Enabling Water Fluoridation on Small Drinking Water Treatment Plants

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TT 347/08

Water Research Commission

ENABLING WATER FLUORIDATION ON SMALL DRINKING WATER TREATMENT PLANTS

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Report to the
Water Research Commission

by

Umgeni Water

WRC Report No TT 347/08
March 2008

Obtainable from

Water Research Commission
Private Bag X03
Gezina
0031

The publication of this report emanates from a project entitled “Enabling water fluoridation on small drinking water treatment plants” (WRC project number K5/1530).

This report is published in two parts, viz.:

- Part A: Enabling water fluoridation on small drinking water treatment plants
- Part B: Guidelines for the implementation of fluoride dosing in small systems

ISBN 978-1-77005-700-5
Printed in the Republic of South Africa

PART A

ENABLING WATER FLUORIDATION ON SMALL DRINKING WATER TREATMENT PLANTS

Executive Summary

Regulations for the fluoridation of South African potable water supplies to an optimum concentration of not more than 0.7 mg/l in order to limit the development of dental caries were published in the Government Gazette of 8 September, 2000. Water Services Providers (WSPs) had to register with the Department of Health (DoH) by 8 September 2001 for fluoridation of their water supplies to consumers – or apply for exemption. Once the WSPs have been successfully registered, they have two years to implement the necessary infrastructure to begin fluoridation – but they may only begin fluoridation once the DoH, with the consent of the Department of Water Affairs and Forestry (DWAF), has given approval.

However, because of the larger safety risk foreseen for both plant operators and water users in smaller and rural water treatment plants, such plants supplying water to less than 60 000 people currently receive, on application, temporary exemption from the Director-General: Health. As pointed out in the desk study, *Feasibility of using water as the vehicle for the distribution of fluoride to the South African population,* this unfortunately excludes a large part of the population from receiving the benefits of fluoridation. By far the majority of water treatment plants fall within the category of supplying less than 60 000 people with potable water. In addition, most of the operators on these smaller plants are not at a skills level required by the regulations for the safe operation of a fluoride dosing facility.

A need therefore exists to enable these smaller plants to administer fluoride safely through the correct choice and operation of instrumentation and equipment, as well as by innovative ways in which to make a plant fail-safe in terms of both technology and human shortcomings. It should be noted that successful execution of this project will benefit the safe implementation and operation of fluoridation in larger water treatment plants as well.

The project aims to enable fluoridation to be done safely on small water treatment plants by means of the evaluation, selection and implementation of safe handling and dosing equipment and monitoring instrumentation. The **objectives** are to:

1. Identify world-wide and exhaustively, suitable existing and emerging instrumentation and equipment used in the whole plant process of adding liquid fluoride solutions to water for the prevention of dental caries. These should include all instrumentation, pumps, telemetry equipment, handling equipment, etc., required to receive, handle, mix, administer and measure water fluoridation chemicals on a water treatment plant in the safest and most operator-independent manner.
2. Characterise the instrumentation and equipment identified in Objective 1 against the criteria of accuracy, dependability, operator skills level requirement, built-in fail-safe measures, cost and other parameters relevant to their use especially on small water treatment plants. Compile a database of such existing instrumentation and equipment, based on the above criteria as supplied by the manufacturers.

3. Select 3-5 types of the most suitable units available on the market (but across the full cost range) and evaluate them as far as practically possible under real or simulated plant conditions. Both technical and social criteria should be applied in the evaluation.
4. Suggest and evaluate innovative measures on how to deploy the instrumentation and equipment, as well as how to structure the daily plant activities to dose fluoride correctly and safely with the least operator input required.
5. Make recommendations on how items of instrumentation and equipment should be incorporated into a fluoridation system in order to ensure the lowest health, safety and environmental risks for both plant personnel and the water consumers.
6. Determine and quantify infrastructure requirements and the associated costs to enable efficient fluoridation.
7. Identify and advise upon fluoridation skills, competencies, training and capacity building required.
8. Develop a methodology and model to determine probable tariff adjustments following the required infrastructure, training and operation and maintenance investments.
9. Compile a user-friendly guide to assist decision makers regarding the correct choice of instrumentation and equipment, as well as the best operational practices, to ensure that water fluoridation could be done accurately and safely in small water treatment systems. This guide should also contain relative cost figures (translated to R/kl) for the equipment, as well as a user-friendly and concise operation manual for each of the technologies covered in the guide.
10. Estimate the cost to the water sector of implementing water fluoridation to the required standards using the required equipment, instrumentation and manpower (including technical, operations & maintenance and human development requirements).

To achieve the stated objectives of the project, an appropriate methodology was developed. The main aspects of the methodology were the following:

- Literature review of fluoridation with emphasis on the dosing equipment, on-line and bench scale analysers, available chemicals, safety, operator and administrator competencies and training requirement.
- Evaluation and verification of the performance of selected fluoride analysers, with specific emphasis on their application to South African rural conditions.
- Implementation of fluoride dosing systems, including storage tanks, make-up units and on-line analysers to fit into two (rural application) water treatment plants to ensure that they deliver doses within the proposed fluoride range of 0.1-1.0 mg/l as fluoride using different chemical sources.
- The evaluation of the analytical and operational performance characteristics of fluoride dosing systems using suitable comparison criteria.

The outcome of the research indicated that the use of equipment that would ensure safety of handling and exposure to operations personnel and safety to the consumer by maintaining an acceptable fluoride dose in the drinking water are the main priorities.

Fluoridation handling and dosing equipment are generally no different to any other equipment that may be required to dose a potentially hazardous chemical safely and accurately. Equipment that meets the required specifications, with respect to materials of construction, accuracy and reliability are available from local suppliers and agents.

The most widely used liquid fluoride chemical source is hexafluorosilicic acid and is available locally at concentrations in the range of 40 - 50%(m/v). At these concentrations, the chemical is hazardous and corrosive and poses a serious environmental risk and safety risk to plant personnel and consumers when applied to small water systems. Therefore provisions have been made for the inclusion of a separate acid dilution centre, operated by appropriately trained and qualified personnel, to supply a safe dilute working fluoride solution to the small treatment systems.

Dry fluoride chemical source for fluoride dosing is relatively more expensive, albeit safer, relative to hexafluorosilicic acid. A dry feeder and saturator are the additional equipment required to produce a constant 4%(m/v) saturated fluoride dosing solution. An interactive decision making spreadsheet-based tool has been developed for a user to choose between a liquid or powder fluoride source.

Evaluation of fluoride analysers indicated that the instrumentation available (at the time of the evaluation) are based on the ion selective electrode principle and are all affected by similar problems associated with accuracy, precision and response due to sensor fouling. All the analysers had the capability of controlling a fluoride dosing pump to maintain a constant fluoride concentration in the water. The cheapest of the three analyzers evaluated, did not have a facility for the addition of chemical buffers and was affected by chemical matrix interference in the water. As accurate fluoride measurement and dosing control was considered crucial, the use of a fluoride analyzer, with chemical buffering capabilities, was preferred for small water systems.

Safety Health and Environmental (SHE) considerations relating to fluoride dosing systems are covered by South African legislation. However, the onus is on the user and/or service provider to implement systems and procedures to ensure the sustainable compliance with legislation.

The cost of fluoride implementation will depend to a large extent on the operational status of the waterworks, logistics and resources. A user friendly spreadsheet-based fluoridation cost estimation tool was developed to assist the fluoridation implementing agent or Service Provider to estimate the cost of fluoridation and other comparisons required to make informed decisions.

A web-based fluoridation user guide has been set up, to provide fluoridation information at the click of a button.

Recommendations

It is recommended that pilot fluoridation projects be undertaken in suitable small systems where further data may be collected for specific outcomes that include:

- Remote intervention for fluoride overdosing
- Operator Training manuals
- Capacity building

Acknowledgments

This research report emanated from a Water Research Commission funded project entitled "Enabling Fluoridation on Small Drinking Water treatment Plants".

The Steering Committee that advised and guided the Project Team consisted of the following persons:

Dr G Offringa	Water Research Commission (Chairman)
Mr CS Crawford	Department of Water Affairs and Forestry
Mr MCL de Klerk	Pelchem
Mr SA Pieterse	City of Cape Town
Ms J de Leeuw	Private Capacity
Prof J Haarhoff	University of Johannesburg
Mr CD Swartz	Chris Swartz Eng

The financial support from the Water Research Commission and the valuable contributions from the Steering Committee is gratefully acknowledged.

The Project Team also places on record the contribution of the service departments in Umgeni Water. The co-operation of the Maintenance Department at Pineside and the accredited laboratory at Pietermaritzburg, is acknowledged.

The following equipment suppliers made their fluoride analysers available free of charge for evaluation purposes :

Asea Brown Boverie (ABB)

HACH

HONEYWELL

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1. Introduction

It is widely accepted that fluoridation has contributed to a significant decline in the prevalence and severity of dental caries (tooth decay). Water fluoridation is primary (i.e. preventative) health care. If optimal amounts of fluoride are consumed from birth, then dental caries can be almost completely prevented. The EPA has ranked water fluoridation amongst the ten greatest public health measures of all time (together with pasteurization of milk, vaccination and chlorination of drinking water). Water industry professionals have been leaders in promoting and implementing this important public health intervention that has contributed to significant improvement in the dental health of consumers. Water fluoridation was found to be very cost-effective in the United States of America (USA). Implementers of water fluoridation in the USA have estimated that every dollar spent on water fluoridation avoids $38 in dental care, while drinking water costs to consumers increase by less than 1%. The cost to fluoridate water for one person for their lifetime is less than the cost to have one dental filling (Centre for Disease Control and Prevention (CDC), Water Fluoridation Training, September 2005).

There are other alternatives to water fluoridation which involves the introduction of fluoride into products that are consumed daily:

- Fluoride Toothpaste
- Fluoridated Salt
- Fluoridated milk
- Fluoride tablets, drops or rinses

Salt fluoridation is the second most common means for fluoride delivery. The World Health Organization (WHO) has stated that salt fluoridation is not a substitute for water fluoridation but should be used when water fluoridation is not practical. Therefore the international consensus is that water fluoridation is the best practice when feasible. The WHO recommends that a country implement either a water program or a salt program, but not both.

Salt fluoridation requires detailed knowledge of natural fluoride in water supplies so that the consumers do not get excessive fluoride exposure from the combination of water and salt. It is easier to manage a water fluoridation program, because the fluoride content of local water supplies can vary within a geographic region from city to city.

Water fluoridation is comparable to addition of iodine to salt, vitamin D to milk, and folic acid to breads and pastas. Water has been proven to be the most effective means for fluoride delivery for optimal oral health benefits. These methods may be impractical for rural applications due to, inter alia, socio-economic factors.

Water fluoridation is the adjustment of the water's natural fluoride concentration to a level that results in optimum oral health benefits.

Water fluoridation is practiced solely to prevent tooth decay. An important challenge is that the range between beneficial and detrimental fluoride dosage is very small. The adverse health outcome from high levels of fluoride in the drinking water is dental fluorosis.

When compared to the cost of restorative treatment, water fluoridation actually provides cost savings, a rare characteristic for community-based disease prevention strategies

- Water fluoridation is an effective and safe method for preventing tooth decay, the benefits of which anyone, regardless of socio- economic level, can enjoy.

- The benefits of water fluoridation decline as the concentration falls below optimum. As the concentration exceeds 2.0 mg/L, there is very little additional tooth decay prevention benefit and a greater potential for fluorosis (Centers for Disease Control and Prevention (CDC), Water Fluoridation Training, September 2005).

Regulations for the fluoridation of South African potable water supplies to an optimum concentration of not more than 0.7 mg/l as fluoride in order to limit the development of dental caries were published in the Government Gazette of 8 September 2000. Water Services Providers (WSP's) had to register with the Department of Health (DoH) by 8 September 2001 for fluoridation of their water supplies to consumers or apply for exemption. Once the WSPs have been successfully registered, they have two years to implement the necessary infrastructure to begin fluoridation, but they may only begin fluoridation once DoH, with the consent of the Department of Water Affairs and Forestry, has given approval.

However, because of the larger safety risk foreseen for both plant operators and water users in smaller and rural water treatment plants, such plants being of capacity less than 2500 kl/day and/or supplying water to less than 60 000 people currently receive, on application, temporary exemption from the Director-General: Health. As pointed out in the desk study, *Feasibility of using water as the vehicle for the distribution of fluoride to the South African population,* this unfortunately excludes a large part of the population from receiving the benefits of fluoridation. By far the majority of water treatment plants fall within the category of those with outputs less than 2500 kl/day. In addition, most of the operators on these smaller plants do not have the skills for the operation of a fluoride dosing facility.

A need therefore exists to enable these smaller plants to administer fluoride safely through the correct choice and operation of instrumentation and equipment, as well as by innovative ways in which to make a plant fail-safe in terms of both technology and human shortcomings. While the project focused on fluoridation in small water treatment systems, the findings will also benefit fluoridation in larger water treatment systems as well.

1.1. Scope and Objectives

The project aims were to enable fluoridation to be done safely on small water treatment plants through the correct choice of an appropriate fluoridation chemical and by means of the evaluation, selection and implementation of safe handling and dosing equipment and monitoring and control instrumentation. The objectives were to:

- Identify fluoridation chemicals suitable for small water treatment systems
- Identify world-wide and exhaustively, suitable existing and emerging instrumentation and equipment used in the whole plant process of adding liquid fluoride solutions to water for the prevention of dental caries. These should include all instrumentation, pumps, telemetry equipment, handling equipment, etc., required to receive, handle, mix, administer and measure water fluoridation chemicals on a water treatment plant in the safest and most operator-independent manner.
- Evaluate the instrumentation and equipment identified in Objective 1 against the criteria of dependability, operator skills level requirement, built-in fail-safe measures, cost and other parameters relevant to their use on especially small water treatment plants. Compile a database of such existing instrumentation and equipment, based on the above criteria as supplied by the manufacturers.
- Select the most suitable 3-5 types of these units available on the market (but across the full cost range) and evaluate them as far as practically possible under real or simulated plant conditions. Both technical criteria and social should be applied in the evaluation.
- Suggest and evaluate innovative measures on how to deploy the instrumentation and equipment, as well as how to structure the daily plant activities to dose fluoride correctly and safely with the least operator input required.
- Make recommendations on how items of instrumentation and equipment should be incorporated into a fluoridation system in order to ensure the lowest health, safety and environmental risks for both plant personnel and the water consumers.
- Determine and quantify infrastructure requirements and the associated costs to enable efficient fluoridation.
- Identify and advise upon fluoridation skills, competencies, training and capacity building required.
- Develop a methodology and model to determine probable tariff adjustments following the required infrastructure, training and operation and maintenance investments.
- Compile a user-friendly guide to assist decision makers regarding the correct choice of instrumentation and equipment, as well as the best operational practices, to ensure that water fluoridation could be done accurately and safely in small water treatment systems. This guide should also contain relative cost figures (translated to R/kl) for the equipment, as well as a user-friendly and concise operation manual for each of the technologies covered in the guide.

- Estimate the cost to the water sector of implementing water fluoridation to the required standards using the required equipment, instrumentation and manpower (including technical, operations & maintenance and human development requirements).

1.2. Methodology

The methodology involved the following:

- A literature review of fluoridation practices was conducted, with emphasis on dosing equipment, on-line and bench scale analysers, available fluoridation chemicals, safety, operator and administrator competencies and training requirement.
- Fluoridation equipment was identified. Umgeni Water's extensive database of existing equipment and instrumentation suppliers was used to source suitable suppliers. A Request for Information (RFI) was issued to all identified suppliers and advertised in newspapers to obtain an up-to-date list of appropriate suppliers. This database was supplemented with a web search to ensure that the latest, emerging suppliers are also included.
- The instruments were evaluated for accuracy, dependability, operator skills level requirement, built-in fail-safe measures, cost and other parameters relevant to their use in small water treatment plants. The information was captured on a database.
- 3-5 types of the most suitable equipment were identified for further evaluation and verification of their performance with specific emphasis on their application to South African rural conditions.
- Dosing systems, storage tanks, make up units and on-line analysers were designed to retrofit into two small water treatment plants to ensure that they deliver doses within the proposed fluoride range of 0.1 - 1.0. mg/l as fluoride using different chemical sources.
- Various suppliers, capable of supplying drinking water quality fluoride chemicals for the South African market, were identified and contacted.
- The selected equipment were evaluated to quantify their analytical and operational performance characteristics using the following parameters:
    - Accuracy
    - Precision
    - Linearity
    - Minimum detection level
    - Matrix interference effects
    - Operator bias
    - Inter-unit reproducibility
    - Ease and frequency of calibration
    - Robustness
    - Response time to stepped changes
    - Sensor fouling
    - Maintenance
    - Chemical usage (running costs)

Where possible, tests were conducted by challenging the analyzers with a variety of test samples, varying in TDS, against an appropriate reference method. Results from the analysers were compared to the reference standards to quantitatively assess accuracy, linearity and detection levels. Multiple runs were conducted to determine precision. Different operators were used to conduct similar runs to test for operator bias. Performance parameters, such as ease of use and reliability, were based on documented observations from operators. Inter unit reliability was assessed by comparing results from different equipment.

- Analytical Quality Control (AQC) samples of known fluoride concentrations were analysed in the same batch as the fluoride samples, to monitor precision and accuracy of sample analysis. Performance Test (PT) Samples and drinking water samples were produced under different operating conditions.
- Data was acquired either electronically or manually by operators and laboratory staff. Operational information, required maintenance, results from verification tests and sampling procedures were documented on data sheets and laboratory books.
- Dosing equipment was purchased. However, due to the high capital costs of on-line analyzers, vendors willing to participate in these evaluations, were requested to hire the equipment to the research team. Vendors also assisted in the setting up and calibration of all equipment.
- The fluoride dosing system was operated by technicians and operators who were undergoing training at the Wiggins Process Evaluation Facility. In this way the ease of operation and user-friendly characteristics of the dosing system were evaluated.
- Procedures to minimise over- or under-dosing are documented in a number of literature sources. These safety procedures were set up for dry chemical feeders, powder feeders and liquid dosing systems and subjected to evaluation by new operators typically being used in small rural treatment plants. Warning systems to minimise public health using technology such as GSM/cell phones were also investigated.
- Skills, competencies, training and capacity building required to efficiently and safely operate these systems were identified during the operation of the various systems.
- A spreadsheet model was developed to determine the capital and operating costs of the effects of fluoridation. The model allows for the input of capital equipments costs, chemical costs, human resource training costs and running costs incurred.
- Using the data and information gathered, a user-friendly guide was compiled to assist decision makers on the correct choice of instrumentation, equipment and fluoridation chemicals, as well as best operational practices, to ensure that water fluoridation may be implemented accurately and safely in small water treatment systems. This guide contains relative cost figures (translated to R/kl) for the equipment, as well as a user-friendly and concise operation manual for each of the technologies covered in the guide.

A model for the calculation of costs to the water sector of implementing water fluoridation to the required standards using the required equipment, instrumentation, manpower, technical, operations, maintenance and human development costs has been developed.

2. Fluoridation Equipment

Fluoridation equipment characteristics and specifications may differ, depending on whether the application is for large water systems or small, rural type water systems.

2.1. Fluoridation in Large Water Systems

Generally fluoridation in large water systems does not present a challenge. The large waterworks have the necessary infrastructure and resources to manage the safety aspects and dosage control necessary for optimum fluoridation. More importantly, large waterworks are mainly located in urban areas where the consumer can afford the relative increase in water costs due to fluoridation. The larger waterworks also have a reasonable capital and operating budget, skilled human resources and level of sophistication in terms of instrumentation and control, to handle fluoride dosing efficiently and cost-effectively.

2.2. Fluoridation in Small Water Systems

Generally, most small water systems are located in the rural and peri-urban areas. These areas are generally characterized by low per capita income, poor infrastructure and scarcity of technical skills. Fluoridation at small water systems presents a challenge due to the relatively higher costs of treated water with respect to additional facilities required, viz. accurate dosing and control equipment and safety.

2.3. Fluoridation Chemicals

The choice of fluoridation dosing equipment is determined by the choice of fluoridation chemicals. The three fluoridation chemicals most frequently utilized in water fluoridation are:

- Sodium Fluoride, NaF
- Sodium Silicofluoride, Na_2SiF_6
- Fluorosilicic Acid, H_2SiF_6

Fluoridation chemicals are available as a solid (sodium fluoride, sodium silicofluoride) or a liquid (fluorosilicic acid).

2.3.1. Sodium Fluoride

Sodium fluoride is available in both powder and crystalline form. The crystalline form is preferred because it produces less dust than the powdered form. The concentration of a sodium fluoride solution remains constant at 4%(m/v) due to its solubility and the saturated solution pH is approximately 7.6.

During preparation of the saturated solution, dust control is important because sodium fluoride dust is harmful to human health.

Personnel protective equipment such as goggles, gloves, aprons, dust masks, respirators must be used and properly maintained to avoid exposure due to accidental inhalation of dust. A good ventilation system is necessary.

2.3.2. Fluorosilicic Acid

Fluorosilicic acid is delivered in liquid form, at concentrations between 40 and 50%(m/m). Fluorosilicic acid will depress pH to a greater extent than sodium fluoride. Low alkalinity water is particularly susceptible to significant drop in pH, when fluorosilicic is dosed. Lower pH waters can be corrosive or contribute to high lead and copper levels in the distribution system due to the material of construction of the pipe work.

Extreme safety precautions, including the use of rubber protective clothing and face shields, must be taken when handling the chemical to avoid human contact. The fumes from the storage tanks are corrosive to glass and metal and must be vented to atmosphere outside the equipment housing.

2.3.3. Sodium Silicofluoride

Sodium silicofluoride is manufactured as a by-product from fluorosilicic acid. Due to its low and varying solubility at different temperatures, sodium silicofluoride is normally fed through dry volumetric feeders followed by vigorous agitation which makes it unsuitable for small plants and is only common in larger plants (Eddy Valkenburgh, 2004). Maximum allowable concentration of fluoride dust in air for both sodium fluoride and sodium silicofluoride is 0.2 - 0.3 mg/m^3.

Table 2.1: Summary of Fluoride Chemicals

Properties	Sodium Fluoride	Sodium Silicofluoride	Fluorosilicic Acid
Formula	NaF	Na_2SiF_6	H_2SiF_6
Form	Powder/Crystals	Powder/Fine Crystals	Liquid
Molecular weight, g/mole	41.99	188.07	144.1
Available fluoride ion (AFI), percent	45.25	60.7	79.2
Purity, percent (m/m)	97-99	98 -99	40-50
pH of saturated solution	7.6	3.5	1.2
Density, kg/m^3	1000-1400	880-1150	1390
Solubility in water, g/l	40.5	7.6	infinite

2.4. Fluoridation Dosing Equipment Required

There is no one specific type of equipment that is used solely for one type of water system. All the fluoridation equipment, with the exception of a saturator, can be used on any system.

2.4.1. Dosing Solution Preparation

Generally fluoridation chemicals are dosed in liquid form into the water stream. Table 2.1 summarises the preparation required for the more widely used fluoride chemical source.

Table 2.2: Fluoridation Chemical Preparation before Dosing

	Fluorosilicic Acid	Sodium Fluoride	Sodium Silicofluoride
SOLUTION PREPARATION	Delivered in a liquid form can be dosed directly or be diluted into the water stream.	Powder or crystals added to makeup water in a saturator to form a saturated 4% solution that is dosed via a pump into the water stream	Dry compound is transported using a dry feeder to a mixing tank, homogenized with water and delivered to the water stream via a dosing pump.

* (Water Fluoridation, A Manual for Engineers and Technicians, September 1986)

2.4.2. Equipment Selection Criteria

The chemical selected as the fluoride source will determine the criteria for the selection of the equipment.

Factors influencing equipment selection include:

- Fluoride dosing equipment compatibility with the existing water system as in most cases the fluoride dosing will be retrofitted into existing water systems
- Point of fluoride addition.
- Number of treatment sites.
- Level of natural fluoride level in the raw water.
- Capital and operating costs.
- Government rules and regulations may influence the equipment selection significantly. Provincial government may standardize on a particular chemical or installation type.

The dosing equipment requirements of adding fluoride to water are:

- Precise Delivery for both treated water meters and fluoride dosing meters
- Small Dosing Quantities/Capacities
- Reliability
- Safety in Handling Hazardous Products
- Corrosion Resistance

To ensure that the fluoridation process is maintained with minimal operator supervision, it is essential that water treatment systems possess dependable facilities and equipment.

2.4.3. Fluoridation Equipment

Fluoridation enabling equipment consists of:

- Fluoride source material storage and handling, dependent on whether the fluoride source is a powder or liquid.
- Fluoride solution preparation for dosing.
- Dosing pump with control features.
- Fluoride measurement and feed back control.

The three commonly used fluoridation system are:

- Fluorosilicic Acid- liquid dosing system.
- Sodium Fluoride- saturator system.
- Sodium Silicofluoride- dry feed dosing system.

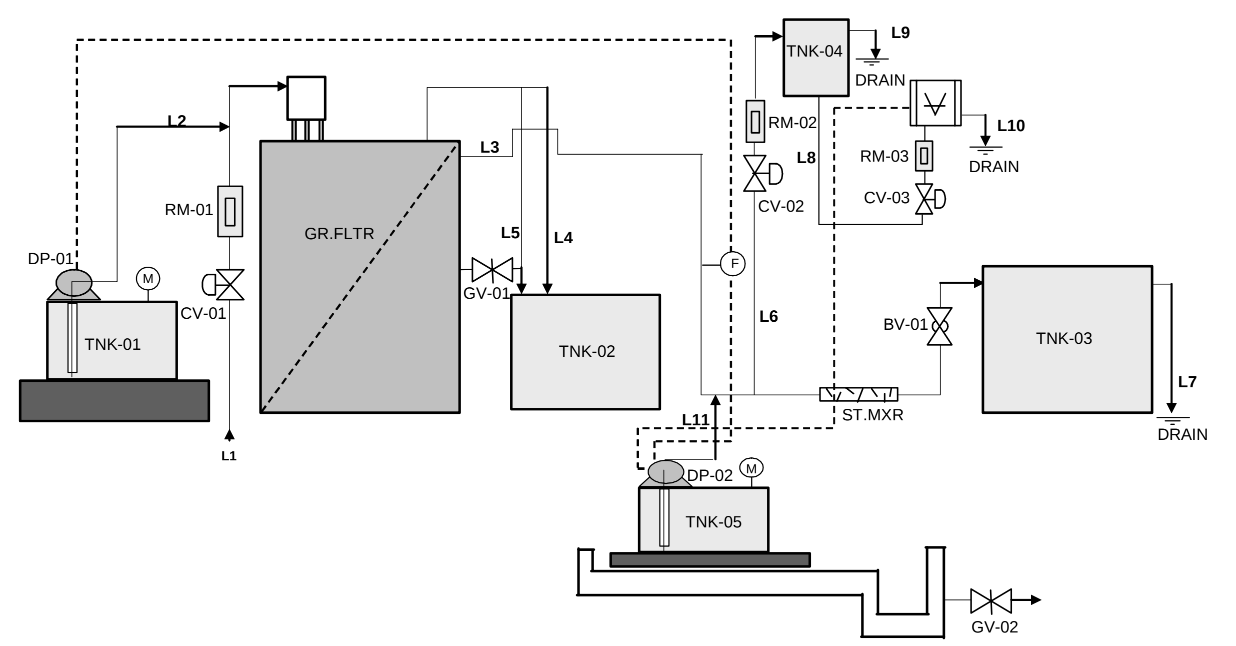
2.4.4. Fluorosilicic Acid Feed Equipment

Fluorosilicic acid can be dosed as supplied into the water main. The concentrate is generally in the range of 40 - 50%(m/m) as fluorosilicic acid. Dosing the concentrated acid directly is easier on large water systems with sophisticated controls, reliable facilities and the large output capacity.

On small rural water systems, there are a number of challenges that will impact negatively on the direct dosing of fluorosilicic acid in its concentrated 'as delivered' form. The most significant factors inherent with local small water systems and their impact on fluoride dosing include:

- Low and variable water production rate causes difficulties in maintaining stable fluoride dosing rates when using highly concentrated fluorosilicic acid (i.e. 40% (m/v).
- Very small and accurate dosing pumps are required. These are not easily available.
- On-site storage of the highly hazardous acid concentrate will create a potentially unsafe environment. The lack of skilled staff and facilities to handle spillages and accidents will further aggravate the situation.
- Most small water systems are located in undeveloped regions where operation, maintenance and water quality monitoring is poor. Dosage control will be extremely difficult.
- Logistics and inaccessibility presents a challenge for regular monitoring, planned maintenance and quality control.
- The high cost of implementing measures to safely and accurately dose the concentrated acid, may not be cost-effective.

A typical fluorosilicic acid dosing system is shown as Figure 2.1.



Equipment List

TNK-01 : HDPE Alum Coagulant Tankl
TNK-02 : SS Backwash Tank
TNK-03 : HDPE Alum Coagulant Tank
TNK-04 : PVC Header Tank
TNK-05 : HDPE Fluorosilicic Acid Tank
GR.FLTR : Gravity Filter (AVGF)
DP-01 : Coagulant Dosing Pump
DP-02 : Fluorosilicic Acid Dosing Pump
F : Acid Resistance Flowmeters
ST.MXR : Static Mixer
M : Electrical Motor Driven Mixer

Valves & Fittings

CV-01/02/03 : Manual Control Valves
GV-01/01 : Manual Gate Valves
BV-01 : Ball Valve
RM-01/02/03 : Rotameters

Line Spec

L1 : Raw Water Inlet
L2 : PVC - Acid Pump Discharge
L3 : PVC - Filtered Water
L4 : SS Backwash
L5 : SS Aux. Backwash
L6 : PVC - Header Tank Feed
L7 : PVC - Storage Tank Overflow
L8 : PVC - Fluoride Analyzer Feed
L9 : PVC - Header Tank Overflow
L10 : PVC - Analyzer Outlet
L11 : Acid Dosing

Figure 2.1: Fluorosilicic Acid Process Diagram

2.4.4.1. Bulk and Day Tanks

The tanks should be robust and resistant to acid corrosion. The most commonly used types of material of construction for fluorosilicic acid storage tanks are polyethylene and polypropylene.

2.4.4.2. Tank Level Switches

To minimize operator intervention, level switches can be used to allow the dosing tanks to function continuously and automatically. The level switch should be linked to the control system that allows for the dosing tank to be filled when it is low or empty.

The different types of level switches available, including their advantages and disadvantages are presented in Table 2.3.

Table 2.3: Comparison of Level Switches

Types of Level Switches	Characteristics	Advantages	Disadvantages
Float / Buoyancy	• Monitors level at a set-point and is activated if the level deviates above or below set-point	• Low cost • Materials compatible for acid application	• Mechanism not sensitive for accurate control • Not suitable for low flow conditions
Capacitance	• Capacitance of the probe changes when immersed in the tank fluid. Change is detected and rectified to display as a level indicator	• Can operate at extreme temperature and pressure. • Easy mounting • No moving parts	• Capacitance systems are intrusive • Not compatible with most dielectric material • Not suitable for liquid that leaves a coating
Vibration	• Consists of a driver, paddle and a sensor • Driver emits a 120 Hz vibration in the paddle • When covered with product, signal decreases and provides a level indication	• Sensitive to small changes in density	• Subject to damage from tank contents
Ultrasonic	• Consists of a transmitter and receiver. • Sound waves are emitted through the fluid, then reflected back to a transducer • Measures time taken for an ultrasonic pulse to travel to the process liquid and back	• No moving parts • No contact with process fluid. • Unaffected by variations in fluid composition, density	• Not suitable for liquids with surface bubble generation • Limited pressure and temperature working range,
Optical	• Operation based on reflection, transmission or refraction of laser or infrared light	• Small, easy installation • Suitable for mixed materials and slurries • No moving parts • Low cost	• Optical windows can get dirty and lose sensitivity

2.4.4.3. Pumps

Positive displacement pumps are best suited for accurate and precise chemical dosing applications. Centrifugal pumps are very dependent on pressure for their operation and will not be able to provide accurate fluoride dosing.

The most commonly used positive displacement pumps available are presented in Table 2.4 together with their advantages and disadvantages.

