WRC REPORT NO. K5/1026

CONSOLIDATION AND TRANSFER OF LIMESTONE MEDIATED STABILISATION TECHNOLOGY FOR SMALL TO MEDIUM SCALE USERS

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REPORT TO THE WATER RESEARCH COMMISSION

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CONSOLIDATION AND TRANSFER OF LIMESTONE MEDIATED STABILISATION TECHNOLOGY FOR SMALL TO MEDIUM SCALE USERS

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FINAL REPORT

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EXECUTIVE SUMMARY

BACKGROUND AND MOTIVATION

A significant proportion of the surface waters of Southern Africa characteristically have low total alkalinity (0-25 mg/L as $CaCO_3$), low calcium (0-25 mg/L as $CaCO_3$) and low pH (4.0 to 7.0). Furthermore, virtually all of the groundwaters of the southern and eastern fringes of South Africa (up to approximately 200 km inland) have similar characteristics. In addition, surface waters of the southern region have variable colour due to the presence of complex Natural Organic Matter (NOM) constituents; the presence of which can further lower pH to as low as 4.0.

These soft, acidic waters attack distribution systems through being aggressive (to cement concrete) and corrosive (to metals). Such attack can have significant implications relating to lost water, distribution network rehabilitation requirements and undesirable change in water quality; accordingly, in larger, formal water supply systems, water conditioning processes are used to stabilise the water thereby ameliorating aggressive and corrosive attack.

Conventionally, stabilisation of soft, acidic waters is achieved via the addition of lime and carbon dioxide. However, for smallholdings, farms, country hotels and smaller municipalities, stabilisation via lime dosing (with or without carbon dioxide), is problematic, requiring skilled, well-trained staff and expensive equipment. Furthermore, stabilisation with lime is expensive; often comprising about half of the overall chemical cost of treating brown waters. For small volume water users, stabilisation is not readily implementable and the costs of corrosion can be significant. However, an alternative means of stabilising soft, acidic waters by contact with limestone ($CaCO_3$) is considered in this report.

Limestone based stabilisation has been shown to be an attractive means of mitigating against both aggression and corrosion, principally because of simplicity of operation, and significantly reduced chemical costs. This project aims to assist in the increased use of limestone mediated stabilisation by providing clarification on constraints and providing implementation guidelines.

These guidelines are based on data and observations from operational systems or field/laboratory based investigations.

AIMS AND OBJECTIVES

(i) Groundwater Stabilisation/Iron Removal Systems

Completion of Research, Development and Implementation (RDI) relating to the use of small scale stabilisation/iron removal systems for groundwater; and in particular, determination of recommended maximum levels of dissolved iron and manganese in the raw feed, and scaling up of the system from 50 m^3/day to the order of 1 ML/day.

(ii) Surface Water Stabilisation Systems

Completion and consolidation of RDI for medium scale (2-40 ML/d) limestone stabilisation systems for surface water; and in particular, to determine the recommended upper colour limit in the raw water feed to the units, and to consolidate existing data on these units.

(iii) Assess Degree of Protection Afforded by Partial Stabilisation

Assessment of the relative degree of protection that limestone mediated stabilisation affords to common conduit materials, namely iron, copper and cement, and to assess the respective costs of protection against the degree of protection afforded.

(iv) Technology Transfer

The effective transfer of small to medium scale limestone mediated treatment technologies via practical design guidelines for both small and medium scale limestone mediated systems.

RESEARCH PROGRAMME

The research programme was designed to address the objectives, thereby necessitating a combination of field based test procedures, and collection of data from existing limestone contactors and municipal distribution networks. Data collection, documentation and interpretation was implemented.

(i) Data was collected from various groundwater stabilisation systems utilising limestone. Results were obtained from Umgeni Water from their initiatives to use a Spraystab system. A workshop was held to determine optimum ways for upgrading capacity of groundwater treatment systems.

(ii) Small field units were installed and monitored at three locations with a range of colour (10 mg/L Pt to 450 mg/L Pt). A large number of operational limestone contactors in the Western Cape were visited to consolidate existing data on these units.

(iii) Corrosion data was collected from two municipal networks, and the protection afforded by partial corrosion assessed. Aggression trials were run by exposing concrete samples to waters with a range of stabilisation characteristics.

(iv) A guideline entitled "A Guideline for the Stabilisation of Waters with Limestone" was developed.

SUMMARY OF RESULTS AND CONCLUSIONS

With this project, limestone mediated stabilisation technology was consolidated, using information gathered through experience of CSIR and various water suppliers that implemented the technology. A number of operational limestone contactor units that treat surface waters have been visited. In all cases the limestone contactors improved the aggressive/corrosive qualities of their feed waters, and in most cases, significantly so. Information gathered from these visits was assessed and used to set out guidelines for the design and operation of limestone contactors. In particular, where shortcomings in the design or operation of a system led to inefficient or sub-optimal performance of the process, these shortcomings were documented, to prevent these mistakes from being repeated. Final design and operational details will be captured in a guidelines document, which will be used to transfer limestone stabilisation technology to potential users.

Particular issues relating to the implementation and design of limestone contactor systems for surface waters, which were identified at the planning stage of the project, were:

(i) the upper limit for colour in the feed water of surface water limestone contactors, and

(ii) the effect of limestone mediated, partial, stabilisation on the reduction of aggressive attack of cement materials and corrosion of metals in reticulation networks.

Conclusions re the above two issues are given below.

Upper limit for colour in the feed water:

The following conclusions were reached w.r.t. limestone stabilisation of coloured surface waters:

- Limestone contactors appear to be capable of partially stabilising acidic coloured waters, with colour ranging from 50 to 450 mg/L Pt, quite readily, if the limestone bed is regularly flushed to remove fines and other loose deposits. It should, however, be noted that partial stabilisation of highly coloured waters should be practically limited to smaller limestone contactors. This is a result of the fact that the limestone bed will eventually become "blocked". At this stage, flushing alone will not clean the bed, and the limestone would need to be replaced. Removal and replacement of limestone for a large contactor would be costly and time consuming. In smaller limestone contact systems, replacement of limestone would not be as problematic.

- Since such effective flushing is not achievable on larger municipal units that treat volumes of 1 ML/day or more, the maximum limit for colour in the feed water to the larger municipal units is set at 30 mg/L. This limit is based on experience on existing municipal units.

- For smaller contact units in which the whole limestone bed can be replaced with relative ease, a higher colour level can be tolerated, bearing in mind that with higher colour levels, the flushing requirement increases.

- Regular flushing (or possibly backwashing in the case of small contactor units), according to a fixed routine, is essential to maintain performance. The cleaning frequency depends on the colour and iron load imposed on the reactor. The insoluble organic and turbidity load will also affect the performance, if regular flushing is not carried out.

The effect of partial stabilisation on cement aggression

Laboratory aggression tests were initiated, to test the effect of limestone partial stabilisation on the rate of aggressive attack on cast cement concrete samples. The experiment was repeated with fully stabilised water (i.e. with slightly positive calcium carbonate precipitation potential, achieved by means of chemical dosage), so that the effect of partial stabilisation can be compared to that of full stabilisation.

Wrt aggression mitigation, it has been shown that:

the samples at a significantly greater rate than both the partially stabilised water and fully stabilised water.

- Comparison of the partially stabilised water with the fully stabilised water indicates that:
  - In both cases, greater dissolution of alkali's existed. The total alkalinity curve includes the dissolution of all alkali's (i.e. calcium and other alkali's), whereas the calcium curve only records dissolution of calcium mineral. Therefore, total alkalinity is the more important measure of the rate of aggressive attack.
  - At the end of the experiment, calcium mineral dissolution had slowed down significantly for the fully stabilised water and was slowing down for the partially stabilised water.
  - Whilst the trendlines of "total attack" (leaching of calcium and other alkali's from the cement matrix - indicated by the total alkalinity curves) for both the partially stabilised and fully stabilised waters indicate that a decreasing rate of attack was occurring, the curves had not yet settled down at the end of the experiment. Results, however, clearly indicate that the rate of attack for both the partially stabilised and fully stabilised waters is very similar (constant difference - delta total alkalinity) and that the curves are tending towards settling. This result suggests that the relative degree of protection against aggressive attack offered by effective limestone mediated partial stabilisation is similar to a fully stabilised water.

The effect of partial stabilisation on corrosion

Data was collected from the Bredasdorp and Stellenbosch reticulation networks, to determine the effect that limestone mediated, partial stabilisation has on iron and copper corrosion in municipal water distribution networks.

It has been shown that partial stabilisation, using limestone contactors, can significantly reduce corrosive

- The unstabilised water is very aggressive towards cement concrete, leaching out calcium and total alkalinity from

attack of iron and copper by soft, acidic waters. Data collected from the Bredasdorp network showed that maintaining a calcium carbonate dissolution potential of below 6.0 mg/L and pH above 7.5 throughout the distribution network effectively eliminated incidences of high rates of iron corrosion. Similarly, maintaining the pH above 7.1 throughout the network eliminated incidences of high rates of copper corrosion.

Data collected from the Stellenbosch network showed copper corrosion was influenced by variable efficiency of partial stabilisation/pH adjustment, and that at pH's above 7.3, copper corrosion was terminated.

It has been shown that partial stabilisation with limestone can achieve the stabilisation levels described above (a calcium carbonate dissolution potential below 6.0 mg/L and pH above 7.5), hence, limestone contact is a viable and attractive means of corrosion prevention for the many small holdings, farms, country hotels and rural villages receiving soft, acidic waters.

Groundwater considerations

Special consideration is needed for the stabilisation of groundwaters. The Spraystab unit, developed during the previous WRC project, has been shown to be effective for iron removal for small scale users (1 to 3 m3/h), where iron is less than 3 mg/ℓ.

Importantly, the Spraystab system is able to achieve iron removal with a total retention time of about fifteen minutes; i.e. considerably less than the two to three hours of a conventional system.

During this project, groundwater treatment and/or iron removal sites were visited. Information gathered from these visits was assessed and used to set out guidelines for the design and operation of Spraystab groundwater treatment systems.

Two particular issues relating to the implementation and design of the Spraystab system that were addressed in this project are discussed below.

Treatment capacity of the Spraystab system

It was found that the present Spraystab system can be up-sized to treat approximately 5 m3/h (if the feed's iron

concentration does not exceed 1 mg/L). Dimensions are given in the report for the upgraded design.

Upper limits for iron and manganese removal with the Spraystab type system

The upper limit for iron in a water to be treated with the Spraystab system is set at 4 mg/L. However, the iron load affects the maximum capacity to which the system can be upgraded. If iron in the feed water exceeds 1 mg/L, the maximum capacity to which the Spraystab can be up-sized is 2.5 m^3/h.

Scaling up of the process to handle larger flow rates than mentioned above is feasible, but not in the single unit configuration as was developed for the smaller units described above. Larger systems would use separate aeration units, incorporating settling tanks in the case of water containing iron, followed by upflow reactor vessels, limestone contact units and multi-media filters or membrane filters. These larger systems have to be designed to suit the requirements of the specific application.

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

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Mr IR Morrison; water chemistry consultant
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Mr DP Theron; Overberg Water
Mr J Weaver; Environmentek, CSIR
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Mr CD Swartz; Chris Swartz Engineering
Mr P Thompson; Umgeni Water
Mr OCE Hempel; Water Research Commission (Committee Secretary)
Mrs CM Smit; Water Research Commission (Secretary)

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CHAPTER 1

INTRODUCTION

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1.1 INTRODUCTION

Where snow melt and mountain catchment waters are found, and where the underlying geology is lacking calcitic and dolomitic deposits, calcium and carbonate deficient waters with low pH occur. Typically these waters have low conductivity (5-50 mS/m), low total alkalinity (0-20 mg/ℓ as $CaCO_3$), low calcium (0-20 mg/ℓ as $CaCO_3$) and low pH (4.0- 7.0). Approximately forty percent of the surface waters of South Africa, and all the surface waters of Lesotho, characteristically have low calcium, total alkalinity and carbonate species concentration (*see Figure 1.1*). In addition, virtually all of the groundwaters of the southern and eastern fringes of South Africa (up to approximately 200 km inland) have similar characteristics. Typically ground and surface waters have low total alkalinity (0-25 mg/ℓ as $CaCO_3$), low calcium (0-25 mg/ℓ as $CaCO_3$) and low pH. Surface waters rarely have pH greater than 6.5, whilst groundwaters brought to the surface have pH levels ranging between 4.0 and 6.0.

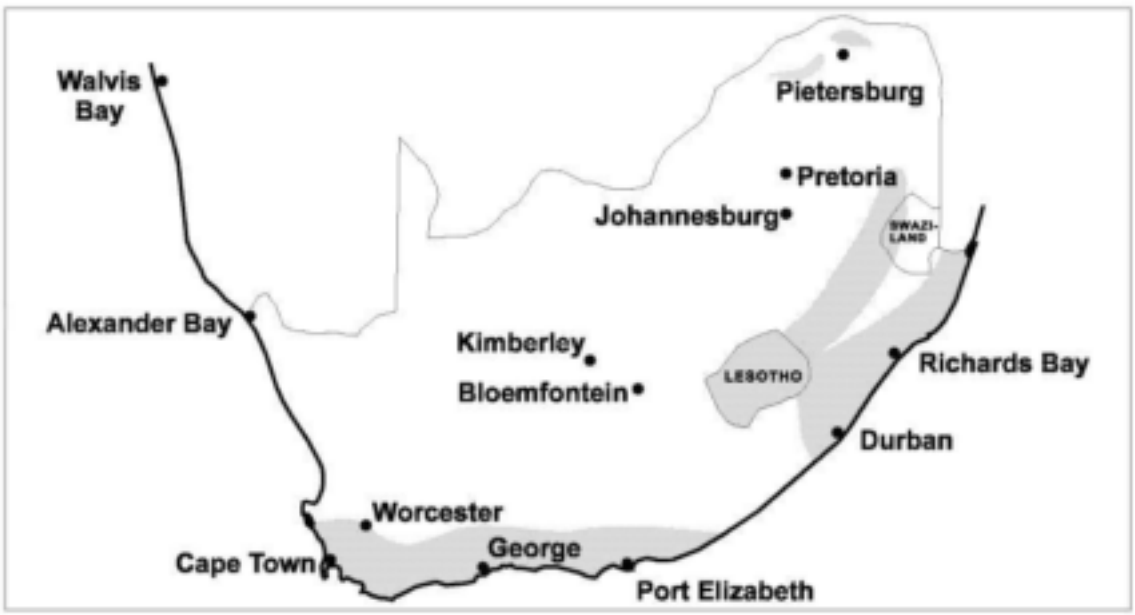

Figure 1.1 Approximate distribution of soft, acidic surface waters in South Africa.

Surface waters of the southern coastal region have variable colour due to the presence of complex Natural Organic Matter (NOM) constituents; mainly humic and fulvic acids. Furthermore, conventional water purification, using floc agents such as ferric chloride, ferric sulphate and aluminium sulphate, further depresses pH and total alkalinity prior to release of the purified water into the distribution network. These characteristics result in the water being aggressive (to cement concrete) and corrosive (to metals), attacking pipes, conduits and reservoirs.

For the many large and smaller towns utilizing soft, acidic waters for domestic supply, aggressive and corrosive attack can have significant financial consequences. Brief examples indicate the severity of typical related problems.

