GUIDELINES FOR THE UPGRADING OF EXISTING SMALL WATER TREATMENT PLANTS

CD SWARTZ

WRC Report No 738/1/00

Water Research Commission

GUIDELINES FOR THE UPGRADING OF EXISTING SMALL WATER TREATMENT PLANTS

REPORT TO THE WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

A project to carry out an investigation into upgrading needs of existing small water treatment plants and to draw up guidelines for upgrading of these plants was undertaken in collaboration with the CSIR. Small water treatment plants are, for purposes of this guidelines document, defined as the small drinking water treatment plants that are generally not well-serviced and that consist mainly, but not exclusively, of the water treatment plants serving rural communities and small municipalities, as well as establishments such as rural hospitals and forestry stations. The capacities of these plants are normally less than 2,5 Mℓ/d.

The project consisted of creating a database of water treatment plants to determine the status quo of existing small water treatment systems in the country. From this database and from treatment plant information from the CSIR, a total of 20 small water treatment plants were selected to identify and investigate typical upgrading needs and methods. The plants were visited and discussions held with CSIR personnel and consulting engineers to establish the conditions of the plants, and identify the weak links and problems that are experienced. A set of criteria for evaluating existing plant conditions and determining upgrading needs were drawn up for investigating treatment plants. Based on the results of the investigation, guidelines were drawn up on how to plan, design and implement upgrading measures for small treatment plants.

The aim of the project was to draw up guidelines for upgrading existing small water treatment plants, thereby creating a better standard of living by optimally using existing facilities. This can be done by physical changes to the treatment plants or by better operation of the plant through training and education of operators.

The specific objectives of the project were to:

a. Determine the status quo of existing small water treatment systems
b. Determine upgrading needs
c. Investigate available technologies and measures with a view to appropriateness for upgrading
d. Develop criteria to evaluate the needs and various upgrading options
e. Determine needs for training and education for upgrading
f. Draw up the guidelines for upgrading of existing small water treatment systems

The guidelines document is intended for use at a basic level by plant supervisors and plant owners, consultants and controlling authorities for upgrading small water treatment systems, and specifically points out the advantages, disadvantages and possible pitfalls of the various treatment options. Key guidelines for selection and operation of the treatment options are given.

ACKNOWLEDGEMENTS

The research in this report emanated from a project funded by the Water Research Commission and entitled:
" Guidelines for the Upgrading of Existing Small Water Treatment Plants"

The Steering Committee responsible for this project consisted of the following persons:

Dr I Msibi	Water Research Commission (Chairman)
Mr M E Mosia	Water Research Commission (Secretary)
Dr G Offringa	Water Research Commission
Mr P Ramlall	Umgeni Water
Mr O Langenegger	Otto Langenegger and Partners cc
Mr C E Fennemore	CSIR Environmentek
Prof C F Schutte	University of Pretoria
Mr P Grobler	Phalaborwa Water
Ms M Hinsch	Dept. of Water Affairs and Forestry

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

The project was only possible with the co-operation of a number of individuals and institutions. The author therefore wish to record his sincere thanks to the following:

- Messrs John Lizamore and Jan Prinsloo of the CSIR Environmentek in Pretoria
- Messrs Chris Fennemore and Kenny Charles of the CSIR Environmentek in Durban
- Mr Zim Mbatani of the CSIR Environmentek in Bisho
- Mr Pierre Smit of the CSIR Environmentek in Bloemfontein
- Department of Water Affairs and Forestry for providing information on registered water treatment plants and database of rural water supply and sanitation systems
- Mr Ronnie Ambachtsheer for assistance in visiting treatment plants
- Michelle Knott and Jackie Roberts for processing data for the database

Personnel at all the treatment plants that were visited are thanked especially for their cooperation and making available of information.

LIST OF TABLES

LIST OF FIGURES

GUIDELINES FOR THE UPGRADING OF EXISTING SMALL WATER TREATMENT PLANTS

TABLE OF CONTENTS

CHAPTER 7
DESIGN CONSIDERATIONS AND GUIDELINES

CHAPTER 8
GUIDELINES FOR OPERATION, MONITORING AND MAINTENANCE OF SMALL WATER TREATMENT PLANTS

CHAPTER 9
EXAMPLES OF UPGRADING PROCEDURE

CHAPTER 1

INTRODUCTION

1.1 NEED FOR GUIDELINES ON UPGRADING OF SMALL WATER TREATMENT PLANTS

In South Africa many small water treatment systems have been installed in rural areas, especially during the last decade, in an attempt to ultimately provide all households in the country with a supply of clean and safe drinking water. However, a large number of these treatment systems do not produce the quantity or quality of drinking water that it was meant to do, for one or more of the following reasons: inappropriate treatment systems installed; lack of knowledge on basic water treatment principles and hence operation of the plants; inadequate maintenance of equipment; financial constraints; lack of community involvement during conception, design and construction of the plant resulting in neglect during operation; and insufficient information on how to upgrade the treatment systems using simple and cost-efficient measures.

These problems with inadequate performance of existing treatment plants are found across the country. The treatment systems involved range from the treatment plants of smaller municipalities through to that of the small rural communities. While a recent study has started to address the water supply to urban areas, which is expected to later include upgrading of large urban treatment plants, no research on upgrading the existing small water treatment plants in South Africa has been undertaken. There was therefore a need to develop guidelines for upgrading existing small water treatment plants of small municipalities and rural communities.

The aim of the project was to draw up such guidelines for upgrading existing small water treatment plants, thereby creating a better standard of living by optimally using existing facilities. This upgrading can be done by physical changes to the treatment plants or by better operation of the plant through training and education of operators.

The specific objectives of the project were to:

a. Determine the status quo of existing small water treatment systems

b. Determine upgrading needs

c. Investigate available technologies and measures with a view to appropriateness for upgrading

d. Develop criteria to evaluate the needs and various upgrading options

e. Determine needs for training and education for upgrading

f. Draw up the guidelines for upgrading of existing small water treatment systems

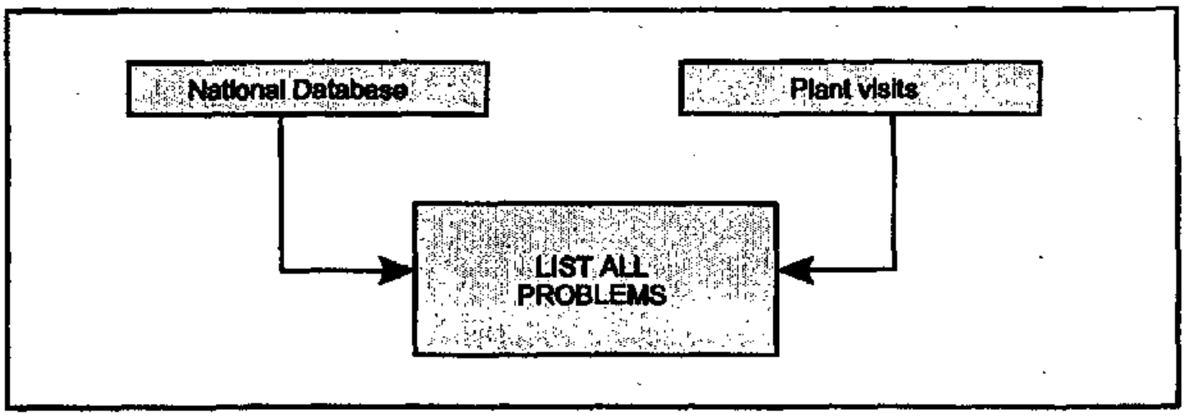
1.2 INTENDED USE OF THE GUIDELINES DOCUMENT

The guidelines document is intended for use at a basic level by plant supervisors and plant owners, consultant and controlling authorities or communities for upgrading existing water treatment systems as a cost-efficient option for improving the standard of living in rural areas, by providing affordable means of improving their supply and quality of drinking water which may lead to improved health, socio-economic satisfaction and a better environment. The guidelines specifically points out the advantages, disadvantages and possible pitfalls of the various treatment options. Key guidelines for selection and operation of the treatment options are given.

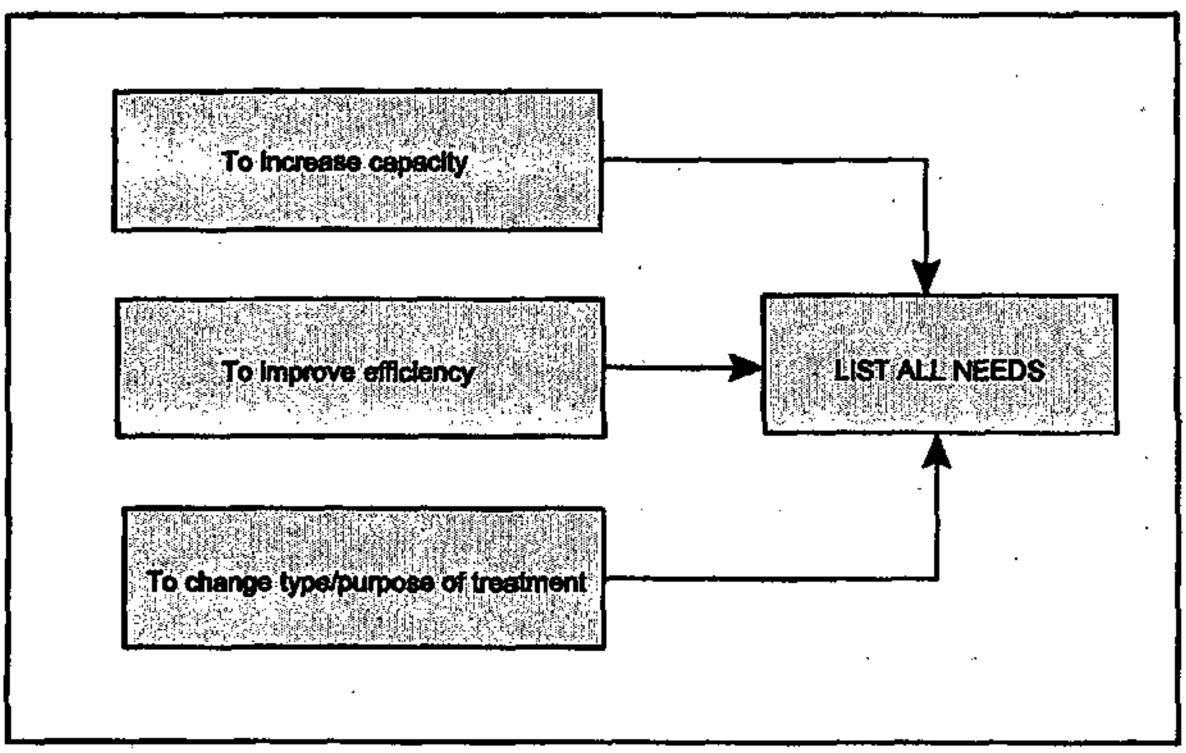
1.3 PROCEDURE FOLLOWED IN DEVELOPING THE GUIDELINES

The procedure that was followed in developing the guidelines for upgrading existing small water treatment plants is shown diagrammatically below.

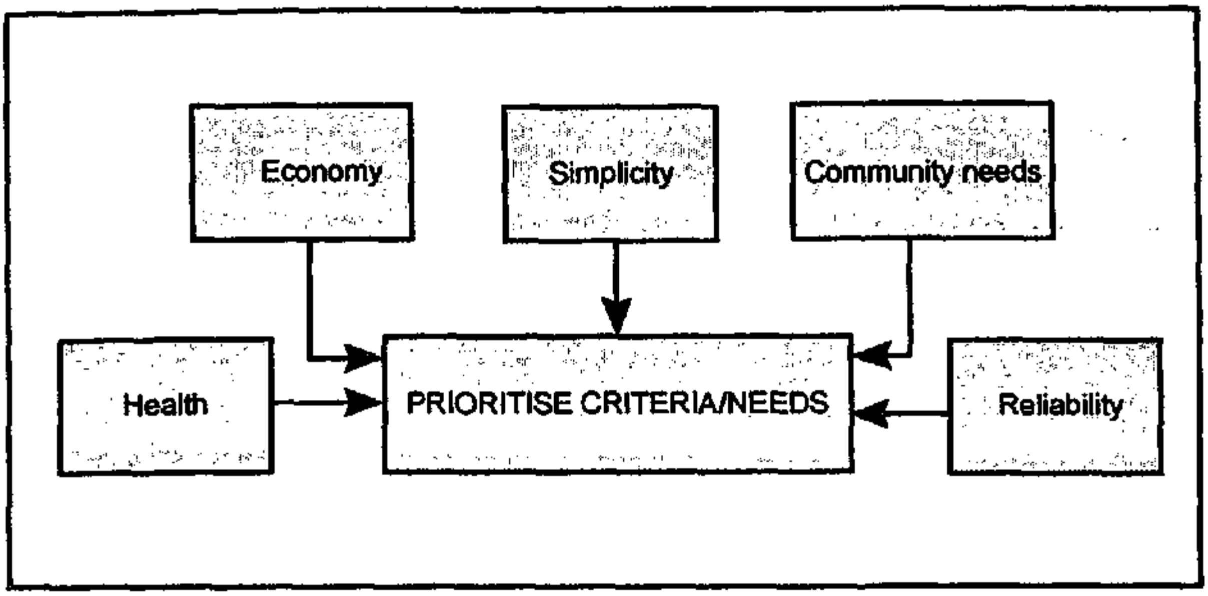
I. IDENTIFY PROBLEMS



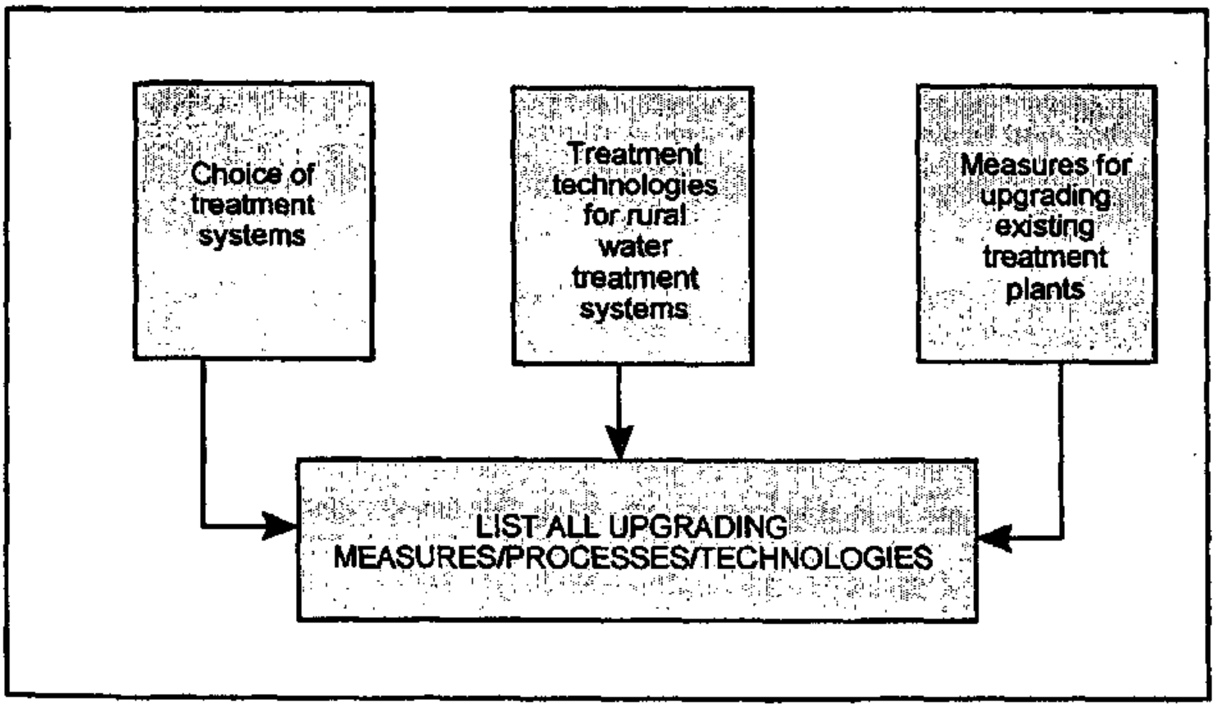
II. DETERMINE UPGRADING NEEDS



III. DETERMINE CRITERIA ON HOW TO EVALUATE THE UPGRADING NEEDS AND MEASURES



IV. INVESTIGATE MEASURES FOR UPGRADING



V. PROVIDE GUIDELINES ON HOW TO

- evaluate
- select
- design
- implement
- operate and maintain
  (after upgrading)

THE ABOVE UPGRADING MEASURES

1.4 STRUCTURE OF THE GUIDELINES DOCUMENT

The structure of the document is based on the procedure that a user will follow when planning upgrading of a small water treatment plant, or evaluating whether (and when) a plant needs to be upgraded. This procedure is as follows (also see diagram on page 1.7) :

- Investigate the conditions of the existing facilities
  See Criteria for ***- Evaluating Existing Condition***
  (CHAPTER 4)

- Determine the upgrading needs of the plant

- Consider institutional aspects relating to the plant(s)
  (CHAPTER 5)

- Evaluate the various options for upgrading
  See ***- List of Upgrading Measures***
  - Criteria to Evaluate Upgrading Options
  (CHAPTER 6)

- Design and implement upgrading measures
  (CHAPTER 7)

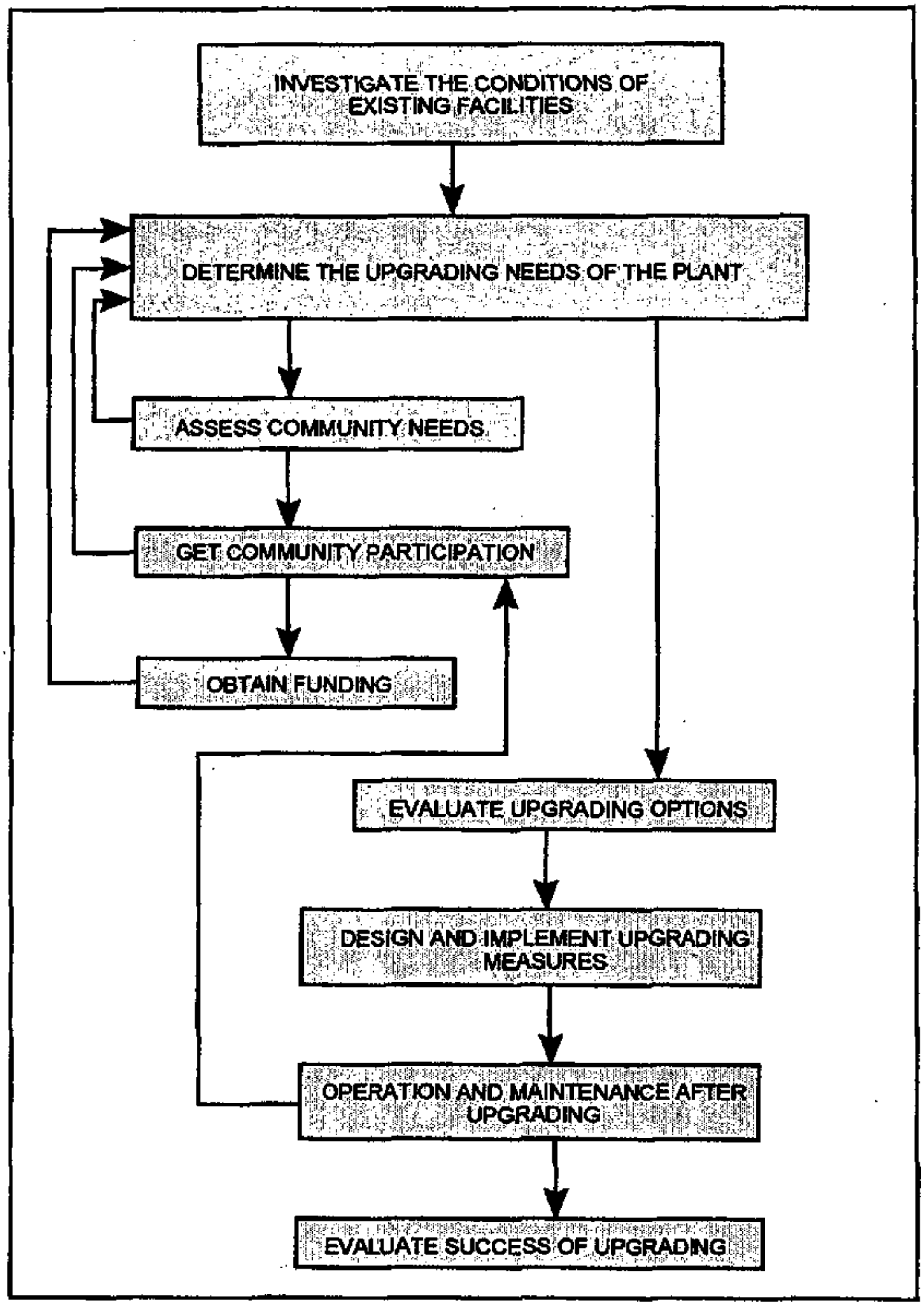
- Operation and maintenance of the plant after upgrading
  See - ***Guidelines for Operating, Monitoring and Maintaining Rural Water Treatment Plants***
  (CHAPTER 8)

- Evaluate success of upgrading
  Use same Criteria for Evaluating Existing Condition as above
  (CHAPTER 4)

The upgrading procedure and necessary feed-back requirements are summarised in the flow diagram on the following page.

Chapter 1 to 3 provides information on the needs and structure of the guidelines document, small water treatment plants in South Africa and the survey of 20 small water treatment plants for purposes of drawing up this document.

PERCEIVED NEED TO UPGRADE A SMALL WATER TREATMENT PLANT



CHAPTER 2

SMALL WATER TREATMENT PLANTS IN SOUTH AFRICA

2.1 DEFINITION

For the purposes of this guidelines document, ***small water treatment plants*** are defined as water treatment systems that are not well-serviced and that normally do not fall within the confines of urban or peri-urban areas. They are therefore treatment plants in rural areas and include water from boreholes and springs that are chlorinated for use as drinking water, small treatment systems for rural communities, treatment plants of the small municipalities in rural areas, and treatment plants for establishments such as rural hospitals and forestry stations. While there are a number of larger plants in rural communities that would also classify as small water treatment plants according to the above, the plants are normally small to medium sized water treatment systems with capacities of less than 2,5 Mℓ/d.

2.2 DATABASE OF SMALL WATER TREATMENT PLANTS

A database was compiled with information on the quality of the raw water, treatment systems employed, operational aspects, if and how the plant is monitored, quality of the treated water, and an identification of needs for improvement, for small water treatment plants in South Africa. Data on the plants was obtained from a number of sources:

- **CSIR reports on monitoring of water treatment plants**
  These consist of rural water treatment plants in areas of the former self-governing states, *i.e.* mainly in Northern Province, Mpumalanga, Kwazulu Natal, Free State and Eastern Cape. These reports contain water quality and process control data for a large number of small water treatment systems that were monitored by the CSIR during the last decade or so.

- **Direct information gathering from local authorities and water boards**
  Information request forms were drawn up to obtain all the necessary data on the treatment plants owned by the various water boards and local authorities in the country.

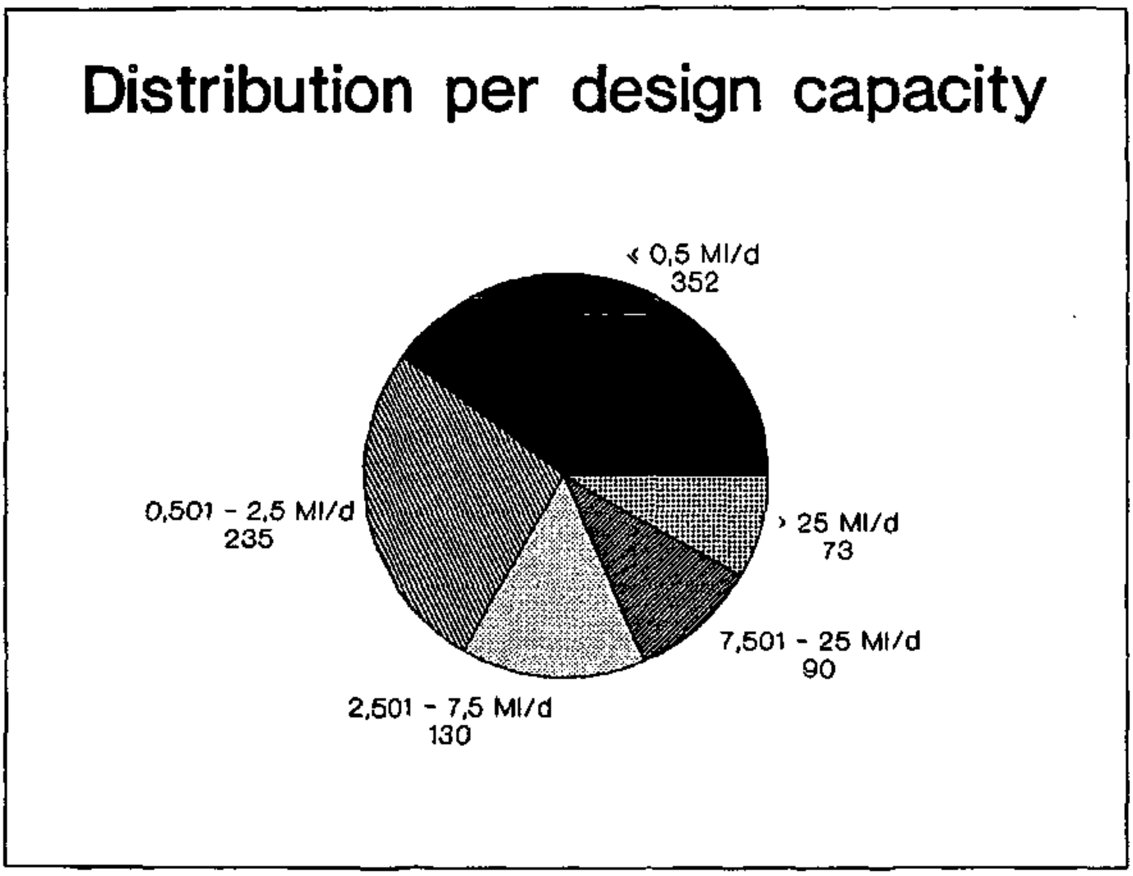
- **Department of Water Affairs and Forestry (DWAF) database on registered water treatment plants**

- **CSIR Durban database of treatment plants in Kwazulu Natal**
  Information was supplied in electronic format (dBase) by the CSIR in Durban on water treatment plants being monitored by them in Kwazulu Natal.

- **Department of Water Affairs and Forestry Community Water Supply and Sanitation (CWSS) database on infrastructure upgrading requirements**
  Databases which are currently available at DWAF consist of the database of registered plants (see above), and a database which is currently being drawn up to determine what the condition of rural water supply and sanitation systems are. This is being done to prioritise the upgrading/ improvement of these systems, and to make an estimate of costs that will be involved. Information of the plants that have been entered on the database to date were supplied by CWSS in electronic format.

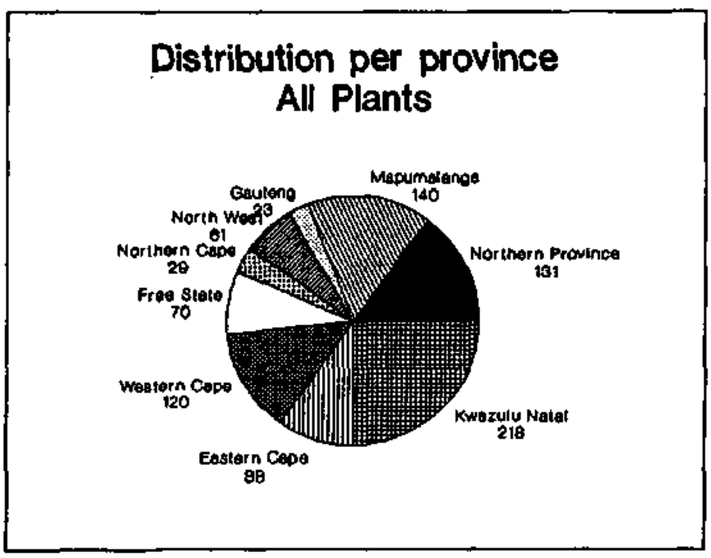
The total number of treatment plants on the database to date (1998) is 880. The distribution of design capacities of the plants and per province is given below.

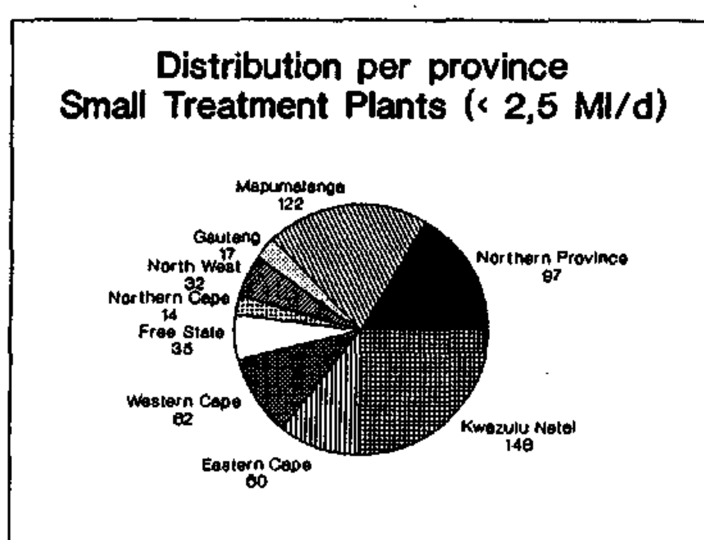
DESIGN CAPACITY RANGE	NUMBER OF TREATMENT PLANTS	% OF TOTAL
≤ 0,5 Mℓ/d	352	40
0,501 - 2,5 Mℓ/d	235	26,7
2,501 - 7,5 Mℓ/d	130	14,8
7,501 - 25 Mℓ/d	90	10,2
>25 Mℓ/d	73	8,3
TOTAL	880	100 %



Total number of plants defined as small water treatment systems (*i.e.* ≤ 2,5 Mℓ/d) = 587, or 66,7 % of tmt plants in the country

PROVINCE	NUMBER OF TMT PLANTS	% OF TOTAL NUMBER TMT PLANTS	NUMBER OF SMALL TMT SYSTEMS (i.e. ≤ 2,5 Mℓ/d)	% OF SMALL TMT SYSTEMS
Northern Province	131	14,9	97	16,5
Mapumalanga	140	15,9	122	20,8
Gautang	23	2,6	17	2,9
North-West	61	6,9	32	5,5
Northern Cape	29	3,3	14	2,4
Free State	70	8,0	35	6,0
Western Cape	120	13,6	62	10,6
Eastern Cape	88	10,0	60	10,2
Kwazulu Natal	218	24,8	148	25,2
TOTAL	880	100	587	100





2.3 SMALL WATER TREATMENT SYSTEM REQUIREMENTS

Many studies have been conducted on the effects of water quality on human and animal health, on its general acceptability, and on the useful life of water conveying structures, including pipes, dams, tanks, water heaters and plumbing fixtures. Following such studies, guidelines have been proposed for quality standards to which domestic water supplies should comply.

A guideline value represents the level (a concentration or a number) of a constituent that ensure an aesthetically pleasing water and does not result in any significant risk to the health of the consumer. The quality of water defined by the guideline values is such that it is suitable for human consumption and for all usual domestic purposes, including personal hygiene. In the case of small community supplies, particularly in the rural areas of developing countries, the number of parameters used in assessing and measuring the quality of water intended for public supply must necessarily be limited. Similarly the guideline values given have often to be considered as long-term goals rather than rigid standards that have to be complied with at all times and in all supply systems.

South African Guidelines

Department of Health Guidelines for Drinking Water Quality

In South Africa three criteria levels or guideline values have been proposed and are currently used. These are as follows:

- *recommended or working limit within which drinking water is considered to be safe for a lifetime's consumption, or maximum level for no risk;*
- *maximum allowable limit or the maximum level for insignificant risk; and*
- *crisis limit or the maximum level for low risk.*

This three tier system allows health authorities to approve water of a poorer quality under certain specific conditions, and makes provision for an upgrading of supplies. The guideline values are given in Appendix B of this document.

SABS Specification for Water for Domestic Use

The water quality guidelines are constantly under review and new guidelines and SABS specifications are currently pending. The new SABS Specifications for Water for Domestic Use which will replace the existing SABS 241 of 1984 will appear in 1999. The SABS Specifications 241 of 1984 are given in Appendix C.