Table 2.4: Comparison of Various Dosing Pumps

PUMP TYPE	PRINCIPLE OF OPERATION	ADVANTAGES	DISADVANTAGES
DIAPHRAGM	• Two speed control variables i.e. stroke length and frequency • Stroke frequency can be external controlled via analog/digital/pulse signal	• Oil-free operation • High gas tightness/low leakage • High reliability and long life	• Single channel operation • Pulsing flow • Moderate precision • Can only dispense • Difficult to sterilize
PERISTALTIC	• Optional feature of a flow totaliser which removes the need for calibration • Two flow control variables, speed of contraction/dilation and diameter of tubing	• Almost noiseless operation • Only tubing is exposed to the fluid • High level of accuracy for small dosing operations	• Pump is expensive • Not suitable for large flow rates • Tubing lifespan is relatively short
PISTON	• Operate on similar principle to diaphragm pump but with a piston instead. Piston moves forward and backwards at various speeds • Stuffing box to prevent fluid from leaking into the pump mechanism	• Handle very viscous fluid • Operate over a wide pressure range • Excellent durability	• Pump is expensive • High maintenance costs
GEAR	• For metering application. • Produce smooth pulse free flow. • Can receive analog signal to adjust a variable speed driving motor	• Low NPSH • Handles very viscous fluids • Very accurate • Low maintenance costs • Can handle back pressure	• Medium pressure • One bearing runs in pumped product • Unbalanced load on shaft bearing
HELICAL	• The pumping gears of this type of pump and are driven by a set of timing and driving gears that help maintain the required close clearances without actual metallic contact of the pumping gears. • Capacity of the pump is dependent on the design of the rotor.	• Produces smooth and even flow • High suction lift • Volumetric accuracy • Low maintenance costs • High energy efficiency	• Small changes in flow result in large changes in pressure
WATER DRIVEN	• Uses the flowing water in the pipeline to draw dosing solution into pipe • Energy required from the momentum of piped water to pump the dosing solution	• No power required for operation • Will not dose chemical if no piped water is present • Inexpensive and relatively cheap	• Minimum pressure required for any pumping to occur

2.4.5. Sodium Fluoride Feed Equipment

Dry fluoride chemicals are usually fed into the water system as a saturated or unsaturated solution. Either a saturator or a feeder can be used.

2.4.5.1. Saturator

A fluoride saturator is a device used to dissolve the dry sodium fluoride, forming a saturated fluoride solution. The saturator generally uses sodium fluoride which must have a consistent fluoride chemical bed in a tank. The water flows through the bed and the fluoride saturated water rises above the fluoride bed. The saturated solution is then drawn from the saturator via a pump and dosed into the water.

Three types of fluoride saturators are available:

- **Upflow Saturator**

  A typical upflow saturator (Figure 2.2) consists of a closed vessel with a spider type water distributor located at the bottom of the tank. Water, forced under pressure through slits in the distributor, flows upward through the sodium fluoride bed at a controlled rate to produce the desired 4%(m/v) fluoride solution. The metering pump intake line floats on top of the solution in order to avoid withdrawal of undissolved sodium fluoride.

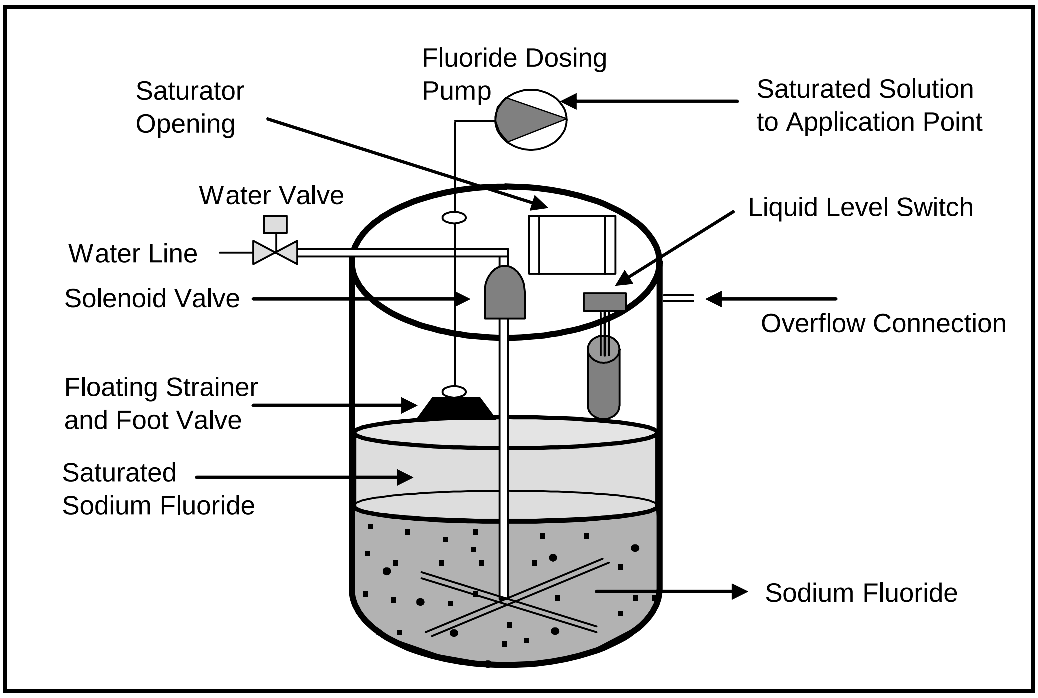


Figure 2.2: Upflow Fluoride Saturator

- **Downflow Saturator**

The downflow saturator, shown in Figure 2.3, has been replaced by the upflow saturator mainly due to operation and maintenance problems with the downflow saturator. One important advantage was that the sand and gravel were eliminated in the upflow saturator.

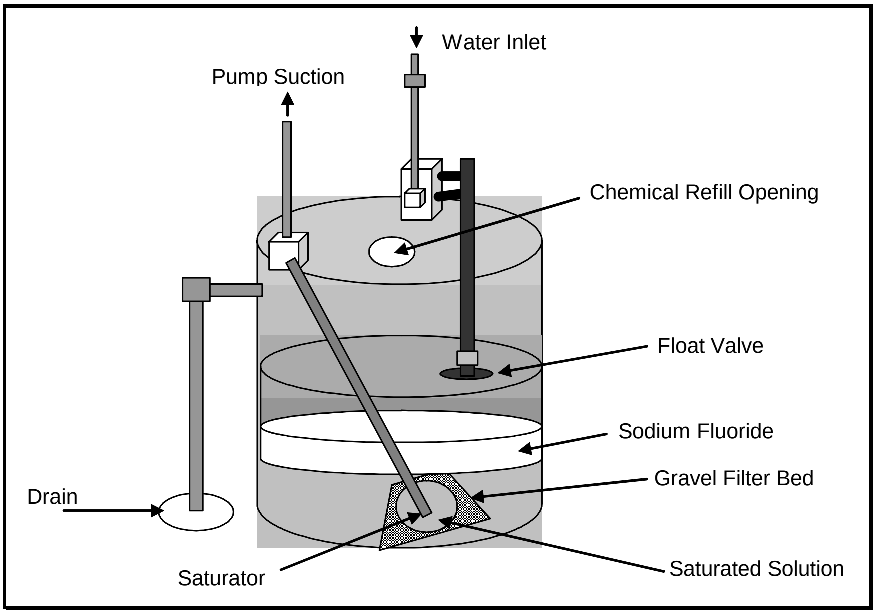


Figure 2.3: Downflow Fluoride Saturator

- **Venturi System**

This fluoridation system, presented in Figure 2.4, though not widely used, is generally found in extremely small community water systems (such as villages, trailer courts, or individual villages, or individual school buildings. The chemical of choice is normally sodium fluoride but the technology is still considered to be in its experimental stages.

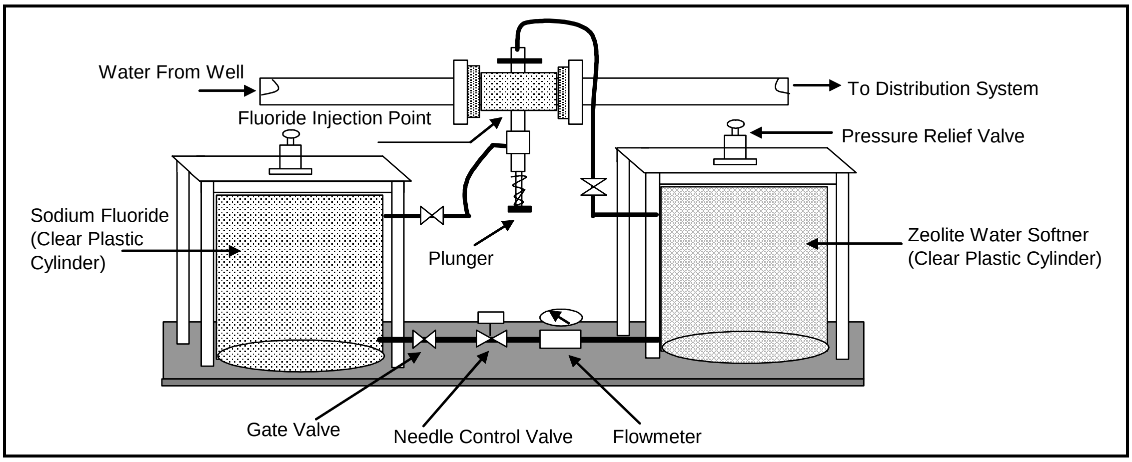


Figure 2.4: Venturi Fluoride System*

* Source: Quick Facts About Fluoridation- Copyright 1999: M. W. Easley, DDS, MPH; National Center for Fluoridation Policy & Research

2.4.5.2. Pumps

The dosing pumps available are discussed under 2.4.4.3 because the pumps apply to any liquid dosing provided that they are compatible with the liquid.

2.4.6. Sodium Silicofluoride Feed Equipment

Dry fluoride chemicals are typically fed into the water system as a saturated or unsaturated solution.

2.4.6.1. Dry Chemical Feeders

A dry feeder places the dry materials into a solution, which is then fed into the treated water. Sodium silicofluoride is the least expensive chemical to use when compared to fluorosilicic acid and sodium fluoride. Sodium silicofluoride is however not as readily soluble as sodium fluoride because its solubility is dependent on temperature.

Dry chemical feeders deliver a fixed quantity of fluoride chemical in a specified time interval. The two types of dry feeders are:

- Volumetric dry feeder: Delivers a precise volume of dry fluoride chemical per unit of time
- Gravimetric dry feeder: Delivers a precise mass of chemical per unit of time

In fluoridation, dry feeders may be used to feed sodium fluorosilicate or sodium fluoride. (Water Fluoridation, A Manual for Engineers and Technicians, September 1986).

Table 2.5 summarises the principle of operation and applicability of 4 types of volumetric dry feeders.

Table 2.5: Types of Volumetric Dry Feeders

TYPE	ROLL-TYPE DRY FEEDER	VIBRATORY-PAN DRY FEEDER	OSCILLATING-PAN DRY FEEDER	ROTATING SCREW DRY FEEDER
DESCRIPTION	Fluoride chemical is placed in the hopper through a top opening. Powder flows by gravity to the feed rolls.	A flat, narrow pan or trough into which the fluoride compound falls from a hopper above.	Discharges a volume of chemical from a pan, chute, or trough that vibrates electrically.	Fluoride chemical is placed in the hopper through a top opening. Powder flows by gravity to a screw feeder.
MATERIAL OF CONSTRUCTION	Stainless Steel	Stainless/Mild Steel	Stainless/Mild Steel	Stainless/Mild Steel
PRINCIPLE OF OPERATION	Feed rollers, form the material into a smooth ribbon of uniform thickness. The feed rate is adjusted externally on a graduated feed slide by varying the width of this ribbon. The feed rate is then adjusted by changing input rpm. Material leaves the rolls at a uniform rate, falls into a solution tank, and discharged to the main water system.	The pan slowly oscillates along the axis of the pan, forcing removal of chemical along the two open edges of the pan Delivery rates are controlled by both the speed of oscillation and the length of the stroke or the thickness of the chemical on the pan.	A magnet is energized by means of a pulsating current The trough is mounted on springs and connected directly to the magnet. The action of the tray is downward and backward on the power stroke, and upward and forward on the next stroke through the action of the springs.	An arrangement with vibrating plates in the hopper walls provides constant agitation. The agitation extends to the feed screw (hopper bottom) and is designed to prevent arching and packing. An eccentric on the feed screw shaft drives a rocker arm connected to vibrating plates in the hopper walls.
ADVANTAGES	Feeds powdery or granular dry, free-flowing materials at rates from 2,7 kg/hr to 950 kg/hr Most widely used	The magnetic-drive of a vibratory feeder is capable of rapidly responding to changes in controller output signal.	Delivery rates more accurately controlled	The feed screw gives single-ended delivery of fluoride to the solution tank at a uniform rate via the discharge line
DISADVANTAGES	Very fine powder tends to run freely through the rollers	Too many moving parts. Complicated mechanical operation	Too many moving parts. Complicated mechanical operation	A gear-motor drive system for a screw feeder, and the screw itself, represents considerable angular ”inertia” which simply can not be made to respond quickly to demand changes.

The two main types of gravitational dry feeders are presented in Table 2.6.

Table 2.6: Types of Gravitational Dry Feeders

TYPE	LOSS IN WEIGHT DRY FEEDER	MOVING BELT DRY FEEDER
DESCRIPTION	Consists of a hopper suspended from a scale system, an electrical mechanical system for moving the poise on the scale beam, a mechanical means for moving the compound from the hopper in an amount depending on the position of the scale beam and a solution tank.	A section of a loaded, moving belt is continuously weighed. The weight of the belt is balanced by a scale beam. The position of the beam controls delivery of the compound onto the belt.
PRINCIPAL OF OPERATION	The lead screw drive (a synchronous motor) moves the poise along the beam at a pre-set rate of speed. If more material is fed momentarily than indicated by the position of the poise, then the beam will lower. This action moves the control wedge (near the oscillator) downward, permitting a decrease in the amplitude of the stroke driving the star wheel or vibrating feeder mechanism. Less material will then be delivered until the weight of the compound remaining in the hopper is again balanced by the weight of the scale beam.	Any deviation from balanced belt weight on the belt causes the vertical gate to go up or down, thus causing more or less material to fall onto the belt. Vibrations imparted to a diaphragm on the hopper are generated by an eccentric and transmitted through a wedge that varies the amplitude of the vibrations, depending on the position of the scale beam.
ACCURACY	Greater than 99%	Greater than 99%

2.4.6.2. Solution Tanks

The dry feeder delivers the dry fluoride chemical into a solution tank. Dry feeders operate differently from a saturator. A saturator produces a saturated solution, whereas a feeder will add a set quantity of dry chemical to a volume of dilution water in a preparation tank. A dry feeder does not need softened water, whilst a saturator often requires softened water.

The minimum time for mixing sodium fluorosilicate is 5 minutes, but sizing the solution mixing tank for a 10 to 30 minute detention will ensure good dissolution (Water Fluoridation Training, Centre for Disease and Prevention, September 2005). A mixer is required to create and maintain a homogenous solution in the solution tank. The solution is then dosed from the tank via a dosing pump.

2.4.7. Auxiliary Equipment

Auxiliary equipment may also be required to measure the quantity of fluoride chemical added to the final water to set the correct dosages, auditing purposes and to keep track of chemical costs.

A scale is generally employed to measure the mass of the liquid holding tank. A mass measurement is preferred over volume measurement because an analogue or digital signal can be produced to assess the exact volume of liquid in the tank.

These scales are also required for the acid dilution process. The amount of fluorosilicic acid and water needed to produce a fixed acid batch concentration can be conducted more precisely and accurately.

The advantages of using scales are:

- Chemical consumption can be monitored very accurately
- If the scale has an analogue output, the mass of chemical can be monitored remotely
- Alarms can be linked to the scale if the output from the chemical tank exceeds a certain set point or if the flow is far less than the set point, e.g. vapour lock
- Equipment such as pumps etc can be shut down automatically using a signal from the scale

Table 2.7 shows the difference between two types of scales that may be used for chemical preparation, monitoring and control.

Table 2.7: Types of Industrial Scales

SCALE TYPE	HYDRAULIC SCALE	ELECTRONIC SCALES
Advantages	1. Simple and easy to operate 2. Very robust 3. No electrical power needed 4. Relatively safe to operate	1. High resolution and sensitivity, particularly in chemical systems with low feed rates 2. Sophisticated data interpretation, such as feed rates and daily usages 3. Feed rate alarms and pump controlling capacity
Disadvantages	1. No control features 2. Operator dependent	1. Relatively expensive 2. Requires trained staff

2.4.8. Process Instrumentation and Devices

Good fluoride dosing control is vital to the success of any fluoride dosing water system due to the narrow range between the beneficial and detrimental fluoride levels.

The three critical parameters in the fluoride dose control loop, to ensure optimum fluoride dosing are:

- Final water flow rate
- Dosing pump rate
- Total fluoride concentration in the water

2.4.8.1. Water Flow Measuring Instrumentation

The role of any instrument used to determine flow is to provide an indication of the total volume of water processed. Another function is for the instrument to be able to control another piece of equipment such as the dosing pump via a flow signal, as well as displaying a flow to any operation monitoring personnel.

There are two main types of instruments that measure flow:

- Water meter
- Flow Meter

Table 2.8 shows a comparison between water meters and conventional flowmeters.

Table 2.8: Comparison between Flow Meter and Water Meters

TYPES	ADVANTAGES	DISADVANTAGES
Flow Meter	1. The flow rate at any instant is measured. 2. Various types are available. 3. Except for a few basic flow meters, most can be used for control purposes. 4. High level of accuracy.	1. Very expensive. 2. Many require electricity. 3. Some require an external data logger, etc for totalisation.
Water Meter	1. Relatively low cost 2. Easy to use. 3. Strong against corrosion.	1. Strainer required when installed on raw water line. This causes significant pressure drop. 2. Cannot be used for control purposes unless fitted with a pulsar output.

2.4.8.2. Flowmeter

This metering instrument indicates the rate at which the water is being piped. Available flow meters are rotometers, turbine type, electromagnetic and ultrasonic.

The selection criteria used for the evaluation of flowmeters are:

- Water Quality
- Level of Accuracy
- Type of Transmitter desired
- Robustness

A comparison of the different types of flowmeters used in a water application is presented as Table 2.8.

Table 2.9: Different types of Flow Meters

TYPE OF FLOW METER	ROTOMETER	TURBINE	ELECTRO-MAGNETIC	ULTRASONIC
PRINCIPLE OF OPERATION	A rotometer consists of a tapered tube, typically made of glass, with a float inside that is pushed up by flow and pulled down by gravity. At a higher flow rate more area (between the float and the tube) is needed to accommodate the flow, so the float rises.	Use the force of the moving fluid to turn a propeller-like blade rotor. The flow rate is proportional to the rotational speed of the rotor. Various types of turbine flow meter, Axial, Jet, etc	Operates on Faradays law of induction. Commonly known as "magflow"	Use ultrasonic waves to measure flow rate. Waves are sent across the flow stream from one side of the pipe to the other and the time it takes is measured.
ADVANTAGES	Simple, relatively cheaper, easy maintenance.	Able to be used in fluid which has a zero conductance.	No obstruction to flow. Almost maintenance free even with high corrosion or abrasive. Measure a wide range of fluids.	Very accurate.
DISADVANTAGES	Always vertically oriented with the fluid flowing upwards. Can restrict fluid flow when blocked.	Contact with fluid Suitable for purified water and not the raw water	Limited to fluid with conductance	Expensive

2.4.8.3. Water Meter

This metering instrument indicates the total volume of water piped. With the use of a magnetic or optical method of producing a pulse, a pulsar output signal allows the water meter to act as a paced flow meter. A pulsar output water meter has the ability to control the stroke frequency of an electrical dosing pump. This pulsar output signal from flow meter can control the dosing pump rate by proportionally increasing the dosing pump rate as the water flow increases and vice versa. When there is no water flow, the dosing pump will stop completely. This is a cheap technique of maintaining a constant fluoride dose even when the raw water flow changes.

Water meters are normally used in most water treatment plants, especially small water treatment systems.

A water meter with a pulsar output for fluoride dosing control is recommended for small water systems because of simplicity of operation and cost effectiveness.

2.5. Fluoride Measuring Instrumentation

On-line fluoride analysers provide continuous measurement and recording of fluoride concentrations in the water with optional control features to ensure safe and effective fluoride dosing. An on-line fluoride analyser enables the fluoridation process to be relatively operator independent. The three methods used for fluoride analysis in water:

- Ion Selective Electrode
- Colorimetric Method
- Inductively Coupled Plasma Spectroscopy or ICP-MS

A comparison of the fluoride analytical techniques is presented in Table 2.9.

Table 2.10: Fluoride Measuring Methods

METHOD	DESCRIPTION	ADVANTAGES	DISADVANTAGES
Ion Selective Electrode	Measures the activity of the ions by measuring the electrical potential. On-line instruments use this technique	Less ionic interference errors in the analysis. Minimizes operator related errors.	Much higher operator skill levels required.
Colorimeter	Compares the reduction in the color of an indicator solution that is reduced by the presence of ions. Used for batch-scale laboratory tests	Cheaper than the other methods available.	Competing ions can cause errors in the analysis. Susceptible to operator related errors.
Inductively Coupled Plasma Spectroscopy	Measures the number of ions in a fixed volume on the basis of mass-to-charge ratio. Used for laboratory tests and research	Very accurate in fluoride measurement.	Very expensive device and therefore rarely used for routine plant analysis and monitoring

The selection criteria used for the determination of the appropriate fluoride measurement method are based on the following parameters:

- Fluoride Measurement Frequency i.e. the number of readings required per day for verification

- Matrix Interference i.e. competing ions
- Cost Implication i.e. capital, operating and maintenance costs
- Requirement for fluoride dose control, i.e. automated control loop or manual control

2.5.1. Ion Selective Electrode Method

The Ion Selective Method is the most popular method that uses a fluoride sensitive ion selective electrode (ISE) to measure fluoride ion concentration similar to the way that a pH sensor measures hydrogen ion concentration. A fluoride crystal at the tip of the sensor develops a voltage that is proportional to fluoride ion activity. Another reference electrode is used to measure the differential voltage developed.

The selective ion electrode measures the fluoride ionic strength in solution, but there are interferences that can cause inaccuracies in the measurement.

The first type of interference occurs when the fluoride ions form complexes with polyvalent cations like Al (lll), Fe (lll) and Si (lV). These complexes are properly detected by the ion selective electrode and a reading will be obtained which is below the actually amount of fluoride ion in solution.

The second type of interference occurs from the variable pH of water. The hydrogen ions tend to form complexes with the fluoride ions and the hydroxide ion directly interferes with the electrode response.

Most ISE analysers compensate for known interferences by using pH correction and ionic strength buffering solutions. A few analysers on the market do not provide for chemical buffering and are cheaper but less reliable than their more expensive counterparts that incorporate the chemical buffering.

The simplest ion electrode analyzer measures and displays the fluoride ion strength of the water. The analyzer also transmits a 4 – 20 mA signal that may be used to control a dosing pump. However, it does not correct for any interferences that may affect the accuracy of the fluoride measurement.

There are more sophisticated analysers called ***sampling analyzers*** because they are not connected directly inline but take a small sample feed off the main feed line. An acidic buffer solution is used to preferentially complex with interfering polyvalent cations. The disadvantage of this type of equipment is that some instruments can have significant lag times, which makes control and monitoring more difficult. Sampling analyzers also adjust the pH of the sample taken to remove the hydrogen and hydroxyl ion interference.

Some analyzers also provide for online calibration, which is done using two standard solutions housed in the analyzer.

2.5.2. Colorimeter Method

This is a simple laboratory method with the following basic components:

- a source of radiant energy or light source, an energy detector to measure how much of the energy passes through the sample, and
- a sample compartment in the path of the energy source.

Results obtained are generally not very accurate or reproducible.

2.6. Process Control Options

2.6.1. Fluoride Dose Control Options

There are many options for fluoride dosing control and monitoring. The key components include:

- Flow meter
- Fluoride dosing pump, and
- Online fluoride analyzer.

An inline static mixer is required to ensure that the concentration of fluoride analyzed by the fluoride analyzer is the same concentration that will reach the consumer.

The various options available for fluoridation dose control are discussed in Table 2.10 with reference to the process control loops in Figures 2.5 – 2.8.

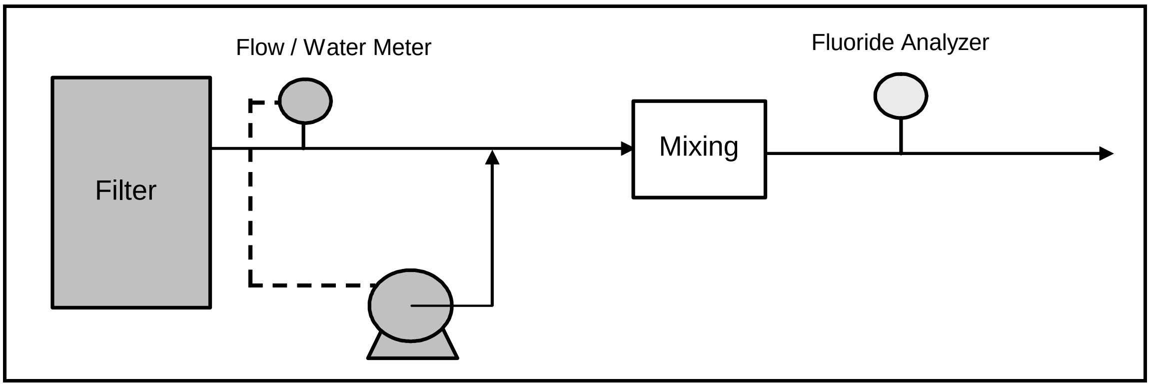


Figure 2.5: Manual / Operator Dosage Control

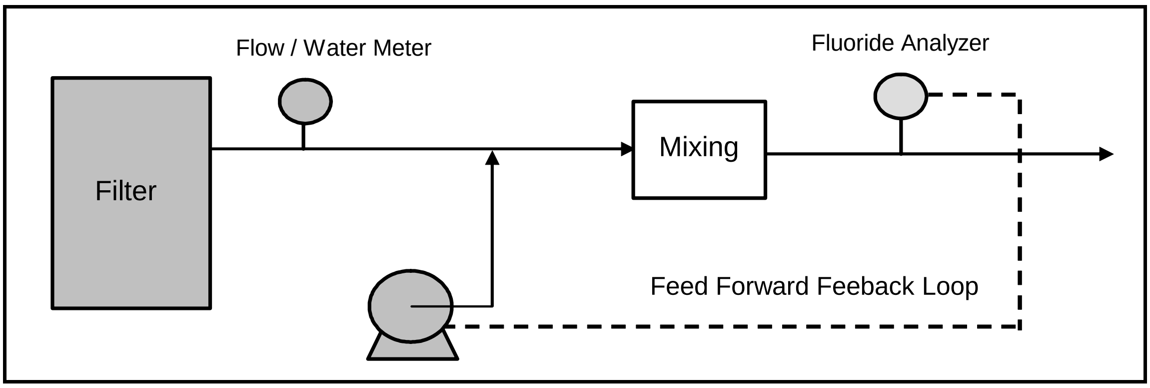


Figure 2.6: Fluoride Dosing Pump Linked to Water/Flow Meter

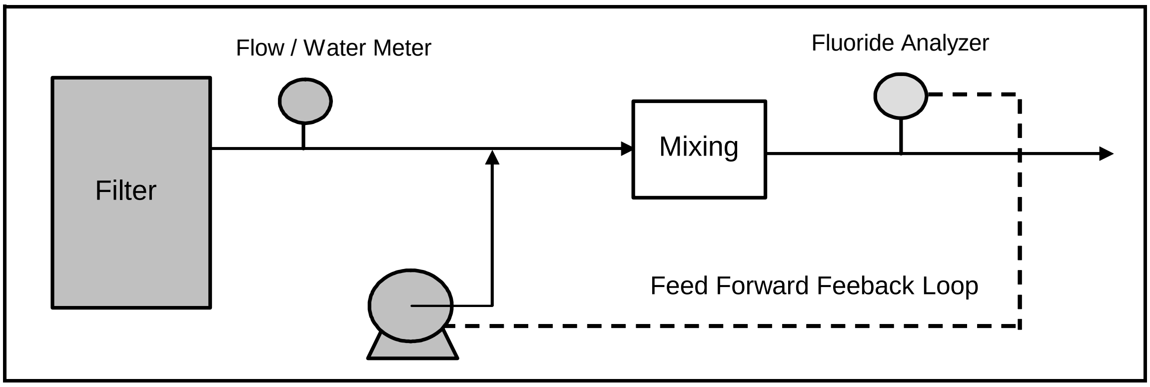


Figure 2.7: Fluoride Dosing Pump Linked to Fluoride Analyzer

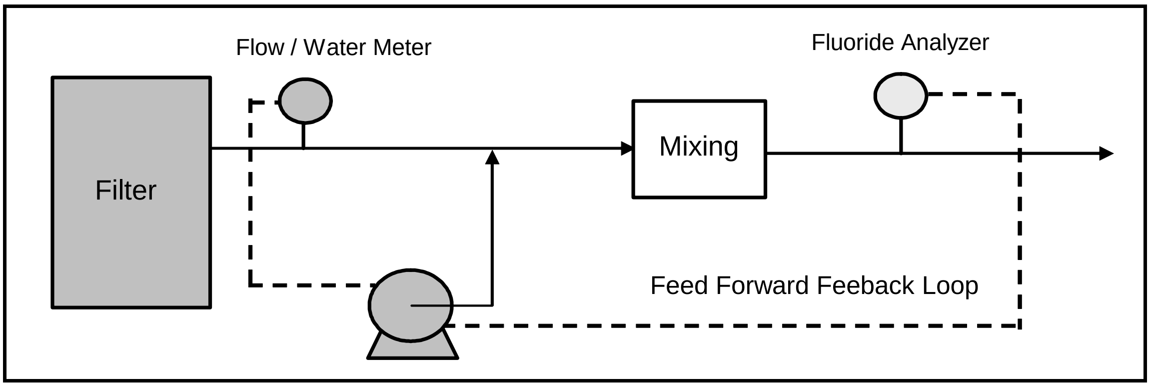


Figure 2.8: Fluoride Analyzer and Water/Flow Meter Linked to Dosing Pump

Table 2.11: Fluoride Dosing Control Options

PUMP CONTROL	OPERATOR/ MANUAL CONTROL [FIGURE 2.5]	FLOWMETER PROPORTIONAL CONTROL [FIGURE 2.6]	FLUORIDE ANALYSER FEEDBACK CONTROL [FIGURE 2.7]	FLOWMETER AND FLUORIDE ANALYSER FEEDFORWARD AND FEEDBACK CONTROL [FIGURE 2.8]
Principle of Operation	Operator controls dosage based on raw water flow, fluoride solution strength and fluoride concentration in treated water	Proportional ratio between fluoride doses and water flow rate. A water meter with a pulse output and a dosing pump that can receive a pulse input is required.	A digital or analog signal is sent from a fluoride analyser to a suitable controller. The output signal from the controller to the dosing pump adjusts itself by comparing the fluoride analyser signal against a programmed fluoride dosage setpoint.	Principles of both a feed forward and feed back control loop are used. The flowmeter and fluoride analyser send analog signals to the controller which then adjusts the fluoride pump flowrate to achieve a dosage within the setpoint.
Advantages	Basic and least expensive	No need for any type of controller. Relatively cheap option.	Less operator input required. More effective than the flow proportional technique since the fluoride concentration in the final water determines the pump flowrate	Ensures the fluoride dose always remains within the set range eliminating the main risk of overdosing associated with fluoride addition in drinking water.
Disadvantages	Operator dependent. Susceptible to human error which could lead to overdosing.	A change in set point of the required dose will have to be done manually on the pump.	Relatively expensive option. Skilled staff needed for troubleshooting.	Expensive option The controller needs to be calibrated very accurately to attain good control.

The feed-forward feedback control is recommended as it eliminates or minimizes the risk of overdosing.

2.6.2. Types of Control Instrumentation

A simple but effective controller maybe employed to carry out the necessary functions discussed above. Table 2.11 gives a summary of the three main options.

