dam, river or borehole). The raw water is then conveyed to the treatment plant where it is treated in different treatment processes. After treatment the water is stored and then distributed to individual users (see following figure: a diagrammatic representation of drinking water treatment).

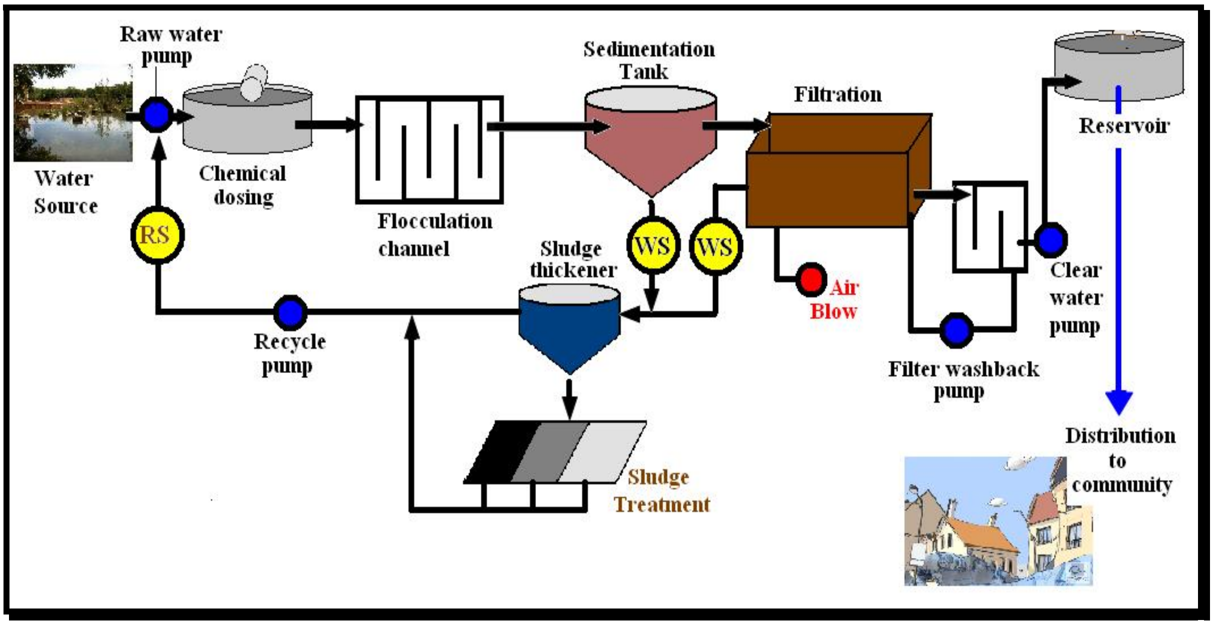


Figure 1: Overview of a typical water purification plant

(RS= Recycle system, WS= Waste sludge)

2.3
What are the substances of concern that must be removed during Water Treatment?

Dirty water

Removal of:

- **Larger suspended particles**
- **Very small particles**

Clean treated water

Suspended particles occur generally in surface water and give water a turbid or murky appearance. They include: clay particles, algae, micro-organisms, decaying plant material and other organic and inorganic substances.

The larger suspended particles can be easily removed from water simply by means of settling, i.e. by allowing the water to stand for a short period and then decanting the clear water.

Very small particles (called colloidal particles) are very difficult to remove from water because they do not settle readily and can therefore not be removed by simple settling. The very small colloidal particles in the water have to be destabilised chemically before the particles can be removed.

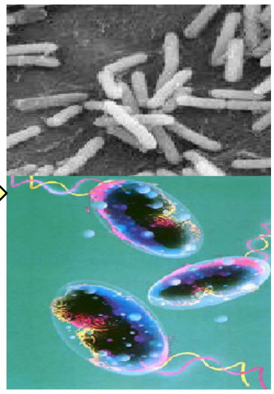
2.3(a) Microorganisms

Microorganisms include bacteria, viruses and other organisms may also be present in water as colloidal particles. Most microorganisms in water are harmless, but disease-causing organisms (called pathogens) may cause diseases if they are present in water that is consumed without treatment.

Example 5: Some waterborne diseases due to non-treatment or inadequate treatment of drinking water

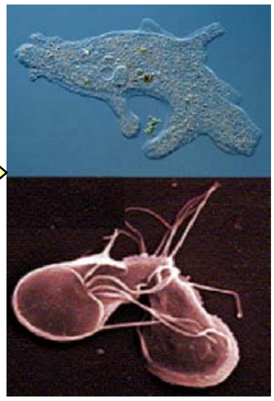
Waterborne diseases caused by bacteria of faecal origin

- Typhoid Fever
- Cholera
- Bacillary dysentery
- Gastroenteritis



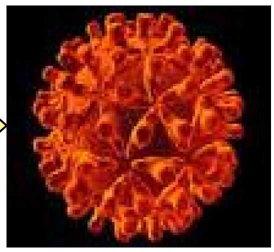
Waterborne diseases caused by protozoa

- Giardiasis (dysentery)
- Cryptosporidiosis
- Amoebic dysentery



Waterborne diseases caused by enteric viruses

- Poliomyelitis
- Aseptic meningitis
- Infectious hepatitis



What happens when you contract Waterborne Diseases?