Guidelines : Quality of Domestic Water Supplies

New guidelines jointly by the Department of Water Affairs and Forestry, Department of Health and the Water Research Commission are also currently being drawn up (Quality of Domestic Water Supplies-Volume 1: Assessment Guide). The guidelines provide a good indication to users of what the consequences are of utilising water that has not been properly treated.

For small water treatment plants, the Department of Health Guidelines for Drinking Water Quality are currently used most widely in South Africa.

Surface Water Sources

Surface water sources are virtually always contaminated with microorganisms and suspended solids, but the level of dissolved solids is usually always acceptable for drinking water (except of course for sea water). The degree of contamination by suspended solids and microorganisms generally increases from source (mountain stream) to the river mouth. In addition contamination usually increases with rainfall events. However, large expanses of stationary surface waters often undergo a self-cleansing process both in terms of suspended solids and microorganisms, though the growth of algae in the dam or lake may actually increase the levels of suspended solids. Surface water sources should always be treated before use for domestic water supplies, at least for disinfection.

Underground water abstracted by means of boreholes, wells and springs is usually of a good quality in terms of microorganisms and suspended solids, but may have high levels of dissolved solids. Boreholes are usually the safest sources of water for domestic supplies, providing a reliable yield even in times of drought and with no additional treatment of the water required. Some boreholes, however, may be brackish (salty) and hence unpalatable, contain high levels of fluorides or nitrates which have health implications, or be corrosive or scale forming. Wells and springs, while potentially supplying a good quality water, are more easily contaminated by surface storm water run-off or through the use of contaminated containers. When adequately protected, these sources can be of a very good quality. Pit latrines or other sanitation systems located close to the point of abstraction may, however, result in bacteriological contamination of this water, or, in the longer term, a build up of nitrates.

Emphasis is placed first and foremost on the microbiological and biological quality of drinking water supplies. Ideally, drinking water should not contain any micro organisms known to be pathogenic (*i.e.* which cause sickness and disease). Since the most common sources of pathogenic micro organisms are from faecal material, drinking water should be free from organisms indicative of faecal pollution. Faecal material can contain a variety of bacterial, viral and protozoan pathogens and helminth parasites. Some of these organisms can cause acute diarrhoea, one of the main cases of infant morbidity and mortality in the developing world.

2.3.1 Bacteriological water quality

To ensure the absence of bacterial pathogens such as *Salmonella, Shigella* and *Vibrio cholerae* the water supply should be free of faecal organisms. The primary bacterial indicator recommended for this purpose is the coliform group of organisms. Although as a group they are not exclusively of faecal origin, they are universally present in large numbers in the faeces of man and other warm blooded animals. A subgroup of these coliform organisms, the faecal (thermo-tolerant) coliforms, or in particular *Escherichia coli*, provides definite evidence of faecal pollution.

In South Africa the guidelines values for bacteriological quality for drinking water as follows:

	NO RISK	INSIGNIFICANT RISK	LOW RISK
E. coli/100 mℓ	0	1	10
Total coliforms/100 mℓ	0	5	100
Standard plate count/mℓ	100	1000	10 000

2.3.2 Chemical and physical water quality

There are a number of chemical and physical parameters which should be assessed when determining the quality of a water source. These include turbidity and colour (surface waters), fluorides, nitrates, iron, total salts (ground waters), hardness and stability (all waters).

a. Turbidity (suspended solids)

Turbidity affects the aesthetic quality of the water, but its primary importance is in relation to water disinfection. The amount of chlorine needed for disinfection often increases as the turbidity increases. Certain suspended solids which are organic in nature may also impart an undesirable taste to the water. The suspended solids are usually clay and silt particles arising from rainfall events, floating plant matter like algae or other water plants, or organic matter from pollution.

> **IMPORTANT!**
> Waters containing turbidity should not be disinfected if the turbidity is not first removed

b. Colour

While colour *per se* only affects the aesthetic quality of the water, it does indicate the presence of dissolved organic matter in the water. This organic matter has been shown to form undesirable disinfection by-products when chlorinated, and should therefore be removed or reduced prior to disinfection.

c. **Fluorides**

Excess fluorides in the diet result in mottling of teeth and bone fluorosis. In some parts of Southern Africa groundwaters contain fluoride levels as high as 15 to 20 mg/ℓ. These levels are a result of the natural geological formations in the area. Some industrial effluents contain high levels of fluorides but by law these may not be discharged into the river courses without sufficient dilution.

d. **Nitrates**

While being relatively non-toxic to adults, nitrate is potentially lethal to infants. Fatal methaemoglobinaemia can occur at nitrate concentrations in excess of 10 mg/ℓ as N. Nitrates occur in underground water from natural formations, from excessive use of fertilizers by farmers and from leachates from pit latrines and other waste disposal sites.

e. **Iron**

While iron in high concentrations is potentially toxic, its aesthetic undesirability manifests well below potentially toxic concentrations. Iron concentrations above 300 μg/ℓ (0,3 mg/ℓ) in water gives rise to discolouration, staining and taste problems. Most groundwaters in Southern Africa contain some iron from the natural geological formations. Iron is also used as a flocculant in water purification, or it can arise from corrosion in the distribution system.

f. **Total salts**

Due to osmotic effects of high salt levels, saline water is generally unpalatable. Certain underground waters in the south-eastern, central, northern and north-western parts of Southern Africa are highly saline and thus not fit for human consumption. In addition saline *water may be very corrosive or scaling in nature. Total dissolved salts are* usually measured by means of the electrical conductivity of the water.

g. Hardness and stability

Groundwaters may often contain high levels of hardness, particularly in the dolomitic zones. The degree to which water will either corrode a metal pipe or form a scale deposit within the pipe is a measure of the stability of the water. *Ideally a water should be just scale forming* so that a thin protective coating is deposited on the inside of the pipes, etc.. The stability of the water is determined from measurement of the pH, calcium content, alkalinity, total salts, and the temperature. A computer programme is available from the Water Research Commission which does the determination automatically, or alternatively graphical methods may be used.

The guideline values for the above physical/chemical quality parameters are given in the table below:

DETERMINANT	UNIT	NO RISK	INSIGNIFICANT RISK	LOW RISK
Turbidity	NTU	1	5	10
Fluoride	mg F/ℓ	1	1,5	3
Nitrate	mg N/ℓ	6	10	20
Iron	mg Fe/ℓ	0,1	1,0	2,0
Hardness	mg $CaCO_3$/ℓ	20-300	650	1300
Electrical Cond.	mS/m @ 25 °	70	300	400

In addition to the above quality parameters, there may be certain organic contaminants which would be of concern. These include the following:

- pesticides, normally chlorinated hydrocarbons, resulting from farming practices and subsequent run-off into the water courses.
- oil and petrol, from leakage or dumping practices which may enter the water sources by seepage or run-off
- various toxic substances, from use of improperly cleaned ex industrial containers.

These contaminants can usually be detected by the taste or odour they impart to the water. Should such contamination be suspected, the water source should not be used until the nature and source of the contaminant has been determined and a decision made on its safety or otherwise. In some cases treatment to remove the contaminant may be required. However it should be appreciated that the contribution of drinking water as a source of organic matter consumed by humans is very low. Food and air intakes normally far surpass those of drinking water, except in the case of chloroform in chlorinated water, or by accidental consumption as in examples given above.

2.4 ESSENTIAL ELEMENTS FOR SUSTAINABLE SMALL WATER TREATMENT SYSTEMS

In striving towards the provision of sustainable small water systems, the following are essential elements that must be borne in mind when planning, designing, managing or upgrading these systems:

2.4.1 Low construction costs

Construction and operation costs should be compatible with the resources and preferences of the users, and limited or no use should be made of imported material.

It is important to note that the community does not always choose the lowest-cost option, but rather an affordable option which they feel will provide them with a service they are satisfied with and are capable of maintaining.

Self-help projects are advocated as ways of extending limited funds.

2.4.2 Low operating costs

Processes that have high chemical or energy costs may be poorly suited for small systems. High operating costs leave meagre financial resources for other needs, such as operator pay or loan repayments, or result in high water tariffs.

In general, technologies offering higher service levels place correspondingly higher resource demands on the benefiting community. This refers to both the initial capital outlay as well as ongoing operation and maintenance costs. These latter costs include both technical skills and materials (fuel, chemicals, spares,etc.). *This is an important consideration in the South* African context where sponsorships or subsidies may be obtained for the initial capital investment, but not for the ongoing operational and maintenance requirements.

2.4.3 Simple operation

The treatment system should, if possible, be adaptable to allow part-time operation. Small treatment systems frequently can afford only part-time operators. Therefore, water treatment processes that require constant monitoring and operator attention are not well suited to small systems.

It is recommended that the plant manager also acquire copies of relevant guideline documents from the Water Research Commission that can assist in operation and management of the plants (see Appendix E).

IMPORTANT !

Operators should not only look at suppliers (chemicals; equipment) or consultants to help them with their problems. They must use guideline documents as well. They should also not only use one supplier, but obtain services of other suppliers as well. It is also important that only experienced and reputable suppliers, equip-ment manufacturers and consultants are used. Water Boards are also available to give advice where needed.

2.4.4 Low maintenance

Service from manufacturers and chemical suppliers should be readily available.

Good access to the plant and to all process units should be provided.

2.4.5 Reliability of service

Provision should be made to prevent, or deal with, possible deterioration of the quality of raw water or breakdown of the treatment system.

To ensure that poor quality water does not leave the plant when dosing pumps are inoperative during power failures, an automatic valve should be provided on the outlet of the plant, which will close automatically during a power cut.

2.4.6 Performance

There should be regular audits of small water systems from government side, or from contractors (consultants) appointed by the authorities.

Appropriate systems should be included to monitor the performance of the treatment system. For instance, pH monitoring facilities with alarm indicators are important to ensure that the required process performance can be maintained under varying conditions (see also Chapter 8).

2.4.7 No serious residuals disposal problems

Disposal options for plant residuals should be readily available.

2.4.8 Provision for future upgrading

Provision for future upgrading requires the generation of finances to create a reserve fund within the system. This is important because outside loans or grants are unlikely to become available at the right time in the future to effect the needed or desired changes. Understanding of the importance of such a reserve fund is usually difficult for a community who often require cash just to secure the basic needs.

2.4.9 Well-trained operators

The plant should have a manager and operators that have a thorough understanding of all functions of a treatment system in order to maintain optimum water quality and to control cost.

Apart from more formal training courses on the principles and basics of water purification, it is even more important that operators should also be given on-the-job training at the plant where they will be employed, for a sufficient period to ensure that they are familiar and confident with all the aspects and responsibilities of operation of the plant. This should also include drills on procedures that needs to be taken during plant upsets or raw water quality changes.

Training should not end after the initial training course and on-site training, but should be followed with regular refresher courses.

2.4.10 Community involvement

Operation, maintenance and construction (if feasible) should be within the competence of local technical staff or the users. Prior to construction or upgrading an assessment should be made of available skills in the community and the authority.

The choice of treatment system, as well as its implementation and management, must take into consideration the aspirations and preferences of the community itself.

2.5 INSTITUTIONAL REQUIREMENTS

Plants treating more than 150 m^3/day of water must be registered by the Department of Water Affairs and Forestry.

In order to achieve successful institutional arrangements, more projects need to be implemented as pilot projects where all the institutional aspects receive attention. In particular, the full co-operation and involvement of the relevant government departments, local institutions, community members and other interested organisations should be assured.

The technology should be sustainable by the community with minimum external support.

The community should be willing to pay for all operation and maintenance costs, as well as contribute to the capital costs, especially for investments above that required to meet basic health requirements.

Particular attention should be given to institution building within the community, aimed at increasing public awareness, self reliance and efficient management. This should be supported by sound government policy, and initiatives by government to actively support and coordinate development activities.

The specific institutional requirements are:

- need for community involvement in all aspects of the projects, including decisions on financing and cost recovery
- need for improved education on domestic hygiene
- need for adequate training of local personnel in the operation and maintenance of schemes
- need for support and training of local community level management structures (*e.g.* water committees)
- need for district and regional structures to provide ongoing support to these local management committees
- need for appropriate technologies which can be operated and maintained at local level

CHAPTER 3

SURVEY OF 20 SMALL WATER TREATMENT PLANTS

3.1 SELECTION OF PLANTS

A total of 20 small treatment plants were selected country-wide to identify and investigate typical upgrading needs and methods. In selecting these 20 plants, the following aspects were taken into consideration as important selection criteria:

- the plants in total should be representative of all types of rural water treatment plants in the country, *i.e.* they should include plants of various capacities; employing different unit treatment processes; treating raw waters of various qualities (*e.g.* waters with low, medium or high turbidities, eutrophic waters, waters containing organic colour, waters containing iron and manganese); plants of varying ages, needing upgrading or in various stages of upgrading; and condition of the plant (whether the plant is under stress at present)

- preferably plants that are being monitored by either the CSIR, consultants or local authorities, for obtaining plant records and information on plant condition, and to facilitate further investigation of the plants

- be spread across the country (geographically)

- not at present be under jurisdiction of a water board

The following plants were selected in cooperation with the CSIR in Pretoria, Durban, King Williams Town (Bisho) and Bloemfontein:

Table 3.1 List of 20 small water treatment plants that were visited

Plant Name	Province	Capacity (Mℓ/d)	Raw water quality	Main treatment process
Mogenyaka	Northern Province	0,8	High turbidity	Flocc. / sed. / slow sand filtration
Tompi Seleka	Northern Province	0,22	High turbidity	Flocc. / sed. / pressure filtration
Vandermerweskraal	Northern Province	0,10	Low turbidity	Chlorination
Hlogotlou	Northern Province	2,5	Low turbidity	Flocc. / sed. / rapid sand filtration
Vergelegen	Northern Province	2,4	High turbidity	Flocc. / sed. / rapid sand filtration
Piet Gouws	Northern Province	1,5	High turbidity	Flocc. / sed. / rapid sand filtration
Boschkloof	Northern Province	0,45	Low turbidity	Flocc / sed. / slow sand filtration
Bethesda Hospital	Kwazulu Natal	0,5	High turbidity	Package plant
Jozini	Kwazulu Natal	1,6	High turbidity	Flocc. / sed. / pressure filtration
Mosvold Hospital	Kwazulu Natal	0,3	Low turbidity	Flocc. / sed. / slow sand filtration
Manguzi Hospital	Kwazulu Natal	0,55	Low turb/eutr	Flocc. / direct filtration
Frischgewaagd	Kwazulu Natal	0,66	Medium turbidity	Flocc. / sed. / slow sand filtration
Upper Mnyameni	Eastern Cape	0,26	Low turbidity	Package plant
Pleasant View	Eastern Cape	0,65	Low turbidity	Flocc. / sed. / pressure filtration
St. Thomas	Eastern Cape	0,2	Medium turbidity	Flocc. / sed. / pressure filtration
Dordrecht	Eastern Cape	1,6	Low turbidity	Flocc. / sed. / rapid sand filtration
Clocolan	Free State	2,0	Low turbidity	Flocc. / sed. / rapid sand filtration
Syferfontein	Free State	3,2	Medium turbidity	Flocc. / sed. / rapid sand filtration
Calitzdorp	Western Cape	0,85	Colour and turbidity	Flocc. / sed. / slow sand filtration
Buisplaas	Western Cape	0,12	Iron	Aeration / sed. / upflow contact filtration / pressure filtration

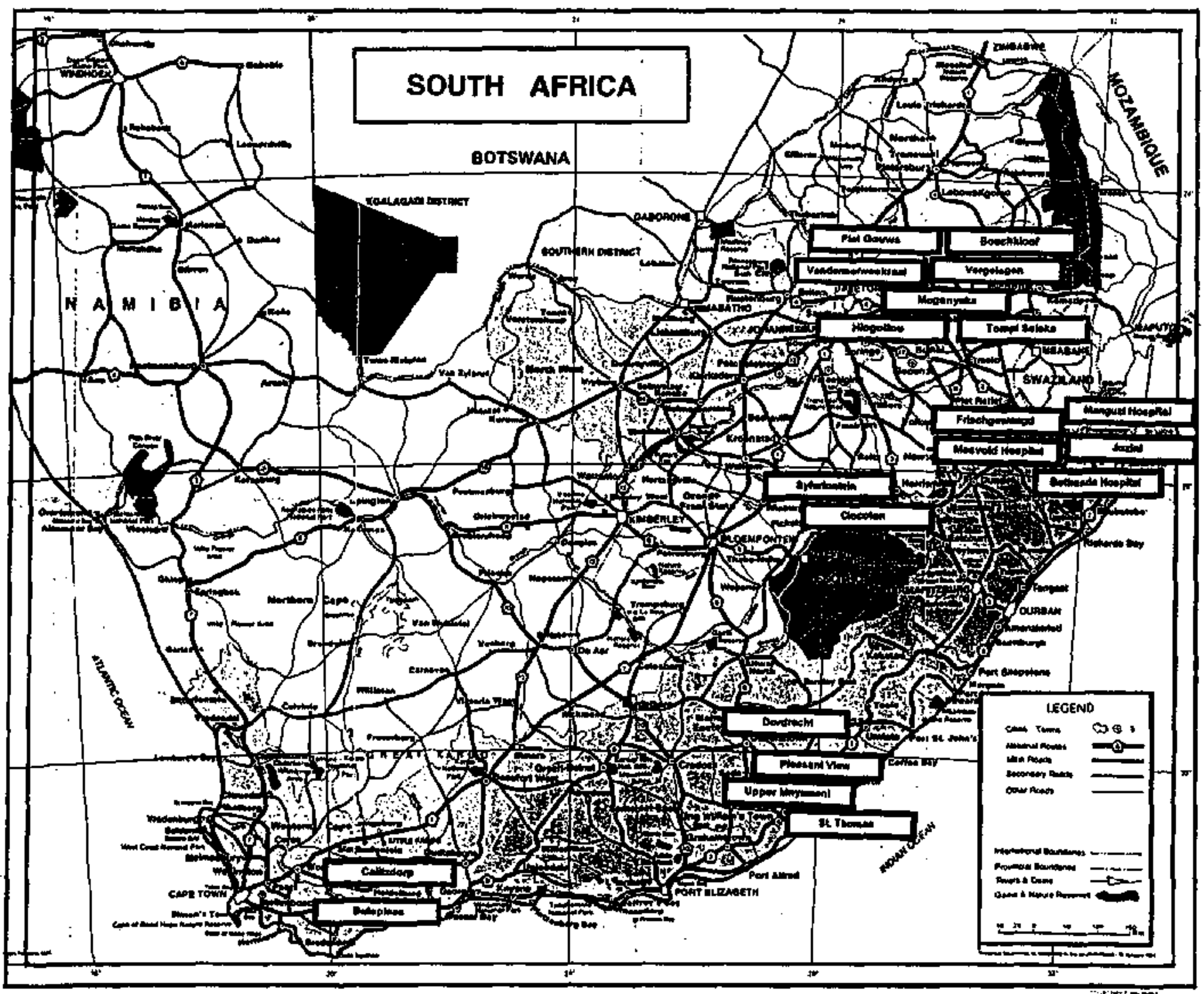


Figure 3.1 Location of treatment plants that were visited

3.2 ANALYSIS OF PLANTS

The plants were visited and questionnaires completed containing information on raw water quality, capacity of the plant, treatment processes employed, condition of the plant, any upgrading that was done/currently being done/planned, operational aspects, maintenance and quality assurance (monitoring).

Details on each of the plants that were visited are given in Appendix A.

3.3 LISTING OF PROBLEMS AND UPGRADING NEEDS

The following problems that are experienced at small water treatment systems were identified during the plant visits, in discussions with CSIR personnel and consultants, and from the completed questionnaires received for the database:

3.3.1 Design

Coagulation and flocculation

In general, coagulation and flocculation in small water treatment systems do not seem to give the same final water quality than one normally gets in large plants. While this is essentially an operational problem relating to control of the chemical mixing and dosing process, there are also a number of design inadequacies that were found, namely:

- chemical mixing is inadequate (chemicals not mixed sufficiently with the water)
- incorrect placing of chemical dosing points
- not sufficient flocculation retention time, or velocity gradient (mixing intensity) too high
- allowance not made for slower floc formation during winter months, resulting in potential poorer plant performance during the cold periods.

Sedimentation

Inlet and outlet arrangements in sedimentation tanks are often neglected during design resulting in poor performance.

Filtration

Design shortcomings of filters used in small water systems have been found to be mainly the following :

- inadequate backwashing facilities for rapid sand filters
- no provision for preventing a slug of poor quality water coming from filters directly after backwashing
- no allowance made for filtration plants using pumps for backwashing, not to cease to function in the event of pump failure
- incorrect choice of filtration system : slow sand filters are sometimes used when a rapid sand filter or pressure filter are better choices (for instance, when turbidities are high and chemicals are dosed). This invariably results in lower flow rates or poorer water quality when the slow sand filters are preceded by chemical dosing
- performance of slow sand filtration process not optimal when operating conditions are not nearly constant
- because of the size limitations of package plants, these systems often have to operate at high filtration rates, resulting in rapid accumulation of solids and hence short filter runs and more frequent backwashing, all of which leads too mechanical wear, wastage of clean water and high energy costs
- poor filtrate quality of short filter runs due to incorrect media in the filters (too coarse or too fine, or depleted)

Disinfection

In the design of disinfection systems (normally chlorination) the following inadequacies are common :

- insufficient chlorine contact time
- no reliable dosing system

General

In general :

- inappropriate process(es) are often used
- small systems based on coagulation, flocculation and filtration still have too many moving parts, resulting in maintenance problems, especially in remote areas
- equipment or plant is not flexible enough, and cannot be adjusted easily or not at all, presenting problems with ensuring sustainable plant performance
- abstraction of raw water from a dam or river is often done at a wrong location or with poor abstraction arrangements
- provision is often not made during the design stage for stabilisation for corrosion control
- lime for stabilisation is dosed at a position where there is poor mixing (usually somewhere between the sand filters and clean water reservoir). The result is sedimentation of lime or the formation of calcium carbonate that also settles in the reservoir
- facilities for cleaning and drainage of tanks and equipment are not provided
- the effect of weather is neglected, and plants can be flooded or subject to corrosion
- too high technology are in some instances used which makes it prone to failure, as well as difficult to operate and maintain

3.3.2 Operation

Operational problems are experienced in by far the largest number of small water treatment plants, and are mostly common to these type of plants.

Coagulation and flocculation

Operators normally do not have a full understanding of coagulation chemistry, and can therefore not control (or be expected to control) the coagulation process properly.

Chemical dosing is not proportional to flow at all times, resulting in either underdosing or overdosing during (sometimes long) periods of operation.

Sedimentation

Settling tanks are not always desludged when required, which leads to compaction of sludge in the bottom of the settling tank. This causes difficulties with withdrawal for disposal. Process controllers therefore do not control the settling process adequately by observing floc carry-over from the settling tanks.

Filtration

Slow sand filters are in most instances not operated properly. The *Schmutzdecke* is not scraped off at the correct intervals and/or the procedure is not carried out correctly. The same applies to the washing and replenishing of the filter sand.

Prescribed procedures for backwashing of rapid sand filters are also often not followed resulting in decrease in filter run time, rapid replacement of filter sand or loss of filter sand with the backwash water.

General

In general, operators are not familiar with the basic principles of water treatment, and are also often not familiar with the working of equipment (they are not shown how it works or how it should be operated). Operators are also too easily convinced by chemical/equipment suppliers to follow certain procedures without being able to exercise their own judgement.

Operators often develops a resistance against certain equipment and then fail to operate it properly. They do not always know how to adjust unit processes, and often take short-cuts and compromise water quality.

An important shortcoming at many of the small plants is that there are not enough personnel for operation, process control or monitoring of the plant, or the monitoring and process control is not performed adequately. The necessary laboratory equipment to perform process control or quality assurance is not available because of economic constraints.

Because of inadequate training or lack of motivation, chemicals are made up inaccurately or dosages not controlled adequately. The same applies for the performing of laboratory analysis.

Process controllers (operators) may have a wrong perception of process control and often too easily falls into a routine for a certain procedure, which may be incorrect or only partially correct. It is in these cases particularly difficult to change perceptions.

Chemicals are not always readily available, especially in remote rural areas. This then seriously hampers continuity of supply of good quality water to the community.

Stabilisation of the final water is neglected at most of the small water treatment plants because the evidence of the results of distributing unstabilised water is not seen visually, or the importance of protecting the distribution system fully understood.

Power failures cause major problems in water supply from small water treatment plants.

3.3.3 Maintenance

Communities often do not realise importance of regular maintenance.

At small plants, the operating personnel normally do not have skills/tools to do maintenance themselves.

Back-up maintenance service is mostly not available, or take very long. Spare parts are also not (readily) available. Problems are therefore experienced with servicing of remote plants and telemetry is generally not feasible. Consultants and contractors are located in distant urban centres, and are not able to visit the plants at the frequency that may be required.

Poor communication exists between communities and support agencies.

At some of the remote plants electricity is not available, making maintenance difficult. Poor access roads also prevents frequent servicing of small water systems.

Probably the most important reason for insufficient or total lack of maintenance at small treatment plants is the unavailability of funds.

3.3.4 Management

A major problem at small treatment plants is insufficient management supervision or interest, leading to workers getting frustrated. There is often a lack of knowledge from management about treatment processes (technical knowledge).

There is minimum cost-recovery, even of the operating costs, resulting in large portions of the government funding for new or improved systems being used merely to operate and maintain existing schemes.

Problems are experienced with working conditions at many of the small plants. These include aspects such as :

- pay
- fringe benefits
- working hours
- distance from home to plant
- access to training
- career development

Problems are also experienced on an interpersonnel level with attitudes and relationships, both upward and downwards, with subordinates, peers or superiors. This obviously has an adverse effect on the performance of the treatment systems.

There is a lack of community involvement, especially over the longer term. They do not feel "ownership" (communities perceive the system as being government and therefore take no responsibility for it).

It can not be emphasized enough that shortcomings in the institutional arrangements can, and mostly do, lead to project failures.

Based on the information obtained during the visits and discussions, the main problems are broadly prioritised as a ***lack*** or ***inadequacy*** of the following:

- **Funding/financing for**
  - **timeous upgrading (plants have to operate under stress)**
  - **maintaining equipment and infrastructure**
- **Back-up service by equipment and chemical suppliers**
- **Supervision and management support**
- **Staffing and training of operators and/or managers**
- **Process control (especially chemical dosing)**
- **Response to changing raw water quality**
- **Corrosion control**

CHAPTER 4

EVALUATING THE EXISTING CONDITION AND UPGRADING NEEDS OF A WATER TREATMENT PLANT

The need to upgrade an existing water treatment plant can be for one or more of the following reasons:

- to increase the capacity
  (supply more treated water)
- to increase the treatment efficiency
  (provide better quality final water at optimum cost)
- to change the type or purpose of treatment
  (changed raw water quality)

In order to be able to systematically determine what the specific upgrading needs of a treatment plant are, it is necessary to evaluate the existing condition of the plant. A procedure which will act as a checklist is given below, followed by a form for listing the upgrading needs of the plant under consideration.

4.1 EVALUATING EXISTING CONDITIONS

4.1.1 Quality of Water Produced by the plant

Obtain information on the quality of the final water that is produced by the plant. This can be done by accessing plant records or by scrutinizing reports by consultants or authorities monitoring the plant. If no or very little information is available from these sources, then a sampling and analysis programme must be implemented to monitor the final water quality over a period of time, say at least one month. Should the water demand be seasonal (in holiday areas) then water quality data must be obtained for both the low and high seasons. A statistical analysis should be performed on the data to determine the percentage of time that the treated water quality does not comply with the guideline values.

4.1.2 Loading on the plant

a. Water demand

i. Design capacity and demand

It should be established, as far as possible, what the original estimate of water demand was to be reached in the design year for the plant, *e.g.* the plant was designed in the year 1985 for a design life of 15 years, and for an expected capacity of 1,2 Mℓ/day to serve a population of around 12 000 people by the year 2000.

ii. Current water demand and flow

Determine what the current flow to the plant is and what the current population is that is served by the plant. From this it will be possible to establish to some degree what the per capita water demand of the particular community is.

iii. Estimation of future water demand

Using the approximate per capita water demand as determined above, and by estimating the expected future water demand with the assistance of the relevant authorities, it will be possible to determine how long the plant under consideration will still be able to operate within the design capacity (plus a certain percentage overloading thereof), if not already exceeded.

b. Raw water quality

i. When plant was designed

As with the determination of inflow as above, information of the raw water quality to the plant when it was designed should be obtained. It is, however, likely that this information will not be available.

ii. Records of raw water quality

Records of raw water quality during the plant's life should be obtained, either from plant operational data or from monitoring reports from consultants or the controlling authorities. This data should be processed and it should be established whether there is any significant change in raw water quality since the design stage of the plant up to present, and if so, which parameters have changed.

iii. Current raw water quality ranges and average raw water quality

The current raw water quality should be established by implementing a sampling and analyses programme, again over a period of time to include any temporal variations that may occur. This data will allow the evaluator to assess whether the existing treatment plant (and the unit processes) are still appropriate and capable of producing a treated water complying with the target treatment requirements, according to the procedures suggested below.

4.1.3 Design aspects

a. Mixing equipment

Is the mixing intensity sufficient? Is duration of rapid mixing sufficient/not too long? Can rapid mixing be improved by minor modifications? Is chemical dosed at the correct point?

b. **Flocculation equipment**

i. <u>Effectiveness</u>

Is good floc formation and floc growth observed? Does the floc settle effectively in a beaker? Is there any break-up of floc? How rapid is the floc formation? Is any polyelectrolyte or weighting agent required to improve the settleability or strength of the flocs?

ii. <u>Dosage</u>

Is the dosing system in good working order? Can the dosing rate be adjusted? Is the make-up solution mixed thoroughly? Can the dosing rate be calibrated? Are there spare dosing pumps for back-up? Is the plant personnel capable of operating and doing basic maintenance on dosing pumps.

iii. <u>Energy consumption</u>

Can mechanical flocculation be replaced by hydraulic flocculation?

iv. <u>Amount of maintenance work</u>

How much effort/time is needed to clean flocculation channels? How frequently must this be done? What service facilities are available for maintenance on mechanical flocculation equipment?

c. **Sedimentation equipment**

i. <u>Effectiveness</u>

Can any floc carry-over from the settling tank be observed? What is the overflow turbidities/suspended solids? Are there any current effects? Is there any short-circuiting in the sedimentation tank? Is the retention time in the tank sufficient? Are settling velocities adequate? Are overflow velocities within design range? Do wind and sun have an effect? Does growth of algae pose a problem? Are the inlet arrangements designed to prevent floc break-up or currents?

ii. <u>Amount of maintenance work, including the renovation of the equipment and parts</u>

Can the tank (or one of the tanks) be taken out of commission for cleaning or maintenance?

iii. <u>Sludge and backwash-water disposal</u>

Are the sludge draw-off facilities adequate? Is the sludge disposed of in an environmentally acceptable manner?

d. **Filtration equipment**

i. <u>Effectiveness</u>

Operation of valves/robustness of filter nozzles/backwash pump and blower/correct medium/protection against corrosion/distribution system (underdrainage).

ii. <u>Requirements of pretreatment</u>

Any flocculants required? Chlorine to prevent algae growth or to oxidise metals such as iron. Lime or soda-ash to increase pH for removal of metals.

iii. <u>Construction cost</u>

Proprietary filtration systems. Cost of civil and of mechanical/ electrical equipment. Cost of slow sand filters.

iv. <u>Filtration rate</u>

Calculate the filtration rate under normal loading and under peak loadings - does it fall within the design range? Are the filter(s) overloaded? Can any modifications be made to allow higher filtration rates?

v. <u>Effectiveness of the filtration system</u>

Quality of the filtered water (turbidity)?

vi. Length of filter runs

How long filter runs can be obtained under varying loadings from the flocculated or settled water? Can longer filter runs be obtained by addition of a polyelectrolyte? Is backwashing done on a routine basis or when a certain head loss is reached?

vii. Amount of water used for backwashing

What percentage of the water treated by the plant is required for backwashing? Will the additional use of air reduce this volume of backwash water? Is the backwash water recycled (after settling)? Is the backwashing procedure optimised? Has the process controller been shown how (and why) to do backwashing?

viii. Amount of maintenance work

How much effort and time is required to

- replace media
- clean and replace nozzles
- clean distribution laterals
- clean slow sand filters

Are there standby filtration or backwash pumps?

e. Other important aspects

i. Temperature and other weather conditions

Is sufficient protection provided against

- corrosion
- floods
- freezing temperatures
- rain
- gale force winds

ii. Conditions of material supply

Are the materials tested? Is the quality checked?

iii. Land occupied and location

Is there space for extension or upgrading of the plant? Are the access routes and communication routes adequate? What is the long term land use?

iv. Technical strength and managing ability

Is management and operation sufficient to ensure long-term sustainability of the present plant and any planned extensions/upgrading? Are attempts made to improve the management, operation and maintenance of the plant?