Lost water

In many smaller municipalities water lost from pipe bursts and leaks is unquantified, yet recognized as being higher than acceptable. It is not unusual for lost water to be as high as 50% of treated water, and the associated cost can be substantial. For example: in the Durban townships of Kwamashu, Umlazi and Ntuzuma, total water losses from service reservoirs and the reticulation network was "found to be around 50% of the total bulk volume of water purchased from Umgeni Water" prior to rehabilitation. The cost of lost water amounted to about twelve million Rand in 1992 (1).

Repairs

The cost of reservoir and pipe rehabilitation can be significant for water supply authorities. For example: in Stellenbosch, prior to the installation of stabilization units, an average of 30 pipe bursts occurred per month at a cost of approximately R5000 per pipe burst (2), and in Durban, Umgeni Water had to carry out expensive repairs to the Durban Heights Reservoir in 1990, to overcome a leak of 300 m^3/day (3). At consumer level, corrosive attack can necessitate expensive replacement of pipes and geysers. For example: corrosive attack of internal plumbing in a six year old five star hotel in the Western Cape, necessitated close to R 1 million of repair (4).

Potability

Corrosive attack of metal conduits and valves can result in a decrease in water quality as a result of raised levels of dissolved metal corrosion products, often in excess of drinking water standards. For example: the occurrence of dissolved iron of 23 mg/L and dissolved copper of 6 mg/L in the potable water of a three star SW-Cape country hotel (5). These characteristics mean that unless the water is conditioned, attack of pipes, conduits and reservoirs will occur.

In addition, groundwaters of these regions frequently contain problematic levels of naturally occurring dissolved iron (typically between 0.5 and 5.0 mg/L), and to a lesser extent occurrence of manganese (0.1 to 1.0 mg/L). The presence of even low levels of these dissolved metals cause *inter alia* poor taste, poor appearance and the staining of laundry and walls.

Treatment technologies and know-how to address these water quality problems are readily available for larger water supply systems and areas close to technical support centres. However, treatment technologies and know-how for small scale and/or remote rural application are not as readily available. Accordingly, WRC funded a project tasked with developing aspects of the use of limestone for treatment of soft, acidic waters. The project entitled "Stabilisation of Soft, Acidic Waters with Limestone" was a introductory investigation into the use of limestone mediated water treatment of soft, acidic waters in South Africa and included:

- identification of suitable limestone sources,
- kinetic modelling of limestone dissolution,
- Research, Development and Implementation (RDI) of small user fixed bed systems (50 m^3/day) and fluidised bed process for larger users,
- an evaluation of influencing water quality parameters (such as iron and colour), and
- a cost benefit analysis of limestone mediated stabilisation.

The findings thereof are captured in the WRC report No 613/1/98 entitled *Stabilisation of Soft, Acidic Waters with Limestone* (6). Considering the useful and positive progress made during the aforementioned WRC project, and also the independent progress by CSIR wrt development and installation of municipal limestone contactors, the then existing WRC Steering Committee and the Project Team made recommendations that an additional follow-up project be supported by WRC. The proposal was accepted, and forms the basis for the objectives of this study.

1.2 PROJECT OBJECTIVES

This project aims to assist in the increased use of limestone mediated stabilisation by providing clarification on constraints and providing implementation guidelines. These guidelines are based on data and observations from operational systems or field/laboratory based investigations. To achieve these objectives the project would take into account the findings of WRC report entitled *Stabilisation of Soft, Acidic Waters with Limestone* (6), and implement the following:

(i) Groundwater Stabilisation/Iron Removal Systems

Carry out further RDI relating to the use of small scale stabilisation/iron removal systems for groundwater; and in particular, determination of recommended maximum levels of dissolved iron and manganese in the raw feed, and scaling up of the system from 50 m^3/day to the order of 1 ML/day (if possible).

(ii) Surface Water Stabilisation Systems

Gather design and operation information relating to medium scale (2 - 40 ML/day) limestone stabilisation systems for surface water. Carry out field trials to determine the recommended upper colour limit in the raw water feed to small scale surface water stabilisation units, and to consolidate existing data on these units.

(iii) Assess Degree Of Protection Afforded By Partial Stabilisation

Assessment of the relative degree of protection that limestone mediated stabilisation affords to common conduit materials, namely iron, copper and cement. This would be achieved by both collecting corrosion data from distribution networks, and carrying out laboratory based aggression trials.

(iv) Technology Transfer

The effective transfer of small to medium scale limestone mediated treatment technologies via practical design guidelines for both small and medium scale limestone mediated systems.

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CHAPTER 2

BACKGROUND

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This chapter provides some relevant background considerations regarding to the stabilisation of soft, acidic waters. As the purpose of this project is to consolidate research and development relating to limestone mediated stabilisation, rather than detailed theoretical consideration only that which is regarded as basic to limestone mediated stabilisation is provided.

2.1 CARBONATE SYSTEM

In terrestrial waters, the carbonate system is the dominating weak acid-base system to the extent that other systems can be neglected. The carbonate system in water is comprised of the species molecularly dissolved carbon dioxide, CO_{2aq}, carbonic acid, H_2CO_3, and the ionic species bicarbonate HCO_3^-, and carbonate, CO_3^{2-}, and the water species, H^+ and OH^-. The relative concentrations of the dissolved species are governed by chemical equilibrium, and it is the interaction between these species that controls the pH of natural waters. For stabilisation of soft, acidic waters consideration needs to be given to inter-phase equilibrium, i.e. water brought into contact with a solid phase (calcium carbonate) or a gaseous phase (carbon dioxide in the air).

For soft, acidic waters, the solubility of the mineral $CaCO_3$ is of importance. It is necessary to obtain both a qualitative description of saturation (i.e. whether the water is saturated, undersaturated or supersaturated with respect to $CaCO_3$), and a quantitative description of the saturation state (i.e. the mass of $CaCO_3$ that will dissolve into or precipitate from the water). Use of non-quantitative methods such as the *Langelier Saturation Index* and the *Aggressiveness Index* should be actively discouraged, as their values are often misconstrued as being of quantitative significance. It is recommended that the Calcium Carbonate Precipitation Potential (CCPP) type approach is used.

The CCPP defines the mass of $CaCO_3$ to be precipitated from a water to attain saturation with respect to $CaCO_3$. For example, a water with a CCPP of 35 mg/L as $CaCO_3$ will precipitate 35 mg/L $CaCO_3$, to reach chemical equilibrium. In doing so, the pH, total alkalinity and calcium levels of the water will decrease, whilst the CCPP will decrease eventually to zero. Conversely, a water with a Calcium Carbonate Dissolution Potential (CCDP) of 10 mg/L as $CaCO_3$ will dissolve 10 mg/L $CaCO_3$ to reach chemical equilibrium. These parameters, CCPP or CCDP, both give a *quantitative* and *qualitative* description of the aggressiveness of a water. Determination of CCPP/CCDP is most easily determined using the computer software, Stasoft4 (1).

For soft, acidic groundwaters consideration of the aqueous-gaseous equilibrium is of importance. Soft, acidic groundwaters usually have very low pH's resulting from very high *in situ* dissolved carbon dioxide content. When pumped to surface and exposed to the air, the difference in partial pressure between air and water creates a driving force for CO_2 expulsion. Whereas equilibrium between species in the aqueous phase is virtually instantaneous, when two or more phases are present (aqueous, solid and gas), the rate to equilibrium is usually relatively slow. When considering stabilisation of a soft groundwater it is critical to consider the effect of this unstable excess CO_2. Determination as to whether a water is at aqueous-gaseous equilibrium, the equilibrium state the water will attain if allowed to reach equilibrium, and the amount of to CO_2 expelled to reach such a state is most easily determined using the computer software, Stasoft4 (1).

2.2 SOFT WATER AGGRESSION AND MITIGATION

In most South African municipal water distribution systems, approximately 90% of the pipes are either composed of a cement-type material, or are cement-lined iron pipes. The remainder of the pipes are metal or UPVC type pipes. This arises for two reasons. Firstly, cement-type pipes are cheaper than metal-type, and secondly, cement material does not undergo redox reactions in an aqueous environment and is therefore not subject to corrosion. However, concrete and cement-lined structures containing or transporting water may be vulnerable to attack as a result of the chemical characteristics of the water. Soft, acidic waters attack cementitious material by leaching free lime, calcium aluminates and silicates out of the cement matrix. Where the chemical characteristics of the water are such that it is undersaturated with respect to calcium carbonate, progressive leaching of calcium minerals will occur, and may result in the eventual failure of the structure. Such attack is referred to as aggressive attack and the water is referred to as aggressive water.

In order to prevent aggressive attack of distribution networks, it is important to alter the chemical characteristics of the water so that it is saturated with respect to $CaCO_3$ prior to distribution in the reticulation network. Under such conditions, initially the dissolution process continues with the more soluble free lime being leached from the outer surface of the cement paste. Dissolution of free lime results in pH increase, and saturation with respect to $CaCO_3$ at the cement surface. Concomitant precipitation of $CaCO_3$ takes place, sealing off the uncarbonated cement surface from the bulk water body, and thereby preventing further dissolution. To guard against the development of undersaturated conditions resulting from carbon dioxide generation by biological activity, a slight degree of supersaturation is desirable.

With regards to mitigation of aggressive attack by soft, acidic waters a CCPP of 1 to 2 mg/L (as $CaCO_3$) is recommended (2).

2.3 SOFT WATER CORROSION

When water is conveyed, stored or heated, it will react with metal components in the water distribution system and with storage tanks, geysers and other plumbing components. In Southern Africa the most commonly utilised metal components are:

- galvanised steel, epoxy lined steel and copper for pipes,
- glass lined or copper domestic hot water cylinders,
- galvanised steel storage tanks, and
- brass or galvanised steel fittings.

Galvanised steel components are mostly confined to the inland hard water areas, whereas copper is commonly used in soft water areas, mostly along the coast. Corrosive attack of metals principally results from oxidation and reduction reactions at sites on the metal-water interface. Depending on the characteristics of the water and the metal, the reactions may give rise to continuous dissolution of the metal into the water (corrosion), or precipitation of stable minerals onto the metal surface, thereby reducing the areas of active electro-chemical sites and the rates of reaction, even eventually stopping the corrosion completely (passivation).

Whilst it is beyond the scope of this chapter to give a detailed account, the following brief background on factors influencing the rate of corrosion will assist in considering corrosion control.

2.3.1 Water quality factors controlling corrosion and passivation of metals in soft, acidic water systems

The tendency for metal corrosion or passivation will depend on both the metal under consideration and the characteristics of the water the metal is in contact with. The corrosion of metals is principally an electrochemical process and, because of this, dissolved substances present in the water influence corrosion. Any constituent that activates or impedes either of the reactions, whether anodic or cathodic, could have a controlling effect on the overall process. Despite the extreme complexity of corrosion processes in water, the water quality variables discussed below have been shown to influence corrosion of commonly used metals in soft, acidic water systems (for further detail see references 1,2,3 and 4).

Dissolved oxygen. Dissolved oxygen in the water is an important constituent in a water system - its significance lies in the fact that it is the most common cathodic stimulant present in natural waters. The concentration of oxygen in water is about 8 mg/L at ambient temperatures and 4 mg/L at 70 °C respectively.

Chlorine. Chlorine, resulting from excessive chlorination of the water, may also act as a cathodic stimulant.

Aggressive anions. Aggressive anions present in the water, for example chlorides and sulphates, also increase the corrosion rate. These ions lower the electrical resistivity of the corrosion cell and in addition play a significant role in the penetration and breakdown of any protective film that might have formed on the metal's surface. Furthermore, the corrosion rate is linked to the ratio

(chloride + sulphate)/total alkalinity; and where this "Corrosivity Ratio" ratio is less than 0.2 (all species concentration expressed as equivalents) the corrosion rate is negligible.

Buffer capacity. If the pH next to the cathode differs significantly from that over the anode, it is less likely that passivation will occur. The magnitude in difference of pH between the cathode and anode is affected significantly by the buffer capacity of the water. If the buffer capacity is high, the relative difference will be low and vice versa. The buffer capacity of a water is defined as the moles/L of strong base required to affect a unit change in pH, i.e. the slope of the strong acid-base titration curve. The buffer capacity in water supplies is most easily reflected in total alkalinity and pH of the water. A low total alkalinity indicates a low buffer capacity.

pH. The pH of a water is a highly important factor in corrosion, but its effect depends on the metal involved. Copper corrosion, for example, is very pH dependent in soft, low mineralised waters.

Calcium and carbonate species. Waters are termed as hard or soft where the so-called hardness is caused by the presence of dissolved magnesium and calcium salts. Waters containing hardness of less than 50 mg/L (reported as $CaCO_3$) are termed soft waters, whilst if hardness exceeds 250 mg/L (reported as $CaCO_3$) the waters are considered hard. Very hard waters (in the absence of high levels of chloride and sulphate) are usually not corrosive to metals because, under such conditions, the presence of calcium bicarbonate can lead to the deposition of stable films of calcium carbonate. In most water supplied by municipalities, manipulation of temporary hardness, caused by the presence of calcium and magnesium bicarbonates, to cause the formation of calcium carbonate scale, is of great importance in reducing corrosion. The scale forming tendency of water is governed by a complex relationship between all the carbonic species in the water; *viz* dissolved carbon dioxide, carbonic acid, bicarbonates and carbonates. Temperatures and the total dissolved solids (TDS) also play a role in determining whether or not a water has a scale forming tendency. Various indices, based on the above, have been derived as guidelines to predict the corrosion/scaling tendency of a water. The calcium carbonate dissolution potential (CCDP), or calcium carbonate precipitation potential (CCPP), is one such index which is very useful and widely used.

Microbiological induced corrosion (MIC). Micro-organisms can cause serious corrosion in water systems. Their spores enter water tanks via the air and they are often found in the bottom muds of storage dams or in underground waters brought to the surface by boreholes. The anaerobic sulphate reducing bacteria (SRB) cause serious corrosion within pipes and also attack pipes externally, particularly in clay type soils. Water treatment, for example chlorination, is critical in the control of this problem.

From the above it can be expected that soft, acidic water waters experience high corrosion rates for four main reasons:

- low pH and low concentrations of carbonate prevent the formation of protective scales,
- low buffer capacity stabilises concentration cells and adversely affects scale formation,
- low conductivity tends to localise corrosion cells and increases pitting penetration, and
- low pH increases hydroxide ion gradients and increases the diffusive transport of hydroxide ions.

2.3.2 Corrosion mitigation

Control of corrosion in low pH, low total alkalinity waters may take several forms including chemical addition and selection of materials resistant to corrosion. In brief, corrosion prevention and minimisation approaches include consideration of the following:

Phosphate. Poly- and/or ortho-phosphate addition with pH adjustment to neutral or slightly alkaline pH values has been found to be effective in reducing iron and galvanised pipe corrosion.

Silicate. Addition of silica with pH adjustment has been found to reduce corrosion in copper, steel and galvanised steel; but the effects are not significantly different from those of pH adjustment only.

Materials selection. Lead pipe, lead solder, uncoated steel and galvanised pipe are not suitable for soft, acidic waters. Whilst iron and copper are subject to corrosive attack, water conditioning requirements to reduce corrosion to acceptable levels are reasonably readily achieved.

Protective films and pH adjustment. If protective films can be formed on plumbing materials, they may become protected from corrosion. Most commonly, pH and total alkalinity can be manipulated to cause supersaturation with respect to calcium carbonate and the precipitation of a continuous and protective film of calcium carbonate which negates corrosion. Furthermore, under certain conditions, most metals can form passivating films of oxides and/or carbonates. In soft, acidic waters the solubility of these films is critical in reducing corrosion rates to acceptable levels. In many cases adjustment of pH and total alkalinity, short of calcium carbonate saturation, gives sufficient protection. For example, with copper, pH increase itself has been found to significantly reduce corrosion (see Figure 2.1).