Table 2.12: Types of Control Logic

CONTROL	ON/OFF	P, PI, PID	PLC
Description	Simple and least expensive means of control. Minimum and maximum set points are set on the controller. When the input signal to the controller falls out of the minimum or maximum set range, an output signal will switch a device (e.g. A pump) either ON or OFF.	Proportional, Proportional and Integral or Proportional, Integral and Derivative controllers provide more control options and the desired setpoint is much easier to obtain. More expensive than the simple ON/OFF controllers.	Programmable Logic Controllers are sophisticated and expensive. They posses unlimited control features which include the On/Off, P, PI and PID control options. Control sequences can be programmed and stored with the aid of a computer. Mostly used for large applications due to cost.

2.7. Fluoridation Monitoring and Data Acquisition

The recording of data can be achieved with the aid of dataloggers. Data logging can be performed on site or off site.

On site data logging can be done manually or by a datalogger and the information stored are accessible at the plant only. Off site data logging can be achieved with the aid of telemetry whereby a telemetry device can be installed on any sensor that needs to be logged and the information may be logged elsewhere via a remote computer.

2.7.1. Dataloggers

Data loggers are electronic instruments that can collect and store process information received via process sensors.

Fluoridation information such as chemical consumption, amount of water fluoridated and the analyzer's readings can be logged and evaluated on a regular basis.

The following criteria should be considered for the selection of data loggers:

- Type of Inputs – analog or digital
- Storage Capacity
- Number of Channels
- Power sources - mains power and battery power
- Telemetry Compatibility

2.7.2. Telemetry

The types of telemetry options available and their advantages and disadvantages are outlined in Table 2.12.

Table 2.13: Comparison of Telemetry Sources

TELEMETRY OPTION	CELLULAR	RADIO	SATELLITE
Advantages	Small, non directional antenna Low maintenance required and small start up costs due to established network Various types of communication available, e.g. voice, sms, internet South Africa is very up to date in terms of cellular technology	There is no direct monthly communication costs involved compared to cellular telemetry, for example roaming charges. Very reliable transmission of data, which is not governed by network problems that can occur with cellular telemetry Encryption is available to prevent information being accessed illegally.	Satellite telemetry would typical be used for very remote locations where cellular and radio technology is not feasible. Low maintenance costs and easy to start up.
Disadvantages	It requires stations to be in cellular phone coverage area The service provider charges a fee for the particular network used Quality and availability of communication at all time is determined by the service provider	High capital cost can be incurred if repeater stations are needed Licensing costs are payable. Qualified personnel required to maintain the radio network Even though radio communications are wireless, there must always be "line of site", where one antenna can see another antenna without any obstruction in between.	Monthly operating costs would be very expensive, especially when large amounts of data are being transferred.

3. Safety Health & Environmental

3.1. Stock Material Handling

All fluoride chemicals used in fluoridation are considered toxic and hazardous in their concentrated state and are therefore harmful to humans and the environment. Proper safety measures are required to eliminate the risks completely or to minimize risks to manageable and acceptable levels.

3.1.1. Sodium Fluoride

During preparation of the saturated solution, dust control is important because sodium fluoride dust is harmful to human health.

Personal protective equipment (PPE) such as goggles, gloves, aprons, dust masks, respirators must be used when handling the chemical to avoid exposure due to accidental inhalation of dust. A good ventilation system in the area where sodium fluoride is being handled by operations personnel is necessary.

3.1.2. Fluorosilicic Acid

The acid is delivered in liquid form, at concentrations between 40 and 50%(m/m).

Extreme safety precautions must be used, including the use of rubber protective clothing and face shields, when handling the chemical to avoid human contact.

The fumes from the storage tanks are corrosive to glass and metal and must be vented to atmosphere outside the equipment housing.

3.1.3. Sodium Silicofluoride

Maximum allowable concentration of fluoride dust in air for both sodium fluoride and sodium silicofluoride is 0.2 - 0.3 mg/m^3.

General guidelines and minimum specifications for the storage of the commonly used fluoride source chemicals are presented in Table 3.1. The material safety data sheets (MSDS) are appended.

Table 3.1: Fluoride Chemical Storage Guidelines

SODIUM FLUORIDE	SODIUM SILICOFLUORIDE	FLUOROSILICIC ACID
1. Keep in a dry place 2. Isolate from other chemicals to prevent intermixing. 3. Provide good ventilation to prevent dust buildup and to control humidity and heat. 4. Provide a containment area that holds 110% of the saturator capacity. 5. Provide a floor drain equipped with running water to clean up spills. 6. Avoid generating dust.	1. Keep containers tightly closed in a dry, cool and well ventilated area. 2. Provide good general ventilation. 3. Prevent product from entering drains.	1. Keep in a cool and dry place. 2. Provide good ventilation for fume extraction. 3. Ensure that storage temperature is above its freezing point. 4. Do not store in direct sunlight. 5. Provide containment to hold 110% of the storage container capacity.

3.2. Personal Protective Equipment

The choice of personal protective equipment for controlling exposure depends on the effectiveness of other control measures. In most existing treatment facilities, while some higher order controls may be in place (e.g. exhaust fans), it is unlikely that they will be sufficient to enable work to be undertaken safely without a range of PPE. This includes general protective clothing and respiratory protection.

General protective equipment may include:

- elbow length impervious gloves; and
- long-sleeved shirt, trousers, and a full length impervious apron or disposable
- impervious overalls; and
- impervious boots.
- In addition, for fluorosilicic acid, a full face shield or chemical goggles.

Respiratory protective equipment may include:

- for dry powdered or granular fluoridating agents
  - a chemical goggle and half face mask fitted with an appropriate filter
- for fluorosilicic acid, where there is a risk of exposure to acid fumes,
  - a full face respirator fitted with an acid gas canister. It should be noted that filter respirators require a good seal around the face, which cannot be achieved where

there is facial hair. A powered air purifying respirator may be required for bearded operators.

PPE should not be left in the open where it can become contaminated by chemical dust but carefully stored in a dustproof cabinet in the vicinity of the work area.

A PPE maintenance program must be implemented. Maintenance procedures should include regular inspection of safety gear and replacement of worn or damaged items.

The PPE Maintenance program should include:

- gloves, aprons and boots should be hosed off after use and dried before storage;
- clothes contaminated with dry fluoridating agent must be changed and washed after handling of fluoride chemicals is completed;
- clothes contaminated with wet fluoridating agent must be changed and washed immediately;
- respirator filters must be replaced regularly. Dust filters require changing whenever an increased resistance to air movement through the filter becomes noticeable.

Extreme care should be taken in the handling of the fluoride chemicals. Table 3.2 presents basic handling guidelines.

Table 3.2: Fluoride Chemical Handling Guidelines

SODIUM FLUORIDE	SODIUM SILICOFLUORIDE	FLUOROSILICIC ACID
1. Use an SABS/SANS approved particulate respirator with a soft rubber face to mask seal and replacement cartridges. 2. Use plash proof safety eye goggles. 3. Use gauntlet neoprene gloves apron. 4. Provide an eye wash station in an easily accessible location.	1. In case of fire, wear a self-contained breathing apparatus. 2. Wear personal protective equipment 3. Use rubber or plastic gloves when in contact with the chemical. 4. Use dust impervious protective suit. Remove and wash contaminated clothing before re-use. 5. Tightly fitting safety goggles.	1. Use splash proof goggles and full face shield. 2. Wear heavy duty, acid proof neoprene apron or acid proof clothing and shoes. 3. Use gauntlet neoprene gloves with cuffs, which should be a minimum length of 300 mm. 4. Provide an eyewash station and safety shower in an easily accessible location.

3.3. Safe Working Procedures

Fluoride remains a safe compound when maintained at the optimal level in water supplied to the distribution system; however, an operator might be exposed to high concentrations of the fluoride solution that may be detrimental to his health. Written safe working procedures, that include the use of personal protective equipment (PPE), are required for tasks that carry a high safety risk for the operator, environment and equipment. The fluoride service provider or implementing agent should provide written safe working procedures that have been tested and verified as well as operator/user training.

Operators should be trained to work safely. Systems should be in place to promote a safe and positive work ethic in the work place and should include the provision of the necessary safety facilities, awareness campaigns, disciplinary interventions, monitoring and continuous improvement.

3.3.1. Exposure to fluoride chemicals

If the operator gets either wet or dry chemicals on the skin, he should thoroughly wash the contaminated skin area immediately. Clothing contaminated with a wet chemical, should be removed immediately. Work clothing contaminated with dry powder during a normal days work, should be changed daily.

3.3.2. Recommended Emergency Procedures for Fluoride Overdosing

When a community fluoridates its drinking water, a potential exists for incidents of fluoride overdosing. Overdosing of short duration may not pose a health risk; however, high fluoride levels for long durations are known to cause immediate health problems. All overdosing problems should be corrected immediately due to their potential to cause serious long-term health effects.

Specific actions should be taken when equipment malfunctions or an adverse event occurs in a community public water supply system that causes a fluoride chemical overdose.

When a fluoride test result is at or near the top end of the analyzer scale, the water sample must be diluted and retested to ensure that the fluoride levels are accurately measured.

Persons who ingest dry fluoride chemicals and fluorosilicic acid should receive emergency treatment.

3.4. Environmental Containment and Disposal

There were no environmental protection acts, specific to fluoridation, in South Africa at the time of this investigation. In terms of the Australian *Environmental Protection Act 1994,* a Municipal Water Treatment Plant was classified as a Level 2 Environmentally Relevant Activity, and as such this activity must not be carried out without approval issued under the Act. This approval would normally be issued subject to certain conditions being met. All levels of plant personnel including the operator have a collective environmental responsibility under the Act not to carry out any activity that causes or is likely to cause environmental harm unless the person takes all reasonable and practicable measures to prevent or minimise the harm. (Code of Practice for the Fluoridation of Public Water Supplies, Oral Health Unit Public Health Services Queensland Health, January 2000).

3.4.1. Storage of Fluoridating Agents

Fluoridating agents must be stored in a designated storage area separate from other chemicals and in accordance with the current legislation on storage of dangerous goods. The storage area may be a designated part of the fluoridation room.

3.4.2. Types of Chemical Containers

Typical chemical containers for the liquid fluoride source materials are polyethylene or polypropylene containers. Powder fluoride source material may be stored in heavy duty polyethylene bags.

3.4.3. Spillages and leaks

Spillage of any fluoridating agent in the room must be carefully managed:

- Any spilt fluoridating agent must be hosed off the floor and not removed by dry sweeping. Removal by vacuum cleaner is permissible only if the cleaner is fitted with a suitable filter;
- Safety procedures detailed in the MSDS should be followed when a large spillage of fluoridating agent occurs.

3.4.4. Disposal of containers

In terms of the Australian fluoridation act, wherever possible, fluoridating agent containers should be returned to the manufacturer for disposal. In circumstances where this cannot be arranged:

- Empty bags which previously contained fluoridating agent should be hosed clean and buried under a minimum of 500 mm depth of soil at an approved waste disposal facility;
- Fluorosilicic acid containers should be thoroughly rinsed and should not be used for any other purpose. Small carboys/drums should be shredded and buried under a minimum of 500 mm depth of soil at an approved waste disposal facility (Code of Practice for the Fluoridation of Public Water Supplies, Oral Health Unit Public Health Services Queensland Health, January 2000);
- Where local disposal is not practical, an approved waste service should be used to arrange disposal of empty containers.

3.4.5. First Aid

The Material Safety Data Sheet (appended) clearly states the first aid procedure applicable in the case of accidental ingestion and physical contact with the fluoridation chemicals. The MSDS gives advice on first aid treatment required for accidental ingestion and eye and skin contact. The operations staff should undergo first aid training specific to the accidents caused through fluoridation chemicals so that all relevant staff are in a state of awareness and readiness when an accident occurs.

4. Fluoride Analysers

4.1. Introduction

Fluoride dosing in potable water applications essentially incorporated four main areas:

- fluoride source/raw material selection;
- fluoride measurement;
- fluoride dosing system and control;
- safety, health and environment.

The evaluation of available on-line fluoride analysers, supplied by local agents and equipment suppliers, is outlined in this chapter.

Three different brand types of Ion Selective Electrode (ISE) fluoride analysers were evaluated against accepted criteria.

Presented in the second part of the report is the investigation into the choice of raw materials for fluoride dosing. Essentially, two common fluoride chemical sources were investigated, namely, fluorosilicic acid (liquid) and sodium fluoride (powder/crystalline). A comparative study of the use of the two fluoride chemical sources, incorporating equipment required, cost of chemicals and safety implications is also presented.

After extensive communications with local suppliers, three on-line fluoride analysers were obtained for evaluation. An on-line instrument analyser station, with treated water supply and facilities for continuous monitoring was designed and installed. The three fluoride analysers were mounted on an analyser station and set up so that each analyser received the same fluoridated water supply at its respective operating flow rate.

4.1.1. Principle of Operation

The Ion Selective Electrode (ISE) technique is the most widely used method of fluoride determination. Most electrodes contain a fluoride solution with the tip of the electrode being crystal doped with fluoride ions. The crystal acts as an ion conductor, so that when the fluoride concentration outside of the electrode is higher than the inside, ions move toward the inside, setting up a voltage potential proportional to the difference in fluoride concentration. When the concentration of fluoride on the outside is lower than the inside, a proportional potential of opposite sign is set up. Some electrodes may not contain an internal solution but the operational principal is the same.

4.1.2. Brief Description of Fluoride Analysers Evaluated

All three of the fluoride analysers evaluated are based on the ISE principle. Two of the analysers were highly sophisticated and have a chemical buffering facility where the pH and ionic strength of the incoming sample is adjusted to reduce matrix interference during the fluoride measurement stage. The third analyser is a very simple unit without a facility for chemical adjustment of the sample. This instrument, like the other two more expensive analysers that were evaluated, has the ability to generate an electrical signal, proportional to the measured fluoride concentration which can control the output of a fluoride dosing pump.

The technical attributes of the individual analysers are presented in Table 4.1.

Table 4.1: Technical Specifications of Fluoride Analysers

Instrument	Analyser 1	Analyser 2	Analyser 3
			
Description	8321EIL Online Fluoride Analyser	CA610 Online Fluoride Analyser	97082 Online Fluoride Analyser
Sensor	Ion Selective Electrode	Ion Selective Electrode	Ion Selective Electrode
Range (mg/l)	0.1 to 1000 mg/l	0.1 to 10 mg/l	0.1 to 10 mg/l
Accuracy	± 5% of reading	± 10% of reading	--
Chemical	Sodium Hexametaphosphate, Sodium Chloride and EDTA solution	TSIAB Reagent and Standard Solutions	No reagents used
Output Signal for Control	4 – 20 mA	4 – 20 mA	4 – 20 mA

4.1.3. Evaluation Criteria

Most of the instrumentation, especially on-line analysers and other sophisticated measuring equipment are imported. They are often designed with the operating environment of their country of origin in mind. This includes aspects like, level of sophistication, sample characteristics, level of expertise of operating and maintenance staff and capital costs. Valuable information can be obtained from the evaluation of selected equipment under controlled conditions of the environment in which the instrument is expected to be operated.

The following evaluation criteria were identified and adopted:

- Analyser Response
- Accuracy
- Precision
- Analyser Sensitivity
    - Interference
    - Detection Limit

    - Linearity
    - Sensor Fouling Potential
- Maintenance
    - Ease and frequency of calibration
    - Planned maintenance, availability of spares, electrodes
    - Reagents used, volume and costs
- User friendliness
    - Operator
    - Instrument technician
    - Level of skill required for operation and maintenance
- Application to process control
- Running costs
    - Chemicals
    - Calibration and maintenance

4.1.4. Evaluation Methodology

Fluoride was dosed in-line into a filtered water supply line to the on-line analyser evaluation station. The flowrates to the respective analysers were set as per the instrument specifications. The local agents/suppliers of the analysers calibrated the equipment and also trained the technicians and researcher on the operating procedure and care of the instruments. A dilute hexafluorosilicic acid solution was dosed at a fixed flowrate to deliver a constant fluoride concentration in the water. The treated water feed flow was also maintained a constant rate.

4.1.5. Summary of Evaluation Results

The evaluation was conducted over a six month period. Experiments were run during the day. To avoid repetition only typical trends are presented here.

4.1.5.1. Analyser Response Time

The analyser response to changes in fluoride concentration in the final water was evaluated (Figure 4.1). Analyser 3 responded the quickest and Analyser 2 responded the slowest to a 0.5 mg/l fluoride dosage. The quick response time of Analyser 3 may be attributed to the fact that the analyser has fewer analytical steps, compared to the others which had a chemical buffering step. The relatively slower response of Analyser 2 has been observed over a number of runs. A similar trend is seen when fluoride dosing is stopped at the end of the run.

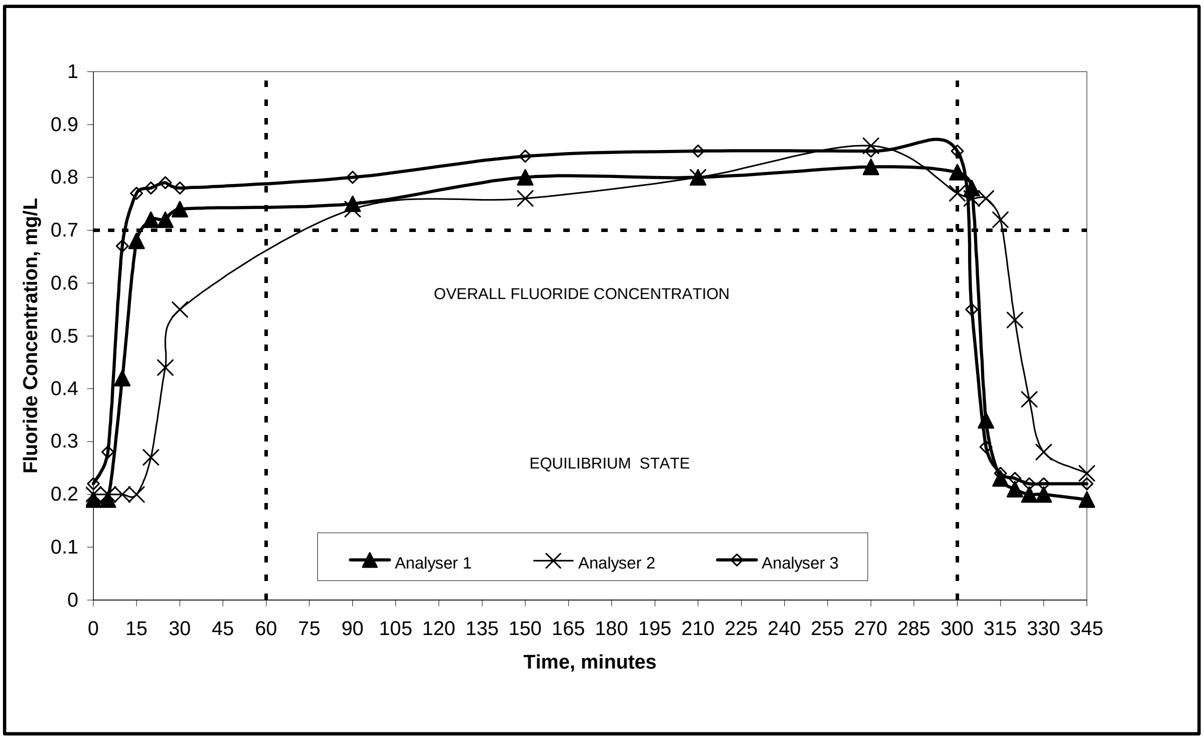


Figure 4.1: Fluoride Analyser Response

4.1.5.2. Analyser Accuracy and Precision

Precision describes the reproducibility of measurements with respect to the mean and may be expressed as the variability of individual measurements from the mean.

Table 4.2: Analytical Variance for a 0.7 mg/l Fluoride Concentration

ANALYSER	MEAN FLUORIDE CONCENTRATION [mg/l]	ANALYTICAL VARIANCE [mg/l]
Analyser 1	0.57	0.52 - 0.62
Analyser 2	0.71	0.65 - 0.77
Analyser 3	0.74	0.61 - 0.87
Lovibond Photometer	0.59	0.57 - 0.61

For the estimation of deviation from a true value, fluoride results from the UW accredited laboratories were used as reference and true value for the comparison of accuracy of the three on-line analysers. Percentage deviation from the true value of less than 5% is generally an acceptable upper limit for on-line instruments.

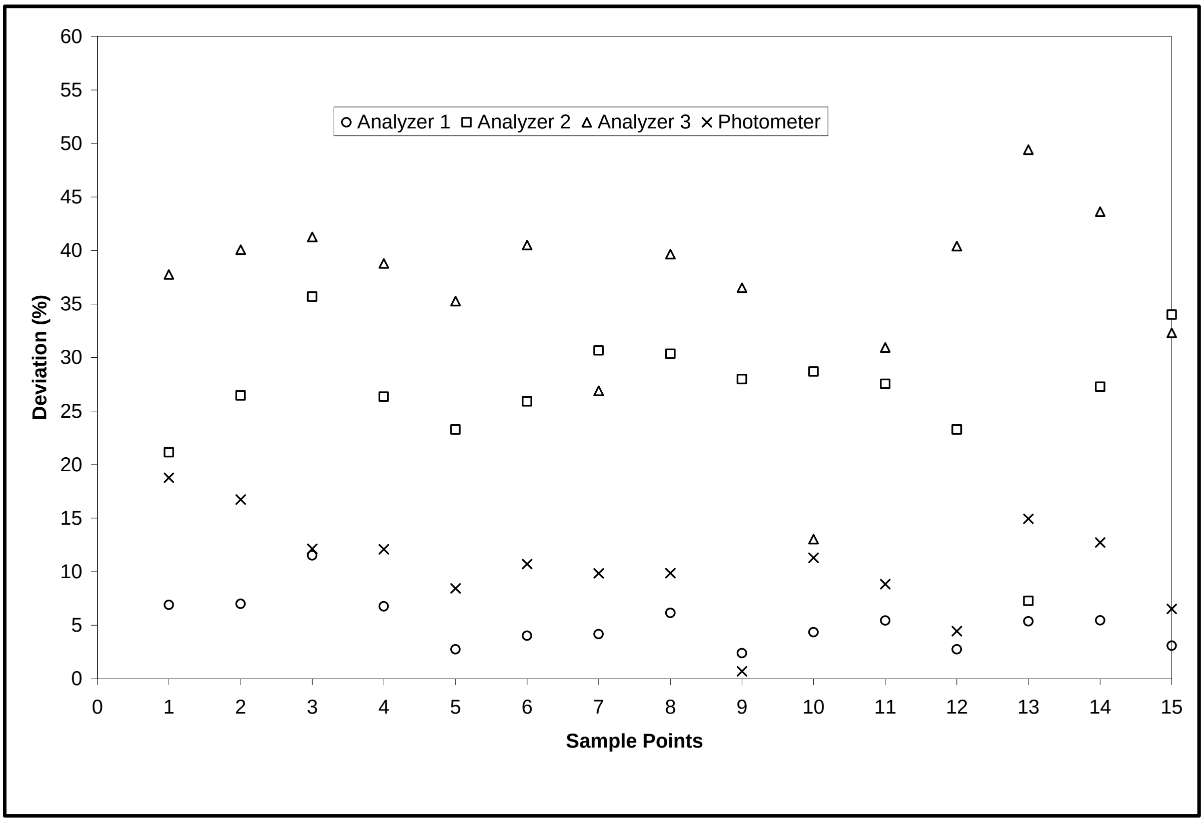


Figure 4.2: Relative Deviation of the Fluoride Analysers with respect to the corresponding laboratory measurements.

Figure 2 indicated that there was a significant variation in the relative difference in fluoride measurements between the on-line analysers. Only Analyser 1, had a deviation of less than 10% relative to the laboratory result.

4.1.5.3. Matrix Interference

Quantification of specific ions in water, especially at the low range, suffers the effects of matrix interference. There is therefore a need for chemical conditioning and/or buffering of the sample water so that matrix interference is kept at a minimum. The problem is most significant in situations of variable water quality or where plant monitoring and control is poor.

<u>Effect of pH Change</u>

At constant fluoride dose of 0.5 mg/l, the pH of the filtered water was increased from 8 to 11 using lime. Analyser 3, the instrument without chemical buffering, was significantly affected by pH change (Figure 4.3). Analyser 1 and Analyser 2 were relatively unaffected by pH change within the range tested.

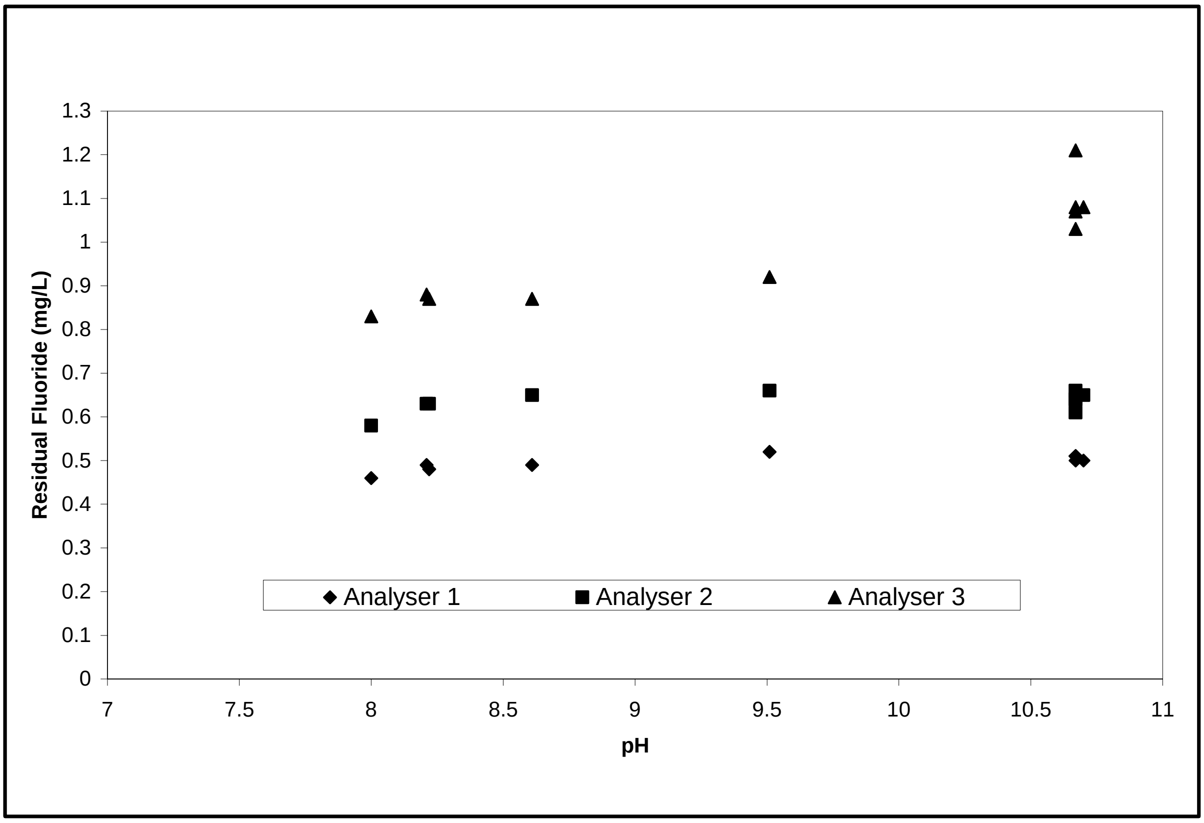


Figure 4.3: Analyser response to pH

Effects of Residual Chlorine

Residual chlorine in the treated water was varied while the fluoride dose was kept constant. The trial was continued for a week to capture any interference effects due to chlorine.

All three fluoride analyser responses were not significantly affected by the usual levels of chlorine present in the treated water (Figure. 4.4). Analyser 3, even without a chemical buffering facility, showed good stability with respect to chlorine interference.

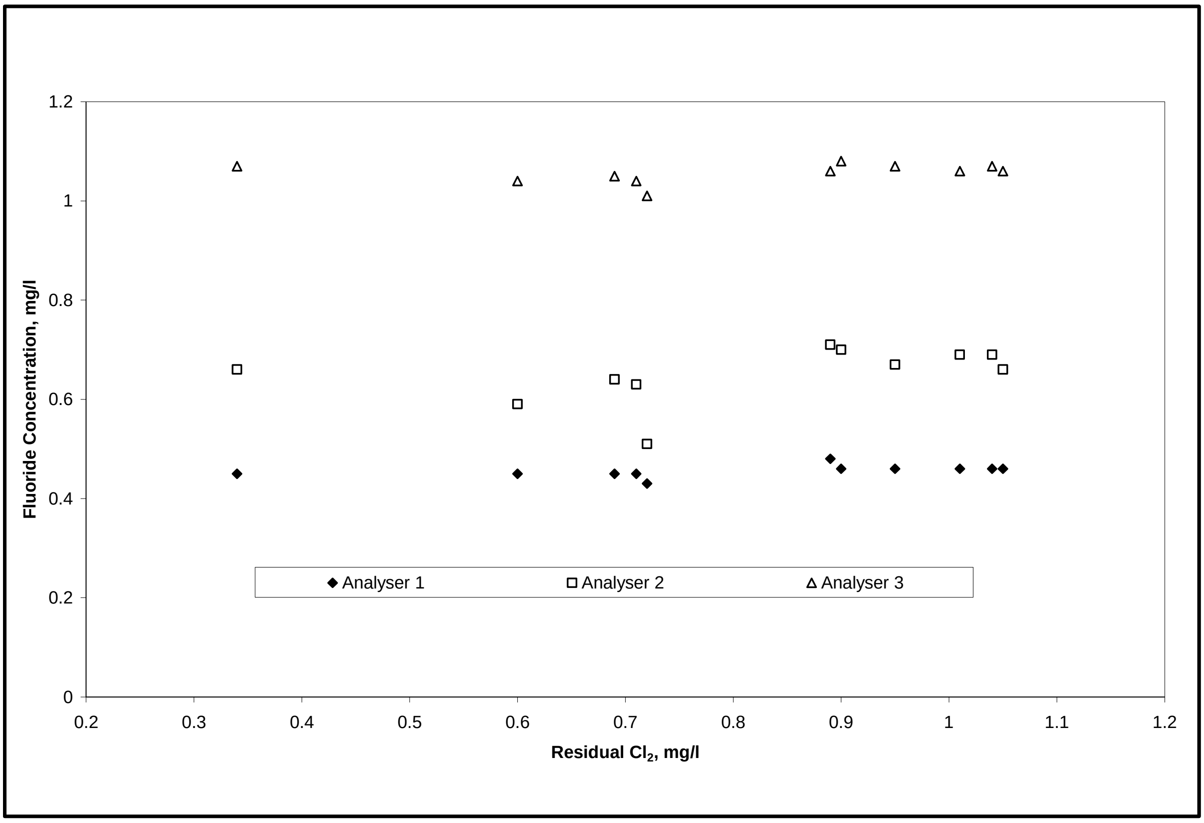


Figure 4.4: Analyser response to residual chlorine interference

4.1.6. Maintenance Requirements

4.1.6.1. Calibration Procedure

Analyser 1 can be calibrated either automatically or manually with two standards of known concentrations. The analyser carries out a two-point calibration. The accuracy of both the standards will have a direct effect upon the accuracy of the analyser as the sensor outputs obtained are used to calculate the calibration graph for the analyser.

The calibration for Analyser 2 is simple and automatic. The instrument performs a two-point calibration using two different standards at a time as selected by the user. Calibration takes approximately 53 minutes. The values of both the standards can be changed to satisfy the fluoride range in the sample.

Calibration of Analyser 3 can be done either manually or automatically. There are two common calibration methods applicable to Analyser 3, viz. the Standard Solution Method and the Grab Sample Method. The Standard Solution Sethod was used as it was considered the most convenient. The Grab Sample Method involves measuring the fluoride concentration of the sample using an independent laboratory instrument. This method of calibration is only feasible if an accredited laboratory is located within close proximity to the on-line instruments.

4.1.6.2. Reagent Use

Reagents for Analyser 1

Two standard solutions of concentrations that are different by at least a factor of 10 (ten) are used. A sodium hexametaphosphate solution can be made. The operating manual provides a recipe for the solution. All reagents should be of Analytical Grade.

Reagents for Analyser 2

Two fluoride standards and a total ionic strength adjustment buffer solution (TISAB) of 500ml each were provided. On site solution preparation was not recommended. The lower concentration standard was 0.5 mg/l as F while the higher standard was 5 mg/l as F.