4.1.4 Operational aspects

a. Coagulation and flocculation

Do operators know how much they are dosing (even qualitatively)?

Can required dosages be calculated by the process controllers? Can the process controllers adjust the dosage rates and monitor how much is dosed? Are they familiar with the basics of coagulation and flocculation for water clarification? Do they have a programme for monitoring floc formation?

Good dosage control is one of the major shortcomings at small water systems and requires specific attention during training.

b. Sedimentation

Is the floc blanket observed and dislodging practices based thereon? Is the overflow weir kept clean? Is the flow to more than one sedimentation tank distributed evenly?

c. **Filtration**

Is backwashing done properly (at the right time and according to the correct procedure)? Is the quality of the filtrate monitored on a regular basis? Is excessive head loss development or turbidity breakthrough monitored?

d. **Disinfection**

Is the chlorine dosed according to previously determined chlorine demand and/or by maintaining an acceptable chlorine residual in the final water? Is the chlorine residual measured correctly and at the suggested frequency?

e. **Stabilisation**

Is the stability of the final water determined? Is the process controller familiar with the reason for stabilisation and how it can be affected and controlled?

4.1.5 Maintenance aspects

a. **Sophistication of equipment**

Is the equipment too sophisticated for the application? Is back-up service available? Is there opportunity for training of the plant personnel in using the sophisticated equipment?

b. **Availability of spare-parts**

Are spare-parts readily available? How long does it take to replace parts? What is the cost of replacing parts (including labour)?

c. **Availability of back-up service**

Is back-up service readily available? Does it take long to get this service? Is the service reliable? Are there ways that the community can do some aspects of the service themselves, or that alternative suppliers can be found?

d. **Communication facilities**

Are there adequate communication facilities between the plant and management, authorities, service providers, suppliers and consultants? Can this be readily improved?

e. **Ability to perform own maintenance**

Can the plant personnel or persons in the community perform their own maintenance (or parts thereof)? Can they be trained and are such training facilities available?

f. **Access to plant**

Is there good access to the plant by motor vehicles and delivery trucks? Are there alternative routes? Can the existing access routes be improved with existing funds?

g. **Availability of funds for maintenance**

Are funds available? Is there possibility of alternative sources of funding for maintenance?

4.2 LISTING OF UPGRADING NEEDS

With the evaluation of the existing condition of the treatment plant completed, a list can be drawn up of all those aspects relating to process variables (residence times, settling rates, etc.), equipment and operation of the plant that requires addition, modification or improvement in order to provide the desired quantity of water of the target quality for a further number of years as determined by the specific plant and community situation.

CHAPTER 5

INSTITUTIONAL ASPECTS

In determining the upgrading needs of a small water system and planning upgrading measures, it is of great importance that due consideration be given to institutional aspects, as this will to a large extent determine the success of a water supply project.

5.1 NEEDS ASSESSMENT

Although the basic needs of rural communities are generally known, the needs and particularly the priorities of a specific community need to be established before venturing on a project. Even if an agency receives a request for assistance by some members of a community, this does not necessarily represent the feelings of the community as a whole. A needs assessment and data collection study should therefore be done if possible.

5.2 COMMUNITY PARTICIPATION

Rural people are often in the grip of a poverty trap, to which factors such as isolation, powerlessness and physical weakness contribute. Often it is the women and children of low-income families who are most affected by poverty. Real change is only possible if they are organised to participate in projects of their own design, by which they learn to look differently at their situation, and start taking control of their lives.

As far as possible all sectors of a community should be involved in a development project. A projects which requires the use of communal resources, such as land and water, and the systematic collection of funds will depend largely on well-organised community support.

Community participation can be defined as the organised and active involvement of the people in a community, or the potential users of services, in defining their problems and making decisions concerning the implementation of development projects. There is no one model of community participation which is applicable to all communities; the form and degree of community participation will differ in accordance with different socio-economic and other conditions. However, if an agency remains in total control of a project and merely calls on villagers to provide voluntary labour, the project does not have true community participation, but merely an element of self-help. More desirable is to have the community take responsibility for managing the project itself. Successful community management depends on the existence of an appropriate community organisation that is able to manage a project effectively and facilitate community participation in the project. Without such an organisation even a project which registered successful community participation during the implementation phase will not be sustainable.

In practice the establishment of a community management system is difficult and time consuming. It is essential that a management committee receives adequate support from organisations in the area with the necessary experience and expertise. Members of support organisations could also serve on the management committee, or on sub-committees responsible for specific matters, such as agriculture and health. The involvement of the community in the election of a committee, and their ongoing involvement in projects to ensure proper accountability, has to be cultivated over several years.

5.3 FINANCING AND FINANCIAL CONTROL

There is a great deal of grant finance flowing into rural development in South Africa. While this is a good thing for getting basic levels of service into areas which have long been neglected, it is important to remember that there is theoretically an infinite demand for free goods. Only if beneficiaries of projects are prepared to contribute from their own pockets, and time, towards projects can one be sure that the projects are meeting real needs. Simple checks must be built into financial systems to ensure transparency and accountability. A minimum level of reporting must be maintained, but not so much that it becomes a burden. Simple book keeping systems that can be understood by the whole committee, and not just by the educated elite, will best serve the purpose.

CHAPTER 6

TECHNOLOGIES AND MEASURES FOR UPGRADING SMALL WATER TREATMENT PLANTS

This chapter provides an overview of treatment systems and technologies that can be used in small water treatment plants and that will therefore also be applicable when planning and designing measures to upgrade an existing treatment plant. It also lists a number of measures that can be taken to improve the performance of existing unit treatment processes.

The summary of treatment processes and technologies appropriate for use in small water treatment plants is largely adapted from the WRC Report **"GUIDELINES ON THE TECHNOLOGY FOR AND MANAGEMENT OF RURAL WATER SUPPLY AND SANITATION PROJECTS"**

6.1 SELECTION OF MAIN TREATMENT SYSTEM FOR THE SPECIFIC APPLICATION

The extent to which water for domestic use is treated will be limited by economic and technical considerations. In rural areas complicated treatment schemes may not be suitable. In cases where it is required, a better solution may in many instances be to exploit an alternative unpolluted source which requires little or no treatment, even when this source is at a greater distance.

When considering the upgrading of existing small water treatment plants, it will in the first instance be necessary to establish what the best treatment systems would be for the specific situation (range of raw water qualities [minimum and especially maximum values]; volume of water required; availability of funds for operation and maintenance; operational skills of operators; etc.), irrespective of the treatment systems that have already been installed. This information will become available when evaluating the existing condition and upgrading needs of the plant according to the procedure suggested in Chapter 4.

In selecting an appropriate treatment system(s) for the plant under consideration, table 6.1 may be used as a rough guide in terms of disinfection and turbidity removal within the constraints of costs and available operating skills. However, it is strongly recommended that each case be thoroughly investigated before making the final choice. In particular, it is recommended that all surface waters should be filtered and disinfected.

TABLE 6.1: Guidelines for the selection of a water treatment system for surface water in rural areas (from WRC Report No. 231/1/93)

Average raw water quality	Water demand (m³/d)	Treatment suggested	Skills need	Capital + Operating costs
Turbidity < 5 NTU Faec coliform 0/100 mℓ Bilharzia not endemic	up to 2000	No treatment (filtration and disinfection recommended for surface water treatment)	nil (low - med)	nil (med + med)
Turbidity < 10 NTU Faec coliform 0/100 mℓ Bilharzia endemic	up to 5000	1. Rapid filtration or 2. Slow sand filtrat	med low	med + low med + v.low
Turbidity < 10 NTU Faec coliform 1 - 500 per 100 mℓ	up to 5000	1. Rapid sand filtration + disinfection (Cl_2) 2. Slow sand filtration + disinf. if poss.	med low	med + med med + low
Turbidity: 20-50 NTU Faec coliform 1-500 per 100 mℓ	up to 5000	1. Sedimentation + rapid sand filtrat. + disinfection (Cl_2) 2. Sedimentation + slow sand filtrat. + disinf. if poss.	med med	high + med high + low
Turbidity: 50-150 NTU Faec coliform > 500 per 100 mℓ	up to 5000	Pretreatment (coag. floc & sedimentat.) + filtration (slow or rapid sand) + disinfection	high	v. high + high
Turbidity > 150 NTU	Detailed investigation and possible pilot study work may be required			

6.2 SUMMARY OF TREATMENT TECHNOLOGIES FOR SMALL WATER TREATMENT SYSTEMS

In order to optimally upgrade small water treatment systems for any of the purposes mentioned in Chapter 4, it is necessary to know what the different treatment technologies/systems are that can be used for treating small water supplies. These technologies are not described in detail and the reader of the guidelines document is referred to the references and to existing CSIR and WRC reports with more detailed information on these treatment systems (see Appendix E). Rather, the different treatment options are listed and briefly described, with comments on how well they have been found to perform locally, and to what extent they can be used and are recommended for use in upgrading existing treatment plants. Chapter 7 provides design considerations and guidelines for the main treatment processes.

The primary treatment requirement is always to ensure a microbiologically safe supply of water for drinking purposes. Hence, disinfection of the water will usually be the primary treatment objective. Secondary objectives may include clarification of the water, and the removal of potentially harmful chemical components.

6.2.1 Disinfection

As mentioned above, the single most important requirement of drinking water is that it should be free from any microorganisms that could transmit disease or illness to the consumer. In cases where no other methods of treatment are available or required, disinfection may be the only treatment process utilised before the water is supplied to consumers.

a. Chlorination

The ability of chlorine and chlorine compounds to destroy pathogens in water quickly, and their wide availability, make them well suited for use as disinfectants. Their cost is moderate and they are therefore widely used as disinfectants throughout the world.

Effective chlorination of water supplies has in many cases achieved a substantial reduction in those enteric diseases that are primarily water-related.

The following three products that are used for chlorination are readily available and are approved by the South African Department of Health and Population Development for use with drinking water.

- Chlorine gas
- Sodium hypochlorite (Jik, Javel, or other non-perfumed bleaches)
- Calcium hypochlorite

(Calcium hypochlorite is commonly supplied in South Africa as HTH dry granular chlorine).

Other chlorination systems

i. <u>Chlorine from salt</u>

Chlorine can be generated from salt on-site using a small chlorine generator. Simple generators employing carbon electrodes may be obtained from swimming pool chemical suppliers. More robust units employing specially coated electrodes and/or an ion selective membrane are commercially available. Units which operate with solar power for use in more remote areas are also available. The chlorine produced is in the form of sodium hypochlorite at concentrations from 0,1 to 5 %. Chlorine produced on-site may often be found to be cheaper than other forms of chlorine if the unit operates efficiently.

ii. <u>In-line tablet chlorinator</u>

In-line chlorinators use calcium hypochlorite tablets. The tablets are available in a cartridge which is fitted to the chlorinator. The chlorine dosage is adjustable and may be set to meet the demand of any specific source. The chlorinator is easy to install and also easy to operate. However, it requires a pressurised pipeline into which it can be connected, and the tablets are more costly than equivalent chlorine in other forms. Furthermore, very little control over the chlorine concentration in the water is possible. These systems find more application in industrial applications and are not recommended for rural applications.

b. UV systems

Water passed in close contact to ultra-violet (UV) lamps can also be disinfected by this means. The low pressure mercury lamps produce light rays of around 254 nanometers wavelength. The lamps are protected from the water by special quartz or plastic shields. Commercially available systems are simple to install and operate. However, the major draw-back with UV systems is that no disinfectant residual is available (reference, Bettina).

NOTE !

UV systems are only appropriate for point-of-use treatment and where all of the population have fridges and store their water hygienically. This is because UV disinfection has no residual effect as for chlorine and treated water can easily be reinfected during transport and storage. UV disinfection is therefore not recommended for the disinfection of rural water supplies.

c. Other disinfection technologies

A number of alternative disinfection technologies have been evaluated by the CSIR with the aim of providing more appropriate systems specifically for the developing communities where funding and operational skills are limited. More information on these technologies, which include UV radiation, mixed oxidant gases generated on-site for disinfection (MOGGOD), microfiltration and the use of metallic ions can be found in the WRC Report No. 449/1/95 by the CSIR Division of Water Technology, entitled "Non-Conventional Disinfection Technologies for Small Water Systems". Chloramination is suitable for long lines, but has to many pitfalls to be suitable for small water systems.

6.2.2 Filtration

Filtration is a process for the removal of suspended matter (turbidity) from a water supply by means of a physical barrier. It is achieved by the passage of water through a porous medium in which the particles are trapped, either superficially when the rate of flow is slow (slow sand filters) or by deep penetration into the bed (rapid sand filters). Two types of filtration mechanisms are therefore used, *viz.*

depth filtration - where the suspended matter is removed as the water passes through a deep layer of large particles, usually sand; and
surface filtration - where the suspended matter is retained on the surface of a physical screen.

Depth filtration will generally have a greater capacity for the removal of suspended matter than surface filtration before cleaning of the filter is required. A number of different filters are used in water treatment, some more suitable for use in rural areas than others.

a. Slow sand filtration

Slow sand filtration can be an effective, simple, and low running cost water treatment processes and may be suitable for rural areas in developing countries, providing it is employed in the correct application. The process differs from rapid sand filtration because of its biological nature, and is in particular suitable for village level operation and maintenance.

A layer of sand having an effective particle size of 0,25 to 0,35 mm is supported on an underdrainage system consisting of graded stone material above a perforated collection pipe, and contained in a suitable reactor constructed from brickwork or concrete.

NOTE!

Slow sand filters are only suitable for low turbidity waters (<10 NTU), and should not be used where chemical dosing is practised.

The lay-out of a typical slow sand filter is shown in Figure 6.1

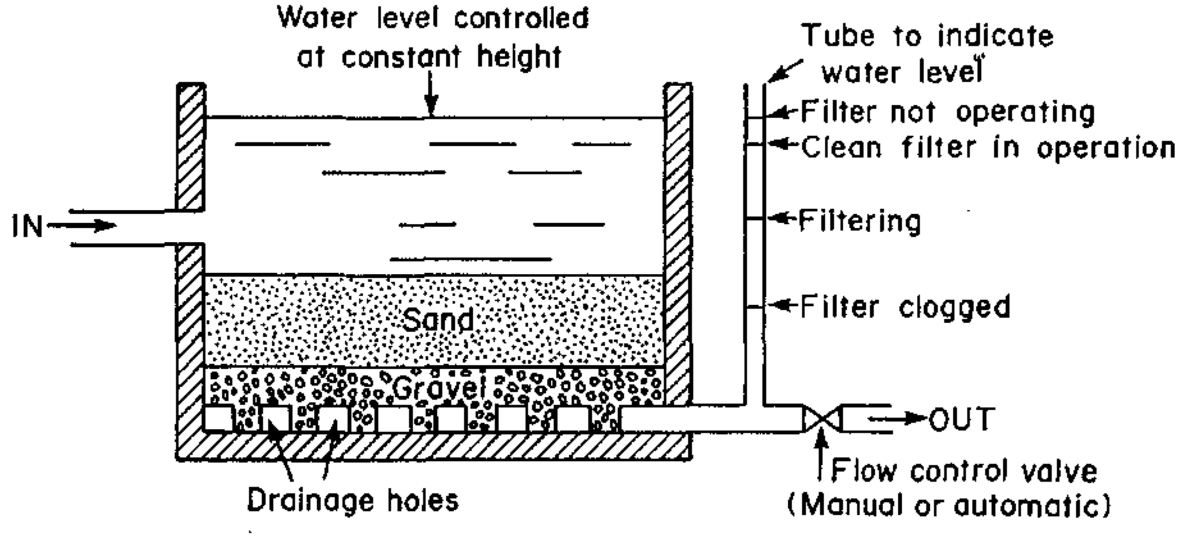


Figure 6.1 Lay-out of a slow sand filter

b. Rapid sand filtration

In rapid sand filtration, sand is also used as the filter medium, but the process is quite different from slow sand filtration. This is so because much coarser sand is used with an effective grain size in the range 0,4 to 1,2 mm, and the filtration rate is much higher, generally between 5 and 15 $m^3/m^2/h$ (120 to 360 m^3/m^2/day). Due to the coarse sand used, the pores of the filter bed will be relatively large and the impurities contained in the raw water will penetrate deep into the filter bed. Thus the capacity of the filter bed to store suspended impurities is much more effectively utilized and even very turbid river water can be treated with rapid filtration.

NOTE!

Filtration rates that can be applied in rapid sand filters depend on the type of filter media used, pretreatmant employed and whether economical filter runs can be obtained. High filtration rates should only be used when effective pretreatment is performed.

Figure 6.2 shows a typical rapid sand filter.

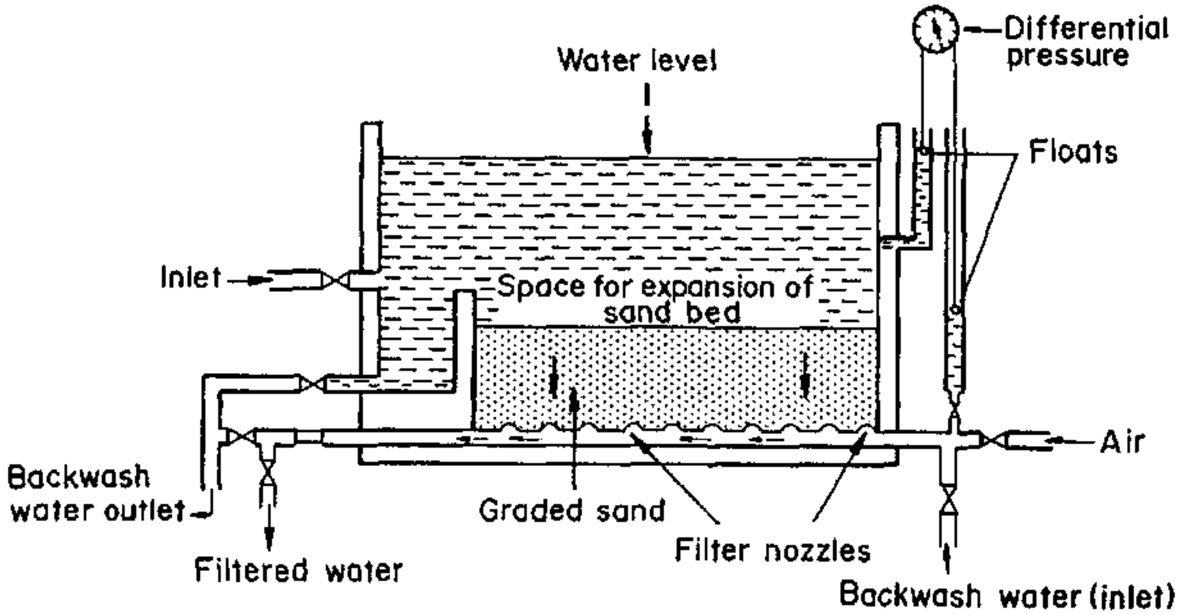


Figure 6.2 Rapid sand filter

For cleaning a rapid sand filter bed, it is not sufficient to scrape off the top layer. Cleaning of rapid sand filters is effected by back-washing. This means directing a high-rate flow of water back through the filter bed whereby it expands and the sand is scoured. The backwash water carries the trapped suspended solids out of the filter. To affect efficient cleaning, the backwashing-step can be preceded by air scouring, or, as is more often used lately, by simultaneous backwashing with water and air. The cleaning of a rapid sand filter can be carried out quickly; it need not take more than about one half an hour. It can be done as frequently as required, if necessary, two or three times per day. This means that a rapid sand filter can treat water in which the suspended solids levels may vary from low levels to very high levels without adversely affecting the production of clean water. Rapid sand filters are often supplied as proprietary units by commercial firms, which includes the pumps, valves, filter nozzles, air blower, control systems and pipework.

Multi-media filters are gravity-type downflow filters with the filter bed composed of several different materials that are placed coarse-to-fine in the direction of flow. The sand can be overlain by a layer of larger diameter particles of lower density than sand (usually anthracite), and/or underlain by a layer of smaller diameter particles of a denser material (garnet). According to theory these filters can be operated at higher filtration rates, and smaller filters are therefore required. The relative diameters of the different filter media and the backwash velocities are interrelated if the layers are to remain separate during backwashing. At rural treatment plants operational skills and controls are generally lacking, with the result that the media gets mixed during backwashing or the anthracite is washed out, and the advantage is lost.

c. Pressure filtration

Pressure filters are of the same construction as gravity-type filters but the filter bed together with the filter bottom is enclosed in a watertight pressure vessel. The driving force for the filtration process is the water pressure applied to the incoming feed water which can be so high that almost any desired length of filter run is obtainable.

NOTE!

The following are important operational aspects of pressure filters :

- **it should never be operated at excessive filtration rates otherwise filtered water quality will be compromised**
- **when a bank of pressure filters is used particular attention must be given to the backwashing procedure**
- **the filters must be regularly opened and inspected and the filter media checked**

Pressure filters are commercially available as complete units. They can be used in modular configurations so that upgrading at a later stage is very simple. The pressure drop across the filters is generally higher than that across a gravity filter, requiring appropriate pumps unless sufficient static head is available.

A typical pressure sand filter is shown in Figure 6.3

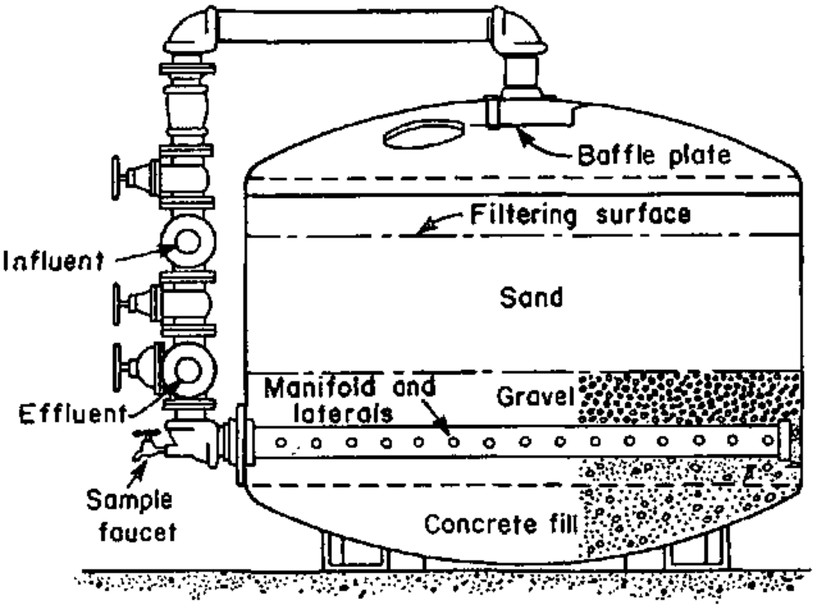


Figure 6.3 Pressure sand filter

d. **Upflow filters**

Upflow filters provide for a coarse-to-fine filtration process. The coarse bottom layer of the filter bed filters out the major part of the suspended impurities, even from a turbid raw water, without an excessive increase of the filter-bed resistance due to the large pores.

The overlaying fine layers have smaller pores but here also the filter resistance will increase slowly as only fine impurities make their way through to the upper layers. *Upflow filters are therefore reputed to* have a much larger dirt-holding capacity than downflow filters.

NOTE!
This type of filter is not used widely any longer as a result of difficulties with backwashing the filters.

e. **Direct series filtration**

Series filtration is a two-stage filtration process consisting of either an upflow or downflow filter as contact clarifier in the first stage, followed by a rapid gravity downflow filter as the second stage.

The application of the direct series filtration process for the treatment of South-African surface waters presents an economical option for the removal of turbidity from surface waters, as a result of the low-cost and ease of constructing these filters. For low turbidity waters only coagulation and direct series filtration need to be used, while for high turbidity waters the filtration step can be preceded by flocculation and settling.

Figure 6.4 shows a schematic lay-out of a direct series filter.

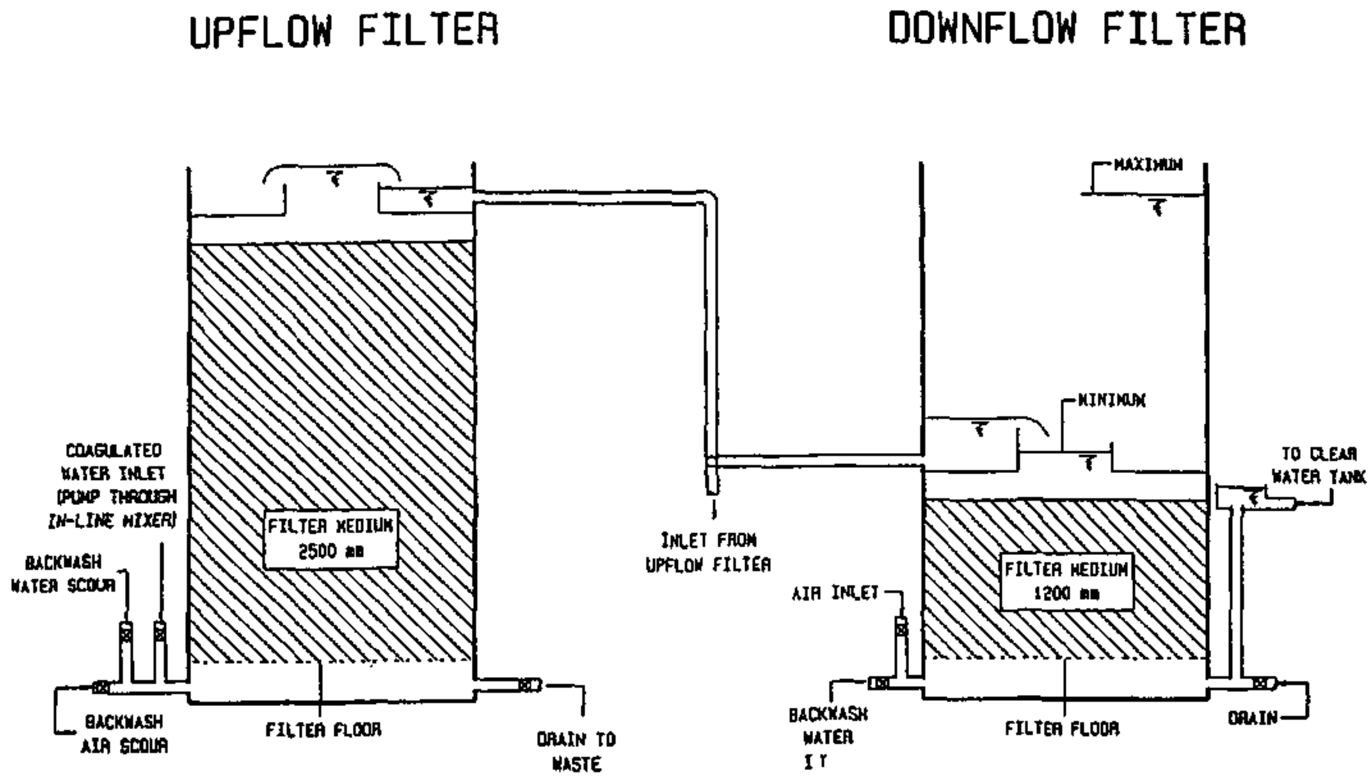


Figure 6.4 Direct series filter

Apart from lower capital costs, direct series filtration also has the following <u>benefits:</u>

- easy and economical upgrading of existing treatment systems
- flexibility because of the use of modular sections
- high filtration rates can be achieved
- low coagulant dosages.

Direct series filtration plants have been built at a number of locations in South Africa. Practical experience gained through operation of these full-scale plants indicates that (Swartz, Van der Walt and Van der Merwe, 1997) :

- the system consistently provides water of acceptable quality and quantity for small, developing communities

- by exploiting modular design and the use of prefabricated concrete pipe sections, capital cost savings of 20 % to 50 % are attained compared to conventional treatment

- indirect evidence suggests that coagulant savings of 20 % could be realised for series filtration

- with appropriate safety factors and degree of automation, the system can be successfully operated with limited operator skill, provided that competent technical back-up and guidance are provided at least monthly

f. Automatic self-backwashing gravity filter (also called valveless filter)

An innovative design of a gravity sand filter is the automatic self-backwashing gravity filter which is being used in both rural areas, and in some industrial water treatment processes. The advantage of the valveless filter is that it can be left to operate on its own without concern of the filter blocking. Once the head loss across the filter increases to a fixed value, the filter automatically goes into a backwash cycle and cleans the filter bed. No electricity is required for the filter to operate valves, etc., and because of the simple, robust design, very few problems due to breakdowns are likely to be experienced. Figure 6.5 illustrates the filter.

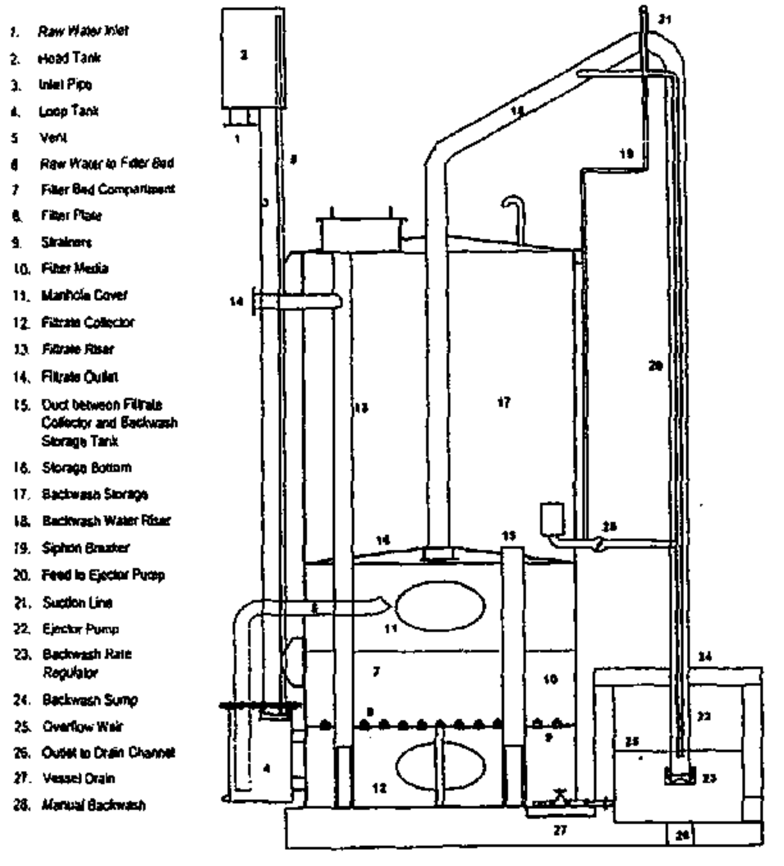


Figure 6.5 Automatic self-backwashing (valveless) filter

Shortcomings of the filter are that the cost is relatively high and that backwashing is not very efficient (because no air-scour is applied) resulting in gradual build-up of impurities in the media and short filter runs. There is also concern over the long-term robustness of the filter, especially corrosion of the construction materials.

In an attempt to improve the performance and robustness of this type of filter, and at the same time reduce the capital cost, Umgeni Water has recently embarked on a WRC project to investigate the filter and develop design criteria.

g. Roughing filtration

Sometimes a more limited treatment than conventional rapid filtration can be used for treating the raw water. This can be accomplished by using gravel or plant fibres as filter material in a filter system. In the upflow mode, three layers would be used having grain sizes of 10 - 15 mm, 7 - 10 mm and 4 - 7 mm from the bottom upward, and with a simple underdrain system. This coarse ("roughing") filter will have large pores that are not liable to clog rapidly. A high rate of filtration, up to 20 m/h, may be used. The large pores also allow cleaning at relatively low backwash rates since no expansion of the filter bed is needed. The backwashing of roughing filters takes a relatively long time, about 20 to 30 minutes.

Guidelines on the design and operation of roughing filters can be found in the book by Wegelin (1996).