Most waterborne diseases stated above result in Diarrhoea and fever.

Sources of Pathogen Contamination

Primary concern:

Faecal matter from humans, livestock and wild animals

- Inadequate sanitation facilities
- Leaking pit latrines
- Overflowing sewers
- Livestock farming
- Inadequately treated sludge
- Effluents from water and wastewater treatment plants

"Major sources of faecal contamination"

2.3(b). Dissolved Inorganic Substances

Dissolved inorganic substances normally do not affect the appearance of water, but may cause the water to have a brackish or salty taste.

Some dissolved substances may also cause the water to be toxic at very low concentrations e.g. arsenic and mercury.

Most of the naturally occurring substances such as sodium chloride (NaCl, table salt) and calcium sulphate ($CaSO_4$, gypsum) are harmless in water for domestic use at the concentrations at which they normally occur.

Other dissolved inorganic substances may be harmful if they are present at concentrations exceeding certain limits, e.g. fluoride.

The presence of other inorganic substances may have different effects, e.g. high concentrations of calcium and magnesium cause excessive hardness in the water. Iron and manganese on the other hand, may cause staining of clothes by the water, while other substances (or a lack there of) may cause the water to be corrosive or to form layers of scale in pipes.

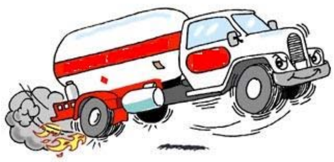
2.3(C). Dissolved Organic Substances

Dissolved organic substances are generally present in most surface waters. Most dissolved organic substances are harmless, e.g. dissolved substances (called humic acids) from decaying plant matter. However, there may also be harmful organic substances in water, such as pesticides and herbicides that find their way into water sources.

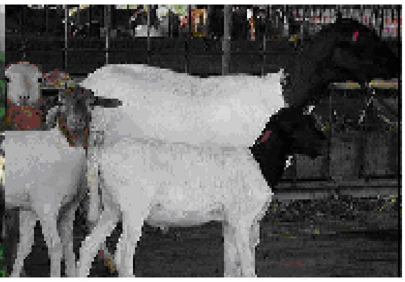
Another category of dissolved organic substances is the so-called disinfection by-products. These are chlorinated organic compounds that form during disinfection of water with chlorine. These chlorinated compounds are called Trihalomethanes (THM's - chloroform is one of the compounds in this group). Different treatment processes are used to remove different types of contaminants.

Sources of Chemical Contamination

- Spills and releases
  - ➢ From transportation accidents and chemical spills.



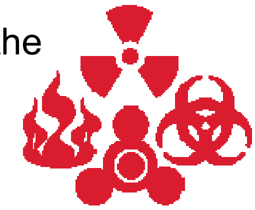
- Agricultural runoff, livestock, urban runoff, land development, landfills, erosion, atmospheric deposition, recreational activities.


- Mine drainage
  - ➢ Disturbance of the surface topography in conjunction with high rates of run-off can cause erosion and re-suspension of

sediments, turbidity, colour and other quality concerns.

- Hazardous waste facilities
  - Affect the quality of the source water through the release of hazardous contaminants into the potable water source.



Problems Associated with Algae

Taste and odour

- presence of inorganic salts or synthetic organics, decaying vegetation and metabolite
- Blue-green algae – geosmin and methylisoborneol (MIB) – earthy, musty odours.
- Threshold odour level <10 ng/L
- Colour
- chlorophyll where slight colouration at <7 µg/L and above this the water has a murky appearance
- Algal toxicity
- Filter clogging
- Slime or biofilm may develop in cement structures with plastic additives
- Corrosion

2.4
When is it necessary to treat water for Domestic Use?

It is normally not possible to tell if water from a particular source has to be treated or not simply by visual inspection of the water.

The reason is that the water may contain substances that are not visible but can make the water unfit for domestic use.

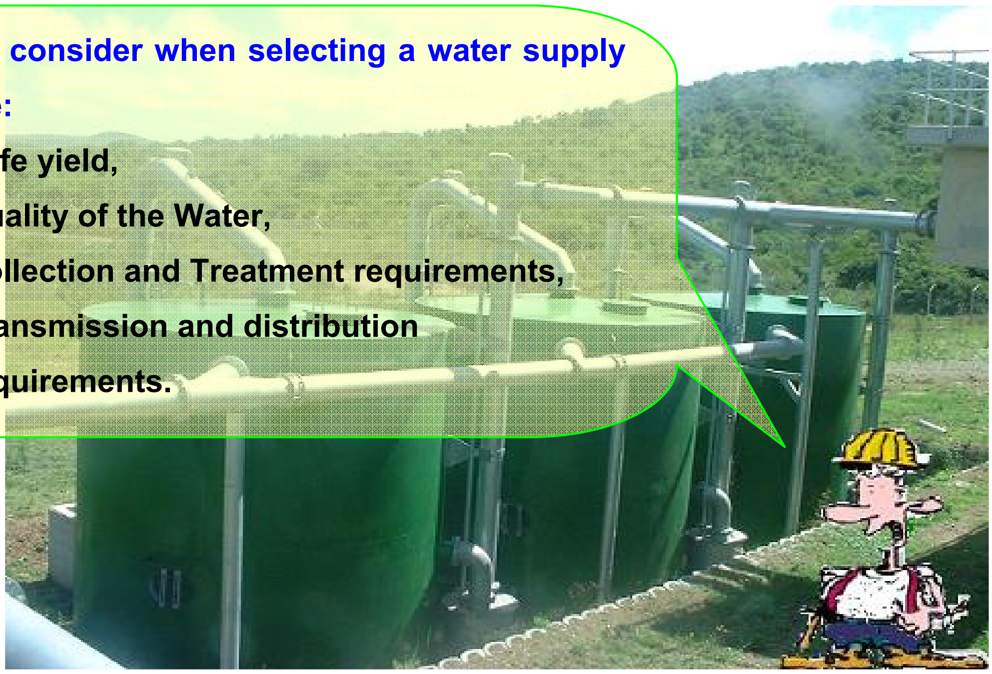
It is therefore essential to have a screening analysis done of the water that is to be used as a source for domestic use.