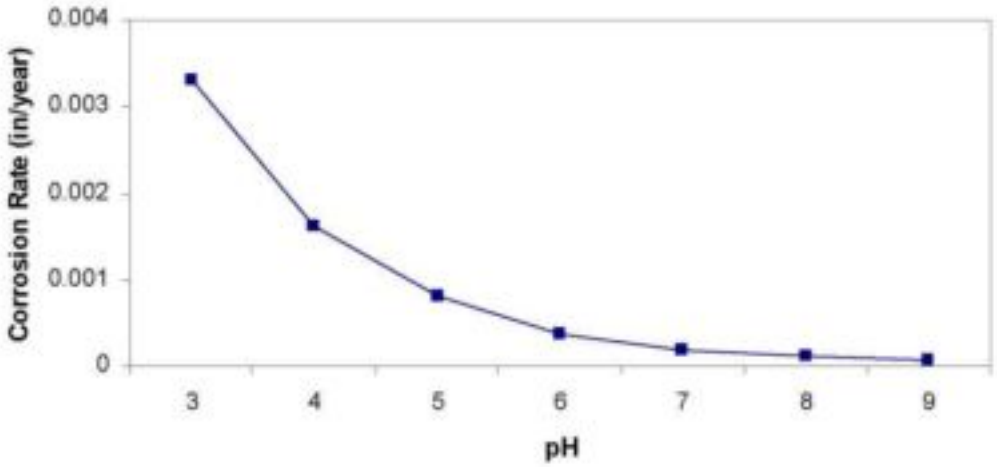

Figure 2.1 Influence of pH on the uniform Corrosion of Copper Tubing.

Iron and steel corrosion can also be significantly reduced by pH and total alkalinity adjustment if the pH is initially very low (see Figure 2.2).

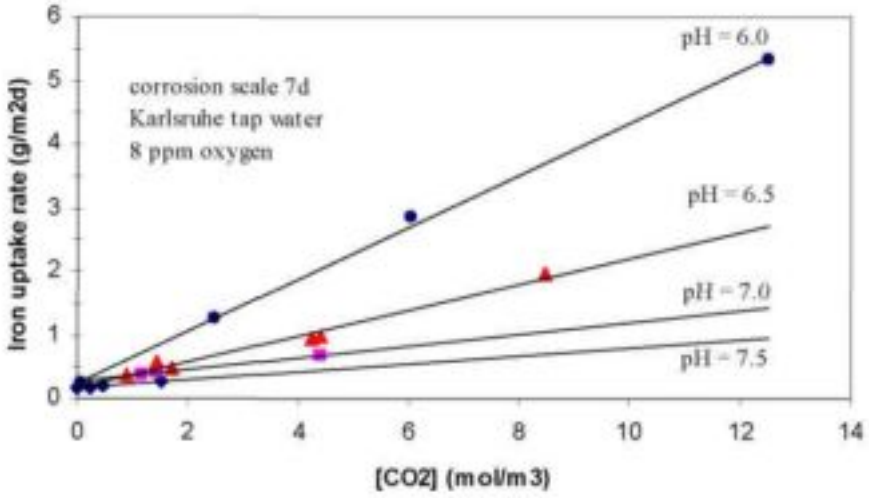

Figure 2.2 Influence of pH and CO2 Concentration of Synthetic Waters on the Iron Uptake Rate in Steel Pipes with Scale.

The predominant corrosion control measure utilised in most parts of the world by water utilities is pH adjustment for calcium carbonate saturation control. This so called "stabilisation" is usually achieved via the addition of lime ($Ca(OH)_2$), to increase calcium (Ca^{2+}) and total alkalinity levels, and the addition of carbon dioxide, (CO_2), to add carbonate species and adjust pH. Most major utilities practice this method of corrosion control because of the relative economy and proven effectiveness in protection of their own piping and equipment.

The principal treatment component of measures to prevent corrosive and/or aggressive attack by Table Mountain Group type soft, acidic waters is the chemical conditioning, or stabilisation, of the water. Water should be treated such that the following corrosion mitigation criteria are satisfied:

With regards to minimising iron corrosion (2):

Guideline 1: The bulk water should be saturated, or slightly supersaturated, with respect to $CaCO_3$.

Guideline 2: Calcium and total alkalinity values should not be less than 50 mg/L (as $CaCO_3$).

Guideline 3: The Corrosivity Ratio (chloride + sulphate)/total alkalinity (where species concentration are expressed on an equivalent scale) must be less than 0.2. Waters should be regarded as potentially corrosive when either the chloride or sulphate levels exceed 50 mg/L.

Guideline 4: Design conduits in reticulation systems to maintain a velocity in excess of 0.2 m/s, preferably > 1 m/s, and avoid dead ends. Where these conditions are not likely to be satisfied, utilise cement type or plastic pipes.

Guideline 5: The dissolved oxygen in the water should be greater than about 4 mg/L (as O_2)

With regards to corrosion of copper and brass (2):

Passivation by the formation of a protective copper oxide layer is generally readily achievable by ensuring pH in the range 7.1 to 8.0, low carbon dioxide and ammonia, and velocity below 1.2 m/s.

2.4 PARTIAL STABILISATION WITH LIMESTONE

Whilst conventional lime and carbon dioxide stabilisation methods are well documented and understood, control of the process requires well trained staff and reliable equipment - both seldom available in the many small towns and communities receiving such waters. At smaller works, it is often the practice that lime is added on its own; thereby creating a poorly buffered product water (no carbonates added) the pH of which will be unstable. (On occasion sodium carbonate, sodium bicarbonate or sodium hydroxide is used; however, this is generally very expensive and is not practically effective with soft water as no calcium is being added.) For the rural small volume user, lime mediated stabilisation is not practically feasible, and the costs of corrosion/aggression are usually significant (3). An alternative approach is partial stabilisation using limestone.

In the limestone contact process the natural driving force (CCDP) of the water is used to take up the necessary carbonate and calcium species by exposing the water to solid limestone ($CaCO_3$). Typically a water with CCDP of 35 mg/L $CaCO_3$ will take up 35 mg/L $CaCO_3$ if sufficient contact time is allowed to reach chemical stability; in doing so pH, total alkalinity and calcium levels of the water naturally increase to desirable levels. Further details relating to limestone mediated stabilisation are available in a previous WRC report (3).

Making use of simple limestone contactors does not provide full stabilisation, but partial stabilisation is effected, and in most cases, anecdotal evidence suggest that this is sufficient to prevent copper corrosion and greatly reduce corrosion of any ferrous material in the water system. Furthermore, stabilisation with limestone has also been shown to have significant advantages over the traditional use of lime and carbon dioxide. These include *inter alia*:

- A significant running cost saving of about 75% relative to lime stabilisation. Limestone is significantly cheaper than suitable quality white lime, approximately SAR 225/t vs. SAR 1200/t (year 2001 prices, Western Cape).
- No carbon dioxide is used.
- pH is controlled naturally at desirable levels as the water approaches chemical equilibrium.
- A well buffered product water.
- The process requires little or no operator skill.

However, shortcomings with regard to limestone mediated stabilisation include lack of sufficient information as to:

- design guidelines and special considerations w.r.t. limestone mediated groundwater stabilisation,
- design guidelines and special considerations w.r.t. surface water systems,
- degree of protection afforded by limestone mediated partial stabilisation.

2.5 IRON AND MANGANESE REMOVAL

Groundwater extracted from aquifers is usually low in suspended solids and bacteriologically safe, making a managed groundwater source usually aesthetically superior to surface water. However, soft acidic groundwaters may contain dissolved iron and manganese at problematic concentrations. For example, significant areas of the southern and eastern fringes of South Africa are underlain by thick sandstone formations of the Table Mountain Group (TMG). The importance of these deposits is that they contain sizeable aquifers of which many are tapped by local towns, villages

and farmers. The TMG groundwaters frequently contain problematic levels of naturally occurring dissolved iron (typically between 0.5 and 5.0 mg/L), and to a lesser extent occurrence of manganese (0.1 to 1.0 mg/L).

Whilst iron concentrations of up to several milligrams per litre can exist without discolouration or turbidity in the water when first brought to the surface, with time the iron will come out of solution giving the water an undesirable reddish-brown colour. Furthermore, the presence of both iron and manganese give water a taste described as metallic, astringent or medicinal. The taste threshold for iron and manganese is approximately 0.3 mg/L and 0.15 mg/L respectively. Iron and manganese may also cause other aesthetic problems such as staining of laundry, walls and plumbing fixtures at levels above 0.2 mg/L and 0.1 mg/L respectively. It is desirable to remove iron and manganese from water to values below 0.1 mg/L and 0.05 mg/L respectively.

2.5.1 Water treatment requirements

Treatment requirements for the removal of both dissolved iron and manganese from water are well understood and documented. All methods will require the oxidation of the relatively soluble Fe (II) and Mn(II) to insoluble Fe(III) and Mn(III, IV). This is followed by conventional coagulation/flocculation, and sedimentation in a settling tank, followed by filtration. Important considerations for the optimisation of iron removal include:

- The rate of oxidation of Fe(II) with oxygen is very pH dependant. In solutions with pH > 5.5 a 100-fold increase in the rate of reaction occurs for a unit increase in pH.
- As shown in Figure 2.3, Fe(II) requires a pH > 7 in order to be oxidised at a reasonably rapid rate.
- Oxidation by aeration is a viable option for iron, and has the additional benefit that concomitant stripping of dissolved carbon dioxide will also occur, thereby raising the pH.
- The oxidation of Fe (II) is catalysed by the reaction product Fe(III). The associated significantly improved efficiency of oxygenation can be capitalised on by contacting the aerated water with Fe(III) in, for example, filter media.
- Ferrous carbonate, such as may be formed when iron rich water is contacted with limestone, is 50-100 times more filterable than the usual Fe (III) form of ferrous hydroxide.
- Soft, acidic waters with low total alkalinity require dosing of an alkali to assist oxidation.

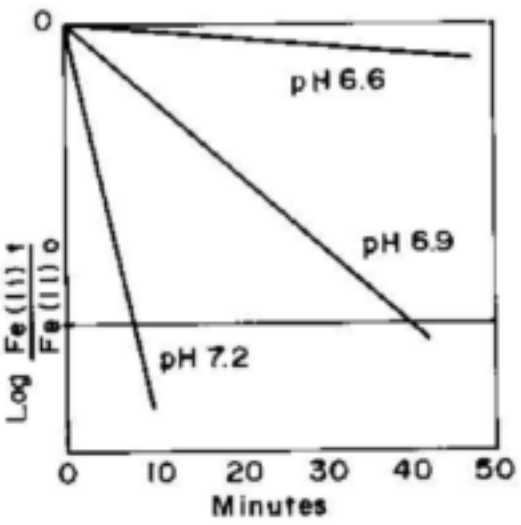

Figure 2.3
Oxidation of iron at various pH values (4)

Important considerations for the optimisation of manganese removal include:

- The chemical behaviour of manganese is similar to that of iron; however, it is more difficult to remove manganese from water than iron.
- As shown in Figure 2.4, the oxidation of Mn(II) to Mn(III) by aeration is a slow process unless the pH is raised above 9.5. Generally, a stronger oxidant than oxygen is required to remove manganese. Under dual precipitation conditions with iron, reasonable oxidation rates occur at a pH of 8.5.
- The presence of a coating of manganese dioxide on sand grains of a filter has an autocatalytic effect and increases the removal efficiency of manganese.
- The presence of dissolved calcium carbonate is beneficial to manganese removal, possibly due to the formation of manganese carbonate; and the rough surface of limestone has been shown to improve flocculation of manganese even though the manganese precipitate does not adhere to the limestone.
- Soft, acidic waters with low total alkalinity require dosing of an alkali to assist oxidation.

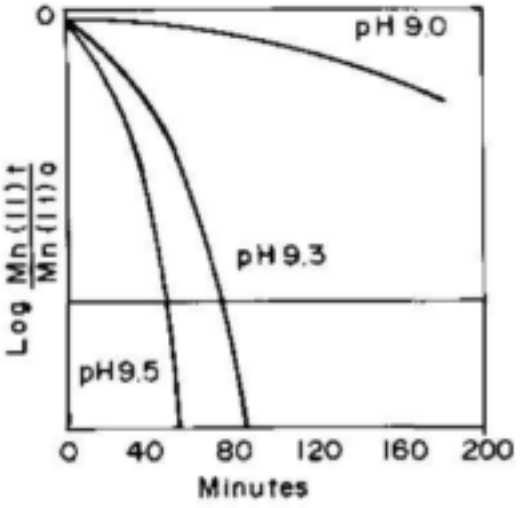

Figure 2.4
Oxidation rate of manganese at various pH values (4)

2.5.2 Conventional iron and manganese removal

Because of the slow reaction kinetics with molecular oxygen, chemical oxidants are often added at the beginning of the water treatment process to oxidise iron and manganese. Common oxidants which may be used are chlorine, potassium permanganate, ozone and chlorine dioxide. With the use of such chemical oxidants, oxidation is quite rapid at pH 7 and higher. Very soft waters with a low total alkalinity and low pH (pH 4 to 6) require pre-dosing with an alkali. Hence, conventionally iron and manganese removal from TMG type soft waters is achieved by dosing of lime (pH and total alkalinity adjustment) followed by chemical oxidant, coagulation, floc formation and settling, followed by filtration. This necessitates a combined retention time of between two and three hours. However, this conventional approach is both impractical (chemical dosing and expert operator input requirements) and too costly (high capital cost and high running costs) for small rural water treatment systems. (For further details of conventional large scale iron and manganese removal, the reader is referred to (4).)

2.5.3 Small scale iron and manganese removal

In rural communities in developing countries, processes requiring dosage of chemicals are to be avoided because of the cost of mechanical plant and chemicals, as well as the lack of technical back-up and frequent failure of poorly maintained water treatment plants. Under these conditions methods using natural processes such as aeration and multi-media filtration should be encouraged. For the use of these simple processes to be effective, maximisation of the optimising factors noted above is crucial; in particular, additional benefit is provided for both removal of iron and manganese by including contact with limestone.

The Spraystab unit (see Chapter 7, Figure 7.1), which was developed during the previous WRC project (3) and is described in more detail in Chapter 7, capitalises on these design considerations and has been shown in the previous study to be effective for iron removal for small scale users (up to 3 m^3/h), where iron is less than 3 mg/L Importantly, the Spraystab system is able to achieve iron

removal with a total retention time of about fifteen minutes; i.e. considerably less than the two to three hours of a conventional system. For rural schemes, these iron/manganese removal systems have significant advantages over conventional processes including:

- Low operator skill and input requirements.
- No risk of oxidant and/or alkali overdosing.
- Significantly reduced capital and operating cost savings.
- pH is controlled naturally at desirable levels.
- No use of industrial type chemicals.
- No use of dosing pumps.

However, shortcomings with regard to limestone mediated groundwater treatment include lack of sufficient information as to:

- design guidelines and special considerations w.r.t. limestone mediated iron an manganese removal,
- size limitation of the present Spraystab system,
- upper limits as to iron and manganese removal with the Spraystab type system.