Horizontal flow-roughing filtration is a treatment process that is based mainly on sedimentation, although with time, biological activity may also play a role. The suspended solids removed from the raw water will slowly build up in the filter. After some time, this will reduce the efficiency of the filter and ultimately lead to complete clogging. Efficiency can be restored by fully opening the underdrain system, and flushing out the deposits by fast drainage and a water spray on the surface. Nevertheless, some solids may remain and make subsequent fast drainage less effective and it may therefore become necessary to clean the filter material after several years. Cleaning can be carried out by removing and washing the filter material, and then replacing it.

h. Cross-flow sand filter

Dynamic cross-flow sand filtration is a special type of slow sand filtration. The major difference between these two types of filters is the way in which the raw water is fed into the unit. Instead of the standard 1 m static head of supernatant water on top of the filter bed in a typical slow sand filter, the dynamic filter has a running flow with a head of a few millimeters. Th effect of this cross flow is to push the heavier suspended solids over a weir at the end of the filter which then drains back into the river. Part of the flow percolates through the sand bed into the underdrain system, and is conveyed to a clear water well or reservoir.

The greatest benefit of the cross-flow sand filter is its cleaning simplicity, which comprises raking the sand surface for only a few minutes on a recommended daily basis. The main disadvantage is that large volumes of feed water is required which reduces the applicability of these filters to mountainous or hilly area where rivers have positive gradients and there is no need for pumping. The excess water overflows back to the river from where it was diverted.

More information on the evaluation of dynamic cross-flow sand filters by the CSIR, and design guidelines, can be found in the WRC Report No. 539/1/97 by Environmentek, CSIR (Kariuki and Solsona, 1997).

6.2.3 Coagulation and flocculation

Coagulation and flocculation is widely used for the removal of turbidity and colour. Both turbidity and colour are mostly present as colloidal particles (or true colour in solution). Colloids are kept in suspension by electrostatic repulsion and hydration.

Certain chemicals (coagulants) have the capacity to compress the double layer of ions around the colloidal particles which reject neighbouring particles. This reduces the electrostatic repulsion, and thus enable the particles to come together and join (*i.e.* to flocculate). The flocs so formed can grow by joining with more and more particles in the same way. When the flocs are of a sufficient size and weight they can be removed by settling or filtration.

a. Rapid mixing systems

Rapid mixing ensures the immediate dispersal of the entire dose of chemicals throughout the mass of the raw water. To achieve this, it is necessary to agitate the water violently and to inject the chemical in the most turbulent zone, in order to ensure its uniform and rapid dispersal.

Many devices are used to provide rapid mixing for the dispersal of chemicals in water. Basically, there are two groups, hydraulic rapid mixing and mechanical rapid mixing.

<u>Hydraulic rapid mixing units</u> that are used are:

- hydraulic jumps
- free falling water over a weir (0,5-1,0m)
- in-line mixer in a pipe (orifice plate)
- suction side of pumps

<u>Mechanical rapid mixing units</u> that can be used include electrical motors with impellers, propellers or turbines. Generally, mechanical rapid mixers are less suitable for rural treatment plants than hydraulic units since they require a reliable and continuous supply of power, as well as regular maintenance.

b. Flocculation systems

Flocculation is the process of gentle continuous stirring of coagulated water for the purpose of forming larger flocs through the aggregation of the minute particles present in the water. It is thus the conditioning of water to form flocs that can be readily removed by *settling or filtration.* The efficiency of the flocculation process is largely determined by the number of collisions which can be induced between the minute coagulated particles per unit of time. As for rapid mixing, there are both mechanical and hydraulic flocculators.

In mechanical flocculators, the *stirring* of the water is achieved with devices such as paddles, paddle wheels or rakes.

In hydraulic flocculators, , the flow of the water is agitated by hydraulic structures which cause a stirring action, such as channels with *baffles, flocculator chambers* placed *in series*, gravel bed flocculators, and hydraulic jet mixer type flocculators.

Baffled channels are the most common and can be either the over-and-under type or round-the-end type. Figure 6.6 shows the two different types of baffled channel flocculators.

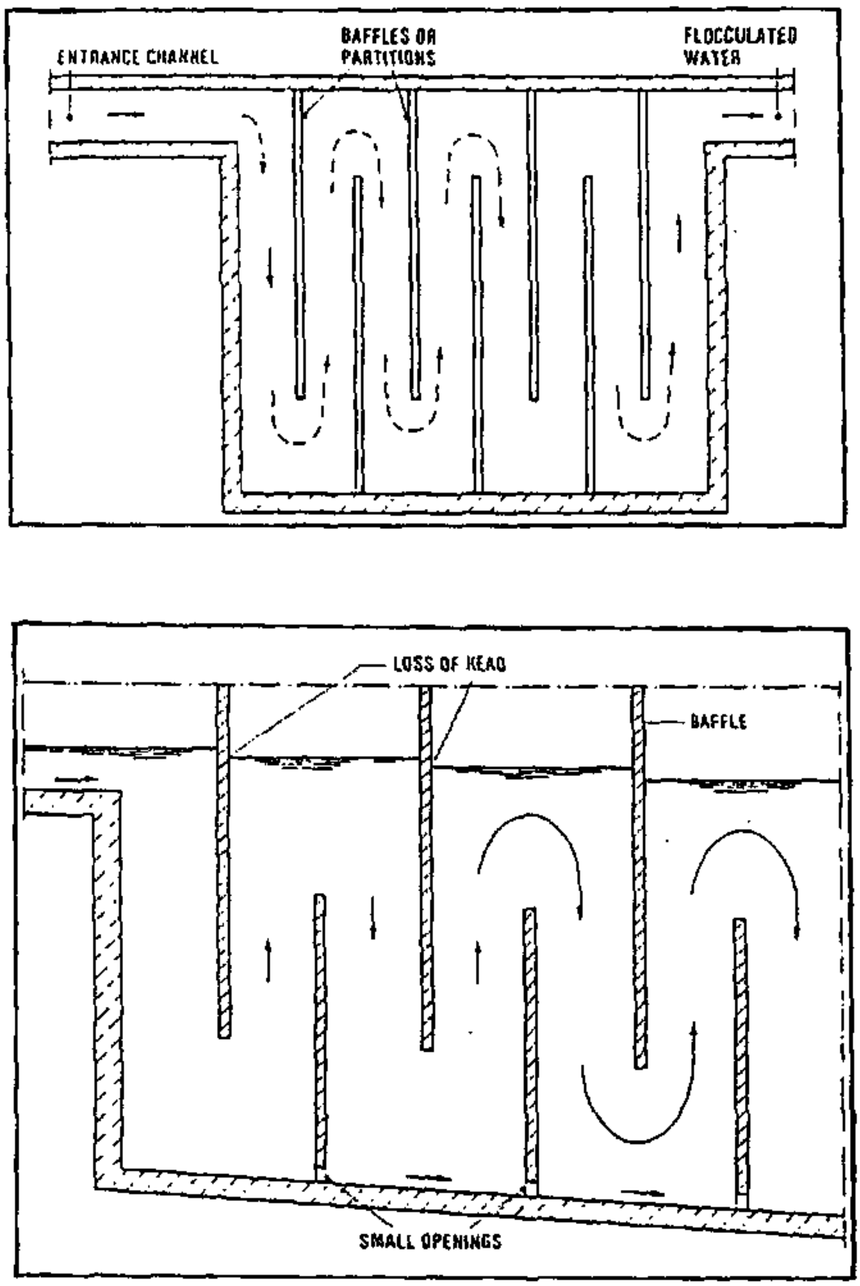


Figure 6.6 Baffled-channel flocculators

As with the rapid mixing units, hydraulic systems are preferred over mechanical ones for rural treatment plants, for the same reasons of power and maintenance requirements.

6.2.4 Sedimentation

Sedimentation is the settling and removal of suspended particles which takes place in static or slow flowing basins. Turbulence is negligible and particles having a specific weight greater than that of water will settle to the bottom of the settling basin.

Two basic types of sedimentation processes are generally used: the horizontal flow type and the upflow clarification type. Upflow type clarifiers work well under conditions of relatively constant hydraulic loadings and raw water quality. Horizontal flow type sedimentation tanks are more tolerant to shock hydraulic and water quality loads, mainly due to a longer detention time.

a. Horizontal flow sedimentation tanks

Horizontal flow settling tanks are rectangular types where the average horizontal flow rate remains constant along its full length.

b. Vertical flow clarifiers

Two basic types of vertical flow tanks have been developed during recent years (Fig. 6.7). The first type consists of a circular tank with the inlet in the centre and an annular section for clarified water on the outside.

The second design makes use of a fluidized floc bed known as a sludge blanket. The design of this type of tank is based on the fact that flocculated water is discharged near the bottom of the tank, which is shaped like an inverted pyramid. The turbulence or agitation caused in the bottom of the tank by the dissipation of kinetic energy enhances floc formation. The water then rises inside the inverted pyramid with decreasing velocity as a result of the widening horizontal diameter of the tank. The vertical velocity of the water is calculated to keep the floc particles in suspension in the lower part of the tank, with a sharp dividing zone between the suspension and the clear water above. The height of the floc bed is regulated by intermittent or continuous withdrawal of settled sludge.

Unlike the floc in a horizontal flow tank, the quality of floc in a vertical flow tank depends on the flow rate, which is therefore of critical importance. If the settling velocity of the finest particles is greater than the upflow velocity of the water inside the tank, they will settle out of suspension and clear water will be produced. If the velocity of settlement is, however, lower than the upward velocity of the water, all the finer floc particles will be carried over the top, with the result that the settled water will be very turbid.

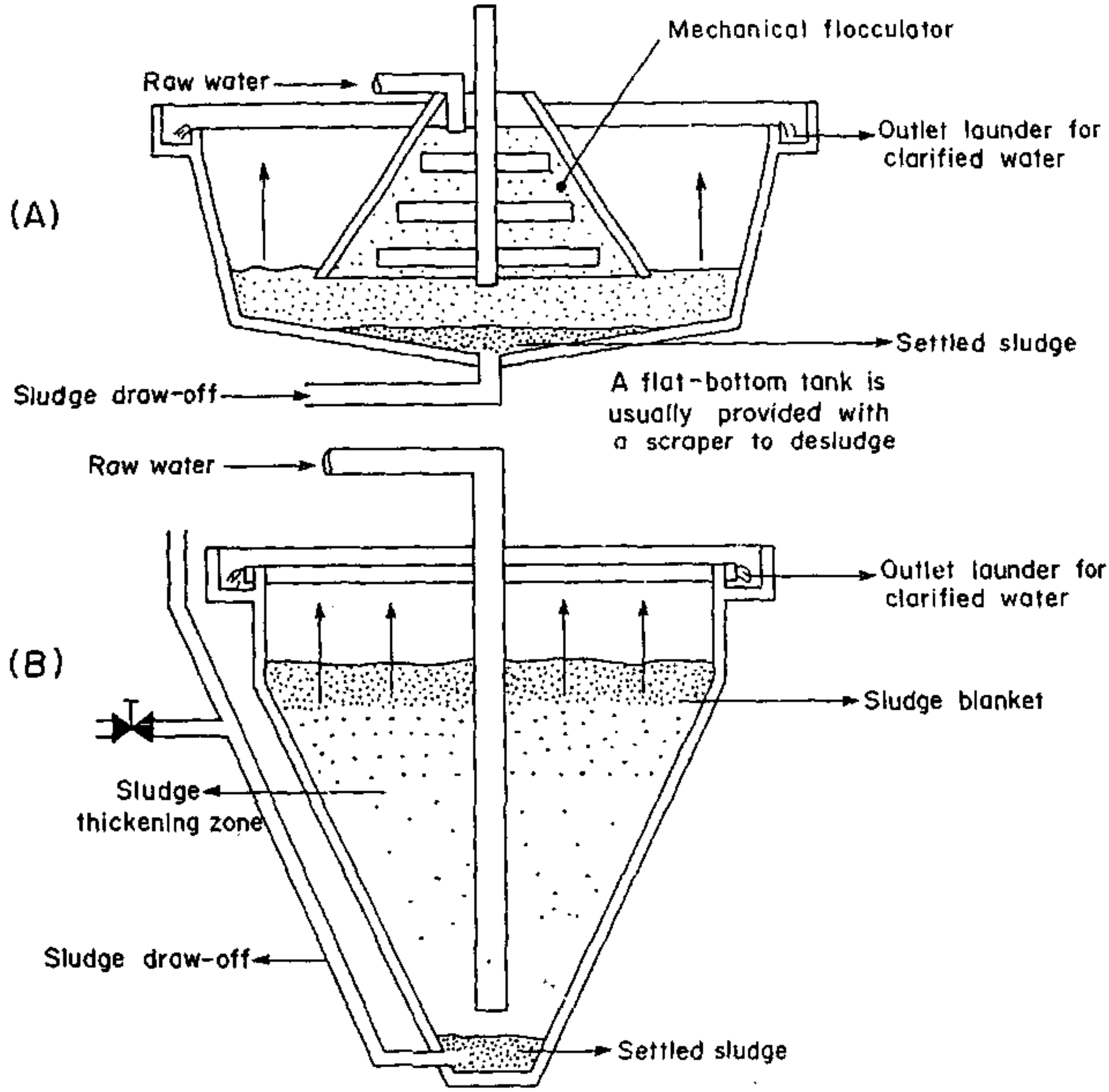


Figure 6.7 Vertical-flow sedimentation tanks

If very turbid water is flocculated, the sludge will constitute a considerable percentage of the total volume until it has had an opportunity to settle out completely and consolidate.

c. **Floc-blanket type sedimentation tanks**

A number of patented designs are available on the market, therefore only the basic principles will be mentioned. Their special feature is flocculation in the presence of previously formed floc; i.e. the 'floc blanket' principle is applied. Freshly dosed raw water is introduced at the bottom of a tank, causing the small floc particles to move upwards through a layer of settling floc particles which move downward. The small particles adhere to the larger particles.

The objective is to obtain a floc that will settle at a rate twice that of the upflow rate of the water. In some units a portion of the flocculated water is recirculated through the zone of agitation.

Tanks of this type are sometimes used in lime-soda softening units.

6.2.5 Oxidation

Oxidation is utilized for various purposes in water treatment. In particular oxidants are used to remove or destroy undesirable tastes and odours, to aid in the removal of iron and manganese, for disinfection, and to help improve clarification and colour removal. Oxygen, chlorine, potassium permanganate and ozone are the most frequently used oxidizing agents, and the use of each is discussed below.

For small water treatment systems, it is recommended that chlorine be considered before other oxidants since chlorine will normally be used for disinfection too. If the use of chlorine for oxidation is not practical, then the use of air, potassium permanganate or ozone could be evaluated on an economic basis. Aeration and ozone requires only a capital investment and perhaps ongoing pumping and electricity costs, as opposed to ongoing chemical costs for chlorination and the use of potassium permanganate.

6.2.6 Special treatments

a. Nitrate removal

In South Africa the recommended limit for nitrate in drinking water is 6 mg/ℓ as N. When waters have a high nitrate content, various methods are available to reduce this to within the recommended limits. Physical-chemical methods include ion exchange, reverse osmosis and distillation, while biological methods include algal ponds and denitrification.

b. Fluoride removal

When water supplies contain excessive fluorides, the growth of the bones and teeth of consumers can be adversely affected. This is often evidenced by the teeth of people using the water being mottled with a permanent black or grey discolouration of the enamel.

Three methods are normally used for fluoride removal. The first two methods employ ion exchange media, *i.e.* activated alumina or bone char, which remove the fluorides as the water percolates through them. The media are periodically regenerated by chemical treatment when they become saturated. In the third method, the fluorides are removed by alum flocculation and settling. The activated alumina ion exchange method is the most efficient, but also costly. The use of crushed bone or bone char has been successfully used in a number of rural applications, and is very cost effective due to the availability of the raw materials. Flocculation with alum is limited to reducing the fluoride content to about 15 mg/ℓ, which is still excessive for drinking water. However, it could be utilised as a first step when the natural fluoride content is very high.

c. **Desalination (brackish waters)**

A number of rural areas in Southern Africa are endowed with saline groundwater resources. A few methods are available for desalinating water, even in rural areas.

The age-old greenhouse type solar still has been tried and tested in many parts of the world. In particular the greenhouse type still has shown considerable potential for rural areas due to its simplicity. However, this still does suffer from problems of low efficiency and relatively high capital costs. Subsequently the cost per litre of fresh water obtained is relatively high. In an attempt to produce a small scale unit with lower capital cost, a solar still was developed by the CSIR for household applications. Further development is continuing in South Africa, also by other institutions.

Reverse osmosis membrane systems have been developed for small scale and household use. The so-called "tap water" units which rely on a low pressure to desalinate are not suited to the high salinity waters (3000 mg/ℓ and more) generally encountered in the problem regions. The alternative reverse osmosis (RO) systems for desalinating brackish water sources require some additional pumping mechanism to pressurise the water on a continuos basis to 15 bar or more. To date, only a few RO units have been installed in South Africa for rural water treatment plants, amongst them the Bitterfontein municipal plant in the Northern Cape. However, such units are fairly widely used in countries where brackish water problems are more severe, such as India.

d. Algae removal

Simple treatment methods are available to treat algae laden waters. These methods are low cost and low maintenance alternatives which are well suited to rural areas. Six methods of interest are presented here, these being slow sand filtration, horizontal roughing filtration, sedimentation, flotation, in-line filters and oxidation with chlorine.

Algae entering a slow sand filter with the raw feed water will be captured in the *Schmutzdecke* and upper sand layer. The algae may also proliferate in the supernatant water. These algae will be beneficial to the treatment process if they are in moderate numbers. Algae add oxygen to the water and filter out certain nutrients and even some metals.

Techniques to prevent or control troublesome algae growth in slow sand filters include pre-treatment, shading, chemical treatment, biological methods and manual removal.

Algae is removed to a large extent in a horizontal roughing filter (HRF). It is also not necessary to cover or shade a HRF as the water remains within the gravel and is not exposed to the surface.

Sedimentation and flotation provide effective means of removing algae (Haarhoff and Van Vuuren, 1993).

NOTE!

While flotation provides an effective means for algae removal, cognisance should be taken that operation of flotation systems requires more attention and skills

In-line cartridge filters and filter screens which are commercially available can be very effective in removing algae, particularly filamentous algae. However, the filters will block fairly rapidly under conditions of high algae loads, and the replacement of cartridges or the cleaning of screens may be expensive and tedious.

Chlorine and other oxidants can be used to inactivate algae cells by attacking the cell walls and reacting with the internal contents. Having inactivated the cell it is more easily removed from the water by conventional or other treatment processes. The use of chlorine for algae control may result in the formation of unpleasant tastes or odours in the water when certain species of algae are present.

e. Organics removal (pesticides, etc.)

The method most suitable for organics removal is activated carbon adsorption. The water is passed through a bed of carbon granules where adsorption of the organics into the fine pores of the carbon particles, takes place. The capacity of the carbon to adsorb organics depends on a number of factors, including the type of carbon used and the type of organics present.

Other methods for removing organics include the desalination methods described above, ultrafiltration (similar to reverse osmosis but using a membrane with larger pores) and oxidation. Oxidation methods will not remove organics, but rather convert the existing organics to other more acceptable compounds.

6.2.7 Package treatment plants

A number of package type treatment plants are commercially available. The conventional plants usually include the following unit processes combined into a complete and compact unit: coagulation and flocculation, filtration and disinfection.

Other package treatment systems which have been developed for small scale water treatment include crossflow microfiltration systems, diatomaceous earth filtration plants, ceramic microfiltration plants and membrane ultrafiltration plants.

These package treatment plants are available in standard modular sizes and hence the capacity of the treatment plant can be built up by incorporating a number of modules in parallel. It is important to assess the operation and maintenance requirements for such plants to ensure that the community utilising the plant will reasonably be able to operate and maintain it.

Because of the variety of package treatment systems that have been developed, Umgeni Water undertook a WRC funded project to evaluate the systems according to a number of criteria relating to its appropriateness for use as treatment system for small communities. A report giving the results of this evaluation of South African package plants has been published and provides guidance in the selection of a suitable package treatment system (WRC Report No. 450/1/97 "Package Water Treatment Plant Selection").

The main findings of the report is as follows :

a. **Water treatment performance**

- Disinfection : Adequate disinfection was obtained where sufficient chlorine contact time was provided.

- Turbidity and Aesthetics : Excellent turbidity removal, beyond that required for potable water was achieved with the two microfiltration units. The dual media and upflow filter systems produced water with a turbidity well below 1 NTU for most of the evaluation period.

- Sludges and Effluents : Most of the plants produced effluents containing various combinations of suspended solids, water treatment chemicals, filter media and cleaning chemicals. Provision for handling and disposal of these waste products must therefore be included in the design phase of water supply schemes where package water treatment plants will be used.

- Robustness and Reliability : In general, the choice of materials in all plants was satisfactory and no failures due to inappropriate materials occurred during the evaluation period.

- Potential for upgrading capacity : The only system in which significant potential for increasing the treatment capacity exists is the crossflow microfiltration unit. The purchase and installation of additional crossflow modules represents a relatively inexpensive method of increasing plant capacity. In all the other systems, significant increases require the purchase of additional package units.

- Control systems : Six of the systems were manually controlled, two were partially automated and two were fully automated. On the whole, the control systems were effective but in many cases, inexpensive modifications were required to improve the overall reliability of the process and reduce the operating workload. Since most manufacturers have attempted to minimize the capital costs, there is a lack of alarm systems or automated cut-outs which shut off the plants when an alarm condition arises. The addition of automated cut-outs for high filter pressures or low chemical tanks levels will remove the requirement for the plant to be continually manned while in operation and will decrease the risk of mechanical failurer or contamination of the treated water supply.

b. Maintenance requirements

Regular maintenance is essential to ensuring that package water treatment systems function correctly. Most of the spares and consumables required for the units that were evaluated are available locally.

c. Operation and operator training requirements

Proper operation of package water treatment plants is essential if a reliable supply of potable quality water is required. The ten systems under investigation were rated in terms of cmplexity of operation on a scale which varied from simple to expert. Recommendations are made for each system with respect to the skills and training that an operator would require. This is an important aspect that will provide a guide as to the level of operator skill required for any of the systems. Recommendations for the content of package plant operating manuals are also provided.

6.2.8 Point-of-entry (POE) units

Point-of-entry (POE) units treating water for an entire household can be an alternative to centralised treatment technology for small systems. The POE water treatment industry is growing rapidly, also in South Africa. It can be an cost-effective solution to very small systems and individual homeowners, eliminating some of the problems small systems face when attempting to finance and operate central treatment facilities. However, the assurance of long-term maintenance and monitoring of POE technology and its performance remains the main problem to be dealt with. It is therefore not applicable or recommended for small water systems in the context of this report.

NOTE!
It is important to note that bacteriological contamination of the filtration media in point-of-entry systems can take place during prolonged use, which may result in deterioration of the microbiological quality of the treated water.

6.3 MEASURES FOR UPGRADING EXISTING TREATMENT PLANTS

6.3.1 General measures

General measures that can be taken for upgrading existing small plants, either to increase its capacity or to improve the quality of the treated water, or to make provision for changes in raw water quality, are the following:

- **Increase capacity (supply more treated water)**

  - increase pumping of
    - raw water
    - treated water
  - increase reservoir capacity
  - increase hydraulic capacity for channel flows, pipe flows, retention times
  - increase unit process capacities to keep flow rates (settling rates, filtration rates, Cl_2 contact time) to within design limits, by
    - temporary measures
    - retrofitting
    - expansion (new reactors/structures)
  - replace instruments/meters to handle higher flow rates
  - modular expansion (package plants, series filtration)

- **Increase treatment efficiency (provide better quality final water at optimum cost)**

    - improve process control
      - chemical dosing
      - settling tank desludging
      - filter backwash
      - slow sand scraping
    - control flow rates (flows more balanced - never too high)
    - improve individual process efficiency through physical changes, retrofits or new processes
      - improve settling
      - improve floc formation (flocculation)
      - rapid mixing system
      - filter media
      - inlet and outlet arrangements
      - *chlorine contact tank and residence time*

    - do regular and correct monitoring for process control
    - use more reliable equipment (*e.g.* dosing pumps)
    - handling of process upsets (correct procedure; timeous action)
    - add polishing process
    - add pre-treatment process
    - better reporting
    - regular optimisation of process by consultant

- **Change type/purpose of treatment (changed raw water quality)**

    - add/remove unit processes
    - change treatment train
    - provide balancing facility (*e.g.* earth dam between river and plant)
    - substitute unit processes

6.3.2 Specific measures

Specific measures can be undertaken or remedies performed to upgrade the capacity or performance of existing unit processes in small water systems. It also include measures that can be taken to provide better operation and control of unit processes to ensure that each unit process produces the quantity and quality of water that it was intended to do, in a cost-efficient manner. The emphasis is also on sustainability of the operation of these processes. The reader should consult Chapters 7 and 8 for more detailed design and operational guidelines on the various unit processes for which upgrading measurements are given below.

a) Disinfection

PROBLEMS AND/OR UPGRADING REQUIREMENTS	UPGRADING MEASURE
∘ Insufficient chlorine contact time	Provide chlorine contact channel/tank to provide contact time of at least 15 minutes
• Unreliable chlorine dosing system	- Use a dosing pump for dosing sodium hypochlorite or use a suitable alternative means of controlled chlorination (propriety systems) - Dosages must be flow related - Chlorine dosage should be uninterrupted - Chlorine residuals in the final water must be determined on at least a 4-hourly basis, and chlorine dosage maintained to produce a minimum free chlorine residual in the final water at all times (minimum level will depend on the chlorine demand of the water and the size of the distribution network)

b) Filtration

PROBLEMS AND/OR UPGRADING REQUIREMENTS	UPGRADING MEASURE
• Poor quality filtered water	- Provide correct type of filtration system for the particular application (see Chapters 6 and 7). This may mean replacing *e.g.* a slow sand filter with a rapid sand filter, or converting the slow sand filter to a rapid sand filter(s) - Add additional filters to ensure that filtration rates are kept within the specified limits - Replace sand, making sure that correct gradings are used - Use dual or multi media rather than single medium - Provide better backwashing facilities for rapid sand filters - Draw up and keep strictly to a suitable backwashing program for the particular treatment plant (frequency/duration) - Scrape and clean *Schumtzdecke* from slow sand filters in the prescribed manner (frequency/method of washing) - Monitor head loss and filtrate quality on at least a daily basis (turbidity measurement)

c) **Coagulation and flocculation**

PROBLEMS AND/OR UPGRADING REQUIREMENTS	UPGRADING MEASURE
• Inadequate chemical mixing	- Provide hydraulic jump, mixing-race or in-line mixing device (*e.g.* pump or static mixer) to ensure good mixing of the coagulant with the water
• Incorrect placing of chemical dosing points	- Place dosing points where sufficient mixing of the chemical(s) can be obtained
• Inadequate floc formation	- Provide flocculation retention time t of at least 10 minutes, but preferably 20 minutes - Ensure that mixing intensity (measured by velocity gradient G) is not too high (causes floc break-up) or to low (causes poor floc growth or settling in the flocculator) - Thus, extend flocculation facilities or provide new facility based on correct G and t values (and temperature effects) - Provide dosing facility for polyelectrolyte or weighting agent for providing a better floc prior to settling and/or filtration

• Dosage control inadequate (underdosing or overdosing takes place)	- Draw up charts and/or tables with prescribed dosages based on raw water quality, and provide training to process controllers on how to monitor and control the dosages - Allow for changes in flow rate through the treatment plant

d) Sedimentation

PROBLEMS AND/OR UPGRADING REQUIREMENTS	UPGRADING MEASURE
• Poor performance of settling tanks (floc carry-over)	- Provide additional settling tanks if settling velocity becomes too high - Use flocculant/weighting agent to increase settling rate and thereby improve the clarification process - Modify inlet arrangement into the settling tank so that floc break-up does not take place - Modify outlet arranged to ensure that overflow rate does not exceed design values - Improve desludging facilities (better sludge draw-off) - Draw up program for regular desludging and show process controllers how to monitor depth of sludge blanket

6.4 CRITERIA FOR EVALUATING UPGRADING OPTIONS

The following checklist can be used to evaluate the different upgrading options with the view of selecting the most suitable process for a specific situation:

6.4.1 Cost

a. *Capital Cost*

The *capital cost of any civil works and/or mechanical/electrical* equipment must be determined. Quotes can be obtained for mechanical equipment, while estimates of civil works costs can be obtained from consulting engineers.

The following table will be useful in determining the capital costs:

Technical part	% of total investment	Depreciation period	Expected operating lifetime
Civil works	35 - 45	30 years	15 years
Process equipment	30 - 40	12 - 16 years	15 years
Electrical equipment	15 - 20	10 - 15 years	15 years
Process control	10 - 20	2 - 10 years	15 years

b. Operating Cost

The operating cost of each unit must comprise of

- labour
- chemicals
- energy
- maintenance costs

Each of these must be estimated to give the planner an appreciation of the cost per unit volume of water produced by each unit process.

6.4.2 Performance of the Upgrading Options

a. Raw water supply

The following information will be available for the plant under consideration from the evaluation of the existing condition of the treatment plant:

- head and flowrate of the raw water supply
- quality of raw water

b. Disinfection performance

The effectiveness of the removal of microorganisms by the treatment option must be addressed with regard to:

- provision of a residual
- consumption of the disinfectant
- ease of maintaining dose concentrations
- safeguards against over or under dosing
- disinfection by-products
- position of dosing points
- taste and odours caused by disinfection
- results of experience gained at other plants using the option/system

c. Turbidity and suspended solids removal performance

The capability of the treatment option should be assessed in terms of:

- the range of raw water turbidities that can be treated to produce acceptable potable water
- the relationship between turbidity removal and chemical consumption
- the proportion of turbidity removed by the clarification and filtration processes

- the susceptibility of the plant to water demand and raw water quality variations
- the water recovery that the process can achieve (*e.g.* backwash water)
- long term decline in the performance of filters

6.4.3 Reliability

The reliability of the treatment plant and its control system must be assessed. The following are important:

- the length of time for which the plant can run without supervision
- incidents of failure during operation and the provision of standby capacity
- circumstances under which untreated and unfinished water can enter the potable water distribution system
- facilities for automatic shutdown in the event of power or component failures
- the delicacy of instruments or automation devices where this restricts the range of potential applications for the plant
- the possible effects of final water quality during process or control system failures

The materials of construction is important in evaluating the expected life of the treatment plant. The materials should comply with the following:

- suitable physical properties (strength, toughness, thermal and chemical tolerance)
- appropriately coated or treated to minimise corrosion, weathering and wear and tear
- no interaction with other adjacent materials in a way that will accelerate corrosion or wear

- not impart undesirable corrosion products or toxic compounds to the water being treated

6.4.4 Operation and Personnel Requirements

A thorough evaluation is made of the workload and required level of competence for each category of personnel.

a. Estimation of operational requirements

The workload and personnel resources required for operation of the plant must be estimated, using the following as guidance of the type of functions of plant personnel:

- sampling
- analysis
- desludging
- backwashing
- replenishment of chemicals
- data management and administration
- cleaning

b. Training requirements for personnel

- Determine the educational or skill level required
- List the training required for the process controller:
  - replenishing chemicals
  - report faults
  - manipulate controls
  - sampling
  - perform simple cleaning and maintenance
  - determine chemical dosages
- Determine the availability of training and operating manuals in the operator's home language

6.4.5 Automation

The degree of automation and the reduction in manual workload that results from automation the following is considered:

- automation of chemical dosing, replenishment and calibration
- control of flowrates
- control of sedimentation tank desludging
- control of filter backwashing

The following factors must also be assessed:

- the effect of the automation system on the susceptablility of the plant to water demand fluctuations
- the effectiveness of automated facilities for shut-down or reducing the flowrate as well as the effect on treated water quality of operation at flows greater than the design capacity

6.4.6 Process Sophistication

The following aspects should be evaluated:

- the number of valves, pumps, control loops, electrical switches and circuits used
- the number of calibrations and settings that need to be made
- the maximum working pressure and the power consumption of the process
- the level of sophistication and additional risks of failure introduced by the complexity
- the type of cleaning methods that are used
- the number of custom made components that can only be repaired or replaced by the supplier
- comments on each component discussing its suitability in terms of type, capacity and materials of construction

6.4.7 Maintenance Requirements

The servicing and maintenance requirements must be assessed:

- pumps, valves, pipework and instruments
- maintenance schedule provided by the suppliers
- availability of spares from suppliers and alternative sources
- maintenance tasks requiring special skills or tools
- the feasibility of entrusting the process controller with certain maintenance tasks

6.4.8 Infrastructure Requirements

The following aspects relating to infrastructure for and around the plant must be considered when evaluating upgrading options:

- road access
- power requirements
- drinking water distribution network
- sludge disposal
- chemical storage facilities
- weather protection

6.5 TRAINING OF PLANT PERSONNEL

Training of waterworks personnel has in the past been virtually confined to in-service training at the water treatment plants. Even then, this was no always practised at all the water care plants and in many instances water treatment systems had to be operated by unskilled or semi-skilled operators.