An assessment of the quality of water must then be done in order to determine whether the water is fit for domestic use as it is, or whether certain contaminants have to be removed and what treatment processes are available to remove these substances (Assessment Guide).

2.4(a) Water Source Selection (Ground water and Surface water)

Factors to consider when selecting a water supply source are:

- **Safe yield,**
- **Quality of the Water,**
- **Collection and Treatment requirements,**
- **Transmission and distribution requirements.**



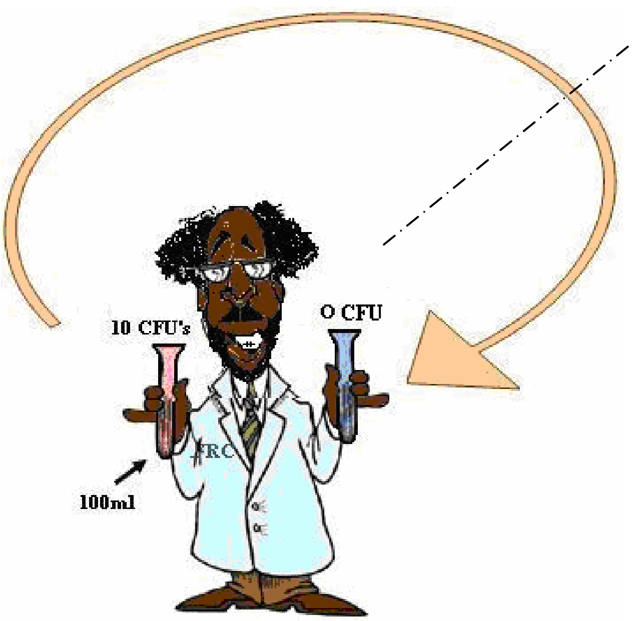
Groundwater, such as boreholes, has less microbial contamination than surface water from rivers, lakes and dams, because soil tends to filter microbes out…

…but groundwater can still be contaminated by pit latrines and leaking septic tanks.

Therefore 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.

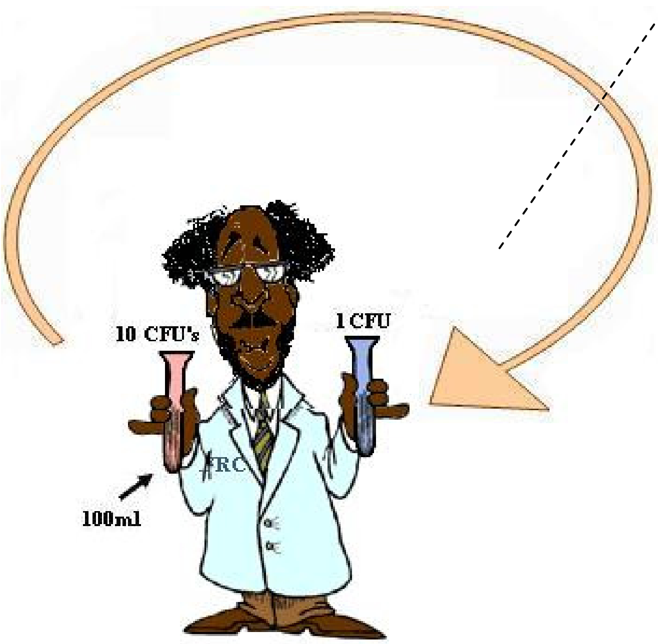
2.4(b) The need for Source Water Protection

Example of Compliance with SANS-241



- Raw water with an average of 10 faecal coliforms/100 mL
- 99% removal efficiency - an average of 0.05 faecal coliform/100 mL
- An average of one faecal coliform detected in 5% of samples.

Example of Non Compliance with SANS-241



- Raw water with 100 faecal coliforms/100 mL
- 99% removal → an average of 1 faecal coliform/100 mL for all samples

2.5

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

Other Strategies for Protection Water Sources

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

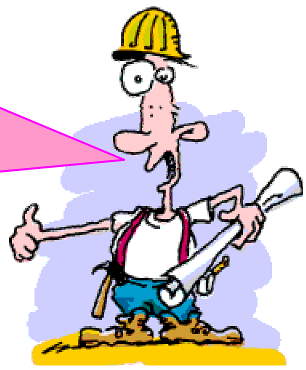
2.6

Aspects to be considered when determining whether a Water Source has be treated to make it fit for Domestic Use

Samples from the water source have to be analysed for the constituents of concern in water for domestic use.