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CHAPTER 3

CONSOLIDATING FIELD OBSERVATIONS AND DESIGN GUIDELINES FOR SURFACE WATER FIXED BED LIMESTONE CONTACTORS

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3.1 INTRODUCTION

In the early 1990's Cape Water Programme, CSIR, initiated research, development and implementation (RDI) initiatives with regards to limestone-mediated stabilisation. These RDI initiatives were prompted by the magnitude of soft, acidic water aggressive and corrosive attack evident in the Western Cape; and glaring lack of suitable, cost-effective, robust and low maintenance pH adjustment/stabilisation systems for smaller water users (including rural municipalities).

The RDI process included:

- identification and assessment of various limestone deposits
- development of standardised procedure for assessing suitability of limestone for stabilisation purposes
- ensuring commercial supply of water treatment grade limestone pebbles
- kinetic modelling of limestone dissolution
- RDI of small user systems; both groundwater and surface water
- RDI of fluidised bed based processes
- RDI of municipal sized fixed bed process
- mobile test rig for on site experimental determination of reactor sizing and process design requirements for full-scale municipal implementation
- development of process design guidelines for municipal sized fixed bed process
- overseeing the design and installation of full-scale municipal limestone based stabilisation systems
- research and development of city sized "sidestream" stabilisation process
- registration of patents covering fixed bed and fluidised bed limestone mediated stabilisation (South African patent #: 94/5602)
- registration of patents covering the sidestream stabilisation process (South African patent #: 96/3012)

These efforts resulted in *inter alia* the implementation of the first municipal sized limestone contact units in South Africa in 1993 (Montagu) and 1994 (Franschhoek), and thereafter a steady trickle of additional units have been installed. So far installation has been limited to the Western Cape, but pilot plant verification of the suitability of the process has occurred in the Free State province, and for the soft waters of the Kuneni, Kovango and Zambezi rivers in northern Namibia. Table 3.1 provides a list of limestone contactors installed at towns in South Africa.

Generally, the use of limestone contactors has proven very effective in bringing about partial stabilisation in distribution networks where otherwise no stabilisation would have been achieved. Significant improvements in drinking-water quality, and reduction in distribution network aggressive and corrosive attack have been achieved. Furthermore, since the first limestone contactors were designed and installed, considerable cumulative design and operational experience has been gained. On the counter side, instances exist where either poor design or poor operating practices have resulted in problematic or non-effective limestone contactors. Prior to this study, limited information had been gathered with respect to the performance of the limestone contactors installed to date. The objective of this part of the investigation was to collect and consolidate information with regards to the design, and operation and maintenance procedures used by plant operators/technicians.

Table 3.1: Operational limestone contactors in South Africa

Unit Location	*Flow Rate (ML/day)*	*Raw Water Characteristics*
Franschhoek	0.2	Groundwater
Franschhoek WTW	2.5	Filtered, chlorinated, mountain catchment water
Jonkershoek, Stellenbosch	2.5	Chlorinated, mountain catchment water
Napier	2	Blend of untreated surface and groundwater
Montagu	3.8	Fully treated surface/dam water
Montagu Extension	5.6	Fully treated surface/dam water
Porterville	4	Filtered, chlorinated mountain catchment water
Bredasdorp	4.8	Fully treated dam water
Rozendal, Stellenbosch	6	Filtered, chlorinated mountain catchment water
Villiersdorp	3.5	Untreated surface and mountain catchment water
Wellington	10	Filtered, chlorinated mountain catchment water
Idas Valley, Stellenbosch	18	Filtered, chlorinated mountain catchment water

In order for the reader to have an idea of the relative size of a limestone contactor, two examples are presented. The installation at Idas Valley (18 ML/day) consists of 3 identical cylindrical limestone contactors, each of height 5.5 m and diameter 6 m. The installation at Napier (2 ML/day) consists of a single rectangular limestone contactor of dimension 13 m x 3 m x 3.2 m.

3.2 Basic CSIR Process Description

In the basic CSIR limestone contact process, the aggressive raw water is contacted with limestone pebbles in a fixed bed reactor as shown in Figure 3.1.

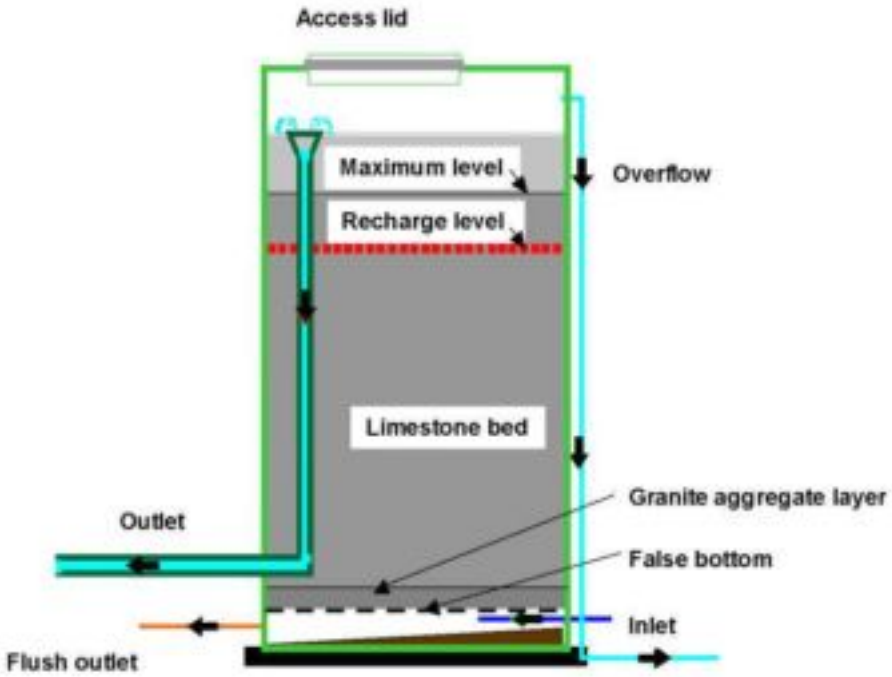

Figure 3.1: Configuration of CSIR-type fixed bed limestone contactor

The raw water is passed through a false bottom (or a slotted pipe distribution manifold), and percolates in an upward flow direction through a fixed limestone bed. The natural $CaCO_3$ dissolution driving force of the water (reflected by the CCDP) is used to take up calcium and carbonate species by exposing the water to graded particles of solid limestone ($CaCO_3$). In this manner, total alkalinity, calcium and pH can all be increased to effect partial stabilisation. Although most of the limestone contactors described in Table 3.1 follow the CSIR basic design

Generalised CSIR design guidelines include:

- Completely enclosed structure, with access hatch on top for limestone addition.
- Cylindrical configuration, with ratio of height to diameter of at least 1:1 (i.e. height always greater than diameter). Tall, small surface area contactors are preferred to shallow, large surface area contactors as they have better flow hydraulics (i.e. less prone to short-circuiting, enable more efficient flushing and all result in no accumulation of fines in "corners"). Use of a cylindrical configuration has been shown to meet these requirements and be financially economical.
- Use of a false bottom feed system (in preference to manifold or other type systems).
- At least two contactor tanks per installation.
- Required limestone contact time to be determined experimentally on a site-specific basis. In general, limestone contact time requirements are between 5 and 15 minutes.

- Loading rate to be no greater than 10 m/hour.
- Two piezometers on each unit to measure pressure loss across the limestone bed; the lower part to be copper pipe and only the minimum necessary top section to be transparent.
- Piping to and from the units should be such that each separate unit must be able to be:
    - Operated independently (i.e. whilst working on unit one, unit two can take full flow).
    - Filled independently, with overflow "high turbidity" waste water discharged to waste.
    - Flushed to waste in both an upflow and downflow mode.
    - Handle excessive flow loading *via* an overflow pipe to waste.
- Heavy-duty high quality valves to be used at all times to ensure durability and low maintenance.
- Only limestone verified as suitable for drinking-water stabilisation by CSIR to be used. This is presently restricted to "Aquastab Pebbles" provided by P&B Limeworks, Bredasdorp, Western Cape. (The reason for this requirement is that most limestones are not suitable for use, and would result in failure/sub-standard performance of units).

Generalised CSIR operational, safety and maintenance guidelines include:

- Formal steps and railings to access lid and roof area to be provided.
- General clarification treatment, filtration and chlorination to take place before limestone contactor. Particular care must be taken to ensure full removal of residual iron and aluminium prior to stabilisation.
- Pre-stabilisation iron levels to be < 0.1 mg/L, and turbidity < 1 NTU. If an aluminium based flocculant is used, pre-stabilisation aluminium levels should be < 0.15 mg/L.
- A gantry loading facility is preferable for limestone addition.
- Consideration should be given to protection of lower internal wall from aggressive and abrasive attack.
- Sample taps should be provided for both pre-stabilisation and post-stabilisation water quality monitoring. Monitoring should be carried out on at least a monthly basis, and testing should cover at least iron, turbidity and stabilisation indicators pH, total alkalinity and calcium (and aluminium where an aluminium based product is used for flocculation purposes).
- Down-flushing of fines to waste should take place at least once a month until site-specific required frequency is determined.
- A record of operation actions should be kept in a limestone contactor logbook, for instance recording periods when the system was out of commission, when flushing/cleaning occurred, when topping up with limestone occurred, the amount of limestone used, etc.
- Ensure equal flow into all limestone contactors, and ensure that flow into limestone contactors is not beyond maximum design capacity. The use of an orifice plate could be considered.
- 150 mm deep, 25 mm diameter granite aggregate between limestone bed and false floor system. A layer of granite stone is required to assist in flushing and to prevent channelling.

3.3 SITE INVESTIGATIONS

CSIR staff visited the sites listed in Table 3.1. During these investigations information was gathered with regards to the design and operation of limestone contactors. To facilitate data collection, a standard checklist was compiled (see Appendix A). Where possible samples of the untreated, treated (pre-stabilisation) and stabilised (post-stabilisation) water were collected, to assess the effectiveness of the various systems. Historic data on plant performance was also gathered where possible. In addition, where available, copies of formal written operating procedures for the units were obtained.

Subsequent to the site visits, and once sample analysis had been completed, a brief fax report was submitted to each of the responsible persons of the various municipalities. These faxes gave feedback with respect to the physico-chemical analyses of the samples collected, highlighted problems with the current operation and provided possible solutions to overcome such problems.

3.4 GENERAL SITE OBSERVATIONS

The following section highlights general observations relating to the limestone contactors that were inspected.

3.4.1 General and Hydraulic Design

On-site investigations indicated that most of the stabilisation units visited were of the CSIR-type design i.e. cylindrical, whilst three installations of the rectangular configuration exist (see Figure 3.2).

Figure 3.2: CSIR-type cylindrical design and alternative rectangular design limestone contact units

All of the limestone contactors visited operate in an "upflow" manner, i.e. with water entering via the bottom of the unit and flowing upwards through a fixed bed of limestone pebbles. In the CSIR-type units, take-off is by a single bell mouth type pipe; whilst for the rectangular units take-off is by a notched weir.

In most cases water distribution systems were of a false-bottom nature, with some older CSIR-type units having a slotted pipe configuration. In addition, all units are constructed from reinforced cement concrete (apart from the unit at Porterville, which is a CSIR-type system constructed from glass-reinforced fibre and the pressurised steel limestone contactor at Franschhoek).

All of the units have facilities for flushing silica and limestone fines to waste by a gravity "down flush" action. CSIR-type units have the ability to decommission one unit whilst the other is able to remain operational. More recent CSIR-type units have the ability to isolate units from each other whilst carrying out both "down flush" and "up flush" procedures to waste independently.

Most of the CSIR-type units include piezometers on the exterior of the limestone contactor. These indicate pressure loss across the limestone bed, and provide a visual indication as to when "down flushing" of insoluble fines is required.

3.4.2 Treatment (Pre- and Post-Stabilisation)

In all of the CSIR-type limestone contactors visited, the limestone contact process occurred after the normal required drinking-water treatment processes (for example coagulation, flocculation, settling, filtration and disinfection). Hence, limestone stabilisation was post-treatment prior to distribution into the drinking-water network.

At two of the three rectangular limestone contactors, the limestone contact process had been placed as the first step of the treatment process chain (i.e. the raw water into the treatment system first passed through the limestone contactor). The pebbles in these limestone contactors appeared visibly fouled with "slush". At the third rectangular limestone contactor, pre-treatment appears ineffective and similar fouling has occurred. This has led to the relatively poor performance of these limestone stabilisation contactors, as the resulting fouling retards the dissolution of the calcium carbonate. At all three of the rectangular limestone contactors, the stabilised water is chlorinated after stabilisation. These circumstances mean that the final treated water distributed into the network is very poorly stabilised as:

- the performance of the limestone contactor is compromised by fouling,
- subsequent water clarification processes may depress pH,
- final chlorination processes further depresses pH.

3.4.3 Water Quality Monitoring

Most of the CSIR-type limestone contactors have pre-stabilisation and post-stabilisation sampling taps for each limestone contactor unit. However, at many sites water quality monitoring practices were irregular. Although the limestone contact process requires very little management, it is important to regularly monitor both the water quality prior to and after stabilisation so as to determine whether the units are operating effectively. Such practices also allow for easy and timeous detection of possible problems originating in the drinking-water treatment system, which may affect the operation of the limestone contactor.

A typical problem originating from inadequate water quality monitoring occurs where coagulation, using ferrous or aluminium salts, is practised. At a number of the sites visited it was observed that

efficiency of residual iron/aluminium removal was poor. However, the high residual iron/aluminium (originating from sub optimal operation of the water treatment works) was not reacted upon by the water treatment plant operators as the limestone contact units were effective in removing the residual metal concentrations. In one extreme case resulting from significant problems with the water treatment plant, the limestone beds were used for final residual iron removal for a period of about six months. The resulting precipitation of iron in the limestone contactors necessitated eventual removal and replacement of the entire limestone media bed. In general, this approach is poor practice as the limestone contactors are not designed for this purpose, and it leads to fouling of the limestone beds.

3.4.4 Operational Procedures and Limestone Recharge

In many instances formal operating procedures were not available or not used by the plant operators/technicians. In addition, in most cases formal logbooks were not maintained. It was evident that regular inspection and maintenance of the limestone contactor units did not occur, and this resulted in decreasing efficiency of stabilisation. In one extreme case, it was reported that a circumstance had arisen where the operators were not aware that limestone topping up was required, and a period of a few years had passed before it was clear that stabilisation efficiency was very poor.

Where piezometers are installed, down flushing is generally carried out when the piezometers indicate that a growing pressure loss is occurring across the limestone bed. Where no piezometers exist, down flushing usually occurs only when it is perceived that a problem with the operation of the stabilisation units exists.

Limestone recharge is carried out when the limestone level in the contactor has dropped to the indicated minimum level. Limestone is manually added to the top of the limestone bed until it reaches the indicated maximum level. In most cases limestone is added using 25 kg bags. Some of the more recent larger units include a gantry to enable limestone recharge with 1 ton bags.

After limestone recharge, and the concomitant increase in water turbidity resulting from limestone fines, water is allowed to run to waste in an "up flush" manner until turbidity is regarded as acceptable.

3.4.5 Limestone

At all of the sites visited, the limestone media used for stabilisation purposes was the commercially available water treatment grade "Aquastab Pebbles", supplied by P&B Limeworks, Bredasdorp. The Bredasdorp limestone can be classified as a high calcium (and low magnesium) limestone, and has been shown to be suitable for limestone mediated stabilisation by CSIR. It is of a friable nature, highly soluble and with low insoluble silica, iron and manganese. The "Aquastab Pebbles" have a grading of +12 mm -15 mm. Limestone is currently delivered in either 25 kg or 1 ton bags (25 kg bags have been recently introduced by P&B Limesworks – previously 50 kg bags). In most cases the small bags are used for general topping up (easier to handle), whilst the 1 ton bags are used for commissioning of the units or when significant addition of limestone is required. The 1 ton bags have the advantage that their use results in the production of less fines during transport and handling.