The CSIR Water Care Programme has for many years provided successful on-site training programmes for treatment plant personnel, which included both basic knowledge of water treatment processes and skills in operating treatment plants (operation, monitoring and maintenance) This service by the CSIR was aimed largely at rural water treatment plants in the former self-governing states, where there was the greater need for this training.

Formal training programmes for Water Care personnel is also available at certain Technical Colleges, leading to National Technical Certificates N1, N2 and N3, as well as at Technikons, where a Diploma in Water Care can be obtained, and, more recently, a B.Tech qualification in Water Care.

The subject matter covered in the certification programmes normally consist of the following (but is obviously subject to change according to requirements and new developments) :

[Only the water treatment subject matter is given].

WATER TREATMENT PRACTICE N1

A. Theory
   1. General introduction
   2. Usages of water
   3. Water sources, supplies and the environment
   4. Water quality
   5. Water treatment

B. Visits to water treatment plants

C. Practical
   1. Elementary laboratory procedures and practice
   2. Elementary control tests

WATER TREATMENT PRACTICE N2

A. Theory
   1. Water quality
   2. Conventional water treatment

B. Visits to water treatment plants

C. Practical

1. Elementary laboratory procedures and practice
2. Control tests

WATER TREATMENT PRACTICE N3

A. Theory

1. General
    - a. The international metric system
    - b. Elementary calculations
    - c. Elementary hydraulics
    - d. Pumps and valves
    - e. Distribution systems
    - f. Elementary water chemistry
    - g. Elementary water biology
    - h. Legislation
    - I. Water sources
    - j. Water quality and specifications

2. Water treatment
    - a. Treatment and units prior to filtration
    - b. Sedimentation
    - c. Filtration
    - d. Disinfection
    - e. Stabilization
    - f. Special treatment processes
    - g. Sludge treatment and disposal
    - h. Process control and record keeping
    - I. Occupational hazards and safety measures

B. Visits to water treatment plants

C. Practical

1. Elementary laboratory procedures and practice
2. The use of standard solutions
3. Analytical determination
4. The use of test kits and its limitations
5. Interpretation of results

Training programmes for water works personnel are also provided in some areas by private companies and water utilities which are offered either on-site or at a centralized training centre.

Process controllers at small water treatment systems should be provided the opportunity to undergo some form of formal training in water treatment or water care, as part of his or her career planning. It is considered **essential** both for improving the quality of life in the community by provision of a better water supply service, as well as capacity building within the community itself for providing their own services and infrastructure.

More information on training programmes can be obtained from the Technikons and Technical Colleges offering these courses whilst the Water Research Commission has published a report giving the Occupational Competencies for the Occupation of Watercare Operator and Water Care Manager (WRC Report No KV55/94, 1994).

CHAPTER 7

DESIGN CONSIDERATIONS AND GUIDELINES

7.1 REFERENCES

Once a selection of a treatment process or processes has been made to be used in upgrading a small water treatment system, it will be necessary to size the unit systems and specify its outlay and materials of construction, all based on sound engineering principles. This should be done to ensure that the treatment plant as a whole, and the unit processes individually, will be able to produce the required quantity of water of a quality complying with the needs for health and hygiene, aesthetics and stability.

This chapter provides the design considerations and guideline values to be used when sizing unit treatment processes for small water systems, consisting of coagulation and flocculation, sedimentation, filtration, disinfection and stabilisation.

The following design manuals and guideline documents were used in compiling this chapter :

Guidelines on the Technology for and Management of Rural Water Supply and Sanitation Projects.

Report to the Water Research Commission by the Appropriate Technology Group, Water Care Programme, Division of Water Technology, CSIR. WRC Report No. 231/1/93. December 1991

Water Purification Works Design.

F A van Duuren (Editor). Water Research Commission. 1997

Design Guidelines for Small Water Purification Works.
Report to the Water Research Commission by WM Malan, Department of Civil Engineering, University of Stellenbosch, Stellenbosch. Draft Final Report. December 1997

Coagulation and Flocculation.
Bratby, John. Upland Press Ltd. Croydon, England. 1980

Guidelines on Hydraulic Flocculation.
Division of Water Technology, CSIR Technical Guide by Felipe Solsona. October 1990

Surface Water Treatment by Roughing Filters : A Design, Construction and Operation Manual.
Martin Wegelin. Swiss Centre for Development Cooperation in Technology and Management. October 1996

Guidelines for the Treatment of Cape Coloured Waters.
Report to the Water Research Commission by the Division of Water Environment and Forestry Technology, CSIR. WRC Report No. 534/1/98. 1998

Manual on Water Purification Technology.
National Institute for Water Research, CSIR. CSIR Technical Guide K73 1995

7.2 COAGULATION AND FLOCCULATION

In general, water treatment processes making use of chemicals are not the best option for small community water supplies, and should be avoided where possible. Chemical coagulation and flocculation should only be used when the required treated water quality cannot be achieved with an alternative nonchemical treatment process (for example slow sand filtration).

Coagulation and flocculation will usually be required when the suspended solid load would cause filters to block too rapidly, when flocculation facilities have already been provided, when space limitations preclude the use of slow sand filters, or when the colloidal matter present in the water is too fine to be removed even by slow sand filters. Some plants have been designed to dose coagulants only when the incoming turbidity is greater than some predetermined value.

<u>Rapid mixing</u>

Rapid mixing aims at the immediate dispersal of the entire dose of chemicals throughout the mass of the raw water. To achieve this, it is necessary to agitate the water <u>violently</u> and to <u>inject the chemical in the most turbulent zone,</u> in order to ensure its uniform and rapid dispersal. The requirement for rapid mixing is based on the property of the coagulant which results in very rapid hydrolysis of the coagulant (within a few seconds). Coagulants which have hydrolysed are less available to destabilise the colloids which the treatment process is aimed at removing. The destabilization of colloids is also very rapid, and hence optimum results are obtained when the coagulant is mixed with the water <u>very rapidly (within one or two seconds).</u>

Utilization of a hydraulic jump downstream of a Parshall flume is one of the most practical methods used in rural areas. This provides the additional advantage of flow measurement in the Parshall flume. Rapid mixing may also be achieved by feeding the chemicals at the suction side of pumps. With a good design, an hydraulic mixer can be as effective as a mechanical mixing device.

RAPID MIXING
Agitate water violently and inject the chemical in the most turbulent zone very rapidly (within one or two seconds)

Flocculation

The energy input for flocculation (as measured by the velocity gradient G) must be high enough to achieve the particle contacts necessary to promote aggregating and floc growth. However, they must not be so high as te lead to floc shear or floc break-up. Floc produced by organic polymers may be stronger than those produced from Fe (III) and Al (III) salts, and can withstand higher shearing stresses. In the case of floc rupture, reaggregation is more likely to occur for Fe (III) and Al (III) flocs than for polymer flocs, because the polymer segments that become detached may fold back and restabilise the particle.

The optimum velocity gradient depends on the coagulant used. For Fe (III) and Al (III) experience has shown that gradients between 20 and 70 s^{-1} gives best results.

The detention time in a flocculation basis is also an import parameter because it determines the amount of time that particles are exposed to the velocity gradient and gives a measure of contact opportunities in the basin.

A detention time of 20 - 30 minutes is usually considered satisfactory, but for certain types of water 10 minutes may suffice.

FLOCCULATION
$G = 20 - 70\ s^{-1}$
$t = 10 - 30$ minutes

Further information on the design of hydraulic flocculation systems is given in the Division of Water Technology, CSIR guide: " Guidelines On Hydraulic Flocculation", as well as the handbook by John Bratby, "Coagulation and Flocculation".

Choice of coagulant/flocculant

Extensive tests should be carried out on the raw water in order to ensure that the coagulant(s) and/or flocculant(s) that are selected will indeed give the best results. Such tests should preferably be carried out over a period of one year, in order to assess that quality of the raw water during all seasons of the year.

In deciding which coagulant(s) flocculant(s) would be most desirable, the following factors should be considered:

- transport and handling costs
- volume of sludge produced
- length of filter runs.

Coagulant dosage and coagulation pH

For good coagulation, the optimal dose of coagulant should be fed into the water and properly mixed with it. The optimal dose will vary depending upon the nature of the raw water and its overall composition. It is not possible to compute the optimal coagulant dose for a particular raw water. A laboratory test called the "jar test" is generally used for the periodic determination of the optimal dose. It is also used to determine (less frequently) what the optimum pH range is for good floc formation.

7.3 SEDIMENTATION

In water treatment plants, sedimentation is used to remove readily settleable particles, flocculated or coagulated impurities, and precipitated impurities from softening operations.

The following factors influence sedimentation:

(a) Size, shape and density of the floc.
(b) Temperature and hence viscosity of the water.
(c) Effective average period available for sedimentation.
(d) Effective depth of the basins.
(e) Basin surface area.
(f) Surface overflow rate.
(g) Velocity of flow.
(h) Inlet and outlet design.

7.3.1 Retention time

The retention time in a tank is the time required to fill the tank at the normal rate of flow; for instance, a tank of 100 m^3 capacity would provide a retention period of 4 h at a flow of 25 m^3/h. Unfortunately, it is a poor parameter, and often bears little resemblance to the actual displacement period because of short-circuiting through the tank.

Some regulatory agencies have arbitrarily required water plant clarifier detention periods of as much as 6 h. Some texts suggest 2 to 4 h, which is not too unreasonable when compared with 6 h. Sedimentation tanks should not be designed on the basis of retention period.

RETENTION TIME
This parameter should not be used as the basis for design of a settling tank

7.3.2 Upward flow velocity

This is expressed in metres per hour or in unit volume per unit area per day. The establishment norms are based on the rate of sedimentation of floc. Well-formed dense floc settles at the rate of about 3 m/h. The upward flow velocity should not exceed one half of this value; *i.e.* 1,5 m/h upward velocity or 36 $m^3.m^{-2}.d^{-1}$. This rate when related to a basin of 3 m, gives a retention period of 2 h.

In practice, factors of safety are provided by selecting lower rates. For instance, an upward velocity of 0,75 m/h or a rate of 18 $m^3.m^{-2}.d^{-1}$ provides a retention period of 4 h and a velocity of approach to outlet weirs low enough to avoid carrying fine floc over in the effluent, provided that the length of the outlet weir is selected accordingly.

UPFLOW VELOCITY
Upward flow velocity must be less than 1 m/h

7.3.3 Weir loading rate

Water leaving the sedimentation tank should be collected uniformly across the width of the tank to prevent high velocities of approach and consequent lifting of the settled sludge over the weir.

Combinations of clarified water orifices ahead of the submerged weir provide efficient outlet arrangements and reduce short-circuiting. A useful, empirical parameter for the weir loading rate is 6,25 m^3/m length of weir/h.

In general, the weir trough group should be distributed from the clarified water end to about halfway toward the influent end. The low flow requires that the weirs be level so as to ensure distribution of the water over their full length. Distribution is facilitated by using 90 $^{\circ}$ V-notches about 15 cm apart and 5 cm depth.

WEIR LOADING RATE
Must be less than 6,25 m^3/m weir length/h

7.3.4 Inlet arrangements

Many tanks have no provision at their inlets for evenly distributing flocculated water, such as an influent channel with openings spaced across the tank. This is serious, as high entering velocities tend to destroy well-formed floc and lead to short-circuiting or turbulent flow. A transverse baffle may be installed to dissipate the energy of a concentrated inlet current, but the best procedure is to use a transverse baffle and also to install a stilling wall about 3 mm from the inlet end of the tank.

Sometimes a false wall having open, checkered brickwork is built into the influent end to provide good lateral distribution. The spacing and net amount of openings must be designed correctly and for one flow rate.

There must be enough head loss for good distribution but not enough to cause floc break-up.

7.4 FILTRATION

7.4.1 Slow sand filtration

In order to guarantee good microbiological filtration in a slow sand filter, attention should be paid to ensuring:

- favourable conditions for biological activity in the water above the sand (including the *Schmutzdecke*), *i.e.* no disinfectants.
- slow filtration rate (0,1 $m^3/m^2/h$); and
- favourable raw water quality (pretreated by sedimentation only, no chemical additives like coagulants, chlorine, etc.)

a. Filter media

To prevent penetration of suspended material, the media must be fine and must not be evenly graded. Typical specifications for sand for slow sand filters are as follows:

- effective grain size : 0,15 - 0,30 mm
- size range : 0,1 - 4 mm
- uniformity coefficient : <3

b. Summary of design criteria for slow sand filters

Design parameters for slow sand filters are given in Table 7.2.

Table 7.1. Design criteria for slow sand filters in rural water supply

Design criteria		Recommended level
Design period		10 to 15 years
Period of operation		24 h/d
Filtration rate in the filters		0,1 to 0,2 m/h
Filter bed area		5 to 200 m^2 per filter, minimum of two units
Depth of sand layer:	Initial	0,8 to 0,9 m
	Minimum	0,5 to 0,6 m
Specification of sand:		
Effective size		0,15 to 0,30 mm
Uniformity coefficient		<3
Height of underdrains including gravel layer		0,3 to 0,5 m
Maximum height of supernatant water		1 m

7.4.2 Rapid filtration

For the design of a rapid filter, three parameters need to be selected:

- grain size of the filter material
- depth of the filter bed
- rate of filtration

These parameters may often be more easily selected by comparison with existing plants treating the same or a comparable water, or by carrying out pilot scale experimental evaluations. Design equations do exist but cannot always be relied upon because of the wide difference in the quality and type of solids found in the waters to be treated.

a. Filter media

The underdrain system is usually made of perforated laterals covered with graded layers of gravel, broken stones or hard bricks chipped to the desired size. The sand to be used in the main filter bed should be graded using suitable sieves to give a uniformity coefficient of 3.0 or less. Effective grain sizes for sand filters used as prefilters or final filters should be 0,8 mm to 1,2 mm; and 1,0 mm to 1,5 mm for iron and manganese removing filters. For prefilters and final filters the sand bed thickness should be 1,0 to 1,2 m and for iron and manganese removing filters 1,5 m. In the event that sand cannot be obtained, similar materials may be used, such as crushed stones or bricks, crystalline calcium-carbonate, dolomite, etc. These should be graded to a size about 40 % larger than the sizes mentioned above. Before the filter is commissioned it should be back-washed for about half an hour to clean the filter material.

b. Backwashing

If possible, filtered water should always be used for back-washing. Filtered water can be stored in an elevated tank for this purpose, or the filtered water from other operating filter units of the filtration plant can be used directly("self-wash arrangements"). The velocity of the upward water flow should be sufficient to produce an expansion of the filter bed. For a filter bed of sand (S.G. = 2,65) typical back-wash rates giving about 20 % expansion are given in Table 7.3.

Recent research to improve the efficiency of backwashing of rapid sand filters has been aimed at minimizing the shear velocity (force) of backwashing to the point where the bed just starts to expand, say at 5 %, and that air is used together with water for backwashing. Considerable work is also directed into the improvement of nozzle design, and selection of the correct type of nozzle for a particular application.

Table 7.2. Backwash-rates for different filter media in rapid sand filters

BACKWASHING RATES IN m/h FOR DIFFERENT EFFECTIVE GRAIN SIZE									
Temp (°C)	Effective grain size (mm)								
	0,4	0,5	0,6	0,7	0,8	0,9	1,0	1,1	1,2
10	12	17	22	28	34	40	47	54	62
20	14	20	26	33	40	48	56	64	73
30	16	23	30	38	47	56	65	75	86

7.4.3 Pressure filters

Filtration rates of 5 m/h are recommended, but in practice higher rates are frequently used because water can be forced through the beds by means of pumps. This is however poor practice and should not be done. It is permissible to allow somewhat higher head losses in pressure filters than in gravity filters, and so obtain slightly longer filter runs. It is seldom economical to operate at head losses in excess of 3 to 4 m.

IMPORTANT!
Pressure filters should be sized so that filtration rates under normal operating conditions do not exceed 5 m/h

Typical sand gradings pressure filters are given in Table 7.4

Table 7.3. Typical sand gradings for pressure filters

Material	Thickness (mm)	Grain size (mm)
Sand	500	0,9 - 1,1
Gravel	100	5
Pebbles	100	10
Stone	100	25
Stone	150	50

7.4.4 Multi-media filters

These filters are intended to provide greater void space for incorporation suspended particles than is the case with rapid gravity sand filters. As described earlier, the additional void space is made available by using a material (*e.g.* anthracite) that is lighter than ordinary sand on top of the sand bed. Typical criteria for dual media filters are given in Table 7.5.

Table 7.4 Typical design criteria for dual media filters

Material	Depth (m)	Effective grain size (mm)
Anthracite	0,5 - 1,0	1,6 - 2,5
Sand	0,5 - 1,0	0,4 - 1,0
Coarse sand	0,1	1,3 - 2,4 size range
Small pebbles	0,1	2,5 - 6,0 size range
Large pebbles	0,1	6 - 12 size range

7.4.5 Roughing filtration

Design criteria are given in Table 7.6. Although turbidity removal will depend on local conditions, particularly on the type of turbidity, it will generally be greater than 70 % and values of 90 % have been reported. The suspended solids removed from the raw water will slowly build up in the filter. After some time, this will reduce the efficiency of the filter and ultimately lead to complete clogging. Efficiency can be restored by fully opening the underdrain system, and flushing out the deposits by fast drainage and a water spray on the surface. Nevertheless, some solids may remain and make subsequent fast drainage less effective and it may therefore become necessary to clean the filter material after several years. Cleaning can be carried out by removing and washing the filter material, and then replacing it.

Table 7.5 Design guidelines for horizontal-flow roughing filters

Parameter	Average suspended solid concentration in raw water	
	High (150 mg/l)	Medium (100-150 mg/l)
Horizontal flow (m/h)	0,5 - 0,75	0,75 - 1,5
Depth (m)	1,0 - 1,5	1,0 - 1,5
Width (m)	1,0 - 5,0	1,0 - 5,0
Length of filter media (m):		
First compartment (15 - 25 mm)	3,0 - 5,0	3,0 - 4,0
Second compartment (8 - 15 mm)	2,0 - 4,0	2,0 - 3,0
Third compartment (4 - 8 mm)	1,0 - 3,0	1,0 - 2,0

More detailed information on the design of roughing filters can be found in the guidelines document by Wegelin (1996).

7.5 DISINFECTION

The following factors influence the efficiency of the disinfection process:

- The nature and number of the organisms to be destroyed.
- The type and concentration of the disinfectant used.
- The temperature of the water to be disinfected (the higher the temperature the more rapidly will disinfection take place).
- The time of contact (the disinfection process becomes more complete when the disinfectant remains for a longer period in contact with the water). The minimum period is 10 to 15 minutes, but should

preferably be several hours because the shorter the contact time the higher the dosage of free available chlorine required to ensure effective disinfection.

- The nature of water to be disinfected (if the water contains particulate matter especially of a colloidal and organic nature, or other chemical components which react with the disinfectant used *i.e.* exerts a demand, the disinfection process will be hampered).
- The pH (acidity/alkalinity) of the water; if chlorine is used, it is considerably more effective a pH 7 than at pH 9.
- Mixing (good mixing ensures proper dispersal of the disinfectant throughout the water, and so promotes the disinfection process).

DISINFECTION WITH CHLORINE

The minimum contact time is 10 to 15 minutes, but should preferably be much longer

Methods of chlorinating small water supplies

The most suitable chlorination equipment to use depends on each particular case. However, the following points should be considered when choosing equipment:

- The person who is responsible for the equipment must be reliable and must be properly trained in how to operate and maintain the equipment correctly. The person must also make sure that there is always enough chlorine product available. This is very important because other people rely on this person to make sure that the water supply is always safe to drink.

- The chlorine product that the equipment uses must be readily available at a reasonable cost.
- The equipment must be properly designed, strong, easy to operate and require little maintenance. It must be made of materials that will not be corroded (eaten away) by chlorine.
- The equipment must be suitable for the particular use, taking account of the water flow rate, whether the flow rate is constant or varies, the quantity of water used per day, whether the chlorine is dosed into a pressurised pipeline and whether electricity is available.
- The equipment must always dose enough chlorine to disinfect the water, but not too much so that it gives the water a bad taste.

It is necessary to have a large water tank after the chlorinator so that there is enough time for the chlorine to react with the water before people drink the water. The size of this tank depends on the water flow rate, but it should have at least one hour's storage volume.

Dosing of chlorine

A number of different ways of dosing chlorine are set out in the CSIR booklet "Disinfection for Small Water Supplies" (1990).

The following are important points that must be taken into consideration in designing and controlling chlorine dosing systems:

- uninterrupted dosing
- uniform distribution to all parts of the water mass
- adjustment of the dosage to the chlorine demand of the water being treated
- control of the dosage to produce safe water without spoiling the taste.

7.6 STABILISATION

One of the major problems experienced at the smaller treatment plants is the lack of stabilisation of the final water, and the aggressive attack on and corrosion of pipes, materials and fixtures containing these waters.

Because there appears to be a general lack of knowledge by the small treatment plant operating personnel about the need for stabilisation of water that is supplied to a community, a brief description of the effects of using an aggresive or corrosive water is given below, followed by guidelines on the use of chemical treatment to obtain a stabilised or partially stabilised water.

Aggression

Aggression is the designation given to the phenomenon whereby water attacks the cement matrix of cement and concrete lined structures. Two distinct aggressive processes have been identified:

- The water has chemical characteristics that cause dissolution of some of the minerals in the cement matrix

- The water contains sulphate species which might react chemically with some of the minerals in the cement matrix to form products which cause physical disruption of the matrix.

For chemical characteristics of aggressive waters, the terms *undersaturation, supersaturation and saturation* with respect to calcium carbonate describe chemical states in a water such that it respectively dissolves solid calcium carbonate (undersaturation), precipitates solid calcium carbonate out of solution (supersaturation) and neither precipitates nor dissolves calcium carbonate (saturation).

Corrosion

Corrosion of the metal components of pipes carrying water is the result of oxidation and reduction reactions at sites on the metal-water interface, by the formation of electro-chemical cells each with an anodic and cathodic area. At the anode metal molecules lose electrones to form metal ions which pass into solution. At the cathode the electrons (generated at the anode) pass from the metal (electron donor) to some chemical species (electron acceptor) in the water adjacent to the cathode; this is usually molecularly dissolved oxygen, if present. Depending on the circumstances, the reactions may cause continous dissolution of the metal into the water at the anode (corrosion), or may give rise to precipitation of minerals over the anode and cathode, thereby minimising the areas of the active electro-chemical sites and the rates of the reactions, and eventually stopping the corrosion completely (passivation of the surface).

Chemical treatment for stabilization

A stable water is essentially one the composition of which does not change when in contact with crystalline calcium carbonate, *i.e.* is saturated with respect to calcium carbonate, as described above. In the water treatment industry the term stabilization has, somewhat loosely, been broadened to describe the process of producing an over-saturated water in order to minimise it's aggressive and corrosive tendencies.

Protection of concrete and fibre-cement pipes, the major consideration, is relatively easy to achieve and involves increasing calcium and/or alkalinity concentrations to values that give a small degree of super-saturation, say between 0,5 and 4 mg/l calcium carbonate precipitation potential. The computer program STASOFT, available from the Water Research Commission and in the process of being further developed, gives guidance in respect of concentrations required.

If the calcium content of the filtered water is low, the preferred treatment chemicals are slaked lime and carbon dioxide. However, the use of sodium carbonate to provide the necessary increases in alkalinity, pH and carbonic species may be considered where sufficient calcium is already present. This may be attractive for small plants where the ease of dosing a solution may outwigh any extra sodium carbonate cost - it is difficult to reliably dose small amounts of lime. The critical requirement here is that the settled or filtered water has a sufficient carbonic species content so that the final pH is not too high when enough sodium carbonate has been added for the required minimum alkalinity. There may be several ways of achieving this.

Small plants often have operational and cost constraints which influence the choice of chemicals but, given the size of the investment in distribution pipework, it should always be possible to find some combination which will provide the required result. With very small supplies or when current treatment only consists of disinfection, limestone beds, although not providing complete protection, will bring about an improvement.

Protection of steel pipes by over-saturating the water with calcium carbonate is more difficult to achieve as over-saturation is not the only requirement. High alkalinity values, at least 50 mg/l as $CaCO_3$ and probably much more, depending also on chloride and sulphate content, are needed. This approach is only considered economical and desirable in areas where the raw water has in any case nearly the right composition and where copper has not been extensively used as a plumbing material.

STABILISATION

Dose lime or sodium carbonate to the final water to obtain a chemical composition approaching the following:

- Calcium carbonate precipitation potential : 4 mg/l as $CaCO_3$
- Alkalinity : 50 mg/l as $CaCO_3$
- Ca-hardness : 50 mg/l as $CaCO_3$

CHAPTER 8

GUIDELINES FOR OPERATION, MONITORING AND MAINTENANCE OF SMALL WATER TREATMENT PLANTS

8.1 INTRODUCTION

A treatment plant, however well it has been designed and operated, is only as good as the way it is operated. During the survey of the small water treatment plants, it was found that monitoring of the plants for process control and quality assurance was in most instances not receiving the attention it should. The plants are therefore not operated optimally and, moreover, the quality of the final water to the consumer often does not comply with generally accepted guidelines for drinking water.

Monitoring programmes for treatment plants are therefore needed to ensure cost-efficient treatment of water for the consumers, and a high quality drinking water complying with the national specifications and guidelines.

8.2 OPERATIONAL CONTROL REQUIREMENTS

8.2.1 Control of chemical dosage in the coagulation/flocculation process

The parameters requiring control are coagulant dose and pH, for which there are three distinct necessary actions at any given treatment plant:

1. Development of local guidelines for dose and pH selection, suited to the particular plant - a long term action.

2. Application of these guidelines in the selection of a target dose and pH value for prevailing conditions - an hourly, daily or weekly action.

3. Maintenance of conditions as closely as possible to the target values - a continuous action.

These actions may be executed with varying degrees of thoroughness, depending on the size of the plant and available facilities and staff. At very small plants they may be carried out by the same person, but should nonetheless be kept distinct. Thus, target doses are changed when raw water quality changes, guidelines are only changed when it is very clear that they inadequately allow for some particular raw water condition and most attention is directed at ensuring that target doses are in fact being delivered as expected.

The main task of plant operators is to ensure that target conditions are maintained, in spite of feeder blockages, raw water flow changes etc. while at the same time keeping an eye open for raw water quality changes.

An excellent simple tool for keeping a general check on the success of this operation is to take a beaker full of coagulated water at regular intervals, stir it for 10 or 15 minutes by hand or by means of the stirrer employed for jar tests and then allow to settle. With a white card at the back, floc formation as well as settlement are easily observed.

Shift operators should have the right to change target doses on a temporary basis if trouble is experienced. When the cause is identified the target value can be re-assessed.

The target pH should seldom if ever be changed and attention should be focused on checking, acid-cleaning and re-buffering the pH meters.

8.2.2 Control of settling processes

The only control of the settling process that can be exercised is by changing the frequency and duration of desludging. Desludging of sedimentation tanks should be carried out routinely with the period and frequency of operation depending on conditions at the plant.

8.2.3 Control of filtration

a. Slow sand filters

The outlet for clear water should be about 30 to 40 mm above the level of the sand in a slow sand filter, so that no filtration can take place until the surface of the sand has been covered with water. Unless this is done, the incoming water would pass through the sand near the inlet point at very high rates initially, carrying suspended matter down into the sand and the filter bed thus spoilt. This would occur progressively along the length of the bed until the whole surface is flooded and the filter bed spoilt. When a new or cleaned filter is put into operation, filtered water should be run in from under the sand bed until the water level has risen to above the level of the sand. Thereafter unfiltered water should be run onto the sand bed at the upper level of the sand. The filtration rate of a new or cleaned filter should be controlled for the first 4 to 7 days to ensure that it does not exceed 150 mm/h.

When the rate of filtration diminishes to a low level, the mat which has formed on the surface of the sand bed can be removed in order to expose a new surface. In the dry, warm climate of South Africa this is usually done by allowing the bed to dry out, and then scraping off the shrivelled surface layer. In recent times automatic, mechanized sand lifting equipment has come into use at larger plants.

b. Rapid sand filters

The decision as to when the filters should be backwashed is made by observing the head loss over the filter and/or the quality of the filtrate. However, many plant managers of water treatment plants find that routine backwashing of filters based on experience provides the most practical option.

Filter backwashing can be controlled by monitoring the quality of the dirty water discharged during backwashing. By determining the suspended solids (or turbidity) of the discharged water at time intervals from commencement of backwashing, the process controller will be able to determine what the optimum range of backwash times for his filters are.

More information on the operation and maintenance of rapid sand filters can be found in the CSIR Technical Guide K73 "Manual on Water Purification Technology", under the following headings:

- commissioning of a new filter
- mudball prevention
- replacing broken nozzles
- keeping logsheets
- treating sandbeds with chlorine

8.2.4 Disinfection control

The disinfection process is controlled by taking regular samples of the final water leaving the plant and analysing for free chlorine residual. This should preferably be done on an hourly basis. It is recommended that chlorine residuals also be determined on a regular basis at selected points in the distribution network to ensure that the initial dosage of disinfectant at the treatment plant is sufficient, and to establish whether additional disinfection at service reservoirs might be necessary.

The efficiency of disinfection must also be controlled by taking samples of the final water at the plant (and occasionally in the distribution network) and analysing the microbiological quality of the water, *i.e.* determination of total plate counts, total coliforms and faecal coliforms. This microbiological control should be done at least on a monthly basis at small to medium-sized plants, and weekly at the larger plants.

Chlorine gas

Gas chlorination equipment is safe to use by properly trained persons, but special safety features should be included in the design of the chlorination building in which the gas cylinders are housed and in the installation of the equipment. Safety equipment, such as a gas mask, should also be provided. Operating personnel must be well trained in the correct use and precautions to be taken with chlorine gas. For this reason:

Chlorine gas is not recommended for very small water systems because any gas leaks will result in a very dangerous situation with serious injury or death of people located close to the treatment plant.

WARNING!
Where chlorine gas is used there should always be a trained person nearby who knows what to do in the case of a gas leak and can warn people to keep away. This is usually not possible with small water supplies.

Sodium hypochlorite liquid

Sodium hypochlorite is supplied as a liquid in 20 or 25 litre containers. It contains 15 % chlorine (150 g/ℓ chlorine) when it leaves the factory, but the chlorine strength gradually reduces to less than 10 % strength during several months storage. This can be prevented by mixing the 20 litres of sodium hypochlorite liquid with 40 litres of water as soon as it is received.

This will make 60 litres of sodium hypochlorite liquid which should have at least 4% chlorine. This solution can be kept for several months without loss of strength provided that it is stored in a cool place.

Calcium hypochlorite

Calcium hypochlorite is supplied as 70 % dry granular chlorine (trade name HTH). The chlorine strength remains about 70 % for several months provided that the compound is kept in a plastic or glass container with a lid and is stored in a cool place.

Chlorine tablets that are sold in stores for use in swimming pools are generally not suitable for disinfecting drinking water. These are usually called 'stabilized chlorine' tablets, which means that they contain a stabilizing chemical that could possibly be harmful to people's health if they are used in drinking water for a long period of time.

Dry granular chlorine can be dissolved in water, and a solution with 4 % chlorine strength can be made by mixing 60 g of chlorine (1/3 cup) with one litre of water. However, calcium hypochlorite contains a small amount of insoluble material which, although not harmful to drink, can cause problems in the operation of some chlorination equipment by blocking pipes or valves of dosing pumps. Therefore solutions made up from dry chlorine should only be used with equipment that has been designed to prevent these problems from happening.

Calcium hypochlorite can also cause a white crust (calcium carbonate) to be deposited inside the equipment. This can be removed by cleaning with dilute hydrochloric acid from time to time.