A unit of standard solution lasted two months while the TISAB reagent lasted a month for a sampling frequency of 1-hour. Reagent use was dependent on the frequency of sampling and analysis.

Analyser 3

Two fluoride standards of a factor of ten difference were provided for calibration.

Table 4.3: Fluoride Analyser Maintenance Schedule

<table>
<tr><th colspan="2">ANALYSER</th><th colspan="2">MANUFACTURER</th><th colspan="2">KEY</th></tr>
<tr><td colspan="2">Analyser 1</td><td colspan="2">ABB</td><td colspan="2">Y</td></tr>
<tr><td colspan="2">Analyser 2</td><td colspan="2">HACH</td><td colspan="2">Z</td></tr>
<tr><td colspan="2">Analyser 3</td><td colspan="2">Honeywell</td><td colspan="2">X</td></tr>
<tr><td colspan="2">Photometer</td><td colspan="2">Lovibond</td><td colspan="2">V</td></tr>
<tr><th>MAINTENANCE TASK</th><th>MONTHLY</th><th>TWO MONTHLY</th><th>QUARTERLY</th><th>HALF YEARLY</th><th>YEARLY</th></tr>
<tr><td>Replenish reagents</td><td>YZ</td><td>V</td><td></td><td></td><td></td></tr>
<tr><td>Renew standards</td><td>YZ</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Refill electrode solution/salt bridge</td><td>YZ</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Replace pump tubing</td><td></td><td></td><td></td><td>Z</td><td>Y</td></tr>
<tr><td>Replace analyser tubing</td><td></td><td></td><td></td><td></td><td>YZ</td></tr>
<tr><td>Replace crystal tip</td><td></td><td></td><td></td><td></td><td>YZ</td></tr>
<tr><td>Replace electrode</td><td></td><td></td><td></td><td></td><td>XYZ</td></tr>
<tr><td>Replace reference electrode</td><td></td><td></td><td></td><td></td><td>XYZ</td></tr>
<tr><td>Calibrate</td><td>VXYZ</td><td></td><td></td><td></td><td></td></tr>
</table>

4.1.7. Electrode Fouling

Both the reference and fluoride measuring electrodes for Analyser 1, Analyser 2 and Analyser 3 have a one year life span due to natural fouling.

4.1.8. User Friendliness

Generally all three analysers are user-friendly. However, Analyser 1 had the most user-friendly interface that was easy to follow and operate. Features were self explanatory and easily accessed.

4.1.9. Control

All three fluoride analysers have facilities that allow for control of fluoride dosing via a 4-20 mA output signal which may be connected to a fluoride dosing pump to control the dosing rate. Each of the analysers has facilities for high and low alarms which can set of warning alarms at preset fluoride concentrations. The digital output signals can also be used to start and stop the dosing pump.

4.1.10.Capital, Operating and Maintenance Costs

A breakdown of the capital, operating and maintenance costs based on 2007 costs is presented in Table 4.4 to illustrate the relative costs between the three analysers evaluated. The reader is cautioned to verify actual costs between suppliers prior to committing to a unit at the time of intended purchase.

Table 4.4: Capital, Operating and Maintenance Costs of Fluoride Analysers

Analyser	ANALYSER 1	ANALYSER 2	ANALYSER 3
Capital Costs [SAR]			
Analyser Cost (2007)	**90,000**	**48,535**	**30,000**
Operating Costs [SAR/yr]			
Reagent 1	694	3,120	--
Standard 1	5	1,800	10
Standard 2	24	2,280	10
Total Operating Costs	**723**	**7,200**	**20**
Maintenance Costs [SAR/yr]			
Electrode kit	4,485	5,000	3,000
Pump Tubing kit	9,358	518	--
Instrumental Tubing kit		485	--
Total Maintenance Costs	**13,843**	**6,003**	**3,000**
Total Annual O&M Cost	**14,566**	**13,203**	**3,020**

4.1.11.Summary of Fluoride Analyser Evaluation

Analyser 1

Analyser 1 was the most accurate of the three analysers tested. It consistently produced results closest to the fluoride analysis results from the accredited laboratory. Although it was the most expensive unit tested, the low operating costs and reliability makes it a more favourable choice for rural applications over Analyser 2 with annual operating costs that were 10 times higher.

Analyser 2

Analyser 2 showed a significant deviation from the accredited laboratory fluoride results. The other disadvantage was the significantly higher running costs.

Analyser 3

Analyser 3, the simplest and least expensive of the three analysers tested, was considered to be suitable in an environment where the final water quality is not variable. It will perform satisfactorily in a well controlled water treatment process. It may be unsuitable for small water systems that generally treat borehole and/or river water with variable raw water quality and are often subject to poor operation and control.

pH and Chlorine Variations

As expected, pH and chlorine variations in the feed water had minimal effect on Analysers 1 and 2 which employ pH correction and buffering chemicals. Analyser 3, with no buffer addition, was unstable when the pH was varied.

Table 4.5: Analyser Performance Rating

PERFORMANCE CRITERIA	ANALYSER 1	ANALYSER 2	ANALYSER 3	COMMENT
Response	Very Good	Fair	Excellent	Analyser 3 has no reagent addition facility
Precision	Very Good	Fair	Poor	
Accuracy	Excellent	Good	Fair	
Linearity	Very Good	Good	Very Good	
Reaction to system changes	Excellent	Good	Good	
Interference	Very Good	Very Good	Poor	
Control	Very Good	Very Good	Very Good	
Operator Friendly	Very Good	Good	Fair	

4.1.12.Laboratory Analysis of Fluoride

Fluoride analysis in water quality monitoring should be given importance because fluoride is known to cause a variety of health problems viz. dental fluorosis, skeletal fluorosis and non-skeletal manifestations when the level exceeds 1.5 mg/l.

The following methods are available for analysis for fluoride:

- Alizarin Visual Method
- SPADNS Method
- Ion Selective Electrode Method.

4.1.12.1.Alizarin Visual Method

The colour developed by the reaction between fluoride and a zirconium-dye lake can be compared visually with the known standard fluoride solutions. A waiting period of 1-hour after the addition of reagent is necessary for satisfactory colour development. The visual colorimetric method requires inexpensive laboratory glassware.

4.1.12.2.SPADNS Method

The SPADNS colorimetric method is based on the reaction between fluoride and zirconium-dye lake. Fluoride reacts with the dye lake, dissociating a portion of it into the colourless complex anion (ZrF_6) and the dye. As the amount of fluoride increases, the colour produced becomes progressively lighter.

The reaction rate between fluoride and zirconium ions is influenced greatly by the acidity of the reaction mixture. If the proportion of acid in the reagent is increased, the reaction can be made almost instantaneous. The selection of dye for this rapid fluoride method is governed largely by the resulting tolerance to these ions.

4.1.12.3.Ion-Selective Electrode Method

The fluoride electrode is an ion selective sensor. The key element in the fluoride electrode is the laser-type doped lanthanum fluoride crystal across which a potential is established by fluoride solutions of different concentrations. The crystal contacts the sample solution at one face and an internal reference solution at the other. The cell may be represented by an Ag/AgCl: Cl (0.3M), F (0.001M)/La F3/test solution/ reference electrode.

The fluoride electrode measures the ion activity of fluoride in solution rather than concentration. Fluoride ion activity depends on the solution total ionic strength and pH, and on fluoride complexing species. Adding an appropriate buffer provides a nearly uniform ionic strength background, adjusts pH, and breaks up complexes so that, in effect, the electrode measures concentration.

5. Evaluation of Fluoride Dosing Systems for Small Water Treatment Systems

5.1. Fluoride Source Material Selection

The dosing of concentrated fluorosilicic acid into small water systems is impractical due to the relatively small raw water flowrate and potentially hazardous nature of the acid. The poor infrastructure and level of operator skills available in rural areas, where a large proportion of small water treatment systems are located, presents a significant challenge to enabling fluoridation in small systems. If fluorosilicic acid was the preferred fluoride source material source, then the use of dilute fluorosilicic acid may be the solution to reducing the potential hazards associated with the handling and dosing of the chemical into drinking water.

The use of a powder, sodium fluoride, in a fluoridation system presents relatively lower handling risks than fluorosilicic acid because a saturated solution of sodium fluoride has a pH of approximately 7.6 and a maximum fluoride concentration of 4% due to its solubility. Therefore direct handling and storage of the chemical on the plant site can be carried out without posing major health risks to the operators and the environment, provided there is compliance with the necessary safety precautions.

The dosing requirements for the two fluoride raw material sources discussed above are shown in Figure 5.1.

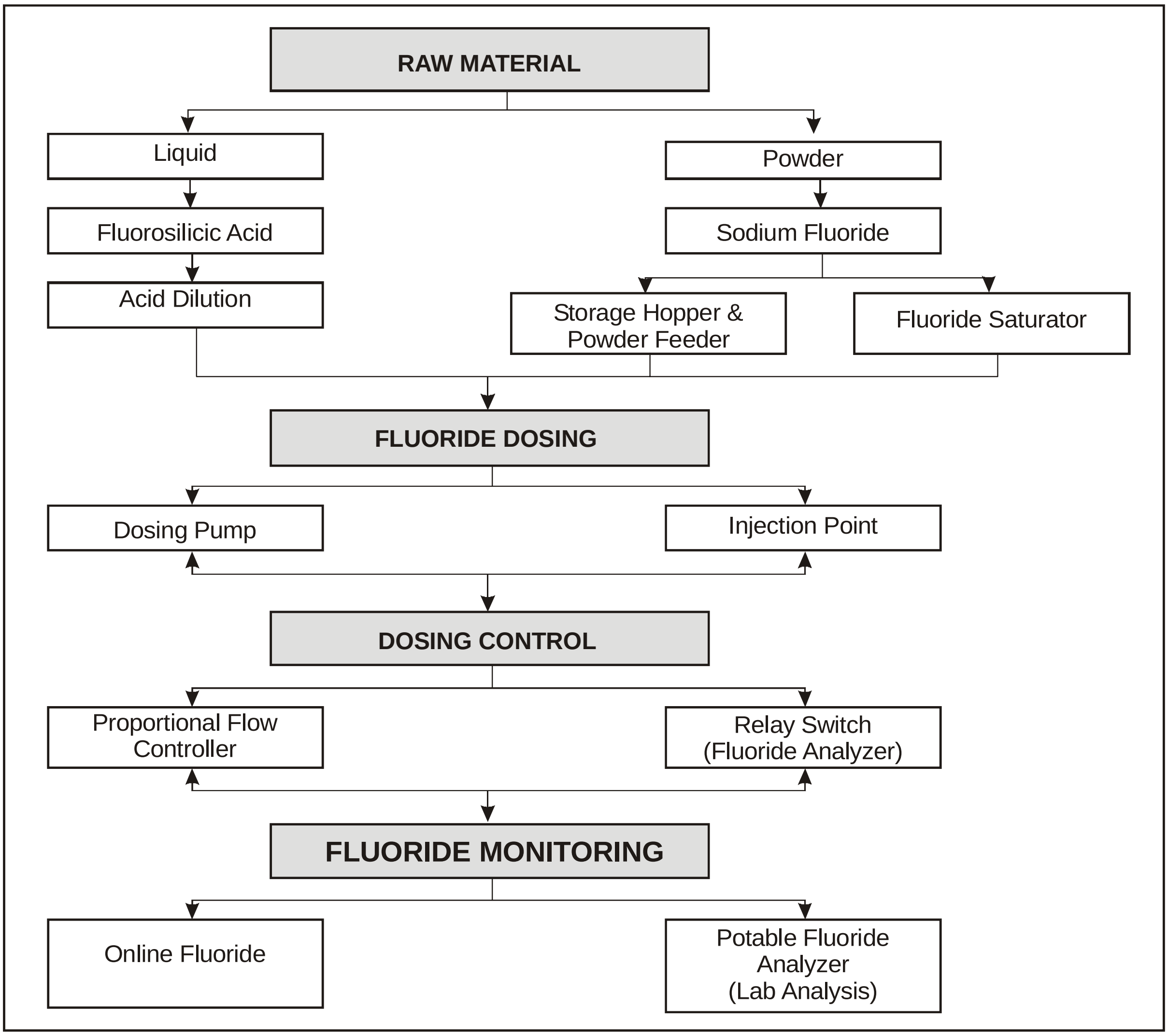


Figure 5.1: Fluoride Dosing Requirements

5.1.1. Fluoride Chemical Properties

The most commonly available fluoride chemicals used in the water industry are fluorosilicic acid and sodium fluoride. (Refer to Table 2.1, Chapter 2 for chemical properties).

5.1.2. Fluorosilicic Acid Dosing Systems

Manufacturers and suppliers of fluorosilicic acid indicated that it was uneconomical to either manufacture a more dilute solution or dilute a concentrated solution at the factory and the transport costs would have been prohibitive.

For cost-effectiveness, practicality and the minimization of safety risks, it was envisaged that an acid dilution facility may be setup so that three or more small water systems may be supplied with diluted fluorosilicic acid on a monthly basis. The facility should be located in a central area within close proximity to these small water treatment systems.

The operator of the dilution facility needs to be well trained and equipped with advanced skills to operate the dilution system safely and efficiently. The diluted acid should be stored in suitable transportable drums for monthly distribution to the small systems for fluoride dosing. The entire dilution facility was envisaged to be a separate operation, located in a well serviced area with water and electricity and equipped with the requisite operational skills and business leadership.

5.1.3. Dilution Facility

In order to test the use of fluorosilicic acid, an acid dilution facility was designed and built. The facility was used to dilute the supplied 40%(m/m) or 50%(m/m) fluorosilicic acid solution to 1 - 2% (m/m), safely and accurately.

The actual dilution process inside the facility was automated, thus reducing operator intervention and exposure. The storage tanks were enclosed within a bund and the bulk and dilution tanks were vented to the outside atmosphere. Personal protective equipment was stored in an easily accessible cupboard away from the process. Warning signs and operational and safety charts were displayed inside the facility to ensure that safety is taken seriously. Spill materials such as lime were placed within easy reach on site to be accessible in the case of an accidental spillage of leakage.

5.1.3.1. Principle of Operation

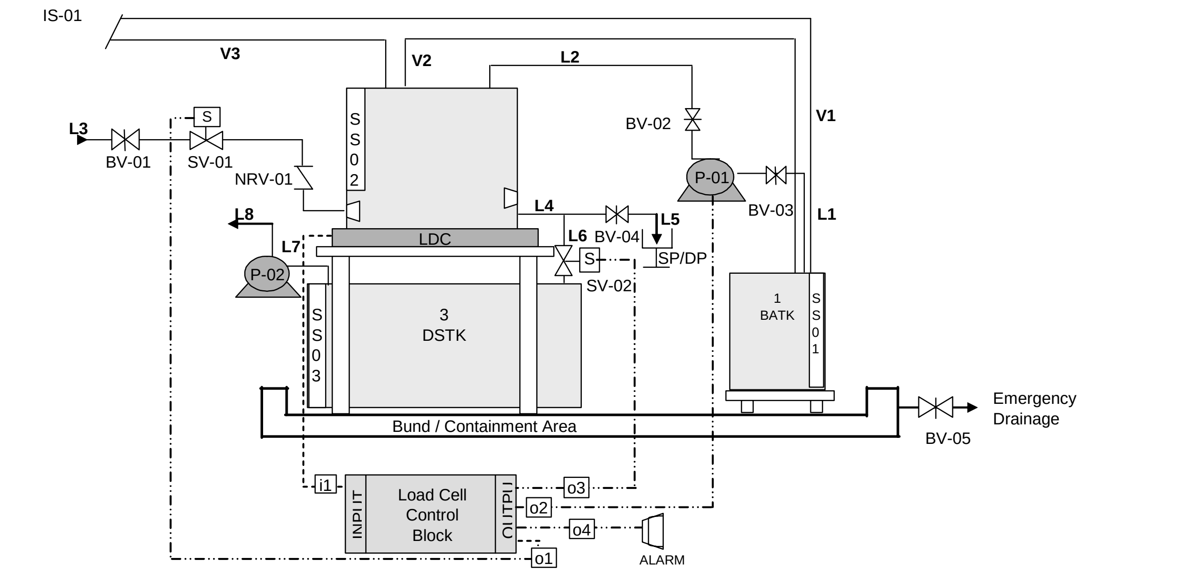
The acid dilution system, a batch process, is based on a mass by mass (m/m) dilution methodology. An electronic scale was used to measure the water and acid required to produce a fixed 1% fluorosilicic acid product or any other appropriate concentration.

The process operation of the dilution unit (Table 5.2) was semi-automatic to make it operator independent. The operator pushed a ‘START’ button to begin the process and ‘ABORT’ to stop the process if necessary. The acid: water ratio was preset in the dilution controller to achieve the desired product concentration.

Table 5.1: Summary of Dilution Facility Operations

SEQ. NO.	ACTIVITY	RESULT	LOCATION/DEVICE	BY
1	Open Water Solenoid Valve	Initial water charge	Control Panel	Operator
2	Close Water Solenoid Valve	Stops water charge	Load Cell Controller	Device
3	Start Acid Transfer Pump	Pump turned on	Load Cell Controller	Device
4	Stop Acid Transfer Pump	Pump turned off	Load Cell Controller	Device
5	Open Water Solenoid Valve	Final water charge	Load Cell Controller	Device
6	Close Water Solenoid Valve	Stops water charge	Load Cell Controller	Device
7	Open Product Solenoid Valve	Product transfer	Control Panel	Operator
8	Close Product Solenoid Valve	Product transfer stops	Load Cell Controller	Device

The Dilution Facility process flow diagram (PFD) is presented in Figure 5.2. The design incorporated a safe and simple operation that avoided operator contact with the hazardous fluorosilicic acid concentrate.



Equipment List	Valves & Fittings	Line Spec
1-BATK : HDPE Bulk Acid Tank	**IS-01** : Insect Screens	**L1** : PVC - Acid Pump Feed
2-DTK : HDPE Dilution Tank	**SV-01/02** : Automated PVC Solenoid Valves N/C	**L1** : PVC - Acid Pump Discharge
3-DSTK : HDPE Dilute Storage Tank	**BV-01/02/03/04/05** : Manual Control Valves	**L3** : PVC - Water Charge
LDC : 4 Load Cells	**NRV-01** : Non Return Valves	**L4** : DTK Oulet
P-01 : Concentrate Acid Transfer Pump	**SP/DP** : Sample/Drainage Point	**L5** : PVC - Drainage/Sample
P-02 : Dilute Solution Dosing Pump		**L6** : PVC - Product Transfer
SS01/02/03: Sight Glass		**L7** : PVC - Dosing Pump Suction
Alarm : System Malfunction Warning Buzzer		**L8** : PVC - Dosing Pump Discharge
		V1 : "50mm" 3m - PVC Ventilation
		V2 : "50mm" 3m - PVC Ventilation

Figure 5.2: Process Flow Diagram of the Dilution Facility

The control system for the dilution unit incorporated simple relay switches and an electronic load cell (Figure 5.3) to deliver the correct amount of acid concentrate and water.

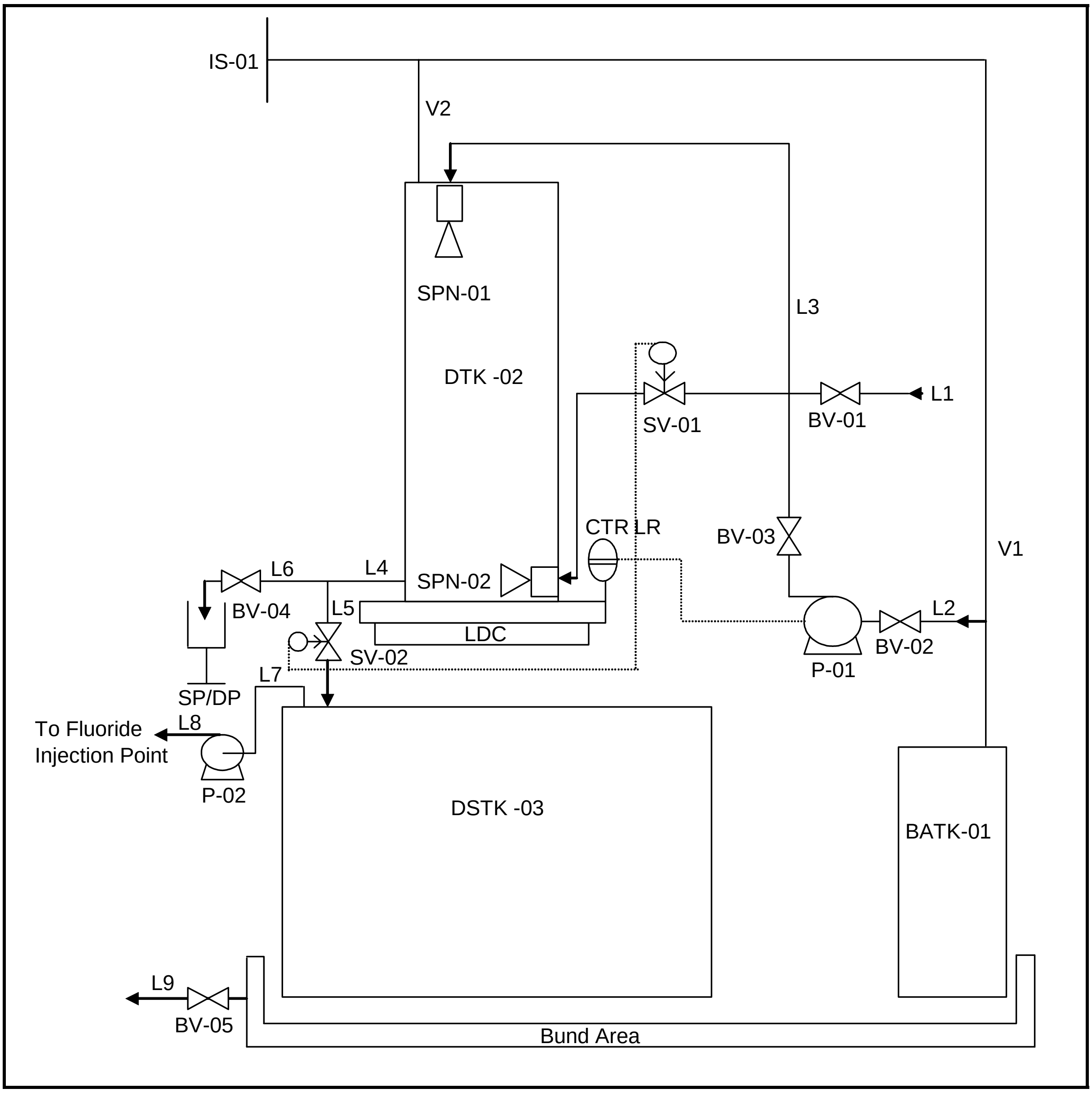


Figure 5.3: Piping & Instrumentation Diagram of the Dilution Facility

5.1.3.2. System Sizing Parameters

The fluorosilicic acid dilution system size was determined on the basis, that the centre will dilute 40% (m/m) fluorosilicic acid to 1% (m/m) concentration. This facility size is dependant on the number of small systems it supplies, their capacities and fluoride dosage.

5.1.3.3. Equipment Selection

Mass flow was selected over volumetric flow in the measurement and control of the dilution system to minimize instrumentation and simplify the process.

The electronic scale works on the principle whereby a shear beam load cell, accepts a load at one end of the beam causing the deflection in a Wheatstone bridge within the load cell. The deflection causes a change in micro voltage proportional to the applied load.

Advantages of using mass flows:

- Chemical consumption can be monitored very accurately
- If a scale has an analogue output, the mass of the chemical can be monitored remotely
- Alarms can be linked to the scale if the output from the chemical tank exceeds a certain set point or if the mass is below the set point, e.g. vapour lock
- Equipment, such as pumps, can be shut down automatically using a signal from the scale.

Advantages of electronic scales are:

- High resolution and sensitivity, particularly in chemical systems with low feed rates
- Sophisticated data interpretation, such as feed rates and daily usages
- Feed rate alarms and pump controlling capacity

A list of the main equipment required for the Dilution Centre is presented in Table 5.3.

Table 5.2: Acid Dilution Equipment Requirements

NO.	EQUIPMENT	MATERIAL OF CONSTRUCTION	TYPE	PURPOSE
1.	Electronic Mass Industrial Scale	Mild Steel (Acid resistance coated)	Load cell	Accurate acid dilution
2.	Acid Transfer Pump	Teflon coated	220V Diaphragm pump	Transfer concentrated acid.
3.	Solenoid Valve	PVC	24V Normally Closed	For fail safe discharge
4.	Storage Tanks	Polyethylene	Cylindrical and Rectangular	Hold and store concentrated/diluted acid
5.	Spray Nozzles	PVC	Pressure Nozzles	Provide efficient mixing of acid and water

5.1.3.4. Control Philosophy

The scale has four preset set points that control the mass of the dilution water and acid required to produce a 1% (m/m) fluorosilicic acid end-product. The signals are sent to the acid transfer pump, dilution water solenoid valve and product transfer valve, operated by relay control.

Failsafe measures and safe guards have been incorporated into the control philosophy (refer to Appendix A: HAZOP Study- Dilution Facility). The scale controller failsafe features were enabled and these alarms were as follows:

- Excess Amount of Water – Alarm 1 and Process Halt

- Excess Mass of Acid – Alarm 2 and Process Halt
- Over/Under Total Batch Mass - Alarm 3 (Siren and Shutdown)

The control logic sequence is shown in Figure 5.4.

CONTROL BLOCK

i1 → Load Cells Weight Signal

o1 → Open/Close Water Solenoid Valve (SV-01)

o2 → Start/Stop Acid Transfer (P-01)

o3 → Dump/Product Solenoid Valve (SV-02)

o4 → Malfunction Alarm

Activated Circuit	Circuit Affected & Required Result	
i1	o1	Open/Close Water Solenoid Valve (SV-01)
	o2	Start/Stop Acid Transfer (P-01)
	o3	Open/Close Valve (SV-02)
i1	o4	Switch On/Off Malfunction Alarm

Figure 5.4: Dilution Logic Control Chart

5.1.3.5. Evaluation Methodology

Random batch samples of 1%(m/m) fluorosilicic acid were sent to the Umgeni Water Main Laboratory in Pietermaritzburg to verify the fluoride concentration.

From these samples, precision, accuracy and stability of each sample was analyzed and recorded.

5.1.4. Dosing System

A demarcated area is required for the small fluoridation system and must include all the necessary warning signs and safe working procedures.

5.1.4.1. System Sizing Parameters

For each small water system the size of the fluoridation process equipment is strongly dependant on the amount of fluoride to be dosed at design flow, the type of fluoride additive used and the design flow of the small water treatment system to reach the optimum fluoride dose of 0.7 mg/l as F in South African drinking water (Regulations on Fluoridating Water Supplies, 2000).

A sample calculation for the sizing of a fluoridation systems presented in Appendix D.

5.1.4.2. Principle of Operation

A dilute 1%(m/m) fluorosilicic acid was added to the small water system after the filtration stage, via a dosing pump and flowmeter to ensure that the final water leaving the small system had an optimum fluoride level of 0.7 mg/l.

5.1.4.3. Process Description

An acid feed system and online monitoring station was built to dose dilute 1% (m/v) fluorosilicic acid into the final water of an Autonomous Valveless Gravity Filter (AVGF) with a maximum treatment capacity of 240 m^3/day.

The fluorosilicic acid solution was dosed via a dosing pump into the filtered water supply line upstream of the online analyser station at a variable flow rate depending on the filter outlet flow meter reading. The flow rates to the respective analyzers were set as per instrument specifications. The local agents/suppliers of the analyzers calibrated the equipment and also trained the project team on the operating procedure and care of the instruments.

An online fluoride analyzer was used to monitor and control the fluoride concentration in the final water. A PFD of the AVGF with a fluoride dosing system is presented in Figure 5.5.

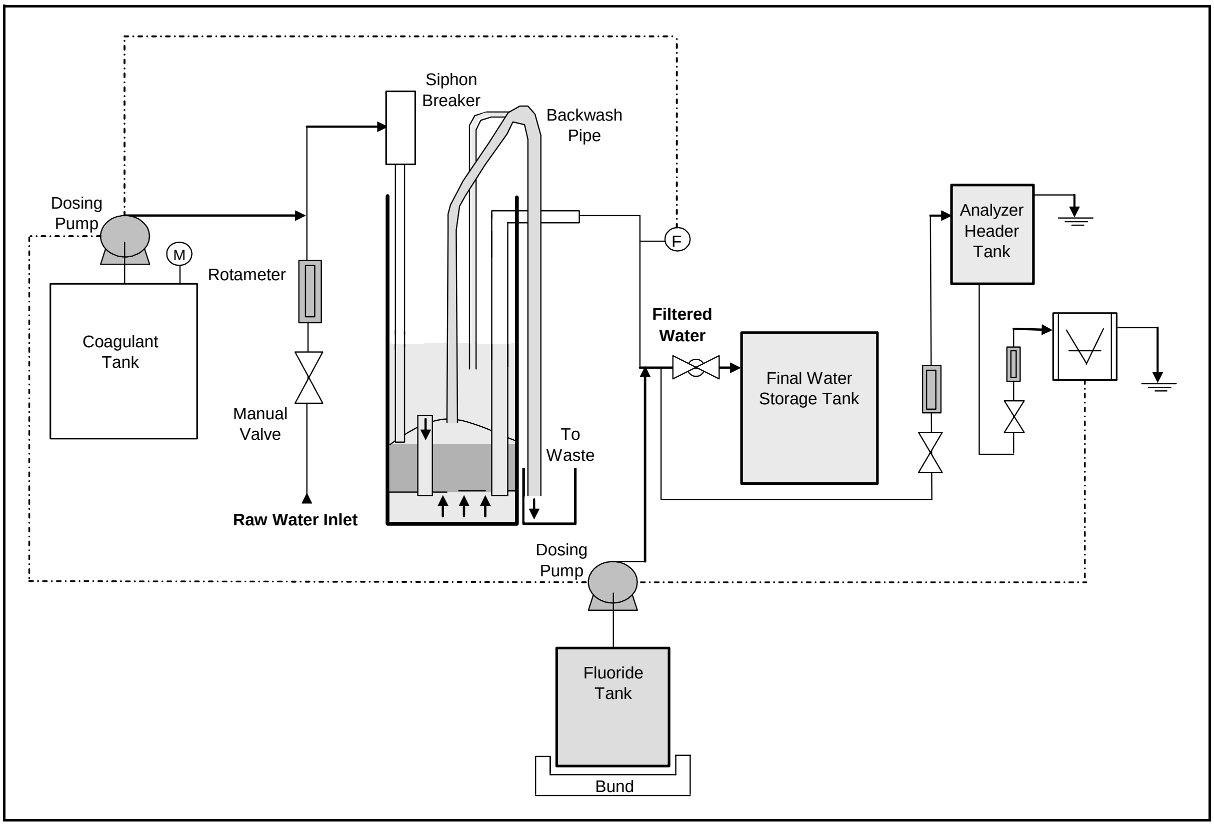
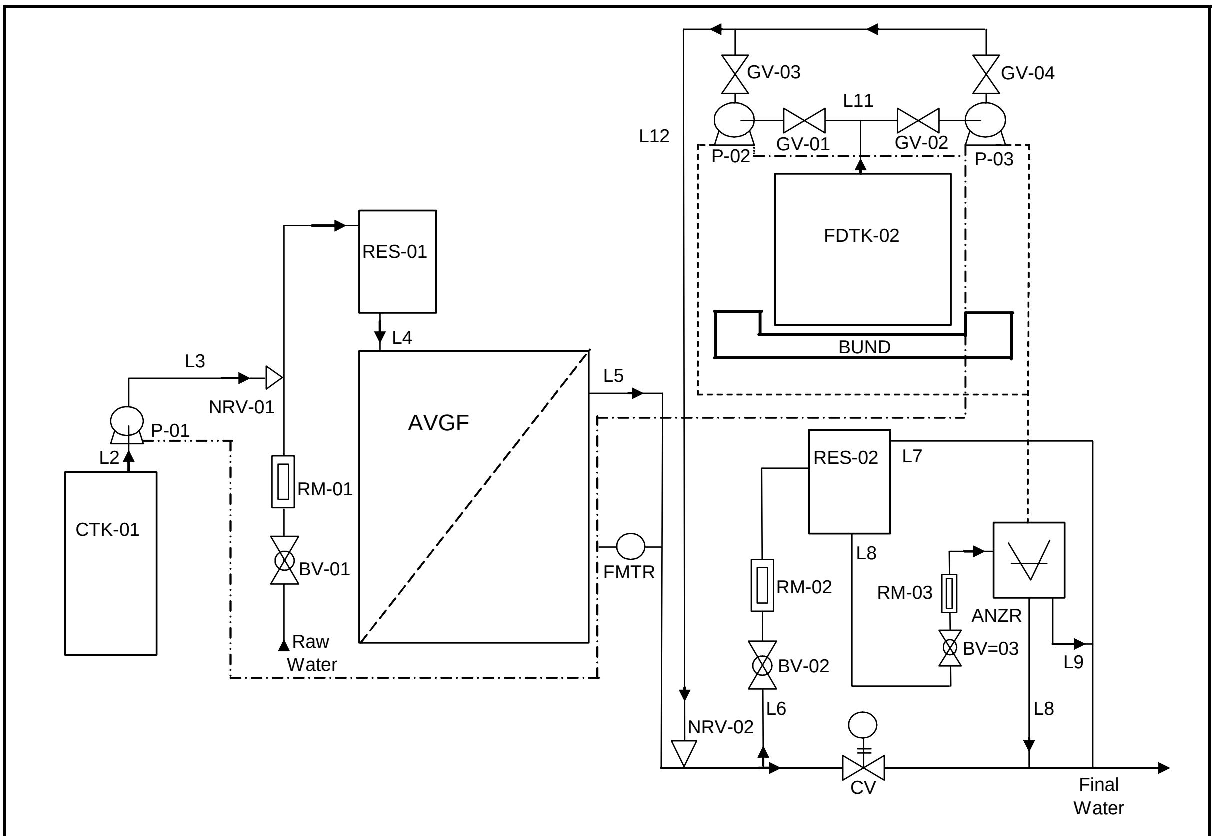


Figure 5.5: Process Flow Diagram of the AVGF Fluoridation System

5.1.4.4. Control Philosophy

A reed pulse sensor controlled, via a pacing signal, the number of strokes at a fixed frequency of the dosing pump. The sensor was linked to both the flowmeter on the final water line and the dosing pump (Figure 5.6).