3.4.6 General Design and Operating Considerations

On most, and all of the more recent, CSIR-type limestone contactors, access to the loading/inspection hatch is *via* a steel staircase to the top of the unit. In contrast, the rectangular units do not provide easy and safe access to the top of the units for inspection or loading of limestone. Clearly, safe operator working environment is important and it is necessary that proper access and safety railings be provided.

Gas bubbles indicating biological activity

It is important that the limestone beds be closed to the atmosphere. This protects the units, and final treated water quality, from air-borne contamination, light penetration, algal growth, etc. In two of the rectangular style contactors the limestone contactors were open to the atmosphere and sunlight. In both of these cases stabilisation occurred prior to conventional treatment. In these instances, significant problems were observed w.r.t. bio-fouling and algal growth. This is clearly shown in the following figures (see Figure 3.3).

Figure 3.3: "Open to atmosphere" limestone contact unit showing algal growth, and close up of algal fouling of limestone pebbles

3.5 SPECIFIC INFORMATION RELATED TO UNITS AT RESPECTIVE SITES

The objective of the following section is to consider the efficiency of treatment at all of the sites visited, and capture any significant additional design/operating "positives" or "negatives" such that these can be used for formulating standardised design/operating guidelines. Results obtained from sample analysis are shown in Table 3.2 at the end of Section 3.5.

3.5.1 Bredasdorp

The Bredasdorp limestone contactor system consists of two reinforced cement concrete limestone contact units with a combined capacity of 4.8 ML/day. The units are cylindrical in shape and stabilise treated dam water originating from the Bredasdorp Water Treatment Works.

During previous visits the units were operating well (see Table 3.2). For the WRC project two site visits were carried out, and the results of both are given and discussed. Observations were as follows:

Negatives:

- As a result of significant changes in raw water quality, poor residual iron removal occurred in the water treatment works. It took the plant operators a number of months to overcome this problem, and the residual iron loading (0.3 to 0.5 mg/L) resulted in fouling of the limestone pebbles, and decreased stabilisation efficiency significantly. This situation resulted in the first WRC project site visits reported final stabilised water quality of pH of 6.8, and high CCDP of 13 mg/L (WRC project sample 1, Table 3.2).
  Note: Once the problem had been resolved and the limestone replaced, stabilisation efficiency improved with final stabilised pH of 8.6 and CCDP of 2.8 mg/L (WRC project sample 2, Table 3.2).

Positives:

- Robust nature of process meant that even when operating below optimum caused by iron coating, the limestone beds were still able to significantly improve pH from 4.2 to 6.8, and improve the CCDP from 482 to 13 mg/L.
- Subsequent to the iron carry over experience, regular monitoring has been introduced to prevent reoccurrence. The fouled limestone has been replaced.

3.5.2 Franschhoek – Pressure Stabilisation Unit

This system consists of a modified pressure vessel and treats borehole water at a design capacity of 0.2 ML/day. It is only used during the summer months when demand for water is higher and is only serviced once a year (at the start of the summer period), or when a significant sludge build-up exists. No carbon dioxide stripping is practised as the product water is blended with surface water within the distribution network. At the time of the site visit the unit was operating satisfactorily, increasing the pH from 5.6 to 7.4 and reducing the CCDP from 135 mg/L to 12 mg/L.

Observations were as follows:

Negatives:

- No monitoring or maintenance programme (only once a year).

Positives:

- Robust nature of process means that despite receiving very little attention, the unit continues to bring about significant partial stabilisation.

3.5.3 Franschhoek - Surface water

The Franschhoek limestone contactor system consists of a single reinforced cement concrete limestone contact unit with a capacity of 2.5 ML/day, stabilising partially treated mountain catchment water. The unit is rectangular in shape and is covered with corrugated iron sheets (to prevent sunlight from entering the bed and the accumulation of leaves, etc on the limestone bed).

The limestone unit is not closely monitored and is only serviced once a year, or when a significant sludge build-up occurs. During the site visit it was noted that the limestone bed was covered in sludge, even though the covers were in place. This indicates poor pre-treatment (filter performance) or a lack of regular flushing.

At the time of the site visit (see Table 3.2) the unit was operating poorly, increasing the pH from 5.8 to 7.1 and reducing the CCDP from 17.7 mg/L to 9.1 mg/L. Observations were as follows:

Negatives:

- No monitoring or maintenance programme (only once a year).

Positives:

- Robust nature of process means that despite receiving very little attention, the unit continues to bring about significant partial stabilisation.

3.5.4 Idas Valley, Stellenbosch

The Idas Valley limestone contactor system consists of three reinforced concrete limestone contact units with a combined capacity of 18 ML/day. The units are cylindrical in shape and stabilise filtered mountain catchment water from the Eerste River (*via* earth storage dams). The units are flushed whenever being topped up with limestone. A comprehensive monitoring and maintenance programming exists with monthly sampling, flushing of fines to waste, and monthly topping up of limestone as required. At the time of the site visit the units were operating well. The pH increased from 4.4 to 9.2, and the CCDP improved from 20 to 0.1 mg/L.

Negatives:

- None.

Positives:

- Well-structured maintenance and monitoring programme.
- Use of gantry system for loading of limestone.
- Good flushing arrangements.

3.5.5 Jonkershoek, Stellenbosch

The Jonkershoek limestone contactors consist of two reinforced cement concrete limestone contact units with a combined capacity of 2.5 ML/day. The units are cylindrical in shape and stabilise chlorinated mountain catchment water from the Eerste River. The units are flushed whenever being topped up with limestone. A comprehensive monitoring and maintenance programming exists with monthly sampling, flushing of fines to waste, and monthly topping up of limestone as

required. At time of visiting, the units were to be decommissioned as a result of the introduction of a water transfer scheme that would negate their further use.

Results obtained from the regular drinking-water quality monitoring programme (see Table 3.2) indicates that the limestone units improve the stabilisation state of the raw water. The pH increased from 6.5 to 7.5, total alkalinity increased from 3.5 to 11 mg/L and the CCDP improved from 13.5 to 7.5 mg/L). The units were operating sub-optimally as the limestone level was not being maintained in preparation for unit decommissioning.

Negatives:

- None.

Positives:

- Well-structured maintenance and monitoring programme.
- Good flushing arrangements.
- Robust nature of process meant that even when operating below optimum (due to low limestone levels), the limestone beds were still able to improve pH from 6.5 to 7.5, and improve the CCDP from 13.5 to 7.5 mg/L. It should be noted that from analysis of historical data (when the units operated optimally), the units were able to improve pH from 5.5 to 9.3 and improve CCDP from 30.8 to 1.02 mg/L.

3.5.6 Montagu

The Montagu limestone contactor system consists of four reinforced cement concrete limestone contact units with a combined capacity of 5.6 ML/day. The units are cylindrical in shape and stabilise treated dam water.

Since the original installation of the units (two units designed by CSIR 3.8 ML/day), the raw water sources and resulting water quality fed into the units has changed to such an extent that the raw water essentially does not require stabilisation (see Table 3.2). (Although this could change depending on the flocculant used for coagulation purposes). During the upgrading to four units treating 5.6 ML/day, the function of the limestone contactors was significantly altered by filling the units with approximately 1.5 m of limestone and 1 m of activated carbon (to alleviate severe taste and odour problems in summer, due to algal growth in the raw water dam).

Negatives:

- At the time of the visit, the water treatment works was not operating effectively. The feed water to the limestone units (after flocculation, coagulation and filtration) showed unacceptably high turbidity and iron levels. CSIR recommended that the coagulation process be reviewed as impact on the limestone bed could be expected.

Positives:

- The unit was capable of acting as a roughening filter decreasing turbidity and iron levels. However, the continued use of the units in this manner will result in eventual bed blockage.

3.5.7 Napier

The Napier limestone contactor system consists of a single reinforced cement concrete limestone contact unit with a capacity of 2 ML/day stabilising a blend of untreated borehole and river water

(i.e. prior to any treatment). The river and borehole water is contacted separately with limestone, and therefore two values in Table 3.2 are given for both the feed and the product. The unit is rectangular in shape and is open to the atmosphere (i.e. does not have a cover over the limestone bed). Furthermore, it was noted that prior to the site visit algal problems had been experienced.

Negatives:

- The unit is the first step in the treatment process and is thus more susceptible to bed blockage (and sub-optimal unit performance).
- The unit is open to the atmosphere and therefore prone to algal problems.
- No monitoring programme (only twice a year).

Positives:

- At the time of the site visit the unit was operating satisfactorily, decreasing the CCDP of the river and borehole waters from 185 and 127 mg/L to 3.2 and 2.4 mg/L respectively.

3.5.8 Porterville

The Porterville limestone contactor system consists of two glass reinforced fibre (GRF) limestone contact units with a combined capacity of 4 ML/day. The units are cylindrical in shape and stabilise a blend of treated mountain catchment and stream water. At the time of the site visit raw mountain water was mixed with re-pumped earthen dam water, but due to turbidity problems this practice has subsequently been discontinued.

The limestone fines are regularly flushed from the beds, and the bed is drained if it appears dirty or clogged. At the time of the site visit, the limestone pebbles appeared clean and un-coloured (no visible sludge). The limestone is, however, not topped up frequently.

Negatives:

- The plant operator is unsure when limestone unit filling, maintenance, etc, should occur. This shortcoming can be addressed by instituting the use of an operation manual.

Positives:

- Results obtained from sample analysis (see Table 3.2) indicated that the stabilisation units were operating effectively, increasing the pH, calcium and total alkalinity and thus providing a degree of pipeline corrosion/aggression protection.
- Anecdotal accounts by Porterville Municipality confirmed that prior to the site visit, no pipe bursts had occurred for a period of 5 months.

3.5.9 Rozendal, Stellenbosch

The Rozendal limestone contactor system consists of two reinforced cement concrete limestone contact units with a combined capacity of 6 ML/day. The units are cylindrical in shape and stabilise chlorinated mountain catchment water. The units are flushed whenever being topped up with limestone. A comprehensive monitoring and maintenance programme exists with monthly sampling, flushing of fines to waste, and monthly topping up of limestone as required.

Results obtained from the regular drinking-water quality monitoring programme (see Table 3.2) indicates that the limestone units improve the stabilisation state of the raw water. The pH increased from 6.2 to 8.0, total alkalinity increased from 2.3 to 8.8 mg/L and the CCDP improved from 14.5

to 4.8 mg/L). However, at time of sampling the limestone units had not been topped up with limestone for over a year, pending reconstruction work on the distribution manifolds. Analysis of historical data (when the units operated optimally) shows that the units were able to increase pH from 5.9 to 8.7 and improve CCDP from 17.1 to 2.7 mg/L.

Negatives:

- None

Positives:

- Well-structured maintenance and monitoring programme.
- Good flushing arrangements.
- Robust nature of process meant that even when operating below optimum (due to low limestone levels), the limestone beds were still able to increase pH from 6.2 to 8.0, and improve the CCDP from 14.5 to 4.8 mg/L.

3.5.10 Villiersdorp

The Villiersdorp limestone contactor system consists of a single reinforced cement concrete limestone contact unit with a capacity of 3.5 ML/day, stabilising a blend of untreated mountain stream and Elandskloof irrigation scheme water (i.e. prior to any treatment). The unit is rectangular in shape and is open to the atmosphere (i.e. no cover over the limestone bed). No formal operating procedure exists, but the limestone bed surface is raked clean and the bed is flushed when it appears dirty or clogged.

Results obtained from sample analysis (see Table 3.2) indicated a relative poor performance of the limestone unit. This can probably be attributed to the thick layer of sludge that surrounded the pebbles, and which appeared to have penetrated the limestone bed. This sludge prevented the natural dissolution of calcium carbonate into the water. It was further noted that the limestone units are not designed to, and are not intended to, treat high turbidity waters (as that from the Elandskloof irrigation scheme). Limestone units are intended to stabilise post-treated water before it enters the distribution network. It was thus recommended that the unit be drained (and the limestone pebbles thoroughly cleaned) on a regular basis. However, flushing of the system seemed to indicate a poor ability of the rectangular design to flush fines to waste.

Negatives:

- The unit is the first step in the treatment process and is thus more susceptible to bed blockage (and sub-optimal unit performance).
- The unit is open to the atmosphere and therefore prone to algal problems.
- No monitoring programme.

Positives:

- At the time of the site visit the unit was able to improve the CCDP of the mountain catchment/irrigation scheme water blend from 72.5/11.5 mg/L to 6.5 mg/L.

3.5.11 Wellington

The Wellington limestone contactor system consists of two reinforced cement concrete limestone contact units with a combined capacity of 10 ML/day. However, at the time of the site visit, the

units were not operational. (This was as a result of a low water level in the raw water storage dam.) In addition, it was revealed that only one unit is used, as the town's current water demand did not require the use of the second unit. The units are cylindrical in shape and stabilise filtered/chlorinated mountain catchment water. The units are flushed whenever being topped up with limestone.

Furthermore it was noted that the final product water (post-limestone contactor) enters an open reservoir/dam. This situation is not ideal and could lead to problematic algal growth.

The units had not yet been commissioned at the close of the project. Typical historical data is included in Table 3.2 and shows the effectiveness of the system. The pH increased from 7.0 to 9.2, total alkalinity increased from 10.1 to 22.6 mg/L and the CCDP improved from 10.3 to 0.43 mg/L.

Negatives:
N/a

Positives:
N/a

Table 3.2 and Table 3.3 summarises results obtained and information gathered on-site during site visits to the respective limestone contactor units between late 1999 and early 2001.