8.2.5 Control of stabilization

The stabilization process is usually carried out in one or two stages, depending on the chemicals used and degree of stabilisation desired. On-line or frequent manual measurement of alkalinity, pH and, sometimes, conductivity are used for control purposes as indicated below.

a. Partial stabilization

A partially stabilised water results if, after sufficient lime or sodium carbonate has been added to filtered water to raise the pH to the allowed limit, the water is still under-saturated with respect to calcium carbonate. Whether or not this happens depends on the carbon dioxide content of the filtered water - low values giving under-saturation.

This process is controlled by monitoring the pH of the water after lime or sodium carbonate addition and sufficient mixing has taken place. For a specific water, a target pH is set. As SABS 241 of 1984 recommends a maximum pH limit of 9,0 for drinking water, the target pH should normally not be higher than about 9,2 to ensure a pH value of less than 9,0 at the consumer's tap.

Plants that practice partial stabilization need only determine alkalinity and calcium content occasionally when the quality of the raw water changes or it is desired to calculate the calcium carbonate precipitation potential by means of the STASOFT programme. The pH of the final water should be monitored by continuous in-line (chart) measurement, or on an hourly basis.

b. Full stabilization

Full stabilisation is either a one- or a two-stage process. A one-stage process results when there is sufficient carbon dioxide in the filtered water, to give a saturated water of pH of 9.2 or less, after adding sodium carbonate or lime. Otherwise an additional carbon dioxide dosage stage will be required.

For the single stage process, either pH or alkalinity can be used to control the amount of alkali added. As pH is easily measured on a continuous basis it is most often used. Alkalinity should then also be measured at least once a shift to detect changes in raw water quality.

With a two stage process, target values for both alkalinity and pH must be chosen. More than one combination of alkalinity and pH will probably suffice and STASOFT can be used to assist in the choice.

Use alkalinity to control the amount of lime added. Automatic control can be based on conductivity measurement, as the conductivity of the limed water before addition of carbon dioxide is proportional to the amount of lime added.

Carbon dioxide dosage control is based on pH measurements, after the addition point. As the final pH is sensitive to small changes in the ratio of carbon dioxide to lime, measurement should be at frequent intervals and preferably continuous.

8.3 PROPOSED MONITORING PROGRAMMES

Every water treatment plant treating water for drinking purposes should have a monitoring programme to ensure that the water it produces is safe for human consumption. The extent of the monitoring will normally depend on the size of the plant or the number of persons served. A comprehensive record should be kept of the data as part of the monitoring programme.

Because of financial constraints, both in terms of purchasing measurement apparatus or appointing suitable operating staff, small treatment plants normally cannot implement a monitoring programme similar to that of the larger water suppliers. However, every treatment plant should have at least an absolute minimum monitoring programme consisting of daily analysis of pH and free chlorine residual of the final water to ensure a safe and wholesome supply of drinking water to the consumer.

The recommended monitoring programme for small treatment plants (treating less than 2,5 Mℓ/day) is given in Tables 8.1. It should be noted that frequency of monitoring the quality of the raw water depends on what the raw water source is. For a large reservoir (dam), weekly monitoring may be sufficient (as indicated in the tables), but if the water is withdrawn from a river, the quality may change hourly, and more frequent analysis of raw water quality will be necessary.

Monitoring by external consultants

Where it is not feasible for a plant owner to have the overall monitoring done by plant personnel themselves, then a consultant can be contracted to do the monitoring on their behalf on a monthly basis. The monitoring done by this consultant will be additional to the basic monitoring which must be performed by the plant process controller(s).

Table 8.1 Recommended monitoring programme for small water treatment plants

RECOMMENDED MONITORING PROGRAMME FOR SMALL WATER TREATMENT PLANTS (treating less than 2,5 Mℓ/day)		
Measurement	**Sample**	**Frequency**
pH	Coagulated water Final water	Hourly, but preferably chart Hourly or chart
Colour (true) or UV absorbance	Raw water Settled water *Filtered water* Final water	Monthly Monthly *Monthly* Daily
Turbidity	Raw water Settled water Filtered water Final water	Weekly Daily Daily 8-hourly or chart
Alkalinity	*Final water*	*Monthly*
Ca, Mg hardness Total hardness	Filtered water Final water	Monthly Monthly
Conductivity	Raw water Final water	Monthly Monthly
Iron	Final water	Monthly
Aluminium	Final water	Monthly
Free chlorine residual	Final water	4-hourly
Total plate count	Final water	The frequency is prescribed by DWAF and depends on the population served
Total coliforms	Final water	
Faecal coliforms (E.Coli)	Final water	

8.4 LABORATORY REQUIREMENTS

To implement the monitoring programmes as proposed above, the treatment plant management should set up and equip a laboratory at the treatment plant to do the required basic physico-chemical analyses on site, apart from the other analyses that can be done at a centralised laboratory of the authority, or by an external consultant.

The minimum laboratory equipment required at a rural water treatment plants is given in Table 8.2.

8.5 SAMPLING, ANALYSIS AND REPORTING

a. Sampling

The objective of sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the material being sampled. This implies that the relative proportions or concentrations of all pertinent components will be the same in the samples as in the materials being sampled, and that the sample will be handled in such a way that no significant changes in composition occur before the tests are made.

Table 8.2 Minimum laboratory equipment requirements for small water treatment plants (treating less than 2,5 Mℓ/d)

Equipment/Apparatus	Reason needed	Approximate cost (1998)
pH meter (Preferably in-line in flocculation chamber and in final water, and/or a good quality bench-model)	Accurate control of coagulation pH for clarification of water Control of stabilization of final water Also measure temperature	R 2 000-R 3 000
Turbidimeter	Control of the settlement and filtration processes	R 7 000-R 13 000
Apparatus and glassware for performing titrations	Alkalinity measurements for stabilization control	R 250-R 500
Comparator for measurement of chlorine residuals	To control disinfection of the final water	R 900
Conductivity meter	To measure conductivity of final water to allow determination of the stability of the final water	R 2 000-R3 000

A sample may be presented to the laboratory for specific analyses with the collector taking responsibility for its validity. Often, the laboratory conducts or prescribes the sampling programme, which is determined in consultation with the user of the test results. The sampling programme defines the portion of the whole to which the test results apply. Account must be taken of the variability of the whole with respect to time, area, depth, and in some cases, rate of flow.

Methods of sampling

Manual sampling

Manual sampling involves no equipment but may be unduly costly and time-consuming for routine or large-scale sampling programmes.

Automatic sampling

Automatic samplers are being used increasingly. They are effective and reliable and can increase significantly the frequency of sampling. Various devices are available but no one sampler is universally ideal.

Preservation

Complete and unequivocal preservation of samples is a practical impossibility. Regardless of the sample nature, complete stability for every constituent never can be achieved. At best, preservation techniques only retard chemical and biological changes that inevitably continue after sample collection. Changes that take place in a sample are either chemical or biological.

b. Analysis

Procedures and methods for the analysis for the various water quality parameters required for process control and quality assurance in water treatment plants, can be found in Standard Methods for the Examination of Water and Wastewater (also refer to Appendix C for SABS Test Methods)

c. Reporting

Records of daily, weekly and monthly monitoring of water quality variables should be kept in books at the treatment plant and thereafter stored on computer to facilitate regular and future processing of data. The results of plant monitoring programmes should be summarised on a monthly basis in the form of reports, and submitted to the engineers for review and taking any actions as may be required. Where the services of external consultants are employed for assurance of quality control and optimum plant performance, the daily monitoring data will be processed and interpreted and proposals made as to how the plant can be operated more cost-efficiently, where appropriate.

8.6 MAINTENANCE REQUIREMENTS

The maintenance of any water treatment plant, and specifically including the small water treatment systems, is of critical importance to ensure that the plant performs at optimum operating conditions. The following guidelines on performing maintenance tasks have been adapted from WATER PURIFICATION WORKS DESIGN (F A van Duuren [Editor]) (1997). Maintenance can be carried out using in-house staff, by subcontracting certain aspects, by full privatisation and by sending out for specialist work.

8.6.1 Routine preventative maintenance

In many ways planned maintenance is the ideal method of coping with the maintenance problem on a works. If all wearing parts could be replaced before their useful life was up, breakdowns would be reduced to a minimum and unforeseen disruptions to the process could be virtually eliminated.

Unfortunately, it is not always possible to accurately predict the service life of many mechanical items. Bearings for example, can last from a few hundred hours to many hundreds of thousands of hours.

If the replacement period is not carefully determined this can lead to breakdowns in the event of early failure, or to the replacement of parts which still retain a good portion of their service life. Nevertheless, for strategic items of equipment it may be preferable to replace items early rather than run a higher risk of breakdowns.

Preventative maintenance is normally regarded as being a high-cost option as it is associated with relatively high replacement costs and man-hours. Each operating authority needs to decide what level of staffing can be justified by the scope of work available at the particular site and whether this warrants full-time staff or whether the work should be subcontracted or sent out.

8.6.2 Corrective maintenance

Corrective maintenance is usually less costly than planned maintenance as the intervals of servicing are normally greater. However when the maintenance is required it is usually quite urgent. It also may be complicated by the fact that two or more items of plant may break down almost simultaneously, necessitating extra manpower or prioritisation of jobs.

Another potential problem is that allowing certain items to operate to the verge of breakdown may result in more expensive repairs than if wearing items were routinely replaced.

All in all corrective maintenance is not always the cheap solution. It can, however, be countenanced if stand-by equipment is available and spares are readily obtainable. However, any operating authority should list all of its equipment and make decisions as to which can be allowed to break down, which can be easily replaced, and which are critical to operation and require an additional stand-by.

8.6.3 Maintenance checklists

Each plant should have a list of items that requires preventative maintenance, stating the frequency of maintenance that is needed, *i.e.* daily, monthly, annually, etc. These checklists should be compiled by the controlling authority or its consultant, and the plant operator(s) should sign against performance of a scheduled maintenance task. The controlling authority should ascertain whether the required maintenance is actually being performed.

CHAPTER 9

EXAMPLES OF UPGRADING PROCEDURE

9.1 INTRODUCTION

As brief illustration of the procedure proposed in this document for determining upgrading needs of existing small water treatment plants, two of the plants that were visited during the course of this project are used as examples. These plants are the Piet Gouws Water Treatment Plant in the Northern Province (1,5 Mℓ/d) and the Calitzdorp Water Treatment Plant in the Western Cape (0,85 Mℓ/d).

The procedure followed for determining upgrading needs for each of the two plants consists of:

- Background information on the water treatment plant and the community that it supplies with water
- Evaluation of the existing condition of the treatment plant according to the criteria in Section 4.1
- Identification and listing of upgrading needs

9.2 PIET GOUWS WATER TREATMENT PLANT

9.2.1 Background information

The Piet Gouws Water Treatment Plant is situated below the dam wall of the Piet Gouws Dam in the Northern Province, near the town of Masemola. The Piet Gouws Dam is fed by the Ngwaritsi River.

The treatment plant is owned by the Department of Water Affairs and Forestry and forms part of the Piet Gouws Regional Water Supply Scheme. It supplies the townships of Masemola and Mahlolwaneng with drinking water. The plant is monitored under contract by the CSIR Division of Water Environment and Forestry Technology in Pretoria.

The 65 m^3/h plant was built in 1994 and consists of the processes of flocculation, sedimentation, filtration and disinfection. The raw water feed to the plant has varying levels of turbidity, with very high levels that are encountered from time to time.

9.2.2 Evaluation of existing condition of the plant

a. Quality of Water Produced by the Plant

The quality of the final treated water leaving the treatment plant is determined by the CSIR during their monitoring visits to the plants. The final water quality measured during 1995 and 1996 is shown in the following table :

QUALITY PARAMETER	FINAL WATER QUALITY : PIET GOUWS TREATMENT PLANT					DEPT. OF HEALTH GUIDELINES FOR DRINKING WATER QUALITY		
						RISK RANGES		
	23-11-95	12-07-95	27-10-96	13-06-96	MEAN	NONE (RECOM-MENDED LIMIT)	INSIG-NIFICANT	LOW
Colour (mg/ℓ Pt)	5	20	6	15	11	20	-	-
Turbidity (NTU)	34	16	1,8	3,3	14	1	5	10
pH	8,8	7,8	7,6	7,8	8,0	6-9	5,5-9,5	4-11
EC at 25 °C (mS/m)	31	36	52	56	44	70	300	400
TDS (mg/ℓ)	187	186	279	273	231	-	-	-
Calcium (mg/ℓ Ca)	31	29	30	36	31	150	200	400
Magnesium (mg/ℓ Mg)	4	6	9	10	7	70	100	200
Tot. hardness (mg/ℓ $CaCO_3$)	94	97	112	131	108	20-300	20-650	1 300
Sodium (mg/ℓ Na)	20	32	61	57	42	100	400	800
Potassium (mg/ℓ K)	4	4	4	4	4	25	50	100
Tot. Alk (mg/ℓ $CaCO_3$)	87	132	139	150	127			
Chlorides (mg/ℓ Cℓ)	56	22	70	58	51	250	600	1 200
Sulphates (mg/ℓ SO_4)	18	12	13	12	14	200	600	1 200
Fluorides (mg/ℓ F)	0,6	0,6	0,8	0,9	0,7	1,0	1,5	3,0
Nitrates (mg/ℓ N)	0,3	0,3	1,8	1,1	0,9	6	10	20
Iron (mg/ℓ Fe)	-	-	-	-	-	0,1	1,0	2,0
Manganese (mg/ℓ Ma)	-	-	-	-	-	0,05	1,0	2,0
Prec. pot (mg/ℓ $CaCO_3$)	8,6	1,1	-2,9	4,3	2,6	Recommended : 4 mg/ℓ as $CaCO_3$		
Faecal coli's (per 100 mℓ)	10	0	16	0	6	0	1	10

The turbidities of the final water were in the insignificant risk area during two occasions and in the high risk area during the other two monitoring visits. On two occasions faecal coliforms were detected in the final water.

Based on these monitoring results, there is a need to improve both turbidity removal and disinfection on the treatment plant.

b. Loading on the plant

I Water demand

- Design capacity and demand

  The plant was designed in 1994.

  According to the plant operating manual, the plant's design capacity is 63 m^3/h, representing 1 512 m^3 per 24 hours.

  The design life or population that it is expected to serve in the design year is not known.

- Current water demand and flow

  Current population served by the plant (1997) is not known.

  Volumes of water produced by the plant during the monitoring visits were as follows :

12 July 1995	:	348 m^3/d
23 November 1995	:	574 m^3/d
27 October 1996	:	1 000 m^3/d

- Estimation of future water demand

  It is expected that the plant's design capacity will be reached by around the year 2003 to 2005 if the current increase in water demand is extrapolated. No major developments in the supply area that would result in a significant deviation from the trend are foreseen.

  There is, therefore, not a need to increase the capacity of the treatment plant at the present date (1997).

ii Raw water quality

The quality of the raw water to the plant is given in the table below.

QUALITY PARAMETER	FINAL WATER QUALITY : PIET GOUWS TREATMENT PLANT				
	23-11-95	12-07-95	27-10-96	13-08-96	MEAN
Colour (mg/ℓ Pt)	15	30	20	Raw water quality not monitored	22
Turbidity (NTU)	540	12	71		208
pH	7,3	7,6	7,9		7,7
EC at 25 °C (mS/m)	22	36	47		35
TDS (mg/ℓ)	108	186	280		191
Calcium (mg/ℓ Ca)	17	29	26		24
Magnesium (mg/ℓ Mg)	5	6	9		7
Tot. hardness (mg/ℓ $CaCO_3$)	63	97	102		87
Sodium (mg/ℓ Na)	23	32	61		39
Potassium (mg/ℓ K)	5	4	5		5
Tot. Alk (mg/ℓ $CaCO_3$)	50	131	172		118
Chlorides (mg/ℓ Cℓ)	13	22	40		25
Sulphates (mg/ℓ SO_4)	12	12	27		17
Fluorides (mg/ℓ F)	0,3	0,6	0,9		0,6
Nitrates (mg/ℓ N)	0,6	0,3	1,9		0,9
Iron (mg/ℓ Fe)	-	-	-		-
Manganese (mg/ℓ Mn)	-	-	-		-
Prec. pot (mg/ℓ $CaCO_3$)	-10,0	1,3	4,4		-1,4
Faecal coli's (per 100 mℓ)	-	-	-		-

It is clear from the above raw water quality data that the turbidity of the feed water varies considerably and can be very high on occasion.

c. Design aspects

i. Rapid mixing

Ferric chloride is dosed into the feed line downstream of the supply pumps by chemical dosing pumps. It is done directly into the flocculation pipe and mixing is accomplished by an in-line static mixer in the pipe just downstream of the point of injection.

Mixing intensity is sufficient and mixing of the chemical with the water takes place rapidly.

There is a second dosing point in the flocculation pipeline downstream of the first for the dosing of lime, but this was not used because the stirrer for the lime make-up solution was out of order. Lime was drip-fed into the inlet to the sedimentation tank.

ii. Flocculation

Flocculation takes place in the supply pipe in the pump room with the pipe running to and fro along the inside wall of the building, thereby providing slow mixing and retention time for flocculation.

There is no sampling points to observe floc formation in the pipe flocculator. Very small flocs were observed in the inlet to the settling tank, indicating that floc growth was not adequate, which was probably caused by too high velocity gradient in the flocculation pipeline. Ineffective flocculation could therefore contribute to the inadequate turbidity removal in the treatment plant.

iii. Sedimentation

Sedimentation takes place in one horizontal settling tank. No floc carry-over from the tank could be observed, but the turbidity of the settled water was 7 NTU.

At the design flow of 65 m^3/h, the settling velocity in the tank is ~ 0,8 m/h. There is no short-circuiting, and the pipe flocculator inlet to the tank would not result in floc break-up (the flocs are in any case small because of insufficient floc growth in the flocculation stage).

As there is only one sedimentation tank, it implies that the plant will have to be stopped when the settling tank is to be cleaned or emptied for maintenance purposes.

iv. Filtration

There are two rapid sand filters housed in a building. Sand filter number 2 was out of operation and has been unserviceable for a considerable period of time already. Problems were experienced with the backwashing and drainage system (broken and blocked nozzles), as well as with the filter media.

The total flow from the settling tank was therefore directed to filter no. 1, resulting in considerable overloading of the filtration system.

The building housing the two rapid sand filters was also in a poor state and in need of repair.

Filter no. 1 has previously been repaired but filter no. 2 has been out of service for a considerable time waiting for repairs and upgrading.

Backwash-water for the filters is obtained from the service reservoir on site. Backwashing is done daily on a routine basis. There is, therefore, a need to upgrade the filtration system as a high priority.

The quality of the filtered water was not assessed by the CSIR on a routine basis, but the turbidity of the final water indicates that poor turbidity removal was accomplished. This would have an adverse effect on disinfection of the final water before supply to the distribution network.

Because the filters are located inside the building, it is a cumbersome task to replenish or replace filter media, or replace nozzles.

v. Disinfection

A gas chlorination system was provided during construction of the plant in 1994. Problems were subsequently experienced with dosing of the chlorine gas and the use of the system was discontinued. One of the problems was that the chlorine dosing room was flooded. The dosing room and chlorination system were never repaired. Chlorination was done by drip-feeding a calcium hypochlorite (HTH) solution into the clear water sump. During one of the monitoring visits no calcium hypochlorite was available and no disinfection was applied.

This method of disinfection is unsuitable because there is no measurement of how much chlorine is dosed; there is no proper mixing of the chlorine with the water and there is also no system to provide good contact for the minimum required contact time of 10 - 15 minutes. Repairs and upgrading of the disinfection is therefore needed as a matter of the highest priority.

vi. Weather conditions

Not sufficient provision has been made for regulating stormwater flow during periods of high rainfall. The plant has been flooded on a number of occasions, causing extensive damage to the chlorine dosing room, high lift pump house and the office building. The most important result of this was that the gas chlorination system was not utilized anymore, and because no repair work was done for some time, it was necessary to revert to an alternative (inadequate) method of chlorination of the final water.

The ceiling of the pump room had also collapsed as a result of rainwater entering through gaps left between the roofsheets.

d. Operational aspects

I. Coagulation and flocculation

Ferric chloride was dosed to the raw water with a dosing pump. With the flow set at a constant rate, and with a known make-up solution, the process controller is able to calculate how much ferric chloride is dosed. The dosage is adjusted emperically based on observation of the quality of the settled water, and is therefore not optimised according to the quality of the incoming raw water, with the result that large quantities of poorly treated water may be produced before the dosage is set to the optimum range for good floc formation.

Because the lime-stirrer is out of service, no pH adjustment for optimizing coagulation can be performed, which may invariably lead to poor turbidity removal or overdosing of ferric chloride.

No sample points have been provided in the flocculation pipe for the process controller to observe floc formation and in that way control the coagulation/flocculation process.

There is hence a need for better control of the coagulation and flocculation process by providing a sampling point and recommissioning the lime dosing after ferric chloride addition, and training the process controller on how adjustments should be made to the ferric chloride and lime dosages.

ii. Sedimentation

The settling tank is desludged on a routine basis and the frequency appeared to be in order under normal operating conditions.

iii. Filtration

Backwashing of the rapid sand filter is also done on a routine basis, but it is unsure whether the prescribed procedure (duration) is always followed.

iv. Disinfection

Because calcium hypochlorite is drip-fed into the clean water sump, the process controller is not able to adjust the dosage accurately, and only use the amount of product dosed per day (kg HTH/day) as measurement. Chlorine residuals in the outflow from the plant is measured from time to time, and more or less calcium-hypochlorite dosed according to whether the measured residual is lower or higher than the target value.

The gas chlorination system should be repaired and put back in operation, and the chlorine residual measured on at least a daily basis (but preferably 4 - hourly).

v. Stabilisation

The stability of the final water is not determined. The pH of the final water is measured and the lime dosage in the inlet to the settling tank varied to attempt achieving a target pH of around 7,5 - 8,0.

e. Maintenance aspects

It appeared that back-up service for this particular plant was inadequate and resulted in poorly motivated process controllers operating the plant. Repair work to the plant has apparently been scheduled, but delays in contractors actually performing the work were experienced.

9.2.3 Listing of upgrading needs

From the above the following more important upgrading needs are identified, provided in approximate order of priority :

- repairing of gas chlorination system and recommissioning
- repairing of sand filter no. 2
- repair of lime - stirrer and resuming lime dosing after ferric chloride in the dosing room
- training of process controllers in operating the plant according to a monitoring programme specifically drawn up for this plant (see Chapter 8)
- provision of basic analytical equipment to perform this monitoring programme (see Chapter 8)
- make provision for diverting storm water from the plant so that no flooding can take place (in particular of the clean water sump which is located below ground level in the open)
- repair pump house and laboratory/administration building
- provide a better flocculation system that will give improved floc formation and hence turbidity removal

9.3 CALITZDORP WATER TREATMENT PLANT

9.3.1 Background Information

The town of Calitzdorp is situated in the Klein Karoo, some 50 km to the west of Oudtshoorn. It has a population of around 7 000.

Water for potable use is abstracted from the Calitzdorp Dam to the north of the town and treated at the municipality's water treatment plant on the outskirts of the town. This water can be supplemented by a supply from a borehole located in the town itself.

The town has four wine estates producing port and other wines, and exercises an increased demand for purified municipal water during the wine producing season.

The original plant was build in 1984 and consisted of sedimentation and slow sand filtration. Coagulation and flocculation facilities as well as gas chlorination was later added to the treatment configuration.

9.3.2 Evaluation of existing condition of the plant

a. Quality of Water Produced by the Plant

The table gives a indication of the quality of the final water that was experienced before upgrading of the treatment plant.

The turbidity of the water was high and fell in the low risk range of the Department of Health Guidelines for Drinking water Quality (see page B.1 for explanation of risk ranges). The colour was also high (45 mg/ℓ as Pt) and exceeded the recommended limit. The pH of the final water was also low, indicating no stabilisation was done and that the water would be substantially corrosive and aggressive.

Since high rainfall and flooding that occurred at the end of 1996, problems have been experienced with the quality of the drinking water and contained visible turbidity and colour from time to time.

QUALITY PARAMETER	FINAL WATER QUALITY : CALITZDORP TREATMENT PLANT	DEPT. OF HEALTH GUIDELINES FOR DRINKING WATER QUALITY		
	20-01-97	RISK RANGES		
		NONE (RECOMMENDED LIMIT)	INSIGNIFICANT	LOW
Colour (mg/ℓ Pt)	45	20	-	-
Turbidity (NTU)	8,2	1	5	10
pH	4,54	6-9	5,5-9,5	4-11
EC at 25 °C(mS/m)	22	70	300	400
TDS (mg/ℓ)	147	-	-	-
Calcium (mg/ℓ Ca)	23,3	150	200	400
Magnesium (mg/ℓ Mg)	5,7	70	100	200
Tot. hardness (mg/ℓ $CaCO_3$)	81,8	20-300	20-650	1 300
Sodium (mg/ℓ Na)	-	100	400	800
Potassium (mg/ℓ K)	-	25	50	100
Tot. Alk (mg/ℓ $CaCO_3$)	0			
Chlorides (mg/ℓ Cl)	16,0	250	600	1 200
Sulphates (mg/ℓ SO_4)	95	200	600	1 200
Fluorides (mg/ℓ F)	-	1,0	1,5	3,0
Nitrates (mg/ℓ N)	-	6	10	20
Iron (mg/ℓ Fe)	<0,1	0,1	1,0	2,0
Manganese (mg/ℓ Mn)	-	0,05	1,0	2,0

b. Loading on the plant

i Water demand

- <u>Design capacity and demand</u>

  The design capacity of the plant is 9 ℓ/s (32 m^3/h), but during summer months the flow through the plants has been as high as 43 - 50 m^3/h. The plant is therefore overloaded during the summer times, especially when winemaking in in progress.

ii Raw water quality

The quality of the raw water feed to the plant is highly variable, according to the plant personnel. Chemical analysis of a raw water sample appears in the table below.

QUALITY PARAMETER	RAW WATER QUALITY : CALITZDORP WATER TREATMENT PLANT
	20-01-97
Colour (mg/ℓ Pt)	262
Turbidity (NTU)	24
pH	6,78
EC at 25 ° C(mS/m)	12
TDS (mg/ℓ)	80
Calcium (mg/ℓ Ca)	20,6
Magnesium (mg/ℓ Mg)	4,6
Tot. hardness (mg/ℓ $CaCO_3$)	70,5
Sodium (mg/ℓ Na)	-
Potassium (mg/ℓ K)	-
Tot. Alk (mg/ℓ $CaCO_3$)	25
Chlorides (mg/ℓ Cℓ)	15,5
Sulphates (mg/ℓ SO_4)	5,1
Fluorides (mg/ℓ F)	-
Nitrates (mg/ℓ N)	-
Iron (mg/ℓ Fe)	0,88
Manganese (mg/ℓ Ma)	-

c. **Design aspects**

i. Mixing

Alum and lime is dosed into an hydraulic jump after which mixing takes place in a mixing race. Rapid mixing is therefore satisfactory.

The alum and lime are both dosed under gravity from make-up tanks into the hydraulic pump. Two dosing pumps are available, but were corroded and not in service. Dosage and dosage control was therefore not accurate. The dosing pumps need to be repaired or replaced.

ii. Flocculation

Alum as dosed at 150 mg/ℓ and considerable overdosing took place (as confirmed by performing beaker tests in the laboratory). Poor floc formation and therefore poor colour removal were achieved as a result of this.

Because of overdosing alum the coagulation pH was 5,18 when the maximum possible quantity of lime was dosed. While coagulation at this pH would give acceptable colour removal, the aluminium is highly soluble at this pH and could result in high aluminium concentrations in the final water. It is recommended that a pH of 5,8 or higher rather be established in the flocculation step.

Flocculation takes place in concentric channels in the centre of the circular settling tanks. The velocity gradient was not calculated, but the retention time was sufficient for flocculation, albeit on the low side.

A practical problem with the flocculation system is that there is no bridge over the surface of the settling tank to allow access to the flocculation channels, which results in difficulties in doing routine cleaning of the channels. A bridge must therefore be provided to allow easier cleaning.

iii. Sedimentation

For a flow to the plant of 32 m^3/h (design flow), the upflow velocity in the settling tank is 0,41 m/h, and at flows of 50 m^3/h that the plant must handle from time to time, the upflow velocity is 0,63 m/h.

The upflow velocities were therefore acceptable in both instances, and the weir loading - rate at the high flow of 50 m^3/h was only 1,53 m^3 /m weir length/h and therefore also acceptable; however, settling was not efficient with an apparent colour of 95 mg/ℓ as Pt in the settling tank overflow and a turbidity of 13 NTU. This results in a high loading on the slow sand filters.

The reason for the poor settling is the overdosing of alum and formation of very small flocs that do not settle readily and is carried over the overflow - weir.

iv. Filtration

There are two circular slow sand filters, each with a diameter of 13 m. Only one of the two filters is in operation at any given time, while the other filter is out of operation to allow the schmutzdecke to dry before scraping off this layer and removing it to be washed.

The filtration rates through the slow sand filters are :

For a flow of 32 m^3/h	:	0,24 m/h
For a flow of 50 m/h	:	0,38 m/h

Design filtration rates for slow sand filters are normally 0,1 - 0,2 m/h. At the low flow the recommended maximum filtration rate was thus just exceeded, but at the high flow the filtration rate was almost double the recommended maximum filtration rate.

The turbidity of filtrate from the slow sand filters was 6,0 NTU, confirming that the filter was overloaded and that breakthrough of suspended solids and flocs were experienced.

The filtration system needed to be upgraded by providing additional filtration capacity, converting the slow sand filters to rapid sand filters and/or using some alternative or supplementary means of filtration.

v. Disinfection

Gas chlorination was used for disinfection of the final water. The chlorine is dosed into the supply to two reservoirs at the plant, and adjacent to the chlorination building, so that contact time is very short before entering the reservoirs.

More contact time should be provided.

d. Operational aspects

i. Coagulation and flocculation

As indicated earlier, considerable overdosing of alum took place. Because the make-up solution of alum was gravitated into the mixing race, the process controller could not accurately control dosage rates, and during the time of the investigation was uncertain of how much alum was actually dosed. There was also no routine observation of floc formation in a sample of flocculated water take in a beaker.

Good dosage control was therefore a lacking at the treatment plant and training of the process controller(s) needed in this regard.

ii. Sedimentation

The settling tank is desludged on a daily basis for about 10 minutes and appeared to be adequate.

iii. Filtration

Operation of the slow sand filters also appeared to be in order. One of the two filters is operated at a time until it is observed that the filter becomes blocked to such an extent that overflowing of the filter tank is approached. The filter is then taken out of operation and the other filter put in operation.

The *schmutzdecke* of the first filter is allowed to dry before being scraped off and taken out of the filter where it is washed. When the layer of remaining filter sand in either of the two filters reaches the minimum allowed depth, new filter sand is added up to the original depth.

iv. Disinfection

Chlorine residuals in the final water are measured on a daily basis by means of DPD tablets and a comparator. When the residuals are too high or too low, the chlorine dosage is adjusted accordingly to provide the target residuals. This is satisfactory; however, the residuals should be measured at the outlet from the two reservoirs rather than in the feed because of the lack of sufficient contact time as mentioned earlier.

v. Stabilisation

The pH of the final water is measured daily with pH - strips and attempts normally made to maintain the final pH between 6,5 and 8,5 by dosing lime after the filters. This was not done during the investigation because the total possible lime dosing was used for coagulation pH - adjustment (overdosing of alum).

More reliable methods for pH measurement are required (*i.e.* good quality hand-held or laboratory pH meter) for cost-efficient control of the coagulation and stabilisation processes.

e. Maintenance aspects

Spare parts and specialized back-up service are not always readily available and have to be acquired from the neighbouring towns or distant urban centres. This has on occasion led to delays in repairs and replacement of malfunctioning or unserviceable equipment. Maintenance personnel from the local authority can however perform most of the basic maintenance tasks themselves.

Availability of funds for maintenance or plant improvements is a major problem for this treatment plant. Additional and alternative sources of funding for maintenance and plant improvements are required.

9.3.3 Listing of upgrading needs

The upgrading needs of the Calitzdorp Water Treatment Plant which are identified from the above, are the following (in priority order) :

- provide training for the process controller(s) in the basis principles of water treatment, and in particular on coagulation and dosage control. Also how to perform basic laboratory analysis and implement a monitoring programme for process control and quality assurance.