- An assessment of the water then has to be made as is described in the Assessment Guide (DWAF *et al.*, 1998).
- All those constituents of concern that exceed the recommended values for domestic use (see Assessment Guide for South African (specifications) must be considered for removal.

Decisions about treatment processes and the design of the processes are based on the substances that exceed recommended values.



Substances that affect the health of consumers are the most important in the evaluation of treatment requirements.

2.7

Processes available to treat water from even highly Polluted Sources to make it fit for Domestic Use

Water treatment technology is highly developed and there are processes available to produce drinking water from just about any source of water, no matter how polluted it is….

…examples include water reclamation processes that produce drinking water from sewage and desalination processes that produce drinking water from seawater…

- …the cost of treating water normally increases in accordance with the number of processes required in a treatment plant to produce water of the required quality.
- The cost of water treatment also increases with the complexity of the processes…

- …the size (capacity) of a treatment plant also plays a major role in determining the treatment costs. The larger the capacity of a plant, the lower the unit treatment costs (cost per unit volume) of water, and conversely the smaller a plant the higher the unit treatment cost.
- The more sophisticated a plant is, the treatments cost would normally be higher.

Section III

Treatment of Drinking Water

3.1

General methods that can be used for Water Treatment

There are many different water treatment methods (generally referred to as treatment processes) that can be used, each on its own, or in combination with others, to treat water for domestic use.

Normally a series of processes is used rather than only one process….

- …clarification processes - used to remove suspended material from water. These processes include coagulation, flocculation, sedimentation, flotation, and filtration
- Disinfection processes - including chemical treatment with chlorine and chlorine compounds, and advanced processes such as the use of ozone as well as physical processes such as ultra violet irradiation
- Advanced/specialised processes - for the removal of dissolved inorganic substances
- Advanced processes - used for the removal of dissolved organic substances.

These processes can be selectively combined in process trains to produce water of the required quality.

After it has been decided that water from a particular source is to be treated, what are the main aspects that must be taken into account when considering different treatment options?

- The quality of the water source (raw water quality) and its variability;
- The quality of the treated water to be produced;
- The volume of water to be treated (capacity of the plant);
- The cost limitations (the water cost/price that is considered to be acceptable to the consumers);
- The level of sophistication that is acceptable taking into account plant locality and level of expertise available to control and operate the plan;
- The support services available to assist with plant optimisation, trouble shooting and maintenance and repair problems.

!! IMPORTANT !!

- The most important consideration in the design of treatment processes is that the water must be safe for human consumption after treatment.
- This means that the water has to be disinfected to ensure that there are no harmful microorganisms in the water.
- Furthermore, it must be ensured that there are no chemical substances in the water at concentrations at which they may be harmful to human health.

3.2

How does Process Selection take place for a Plant to treat water from a Particular Source?

The process of designing a treatment plant goes through a number of steps before the design is finalized.

Step 1: Evaluation of the raw water quality – This includes evaluation of all the constituents and groups of constituents that must be removed from the water and the alternative processes and combinations that can be used for their removal.

Step 2: Conceptual process design in which alternative processes and combinations are evaluated to determine the performance of each combination in terms of efficiencies and product water quality as well as possible problems.

At this point the laboratory and bench scale testing is done to determine the best coagulants and other chemicals to be used and their dosages. If problems are evident at this point, further tests and pilot scale studies may be necessary.

Step 3: Estimation of the treatment costs for the different options to be made - the projected treatment costs of the different options and process efficiencies are evaluated in selecting combinations for inclusion in the final design.

Step 4: Detailed drawings of the different process units, sizes, chemicals, pumps, other equipment together with instructions for the operation and maintenance of the equipment.

PART 2

ON-SITE TRAINING OF THE WATER TREATMENT OPERATORS

What is conventional water treatment?

The term conventional water treatment refers to the treatment of water from a surface water source by a series of processes aimed at removing suspended and colloidal material from the water, disinfecting the water, and stabilising the water chemically.

Treatment of drinking water involves the removal of suspended and colloidal matter to an acceptable level. This is by means of processes such as coagulation-flocculation, sedimentation and sand filtration (see Assessment Guide, for acceptable levels of turbidity)...

…disinfection to produce water that is safe to drink…

….chemical stabilization of the water to prevent corrosion of pipelines or the formation of chemical scale in distribution systems and fixtures.

Section IV

What does Conventional Water Treatment Involve

4.1

Process Control

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…

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

…At which stages of the treatment will samples be collected and measurements made?

….How often will samples be collected and analysed?

Process control requires that a further two components be specified

Acceptable ranges of values for the measurements made must be defined…

…and procedures for adjusting the treatment processes to meet required performance standards must be established.

Every treatment plant should be equipped to measure at least turbidity, pH, free chlorine, filter run time, flow rate and/or hours of operation.