Table 3.2: Summary of analytical data collected from field visits to limestone contactor units

		Bredasdorp			Franschhoek - Groundwater		Franschhoek – Surface water	Jonkershoek		Idas Valley	Montagu	Napier	Porterville		Rozendal		Villiersdorp	Wellington
		WRC Project sample1	WRC Project sample2	Prior CSIR sample	WRC Project sample	Prior CSIR sample	WRC Project sample	WRC Project sample	Prior CSIR sample	WRC Project sample	WRC Project sample	WRC Project sample	WRC Project sample	Prior CSIR sample	WRC Project sample	Prior CSIR sample	WRC Project sample	Prior CSIR sample
FEED	Fe (mg/L)	0.06	< 0.05	N/a	< 0.05	N/a	0.36	0.07	0.1	0.08	0.45	0.07	0.19	0.08	0.07	0.08	0.13 – 0.78 (blend)	N/a
	Turbidity (NTU)	0.13	N/a	0.47	0.47	N/a	0.73	0.39	0.5	0.36	5.1	0.8	3.4		0.47	1.5	0.28 – 7.9	N/a
	pH	4.2	4.6	5.1	5.6	5.5	5.8	6.5	5.5	4.4	8.0	4.8	7.1	4.6	6.2	5.9	5.1 – 7.0	7.0
	Alkalinity (mg/L $CaCO_3$)	0	0.3	0.8	10	11	1.5	3.5	1.8	0	36.5	1	5.0	0.3	2.3	2.0	1.5 – 10.8	1.1
	Calcium (mg/L Ca)	4.7	8.1	4.7	4	3.7	0.25	0.4	0.5	0.9	11.1	1.7	2.0	0.4	0.4	1.1	0.19 – 2	10.1
	Colour (filtered mg/L Pt)	7.5	N/a	N/a	< 10	N/a	30	N/a	20	N/a	30	10	20	N/a	N/a	N/a	40 – 45	N/a
	Colour (unfiltered mg/L Pt)	N/a	N/a	N/a	< 10	N/a	20	N/a	25	7	10	10	10	N/a	N/a	10	40 – 20	N/a
	CCDP (mg/L $CaCO_3$)	482.0	162.2	51.2	138	135	17.7	13.5	30.8	20	4.9	127.0	10.9	211	14.5	17.1	11.5 - 72.5	10.3
PRODUCT	Fe (mg/L)	0.05	< 0.05	N/a	0.06	N/a	0.36	< 0.05	< 0.05	0.08	0.16	0.07	0.18	N/a	0.06	0.09	0.34	N/a
	Turbidity (NTU)	0.83		0.4	0.84	N/a	0.70	0.32	0.5	0.56	0.81	0.74	3.2	N/a	0.45	1.8	4.4	N/a
	PH	6.8	8.6	9.0	7.4	7.2	7.1	7.5	9.3	9.2	7.9	7.8	8.0	8.1	8.0	8.7	7.6	9.2
	Alkalinity (mg/L $CaCO_3$)	11	13.8	15	80	151	7.8	11	15.7	19	42.7	103	34	22.5	8.8	17.3	18.5	6.5
	Calcium (mg/L Ca)	11.6	13.4	11	31	63.7	3.7	4.57	6.0	8.4	14.2	44	10.7	11.1	9.9	7.9	6.5	22.6
	Colour (filtered mg/L Pt)	10	N/a	N/a	< 10	N/a	25	N/a	20	N/a	10	10	15	N/a	N/a	N/a	40	N/a
	Colour (unfiltered mg/L Pt)	N/a	N/a	N/a	< 10		20	N/a	25	7	10	10	10	N/a	N/a	10	20	N/a
	CCDP (mg/L $CaCO_3$)	12.9	2.8	1.8	11.8	11.4	9.1	7.5	1.02	0.1	4.8	2.4	4.2	2.7	4.8	2.7	6.5	0.43

Table 3.3: Summary of observations during on-site visits at limestone contactor units in the Western Cape

	Bredasdorp	***Franschhoek PRESSTAB***	***Franschhoek***	***Idas Valley Stellenbosch***	***Jonkershoek Stellenbosch***	***Montagu***	***Napier***	***Porterville***	***Rozendal Stellenbosch***	***Villiersdorp***	***Wellington***
Commissioned (year)	1996	1994	1998	1996 Extension - 2001	1994	1993 Recent extension	1998	1997	1994	1999	1996
Hydraulic Design											
Shape	Cylindrical	Cylindrical	Rectangular	Cylindrical	Cylindrical	Cylindrical	Rectangular	Cylindrical	Cylindrical	Rectangular	Cylindrical
Flow (ML/day)	4.8	0.2	2.5	18	2.5	5.6	2	4	6	3.5	10
Operational flow direction	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed	Upwards through fixed bed
Flow distribution system	Cross-slotted pipe	False bottom stainless steel plate	False bottom stainless steel plate	False bottom stainless steel plate	Cross-slotted pipe and false bottom stainless steel plate *	Slotted pipe	False bottom stainless steel plate	Cross-slotted pipe	False bottom stainless steel plate	False bottom stainless steel plate	Slotted pipe
Operation											
Formal operating procedure	Yes	Unsure if on file Do not use	Yes, but copy with contractor	No	No	No	Yes	No	No	No	No
Operational Logbook	Yes	No	No	No	No	Yes	No	No	No	No	Yes
Checks/maintenance	Limestone bed and levels checked once a week. Unit drained if iron build-up occurs	Limestone level checked once a year Unit backwashed 2-3 times a year	Limestone level checked once a year Unit drained when sludge accumulates on bed	Limestone bed and levels checked once a week Unit drained if restriction in water flow noticed	Limestone bed and levels checked once a week. Unit drained if restriction in water flow noticed	Limestone level not really monitored Unit drained weekly due to accumulation on pebbles	Limestone bed and level checked daily Unit drained monthly as part of maintenance procedure	Limestone level not really monitored Unit drained if bed appears dirty/clogged	Limestone bed and levels checked once a week Unit drained if restriction in water flow noticed	Limestone level not really monitored Unit drained if bed appears dirty or clogged - seldom	Limestone level checked monthly Unit flushed when filling with new limestone
Limestone											
Type	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm	Aquastab +12 – 15 mm

	Bredasdorp	***Franschhoek PRESSTAB***	***Franschhoek***	***Idas Valley Stellenbosch***	***Jonkershoek Stellenbosch***	***Montagu***	***Napier***	***Porterville***	***Rozendal Stellenbosch***	***Villiersdorp***	***Wellington***
Packaging	25 kg bags	25 kg bags	25 kg bags	25 kg and 1 ton bags	25 kg and 1 ton bags	25 kg bags	1 ton bags	25 kg bags	25 kg and 1 ton bags	25 kg bags	25 kg bags
Distance to mine	~ 3 km	~ 165 km	~ 165 km	~ 165 km	~ 165 km	~125 km	~ 20 km	~ 275 km	~ 165 km	~ 135 km	~ 190 km
Many fines after transport	No	No	No	No	No	No	No	Yes	No	Yes	Yes
Treatment at WTP											
Pre-stabilisation	Coagulation Settling Sand filtration Disinfection – Cl_2 gas	-	Pressure sand filtration Disinfection - Cl_2 gas	Slow sand filtration Disinfection – Cl_2 gas	Strainer	Coagulation Settling Sand filtration	-	Pressure sand filtration Disinfection – Cl_2 gas	Slow sand filtration Disinfection – Cl_2 gas	-	Pressure sand filtration Disinfection - Cl_2 gas
Post-stabilisation	-	-	-	Disinfection – Cl_2 gas	Disinfection – Cl_2 gas	Activated carbon Disinfection – Cl_2 gas	Settling Pressure sand filtration Disinfection – Cl_2 gas	-	Disinfection – Cl_2 gas	Pressure sand filtration Disinfection – CL_2 gas	Product water is again chlorinated before entering distribution network
Water quality monitoring											
Frequency	Every 2 hrs	Once a month	Once a month	Once a month	Once a month	Daily	Twice a year		Once a month	Since commission only 1 set of samples collected	Once a month
Samples collected	Feed, final	Final	Final	Feed, final	Feed, final	Feed, final	Final	Final	Feed, final		Final
Parameters tested	PH, residual chlorine, turbidity, Colour, iron	E-coli	E-coli	PH, Ca, Alkalinity, residual chlorine, turbidity	PH, Ca, Alkalinity, residual chlorine, turbidity	PH, turbidity	Unsure – pH, E.coli	PH (daily) ♦ E.coli (monthly)	PH, Ca, Alkalinity, residual chlorine, turbidity		E.coli
General											
Unit closed/covered	Yes Access via manhole	Yes Access via manhole	Yes Zinc plates cover unit	Yes Access via manhole	Yes Access via manhole	Yes Access via manhole	No Open to atmosphere	Yes Access via manhole	Yes Access via manhole	No Open to atmosphere	Yes Access via manhole
Ease of contactor filling	Via staircase and hatch at top of unit	Via hatch at top of unit	Unit at waist level	Via staircase and hatch at top of unit	Via staircase and hatch at top of unit	Via staircase and hatch at top of unit	Unit is high and no formal staircase to	Via hatch at top of unit	Via staircase and hatch at top of unit	Unit at waist level	Via staircase and hatch at top of unit

	Bredasdorp	***Franschhoek PRESSTAB***	***Franschhoek***	***Idas Valley Stellenbosch***	***Jonkershoek Stellenbosch***	***Montagu***	***Napier***	***Porterville***	***Rozendal Stellenbosch***	***Villiersdorp***	***Wellington***
							assist filling				
Access to sampling points	Dedicated taps for sample collection	Dedicated taps for sample collection	No formal taps for sample collection	Dedicated taps	Dedicated taps	No formal taps for sample collection	No formal taps for sample collection	Dedicated taps for sample collection – currently not functional	Dedicated taps	No formal taps for sample collection	Dedicated taps

** Originally both contactors had a slotted pipe distribution system. One of these systems, however, failed due to cavitation caused by the accumulation of leaves, etc within the pipe. This resulted in the inclusion of a stainless steel plate false bottom to serve as the distribution system for the limestone contactor*

♦ Subsequent to the initial site visit a further set of physico-chemical samples have been collected and analysed. It is the intention of the officials at Porterville to perform the required analysis on a monthly basis.

3.6 DISCUSSION AND CONCLUSION

In all cases the limestone contactors improved the aggressive/corrosive qualities of their feed waters, and in most cases, significantly so. However, in a number of cases, operation of the units was not optimal, resulting in a poorer performance than expected.

Poor performance of limestone contactors can generally be attributed to the following factors:

- Feed water into the limestone contactor units does not meet acceptable drinking-water quality requirements (SABS 241 – 1999 Class 1). In most cases this is either due to the ineffective operation of the treatment processes prior to stabilisation or the incorrect positioning of the limestone contactor (i.e. before any treatment – the limestone contactor stabilises raw water). In general, problems relating to feed water quality not meeting acceptable standards were due to:
    - Increased iron levels in the feed (it seems as if operation of the units were largely unaffected at iron levels below 0.1 mg/L). *NOTE:* Although aluminium based flocculants were not used at any of the sites investigated, care should be taken to ensure that, if used, pre-stabilisation aluminium levels are below 0.15 mg/L.
    - Increased turbidity levels in the feed (a maximum turbidity of 1 NTU is recommended, to prevent sludge build-up around the limestone pebbles).
- The limestone beds are not cleaned (drained/flushed) on a regular basis. This results in the accumulation of sludge on the limestone pebbles that inhibits the dissolution of calcium carbonate into the water. Ineffective draining/flushing of the limestone bed may also be as a consequence of a badly/ill designed bed. Cylindrical units are generally of greater height, thus allowing more head (pressure) for flushing the limestone bed.
- Inadequate limestone contact time is allowed. This occurs as a result of not operating the bed at its designed limestone level, or exceeding the design capacity of the unit.
- The process is being used for non-intended purposes such as the removal of iron, turbidity and/or tastes and odours.
- The process is being used on the wrong type of water (e.g. pressurised, un-aerated groundwater).
- Inadequate isolation from sunlight and air-borne contamination for the prevention of biological and algal growth.

In addition, a number of general operation / maintenance points are of relevance:

- Experience has shown that false-bottom water distribution systems are more robust than units having a slotted pipe configuration; thereby ensuring better long term performance.
- In many instances formal operating procedures were not available or not used by the plant operators/technicians. In addition, in most cases formal logbooks were not maintained. This results in a lack of regular inspection and maintenance, which are necessary for efficient stabilisation.
- In all limestone contactor units visited the limestone used was Aquastab Pebbles, supplied by P&B Limeworks, Bredasdorp. Limestone was delivered in either 25 kg or 1 ton bags. Investigations revealed that in most instances 1 ton bags were preferred to 25 kg bags as they are perceived to result in the production of less fines during transport. 25 kg bags are often used for "topping up" limestone contactors as they are easy to handle.

- At many sites water quality monitoring practices were poor to very poor. It is important to monitor the water quality both prior to and after stabilisation, to assess whether the units are operating effectively. Such practices also allow for easy detection of possible problems in the treatment system, which may affect the operation of the limestone contactor units.

3.7 RECOMMENDATIONS

It is recommended that:

- The existing generalised CSIR design guidelines and generalised CSIR operational, safety and maintenance guidelines be used.

CHAPTER 4

EFFECT OF COLOUR ON THE LIMESTONE CONTACT STABILISATION PROCESS

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4.1 INTRODUCTION

A significant proportion of the waters of South Africa are soft and acidic with low pH. In addition, surface waters of the southern and south-western coastal region have variable colour due to the presence of complex Natural Organic Matter (NOM) constituents, the presence of which can further lower pH to as low as 4.0.

Small-scale private water users using these low pH, soft and acidic waters usually fail to stabilise the water prior to introduction to household and other piping systems. The resulting corrosive attack has substantial cost implications in terms of replacement of piping and geysers, washing machines and the like, and not insignificant inconvenience resulting from the staining of baths, clothes and hair. Furthermore, failure to stabilise results in an associated decrease in water quality resulting from raised dissolved metal levels (such as iron, copper and zinc). In many cases dissolved metal levels resulting from corrosion exceed SABS 241-1999 domestic supply requirements.

It had been previously established that soft, acidic surface waters can be readily partially stabilised using limestone contactors, but that the efficiency thereof can be detrimentally influenced by the presence of high levels of colour. As most of these surface waters have a typical brown colour, the effect of the degree of colour on the stabilisation process had to be established. The colour content of these waters ranges from low (10 – 50 mg/L Pt) to high (up to 450 mg/L Pt). In order to determine at what level the colour affects the limestone stabilisation process, it was decided to run pilot trails at three sites where there are surface waters typically having high, medium and low colour.

The three test sites selected for trials with small-scale limestone contactors were Jonkershoek (Eerste River) at Stellenbosch, Steenbras Dam, near Gordon's Bay, and Suurbraak, near Swellendam. These sites have waters that fall in the low, medium and high colour ranges respectively.

Table 4.1 shows the typical range of colour and other chemical characteristics of the water at the three chosen sites.

Table 4.1: Comparison of typical water characteristics at the test sites.

	Jonkershoek	***Steenbras***	***Suurbraak***
Colour - unfiltered (mg/L Pt)	15 - 30	60 - 110	200 - 450
- filtered (mg/L Pt)	15 - 25	50 - 100	175 - 400
pH	6.4	5.4	4.4
Total alkalinity as $CaCO_3$ (mg/L)	3.0	2.0	0
Calcium as Ca (mg/L)	0.5	1.3	0.4

4.2 APPARATUS AND METHOD OF OPERATION

A small-scale limestone test column was installed at each of the test sites. These columns were1.0 m high and had an internal diameter of 0.3 m. The limestone bed, 0.8 m high, rested on a perforated support/distribution plate near the bottom of the column, the feed water entering the chamber below the support plate and flowing upwards through the column. The unit was covered to prevent leaves or other material from falling onto the bed. The flow rate through the limestone contactor was 130 L/h. This flow rate was selected to obtain a similar loading rate as that used in full-scale limestone contact units (approximately 4.7 m/h). This equates to a retention time of approximately 10 minutes in the limestone bed.

A submersible pump supplied the water to each test column. A coarse strainer was fitted in the supply line. The flow rate was monitored by a rotameter in the feed line.

Figure 4.1 shows the layout of the test apparatus at a typical site.