- purchasing of laboratory equipment for the above process control and quality assurance, *i.e.* at least a good quality pH meter and a turbiditimeter

- provision of two reliable chemical dosing pumps (one duty and one standby) with which the process controller can adjust alum dosages to target values provided in tabular form or on graph by an external consultant. As an alternative some means of accurate gravity dosing system (properly calibrated) can also be used

- installation of a reliable dry-line feeder with which sufficient lime can be dosed both for coagulation pH adjustment and stabilisation of the final water

- upgrade of the filtration system either by providing an additional slow sand filter (not recommended), conversion of the slow sand filters to rapid sand filters, or provision of new rapid sand filters or pressure sand filter (proper investigation required as to which will be the best filtration system for this specific treatment plant)

- provision of chlorine contact channels to allow at least 15 minutes for efficient disinfection

- provide new overflow-weir for settling tank, as well as bridge to allow easy access to the centre flocculation channels

- do modifications to existing administrative building to form a separate office and laboratory

- upgrade security of the treatment plant (fencing)

- implementation of a public relations programme by the municipality to inform the users of the water of quality of the drinking water, problems that may be experienced, and generally to provide public awareness and good communication channels

CHAPTER 10

RECOMMENDATIONS FOR FURTHER RESEARCH

In the process of determining the upgrading needs of small water treatment plants in South Africa, and drawing up guidelines on how to address these upgrading needs, a number of research needs were identified. These are listed below under headings relating to the type of R & D or training required.

10.1 TECHNOLOGY TRANSFER

a. Draw up guidelines on design and operation of settling and filtration systems for small water treatment plants.

b. Do technology transfer and implementation of reliable and efficient small scale disinfection systems (on which considerable research and development work is and has been done).

c. Draw up guidelines for corrosion control (stabilisation) options for small water systems (including methods to monitor efficiency of corrosion control).

d. Draw up guidelines for disposal of residuals (sludge and backwash water) from small water systems.

e. Do technology transfer of "new" (higher tech/unconventional) technologies for small water treatment systems, *e.g.* membrane filtration.

10.2 TRAINING AND EDUCATION

a. There is still a need for more attention to be paid to the education and training aspects of small water supply schemes. Regional centres, or preferably regional training teams who can move from district to district, need to be established to provide the training and follow-up support needed.

b. Determine needs and develop manuals for training and education for upgrading.

10.3 RESEARCH AND TECHNOLOGY DEVELOPMENT

a. Develop effective and reliable chemical dosing systems and cost-efficient instrumentation for controlling chemical dosages under varying conditions in small water systems.

b. Perform on-going research on reducing costs of treatment processes for small water systems, but which can still supply safe and acceptable water.

c. Investigate and develop technologies that will create jobs.

10.4 PROCESS EVALUATION

a. Evaluate point-of-entry household water treatment units, and establishment of methods to monitor its performance and maintenance programmes.

10.5 INSTITUTIONAL

a. Investigation into financial and institutional arrangements for rural small water treatment systems (similar to the Palmer Development Group manuals for urban areas).

b. The Department of Water Affairs and Forestry to do a study on raw water qualities country-wide, that will assist consulting engineers in planning and designing new treatment plants.

c. Further promotion of privatization of many of the functions related to water supply, and emphasis on maintenance programmes for small water systems.

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APPENDIX A

DETAILS OF PLANTS SURVEYED

In the tables presenting raw water and final water qualities, the following units of measurement apply :

Turb	=	Turbidity in NTU
Colour	=	Colour in mg/ℓ as Pt
pH	=	pH units
Alk	=	Alkalinity in mg/ℓ as $CaCO_3$
Ca	=	Calcium in mg/ℓ as Ca
Mg	=	Magnesium in mg/ℓ as Mg
Cℓ	=	Chloride in mg/ℓ as Cℓ
TDS	=	Total Dissolved Solids in mg/ℓ
F	=	Fluoride in mg/ℓ as F
NO_3	=	Nitrate in mg/ℓ as N
Fe	=	Iron in mg/ℓ as Fe
Mn	=	Manganese in mg/ℓ as Mn

1. MOGANYAKA, Northern Province

The town of Moganyaka is situated near to Marble Hall in the Northern Province. The treatment plant is situated on the outskirts of the town and withdraws its water from the Olifants River. The plant is owned by the Department of Water Affairs and Forestry and is monitored by the CSIR Environmentek under contract.

CAPACITY: 0,8 Mℓ/d		RAW WATER SOURCE: Olifants River		RAW WATER QUALITY: High turbidity		YEAR BUILT: 1973	
RAW WATER QUALITY (Average and [range])							
Turb	9 [3,6-13]	Colour	15 [10-20]	pH	7,9 [7,6-8,2]	Alk	190 [148-213]
Ca	47 [42-57]	Mg	31 [24-39]	Cℓ	118 [75-153]	TDS	613 [435-667]
F	1,0 [0,8-1,1]	NO_3	0,5 [0,2-0,7]	Fe	-	Mn	-
FINAL WATER QUALITY (Average and [range])							
Turb	0,7 [0,3-1,2]	Colour	5 [5-20]	pH	7,7 [7,6-7,8]	Alk	173 [122-186]
Ca	44 [35-52]	Mg	31 [21-42]	Cℓ	112 [44-155]	TDS	581 [322-715]
F	0,9 [0,7-1,1]	NO_3	0,4 [0,2-0,6]	Fe	-	Mn	-

TREATMENT PROCESSES:

Hydraulic flocculation
4 x circular upflow sedimentation tanks
Slow sand filtration (2 x slow sand filters)
Gas chlorination

PROBLEMS EXPERIENCED:

- Plant under stress (water demand in town exceeds plant capacity) (design capacity 0,8 Mℓ/d; current capacity [Sept 1996] 1,2 Mℓ/d)
- Flow rate through filters therefore too high - cause turbidity break-through and rapid clogging - to overcome this the operators simply bypass one of the two slow sand filters and chlorinate the settled water directly before pumping to town - this is being done for some time already
- Both raw water flow meters in pump line from river out of order
- Lime feeder not working - not being repaired because supplier of new chemical that has replaced alum has told operators that lime dosing is not required for their chemical - it was recommended by CSIR that lime still be dosed for stabilisation, but this has not been done
- Corrosive water from plant has resulted in replacement of clean water AC pipe to town
- Electrical disruptions (plant was not running during inspection)
- Poor electrical connections
- Access road in poor condition (chemical suppliers reluctant to deliver to plant)

2. TOMPI SELEKA, Northern Province

The Tompi Seleka water treatment plant is situated further north of Marble Hall near the *Olifants River (next to the* Lolamontes Dam), and supplies drinking water to the College of Agriculture and its residence (± 600 students and 50 staff). It is also owned by DWAF.

CAPACITY: 0,22 Mℓ/d		**RAW WATER SOURCE:** Lolamontes Dam		**RAW WATER QUALITY:** High turbidity		**YEAR BUILT:**	
RAW WATER QUALITY (Average and [range])							
Turb	10 [10-40]	Colour	11 [10-12]	pH	8,0 [7,2-8,4]	Alk	54 [52-57]
Ca	6 [6]	Mg	2 [2]	Cℓ	10 [9-12]	TDS	85 [92-93]
F	0,6 [0,5-0,9]	NO_3	0,4 [0,4]	Fe	-	Mn	-
FINAL WATER QUALITY (Average and [range])							
Turb	0,7 [0,7-7,5]	Colour	5 [4-5]	pH	6,6 [6,3-7,5]	Alk	30 [23-45]
Ca	21 [20-23]	Mg	2 [2]	Cℓ	11 [10-13]	TDS	152 [136-156]
F	0,4 [0,3-0,6]	NO_3	0,4 [0,4-0,5]	Fe	-	Mn	-

TREATMENT PROCESSES:

Hydraulic flocculation (alum)
3 x circular upflow settling tanks
Calcium hypochlorite chlorination
Pressure filtration (1 x pressure filter)

PROBLEMS EXPERIENCED:

- No flow meter was available - there is a V-notch, but flows are not recorded
- No records available of chemical usage
- No chemical dosing equipment was available - chemical solutions were drip fed - dosing rate only controlled by visual observation of flocs formed - overdosing appears to take place most of the time
- Settling tanks appeared to be overloaded - the flow of flocculated water to the three settling tanks is not distributed evenly
- The pressure filter and its components were severely corroded
- Inspection of the filter media was overdue - the sand has probably never been replaced yet
- No measurements are taken - process control only done visually
- Store, chemicals and office all in the same room

3. VANDERMERWESKRAAL, Northern Province

The Vandermerweskraal water treatment system is located on the western bank of the Olifants River and withdraws water directly from a well in the sandbed. The process only consists of chlorinating the water with calcium hypochlorite before pumping it to the Elandskraal community.

CAPACITY: 0,10 Mℓ/d		RAW WATER SOURCE: Well in Olifants River		RAW WATER QUALITY: Low turbidity		YEAR BUILT: 1973	
RAW WATER QUALITY (Not available)							
FINAL WATER QUALITY (Typical)							
Turb	3,8	Colour	15	pH	7,3	Alk	112
Ca	50	Mg	27	Cℓ	159	TDS	559
F	0,7	NO_3	0,6	Fe	-	Mn	-

TREATMENT PROCESSES:

Calcium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- The HTH solution is made up from well water and then drip fed into the well - there is no control valve to regulate the dosing rate
- The water is also corrosive and aggressive

4. HLOGOTLOU, Northern Province

The treatment plant is also a Department of Water Affairs plant and is situated outside the town of Hlogotlou, which lies to the east of Groblersdal. Water is abstracted from the Mhlangu Dam and the treated water supplied to the town and surrounding villages (it is a regional water supply scheme).

CAPACITY: 2,5 Mℓ/d		RAW WATER SOURCE: Mhlangu Dam		RAW WATER QUALITY: Low turbidity		YEAR BUILT: 1982	
RAW WATER QUALITY (Average and [range])							
Turb	4,2 [4,0-4,5]	Colour	10 [5-15]	pH	7,5 [7,1-7,9]	Alk	26 [22-30]
Ca	5 [4-5]	Mg	1 [1]	Cℓ	5 [5]	TDS	48 [45-50]
F	0,2 [0,2]	NO_3	0,2 [0,2]	Fe	-	Mn	-
FINAL WATER QUALITY (Average and [range])							
Turb	1,8 [0,4-3,2]	Colour	5 [5]	pH	6,8 [6,6-7,0]	Alk	28 [18-37]
Ca	4 [4]	Mg	2 [1-2]	Cℓ	7 [6-7]	TDS	48 [40-56]
F	0,2 [0,2]	NO_3	0,2 [0,2]	Fe	-	Mn	-

TREATMENT PROCESSES:

Hydraulic flocculation (alum)
Horizontal sedimentation (1 x settling tank)
Rapid sand filtration (3 x rapid sand filters)
Gas chlorination

PROBLEMS EXPERIENCED:

- Lime feeder serviceable but not in use because supplier of new chemical that has replaced alum has told operators that lime dosing is not required for their chemical - it was recommended by CSIR that lime still be dosed for stabilisation, but this has not been done
- Final water hence aggressive
- Faulty control valves on the filters (feed and backwash) resulting in improper operation of filters
- Safety measurements at gas chlorination facility inadequate

5. VERGELEGEN, Northern Province

The Vergelegen water treatment plant is also one of DWAF's regional water supply schemes. The plant was recently (1996) upgraded by the provision of a new section consisting of 2 new horizontal flow settling tanks and 4 new rapid sand filters. The plant supplies water to the Jane Furse Hospital, Glen Cowie and Riverside.

CAPACITY: 2,4 Mℓ/d		RAW WATER SOURCE: Lehlagare Matlala Dam		RAW WATER QUALITY: High turbidity		YEAR BUILT: 1982	
RAW WATER QUALITY (Average and [range])							
Turb	66 [24-233]	Colour	84 [20-240]	pH	7,7 [7,5-7,9]	Alk	123 [84-147]
Ca	19 [19-21]	Mg	8 [7-8]	Cl	14 [12-16]	TDS	179 [169-189]
F	0,6 [0,4-0,7]	NO_3	0,4 [0,2-0,6]	Fe	-	Mn	-
FINAL WATER QUALITY (Average and [range])							
Turb	3 [0,3-16]	Colour	8 [5-60]	pH	7,5 [6,8-8,2]	Alk	99 [38-137]
Ca	25 [21-28]	Mg	7 [4-9]	Cl	43 [13-73]	TDS	178 [157-199]
F	0,6 [0,3-0,7]	NO_3	0,4 [0,2-0,6]	Fe	-	Mn	-

TREATMENT PROCESSES:

Hydraulic flocculation ($FeCl_3$)
Horizontal flow sedimentation (2 x new settling tanks; 2 x existing settling tanks)
Rapid sand filtration (4 x new filters; 3 x existing filters)
Calcium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- Unbalanced flow in the water supply results in the plant continually switching on:off and only in operation for about 4 hours per day - processes do not get chance to stabilise properly
- Gas chlorination system has not been in use since upgrading in 1996 because of problem with sufficient pressure in water supply to injector
- Lime feeder available but not in use
- Final water most of the time not stable i.t.o precipitation potential
- pH meter and conductivity meter out of order - jar test equipment not used
- Contractor did not commission the plant properly after upgrading, and CSIR had to spend considerable time to do this

6. PIET GOUWS, Northern Province

The plant is situated near the town of Lebowakgomo. More information on the plant can be found in Chapter 9.

CAPACITY: 1,5 Mℓ/d		RAW WATER SOURCE: Piet Gouws Dam		RAW WATER QUALITY: High turbidity		YEAR BUILT: 1994	
RAW WATER QUALITY (Range or typical)							
Turb	12-540	Colour	22	pH	7,7	Alk	118
Ca	24	Mg	7	Cl	25	TDS	228
F	0,6	NO_3	0,9	Fe	-	Mn	-
FINAL WATER QUALITY (Range or typical)							
Turb	1,8-34	Colour	11	pH	8,0	Alk	127
Ca	32	Mg	7	Cl	52	TDS	284
F	0,7	NO_3	0,9	Fe	-	Mn	-

TREATMENT PROCESSES:

Hydraulic (pipe) flocculation ($FeCl_3$)
Horizontal sedimentation (1 x horizontal flow settling tank)
Rapid sand filtration (2 x rapid sand filters)
Calcium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- This plant is typical of a plant in poor condition as a result of design inadequacies and lack of proper maintenance
- The lack of maintenance of equipment and treatment systems at the plant is demoralising for the plant personnel - "discouraged to do proper measurements and plant control because nobody comes to fix the plant"
- Only one of the two filters in operation because of problems with nozzles in the one filter and depleted filter media - for the past two years already
- The chlorine dosing room, high lift pump house and office building has been flooded by storm water - the ceiling of the pump house had collapsed due to rain water entering through gaps left between the roof sheets
- Clean water tank is below ground level and is flooded during heavy rains
- Gas chlorination out of order for considerable time already - HTH drip fed into clean water tank
- No provision made for sampling points
- Lime is dosed in the inlet of the horizontal settling tank
- Pipe flocculation does not give good floc formation

7. BOSCHKLOOF, Northern Province

The Boschkloof water treatment plant supplies Boschkloof with drinking water and is situated near Steelpoort. It is a remote plant with poor access roads. The capacity of the plant is unknown.

CAPACITY:		RAW WATER SOURCE: Steelpoort River		RAW WATER QUALITY: Low turbidity		YEAR BUILT: 1973	
RAW WATER QUALITY (Average and [range])							
Turb	4,6 [4,5-4,6]	Colour	10 [10]	pH	7,7 [7,7]	Alk	141 [134-147]
Ca	28 [27-29]	Mg	17 [14-20]	Cl	33 [31-34]	TDS	208 [195-221]
F	0,3 [0,2-0,3]	NO_3	0,2 [0,1-0,2]	Fe	-	Mn	-
FINAL WATER QUALITY (Average and [range])							
Turb	0,8 [0,5-1,0]	Colour	7 [5-8]	pH	7,4 [7,3-7,5]	Alk	137 [125-148]
Ca	28 [28-29]	Mg	16 [13-19]	Cl	31 [31	TDS	205 [195-215]
F	0,2 [0,2]	NO_3	0,2 [0,1-0,2]	Fe	-	Mn	-

TREATMENT PROCESSES:

Hydraulic flocculation (alum)
Horizontal sedimentation (1 x tank with three hoppers)
Slow sand filtration (2 x slow sand filters)
Calcium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- Complaints from the community because of lack of sufficient water supply to the town - inadequate capacity of the high lift pump at the treatment plant - standby pump needed
- Mixing race for rapid mixing of coagulant develops too high head loss and overflows - the operator then uses an irrigation pipe to bypass the mixing race and goes directly in the flocculation section
- The valves in the filtered water lines are leaking and fills the valve manholes completely with water (2 m deep) - operator must then submerge himself totally to operate the valves
- The result of the above is that the operator has provided a bypass pipe directly from the end of the mixing race to the clean water reservoir and bypasses both the settlers and slow sand filters when he experiences too many problems
- No measurements are made - all process control done by visual observations

8. BETHESDA HOSPITAL, Kwazulu Natal

This package treatment plant is located in northern Kwazulu Natal and supplies drinking water to the Bethesda Hospital and surrounding villages. Raw water is withdrawn from the Mkuze River, and very high turbidities are experienced from time to time. Due to a rapid increase in water demand the capacity of the plant had to be extended recently.

CAPACITY: 0,5 Mℓ/d		RAW WATER SOURCE: Mkuze River		RAW WATER QUALITY: High turbidity		YEAR BUILT: New plant 1995	
RAW WATER QUALITY (Average and [range])							
Turb	[0,3-465]	Colour	7 [3-12]	pH	8,1 [7,9-8,3]	Alk	251 [154-340]
Ca	52 [42-67]	Mg	60 [35-90]	Cℓ	267 [56-457]	TDS	1040 [517-1261]
F	0,3 [0,2-0,4]	NO_3	0,4 [0-1]	Fe	-	Mn	-
FINAL WATER QUALITY (Average and/or [range])							
Turb	0,2	Colour	2	pH	8,1	Alk	186
Ca	39	Mg	50	Cℓ	164 [62-316]	TDS	887 [520-1560]
F	0,3	NO_3	0,3	Fe	-	Mn	-

TREATMENT PROCESSES:

Package Plant: Hydraulic (pipe) flocculation (Primco)
Upflow sedimentation (4 x settling tanks)
Pressure filtration (4 x filters)
Sodium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- The package plant has been installed to supplement the old Bethesda treatment plant at the hospital; however the total water demand is already exceeding the combined capacity of the two plants - the capacity of the package plant therefore needs to be expanded further (from 25 m^3/h to 40 m^3/h)
- Varying raw water quality makes it difficult to optimise plant at all times
- Pipe flocculation not efficient - floc carry-over from settling tanks

9. JOZINI, Kwazulu Natal

This treatment plant is located in the town Jozini in northern Kwazulu Natal, at the wall of the Jozini Dam (Pongolapoort Dam). The plant is under control of the provincial Local Government and Housing department/Zululand Joint Services Board, and serves a population of around 6 000 people. The plant was also recently upgraded by the provision of additional settling tanks and filters.

CAPACITY: 1,6 Mℓ/d		RAW WATER SOURCE: Jozini Dam		RAW WATER QUALITY: High turbidity		YEAR BUILT:	
RAW WATER QUALITY (Average and/or [range])							
Turb	[1,3-120]	Colour	56 4-98	pH	7,8 [7,5-8,7]	Alk	83 [70-102]
Ca	12 [10-12]	Mg	11 [9-13]	Cℓ	19 [15-25]	TDS	130 [107-152]
F	0,2 [0-0,3]	NO_3	0,7 [0-1,2]	Fe	-	Mn	-
FINAL WATER QUALITY (Average and/or [range])							
Turb	0,4 [0,2-0,7]	Colour	3 [1-4]	pH	7, [7,1-7,8]	Alk	80 [72-93]
Ca	11 [9-12]	Mg	11 [8-12]	Cℓ	-	TDS	176
F	-	NO_3	-	Fe	-	Mn	-

TREATMENT PROCESSES:

Hydraulic (pipe) flocculation (Primco)
Sedimentation (Horizontal and upflow) (2 x horizontal flow tanks; 4 x upflow tanks)
Pressure filtration (bank of 19 pressure filters)
Sodium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- The town had a very old plant with slow sand filters - a new plant was subsequently built, and again upgraded in 1996 (new flocculation system; clarifiers)
- Gas chlorination system was removed for repairs some time ago - still not received back - in the interim using sodium hypochlorite, but do not get a residual (chlorine solutions presumably stored too long)
- Difficult to monitor and operate the 18 pressure sand filters
- *Plant well equipped with process control equipment and laboratory kits, but operators do not* know how to employ it all
- Limited space available for upgrading

10. MOSVOLD HOSPITAL, Kwazulu Natal

This plant of the Department of Works supplies water to the Mosvold Hospital in northern Kwazulu Natal. It is located in the Ingwavuma district. The plant consists of an old concentric flow combined flocculation/settling/filtration unit, but construction of a concrete slab for a new package plant was in progress during the visit to the plant. The planning was to relocate the plant at Bethesda Hospital to Mosvold, and to build a new plant at Bethesda.

CAPACITY: 0,3 Ml/d		RAW WATER SOURCE: Dam		RAW WATER QUALITY: Low turbidity		YEAR BUILT: Currently being upgraded	
RAW WATER QUALITY (Average)							
Turb	3,6	Colour	22	pH	7,2	Alk	26
Ca	6	Mg	8	Cl	83	TDS	171
F	0,1	NO_3	0,3	Fe	-	Mn	-
FINAL WATER QUALITY (Average)							
Turb	3,8	Colour	5	pH	6,9	Alk	16
Ca	7	Mg	8	Cl	92	TDS	260
F	0,3	NO_3	0	Fe	-	Mn	-

TREATMENT PROCESSES:

Concentric unit: Hydraulic flocculation (alum)
- Upflow sedimentation
- Slow sand filtration

Calcium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- Flow meter out of order
- Depth of sand in slow sand filter is only 60 mm
- Filtration rate in slow sand filter too high
- No control of rate of alum and chlorine drip feed dosing
- Operators not familiar with all aspects of plant operation
- Access road to treatment plant in very poor condition

11. MANGUZI HOSPITAL, Kwazulu Natal

The Manguzi Hospital and village is located near Kosi Bay, and the water treatment plant withdraws raw water from the Lake Shengeza and also from the Maputo River. The lake is eutrophic and algae is found in the raw water supply to the treatment plant. The plant supplies drinking water to some 3 100 people.

CAPACITY: 0,55 Mℓ/d		RAW WATER SOURCE: L. Shengeza/Maputo River		RAW WATER QUALITY: Low turbidity/eutrophic		YEAR BUILT:	
RAW WATER QUALITY (Average)							
Turb	4,4	Colour	31	pH	7,1	Alk	36
Ca	7	Mg	7	Cℓ	76	TDS	173
F	0,1	NO_3	0,3	Fe	-	Mn	-
FINAL WATER QUALITY (Average)							
Turb	3,9	Colour	26	pH	7,0	Alk	35
Ca	7	Mg	7	Cℓ	86	TDS	200
F	0,1	NO_3	0,6	Fe	-	Mn	-

TREATMENT PROCESSES:

Hydraulic flocculation (alum)
Direct filtration (no sedimentation step) (2 x rapid gravity filters)
Calcium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- Raw water from the lake contains algae (presumably blue-green) - no measures taken to remove the algae in conjunction with the turbidity
- Flocculation channel very short and does not provide enough retention time (design)
- No settling causes high loading on sand filters from time to time
- No air scour for backwashing sand filters, only water backwash
- Chlorine is dosed together with alum at the inlet of the plant - very low chlorine residual measured in the final water - CSIR has recommended that they rather chlorinate after filtration, but this was not done
- Gas chlorinator not in operation - HTH drip fed at plant inlet
- There is no operator for the plant, only a person that maintains the grounds

12. FRISCHGEWAAGD, Kwazulu Natal

The plant at Frischgewaagd obtains its raw water both from a dam as well as a spring. The community is located in the Ssimdlengentsha district and is under control of the Department of Local Government and Housing, Ulundi.

CAPACITY: 0,68 Ml/d		RAW WATER SOURCE: Dam and Spring		RAW WATER QUALITY: Medium turbidity		YEAR BUILT:	
RAW WATER QUALITY (Typical)							
Turb	43	Colour	71	pH	7,4	Alk	53
Ca	7	Mg	7	Cl	4	TDS	59
F	0,1	NO_3	0,8	Fe	-	Mn	-
FINAL WATER QUALITY (Typical)							
Turb	0,4	Colour	2	pH	6,9	Alk	-
Ca	-	Mg	-	Cl	-	TDS	68
F	-	NO_3	-	Fe	-	Mn	-

TREATMENT PROCESSES:

Concentric unit: Hydraulic flocculation (alum)
Upflow sedimentation
Slow sand filtration
Calcium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- Lime dosing pump out of order - the water was therefore not stabilised
- Flocculation poor as a result of inadequate dosage control
- Depth of sand in slow sand filter only half of the recommended depth
- The plant is normally operated by labourers who have very little knowledge on water Treatment and due to their low educational qualifications, cannot be easily trained

13. UPPER MNYAMENI, Eastern Cape

This Department of Water Affairs and Forestry plant is situated near King Williams town in the Keiskammahoek district, and serves a community of around 2 700 people. The plant is a package treatment system employing direct filtration and chlorination. The quality of the raw water is good requiring very low polyelectrolyte dosages.

CAPACITY: 0,26 Mℓ/d		RAW WATER SOURCE: Mnyameni Dam		RAW WATER QUALITY: Low turbidity		YEAR BUILT:	
FINAL WATER QUALITY (Average and [range])							
Turb	8,2 [3,5-15]	Colour	26 [10-70]	pH	7,3 [6,8-7,6]	Alk	25 [21-30]
Ca	5,2 [3-10]	Mg	11 [3-35]	Cℓ	8,8 [7-13]	TDS	5,2 [34-40]
F	-	NO_3	-	Fe	-	Mn	-

TREATMENT PROCESSES:

Package Plant: Polyelectrolyte dosing directly ahead of filters
Pressure filtration (4 x dual media pressure filters)
Calcium hypochlorite chlorination (after filtration)

PROBLEMS EXPERIENCED:

- The original dosing pumps broke down and no spare parts are available - they are waiting for the area to be electrified, then electric dosing pumps can be installed; however, the raw water source is of a very high quality requiring virtually no dosing

14. PLEASANT VIEW, Eastern Cape

This plant, also under ownership of the Department of Water Affairs, falls under the Victoria East District and is monitored by the CSIR. The plant has a design capacity of 650 m^3/d, but currently produces around 75 m^3/d, supplying drinking water to around 400 people. The raw water quality is very good.

The plant was upgraded in 1994.

CAPACITY: 0,65 Mℓ/d		RAW WATER SOURCE: Pleasant View Dam		RAW WATER QUALITY: Low turbidity		YEAR BUILT: Upgraded 1994	
FINAL WATER QUALITY (Average and [range])							
Turb	7,3 [1,4-15]	Colour	30 [5-60]	pH	7,6 [7,4-7,7]	Alk	46 [34-56]
Ca	14 [10-18]	Mg	11 [6-21]	Cℓ	15 [12-18]	TDS	80 [67-94]
F	-	NO_3	-	Fe	-	Mn	-

TREATMENT PROCESSES:

Flocculation ($FeCl_3$) (In-line mixing and pipe-flocculation)
Sedimentation (1 x circular settling tank)
Pressure filtration (3 x filters)
Calcium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- Difficulty in obtaining spare parts for dosing pumps

15. ST. THOMAS, Eastern Cape

This plant supplies water to the St Thomas School for the Deaf (total of 342 people). The plant is also monitored by the CSIR. It is located in the Zwelitsha district.

CAPACITY: 0,2 Mℓ/d		RAW WATER SOURCE: River		RAW WATER QUALITY: Medium turbidity		YEAR BUILT: 1979	
FINAL WATER QUALITY (Averange and [range])							
Turb	6,0 [0,2-19]	Colour	23 [5-70]	pH	6,4 [4,8-7,2]	Alk	21 [7-50]
Ca	25 [15-46]	Mg	18 [3-58]	Cℓ	17 [14-23]	TDS	134 [101-208]
F	-	NO_3	-	Fe	-	Mn	-

TREATMENT PROCESSES:

Flocculation (alum) (baffled flocculation chamber)
Sedimentation (1 x circular settling tank)
Pressure filtration (1 x filter)
Calcium hypochlorite chlorination (floating tablets)
Lime stabilisation

PROBLEMS EXPERIENCED:

- Dosing equipment is inadequate
- Flocculation chamber is too small - this is due to flocculation in the pipe with resultant Blockage of the pipe and insufficient water supply
- Short circuiting in settling tank (overflow weir damaged)
- Personnel not trained properly on how to handle large variations in raw water quality, Especially pH and turbidity
- Inadequate disinfection - a floating HTH pill is used - no residual is obtained

16. DORDRECHT, Eastern Cape

This plant supplies the municipality of Dordrecht with drinking water (population 15 000). The plant was built in 1961, and upgraded recently (1997). The design capacity of the plant is 68 m^3/h and it was operating at 70 m^3/h during the visit.

CAPACITY: 1,6 Mℓ/d	RAW WATER SOURCE: Anderson Dam	RAW WATER QUALITY: Low turbidity	YEAR BUILT: 1961 Upgraded 1997

TREATMENT PROCESSES:

Flocculation (PAC) (flocculation channel : round-the-end baffles)
Sedimentation (1 x Moore clarifier)
Rapid sand filtration (2 x filters)
Gas chlorination
Lime stabilisation (when required)

PROBLEMS EXPERIENCED:

- *Water driven scraper in the Moore clarifier prone to stoppages when the sludge* concentration in the clarifier gets too high
- Presently upgrading the flocculation system and building two new filters; however, no funds available for an *additional clarifier*

17. CLOCOLAN, Free State

Clocolan water treatment plant uses conventional water treatment processes to supply the town of some 24 000 residents with potable water. The design capacity of the plant is 82 m^3/h. Raw water is withdrawn from the Mopedi dam.

During the upgrading in 1978 the existing filter was retrofitted and two additional rapid sand fitlers constructed.

CAPACITY: 2,0 Mℓ/d		RAW WATER SOURCE: Mopedi Dam		RAW WATER QUALITY: Low turbidity		YEAR BUILT: Upgraded 1978	
FINAL WATER QUALITY (Average and [range])							
Turb	1,3 [0,1-8,7]	Colour	17 [6-29]	pH	7,4 [6,8-8,4]	Alk	-
Ca	-	Mg	4 [2-7]	Cℓ	12 [10-15]	TDS	132 [87-188]
F	0,1 [0,1-0,2]	NO_3	0,7 [0,4-1,0]	Fe	-	Mn	-

TREATMENT PROCESSES:

Flocculation (PAC) (mechanical rapid mixing; flocculation channel with round-the-end baffles)
Sedimentation (1 x Moore clarifier)
Rapid sand filtration (3 x filters)
Sodium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- Corrosion of clarifier scraper mechanism
- Inadequate performance of chlorination system - expensive to replace

18. SYFERFONTEIN, Free State

This plant supplies potable water to the town of Senekal in the Eastern Free State (20 000 people). The plant is an old plant that was built in 1945, with a design capacity of 136 m^3/h. The current flow is about 90 m^3/h. The plant was upgraded in 1994 by providing an additional Moore clarifier and 2 new rapid sand filters.

CAPACITY: 3,2 Mℓ/d		RAW WATER SOURCE: Sand River		RAW WATER QUALITY: Medium turbidity		YEAR BUILT: 1945 Upgraded 1994	
FINAL WATER QUALITY (Average and [range])							
Turb	1,4 [0,2-8,5]	Colour	7 [3-23]	pH	8,0 [7,5-8,7]	Alk	-
Ca	-	Mg	9 [5-15]	Cℓ	12 [7-17]	TDS	188 [147-295]
F	0,4 [0,2-0,5]	NO_3	0,5 [0,2-0,6]	Fe	-	Mn	-

TREATMENT PROCESSES:

Flocculation (PAC) (hydraulic jump; baffled channel [around-the-end baffles])
Sedimentation (2 x circular settling tanks; 1 x Moore clarifier)
Rapid sand filtration (5 x rapid sand filters)
Sodium hypochlorite chlorination

PROBLEMS EXPERIENCED:

- The initial plan was to decommission the old works, but due to the present increase in demand, retrofitting of the original works took place to assist with the supply to meet the demand
- The filters from the old plant were planned to be incorporated in the plant, but were retrofitted
- The new works is currently being operated at much lower than its design capacity causing settling of flocs in the baffled channel
- No scouring facility is available in the flocculation chamber
- No overflow facility exists in the clear well causing the clear well to overflow into the building

19. CALITZDORP, Western Cape

The Calitzdorp treatment plant is used as an example for determining upgrading needs of a small water treatment plant, and more information can be found in Chapter 9.