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 in and out, and hours of pumping for all storage tanks and reservoirs in the distribution system should also be recorded…

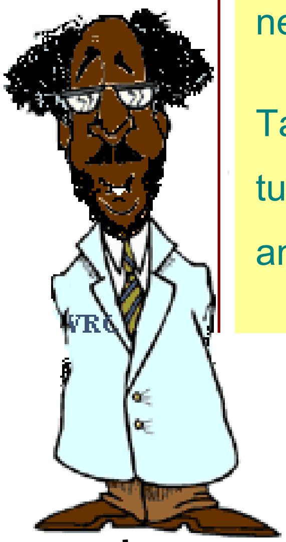
…and all process control decisions and adjustments (including time and date) should also be recorded.

All measurements must be recorded on log-sheets along with the time and date they were measured and any comments.

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.

Table 4 list the points in the treatment plant where turbidity should be measured, the frequency of sampling and the recommended control limits.



pH is a critical control parameter because it impacts the efficiency of the three key processes: coagulation, disinfection and stabilization.

Table 5 list the points in the treatment plant where pH should be measured, the frequency of sampling, the person in charge and the recommended control limits.

Table 4: 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 whenever 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 5: pH monitoring					
Sampling point	**Frequency**	**Person**	**Target Ranges (NTU)**		
			Ideal	**Good**	**Acceptable**
Raw water	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.	Operator/ supervisor.	-	-	-
Flocculated water			Determined from jar test.	6.0-7.4 (alum*) 5.0-8.0 (ferric) For other coagulants, check with manufacturer/supplier.	
Settled water					
Filtered water					
Finished water	At least once per shift, preferably once every two hours.		Based on disinfection efficiency and corrosion control requirements for specific system .	6.5-8.0 **	
Point of use (distribution system) ***	Monthly. Daily if problem detected or reported by public.	Supervisor and/or monitoring agency.	6.0-9.0	5.0-9.5	4.0-10.0

* This pH range is required both to ensure good coagulation and to prevent high aluminium residuals in the finished water (DWAF *et al*., 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 SANS-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.

Free chlorine residual is the primary indicator of microbial safety used in process control.

One of the most important steps in water treatment is ensuring there is adequate chlorine residual in the finished water.

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

Sampling points and required ranges of chlorine residual are summarised in Table 6.

Table 6: Chlorine residual monitoring

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		
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.

4.2

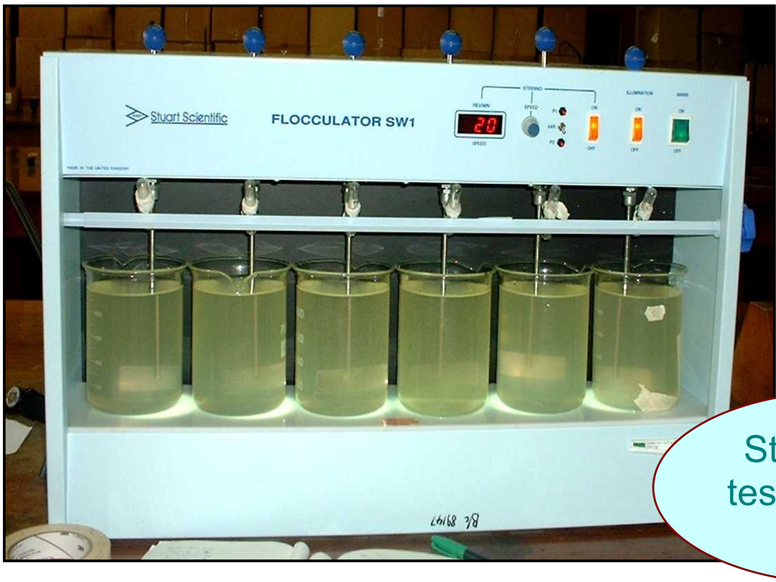
Equipment required for Process Control

In order to implement process control measures, operators need to have the right equipment and instrument. The minimum requirements for equipment and instrumentation are as follows:

Turbidity meter

pH meter

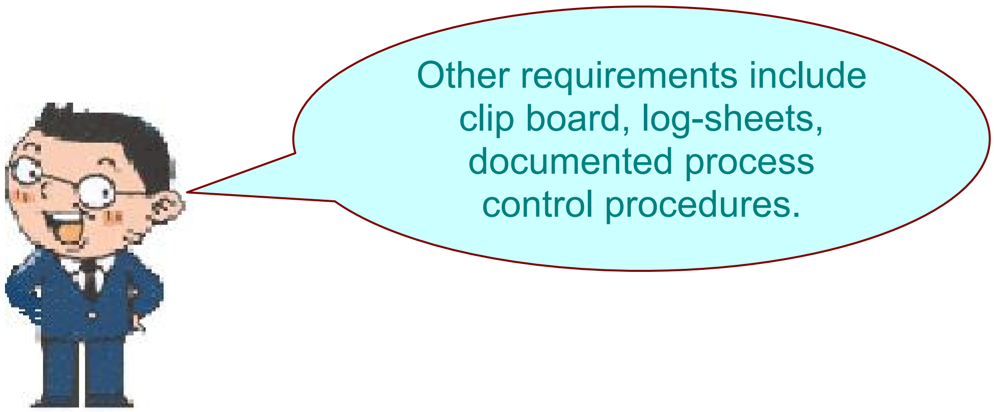
Conductivity meter, Chlorine meter or chlorine comparator



Standard jar test apparatus

Kitchen scale and a stop watch to measure dry chemical dose rates if dry feeders are used.