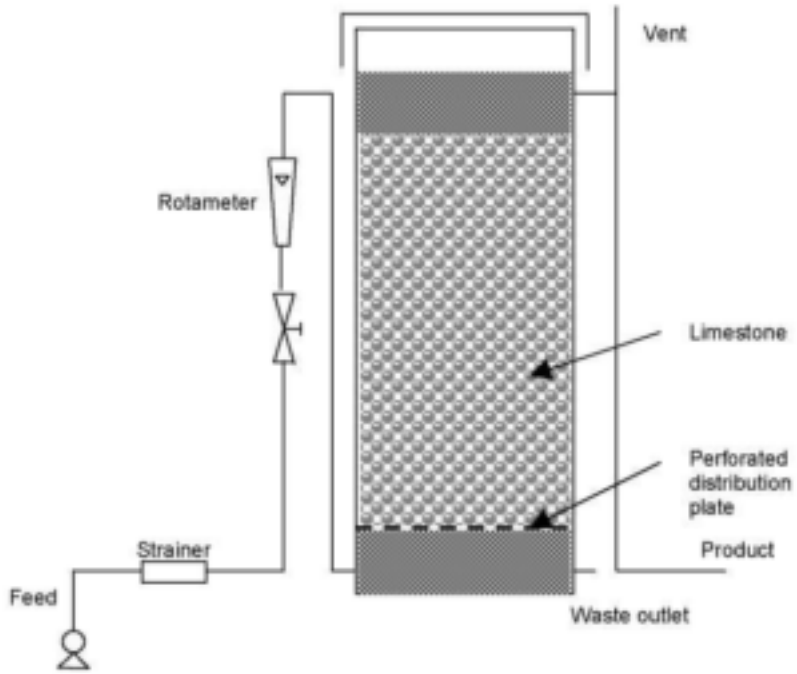

Figure 4.1: Layout of coloured water test apparatus

During each visit, the following procedure was carried out:

Step One:

On arriving at the test site, the condition of the limestone bed was carefully checked and observations recorded, such as colour, accumulation of fines, size of the pebbles, some pebbles were broken open to check colour penetration, general condition, the presence of organic slime in the bed. The feed water flow to the test column was adjusted, if necessary, to the required flow rate of 130 L/h. Time was allowed for three bed volumes of water to pass through the bed and then samples of the feed and product were taken.

Step Two:

On completing the sampling procedure, the test units were drained and refilled three times (at the normal operating rate) to flush any lose organic deposits and limestone fines from the reactor. Care was taken not to employ any vigorous cleaning methods on these small units, because such methods could not be replicated on a full-scale unit. Consequently, downward flushing was done by gravity draining the bed (not by using a strong jet from a hosepipe, which would be much more effective for a small unit, but impractical on a large scale unit), and refilling was done at the normal operating flow rate. The height of the limestone bed was recorded and the limestone level was topped up when the level was below 50 mm from the original starting level. The rotameter and strainer were cleaned if necessary.

The samples were transported to the analytical laboratory at CSIR, Stellenbosch for analysis. On occasion the pH and temperature readings were taken on site.

4.3 TEST RESULTS AND COMMENTS

4.3.1 Jonkershoek (Low coloured water)

The results for analyses of samples taken at Jonkershoek (over the period November 1999 to October 2000) are shown graphically in Figures 4.2 to 4.6. The actual numeric values, as well as additional chemical parameters, are given in Appendix B.

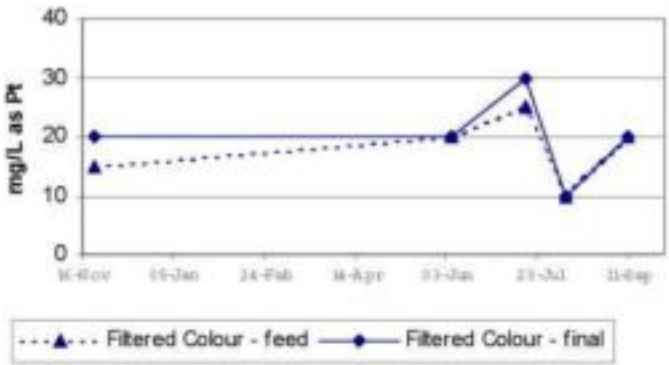

Figure 4.2: Filtered colour of feed and final water at Jonkershoek.

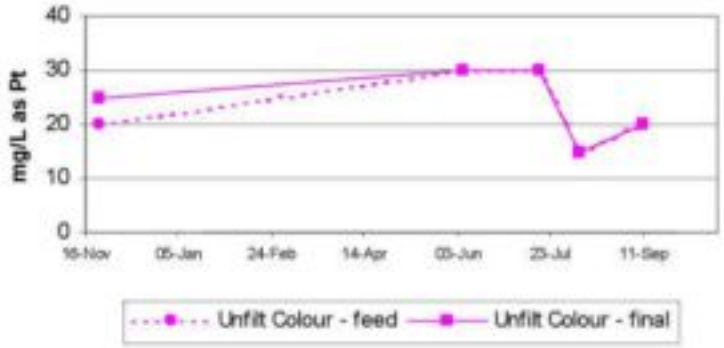

Figure 4.3: Unfiltered colour of feed and final water at Jonkershoek.

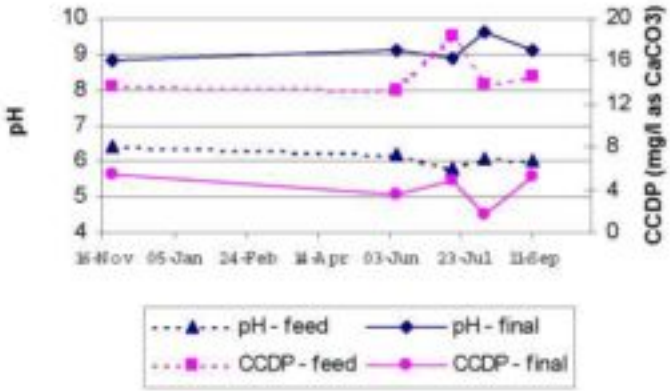

Figure 4.4: pH and CCDP of feed and final water at Jonkershoek.

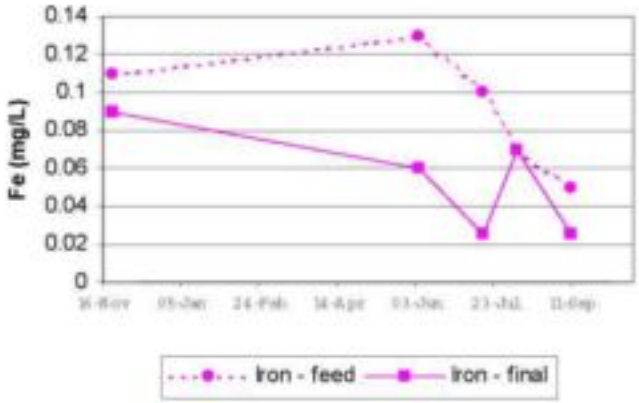

Figure 4.5: Iron of the feed and final water at Jonkershoek.

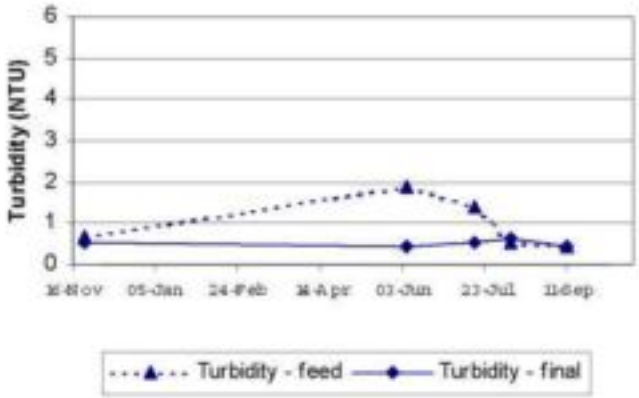

Figure 4.6: Turbidity of the feed and final water at Jonkershoek.

The overall performance of this test unit remained fairly constant, in spite of a number of interruptions in the feed supply. The degree of stabilisation achieved is reflected by the increase in pH, calcium and total alkalinity. The calculated CCDP decreased on average by approximately 73%. The sudden increase in colour, turbidity, calcium, iron, and total alkalinity that occurred in the last sample taken was due to the unit having stopped at some undetermined time and being restarted shortly before the sample was taken.

The results indicate that the long-term stabilisation performance was not materially affected by the colour (filtered and unfiltered), which fluctuated between 15 to 30 mg/L Pt, and 10 to 25 mg/L Pt, respectively.

The limestone bed remained fairly clean, with minor accumulations of brownish discoloured material on the top and at the base of the unit. Some fines accumulated at the base of the unit, but these were easily flushed out. After flushing, the limestone bed returned to its normal yellow to light brown colour. Fines were present in the water drained from the unit. Occasionally darker particles were also evident in the drained water.

4.3.2 Steenbras (Medium coloured water)

Analytical results of the samples taken from the Steenbras test unit during the test period (28 January 2000 – 9 October 2000) are shown graphically in Figures 4.7 to 4.11. Numeric values of the results are tabulated in Appendix B.

Throughout the test period, the degree of stabilisation was reasonably good, in spite of fluctuations in the colour, turbidity, iron content and pH of the feed water. The quality of the stabilised product generally tracked the feed water characteristics, and it was evident that a significant amount of iron and turbidity was removed in the limestone bed. There was a gradual decrease in the stabilisation performance of the unit, the total alkalinity and the calcium exhibiting a general downward trend. In spite of this, the unit achieved an average CCDP reduction of 83% over the duration of the test.

The limestone bed was always reported as being covered with a brown/black "mud" deposit and generally the entire bed was discoloured. Only during the first visit was the bed reported to be yellowish-brown. No fines were visible in the limestone bed due to its dark colour. During

flushing, some difficulty was experienced as the bed was often partly blocked. Only after the second flush did it drain at a reasonable rate. The water that drained out was very dark brown to black, with a very bad "old rotten mud" odour. Generally, however, the limestone bed cleaned up reasonably well, although the pebbles were still heavily discoloured on the surface.

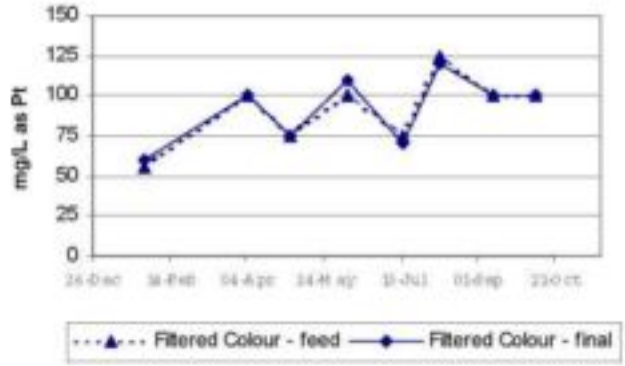

Figure 4.7: Filtered colour of feed and final water at Steenbras.

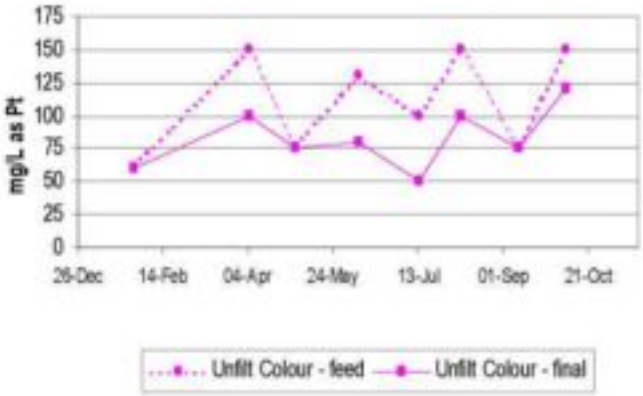

Figure 4.8: Unfiltered colour of feed and final water at Steenbras.

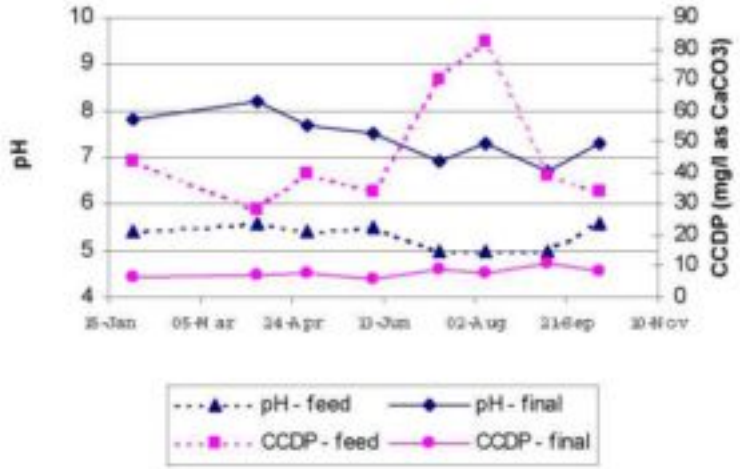

Figure 4.9: pH and CCDP of feed and final water at Steenbras.

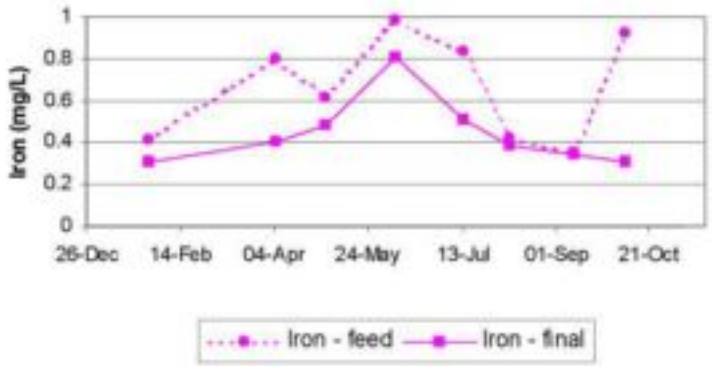

Figure 4.10: Iron of the feed and final water at Steenbras.

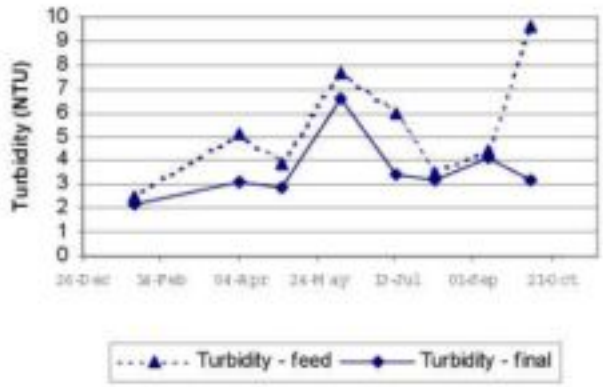

Figure 4.11: Turbidity of the feed and final water at Steenbras.

There was very little change in the filtered colour of the water after passing it through the bed, but a considerable change in the unfiltered colour occurred. This would indicate a removal of

suspended colour, iron and turbidity on the limestone bed, which resulted in the "visible" mud formation as described above. Most of this suspended material was removed during flushing, but some of it appeared to have permanently coated the surface of the limestone pebbles, which apparently reduced their stabilising efficiency.

4.3.3 Suurbraak (Highly coloured water)

Analytical results of samples from the Suurbraak test unit treating a highly coloured water during the test period (28 June 1999 to 21 September 2000) are shown graphically in Figures 4.12 to 4.15. Numeric values of these results are tabulated in Appendix B.

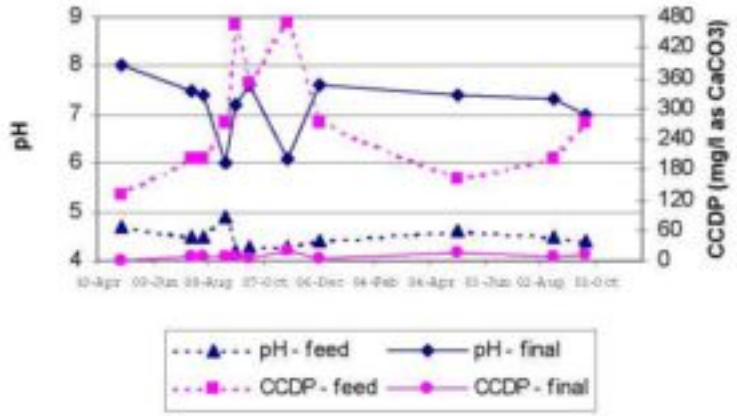

Figure 4.12: pH and CCDP of feed and final water at Suurbraak.