The alarm relay switches that were available on the instrument were used as a failsafe measure to stop the pump if overdosing occurred. A High-High alarm setpoint was entered manually via the fluoride analyzer keypad to enable the instrument to shutdown the dosing pump when the upper fluoride limit on the setpoint was reached.



Equipment List	Valves & Fittings	
CTK-01 : Coagulate	NRV-01 : Non Return Valve	GV-01 : Gate Valve
RES-01 : Reservoir tank	RM-01 : Rotameter	GV-02 : Gate Valve
AVGF : Autonomous Valve Gravity Filter	BV-01 : Ball Valve	GV-03 : Gate Valve
FDTK-02 : Fluoride Dosing Tank	NRV-02 : Non Return Valve	GV-04 : Gate Valve
RES-02 : Reservoir tank	RM-02 : Rotameter	
P-01 : Coagulate Pump	BV-02 : Ball Valve	
P-02 : Fluoride Dosing Pump	RM-03 : Rotameter	
P-03 : Standby Pump	BV-03 : Ball Valve	
FMTR : Flowmeter	CV : Control Valve	
ANZR : Fluoride Analyzer		

Figure 5.6: Piping & Instrumentation Diagram for the AVGF Fluoridation System

5.1.4.5. Evaluation Methodology

The performance of the dosing system and online fluoride analyser was monitored against the target of maintaining a constant fluoride concentration in the treated water.

5.2. Sodium Fluoride Dosing System

A saturator system was installed to produce a saturated solution of the sodium fluoride powder.

5.2.1. Principle of Operation

Sodium fluoride solid was added using an electrical screw feeder into the saturator. Water was allowed to trickle through a bed containing an excess of sodium fluoride. The resulting saturated fluoride solution was dosed into the water supply system. Although saturated solutions of sodium fluoride can be manually prepared, automatic feed solution is recommended for safety reasons. To ensure a saturated solution of sodium fluoride, the saturator should always contain excess sodium fluoride.

5.2.2. Equipment Selection

The selection of the equipment, detailed in Table 5.4, was based on the following criteria:

- Compatibility with the fluoride additive
- Reliability of performance
- Local availability
- Cost effectiveness

Table 5.3: Sodium Fluoride Fluoridation System Requirements

EQUIPMENT	DESCRIPTION	OPERATION	SPECIAL PRECAUTIONS	SAFETY
Screw feed storage hopper	Gravimetric timer controlled, calibrated powder feeder	Motor driven screw feeder that transfers sodium fluoride from storage to the saturator	Ensure the powder discharge line is opened before start-up and closed after shutdown. This is to prevent the powder from "caking".	PPE should be used when filling the hopper with sodium fluoride. Dust Extractor is required.
Fluoride saturator	Upflow saturator system houses the saturator components, including solenoid valve, siphon breaker, and liquid level switch	Provides an easily maintained source of saturated sodium fluoride solution.	Ensure that all the electrical components are serviced regularly as stated by the supplier. Place saturator within a bund wall.	Eyewash station and shower needs to be installed nearby.
Metering Pump	Positive displacement with flow control	Dose saturated sodium fluoride solution into the final water.	Ensure the pump is connected and sized correctly to prevent overdosing.	

The fluoride dosing system using sodium fluoride crystals as the fluoride source is shown in Figure 5.7. The saturator (presented diagrammatically in Figure 5.8) is an American design specific for fluoridation using a powder source and was obtained through a South African agent. The screw feeder and controls were designed and manufactured locally.

Figure 5.7: Powder Feeder and Fluoride Saturator System

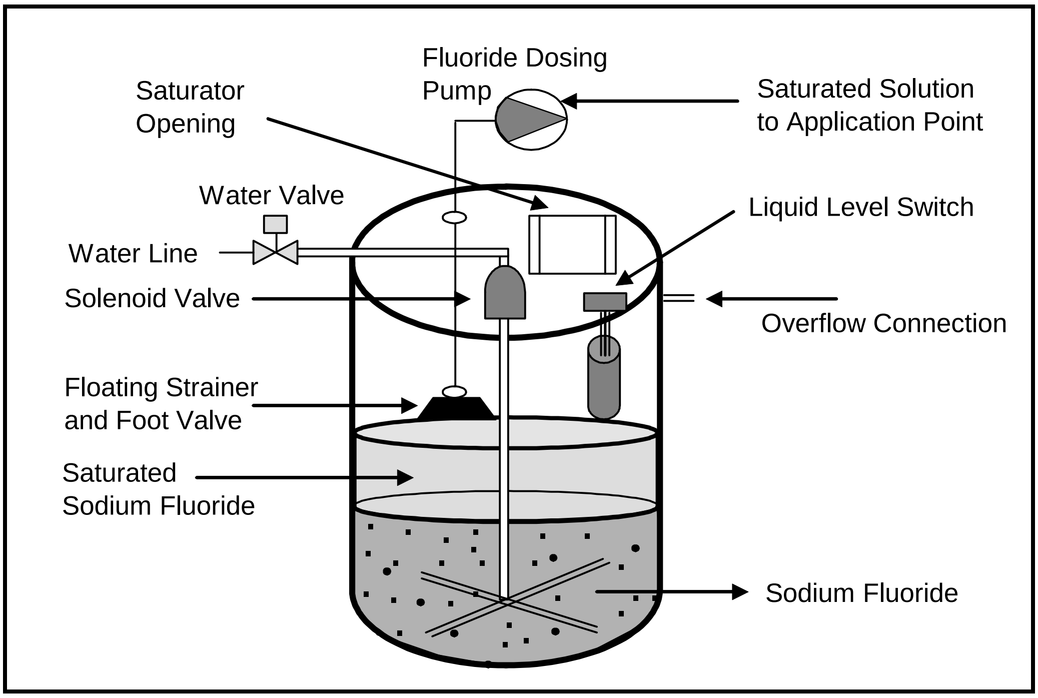


Figure 5.8: Fluoride Saturator

5.2.3. Control Philosophy

An excess amount of sodium fluoride was maintained in the saturator through the constant addition of sodium fluoride through the screw feeder. The hopper screw feeder dispensed a fixed amount of chemical based on its feed rate of 1800 g/h for the current application. It took 30 minutes for the screw feeder to transfer a 3-day chemical supply into the saturator to dose the optimum fluoride level into the pressure filter final water line. The pressure filter treatment capacity was 240 m^3/day.

A reed pulse sensor on the water meter at the outlet of the pressure filter was connected to the fluoride dosing pump to control the dosing flowrate.

An on-line fluoride analyzer was included in the system to monitor fluoride levels in the final water and also for control purposes.

The alarm relay switches that are available on the instrument are used as a fail safe measure to stop the pump if overdosing occurred. A High-High alarm setpoint was entered manually via the fluoride analyzer keypad to enable the instrument to stop the dosing pump when the upper limit setpoint was exceeded.

5.3. Comparison between the Fluorosilicic Acid Dosing System and the Sodium Fluoride Powder Dosing System

Table 5.4: Comparison of the Factors Affecting the Choice of Fluoridation Chemical Used

FLUORIDATION SYSTEM	Fluorosilicic Acid System	Sodium Fluoride System
APPLICATION	Undiluted acid : Large Waterworks Diluted Acid : Small Systems	Small systems
SYSTEM REQUIREMENTS	Acid Dilution Centre Fluoride Dosing Pump Fluoride analyser and dose control	Dry Feeder Fluoride Saturator Dosing Pump Fluoride analyser and dose control
ADVANTAGES	Dilute acid safe to handle on site Relatively easy availability Less handling and exposure High fluoride content	Saturator ensures safe and constant concentration fluoride solution. Minimum handling of chemical No solution stored on site
DISADVANTAGES	Dilute acid will suffer from batch to batch variations in fluoride concentration. Dilution and transport cost. Safety hazards in handling and storage. Depresses pH therefore resulting in corrosion.	Chemical cost Dust Poor availability Does not work on water with hardness > 50 mg/l High moisture levels in powdered feed can lead to inefficient hopper operations.
CAPITAL COSTS* (2007)	R2.6 million	R2.3 million
OPERATING COSTS* (2007)	R642 K per annum	R667 K per annum
MAINTENANCE COSTS* (2007)	R375 K per annum	R417 K per annum

* based on a 2 Ml/day treatment plant

6. Cost Structure for Fluoridation Implementation

6.1. Introduction

Small water systems are generally owned by municipalities who have the responsibility of providing an acceptable quality and quantity of water to the consumers. Some municipalities operate and maintain their waterworks, while other municipalities, especially the smaller municipalities in the peri-urban and rural areas, have external water service providers to operate and maintain their waterworks.

Generally small water treatment systems are located in peri-urban and rural areas where the recovery of costs from consumers is problematic. Most rural water schemes are operated on a shoe-string budget as evidenced by the poor condition of the infrastructure, unreliable water supply and poor water quality. These schemes are generally subsidized by government grants to provide the basic requirements for their operation and maintenance.

Therefore, for small water systems where the consumer does not pay for water, any additional costs for fluoridation will have to be funded by increased government grants. The cost impact of fluoridation on the cost of treating water (R/kl) will be more useful here than the tariff model.

In cases where consumers pay for water, the tariff model may be used to determine the cost impact of fluoridation and tariff adjustments will apply.

Funding for small water systems fluoridation will be based on social upliftment rather than investment for profit. Therefore, private funding may not be easily forthcoming due to the high risk on return on investments.

Since government, through the Department of Health, is advocating fluoridation, government needs to implement funding initiatives. The tariff model for small systems may not address cost recovery for fluoridation for small water treatment systems. However, tariff models will be useful for small water systems in more affluent areas, e.g. Golf Estates, Hotels, etc.

The usefulness of the model should then be in deciding whether:

- Fluoridation is the most cost-effective way to introduce fluoride in the diet of rural communities, especially children.
- A liquid or powder source of fluoride should be used for a particular application.

6.2. Cost Structure Model

The typical costs associated with this project include:

- Capital Costs
- Equipment Replacement Costs
- Operating Costs
- Annual Inflation Costs
- Maintenance Costs

In any financial investment or project that needs to be undertaken, the investor wants to be assured that the investment is feasible and realistic. The common financial tools or indicators used to evaluate whether a project is profitable in the long term are:

- Net Present Value (NPV)
- Internal Rate of Return (IRR)
- Profit Index (PI)

The above are used together to predict the financial viability of a project. These tools or indicators form the selection criteria of any given long term investment.

Two fluoride dosing systems were designed, built and operated:

- System 1 – Sodium Fluoride Saturator System
- System 2- Fluorosilicic Acid System

Two fluoridation financial models were developed to determine feasibility, and to propose a tariff charge for each fluoride dosing system.

Financial Model A: A fluorosilicic acid dilution facility that will operate independently from the small water systems. The purpose of this facility, if fluorosilicic acid is preferred, is to provide the small water systems with diluted acid on a monthly basis.

Financial Model B: A financial comparison between a Fluorosilicic Acid and Sodium Fluoride System. It carries out the necessary calculations to predict which system should be used.

The user has the option to adjust the following parameters in the model to arrive at the most cost-effective solution:

- Cost Mark-up
- Annual Inflation Rate
- Opportunity Cost of Capital
- Investment Period (i.e. 5, 10, 15, 20, 25 years)
- Fixed Costs
- Annual Variable Costs

Both the Financial Models' outcomes determines the:

- Investment Profitability
- Project Cost Effectiveness

6.2.1. Financial Theory of the Fluoridation Models

6.2.1.1. Net Present Valve (NPV)

For long term projects, the NPV method is used for financial evaluation purposes. It determines the excess or shortfall of Present Value (PV) cash flow once economic charges are achieved. A positive NPV shows that the project is profitable but does not necessarily mean that the project should be implemented since NPV does not take Opportunity Cost into consideration. A proposed project should only be considered if the NPV is greater than the Opportunity Cost. If two mutually exclusive alternatives exist, then the one with the higher NPV should be selected.

The formula for NPV is

$$\mathrm{NPV} = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} \quad \ldots (1)$$

Where

t - time of the cash flow
n - total time of the project
r - discount rate

6.2.1.2. Discount Rate

The interest rate used to discount future cash flows (i.e. discount rate) to their present values is a key input of long term investment profitability prediction.

6.2.1.3. Internal Rate of Return (IRR)

This capital budgeting method is used by firms to determine whether they should make long-term investments. The IRR is the return rate which can be earned on the invested capital, i.e. the yield on the investment.

A project is a good investment proposition if its IRR is greater than the rate of interest that could be earned by alternative investments (investing in other projects, buying bonds, even putting the money into a bank account). The IRR should include an appropriate risk premium. Mathematically the IRR is defined as any discount rate that results in a NPV of zero of a series of cash flows.

In general, if the IRR is greater than the project's cost of capital, or *hurdle rate,* the project will add value for the company.

The Internal Rate of Return (IRR) equation is a unique case of the Net Present Value (NPV) equation. The IRR is found by solving the NPV equation for the rate that will yield a NPV equal to zero:

Internal Rate of Return (IRR) Equation:

$$NPV = 0 = \text{inital investment} + \frac{\text{Cash flow Year 1}}{(1+IRR)^{1}} + \ldots \frac{\text{Cash flow Year n}}{(1+IRR)^{n}}$$

The formula for NPV is:

$$NPV = \text{inital investment} + \sum_{t=1}^{t=\text{end of project}} \frac{\text{(Cash Flows at Year t)}}{(1+r)^{t}} \quad \text{.... (2)}$$

6.2.1.4. Shortcomings of IRR

As an investment decision tool, the calculated IRR should not be used to rate mutually exclusive projects, but only to decide whether a single project is worth investing in. In cases where one project has a higher initial investment than a second mutually exclusive project, the first project may have a lower IRR (expected return), but a higher NPV (increase in shareholders' wealth) and should thus be accepted over the second project. A method called marginal IRR can be used to adapt the IRR methodology to this case.

The IRR method should not be used in the usual manner for projects that start with an initial positive cash inflow, for example where a customer makes a deposit before a specific machine is built, resulting in a single positive cash flow followed by a series of negative cash flows (+ - - - -). In this case the usual IRR decision rule needs to be reversed.

If there are multiple sign changes in the series of cash flows, e.g. (- + - + -), there may be multiple IRRs for a single project, so that the IRR decision rule may be impossible to implement.

A critical shortcoming of the IRR method is that it is commonly misunderstood to convey the actual annual profitability of an investment. However, this is not the case because intermediate cash flows are almost never reinvested at the project's IRR; and, therefore, the actual rate of return (akin to the one that would have been yielded by stocks or bank deposits) is almost certainly going to be lower. Accordingly, a measure called Modified Internal Rate of Return (MIRR) is used, which has an assumed reinvestment rate, usually equal to the project's cost of capital.

6.2.1.5. Profit Index (PI)

The PI can be used to figure out the "benefit to cost ratio" of an investment. Profitability Index is simply the present value of future cash flows divided by the initial investment. When the profitability index is greater than 1.0 the present value of cash flows must be greater than the initial investment, therefore the investment must also have a positive NPV.

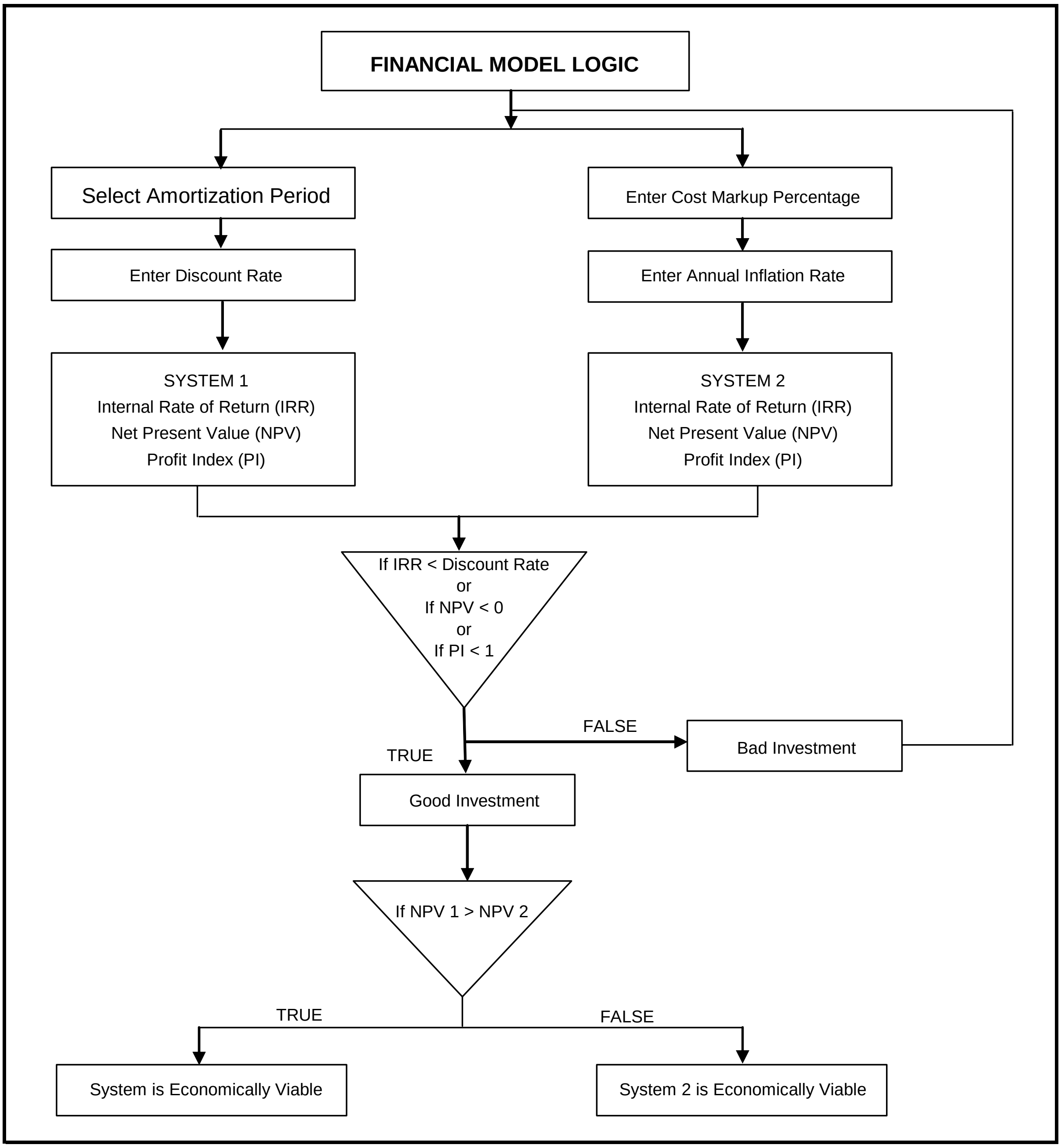


Figure 6.1: Fluoridation System Decision Flowchart

6.2.2. Fluoridation Financial Models

The financial theory of the models is based on all three investment evaluation tools, i.e. Internal Rate of Return (IRR), Net Present Value (NPV) and the Profit Index (PI).

These models are unique to small system fluoridation because it provides a cost recovery plan which is one method to maintain viability and sustainability for fluoridation. Other ways of ensuring viability and sustainability are being investigated. The model allows for the costs to be simulated until economical tariff charges are achieved.

6.2.2.1. Model A: Fluorosilicic Acid Dilution Facility

This model assesses the cost data entered by the user and generates NPV, IRR and PI values for a given input. A decision box reveals to the user whether the project is feasible over the prescribed time period. A selling price is calculated at which a batch of diluted fluorosilicic acid needs to be sold at to satisfy the investment criteria.

A graph representing the cumulative present value of the cash flow shows how the project cash flow changes with time.

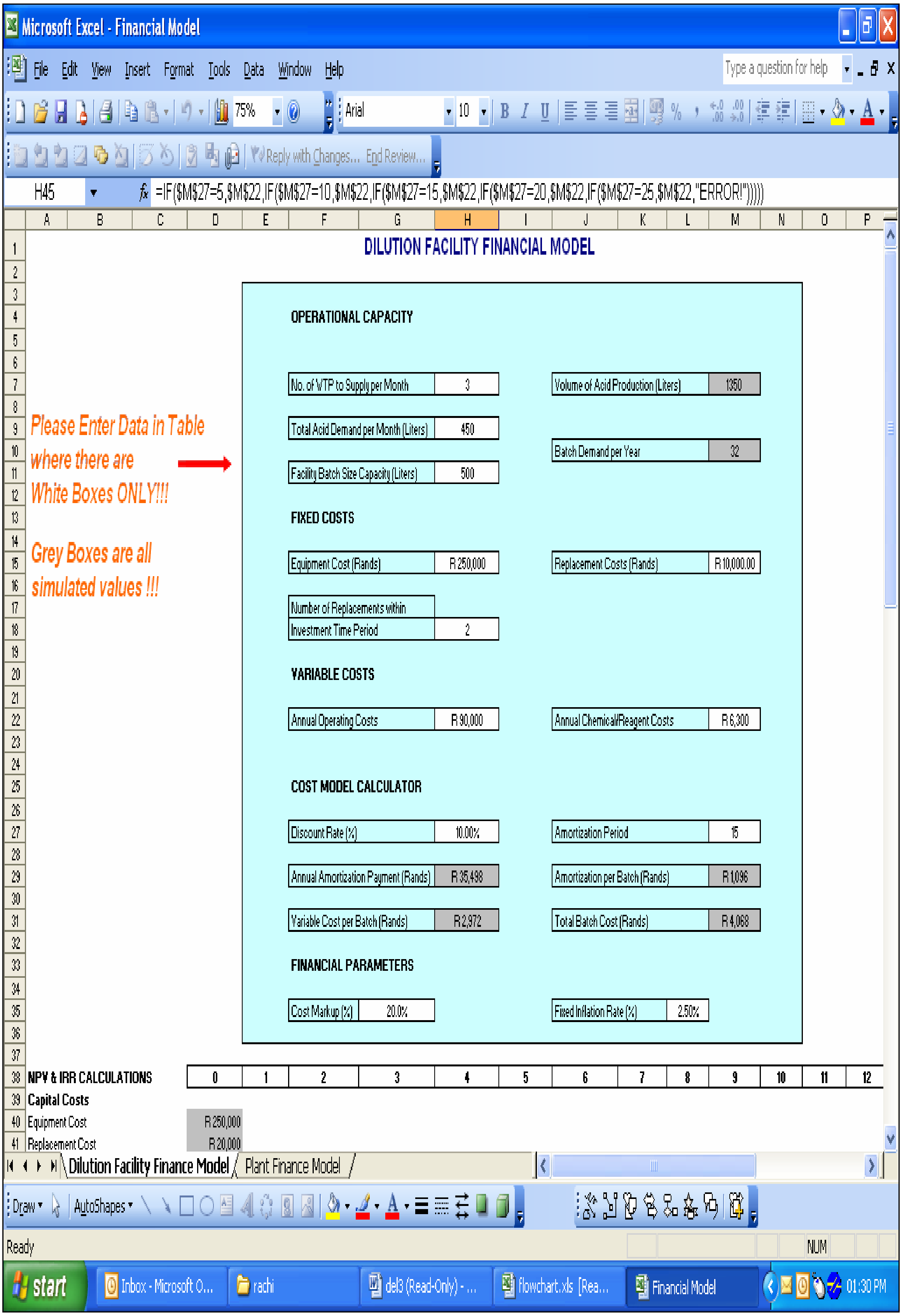
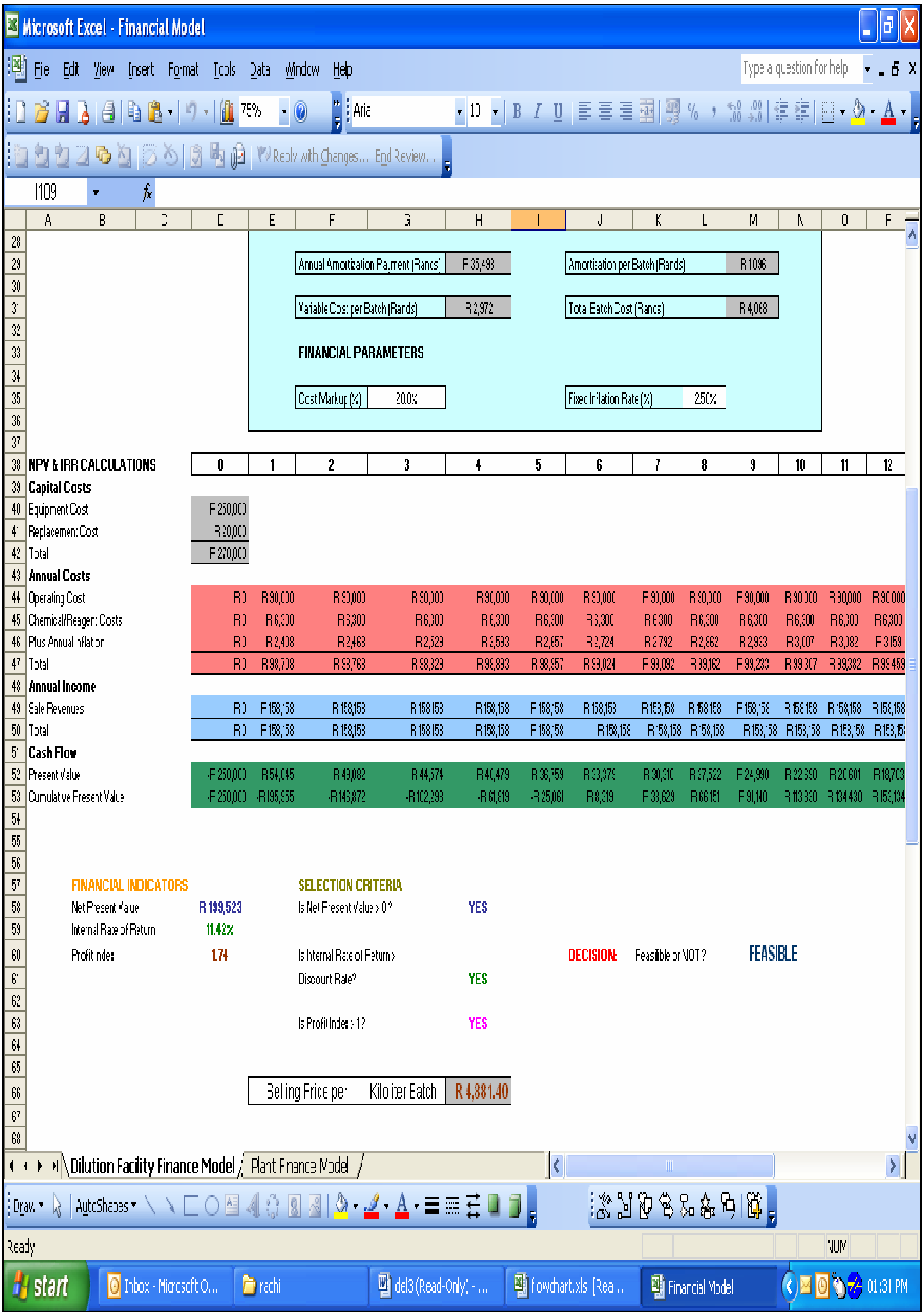


Figure 6.2: Screenshot of the Model A Data Entry Boxes



Annual Amortization Payment (Rands)	R 35,498
Amortization per Batch (Rands)	R 1,096
Variable Cost per Batch (Rands)	R 2,972
Total Batch Cost (Rands)	R 4,068

FINANCIAL PARAMETERS

Cost Markup (%)	20.0%
Fixed Inflation Rate (%)	2.50%

NPV & IRR CALCULATIONS	0	1	2	3	4	5	6	7	8	9	10	11	12
Capital Costs													
Equipment Cost	R 250,000												
Replacement Cost	R 20,000												
Total	R 270,000												
Annual Costs													
Operating Cost	R 0	R 90,000	R 90,000	R 90,000	R 90,000	R 90,000	R 90,000	R 90,000	R 90,000	R 90,000	R 90,000	R 90,000	R 90,000
Chemical/Reagent Costs	R 0	R 6,300	R 6,300	R 6,300	R 6,300	R 6,300	R 6,300	R 6,300	R 6,300	R 6,300	R 6,300	R 6,300	R 6,300
Plus Annual Inflation	R 0	R 2,408	R 2,468	R 2,529	R 2,593	R 2,657	R 2,724	R 2,792	R 2,862	R 2,933	R 3,007	R 3,082	R 3,159
Total	R 0	R 98,708	R 98,768	R 98,829	R 98,893	R 98,957	R 99,024	R 99,092	R 99,162	R 99,233	R 99,307	R 99,382	R 99,459
Annual Income													
Sale Revenues	R 0	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158
Total	R 0	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,158	R 158,15
Cash Flow													
Present Value	-R 250,000	R 54,045	R 49,082	R 44,574	R 40,479	R 36,759	R 33,379	R 30,310	R 27,522	R 24,990	R 22,690	R 20,601	R 18,703
Cumulative Present Value	-R 250,000	-R 195,955	-R 146,872	-R 102,298	-R 61,819	-R 25,061	R 8,319	R 38,629	R 66,151	R 91,140	R 113,830	R 134,430	R 153,134

FINANCIAL INDICATORS

Net Present Value	R 199,523
Internal Rate of Return	11.42%
Profit Index	1.74

SELECTION CRITERIA

Is Net Present Value > 0 ?	YES
Is Internal Rate of Return > Discount Rate?	YES
Is Profit Index > 1 ?	YES

DECISION: Feasible or NOT ? FEASIBLE

Selling Price per Kiloliter Batch: R 4,881.40

Figure 6.3: Screenshot of Model A: NPV Table

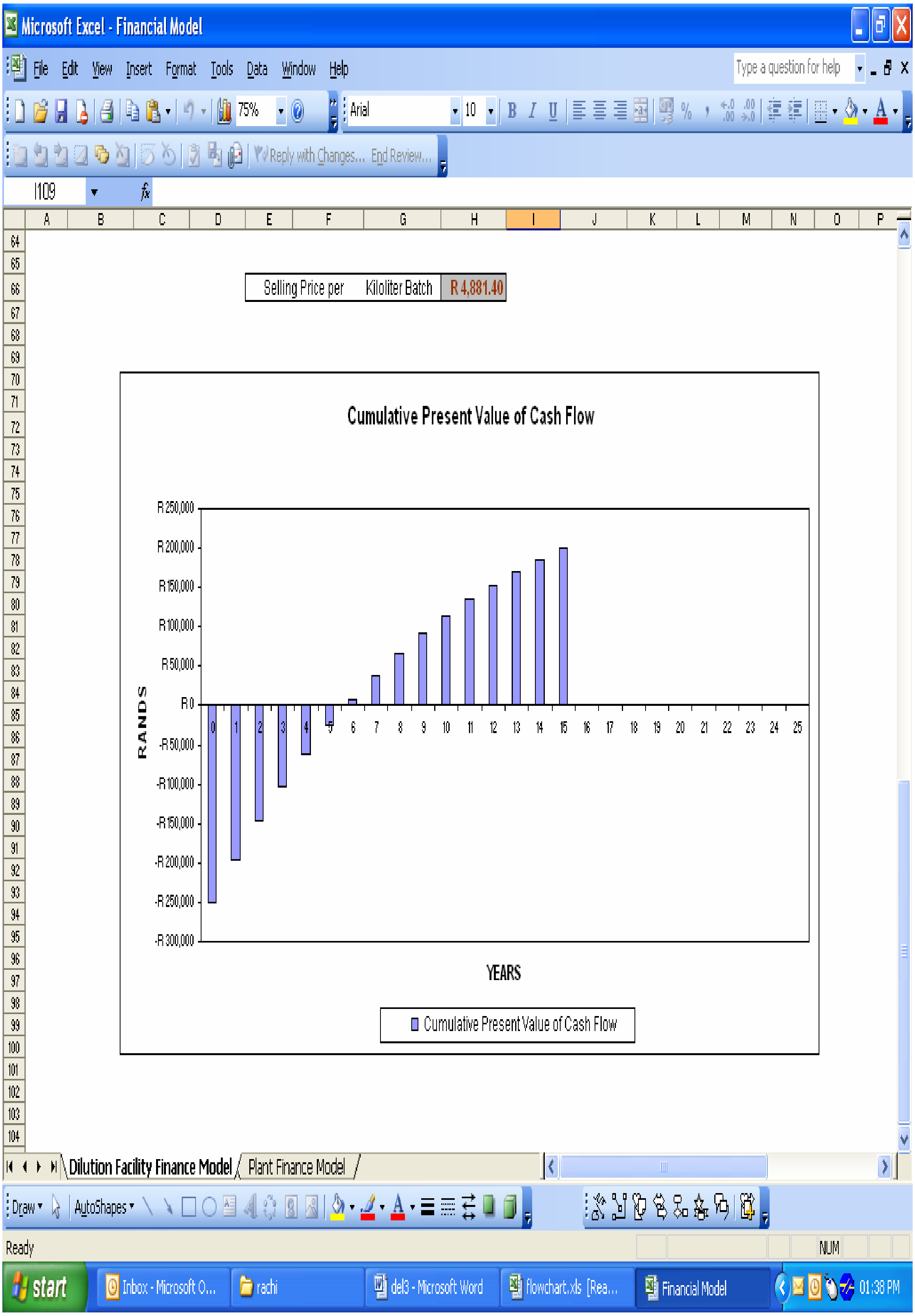


Figure 6.4: Screenshot of Model A: Cash Flow Graph

6.2.2.2. Model B: Financial Comparison of Fluoridation Systems

This model accesses the Internal Rate of Return, Net Present Value of both the Fluorosilicic Acid and Sodium Fluoride Systems projects based on the user's cost input data and then calculates the feasibility of each system. It also advises which is the best economically viable system of the two.