Measuring cylinders or dosing tanks, with calibrated sight glasses, to measure dosing rates for dosing pumps.



SUPPLIERS OF THE EQUIPMENT REQUIRED FOR PROCESS CONTROL

- **Pelican (Pty) Ltd**

1052 Schooner Street
Lazer Park
Honeydew
Johannesburg
Tel 011 794 5902/794

- **Laboratory & Scientific Equipment Company (LASEC) Pty Ltd**

7 Keilboot Road
Laser Park
Honeydew
2170
Tel 011 531 7504

- **Hanna Instruments (Pty) Ltd**

48 Sunnyside Lane
2 Sunnyside Centre
Pinetown
Tel 031 701 2711

Section V

Practical Activities in Conventional Water Treatment Plants

5.1

Flow Measurement and Dose Calculations

- It is important to know what the flow rate is in order to have the correct dose.
- 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.

There are two ways to measure flow.

Firstly the V-Notch Weir

- The flow can be determined from the water level at the V-notch weir. This measurement may be 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 no flow measurement at all.

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

For a 90° V-notch weir, the total flow rate, *Q*, is related to the height of the crest over the weir, *H* (m) is the height of water above the weir crest.

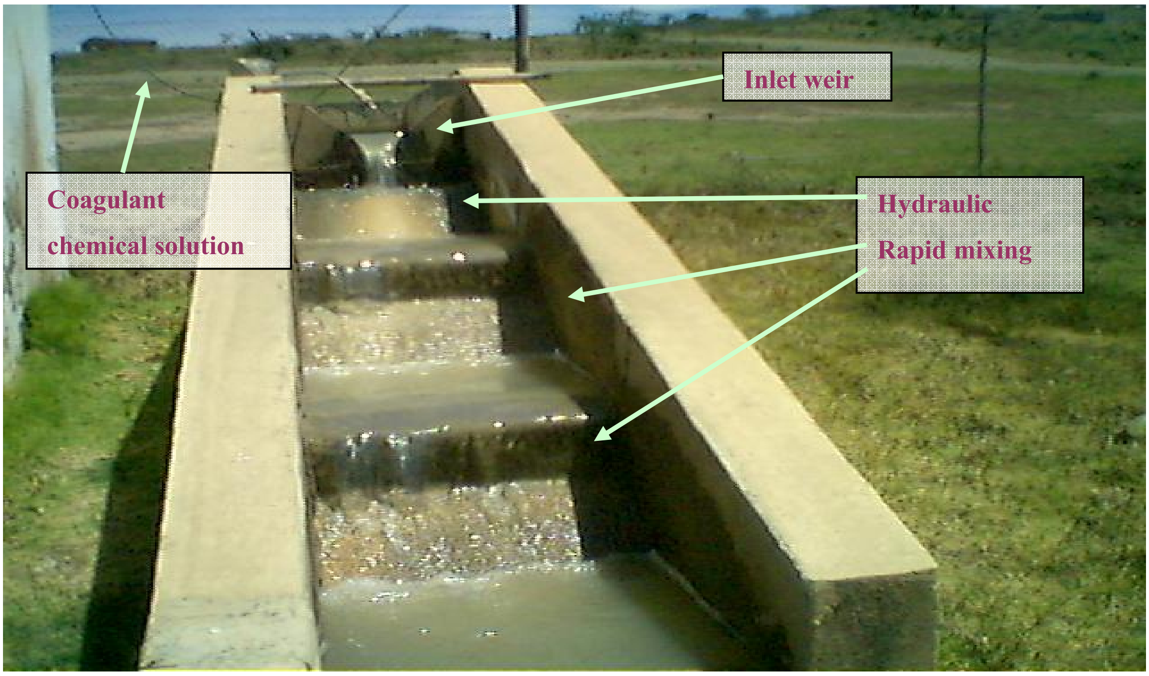


Table 7 below shows H values with corresponding flows as calculated using the hydraulic equation given above.

Table 7: 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 (m^3/s) =>$1.40H^{2.5}$ =	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)=>$121H^{2.5}$ =	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

Secondly, flow can be measured by Flow meter. It is possible to get the raw water flow from the flow meter. This will be more accurate than the V-notch weir.

Changing the Flowrate

- Changing the flow rate causes some problems for the plant
- The coagulant and chlorine rates must also be changed to keep the right dose
- The filtrate turbidity may get worse if the dose is not changed
- The plant works better if the flow does not have to change much
- If it is necessary to change the flow, it is better to change it by small amounts rather than by big amounts

5.2
Coagulation and Flocculation

The following Table shows some of the chemicals used during the coagulation process.