CAPACITY: 0,85 Mℓ/d		RAW WATER SOURCE: Dam		RAW WATER QUALITY: Colour and turbidity		YEAR BUILT: 1984	
RAW WATER QUALITY (Range or typical)							
Turb		Colour		pH		Alk	
Ca		Mg		Cℓ		TDS	
F		NO_3		Fe		Mn	
FINAL WATER QUALITY (Range or typical)							
Turb		Colour		pH		Alk	
Ca		Mg		Cℓ		TDS	
F		NO_3		Fe		Mn	

TREATMENT PROCESSES:

Flocculation (alum) (mixing in mixing race; flocculation in centre of settling tank)
Sedimentation (1 x circular settling tank)
Slow sand filtration (2 x slow sand filters)
Lime stabilisation
Gas chlorination

PROBLEMS EXPERIENCED:

- No control over coagulant dosage rate, leading to either under or overdosing of alum
- Inaccurate dosing of lime for coagulation pH adjustment resulting in variable floc formation depending on the quality of the raw water
- Rapid clogging of slow sand filters, *i.e.* short filter runs (only two weeks), as a result of chemical overdosing and floc carry - over from settling tank
- No stabilisation of the final water, because maximum possible lime dosage was required for coagulation pH adjustment. Hence, problems with corrosive and aggressive water
- Process controller requires training regarding basic principles of chemical dosing in water purification and plant control and monitoring
- Inadequate equipment for performing process control and quality assurance

20. BUISPLAAS, Western Cape

This plant is owned and operated by the South Cape District Council. It is located next to the N2 National Road just outside of Albertinia, and supplies water to the Buisplaas community some 14 km away on the banks of the Gouritz River. The raw water supply is two boreholes containing appreciable quantities of iron. This is the closest practical water source to the community because the water in the Gouritz River is too brackish to be used for potable purposes.

The plant is housed in an existing concrete structure that previously belonged to Spoornet (it is directly next to the railway line). A process sequence developed by the CSIR in Stellenbosch for iron removal is used for this treatment plant.

CAPACITY: 0,12 Mℓ/d		RAW WATER SOURCE: Boreholes		RAW WATER QUALITY: Iron		YEAR BUILT: 1994	
RAW WATER QUALITY (Range or typical)							
Turb	-	Colour	-	pH	6,4-6,8	Alk	18-110
Ca	8,8-42,5	Mg	10,2-10,8	Cℓ	152-171	TDS	310-387
F	-	NO_3	<0,1	Fe	4,6-7,7	Mn	0,28-0,96

TREATMENT PROCESSES:

Aeration for oxidation of iron
pH adjustment with sodium carbonate
Sedimentation (in aeration tank)
Upflow contact filtration (using inert stone)
Pressure filtration (1 x filter)
Gas chlorination

PROBLEMS EXPERIENCED:

- Changing raw water quality (pH and iron) affects efficiency of iron removal
- Mechanical problems with soda-ash dosing
- Rapid clogging of filters with iron precipitate
- Problems with consistent reliable dosing of chlorine (not sufficient pressure to injector)

APPENDIX B

DEPARTMENT OF HEALTH GUIDELINES FOR DRINKING WATER QUALITY

DEPARTMENT OF HEALTH GUIDELINES FOR DRINKING WATER QUALITY

Three different health risk areas are defined for contaminants. These definitions are summarised here for convenience (adapted for simplicity):

The recommended limit (no health risk area) : The primary water quality limit. There is a built-in safety factor and no immediate risk to health exists if this limit is not exceeded.

The insignificant health risk area : This area still represents safe potable water but the specified limits should not be exceeded. Immediate action should be instituted to reduce the concentration of determinants if it falls in this risk area.

The low health risk area : Water falling in this category may constitute a minimal health risk to individuals. Various considerations apply to the use of such waters:

- there should be no economically viable alternative source
- vulnerable consumers (expectant mothers, children, the elderly) must be considered
- the consumers and local medical personnel must be informed of the risk

High health risk area : Waters where the contaminant concentrations exceed the limits of the low health risk area fall into **the greater (unacceptable) health risk area.** Waters of this quality may cause serious health effects and extreme action must be taken to find an alternative supply or improve the water quality immediately.

Tables B1 to B4 list contaminants of health and aesthetic significance together with the concentrations at which the various risk levels occur.

Table B.1 : Guideline values for microbiological and biological quality of drinking water

Determinants	Units	Health risk ranges		
		None (Recommended limit)	Insignificant	Low
Standard plate count	/mℓ	< 100 *	1000	10000
Total Coliforms	/100 mℓ	0 *	5	100
Faecal Coliforms	/100 mℓ	0 *	1	10
Clostridium per fringes	/100 mℓ	0 *	1	10
Coliphages	/100 mℓ	0 *	10	100
Enteric viruses	/10ℓ	0 *	1	10
Giardia lamblia	/2ℓ	0 *	2	5

* In 95 % of annual samples

Table B.2 : Guideline values for substances affecting the aesthetic quality of drinking water

Determinants	Units	Aesthetic risk ranges		
		None (Recommended limit)	Insignificant	Low
Colour	mg/ℓ Pt	20		
Conductivity	mS/m	70	300	400
Dissolved organic carbon	mg/ℓ DOC	5	10	20
Dissolved oxygen	% Satn.	> 70	> 30	10
Hydrogen sulphide	µg/ℓ	100	300	600
Methylene blue active substances	mg/ℓ LAS	0,5	1,0	2,0
Odour	TON	1	5	10
pH	pH units	6 to 9	<5,5or>9,5	<4or>11
Taste	TTN	1	5	10
Temperature	°C	<25	<30	<40
Turbidity	NTU	1	5	10
Aluminium	µg/ℓ Al	150	500	1000
Copper	mg/ℓ Cu	0,5		
Chloride	mg/ℓ Cl	250	600	1200
Iron	µg/ℓ Fe	100	1000	2000
Manganese	µg/ℓ Mn	50	1000	2000
Sulphate	mg/ℓ SO_4	200	600	1200
Zinc	mg/ℓ Zn	1,0	5,0	10

Table B.3: Guideline values for inorganic and radioactive substances of health significance in drinking water

Determinants	Units	Health risk ranges		
		None (Recommended limit)	Insignificant	Low
Aluminium	mg/ℓ Al	0,15	0,5	1,0
Ammonia	mg/ℓ NH_4	1,0	2,0	4,0
Barium	mg/ℓ Ba	0,5	1,0	2,0
Boron	mg/ℓ B	0,5	2,0	4,0
Bromide	mg/ℓ Br	1,0	3,0	6,0
Calcium	mg/ℓ Ca	150	200	400
Cerium	mg/ℓ Ce	1,0	2,0	4,0
Chlorine (free residual)	mg/ℓ Cl	0,2-5	<0,2->5	
Chloride	mg/ℓ Cl	250	600	1200
Copper	mg/ℓ Cu	0,5	1,0	2,0
Fluoride	mg/ℓ F	1,0	1,5	3,0
Total hardness	mg/ℓ	20-300	<20or>650	1300
Iodide	mg/ℓ I	0,5	1,0	2,0
Lithium	mg/ℓ Li	2,5	5,0	10
Magnesium	mg/ℓ Mg	70	100	200
Nitrates	mg/ℓ N	6	10	20
Phosphate	mg/ℓ P	0,1	0,25	2,0
Potassium	mg/ℓ K	25	50	100
Rubidium	mg/ℓ Ru		5,0	
Silica	mg/ℓ Si		18,0	
Sodium	mg/ℓ Na	100	400	800
Sulphate	mg/ℓ SO_4	200	600	1200
Strontium	mg/ℓ Sr	2,0		10
Uranium	mg/ℓ U	1,0	4,0	8,0
Antimony	µg/ℓ Sb	50	100	200
Arsenic	µg/ℓ As	100	300	600
Beryllium	µg/ℓ Be	2	5	10
Bismuth	µg/ℓ Bi	250	500	1000
Cadmium	µg/ℓ Cd	10	20	40
Chromium	µg/ℓ Cr	100	200	400
Cobalt	µg/ℓ Co	250	500	1000
Cyanide	µg/ℓ CN	200	300	600
Gold	µg/ℓ Au	2	5	10
Lead	µg/ℓ Pb	50	100	200
Mercury	µg/ℓ Hg	5	10	20
Molybdenum	µg/ℓ Mo	50	100	200
Nickel	µg/ℓ Ni	250	500	1000
Radium	µg/ℓ Ra		.1	
Selenium	µg/ℓ Se	20	50	100
Silver	µg/ℓ Ag	20	50	100
Tellurium	µg/ℓ Te	2	5	10
Thallium	µg/ℓ Tl	5	10	20
Thorium	µg/ℓ Th		0,5	
Tin	µg/ℓ Sn	100	200	400
Titanium	µg/ℓ Ti	100	500	1000
Tungsten	µg/ℓ W	100	500	1000
Vanadium	µg/ℓ V	250	500	1000
Yttrium	µg/ℓ Y		1	

Table B.4: Guideline values for organic substances of health significance in drinking water

Determinants	Units	Health risk ranges		
		None (Recommended limit)	Insignificant	Low
Aldrin/Dieldrin	µg/ℓ	0,2		2
Atrazine	µg/ℓ	2,5		25
Propazine	µg/ℓ	8		80
Chlordane	µg/ℓ	1		10
D, 2,4-	µg/ℓ	10		100
DDT	µg/ℓ	2		50
Endrin	µg/ℓ	0,2		1
Heptachlor	µg/ℓ	0,1		1
Lindane	µg/ℓ	2		5
Malathion	µg/ℓ	50		100
Methoxychlor	µg/ℓ	10		1000
Parathion	µg/ℓ	0,1		1
Toxaphene	µg/ℓ	5		5
T,2,4,5-	µg/ℓ	1		10
TP,2,4,5-	µg/ℓ	10		80
Polycyclic aromatics	µg/ℓ	0,2		5
Total THM	µg/ℓ	100		
Chloroform	µg/ℓ	2		18
Dibromochloromethane	µg/ℓ	2		24
Bromodichloromethane	µg/ℓ	2		20
Bromoform	µg/ℓ	3		38
Trichloroethylene	µg/ℓ	14		144
Diethyl phthalate	µg/ℓ	23,4		234
Dimethyl phthalate	µg/ℓ	17,3		173
Dibutyl phthalate	µg/ℓ	14,3		143
Butyl benzene phthalate	µg/ℓ	20,3		203
Bis (ethylhexyl) phthalate	µg/ℓ	15,1		151
Di-iso-butyl phthalate	µg/ℓ	0,042		0,42
Benzothiazole	µg/ℓ	2		20
1,3 isobenzofuran-dione	µg/ℓ	6		60
Octadecanol	µg/ℓ	0,06		0,6
Phenol	µg/ℓ	0,9		9
2-Chlorophenol	µg/ℓ	1,5		15
2-Nitrophenol	µg/ℓ	2,5		25
2,4-Dichlorophenol	µg/ℓ	2,5		25
p-Chloro-m-cresol	µg/ℓ	5,5		55
2,4,6-Trichlorophenol	µg/ℓ	1,9		19
2,4-Dinitrophenol	µg/ℓ	0,14		1,4
4-Nitrophenol	µg/ℓ	0,9		9
4,6-Dinitro-o-cresol	µg/ℓ	0,14		1,4
Pentachlorophenol	µg/ℓ	0,5		5

APPENDIX C

SABS SPECIFICATION FOR WATER FOR DOMESTIC USE

SOUTH AFRICAN BUREAU OF STANDARDS
SPECIFICATION
for
WATER FOR DOMESTIC SUPPLIES
SABS 241 of 1984

1. SCOPE

1.1 This specification lays down the minimum physical, chemical and bacteriological requirements for the purity (as delivered to the consumer) of water for domestic supplies.

NOTE

a) Water for domestic supplies includes water for culinary purposes and general household usage, but not necessarily water for het water systems (for which a special treatment might be required to prevent problems such as scale formation or corrosion or both).

b) The standards referred to in this specification are listed in Appendix A.

c) Information regarding the frequencies and the techniques of sampling to be used to assess compliance of water with the specification is given in Appendix B.

2. REQUIREMENTS

2.1 GENERAL

2.1.1 Suitability. The assessment of the suitability of water for domestic supplies shall be based on consideration of its physical and chemical properties as well as its bacterial content.

2.1.2 Classification of Requirements. Both of the limits specified as "recommended" and "maximum allowable" represent water fit for human consumption and for domestic purposes.

NOTE: The "recommended" limit should, if possible, be applied to all water supplied for domestic use, and the "maximum allowable" limit should never be resorted to unless no other water supply is practicably available. In this case, steps should be taken to improve the quality in a reasonably short time by practicable technology.

2.2 PHYSICAL REQUIREMENTS

2.2.1 Turbidity. The turbidity, determined in accordance with 3.1 and expressed in nephelometric turbidity units, shall not exceed the following:

Recommended limit	:	1
Maximum allowable limit	:	5

2.2.2 Colour. The colour, determined in accordance with 3.2, shall not exceed the following:

Recommended limit	:	20 mg/ℓ of platinum
Maximum allowable limit	:	Not specified

2.2.3 Odour and Taste. The odour and taste shall not be objectionable.

2.3 CHEMICAL REQUIREMENTS

2.3.1 pH Value. The pH value, determined in accordance with 4.22, shall be within the following limits:

Recommended limits	:	6,0 min.
		9,0 max.
Allowable limits	:	5,5 min.
		9,5 max.

2.3.2 Conductivity. The conductivity of the water, when determined in accordance with 4,5 shall not exceed the following:

Recommended limit	:	70 mS/m
Maximum allowable limit	:	300 mS/m

2.3.3 Macro-determinants. The macro-determinants (macro-constituents) of the water, determined in accordance with the relevant methods given in Column 4 of Table 1, shall comply with the values given in Column 2 or 3 as relevant.

Table 1. Macro-Determinants

1	2	3	4
Determinant, mg/ℓ	Recommended limit	Maximum allowable limit	Test method subsection
Total hardness (as $CaCO_3$)	20 min.	Not specified	4.20
	300 max.	650	
Magnesium (as Mg)	70 max.	100	4.11
Sodium (as Na)	100 max.	400	4.17
Chloride (as Cl)	250 max.	600	4.4
Sulphate (as SO_4)	200 max	600	4.18
Nitrate + nitrite (as N)	6 max	*10	4.14
Fluoride (as F)	1.0 max.	1.5	4.8
Zinc (as Zn)	1.0 max.	5.0	4.19

*If nitrate plus nitrite (expressed as N) is present in concentrations in excess of 10 mg/ℓ, the water may be unsuitable for use by infants under 1 year of age and an alternative source of supply must be found for such infants' use.

2.3.4 Micro-determinants. The micro-determinants (micro constituents) of the water, determined in accordance with the relevant methods given in Column 4 of Table 2, shall comply with the values given in Column 2 or 3, as relevant.

Table 2. Micro-Determinants

1	2	3	4
Determinant, mg/ℓ	Recommended maximum limit	Maximum allowable limit	Test method subsection
Arsenic (as As)	100	300	4.2
Cadmium (as Cd)	10	20	4.3
Copper (as Cu)	500	1 000	4.6
Cyanide (as CN)	200	300	4.7
Iron (as Fe)	100	1 000	4.9
Lead (as Pb)	50	100	4.10
Manganese (as Mn)	50	1 000	4.12
Mercury (as Hg)	5	10	4.13
Phenolic compounds (as phenol)	5	10	4.15
Selenium (as Se)	20	50	4.16

2.3.5 Other Constituents. The water shall not contain any other constituents in concentrations which may render it unsuitable for use domestic supplies. Radioactivity, if present, shall be within the limits laid down by the International Commission for Radiological Protection.

2.4 BACTERIOLOGICAL REQUIREMENTS

When tested in accordance with the methods given in Column 4 of Table 3, the water shall comply with the limits given in Column 2 or 3, as relevant.

Table 3. Bacteriological Limits

1	2	3	4
Property	Recommended maximum limit	Maximum allowable limit	Test method subsection
Total coliform bacteria count per 100 mℓ	Nil*	5	5.2
Faecal coliform bacteria count per 100 mℓ	Nil	Nil	5.3
Standard plate count per millilitre	100	Not specified	5.4

*a) If any coliform bacteria are found in a sample, take a second sample immediately after the tests on the first sample have been completed: this shall be free from coliform bacteria; and

b) not more than 5 % of the total number of water samples (from any one reticulation system) tested per year

3. PHYSICAL TEST METHODS

3.1 TURBIDITY. Use SABS Method 197.

3.2 COLOUR. Use SABS Method 198.

3.3 ODOUR AND TASTE

3.3.1 Test by Sampler. As the odour and taste of water are not necessarily permanent characteristics and may be altered or even lost in transit, it is essential that the sampler test these properties at the site of sampling and submit his findings in the list of particulars supplied with each sample. The description of any odour or taste is left to the sampler but, whatever description is given, the sampler shall state whether or not the odour or the taste or both are considered objectionable.

3.3.2 Laboratory Test

NOTE: This test should be carried out by a panel of at least three people.

Use a wide-mouth glass-stoppered bottle reserved specially for odour testing. As soon as possible after receipt of the sample, half-fill a prepared odour-free bottle with the sample and insert the stopper. With the sample at a temperature not lower than 15 °C, shake vigorously for a few seconds, remove the stopper, and check immediately for the presence of any odour. Check the taste by tasting a little water poured from the sampling bottle into a clean beaker.

Record whether or not the odour or the taste or both are considered objectionable. Compare the results obtained by each member of the testing panel with those recorded by the sampler and, if the results differ greatly, have another observation taken at the sampling point.

4. CHEMICAL TEST METHODS

NOTE

a) Unless otherwise specified, use only analytical reagent grade reagents and distilled water.

b) The methods given in this section shall be used in cases of dispute over a water supply. Other methods may be preferred for routine testing.

4.1 TREATMENT OF TEST SAMPLES

4.1.1 Clarification. Carry out all determinations on clear test samples (i.e. practically free from suspended solids and sediment) that have, if necessary, been obtained by centrifuging or filtering the original sample.

4.1.2 Stabilization. Analyse all samples as soon as possible after collection. This is particularly important in the cases of the copper determination. In the cases of the constituents listed in Table 4, unless analysis can be carried out immediately on receipt of the samples, stabilize special test samples by the relevant procedure given in Table 4.

Table 4 Stabilization Procedures

1	2	3
Determinant	Test method subsection	Stabilization procedure
Calcium, copper iron, lead, manganese, zinc	4.3, 4.6 4.9, 4.10 4.12 4.19	Add 1,5 mℓ of concentrated nitric acid (or sufficient to lower the pH value of the sample to less than 2,0) per litre of sample.
Cyanide	4.7	Add sufficient sodium hydroxide to the sample to raise the pH value to at least 12,0. Cool to 4 °C and analyse within 24 h.
Phenolic compounds	4.15	Analyse within 4 h of collection, or bring the sample to a pH value of approximately 4,0 with phosphoric acid using methyl orange indicator (or a pH meter), add 1 g of copper sulphate per litre of sample, cool to 4 °C and analyse within 24 h.

4.2 ARSENIC CONTENT. Use SABS Method 200.

4.3 CADMIUM CONTENT. Use SABS Method 201.
NOTE: Stabilize the sample unless it can be analysed immediately.

4.4 CHLORIDE CONTENT. Use SABS Method 202

4.5 CONDUCTIVITY. Use SABS Method 1057.

4.6 COPPER CONTENT. Use SABS Method 203.
NOTE: Analyse the sample as soon as possible after collection.

4.7 CYANIDE CONTENT. Use SABS Method 204.
NOTE: Stabilize the sample unless it can be analysed directly.

4.8 FLUORIDE CONTENT. Use SABS Method 205.

4.9 IRON CONTENT. Use SABS Method 207.
NOTE: Stabilize the sample unless it can be analysed immediately.

4.10 LEAD CONTENT. Use SABS Method 208.
NOTE: Stabilize the sample unless it can be analysed immediately.

4.11 MAGNESIUM CONTENT. Use either of the following methods:

a) Determine the magnesium content by calculation as follows:
Magnesium (as Mg), mg/ℓ = 0,243 (A-B)
where A = total hardness, mg of $CaCO_3$ per litre (from 4.20)
B = calcium hardness, mg of $CaCO_3$ per litre (from 4.21)

b) Use SABS Method 1071.

4.12 MANGANESE CONTENT. Use SABS Method 209.
NOTE: Stabilize the sample unless it can be analysed immediately.

4.13 MERCURY CONTENT. Use SABS Method 1059.

4.14 NITRATE PLUS NITRITE CONTENT. Use SABS Method 210.

4.15 PHENOLIC COMPOUNDS CONTENT. Use SABS Method 211.
NOTE: Stabilize the sample unless it can be analysed immediately.

4.16 SELENIUM CONTENT. Use SABS Method 1058.

4.17 SODIUM CONTENT. Use SABS Method 1050.

4.18 SULPHATE CONTENT. Use SABS Method 212.

4.19 ZINC CONTENT. Use SABS Method 214.
NOTE: Stabilize the sample unless it can be analysed immediately.

4.20 TOTAL HARDNESS CONTENT. Use SABS Method 215.

4.21 CALCIUM HARDNESS CONTENT. Use SABS Method 216.

4.22 pH VALUE. Use SABS Method 11, carrying out the determination within 6 h of sampling.

5. METHODS OF MICROBIOLOGICAL EXAMINATION

5.1 TEST CONDITIONS

Start the microbiological examination within 6 h (24 h if kept at between 1 °C and 10 °C, but not frozen) of the time of sampling, and perform the tests under strictly aseptic conditions. The temperature of the samples should preferably be kept below 10 °C during transportation and storage.

Ensure that all personnel doing the testing are adequately trained and experienced in microbiological techniques.

NOTE

a) If a sample is to be analysed after more than 6 h from the time of sampling (24 h for cooled samples), carry out the examination but state on the report that because of the delay in commencement the examination does not comply with the requirements of the specification and that the results should be evaluated accordingly.

b) Samples that are more than 24 h old may be tested only for the presence or absence of faecal coliform bacteria. State on the report of the result of the test that because of the delay in commencement the examination does not comply with the requirements of the specification.

c) Do not test any sample older than 48 h.

d) In the case of any examination commenced more than 6 h (24 h for cooled samples) after sampling (see (a) and (b) above), the results obtained are not to be used to assess compliance or non-compliance with the requirements of the specification. Such results may be used only for purposes of information.

5.2 TOTAL COLIFORM BACTERIA COUNT. Use SABS Method 221.

5.3 FAECAL COLIFORM BACTERIA COUNT. Use SABS Method 221.

5.4 STANDARD PLATE COUNT. Use SABS Method 221.

APPENDIX D

METHODS OF TESTING WATER

Certain laboratories in Southern Africa are set up to test water samples, and should be used when good, accurate analyses are required. Many hospitals will also be able to carry out bacteriological analyses. Water laboratories will be found at most water boards, the SABS, CSIR, some of the larger municipalities, some mining houses and some private consultants.

However, a knowledge of methods of analysing water quality is important for four reasons:

- certain analyses must be carried out immediately the sample is taken, otherwise the parameter to be measured may change;

- the cost of having the samples analysed may not be justified or affordable;

- the results can be interpreted more accurately when some concept of the methods of analysis and their limitations, are known;

- it may not be possible to send the samples to a laboratory within the required time period.

It is not the purpose here to give comprehensive methods on the different chemical, physical and bacteriological analyses of water, but rather to list some of the most common methods and discuss those which can be used for field testing in particular.

1. BACTERIOLOGICAL ANALYSES

This is probably the most difficult analysis to carry out as sterile conditions must be maintained and incubation of the prepared cultures must be carried out. It is important that sterile sample bottles be used for collecting the samples. The bottles can be sterilized by "autoclaving" in a pressure cooker at 15 psi for 20 to 30 minutes, or by heating in a dry oven at 170 °C for 1 hour. The samples, once collected, should be stored in covered cooled containers (cool boxes) at a temperature of 4 to 10 °C.

There are two methods available for counting the number of faecal indicator organisms present in the sample:

The ***multiple tube fermentation technique*** in which measured volumes of sample are added to sterile tubes containing a suitable growing medium. After incubation (37 °C for 48 hours) gas and acid production is measured. The results given statistical estimate of the most probable number of organisms present.

The ***membrane filtration technique*** in which measured volumes of sample are filtered through a membrane filter (0,45 μm pore size). The micro-organisms remain on the filter which is then incubated face upwards in a suitable growing medium. After 24 hours visible colonies can be counted, and expressed in terms of the number present in 100 mℓ of original sample.

Of these two methods, the membrane filtration method is more accurate. Equipment for incubation, sample filtration, etc. are fairly expensive, and the person carrying out the analyses should receive adequate training.

A third method which can be used to get an indication of whether contamination has taken place, and to give some indication of the severity of the contamination, is with the use of commercially prepared ***"dip-sticks"***. These dip-sticks have a growing medium coated on a stick marked with a grid. The stick is kept sterile until used. It is then brought into contact with the sample and some of the bacteria attach themselves to the growing media. The dip-sticks must then be incubated for 24 hours and the colonies can be counted. It is possible to achieve a reasonable incubation at 35 to 37 °C by carrying the dipsticks close to one's own body.

2. CHEMICAL AND PHYSICAL ANALYSES

Chemical and physical analyses are usually much more rapid than bacteriological analyses. Sample bottles need not be sterile and hence cheaper plastic bottles can be used. The main techniques for field chemical analysis are:

- ***Colorimetric***, in which the constituents in the water react with chemicals to produce a coloured product. The intensity of the colour indicates the concentration of the constituent. This may be done in practice by
    - paper test strips
    - printed colour comparator cards
    - discs and comparators
    - field spectrophotometers

- ***Titrimetric***, in which a selected titrant reacts with the constituent in the water, resulting in the development or disappearance of a colour indicator. The amount of titrant used to reach the end point (i.e. when all of the measured constituent in the water was reacted with the titrant) gives a measure of the amount of the constituent in the water. In practice this is done by
    - dropping burettes
    - digital titrators
    - tablets

- ***Specific ion electrometric*** in which an electrode is able to measure the concentration of a specific ion (e.g. fluoride) directly.

The methods used for the various analyses of interest are as follows:

Chlorine (free and / or combined)	:	colorimetric - usually with discs and comparator or colorimeter
Turbidity	:	turbidimeter
Colour	:	colorimetric - usually with colour cards or cubes, or colorimeter
Fluoride	:	specific ion electrode or colorimetric
Nitrate	:	specific ion electrode or colorimetric
Iron and manganese	:	colorimetric - usually with colour discs, colorimeter or spectrophotometer
Hardness	:	titrimetric
Conductivity	:	conductivity meter

Specific organic analyses should be carried out by a laboratory, but smell can often be used to detect the presence of certain organics, e.g. pesticides, oil or petrol.

APPENDIX E

LIST OF SOUTH AFRICAN GUIDELINE DOCUMENTS AND PUBLICATIONS ON DRINKING WATER TREATMENT

WRC REPORTS:

WRC Report No. TT 53/92 : **STASOFT III - Computer Program for Chemical Conditioning of Low and Medium Salinity Waters**

WRC Report No. 571/1/94 : **Overview of Institutional and Financial Arrangements in Water Supply and Sanitation (with a focus on the urban areas in South Africa)**

WRC Report No. TT 68/95 : **Water and Sanitation Handbook for Community Leaders (Urban and Peri-Urban)**

WRC Report No. 449/1/95 : **Non-Conventional Disinfection Technologies for Small Water Systems**

WRC Report No. 450/1/97 : **Package Water Treatment Plant Selection**

WRC Report No. 354/1/97 : **Evaluation of Direct Series Filtration for the Treatment of South African Surface Waters**

WRC Report No. 649/1/98 : **An Assessment of Common Problems Associated with Drinking Water Disinfection in the Developing Areas**

WRC (1998) : **Water Purification Works Design, FA van Duuren (Editor)**

CSIR REPORTS:

National Institute for Water Research, CSIR : **Manual for the Operation of Small Water Works. (1967)**

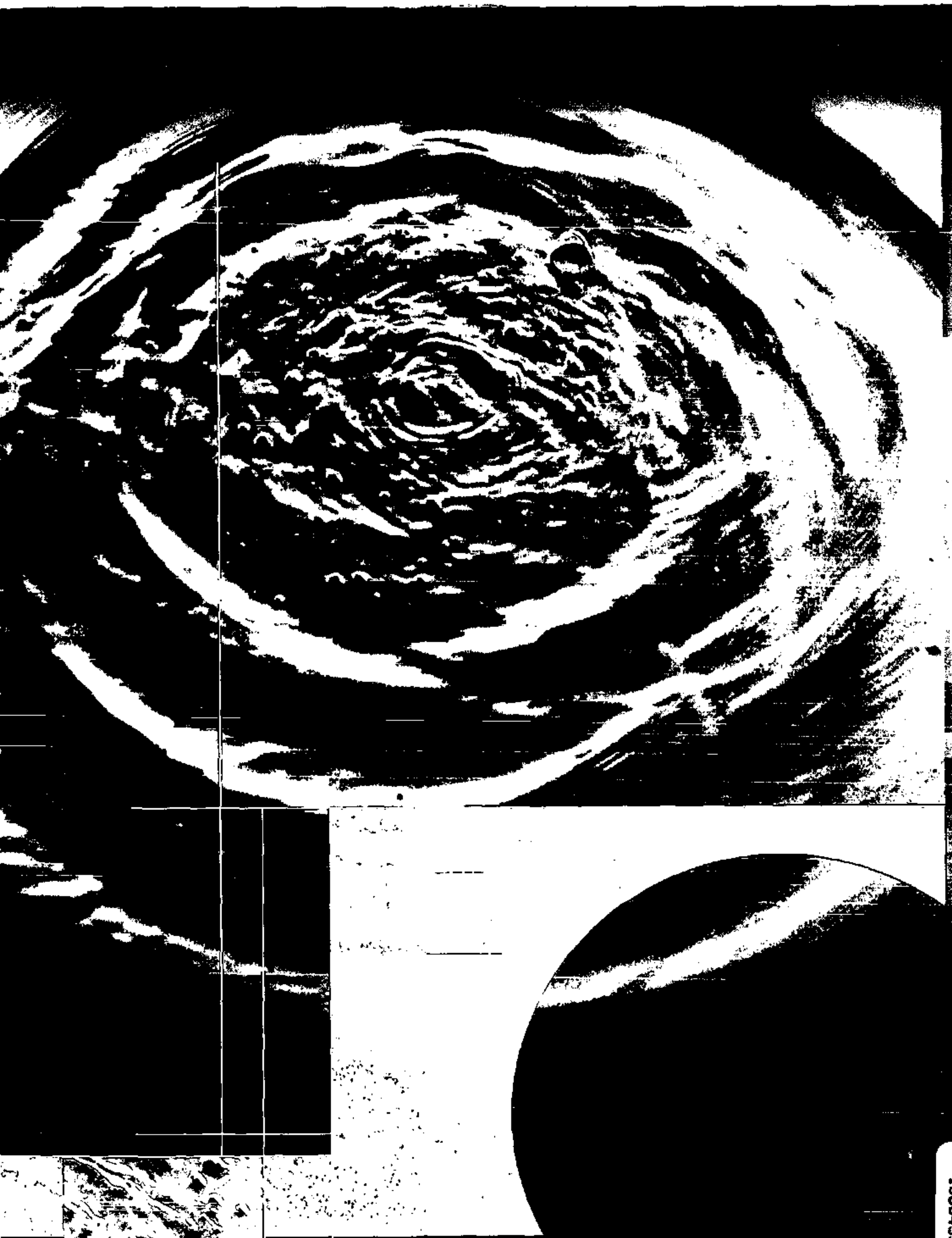
National Institute for Water Research, CSIR : **Simple Control Tests for Operators of Small Wastewater Treatment Plants.** (1980)

National Institute for Water Research, CSIR : **Manual on Water Purification Technology.** CSIR Technical Guide K73. (1985)

Division of Water Technology, CSIR : **Guidelines on Hydraulic Flocculation.** October (1990)

*Division of Water Technology, CSIR : **Disinfection for Small Water Supplies***

Division of Water Technology, CSIR : **Education and Training for Community-Based Management of Water Supply Services.** (1992)



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