Two types of tariff charges are calculated:

- Cost recovery: with fixed tariff charge that pays towards the project investment.
- No cost recovery: average annual cost of the system's operation and start-up capital.

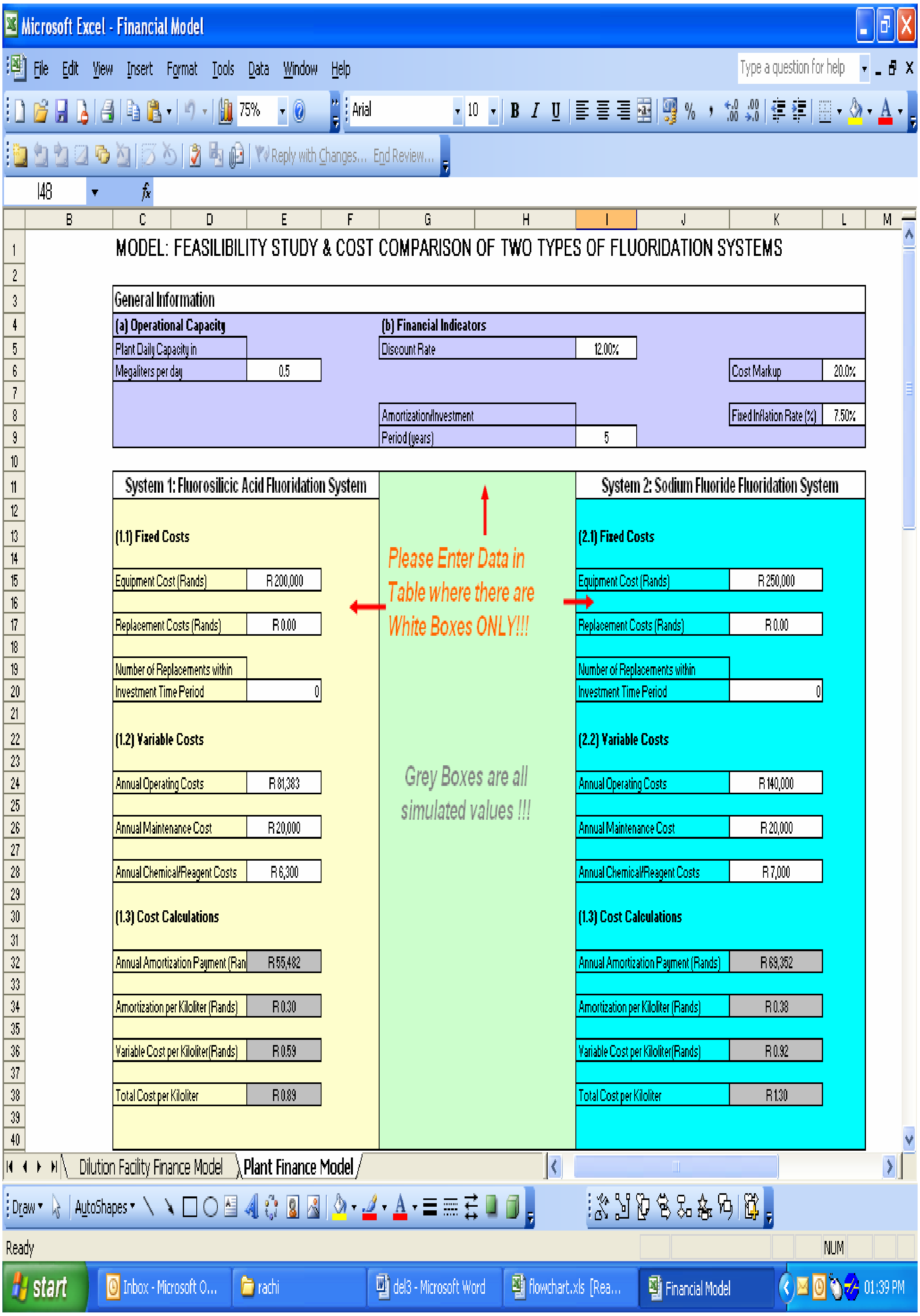


Figure 6.5: Screenshot of the Financial Model's Adjustment Boxes

6.2.2.3. Model’s Selection Criteria

Each fluoridation system is evaluated independently based on their Internal Rate of Return, Net Present Value and Profit Index values.

For a viable investment as seen in figure 6.5, the following constraints must be met:

Table 6.1: Financial Constraints

<table>
<tr><th>Constraint</th><th>Model’s Response</th></tr>
<tr><td>IRR > Discount Rate</td><td rowspan="3">VIABLE</td></tr>
<tr><td>NPV >0</td></tr>
<tr><td>Profit Index > 1</td></tr>
</table>

If any of the above constraints are not met, the model response will display “NOT VIABLE” in the investment box. The user has to optimize his cost data and retest to achieve better results.

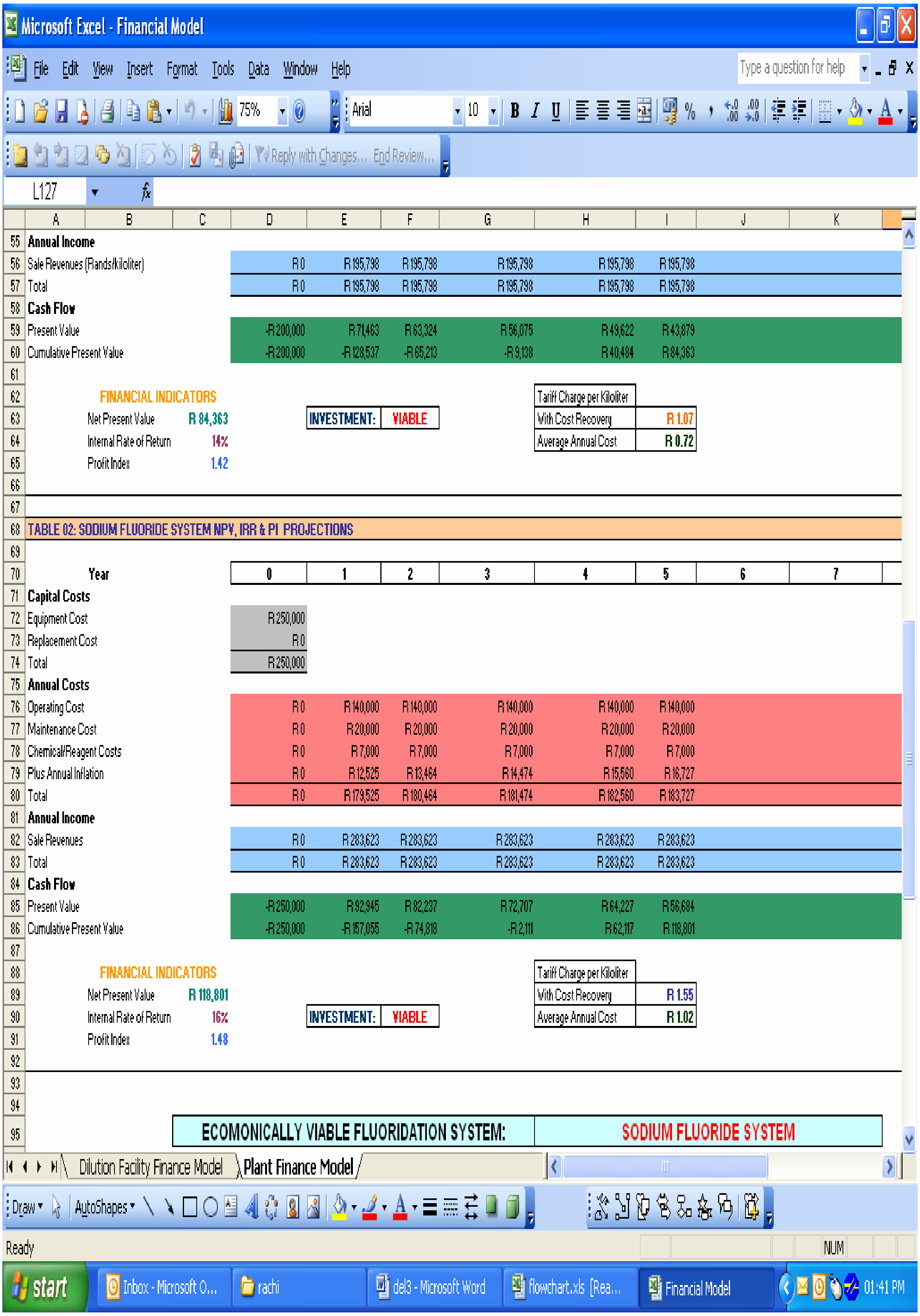


Figure 6.6: Screenshot of the Financial Model's Investment Boxes

6.2.2.4. Fluoridation System Selection

In the case of both investment boxes having “NOT VIABLE” displayed then the user has to change some of the financial parameters, i.e. Cost Mark-up, Annual Inflation Rate, Opportunity Cost of Capital Investment Period (i.e. 5, 10, 15, 20, 25 years), Fixed Costs and Annual Variable Costs.

When both the systems display “VIABLE” then the model then compare the Internal Rate of Returns and the Net Present Values of both systems. The system that has a higher NPV with its IRR greater than the Opportunity Cost is selected and revealed as the better economically viable system of the two.

7. Conclusions and Recommendations

In the South African context, the occurrence of dental caries and poor bone structure, that can be prevented or reduced by fluoridation, is more prevalent in disadvantaged rural communities that generally rely on small water treatment systems for their water supply. Therefore, fluoridation at small water treatment systems may be relatively more important than fluoridation at large water treatment systems in urban or peri-urban areas. However, enabling fluoridation in small water treatment systems is more challenging relative to larger water treatment systems that normally have suitable expertise, sophistication, monitoring and control.

Conclusions

The outcome of the research indicated that the use of equipment that would ensure safety of handling and exposure to operations personnel and safety to the consumer by maintaining an acceptable fluoride dose in the drinking water are the main priorities.

Fluoridation handling and dosing equipment are generally no different to any other equipment that may be required to dose a potentially hazardous chemical safely and accurately. Equipment that meets the required specifications, with respect to materials of construction, accuracy and reliability are available from local suppliers and agents.

The most widely used liquid fluoride chemical source is hexafluorosilicic acid and is available locally at concentrations in the range of 40 - 50%(m/v). At these concentrations, the chemical is hazardous and corrosive and poses a serious environmental risk and safety risk to plant personnel and consumers when applied to small water systems. Therefore provisions have been made for the inclusion of a separate acid dilution centre, operated by appropriately trained and qualified personnel, to supply a safe dilute working fluoride solution to the small treatment systems.

Dry fluoride chemical source for fluoride dosing is relatively more expensive, albeit safer, relative to hexafluorosilicic acid. A dry feeder and saturator are the additional equipment required to produce a constant 4%(m/v) saturated fluoride dosing solution. An interactive decision making spreadsheet-based tool has been developed for a user to choose between a liquid or powder fluoride source.

Evaluation of fluoride analysers indicated that the instrumentation available (at the time of the evaluation) are based on the ion selective electrode principle and are all affected by similar problems associated with accuracy, precision and response due to sensor fouling. All the analysers had the capability of controlling a fluoride dosing pump to maintain a constant fluoride concentration in the water. The cheapest of the three analyzers evaluated, did not have a facility for the addition of chemical buffers and was affected by chemical matrix interference in the water. As accurate fluoride measurement and dosing control was considered crucial, the use of a fluoride analyzer, with chemical buffering capabilities, was preferred for small water systems.

Safety Health and Environmental (SHE) considerations relating to fluoride dosing systems are covered by South African legislation. However, the onus is on the user and/or service provider to implement systems and procedures to ensure the sustainable compliance with legislation.

The cost of fluoride implementation will depend to a large extent on the operational status of the waterworks, logistics and resources. A user friendly spreadsheet-based fluoridation cost estimation tool was developed to assist the fluoridation implementing agent or Service Provider to estimate the cost of fluoridation and other comparisons required to make informed decisions.

A web-based fluoridation user guide has been set up, to provide fluoridation information at the click of a button.

Recommendations

It is recommended that pilot fluoridation projects be undertaken in suitable small systems where further data may be collected for specific outcomes that include:

- Remote intervention for fluoride overdosing
- Operator Training manuals
- Capacity building

8. References

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PART B

Guidelines for the Implementation of Fluoride Dosing in Small Systems

Contents

List of Tables

1. Framework of the Guideline Manual

1.1. Introduction

Drinking water fluoridation is accomplished simply by dosing a controlled amount of a suitable fluoride source chemical into the water to be fluoridated. In effect, fluoridation of drinking water is just the dosing of another chemical. Given the right conditions and facilities, fluoridation can be achieved safely and efficiently. Safe fluoridation implies dosing fluoride within the range that is most beneficial to the consumer, consistently and in a manner that does not compromise the health of the waterworks personnel or the environment.

Therefore, fluoridation in large waterworks with the right infrastructure and facilities may be easily implemented. Fluoridation in small water systems, on the other hand, presents a challenge due to a number of factors that include:

- Poor supporting infrastructure
- Poor operational condition of waterworks
- Unskilled/semi-skilled personnel
- Financial constraints due consumers inability to pay for services

1.2. Presentation / Structure of Guideline Manual

The manual is arranged in chapters covering the important topics that need to be understood and applied for a cost-effective and efficient fluoridation system applicable to small water treatment systems.

The administrative aspects of fluoridation are covered in Chapter 2. These include a summary of South African Fluoridation Acts, personnel requirements and training, reporting guidelines, inspection of fluoridation installations and suggested course of action in the event of fluoride overdosing.

The important component of monitoring and surveillance during fluoridation is the subject of Chapter 3. The systematic monitoring of fluoride concentrations in the treated water and raw water, use of on-line fluoride monitoring instruments at waterworks, record-keeping and telemetry are the main topics discussed in this chapter.

Chapter 4, covering technical requirements for fluoridation, is the main chapter in the Fluoridation Guideline Manual. This chapter deals with a number of important issues including, appropriate fluoride source chemicals, safe handling, use and storage. All aspects of fluoridation dosing systems, commissioning and decommissioning of fluoridation plants, removal and disposal of fluoride chemicals are discussed. This chapter also includes skills development and operator competencies.

The last chapter deals with safety issues encompassing operator safety, personal protective equipment (PPE), safe working procedures and safety, health and environmental considerations.

2. Administration

2.1. Summary of South African Fluoridation Legislation

The Minister of Health has, under sections 3 and 90 (1) of the National Health Act (Act No. 61 of 2003) in consultation with the Ministry of Water Affairs and Forestry, made the regulations of fluoridating water supplies in the Schedule. Only the main extracts of the act have been presented. For the complete regulations, the latest act may be consulted.

REGULATIONS OF FLUORIDATING WATER SUPPLIES	
1	**Definitions**
	In these regulations any expression to which a meaning has been assigned in the Act shall have such meaning and, unless the context indicates otherwise – **"authorised officer"** means an officer of the national Department of Health, provincial or of a local government or any other person generally or specifically authorised in writing by the Director-General; **"department"** means the national Department of Health; **"Director-General"** means the head of the national Department of Health; **"fluoridation"** means to adjust the fluoride concentration of a water supply by the addition of a fluoride compound to obtain an optimal fluoride concentration; **"fluoride compound"** means sodium fluoride (NaF), sodium fluorosilicate (Na_2SiF_6) (also known as sodium silicofluoride) or fluorosilicic acid (H_2SiF_6); **"non-official"** means a person who holds an office in an organisation not attached to any governmental or province institution or body; **"official"** means a person who holds an office in a province or governmental institution or body; "optimum fluoride concentration" means a fluoride concentration determined by the Director-General for a particular water services authority and should not be more than 0,7 mg/l Fluoride as F, in a water supply; **"the Act"** means the National Health Act, 2003 (Act 61 of 2003) **"the committee"** means the National Fluoridation Committee, **"waste water discharges"** means water discharges containing waste; **"waste"** means any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the

water resource to be polluted;

"water distribution system" means the supply of water by a water services authority through pipes to the end user;

"water fluoridation plant" means the equipment used and the procedures applied in the addition of a fluoride compound to a water supply;

"water fluoridation scheme" means the delivery to the end user of water containing an optimum concentration of fluoride, which is supplied by a water fluoridation plant through a water distribution system;

"water resources" means a watercourse, surface water, estuary or aquifer;

“water services authority” means a municipality that has the executive and legislative authority to provide water services within its area of jurisdiction in terms of the Municipal Structures Act, 1998 (Act 117 of 1998) or the ministerial authorisations made in terms of that Act.

“water services provider” means the public, private or mixed entities, or water services authority providing water services and performing the duties as required in the service level agreement, the Water Service Act, 1997 (Act 108 of 1997) and the Constitution (Act 108 of 1996).

"water supply" means the supply of water intended for human use or food processing.

2 Obligation

(1) Every water services authority, with exception with those mentioned in regulation 6(8), practising water fluoridation immediately prior to the promulgation of these regulations must, within 12 months after the promulgation of these regulations, submit –

(a) an application for registration, in duplicate, in the format set out in Annex A; and
(b) a form on technical information set out in Annex C, to the Director-General.

(2) A water services authority commencing operations as such after the promulgation of these regulations must, within 12 months of becoming a water services authority, register with the Director-General as contemplated in sub-regulation (1).

(3) If a water services authority is itself not a water services provider, it must enter into an agreement with a water services provider which provides its population with water services.

4 Public Information

(1) The applicable water services authorities must, once these regulations have been promulgated, inform its local community by means of a notice in two or more regional newspapers generally read by the public in the area regarding the intended fluoridation of their water supply.

(2) The notice referred to in sub-regulation (1) must invite interested persons to submit any substantiated comments on the intended fluoridation of their water supply or make representations to their water services authority within 30 days of the date of publication of such notice.

(3) The water services authority must in addition to the publication of the notice referred to in sub-regulation (1) broadcast the content of such notice on appropriate radio stations.

(4) A water services authority must attach the comments received from the public to the

		application for registration referred to in regulation 3.
5	**Consideration by Director-General regarding implementation of fluoridation by water services authority**	
	(1)	The following information must be taken into account by the Director-General when considering applications:
		(a) Dental caries experience in the supply area of the water services authority; (b) the population size in the supply area of the water services authority; (c) the estimated costs of fluoridation supplied by the water services authority; (d) the feasibility of using alternative fluoride supplements; (e) the information required in Annex A; and (f) evidence based information.
	(2)	The information referred to in sub-regulation (1) must, at the written request of the Director-General, be submitted by provincial authority responsible for oral health services, water services authorities and any other authorised person as applicable.
	(3)	The Director-General must consult with the Director-General of the Departments of Water Affairs and Forestry, and Provincial and Local Government regarding any possible influence of the proposed fluoridation of the water resources in the affected areas and, should the Director-General of either department, taking into consideration previous studies, if available, be of the opinion that there may be an unacceptable impact on the water resources or any other negative impact on water services delivery or water services delivery institutions, the Director-General concerned may be required to carry out an assessment of such an impact.
	(4)	The outcome of the assessment referred to in sub-regulation (3) must be evaluated by the Director-Generals of Health; and Water Affairs and Forestry; Provincial and Local Government to determine the necessity to proceed with water fluoridation.
	(5)	After a water services authority had been registered by the Department of Health, such water services authority must implement fluoridation within a period of not more than two years, or within such extended period as determined by the Director-General upon a written request by the water services authority concerned.
	(6)	The Director-General may at any time before or after a water fluoridation plant comes into operation, request a water services authority to submit any other additional information on the water fluoridation scheme within its area of supply.
	(7)	(a) If a water services authority effects any changes, after the implementation of fluoridation, which differ with regard to any of the items specified as technical information in Annex C, such water services authority must inform the Director-General in writing regarding such changes and the reasons therefore, and (b) It shall remain the responsibility of a water services authority, which had entered into a water service agreement with a water services provider, to ensure that the information referred to in subsection (a) is submitted to the Director-General
	(8)	The Director-General determines the optimum concentration of fluoride in the water supplied by a water services authority.
	(9)	(a) If a water services authority wishes to amend the optimum fluoride concentration referred to in sub-regulation (8), as approved by the Director-General, such water services authority must apply in writing to the Director-General for approval to amend the optimum fluoride concentration, stating the reasons for such amendment. (b) A water services provider which has entered into a water service agreement with a water services authority, must apply in writing to the water services authority concerned if it wishes to amend the optimum fluoride concentration referred to in sub-regulation (8), and such an application shall be forwarded to the Director-General by the water services authority under whose jurisdiction such water services provider falls.

	(10)	The Director-General may authorise an officer from the national or a provincial Department of Health or any authorised person to carry out an assessment of a planned water fluoridation scheme and verify the information supplied in the application.
6	**Exemption of a water services authority from implementation of fluoridation, or termination of fluoridation**	
	(1)	If a water services authority wishes to be exempted from the implementation of fluoridation or wishes to terminate the fluoridation of a water supply within its area of jurisdiction such water services authority must submit its application for such exemption or termination in duplicate, to the Director-General in the format set out in Annex B.
	(2)	The Director-General must use the criteria and guidelines in Annex D to determine whether an application referred to in sub-regulation (1) should be approved or not.
	(3)	If the Director-General is of the opinion that such an exemption or termination is necessary, the Director-General must approve such an exemption or termination.
	(4)	If the Director-General exempts a water services authority from the implementation of water fluoridation, she or he must indicate the period of such exemption.
	(5)	The Director-General may withdraw his or her approval referred to in sub-regulation (3) for a specific period if he or she is of the opinion that such an exemption or termination is unnecessary.
	(6)	If after the Director-General has made a decision referred to in sub-regulation (3), the Director-General of either the Departments of Water Affairs and Forestry and/or Provincial and Local Government, based on evidence, is still of the opinion that the water services authority concerned should be exempted from the implementation of fluoridation or permitted to terminate the fluoridation of a water supply owing to the unacceptable impact on the water resources receiving fluoridated water or waste water discharges, then the Director-General may approve such an application.
	(7)	The Director-General must inform the water services authority concerned in writing whether its application referred to in sub-regulation (1) has been approved or not, as well as provide the reasons in the case of disapproval.
	(8)	A water services authority that provides water to a community less than 100 000 inhabitants shall be exempted from fluoridation.
	(9)	Should such a water services authority wish to fluoridate to a community of less than 100 000 inhabitants, the provisions of regulations 5 and Annex H shall be applicable.
7	**Appeals**	
	(1)	Any water services authority aggrieved by a decision of the Director-General, or a person, other authority, public organisation, or body whose rights are adversely affected by the decision of the Director-General may within a period of 60 days of the decision of the Director-General having come to their knowledge, appeal such decision to the Minister.
	(2)	Such an appeal must clearly state: (a) against which decision such appeal is lodged; and (b) the grounds on which such appeal is lodged.
	(3)	The Minister shall, after considering such an appeal confirm, set aside or vary the decision of the Director-General.

8	**Privileges of committees**	
	(1)	The committee or the appeal committee appointed in terms of these regulations or any member of the committee or of any such appeal committee shall not be liable in respect of anything done in good faith under these regulations.
	(2)	An official member of the appeal committee may not receive additional remuneration. Subsistence and other allowances may be paid to the official member by the institution that employs the official member in accordance with his or her conditions of service.
	(3)	A non-official member of the appeal committee shall be remunerated according to scales approved by the National Treasury.
	(4)	Should the Minister deem it necessary, he or she can determine other remuneration, provided that: (a) the terms of reference are properly defined in terms of time and cost; and (b) if applicable, the remuneration is considered taking into account the tariffs as determined by the institute that regulates the profession that the non-official member belongs to.
	(5)	The remuneration of all members of the appeal committee must be disclosed as notes to the financial statements of the department.
9	**Safety and adequacy of water fluoridation and continuity of supplying fluoridated water**	
	(1)	The water fluoridation plant must be of such design to allow the dosing of the fluoride concentration of not more than 0,7 mg/l Fluoride (as F), as indicated under point 3 (d) of Annex C.
	(2)	Only a fluoride compound approved by the Director-General in terms of regulation 16 of these regulations shall be used to fluoridate a water supply.
	(3)	(a) The fluoride concentration of the fluoridated water leaving the water fluoridation plant must be monitored at least once in every 8 hour shift to ensure that the fluoride concentration does not exceed 2 mg/l fluoride (as F) for 16 hours. (b) A water services authority or delegated service provider must ensure that the fluoride concentration in the fluoridated water, measured at a point within the water purification plant, is maintained within 0,2 mg/l fluoride (as F) of the optimum fluoride concentration indicated under point 3 (d) of Annex C. (c) The fluoride concentration referred to in sub-regulation (b) must be maintained at least 90 percent of the time, measured at least 8 hourly over the period of a calendar month. (d) The average fluoride concentration of the fluoridated water, calculated for the periods when the water fluoridation plant is in operation in a calendar month, must not deviate by more than 0,1 mg/l fluoride (as F) above the optimum fluoride concentration indicated under point 3 (d) of Annex C. (e) Samples must be taken randomly from a number of places in the distribution system as prescribed in SANS 241, set out in Annex H, and the result recorded. (f) The number of samplings referred to in sub-regulation (e) must be undertaken as prescribed in SANS 241, set out in Annex H.
10	**Safety and management of the fluoridation plant**	
	(1)	The fluoride compounds referred to in regulation 16 must be stored in a secure place by a water services authority so that – (a) any unforeseen or accidental spillage of such fluoride compound does not contaminate the environment or cause harm; and (b) no unauthorised person can interfere with such fluoride compounds.
	(2)	If a water fluoridation plant is shut down for operational reasons for a period of less than

		two months but more than one week, the water services authority concerned must inform the department in the monthly report as prescribed in Annexure E.
	(3)	If a water fluoridation plant is envisaged to be shut down for a period of longer than two months, it must be done with the prior approval of the department, and the water services authority concerned. The relevant local authorities and the public concerned must also be informed by means of a notice in two or more local newspapers and broadcasting on the appropriate radio stations, before the intended shutdown.
	(4)	The water fluoridation plant must be inspected at least once in every 8 hour shift to ensure proper functioning.
11	**Record keeping and reporting**	
	(1)	The water services authority(ies) must ensure that the particulars as required in Annex: E are recorded monthly and forwarded to the national and applicable provincial health department(s) within 14 days of the last day of the month being reported on.
	(2)	An incident of an overdose of between 2 and 10 mg/l fluoride (as F) in a 24-hour period must be recorded and reported within 2 working days, to the department and applicable provincial health department(s).
	(3)	Any accidental over-fluoridation of more than 10 mg/l fluoride (as F), as measured during a single shift, or a major spill must be recorded, and the water services authority must inform the Director-General, provincial health department and the users of such water, immediately or as soon as is practicable.
	(4)	All records and reports of a water services authority relating to fluoridation must be open for public inspection and must be kept by the water services authority for a period of ten years.
	(5)	Actions for fluoride overfeed are set out in Annex G.
12	**Inspections**	
	(1)	An authorised officer may at any time, and as often as he or she may deem necessary, inspect a water fluoridation plant.
	(2)	The owner or occupier or the person in charge or apparently in charge of, or any employee on or in a water fluoridation plant, must provide to the authorised officer in terms of these regulations all information the authorised officer may require with regard to the organisation and management of a water fluoridation plant and the process of fluoridation.
	(3)	No person may in any way obstruct an authorised officer in carrying out his or her inspections or refuse to furnish to the best of his or her knowledge any information requested by such an authorised officer.
13	**The operation, maintenance and employees of a water fluoridation plant**	
	(1)	A water services authority must ensure that the water services provider establish a comprehensive operational programme, safety measures and emergency procedures regarding - (a) the operation of the water fluoridation plant; (b) the inspection, servicing and maintenance of the equipment of the water fluoridation plant; (c) the monitoring of the fluoride concentration referred to in regulation 9; (d) the storage and handling of fluoride compounds at the water fluoridation plant, in order to achieve consistent, effective and safe operation of the water fluoridation plant; and

		(e) reporting requirements between the water services authority and water services provider as indicated in regulation 11.
	(2)	The operational programme, safety measures and emergency procedures referred to in sub-regulation (1) must be made available in written format to the managers, supervisors, operators, maintenance staff and other employees working at the water fluoridation plant in accordance with their duties, responsibilities and tasks.
	(3)	A water services authority must ensure that the people referred to in sub-regulation (2) are adequately trained in all aspects of their duties, responsibilities and tasks by a training course approved by the National Fluoridation Committee.
	(4)	The superintendent of a water fluoridation plant must have a classification of at least Class III, in accordance with the classification system for water-care plant operators of the Department of Water Affairs and Forestry.
14	**Financing of a water fluoridation plant**	
	(1)	The year prior to the implementation of water fluoridation, after being registered with the department to fluoridate, the water services authority must submit a detailed costed plan as required in Annex F.
	(2)	On approval from National Treasury the department will fund through a conditional grant the capital expenditure of the water fluoridation plant.
	(3)	Funds for the operating costs of a water fluoridation plant will be made available by the department, on approval from National Treasury, to cover the anticipated shortfall between expected income and expenditure. A statement of expected income and expenditure must be submitted to the department 3 months before the commencement of the financial year of the water services authority to the Director-General for consideration of the amount to be contributed for the operating costs for a phasing in period of 5 years.
	(4)	The arrangement for funding as per sub-regulation (3) will be managed through a service level agreement between the department and the water services authority.
15	**Health and Safety**	
	(1)	All activities related to a water fluoridation plant must be in compliance with all the relevant acts regarding health and safety.
16	**Fluoride compounds**	
	(1)	The following fluoride compounds may be used in the fluoridation of a water supply: (a) Sodium fluoride; (b) fluorosilicic acid; (c) sodium fluorosilicate.
	(2)	Potential importers or manufacturers must apply to the Director-General for registration and approval of fluoride compounds other than those mentioned in sub-regulation (1) prior to the fluoridation of a public water supply.
	(3)	A water services authority must ensure that the fluoride compounds used for water fluoridation meet the quality standards developed by the South African Bureau of Standards. These quality standards are contained in the Water Fluoridation Technical Manual for Water Plant Operators which was published by the department.
	(4)	Documentary evidence of the quality of the fluoride compound to be used must be submitted to the department by the water services authority concerned.