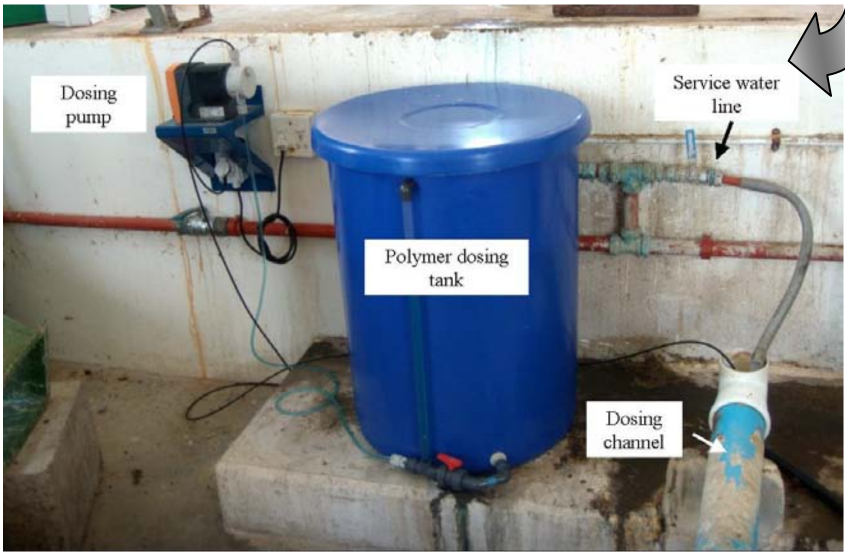
Table 8: Common coagulation chemicals		
Common Name	**Chemical Formula**	**Comments**
Aluminium sulphate	$Al_2(SO_4)_3 \bullet 14(H_2O)$	Most common coagulant; often used with cationic polymers
Ferric chloride	$FeCl_3$	May be more effective than alum in some applications
Ferric sulphate	$Fe_2(SO_4)_3$	Often used with lime softening
Ferrous sulphate	$Fe_2(SO_4)_3 \bullet 7H_2O$	Less pH dependant than alum
Aluminium polymers	-	Include polyaluminium chloride and polyaluminium sulphates
Cationic polymers	-	Synthetic polyelectrolytes; large molecules
Sodium aluminate	$Na_2Al_2O_4$	Used with alum to improve coagulation
Sodium silicate	$Na_2O \bullet (SiO_2)_x$	Can range from 0.5 to 4.0; ingredient of activated silica coagulant aids

5.2.1
Determination of the Optimum Coagulant Dose

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

- 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
- In the jar test we add different numbers of ml of coagulant solution to 1 L of raw water. The aim is to find the dose which gives the best settled water turbidity.

- In the plant, the dosing pump adds coagulant solution at the dosing rate (Litres/day) to the raw water flow (Mega litres/day or cubic meters/second).
- The dosing rate is controlled by the dosing pump setting.



The jar test consists of: rapid mixing step, a slow mixing step, a settling step

- 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.
- The slow mixing step corresponds to the channels between the jump and the settlers. This is where the floc grows.
- The settling step corresponds to the settling tanks.

5.2.2

Jar Test Procedure

Equipment required are Jar stirrer, two 5 L containers for collecting raw water, 1 L plastic measuring cylinder, 1 L flask distilled water, five 1 L beakers, all the same size and shape, syringes, watch (preferably a digital stop watch),two small clean beakers and a turbidity meter.

- The jars must all be labelled, for example: 1, 2, 3, etc. … and before you start the experiment, you must write down the number of ml's of coagulant to be added to each jar.

Jar test apparatus in use

- A 100 time 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.
- Collect some coagulant dosing solution from the coagulant dosing tank in a small clean beaker.
- Fill a clean 100 ml volumetric flask with distilled water to halfway.
- Add 1 mL 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.
- Fill the flask up to the 100 ml mark with distilled water, put the lid on and mix by shaking.

- Collect raw water in a 5 L container just before performing the test, i.e., water must not stand for a long time before it is used.
- Measure the turbidity.
- 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 Coagulant Dose

- Put some stock solution in another clean beaker (not the same you used for the plant dosing solution)
- Measure different amounts of stock solution using the syringes. Following is the example of different volumes:

1 mL, 1.5 mL, 2 mL, 2.5 mL, 3 mL and 3.5 mL.

The Jar Test

- Increase the stirring speed to the maximum which does not cause the water to spill.
- Add the coagulant to all beakers at exactly the same time. The Smallest dose goes to jar 1 and the largest to jar 6.
- 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.
- After 20 minutes, stop the stirrers and pull them out of the jars. Let the floc settle for 20 minutes.
- After 20 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.
- Now measure the turbidity. Record the turbidity.
- Repeat for all 6 jars. You must try to do this step quickly so that the settling times for the different jars are not very different.
- Compare the results for the different jars. Which is the best turbidity? Usually a turbidity of 5 NTU or less is good.

Always keep record of the data

Notes --

5.3

Setting the Correct Dose at the Plant

In order to set the correct dosing rate for the pump, you need to know:

- The correct dose from the jar test.
- The raw flow rate.

The correct plant dose rate is:

Dose rate in L/day = mL stock from jar test X raw flow rate (ML/day)

If the best dose from the jar test is 10 mL (millilitres) and the flow rate is 3.5 ML/d (Megalitres per day), then the dosing rate is:

10 X 3.5 = 35 L/day

Notes --

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 turbidity every half hour and the final water turbidity every hour until you are happy that they have improved.