25	Repeal of regulations	
	(1)	The regulations published under Government Notice R873 of 8 September 2000 are hereby repealed.
	(2)	Anything done or deemed to have been done in terms of the provisions of the regulations repealed by sub-regulation (1) and which may or shall be done in terms of these regulations shall be deemed to have been done in terms of the corresponding provision of these regulations.
26	**Short title and commencement**	
These regulations are called Regulations on Fluoridating Water Supplies and takes effect on the date of publication.		

2.2. Personnel

Effective support structures should be put in place to facilitate fluoridation, especially during the implementation stages. The following personnel framework, adapted from the American model, is suggested.

Each province should designate a provincial fluoridation administrator.

The fluoridation administrator will be responsible for:

- managing the fluoridation program,
- promoting water fluoridation, and
- providing liaison with other provincial and governmental agencies.

This person should be selected from either the dental program or the drinking water program.

Each province should employ at least one full-time provincial fluoridation specialist.

The fluoridation specialist's primary responsibilities will be to:

- provide for site visits,
- provide for start-up visits,
- assist in the training of water plant operators,
- provide surveillance for all fluoridated water systems, and
- resolve problems.

The staff of both the governmental dental and drinking water programs should maintain communication regarding all aspects of water fluoridation in the province.

2.3. System Reporting Requirements

An effective but simple reporting system was deemed necessary for proper control and monitoring of the fluoridation process. Some reporting guidelines drawn from the Australian and American experiences are presented.

Whenever water fluoridation is practiced, a person should be designated to report daily fluoride test results to the appropriate provincial agency. These reports should be submitted each month.

2.4. Fluoride Reporting Requirements

Each month, the provincial agency should report back to the respective operators the test results of monthly split or check samples taken from each fluoridated water system.

Each province should compile and maintain the following information on fluoridation:

- Names of all drinking water treatment works that practice fluoridation
- Names of all consecutive systems (i.e. a public water system that buys water from another public water system) that purchase water from fluoridated water systems and
- Names of all communities served by each fluoridated water system and each consecutive water system.

Each province should participate in a designated health structure that will assist provinces by providing national data against which to compare their quality and by providing a standard procedure for conducting quality assessments of their fluoridation systems.

Each province should develop a system to notify health-care providers (i.e. dentists, pharmacists, and physicians) when a new fluoridation system is initiated and when one is discontinued.

2.5. Inspection

Detailed on-site inspection of each new fluoridation system should be conducted before the system start-up to ensure that construction and installation are in accordance with applicable regulations.

Individual water fluoridation systems should be inspected at least once a year. This comprehensive inspection should include, at a minimum, the following:

- An evaluation of the fluoride testing equipment;
- An inspection of the chemical (fluoride) storage area;
- An inspection of the operation and maintenance manuals;
- A check to ensure that only approved backflow preventers and anti-siphon devices (as well as testing procedures for such equipment) are being used;
- An evaluation of the on-site emergency plans (stipulated actions in case of overfeed and public-notification procedures to be followed)
- An inspection of the plant's security (e.g. placement of appropriate signs and fences and preventing entrance by unauthorized persons) and
- An inspection of the on-site safety equipment and first aid facility available to the operator.

2.6. Actions in Case of Fluoride Overdosing

Each water plant must be provided with procedures to follow in the event of a fluoride overdosing situation (Table 2.1).

Table 2.1: Operator intervention guidelines for fluoride overdose

FLUORIDE CONCENTRATION	ACTIONS RECOMMENDED
0.1 mg/l above control range to 2.0 mg/l	1. Leave the fluoridation system on. 2. Determine malfunction and repair.
2.1 mg/l to 4.0 mg/l	1. Leave the fluoridation system on. 2. Determine malfunction and repair. 3. Notify the supervisor, who must report the incident to the appropriate country or provincial agencies.
4.1 mg/l to 10.0 mg/l	1. Turn off the fluoridation system immediately. 2. Determine malfunction and immediately attempt repair. 3. Notify the supervisor, who must report the incident to the appropriate country or provincial agencies. 4. Take water samples at several points in the distribution system and test the fluoride content. Retest if results are still high. 5. With the supervisor's permission, restart the fluoridation system.
10.1 mg/l or greater	1. Turn off the fluoridation system immediately. 2. Notify the supervisor that must report the incident immediately to the appropriate country or provincial agencies and follow their instructions. 3. Take water samples at several points in the distribution system and test the fluoride content. Retest if results are still high. Save part of each sample for the accredited laboratory to test. 4. Determine malfunction and repair. Then, with supervisor's and the fluoridation controlling authority's permission, restart the fluoridation system.

2.7. Skills Development and Training

Fluoridation training programs need to be developed to provide operators with essential knowledge related to water fluoridation.

The treatment facility operator ultimately determines the success or failure of any water treatment process. Good operator training is essential. This includes the need for both formal classroom training and standard operating procedures that include detailed instructions and guidance on best practices. To protect the public and ensure that water is safe, it is essential that formal certificated training is sought for operators.

Studies by the United States Environmental Protection Agency (USEPA) have found that one-half of operating problems are a result of inadequate operator training and/or incorrect process understanding or application by an operator. If operators are not shown how to do their job correctly in the first place, they may not be doing it right.

2.8. Training

All fluoridation control technical personnel should attend a fluoridation training course or similar courses.

Suitably qualified fluoridation technical personnel must provide training for all water plant operators at each new fluoridated water treatment works before that system is started. This start-up training must address the following:

- Information specific to the water plant and equipment
- How to test water for fluoride, under the supervision of qualified personnel
- Reporting requirements to the province and,
- Information on public health benefits of fluoride and the role of water plant personnel in providing these benefits.

Each province should integrate a minimum of 1-hour of pre-certification training in water fluoridation into the basic certification training course for water plant operators. This pre-certification training should include the following:

- Public health benefits of fluoridation and the operator's key role in preventing dental caries;
- The importance of maintaining the optimal fluoride level and,
- Technical requirements regarding the types of dosing, monitoring and control systems and the testing procedures

An annual fluoridation training course for operators should be provided by the provinces.

2.8.1. Operator Qualification and Training

Operators of fluoridation plants must receive appropriate training before operating the equipment to ensure that they are competent to do so.

Such training should include:

- principles of fluoridation; public health benefits and issues;
- operation and maintenance of fluoridation equipment;
- analysis of samples of water to determine the concentration of fluoride;
- workplace health and safety issues relevant to the operator;
- first aid;
- overview of the relevant legislation.

Induction and training required to become proficient as an operator of a fluoridation plant should include training in the health and safety aspects of handling fluoride compounds as required.

3. Monitoring and Surveillance

3.1. Assessment of Fluoride Concentration in Raw Water

Continuous fluoride monitoring, linked to an appropriate alarm monitoring system and automatic plant shutdown, is required for all dosing installations. The instrument must meet the following criteria:

- The sample point supplying the instrument should be located such that adequate mixing has taken place before the sampling point. The sampling point must be before the first draw off for a consumer. The time taken for the sample to travel from the sampling point to the instrument should be kept to a minimum;
- The performance of the online instrument as installed, maintained and operated should meet the following criteria:
  - **accuracy** or **trueness** not exceeding 10% of the result or 0.15 mg/l F (whichever is the greater) at the 95% confidence level;
  - **precision** or **total standard deviation** (under repeatable conditions) not exceeding 10% of the result or 0.15 mg/l F (whichever is the greater);
  - **limit of detection** not greater than 0.20 mg/l F;
- The instrument should be subject to an automatic standardisation at least once in every 24-hour period. Standardisation must include at least two concentrations spanning the target concentration (normally 0.7 mg/l F) and within the range 0.5 to 1.5 mg/l F. Where the instrument is used to control (or trim) the amount of chemical dosed, the lower concentration of the standardisation should be close to the target dose; It is advisable to optimise the accuracy of the measurements at the normal operating fluoride concentration. In the event of overdosing in the range that exceeds the maximum calibration standard of the instrument, the measurements may be outside the acceptable level of accuracy. In any case, water samples should be taken for independent analysis at an accredited laboratory on a regular basis for quality control and auditing purposes.
- Where standardisation results in the adjustment of the instrument's response slope, any adjustment outside of the manufacturers' recommended response range should result in appropriate remedial action being taken. Where monitors do not record such adjustments, the response slope should be checked in line with the manufacturers recommendations;
- The instrument should allow the manual initiation of a standardisation;
- The instrument should be calibrated, at a frequency in accordance with the manufacturer's instructions, including the verification of the value and alarms displayed in the manned control room;
- The instrument should register a low level alarm at 80% of the target concentration and a high level alarm at 120% of the target concentration, provided that this higher value does not exceed 1.4 mg/l F;

- The instrument should register a high-high alarm at 1.4 mg/l F. An alarm should be generated on failure of the instrument;
- An alarm should be generated on loss of water sample to the instrument;
- Failure of the instrument or loss of water sample to the instrument should result in the cessation of fluoride dosing;
- Where instrument alarms can be manually overridden (for maintenance purposes) any override events should be logged and the facility configured so that the operator is aware that the override is activated;
- Fluoride concentration alarms from the instrument should be transmitted to a permanently manned control room;
- Instrument performance should be compared, at a frequency not less than monthly, to the results from the laboratory analysis and,
- Instrument readings should be logged and kept for a minimum period of five years.

Manual checks of fluoride residual at dosing sites

Water providers may also manually test (using a portable test kit) the fluoride concentration in the dosed water as an additional check. Where such tests are carried out, water providers should have in place guidance to operating staff on the permitted variance of manual test results from the on-line monitor readings and instructions as to the action(s) to be taken when this permitted variance is exceeded.

Monitoring at consumer taps / authorised supply points

Water supplies must be sampled and analysed for fluoride content at the frequencies specified in Tables 2 and 3 of Schedule 3 to the Water Supply (Water Quality) Regulations 20001 (as amended).

Water providers are referred to the current guidelines on the Regulations available on the DWI website for further information.

3.2. Record Keeping and Reporting

11	Record keeping and reporting	
	(1)	The water services authority(ies) must ensure that the particulars as required in Annex: E are recorded monthly and forwarded to the national and applicable provincial health department(s) within 14 days of the last day of the month being reported on.
	(2)	Incidents of fluoride overdose i.e. fluoride concentrations between 2 and 10 mg/l F in a 24-hour period must be recorded and reported within 2 working days, to the department and applicable provincial health department(s).
	(3)	Any accidental over-fluoridation of more than 10 mg/l F, as measured during a single shift, or a major spill must be recorded, and the water services authority must inform the Director-General, provincial health department and the users of such water, immediately or as soon as is practicable.
	(4)	All records and reports of a water services authority relating to fluoridation must be open for public inspection and must be kept by the water services authority for a period of ten years.
	(5)	Actions for fluoride overfeed are set out in Annex G.

3.3. Inspection

12	Inspections	
	(1)	An authorised officer may at any time, and as often as he or she may deem necessary, inspect a water fluoridation plant.
	(2)	The owner or occupier or the person in charge or apparently in charge of, or any employee on or in a water fluoridation plant, must provide to the authorised officer in terms of these regulations all information the authorised officer may require with regard to the organisation and management of a water fluoridation plant and the process of fluoridation.
	(3)	No person may in any way obstruct an authorised officer in carrying out his or her inspections or refuse to furnish to the best of his or her knowledge any information requested by such an authorised officer.

4. Technical Requirements

4.1. Infrastructure Requirements

The proper infrastructure needs to be in place to ensure safe and effective fluoride dosing since the range between beneficial and detrimental fluoride dosage is very small. Some basic considerations include suitable dosing equipment with the appropriate accuracy to meet the stringent dosing tolerance, safety of operating personnel during storage and handling of fluoride source chemicals. These requirements must be in accordance with the governmental regulations and acts.

4.2. Technical Requirements

4.2.1. Fluoridation Facility

The fluoridation equipment must be located in a room provided exclusively for fluoridation. The fluoridation room should have a ceiling to prevent dust accumulation, e.g. on roof beams. The construction of the fluoridation room should consist of:

- Smooth waterproof surfaced walls to minimize dust accumulation.
- Concrete well graded floors with a waste sump to collect spillages for controlled disposal.
- Smooth finish, no ledges doors.
- Flush fitted wall windows.
- Dry conditioned chemical storage room.
- Exhaust fan for the removal of acid fumes or dust. Advice should be sought on the appropriate design and installation of the exhaust fan.
- Appropriate occupational and safety signs on doors.
- Suitable specified bund-walled enclosures for fluoride storage tanks.

4.2.2. General Requirements of Fluoridation Equipment

The choice of fluoridation chemicals determines the choice of fluoridation equipment. There is no one specific type of equipment that is used solely for one type of water system. All the fluoridation equipment, with the exception of a saturator, can be used on any system (Water Fluoridation Training, Centres for Disease and Prevention, September 2005).

4.2.2.1. Processed Water Flow Measurement

The most important function of any instrument used to measure flow is to give an indication of the total volume of water processed to enable an accounting on the fluoride dosed.

Another function is for the instrument to be able to control another piece of equipment, i.e. a dosing pump.

4.2.2.2. Fluoride Dosing Measurement

For dosing control, all fluoridation systems must have a primary flow-measuring device appropriately located to measure the flow rate and the volume of water to be fluoridated. The accuracy of the flow meter should be within 2 percent over the range (Code of Practice for the Fluoridation of Public Water Supplies, Public Health Services Queensland, 2004).

4.2.3. Operational Principle of the Fluoridation Systems

- The fluoride dosing system must have failsafe measures like electrical interlocks to guarantee that it cannot function unless the water flowrate is greater than a minimum flow relative to full flow, depending on the sensitivity of the flow-proportional controller. Signals from two independent flow detection devices should be available to stop and start the dosing equipment. The flow detection devices should be wired in series in the control circuit loop so that the absence of a signal from either one will prevent the fluoride equipment from operating. One of the signals should be from the actual flow to which the fluoridating chemical is added.
- For a gravity flow situation, the first flow signal should originate from the primary flow measuring device (upstream location). The second signal should come from a secondary flow-based control device installed on the downstream side of the dosing point.
- For pumped supplies, the fluoride dosing pump may be electrically interlocked with the pump supplying water. A back-up secondary flow-based control device should be provided.
- Online monitoring of fluoride concentration in the fluoridated water may also be used as part of the fail-safe system. The on-line monitoring system is interlocked with the dosing system to shutdown when the concentration of fluoride exceeds a maximum set point.
- It should be made physically impossible to connect any component of the fluoridation equipment to any electrical outlet that allows the equipment to be operated independently of the interlocked circuit. Where possible equipment should be wired directly into the interlocked circuit.
- The manual/testing switch for the fluoride agent feeding equipment should be spring loaded to prevent continuous operation. The switch should be linked to an alarm light activated when the switch is on.
- The installation and arrangement of the equipment should ensure that the handling and operation of the equipment meet the relevant workplace health and safety legislation.

4.2.4. Fluoride Dosing Requirement

- Sufficient fluoridating agent must be added by automatic dosing equipment to maintain the final fluoride content in the water within the maximum and minimum limits.
- The fluoride dose rate should be directly proportional to the rate of flow of the water.
- The dosing accuracy of the fluoridation system must be within 0.2 mg/l F of the optimum fluoride concentration stipulated (South African Fluoridation Regulations under the National Health Act, Department of Health, 2003)

4.2.5. Dosing Point

- The fluoride dosing point should be located where all the water to be treated passes and which allows intimate mixing of the fluoride chemical with the water.
- The dosing point should preferably be after any coagulation, filtration and pH adjustment to avoid substantial losses that can occur by the reaction of fluoride with water treatment chemicals such as aluminium, calcium and magnesium.
- No water service within the plant or to consumers should be taken directly off the water line to which fluoride is dosed. A storage reservoir (or similar barrier) should be provided between the fluoride dosing point and all water service off-takes.

4.2.6. Dry Fluoride Feed Systems

4.2.6.1. System Components

- The system should consist of a dust extraction system, a bag loader, a storage/feed hopper, a volumetric or gravimetric dry feeder, a mass-loss system to measure the mass of fluoride chemicals used, a dissolving tank with mechanical mixer, and a solution transfer pump unless gravity feed is used.
- The bag loader should be provided with direct dust extraction when it is opened for manually filling the storage/feed hopper.
- The maximum feeder capacity should not exceed the required dosing rate at the maximum plant flow.
- The capacity of the storage/feed hopper should be sufficient to ensure continuity of fluoridation, but should not exceed seven days supply to minimise the risk of overfeeding.
- Backflow prevention must be provided on the water service to the building. An air gap (free discharge) must be provided at the dissolving tank where it is connected to the inflow water line. An air gap is the minimum space between the maximum water level in the chemical preparation tank and the make-up water outlet pipe, required to prevent backflow from the chemical preparation tank into the clean water system.

4.2.6.2. System Operation

- Interlocking of dry feeder, tank solution level, mixer, and transfer pump should be provided to ensure system shutdown when a malfunction of any one of these units occurs.
- All equipment should be failsafe (e.g. solenoids close on power failure, appropriate measures to prevent siphoning).
- Daily checks on system operation and dosing accuracy should be made.

4.2.7. Liquid Fluoride Feed Systems

4.2.7.1. System Components

- The feed system should consist of two batching tanks, configured as duty and standby units, with mechanical mixers and a metering pump with a graduated calibration tube on the suction side. Positive displacement metering pumps should have a loading valve on the delivery side.
- The system should include a water softener where the total hardness of the water used for dissolving the fluoride chemical exceeds 75 mg/l as $CaCO_3$ (Code of Practice for the Fluoridation of Public Water Supplies, Public Health Services Queensland, 2004).
- The maximum dosing pump capacity should not exceed the required dosing rate at maximum plant flow.
- The capacity of the tanks should be sufficient to ensure continuity of fluoridation, but should not exceed seven days supply to minimise the risk of overdosing.

> Backflow prevention must be provided on the water service to the building. An air gap (free discharge) must be provided between the inflow water line and the chemical preparation tank. An air gap is the minimum space between the maximum water level in the chemical preparation tank and the make-up water outlet pipe, required to prevent backflow from the chemical preparation tank into the clean water system.

4.2.7.2. System Operation

- Interlock of the dosing pump and tank solution level should be provided to ensure automatic system shutdown when the level of solution in the tank is low.
- All equipment should be failsafe (e.g. solenoids close on power failure, appropriate measures to prevent siphoning).
- Daily checks on system operation and dosing accuracy should be made.

4.2.8. Fluoride Saturator System

4.2.8.1. System Components

- The saturator system should consist of a saturator tank, a bag loader, and a dosing pump with a graduated calibration tube on the suction side. Positive displacement dosing pumps should have a loading valve on the delivery side.
- The system should include a water softener if the total hardness of the water to be used in the saturator exceeds 75 mg/L as $CaCO_3$ (Code of Practice for the Fluoridation of Public Water Supplies, Public Health Services Queensland, 2004).
- The maximum dosing pump capacity should not exceed the required dosing rate at maximum plant flow.
- Provision for visual checking of the sodium fluoride depth in the tank should be provided.
- A water meter must be provided on the make-up water line for the saturator so that calculations can be made to confirm that the proper amounts of fluoride solution are being added.

> Backflow prevention must be provided on the water service to the building. For a downflow saturator, an air gap (free discharge) must be provided between the inflow water line and the saturator tank. For an upflow saturator, a siphon break must be incorporated in the inflow water line to the saturator tank.

4.2.8.2. System Operation

- Only granular sodium fluoride should be used in a saturator as powdered and fine material cause plugging.
- The layer of un-dissolved granular sodium fluoride in the saturator tank should be maintained at a minimum depth of 150 mm above the sand media.
- The saturator should never be filled so high that un-dissolved chemical is drawn into the suction line.
- All equipment should be failsafe (e.g. solenoids close on power failure, appropriate measures to prevent siphoning).
- Daily checks on system operation and dosing accuracy should be made.

4.2.9. Fluorosilicic Acid System

4.2.9.1. System Component

- No more than a 7-day supply of fluorosilicic acid should be connected at any time to the suction side of the chemical feed pump. All bulk storage tanks with more than a 7-day supply should have a day tank. A day tank should only contain a small amount of acid, usually a one or two day supply.

- For large plants where bulk fluorosilicic acid is used, the dosing system should consist of a bulk storage tank, a day tank, weighing platform for the day tank, and a dosing pump with loading valve on the delivery side and a graduated calibration tube on the suction side.
- For small plants where direct feed from specifically designed drums is suitable, the dosing system should include a weighing platform for the acid container, and a dosing pump with loading valve on the delivery side and a graduated calibration tube on the suction side.
- The bulk storage tank must be contained within a bunded area of sufficient volume such that no acid can escape to the environment.
- Carboys, drums, day tanks, indoor bulk storage tanks and graduated calibration tubes containing hexafluorosilicic acid must be completely sealed and vented to the outside.
- Backflow prevention must be provided on the water service to the building.

4.2.9.2. System Operation

- All equipment should be failsafe (e.g. solenoids close on power failure, appropriate measures to prevent siphoning).
- Interlock of the metering pump should be provided to ensure system shutdown when low level in the day tank or drum occurs.
- Daily checks on system operation and dosing accuracy should be made.

4.2.10. Fluoride Chemical Quality

Chemicals added to drinking water must not contain impurities in a quantity that will cause health problems for consumers. Metals are the main impurities of health significance likely to be found in fluoride chemicals. Other characteristics that need to be known are the purity of the chemical (necessary for accurate dose control) and the amount of insoluble matter (can cause operational problems).

Pending the establishment of national guidelines or standards for chemicals used for fluoridation, the chemicals used should meet the specifications listed in the **fluoridation regulations act.**

Suppliers should provide a full chemical analysis of each batch of chemical delivered. The analysis should identify the amounts of lead, cadmium, mercury, arsenic, aluminium, copper, zinc, and any other chemicals that may be of concern.

As an added precaution, it is recommended that users conduct their own independent analyses periodically to confirm chemical quality.

4.2.11.Analysis of Water Samples

4.2.11.1.Methods of Analysis

Either the Ion Selective Electrode (ISE) Method or the SPADNS Method must be used. The ISE Method is the preferred and recommended method for fluoride ion determination in water as it is reliable and less technique-sensitive than the alternative.

The SPADNS colorimetric method for fluoride determination was found unsuitable for the application.

4.2.11.2.Quality Assurance

The analysis of fluoride in water samples should include at least one independent check sample or other recognized quality assurance measure. If the fluoride result of this check sample lies outside the normal range of values, corrective action should be taken to ensure the accuracy of results in samples of interest are not being compromised.

5. Safety Procedure

Waterworks personnel working on fluoridation systems must be made aware of the hazardous nature of fluoride chemicals. A written procedure should be generated for all activities that include handling fluoride chemicals. Adherence to the safe working procedures should be monitored and enforced to ensure that incidents and accidents are minimized.

5.1. Loading Bay

The design of the loading bay should facilitate good manual handling practices to facilitate the unloading of the chemical. The floor should have a non-slip finish.

5.2. Material Safety Data Sheets (MSDS)

The MSDS must be kept on a register and a copy placed close to where the substance is used to enable reference to it by a worker who uses the substance.

5.3. Labelling

All hazardous substances used at a workplace must be appropriately labelled. Whilst the supplier is responsible for ensuring that substances are labelled on delivery, the employer should also ensure that unlabelled or improperly labelled substances are not accepted into the workplace.

Following delivery of a hazardous substance, it is the employer’s obligation to ensure that it remains labelled. If a hazardous substance is decanted into another container, the second container must also be labelled if the contents are not used immediately, capturing the details of the original batch from which the transfer is made, particularly where an expiry date of the chemical is applicable.

5.4. Risk Assessment

For every hazardous substance used at a workplace, a risk assessment exercise must be undertaken. The chemical characteristics, toxic effects due to exposure and first aid procedures for emergency treatment are obtained from the MSDS. The MSDS also details the safe handling procedures required. With this information and the ‘on the job observation data’ relating to the operator’s daily activities, it is possible to assess whether there is potentially harmful exposure to the operator. Steps to mitigate the danger must be taken and implemented in the safe working procedure.

In situations where risk assessments are difficult, e.g. where there is airborne contamination from dust, mist, gas, fume or vapour, specialised monitoring of the work environment by an occupational hygienist should be considered. The original comprehensive records of risk assessments must be dated, signed and retained safely.

5.5. Control of Exposure

Where the risk assessment identifies that a worker is exposed to hazardous substances such as those used for water fluoridation, the employer must ensure that effective control measures are applied. The order of control measures from most to least favourable, known as the "hierarchy of controls" are:

- ***Elimination*** - removal of unnecessary processes.
- ***Substitution*** **-** replacement of toxic substances with less or non- toxic ones.
- ***Engineering*** **-** isolation of equipment and personnel by enclosures and the use of ventilation to dilute or extract contaminants.
- ***Administration*** - adoption of work practices and procedures to reduce exposure.
- ***Personal Protective Equipment (PPE)*** - use of respirators, gloves and special clothing to minimise contact with or intake of a hazardous substance.

Irrespective of the control measure used the worker must not be exposed to an airborne contaminant at a level which exceeds the national exposure standard level, if it exists, for that substance. The current (1998) national exposure standard for fluorides is a Time-Weighted Average (TWA) level of 2.5 mg/m^3 (Code of Practice for the Fluoridation of Public Water Supplies, Public Health Services Queensland, 2004).

5.6. Use of Personal Protective Equipment (PPE)

The choice of PPE for controlling exposure depends on the effectiveness of other control measures. In most existing treatment facilities, whilst some higher order controls may be in place (e.g. exhaust fan), it is unlikely that they will be sufficient to enable work to be undertaken safely without a range of PPE. This includes general protective clothing and respiratory protection.

General protective equipment may include:

- elbow length impervious gloves,
- long sleeved shirt, trousers and a full length impervious apron or disposable impervious overalls and impervious boots.
- In addition, for hexafluorosilicic acid, a full face shield or chemical goggles.

Respiratory protective equipment may include:

- for dry powdered or granular fluoridating agents a chemical goggle and half face mask fitted with a suitable filter

- for hexafluorosilicic acid, where there is a risk of exposure to acid fume, a full face respirator fitted with an acid gas canister. It should be noted that filter respirators require a good seal around the face, which cannot be achieved where there is facial hair. A powered air purifying respirator may be required for bearded operators.

5.7. Maintenance of PPE

A maintenance program should be established where PPE is used. Items of PPE should be stored in a proper cabinet near where it is used and not left lying about or hung on a nail where it can become contaminated by chemical fallout.

- Maintenance procedures should include regular inspection of safety gear and replacement of worn or damaged items.
- Maintenance should include:
  - gloves, aprons and boots should be hosed off after use and dried before storage;
  - clothes contaminated with dry fluoridating agent must be changed and washed after work with fluoride chemicals is completed;
  - clothes contaminated with wet fluoridating agent must be changed and washed immediately;
  - respirator filters must be replaced regularly.
  - dust filters require changing whenever an increased resistance to air movement through the filter becomes noticeable.

5.8. Health Surveillance of Workers

Health surveillance is the regular monitoring of the health of workers by medical assessment and includes biological monitoring (laboratory testing of body fluids) where this is appropriate.

5.9. Washing Facilities

Each place in which the fluoridating agent is handled should contain facilities for washing, including a hand basin, soap, nail brush and provision for hand drying.

Where fluorosilicic acid is used, an emergency shower and eye wash station should be provided as close as practicable to any area where there is a risk of accidental splashing. The water supply to the emergency washing facilities should be designed so that the supply cannot be interrupted, and the equipment should be tested on a regular basis.

5.10. Environmental Considerations

A Municipal Water Treatment Plant is not permitted to carry out, without an approval issued under the Act, any activity that is likely to cause environmental harm, unless the person takes all reasonable and practicable measures to prevent or minimise the harm.

5.10.1.Storage of Fluoridating Agents

Fluoridating agents must be stored in a designated and secure storage area separate from other chemicals. The storage area may be a designated part of the fluoridation room

5.11. Spillage or Leaks

Spillage of any fluoridating agent in the room must be carefully managed:

- Any spilled fluoridating agent must be hosed off the floor and not removed by dry sweeping. Removal by vacuum cleaner is permissible only if the cleaner is fitted with an appropriate filter.
- Safety procedures detailed in the MSDS should be followed when a large spillage of fluoridating agent occurs.

5.11.1.Disposal of Containers

Wherever possible, fluoridating agent containers should be returned to the manufacturer for disposal. In circumstances where this cannot be arranged:

- empty bags which previously contained fluoridating agent should be hosed clean and buried under a minimum of 500 mm depth of soil at an approved waste disposal facility;
- fluorosilicic acid containers should be thoroughly rinsed and should not be used for any other purpose. Small carboys/drums should be disposed by an approved waste disposal facility;
- where local disposal is not practical, an approved waste service should be used to arrange disposal of empty containers.

5.11.2.Plant Security

Waterworks officials must ensure that visits by any persons to the fluoridation room are authorized and controlled and visiting persons are accompanied by a qualified operator. Once visitors have entered the fluoridation room, the presence of the qualified operator may be exempted if a qualified operator is satisfied that:

- the personnel have been adequately instructed and will not be in contact with the fluoridating agent or any part of the fluoridation equipment ; or
- the personnel have been given appropriate instruction and provided with the appropriate PPE if contact with fluoridating agent is likely when maintaining specific items of the fluoridating equipment; or
- the nature of visit is for general inspection or taking recorder data without the need for touching any fluoridating agent or equipment.

5.11.3.Contingency Plans

Water authorities should develop a contingency plan to deal with events of overdosing and no dosing. These plans should address as a minimum:

- procedures for shutting down the equipment in the event of overdosing;
- the action required to identify and rectify the problem;
- action required to warn and protect the public in the event of a significant overdosing event and
- reporting protocols including a clear chain of command and designated responsibility.

Appendix 1

APPENDIX 1

GOVERNMENT NOTICE

Regulation No. R 2007

DEPARTMENT OF HEALTH

REGULATIONS UNDER THE NATIONAL HEALTH ACT, 2003 (ACT NO. 61 of 2003)

The Minister of Health has, under sections 3 and 90 (1) of the National Health Act, 2003 (Act No. 61 of 2003) in consultation with the Ministry of Water Affairs and Forestry, made the regulations in the Schedule.