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. It is very important to do the jar test after a heavy rain.

Chlorine Dosing

Chlorine Demand Test

Equipment used includes; 1% chlorine stock solution, 6 containers (same and not metal), 5 ml syringe, DPD1 tablets, Chlorine meter and Stop watch.

Method

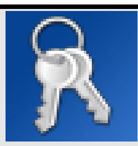
- Prepare a chlorine stock solution: Add 2 ml Jik to 1 L distilled water
- Measure the concentration by diluting 1 ml of the stock solution by 100 ml of water
- Fetch water from the filter, 1 L from each filter and mix
- Take 4-6 non-metallic containers of known volumes
- Fill the containers with 100 ml of the filtered water
- Add to each container a progressively greater dose of the stock solution with a syringe as follows:
- 1 ml, 1.5 ml, 2 ml, 2.5 ml, 3 ml, 3.5 ml
- Wait for the required contact time (20-30 minutes)
- Measure the free chlorine residual in each container
- Choose the sample which shows a free residual chlorine level between 1.5 and 2 mg/L
- Calculate the chlorine flow rate required for the raw water flow rate

Notes

Calculating the exact flow rate of chlorine to be used in the plant

Chlorine flow rate = concentration of the diluted stock x volume stock (ml) x 100/24 x raw water flow rate

Notes --



CALCULATION OF THE RAW WATER FLOW RATES FROM THE HEIGHT OVER THE V-NOTCH WEIR – see Appendix 1

SETTING THE COAGULANT DOSING PUMP FROM THE JAR TEST RESULTS – see Appendix 2

ESTIMATING CONTACT TIME FROM THE RAW WATER FLOW RATE VALUES – see Appendix 3

Important Sources of Free Information

Several other documents and guidelines published by the Department of Water Affairs and Forestry (DWAF) and the South African Water Research Commission (WRC) can be used during the on-site training of water operators. 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 South African National Standards 241(SANAS 241, 2005/2006) can be purchased from South African Bureau Standard (SABS) in Pretoria.

In addition, anyone in South Africa can request free copies of most WRC publications. These include research reports on many of the technologies currently used in rural treatment plants including many not cited in this illustrative training manual kit. 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 sending an e-mail to orders@wrc.org.za.

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Appendix 1
Table for the Calculation of the Raw Water Flow Rates from the Height over the V-Notch Weir

Plant flow from V-notch											
Height	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15	cm
Flow	0.43	0.49	0.54	0.60	0.67	0.74	0.81	0.89	0.97	1.05	ML/d
Height	15.5	16	16.5	17	17.5	18	18.5	19	19.5	20	cm
Flow	1.14	1.24	1.34	1.44	1.55	1.66	1.78	1.90	2.03	2.16	ML/d
Height	20.5	21	21.5	22	22.5	23	23.5	24	24.5	25	cm
Flow	2.30	2.45	2.59	2.75	2.91	3.07	3.24	3.41	3.60	3.78	ML/d
Height	25.5	26	26.5	27	27.5	28	28.5	29	29.5	30	cm
Flow	3.97	4.17	4.37	4.58	4.80	5.02	5.25	5.48	5.72	5.96	ML/d
Height	30.5	31	31.5	32	32.5	33	33.5	34	34.5	35	cm
Flow	6.22	6.47	6.74	7.01	7.29	7.57	7.86	8.16	8.46	8.77	ML/d
Height	35.5	36	36.5	37	37.5	38	38.5	39	39.5	40	cm
Flow	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

Appendix 2

Setting the Coagulant Dosing Pump from the Jar Test Results

Dose from jar test (mL)	Setting the dosing pump (very low flow) Raw Water Flow rate (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)

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)

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

Dose from jar test (mL)	Setting the dosing pump (high flow) 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)

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 3

Estimating Contact Time from the Raw Water Flow Rate Contact time

Flow ML/d	0.43	0.49	0.54	0.60	0.67	0.74	0.81	0.89	0.97	1.05
Time minutes	333.12	296.55	265.36	238.57	215.43	195.31	177.72	162.28	148.65	136.57
Flow ML/d	1.14	1.24	1.34	1.44	1.55	1.66	1.78	1.90	2.03	2.16
Time minutes	125.82	116.22	107.61	99.87	92.89	86.58	80.84	75.63	70.87	66.53
Flow ML/d	2.30	2.45	2.59	2.75	2.91	3.07	3.24	3.41	3.60	3.78
Time minutes	62.54	58.89	55.52	52.42	49.56	46.91	44.45	42.17	40.06	38.08
Flow ML/d	3.97	4.17	4.37	4.58	4.80	5.02	5.25	5.48	5.72	5.96
Time minutes	36.24	34.53	32.92	31.42	30.01	28.69	27.45	26.28	25.18	24.14
Flow ML/d	6.22	6.47	6.74	7.01	7.29	7.57	7.86	8.16	8.46	8.77
Time minutes	23.16	22.24	21.37	20.54	19.76	19.02	18.32	17.66	17.02	16.42
Flow ML/d	9.09	9.41	9.74	10.08	10.42	10.77	11.13	11.49	11.87	12.24
Time minutes	15.85	15.30	14.79	14.29	13.82	13.37	12.94	12.53	12.14	11.76