SCHEDULE

REGULATIONS ON FLUORIDATING WATER SUPPLIES

1 Definitions

In these regulations any expression to which a meaning has been assigned in the Act shall have such meaning and, unless the context indicates otherwise –

"Authorised officer" means an officer of the national Department of Health, provincial or of a local government or any other person generally or specifically authorised in writing by the Director-General;

"Department" means the national Department of Health;

"Director-General" means the head of the national Department of Health;

"Fluoridation" means to adjust the fluoride concentration of a water supply by the addition of a fluoride compound to obtain an optimal fluoride concentration;

"Fluoride compound" means sodium fluoride (NaF), sodium fluorosilicate (Na_2SiF_6) (also known as sodium silicofluoride) or fluorosilicic acid (H_2SiF_6);

“non-official” means a person who holds an office in an organisation not attached to any governmental or state institution or body;

“Official” means a person who holds an office in a state or governmental institution or body;

"Optimum fluoride concentration" means a fluoride concentration determined by the Director-General for a particular water services authority and should not be more than 0.7 mgF/l in a water supply;

"The Act" means the National Health Act, 2003 (Act 61 of 2003)

“The committee” means the National Fluoridation Committee,

"Waste water discharges" means water discharges containing waste;

"waste" means any solid material or material that is suspended, dissolved or transported in water (including sediment) and which is spilled or deposited on land or into a water resource in such volume, composition or manner as to cause, or to be reasonably likely to cause, the water resource to be polluted;

"Water distribution system" means the supply of water by a water services authority through pipes to the end user;

"Water fluoridation plant" means the equipment used and the procedures applied in the addition of a fluoride compound to a water supply;

"Water fluoridation scheme" means the delivery to the end user of water containing an optimum concentration of fluoride, which is supplied by a water fluoridation plant through a water distribution system;

"Water resources" means a watercourse, surface water, estuary or aquifer;

"water services authority" means a municipality that has the executive and legislative authority to provide water services within its area of jurisdiction in terms of the Municipal Structures Act, 1998 (Act 117 of 1998) or the ministerial authorisations made in terms of that Act.

"water services provider" means the public, private or mixed entities, or water services authority providing water services and performing the duties as required in the service level agreement, the Water Service Act, 1997 (Act 108 of 1997) and the Constitution (Act 108 of 1996).

"Water supply" means the supply of water intended for human use or food processing.

2 Obligation

Every water services authority with exception of the water services authorities mentioned in regulation 6(8), must practise fluoridation, unless exempted in writing by the Director-General.

3 Registration

(1) Every water services authority, with exception with those mentioned in regulation 6(8), practising water fluoridation immediately prior to the promulgation of these regulations must, within 12 months after the promulgation of these regulations, submit –

(a) an application for registration, in duplicate, in the format set out in Annex A; and

(b) a form on technical information set out in Annex C,

to the Director-General.

(2) A water services authority commencing operations as such after the promulgation of these regulations must, within 12 months of becoming a water services authority, register with the Director-General as contemplated in sub-regulation (1).

(3) If a water services authority is itself not a water services provider, it must enter into an agreement with a water services provider which provides its population with water services.

4 Public information

(1) The applicable water services authorities must, once these regulations have been promulgated, inform its local community by means of a notice in two or more regional newspapers generally read by the public in the area regarding the intended fluoridation of their water supply.

(2) The notice referred to in sub-regulation (1) must invite interested persons to submit any substantiated comments on the intended fluoridation of their water supply or make representations to their water services authority within 30 days of the date of publication of such notice.

(3) The water services authority must in addition to the publication of the notice referred to in sub-regulation (1) broadcast the content of such notice on appropriate radio stations.

(4) A water services authority must attach the comments received from the public to the application for registration referred to in regulation 3.

5. Consideration by Director-General regarding implementation of fluoridation by water services authority

(1) The following information must be taken into account by the Director-General when considering applications:

(a) Dental caries experience in the supply area of the water services authority;

(b) the population size in the supply area of the water services authority;

(c) the estimated costs of fluoridation supplied by the water services authority;

(d) the feasibility of using alternative fluoride supplements;

(e) the information required in Annex A; and

(f) evidence based information.

(2) The information referred to in sub-regulation (1) must, at the written request of the Director-General, be submitted by provincial authority responsible for oral health services, water services authorities and any other authorised person as applicable.

(3) The Director-General must consult with the Director-General of the Departments of Water Affairs and Forestry, and Provincial and Local Government regarding any possible influence of the proposed fluoridation of the water resources in the affected areas and, should the Director-General of either department, taking into

consideration previous studies, if available, be of the opinion that there may be an unacceptable impact on the water resources or any other negative impact on water services delivery or water services delivery institutions, the Director-General concerned may be required to carry out an assessment of such an impact.

(4) The outcome of the assessment referred to in sub-regulation (3) must be evaluated by the Director-Generals of Health; and Water Affairs and Forestry; Provincial and Local Government to determine the necessity to proceed with water fluoridation.

(5) After a water services authority had been registered by the Department of Health, such water services authority must implement fluoridation within a period of not more than two years, or within such extended period as determined by the Director-General upon a written request by the water services authority concerned.

(6) The Director-General may at any time before or after a water fluoridation plant comes into operation, request a water services authority to submit any other additional information on the water fluoridation scheme within its area of supply.

(7) (a) If a water services authority effects any changes, after the implementation of fluoridation, which differ with regard to any of the items specified as technical information in Annex C, such water services authority must inform the Director-General in writing regarding such changes and the reasons therefore, and

(b) It shall remain the responsibility of a water services authority, which had entered into a water service agreement with a water services provider, to ensure that the information referred to in subsection (a) is submitted to the Director-General

(8) The Director-General determines the optimum concentration of fluoride in the water supplied by a water services authority.

(9) (a) If a water services authority wishes to amend the optimum fluoride concentration referred to in sub-regulation (8), as approved by the Director-General, such water services authority must apply in writing to the Director-General for approval to amend the optimum fluoride concentration, stating the reasons for such amendment.

(b) A water services provider which has entered into a water service agreement with a water services authority, must apply in writing to the water services authority concerned if it wishes to amend the optimum fluoride concentration referred to in sub-regulation (8), and such an application shall be forwarded to the Director-General by the water services authority under whose jurisdiction such water services provider falls.

(10) The Director-General may authorise an officer from the national or a provincial Department of Health or any authorised person to carry out an assessment of a planned water fluoridation scheme and verify the information supplied in the application.

6 Exemption of a water services authority from implementation of fluoridation, or termination of fluoridation

(1) If a water services authority wishes to be exempted from the implementation of fluoridation or wishes to terminate the fluoridation of a water supply within its area of jurisdiction such water services authority must submit its application for such exemption or termination in duplicate, to the Director-General in the format set out in Annex B.

(2) The Director-General must use the criteria and guidelines in Annex D to determine whether an application referred to in sub-regulation (1) should be approved or not.

(3) If the Director-General is of the opinion that such an exemption or termination is necessary, the Director-General must approve such an exemption or termination.

(4) If the Director-General exempts a water services authority from the implementation of water fluoridation, she or he must indicate the period of such exemption.

(5) The Director-General may withdraw his or her approval referred to in sub-regulation (3) for a specific period if he or she is of the opinion that such an exemption or termination is unnecessary.

(6) If after the Director-General has made a decision referred to in sub-regulation (3), the Director-General of either the Departments of Water Affairs and Forestry and/or Provincial and Local Government, based on evidence, is still of the opinion that the water services authority concerned should be exempted from the implementation of fluoridation or permitted to terminate the fluoridation of a water supply owing to the unacceptable impact on the water resources receiving fluoridated water or waste water discharges, then the Director-General may approve such an application.

(7) The Director-General must inform the water services authority concerned in writing whether its application referred to in sub-regulation (1) has been approved or not, as well as provide the reasons in the case of disapproval.

(8) A water services authority that provides water to a community less than 100 000 inhabitants shall be exempted from fluoridation.

(9) Should such a water services authority wish to fluoridate to a community of less than 100 000 inhabitants, the provisions of regulations 5 and Annex H shall be applicable.

7 Appeals

(1) Any water services authority aggrieved by a decision of the Director-General, or a person, other authority, public organisation, or body whose rights are adversely affected by the decision of the Director-General may within a period of 60 days of the decision of the Director-General having come to their knowledge, appeal such decision to the Minister.

(2) Such an appeal must clearly state:

(a) against which decision such appeal is lodged; and

(b) the grounds on which such appeal is lodged.

(3) The Minister shall, after considering such an appeal confirm, set aside or vary the decision of the Director-General.

8 Privileges of committees

(1) The committee or the appeal committee appointed in terms of these regulations or any member of the committee or of any such appeal committee shall not be liable in respect of anything done in good faith under these regulations.

(2) An official member of the appeal committee may not receive additional remuneration. Subsistence and other allowances may be paid to the official member by the institution that employs the official member in accordance with his or her conditions of service.

(3) A non-official member of the appeal committee shall be remunerated according to scales approved by the National Treasury.

(4) Should the Minister deem it necessary, he or she can determine other remuneration, provided that:

(a) the terms of reference are properly defined in terms of time and cost; and

(b) if applicable, the remuneration is considered taking into account the tariffs as determined by the institute that regulates the profession that the non-official member belongs to.

(5) The remuneration of all members of the appeal committee must be disclosed as notes to the financial statements of the department.

9 Safety and adequacy of water fluoridation and continuity of supplying fluoridated water

(1) The water fluoridation plant must be of such design to allow the dosing of the fluoride concentration of not more than 0.7 mgF/l as indicated under point 3 (d) of Annex C.

(2) Only a fluoride compound approved by the Director-General in terms of regulation 16 of these regulations shall be used to fluoridate a water supply.

(3) (a) The fluoride concentration of the fluoridated water leaving the water fluoridation plant must be monitored at least once in every 8 hour shift to ensure that the fluoride concentration does not exceed 2 mgF/l for 16 hours.

(b) A water services authority or delegated service provider must ensure that the fluoride concentration in the fluoridated water, measured at a point within the water purification plant, is maintained within 0.2 mgF/l of the optimum fluoride concentration indicated under point 3 (d) of Annex C.

(c) The fluoride concentration referred to in sub-regulation (b) must be maintained at least 90 percent of the time, measured at least 8 hourly over the period of a calendar month.

(d) The average fluoride concentration of the fluoridated water, calculated for the periods when the water fluoridation plant is in operation in a calendar month, must not deviate by more than 0.1 mgF/l above the optimum fluoride concentration indicated under point 3 (d) of Annex C.

(e) Samples must be taken randomly from a number of places in the distribution system as prescribed in SANS 241, set out in Annex H, and the result recorded.

(f) The number of samplings referred to in sub-regulation (e) must be undertaken as prescribed in SANS 241, set out in Annex H.

10. Safety and management of the fluoridation plant

(1) The fluoride compounds referred to in regulation 16 must be stored in a secure place by a water services authority so that –

(a) any unforeseen or accidental spillage of such fluoride compound does not contaminate the environment or cause harm; and

(b) no unauthorised person can interfere with such fluoride compounds.

(2) If a water fluoridation plant is shut off for operational reasons for a period of less than two months but more than one week, the water services authority concerned must inform the department in the monthly report as prescribed in Annexure E.

(3) If a water fluoridation plant is envisaged to be shut off for a period of longer than two months, it must be done with the prior approval of the department, and the water services authority concerned. The relevant local authorities and the public concerned must also be informed by means of a notice in two or more local newspapers and broadcasting on the appropriate radio stations, before the intended shutdown.

(4) The water fluoridation plant must be inspected at least once in every 8 hour shift to ensure proper functioning.

11 Record keeping and reporting

(1) The water services authority(ies) must ensure that the particulars as required in Annex: E are recorded monthly and forwarded to the national and applicable provincial health department(s) within 14 days of the last day of the month being reported on.

(2) An incident of an overdose of between 2 and 10 mgF/l in a 24-hour period must be recorded and reported within 2 working days, to the department and applicable provincial health department(s).

(3) Any accidental over-fluoridation of more than 10 mgF/l , as measured during a single shift, or a major spill must be recorded, and the water services authority must inform the Director-General, provincial health department and the users of such water, immediately or as soon as is practicable.

(4) All records and reports of a water services authority relating to fluoridation must be open for public inspection and must be kept by the water services authority for a period of ten years.

(5) Actions for fluoride overfeed are set out in Annex G.

12 Inspections

(1) An authorised officer may at any time, and as often as he or she may deem necessary, inspect a water fluoridation plant.

(2) The owner or occupier or the person in charge or apparently in charge of, or any employee on or in a water fluoridation plant, must provide to the authorised officer in terms of these regulations all information the authorised officer may require with regard to the organisation and management of a water fluoridation plant and the process of fluoridation.

(3) No person may in any way obstruct an authorised officer in carrying out his or her inspections or refuse to furnish to the best of his or her knowledge any information requested by such an authorised officer.

13 The operation, maintenance and employees of a water fluoridation plant

(1) A water services authority must ensure that the water services provider establish a comprehensive operational programme, safety measures and emergency procedures regarding -

(a) the operation of the water fluoridation plant;

(b) the inspection, servicing and maintenance of the equipment of the water fluoridation plant;

(c) the monitoring of the fluoride concentration referred to in regulation 9;

(d) the storage and handling of fluoride compounds at the water fluoridation plant, in order to achieve consistent, effective and safe operation of the water fluoridation plant; and

(e) Reporting requirements between the water services authority and water services provider as indicated in regulation 11.

(2) The operational programme, safety measures and emergency procedures referred to in sub-regulation (1) must be made available in written format to the managers, supervisors, operators, maintenance staff and other employees working at the water fluoridation plant in accordance with their duties, responsibilities and tasks.

(3) A water services authority must ensure that the people referred to in sub-regulation (2) are adequately trained in all aspects of their duties, responsibilities and tasks by a training course approved by the National Fluoridation Committee.

(4) The supervisor of a water fluoridation plant must have a classification of at least Class III, in accordance with the classification system for water-care plant operators of the Department of Water Affairs and Forestry.

14 Financing of a water fluoridation plant.

(1) The year prior to the implementation of water fluoridation, after being registered with the department to fluoridate, the water services authority must submit a detailed costed plan as required in Annex F

(2) On approval from National Treasury the department will fund through a conditional grant the capital expenditure of the water fluoridation plant.

(3) Funds for the operating costs of a water fluoridation plant will be made available by the department, on approval from National Treasury, to cover the anticipated shortfall between expected income and expenditure. A statement of expected income and expenditure must be submitted to the department 3 months before the commencement of the

financial year of the water services authority to the Director-General for consideration of the amount to be contributed for the operating costs for a phasing in period of 5 years.

(4) The arrangement for funding as per sub-regulation (3) will be managed through a service level agreement between the department and the water services authority.

15 Health and safety

All activities related to a water fluoridation plant must be in compliance with all the relevant acts regarding health and safety.

16 Fluoride compounds

(1) The following fluoride compounds may be used in the fluoridation of a water supply:

(a) Sodium fluoride;

(b) fluorosilicic acid;

(c) sodium fluorosilicate.

(2) Potential importers or manufacturers must apply to the Director-General for registration and approval of fluoride compounds other than those mentioned in sub-regulation (1) prior to the fluoridation of a public water supply.

(3) A water services authority must ensure that the fluoride compounds used for water fluoridation meet the quality standards developed by the South African Bureau of Standards. These quality standards are contained in the Water Fluoridation Technical Manual for Water Plant Operators which was published by the department.

(4) Documentary evidence of the quality of the fluoride compound to be used must be submitted to the department by the water services authority concerned.

17 National fluoridation committee

There is hereby established a body to be known as the national fluoridation committee.

18. Constitution of the Committee

(1) The members of the committee are constituted by the following persons -

(a) Three specialists in community dentistry;

(b) An engineer with technical knowledge of water purification plant;

(c) One official from the Department of Water Affairs and Forestry designated by that department;

(d) One official from the Department of Provincial and Local Government designated by that department;

(e) One person from the South African Local Government Association (SALGA) designated by that organisation;

(f) One person from the South African Association of Water Utilities (SAAWU) designated by that organisation;

(g) Three oral health professional officials of the Directorate: Oral Health from the department;

(2) The senior administrative officer of the Directorate: Oral Health to be the secretariat of the committee

(3) The committee may on an ad hoc basis co-opt any person(s) to advise and assist the committee on any matter in order to achieve the objectives of these regulations;

(4) The Minister of Health appoints the members of the committee including the designated persons.

(5) The members of the committee shall hold office for a period of five years, but shall be eligible for reappointment.

(6) Not less than three months prior to the date of expiry of the term of office of the members of the committee, the persons and bodies referred to in sub-regulation (1), must inform the Minister in writing of the names of the persons to be designated by them in terms of that sub-regulation.

(7) As soon as possible after the process referred to in sub-regulation (3), the Directorate: Oral Health must inform the committee of the names of persons appointed by the Minister in terms of sub-regulation (1).

(8) If any of the persons or bodies referred to in sub-regulation (1), except the Minister, fails to make a designation or an appointment or to inform the Minister in terms of sub-regulation (3) of the names of the persons to be designated by them, the Minister shall make the necessary designation, and any designation so made by the Minister shall be deemed to have been properly made in terms of the appropriate paragraph of sub-regulation (1).

19 Objects of the Committee

The objects of the committee are to -

(a) Facilitate the establishment of appropriate measures to fluoridate the mouths of communities in South Africa;

(b) Monitor and evaluate on an ongoing basis, the operation of water fluoridation plants, by studying the records and reports, as described in regulation 11;

(c) Develop and advise appropriate measures for needy communities to receive the benefits of fluoride where water fluoridation is not possible, because of lack of access or because of economies of scale;

(d) Advise the Minister of Health on any matter pertaining to fluoridation; and

(e) Advise on the safe implementation and operation of water fluoridation.

20 Functions of the Committee

(a) Meet on regular basis to evaluate and monitor progress of water fluoridation;

(b) Give guidance to provincial fluoridation committees and water services authorities;

(c) To assess compliance with the regulations by visiting water treatment plants;

(d) Commission research/surveys on dental health of the affected community before and after water fluoridation has commenced;

(e) Perform any function that may be referred to the Committee by the Minister of Health or Director-General; and

(f) Perform such other function as may be requested to further the objects of these regulations.

21 Vacation of office and filling of vacancies

(1) A member of the committee shall vacate his or her office if-

(a) his or her estate is sequestrated or he or she has entered into a composition with the creditors of his or her estate;

(b) he or she has been absent for more than two consecutive ordinary meetings of the committee without the committee’s leave;

(c) he or she ceases to hold any qualification necessary for his or her designation or appointment or tenders his or her resignation in writing to the person or body by whom he or she was designated or appointed and that person or body accepts his or her resignation;

(d) he or she ceases to be a South African citizen;

(e) he or she becomes a state patient as defined in section 1 of the Mental Health Act, 2002 (Act 17 of 2002);

(f) he or she is convicted of an offence in respect whereof he or she is sentenced to imprisonment without the option of a fine; or

(g) the Minister, in the public interest and for just cause, and after consultation with the person or body by whom the member was designated or appointed, terminates his or her membership.

(2) Every vacancy on the committee arising from a circumstance referred to in subsection (1) and every vacancy caused by the death of a member, shall be filled by designation or appointment by the person or body by whom and in the manner in which the vacating member was designated or appointed, and every member so designated or appointed shall hold office for the unexpired portion of the period for which the vacating member was designated or appointed.

22 Chairperson and Vice-Chairperson

(1) At the first meeting of every newly constituted committee the members of the committee shall elect the chairperson and a vice-chairperson from among themselves.

(2) The chairperson and vice-chairperson shall hold office during the term of office of the members of the committee unless the chairperson and the vice-chairperson shall sooner resign or cease to be a member of the committee.

(3) The vice-chairperson may, if the chairperson is absent or for any reason unable to act as chairperson, perform all the functions and exercise all the powers of the chairperson.

(4) If both the chairperson and vice-chairperson are absent from any meeting, the members present shall elect one of their members to preside at that meeting and the person so presiding may, during that meeting and until the chairperson and the vice-chairperson resumes duty, perform all the functions and exercise all the powers of the chairperson.

(5) If both the chairperson and the vice-chairperson have been given leave of absence, the members of the committee shall elect one of their members to act as chairperson until the chairperson and the vice-chairperson resumes duty or vacates office.

(6) If the office of chairperson and the vice-chairperson becomes vacant, the members of the committee shall, at the first meeting after such vacancy occurs or as soon thereafter as may be convenient, elect from among themselves a new chairperson and the vice-chairperson, as the case may be, and the member so elected shall hold office for the un-expired portion of the period for which his or her predecessor was elected.

(7) The chairperson and the vice-chairperson may vacate office as such, without such vacation by itself, terminating his or her membership of the committee.

23 Meetings of the committee

(1) The committee shall hold at least two meetings in each year at venues to be determined by the committee, and may in addition hold such further meetings as the committee may from time to time determine.

(2) The chairperson may at any time convene a special meeting of the committee, to be held on such date and at such place as he or she may determine and he or she shall, upon a written request by either the

Minister, Director-General or a written request signed by at least six members, convene a special meeting to be held, within thirty days after the date of receipt of the request, on such date and at such place as she or he may determine: Provided that such written request shall state clearly the purpose for which the meeting is to be convened.

24 Quorum and procedure at meetings

(1) The majority of the members of the committee shall constitute a quorum at any meeting of the committee.

(2) A decision of the majority of the members of the committee present at any meeting shall constitute a decision of the committee: Provided that in the event of an equality of votes the member presiding shall have a casting vote in addition to a deliberative vote.

(3) No decision taken by the committee or act performed under authority of the committee shall be invalid by reason only of an interim vacancy on the committee or of the fact that a person who is not entitled to sit as a member of the committee sat as a member at the time when the decision was taken or the act was authorized, if the decision was taken or the act was authorized by the requisite majority of the members of the committee who were present at the time and entitled to sit as members.

25. Repeal of regulations

(1) The regulations published under Government Notice R873 of 8 September 2000 are hereby repealed.

(2) Anything done or deemed to have been done in terms of the provisions of the regulations repealed by sub-regulation (1) and which may or shall be done in terms of these regulations shall be deemed to have been done in terms of the corresponding provision of these regulations.

26. Short title and commencement

These regulations are called Regulations on Fluoridating Water Supplies and takes effect on the date of publication.

MINISTER OF HEALTH

DATE:

ANNEX A

APPLICATION BY A WATER SERVICES AUTHORITY FOR REGISTRATION TO FLUORIDATE A WATER SUPPLY

1. Name and address of water services authority:
Name of responsible person: Position/rank: Telephone no: Cellular no: Fax no: Email:
2.Volume of water supplied per month:
3. Indicate the number of households supplied with drinking water by the water services authority within its supply area(s).
4. Natural Fluoride concentration in existing water supply ………mg F/l List all the available results over the past 24 months including those available from other bodies/institutions
5. The following information may also be provided separately if more space

is required: (a) Source(s) of raw water [i.e. point(s) of abstraction] • River catchment(s) • River(s)/Dam(s)/Other • Location(s) of drinking water treatment facility/facilities (b) Point(s) of discharge of effluent(s) originating from the proposed fluoridated water supply/supplies in the supply area covered by the water services authority • River catchment(s) • River(s)/Dam(s)/Other • Location(s) of effluent treatment facility/facilities
6. Name the water services provider/s providing water to the water services authority:
7. Mention the institutional arrangements in place for water services delivery:
8. Attach evidence based comments received from the public [regulation 4(4)]
Signature: Name: Position/Rank:

On behalf of:
Date:

For office use only:

Registration number:

Registration date:

....

For Director-General

Department of Health

Date:

ANNEX B

APPLICATION BY A WATER SERVICES AUTHORITY TO BE EXEMPTED FROM THE IMPLEMENTATION OF FLUORIDATION OR TO TERMINATE THE FLUORIDATION OF A WATER SUPPLY

1. Name and address of water services authority
Name of responsible person: Telephone no: Cellular no: Fax no: Email:
Position/rank:
2. Place where water fluoridation plant is installed: (in the case of termination only)

3. Reason(s) for requesting exemption from the implementation of fluoridation or for the termination of fluoridation of a water supply
Signature Name: Position/rank:
On behalf of:
Date:

For office use only:

Approved/Not approved

....

Director-General

Department of Health

Date:

ANNEX C

TECHNICAL INFORMATION PROVIDED BY THE WATER SERVICES AUTHORITY

Technical information to be submitted by the water services authority to the Director-General.

1. Name and address of water services authority
Name of responsible person Position/Rank Telephone no: Cellular no: Fax no: Email:
2. Place where water fluoridation plant is installed:
3. (a) Amount of water to be fluoridated per month

(b) Fluoride compound to be used:
(c) Mean annual fluoride concentration of present water supply: mgF/l List all the available results over the past 24 months including those available from other bodies/institutions
(d) Proposed optimum fluoride concentration (not more than 0.7 mgF/l): …….. mgF/l
4. Name and description of areas to be supplied with fluoridated water:
5. Explanatory documentation attached: a. Steps taken to inform the public. b. Types and names of fluoridation monitoring equipment and description of fluoride monitoring and alarm system.

c. Fluoridation plant inspection, servicing and maintenance programme, and emergency procedures. d. Employee training programme and duty sheets. e. Agreement between water services provider and water services authority, if applicable.
Signature Name: Position/rank
On behalf of:
Date:

For office use only:

Registration number:

Registration date:

……………………….

For Director-General

Department of Health

Date:

....

ANNEX D

Criteria and guidelines for the exemption of a water services authority from the implementation of fluoridation or for the termination of fluoridation

Introduction

On a submission of an application and under specific circumstances the Director-General may allow the exemption of a water services authority from the implementation of fluoridation or for the termination of fluoridation of a water supply. This document defines the nature of the circumstances under which such an exemption or termination should be granted. It focuses on the criteria that should be used in determining the outcome of an application for exemption or termination. Such an application by the water services authority must be submitted in the format provided for in Annex B.

Criteria

The following three elements are necessary for successful fluoridation:

a. The water;
b. the community; and
c. specific resources.

Difficulties with any one of these elements can make the implementation of a fluoridation programme impossible for a period of time. Taking these three elements into consideration, the Director-General should specify the period for which exemption from the implementation of fluoridation is granted.

These elements are examined separately to determine the criteria that would make fluoridation either impossible or unnecessary, which would then mean that alternative methods of fluoride supplementation should be considered.

a. The water

- If the raw water available to a supplier already contains the optimum concentration of fluoride as defined in the regulations, or more, then fluoridation is unnecessary and should not be undertaken.
- If the raw water available to a supplier is available intermittently only, then reliable fluoridation can be problematic and should not be undertaken.
- If it is demonstrated that fluoridation of a water supply will have unacceptable impacts on those water resources, which receive effluent or diffuse discharges originating from the fluoridated supplies, exemption or termination should be approved.

b. The community

- A community may have limited experience of dental decay and therefore, so long as this remains the case, there is no need for fluoridation.

c. Specific resources

- Staff - Properly trained staff is vital to the success of fluoridation. Until such staff is appointed, temporary exemption from the implementation of fluoridation should be granted.
- Equipment - Fluoridation requires accurate and well-maintained equipment. Until such equipment is available, temporary exemption from the implementation of fluoridation should be granted.
- Chemicals - Specific chemicals in appropriate quantities are needed on a continuing basis for successful fluoridation. Until such chemicals are available, temporary exemption from the implementation of fluoridation should be granted.
- Finance -

(1) The financing of water fluoridation plant would be

done in accordance with the provisions of regulation 14.

(2). Until such finances are available, temporary exemption from the implementation of fluoridation would be granted.

ANNEX: E

MONTHLY RECORD KEEPING AND REPORTING

This form has to be completed on the last day of the month.

1. Volume of water fluoridated since previous recording ………….kl

2. Mass of fluoride added since previous recording ………….kg

3. Average fluoride dosage during reporting period ………….mgF/l

4. Average fluoride concentration in raw water (from measurements taken during reporting period) …………mgF/l

5. Average fluoride concentration in fluoridated water (from measurements taken during each shift) ………….mgF/l

6. Incidents: F between 2mg/l and 10mg/l [Regulation 11(2)]

   No. of incidents ………..
   Date(s) of incidents …………………

7. Incidents: F more than 10mg/l [Regulation 11(3)]

   No. of incidents ……….
   Date(s) of incidents ………………….

8. Continuity of fluoridation [Regulation 9(3) (c)]

   Percentage of time fluoridated ……..%

9. Reporting of any breakdowns, equipment failure, repairs or maintenance of equipment:

10. Reporting on any corrective measures taken to prevent non-compliance to ensure an optimum fluoride concentration:

11. Reporting on the preventative measures for future incidents of over-dosage or accidental over-fluoridation or major spill, once occurred:

COMPLETED BY:

SIGNED
DATE:

ANNEX: F

Finances

Capital costs

Buildings:	R………………..
Equipment:	R………………..
Other (specify): ………………..	R………………..
………………………………..	R………………...
………………………………..	R………………...
Total:	R______________

Operating costs

Income (specify): ………………	R…………………
…………………………………	R…………………
…………………………………	R…………………
…………………………………	R…………………
…………………………………	R…………………
Total:	R_______________

Expenditure (specify)…………..	R…………………
…………………………………	R…………………
…………………………………	R…………………
…………………………………	R…………………
…………………………………	R…………………
Total:	R________________
Shortfall/surplus	R________________

ANNEX G

ACTIONS FOR FLUORIDE OVERFEED

If the fluoride content (mg/l) is	**Then, perform the following actions:**
0.5 above optimum to 2.0	• Leave the fluoridation system on • Determine what has malfunctioned and repair it
Above 2.0 to 4.0	• Leave the fluoridation system on • Determine what has malfunctioned and repair it • Notify your supervisor
Above 4.0 to 10.0	• Determine what has malfunctioned immediately try to repair it • If the problem is not found and corrected quickly, turn off the fluoridation system • Notify your supervisor • Take water samples at several points in the distribution system and test the fluoride content (Save the part of the water samples not used) • Determine what has malfunctioned and repair it. Then, with supervisor's permission restart the fluoridation system.
Above 10.0 .	• Turn off the fluoridation system immediately • Notify your supervisor • Take water samples at several points in the distribution system and test the fluoride content. Save part of the sample for the lab to test. • Determine what has malfunctioned and repair it. Then, with supervisor's permission restart the fluoridation system.

FLUORIDE SAMPLING COLLECTION

The reliability of an analysis of the concentration of fluoride in a water sample depends upon the sampling method. The water samples must be representative of the water to be examined. Meaning that water samples must be collected at a point where the fluoride has become completely mixed with the entire volume of water entering the distribution system. Otherwise, the results will have no significance.

If a sample is collected from a tap, the water should first be run long enough to empty the service pipe and thus obtain a sample representative of the water in the main.

It is not possible to specify the sampling points in general that would be applicable to a particular water supply. The important point is that the samples for analysis show the fluoride content of the water delivered to the consumer. A possible sampling point could be from a water tap in the home of the plant operator, if the operator's house is served by the distribution system being tested.

Water samples should be taken and tested for fluoride every 8 hours by the plant operator.

The department may require a certain number of water samples to be submitted each month for fluoride analysis. These are called check samples. (At least one check sample should be taken per month). When collecting such water samples, it is good practice to collect two samples at the same time, one for submission to the national laboratory and another one for analysis by the plant operator. Comparison of these two results can verify the accuracy, or point out any discrepancy, in the results of the tests.

ANNEX H

Sampling

A.1 Suggested minimum frequency of sampling

Table A.1 – Suggested minimum frequency of sampling (water works final sample)

1	2
Population served	Frequency
More than 100 000	10 every month per 100 000 of population served
25 0001 – 100 000	10 every month
10 0001 – 25 000	3 every month
2 500 – 10 000	2 every month
Less than 2 500	1 every month
During the rainy season, sampling should be carried out more frequently	

A.2 Frequency of sampling (distribution networks)

Frequency of sampling in distribution networks should be dictated by the size and nature of the distribution network, parameter variability, as well as by the incidence pattern of consumer complaints. It is a minimum requirement that at least some regular sampling within the distribution networks be done.

Note: It is not practicable to prescribe a standard frequency of sampling without taking into consideration all the variables associated with a water supply, which include effects on the water from climatic, human and industrial activities, the volume of water processed, the population served, the area of reticulation and the capabilities of the analytical facility (both in terms of capacity and in terms of analytical performance). For this reason, a sampling programme should take into consideration appropriate international recommendations.

A.3 Points of sample collection

Ongoing monitoring should include the monitoring of drinking water quality from source, through treatment and distribution, to the end-user. Monitoring points within the network need to include post-water treatment works, reservoirs, major delivery points, network dead-ends, high occupancy buildings, hospitals and schools, and areas perceived to be problematic.

Note 1: The preliminary water quality investigation should ideally be conducted during peak demand or during periods of the poorest raw water quality to determine site-specific water quality risks.

Note 2: An annual review of the water quality should be undertaken and recommendations made to modify the monitoring programme. This is to ensure that the monitoring programme remains dynamic and relevant to the changing process, environmental, and demand conditions.