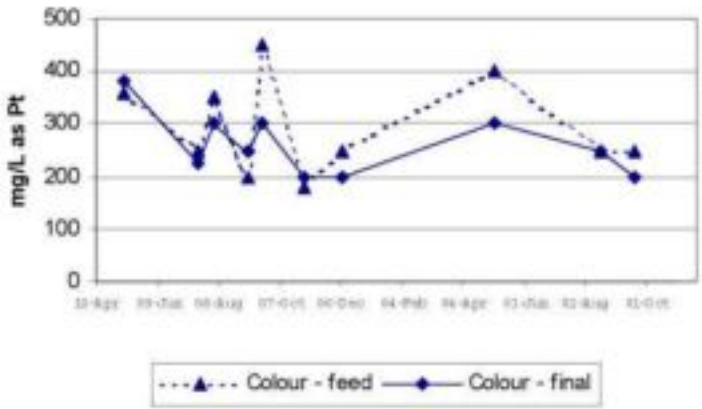

Figure 4.13: Unfiltered colour of feed and final water at Suurbraak.

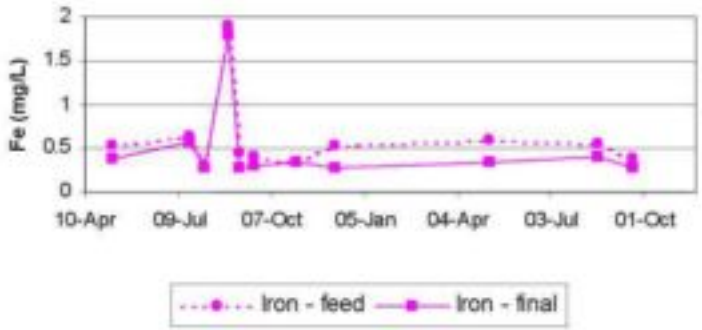

Figure 4.14: Iron of feed and final water at Suurbraak.

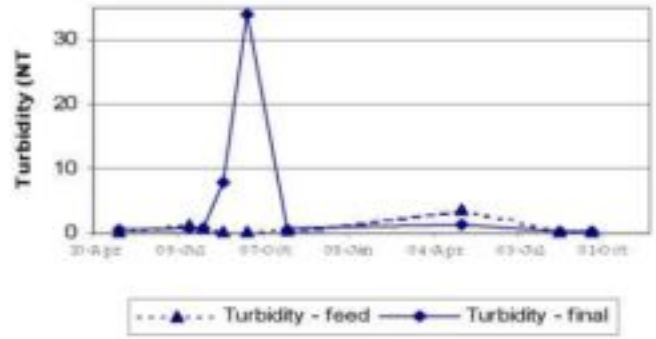

Figure 4.15: Turbidity of feed and final water at Suurbraak.

The stabilisation performance was good, the overall CCDP reduction averaging 96% over the test period, but there was a gradual but definite increase evident in the final (product) CCDP throughout the test. A gradual decline in the product pH was evident, but the average calcium and total alkalinity remained high, with large fluctuations occurring from July to October 1999. These fluctuations were probably a consequence of changes in the feed rate owing to operational problems.

A considerable amount of suspended (unfiltered) colour, turbidity and iron was removed in passing through the limestone bed. These constituents contributed to the discolouration and coating of the limestone, as was observed throughout the test. In spite of the dark colouration on the outside of the limestone pebbles, the actual colour penetration depth was only about 0.2 to 0.3 mm, which was evident when breaking open some of the pebbles. Some fines accumulated at the bottom of the bed. These washed out relatively easily during flushing, but the flushing water was always heavily coloured, appearing blackish brown, and a definite oily layer was evident on the top of the drained water. This oily layer may have been caused by the action of iron bacteria.

On 4 December 2000 when the test unit was finally stripped at the end of the run, it was found that all the pebbles were evenly coloured dark brown, except for a largish lump (± 10 cm in diameter), in the lower centre of the column, which was still the original limestone yellowish colour. This lump consisted of limestone pebbles entrapped in a mass of fines. The pebbles all still had their original yellowish colour. It would appear as if this "lump" must have formed very early on in the test run, hence the unchanged colour of the limestone pebbles, and that the water had bypassed the lump for most of the duration of the test. The pebbles trapped inside this lump were very friable and crumbled easily when handled.

It is remarkable that the test unit performed well, with apparently a considerable portion of the bed inactive.

4.4 CONCLUSIONS

- Limestone contact was confirmed as a suitable means of partially stabilising soft, acidic coloured waters and thereby providing corrosion and aggression mitigation. These observations were valid for waters with colour ranging from 50 to 450 mg/L Pt. It should, however, be noted that partial stabilisation of highly coloured waters should be practically limited to smaller limestone contactors. This is a result of the fact that the limestone bed will eventually become "blocked". When this occurs, flushing alone will not clean the bed, and the limestone would need to be replaced. Removal and replacement of limestone for a large contactor would be costly and time consuming. In smaller limestone contact systems, replacement of limestone would not be as problematic.

- The organic "colour" does not penetrate very deeply into the limestone pebbles and does not appear to materially affect their stabilisation capabilities.

- Although considerable discolouration occurs on the media when treating coloured waters, there is only a gradual reduction in the stabilisation performance of the process. A coating on the surface, caused by iron, turbidity and organic (slimes, etc.) deposits has a deleterious effect, can generally be reduced by flushing the limestone bed regularly.

- Limestone contactors are not intended to act as roughing filters. Minimum "pre-treatment" of settling, and preferably also filtration, prior to limestone contact should be implemented to minimise the deleterious effect on stabilisation of filterable iron, turbidity and organic matter.

- Regular flushing (or possibly backwashing in the case of small household contactor units), according to a fixed routine, is essential to maintain performance. The cleaning frequency depends on the colour and iron load imposed on the reactor, and should be determined on a case by case basis. This can be initiated using weekly flushing. The insoluble organic and turbidity load will also affect the performance, if regular flushing is not carried out.

- If flushing is too infrequent, accumulation of fines and debris may partially or even completely block the limestone bed.

- The limestone bed must be topped up when necessary, as is the case with similar systems treating non-coloured water.

- Care must be taken when the column is initially filled with limestone. The column must first be filled with water, and the limestone added slowly, occasionally draining the column to flush out fines trapped in the bed. This should eliminate the formation of dead spots or "lumps", as experienced during the test at Suurbraak.

- Since effective flushing is not achievable on larger municipal units that treat volumes of 1 ML/d or more, the maximum limit for colour in the feed water to the larger municipal units is set at 30 mg/L. This limit is based on experience on existing municipal units.

- For smaller contact units in which the whole limestone bed can be replaced with relative ease, a higher colour level can be tolerated, bearing in mind that with higher colour levels, the flushing requirement increases.

CHAPTER 5

TRIALS TO DETERMINE THE EFFECT OF PARTIAL STABILISATION ON AGGRESSION

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5.1 INTRODUCTION

The soft, acidic surface waters of the Southern and South Western Cape are aggressive towards pipes and structures made from cement (fibre-cement, concrete, etc) and cause extensive deterioration in these items in a relatively short time. Even after being treated in many of the water treatment facilities that do not practise full stabilisation after purification, the water may still tend to leach out free lime and calcium carbonate from the cement-containing structures in the storage and distribution network. The larger treatment facilities are usually equipped to fully stabilise the final product to have a slightly positive calcium carbonate precipitation potential (CCPP), by treatment with lime and carbon dioxide. Smaller works usually only increase the final water pH by lime or sodium carbonate addition, which may ameliorate the aggressive tendency slightly, but can still result in considerable damage to the network. Treating the final water by passing it through a limestone reactor will partially stabilise water to the extent where its aggressive tendencies are greatly reduced. This form of treatment is suitable for both small and large water treatment works as it requires only occasional operator attention and effects a large degree of stabilisation at very low cost.

Full stabilisation, i.e. where the treated water attains a slight positive CCPP, is usually not attained when treating surface waters with limestone. These trials were designed to investigate the degree of protection afforded to cement structures and pipes by partially stabilised, limestone treated water.

Aggressive attack by water in contact with cement structures can be monitored by either measuring the physical changes to the cement (cement concrete) sample with time (e.g. loss of mass), or by measuring changes to the water's chemical characteristics with time (e.g. changes in pH, calcium content, total alkalinity). Accurate measurement of physical changes to the cement samples are difficult and require extended exposure periods before noticeable trends develop. Changes in the chemical characteristics of the water can be relatively easily monitored and are considerably more sensitive, making this approach preferable for small-scale laboratory tests.

The ability to monitor the reactions between water and a cement structure or pipe will not only be dependent on the aggressiveness of the water but also on parameters such as the water volume to concrete surface area ratio and the flow regime at the cement and water interface. For example, it would be easy to monitor water quality changes to an aggressive water over a length of one kilometre of cement type pipe, as the changes would be substantial. On the other hand, water quality changes to an aggressive water where large volumes of this water are in contact with a small area of cement concrete are likely to be small and difficult to monitor. Unfortunately the use of extended pipe systems for tests in a laboratory is impractical. However, a simulation is possible by immersing cement concrete samples into tanks containing stirred water. A fixed water volume to cement concrete surface area ratio is chosen, the same ratio for each experiment with the different waters. This approach makes use of exposure cycles where the cycle duration is chosen to be such that significant changes in the chemical characteristics occur during a cycle. At the end of a cycle, a new cycle is started by replacing the "old" water with fresh "new" water.

For this investigation it was decided to evaluate the aggressiveness towards cement concrete samples of the following water types:

1. ***An aggressive, unstabilised water.*** This was a coloured surface water from Theewaterskloof that had passed through a full-scale treatment works at Paradyskloof, Stellenbosch. The treatment comprised lime and alum dosing, coagulation, flocculation, settling and sand

filtration. This water has had virtually all its colour removed, but still had typical aggressive characteristics, i.e. low pH, low calcium content, low total alkalinity, and a high calcium carbonate dissolution potential (CCDP).

2. ***A partially stabilised water***. This water was made by passing water (1) through a limestone column at a high rate (resulting in a 2.5 minute contact time) to effect a relatively low degree of stabilisation.

3. ***A more stabilised water***. This water was made by passing water (1) through a limestone column (with a twenty minute contact time), producing a water with a greater degree of stabilisation.

4. ***A fully stabilised water***. This water was produced by treating the water as used for (3) above with additional alkali to produce a water having a positive CCPP of approximately 5 mg/L, which is considered to be a fully stabilised water (1).

5.2 TEST EQUIPMENT

5.2.1 Dissolution tanks

Four dissolution tanks were constructed from Perspex sheeting, 6 mm thick. The tanks were square, with base measurements of 490 x 490 mm and height of 680 mm. A sampling port was fitted near the base of each tank. This was used for taking samples, draining and refilling the tanks at set intervals (every three days under normal operation as described below).

A metal H-frame resting on the upper edges of each tank supports an electric paddle stirrer, which runs continuously. Four cement concrete samples, suspended from the H-frame by nylon fishing line, hang at different levels (approximately 220 mm, 280 mm, 350 mm and 430 mm from the base) in a tank, shown in Figure 5.1. A square expanded polystyrene board with a 3 mm marine plywood backing floats on the water surface to minimize atmospheric carbon dioxide dissolution in the water in the tank.

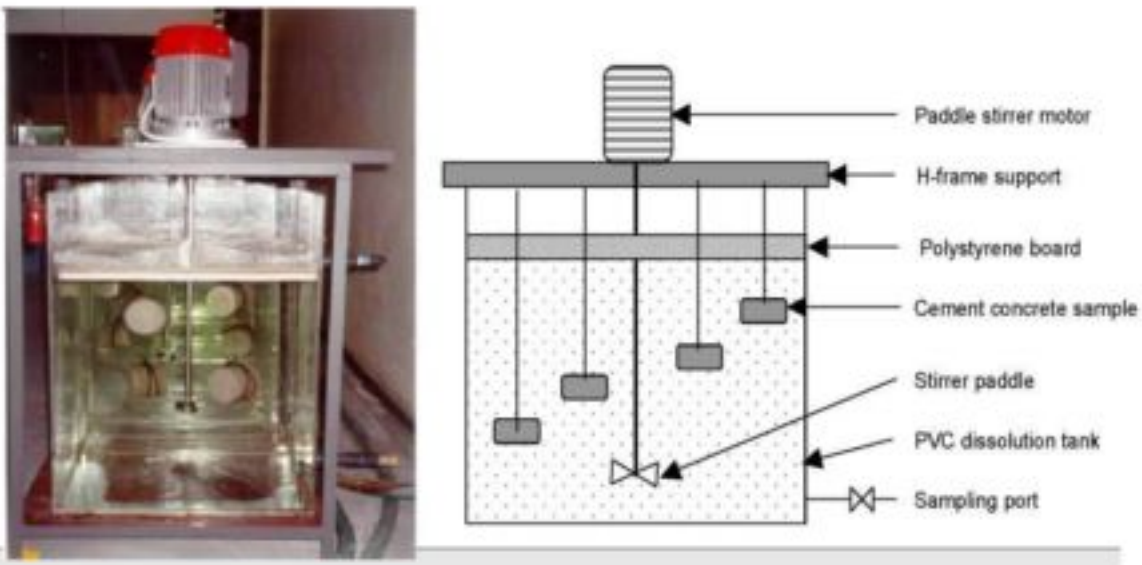

Figure 5.1: Aggression test apparatus.

Each tank was filled to a mark, giving an exact water volume of 120 litres.

Initially, the stirrers used operated at a high rate (1405 RPM), which resulted in excessive turbulence within the tanks. Subsequently, the impeller size was reduced to decrease energy input into the tank, thereby reducing the turbulence within the tank and stimulating actual pipe flow conditions.

The four test tanks, stirrers, and the cement concrete samples, were identical in all respects, to allow a direct comparison to be made of the aggressive characteristics of the four water types.

5.2.2 Cement concrete samples

The cement concrete samples were prepared by the Civil Engineering Department of the University of Cape Town. The mix design for the OPC concrete was 3,10 : 3,18 : 1,00 : 0.80 of washed gravel : sand : ordinary Portland cement : water. When preparing the mix, cement, sand and dry aggregate were placed into a mechanical mixer. The mixer was started and the water slowly added.

The freshly mixed concrete was cast into cylindrical moulds of dimensions:

- Diameter 70.6 mm.
- Height 75.0 mm.

To cast the concrete, the lightly oiled moulds were placed onto a vibrating table where the concrete was cast in three compacted layers. The exposed face of the sample was towelled and the samples were left to set under wet Hessian for 24 hours. After the initial 24 hour period the samples were placed in 20 °C water baths for 28 days.

5.3 TEST WATER PREPARATION

The following 4 test waters were prepared for the experiment:

- aggressive, unstabilised water,
- partially stabilised water,
- more stabilised water,
- fully stabilised water.

Tank No. 1: ***A typical aggressive water.***

This was a coloured surface water from Theewaterskloof that had passed through a full-scale treatment works at Paradyskloof, Stellenbosch. The treatment comprised lime and alum dosing, coagulation, flocculation, settling and sand filtration. This water has had virtually all its colour removed, but still had typical aggressive characteristics, i.e. low pH, low calcium content, low total alkalinity, and a high calcium carbonate dissolution potential (CCDP).

Tank No. 2: ***A partially stabilised water.***

This water was prepared by passing the decolourised water from the water treatment plant, as used in tank 1, upwards through a 200 mm diameter, 2000 mm high clear PVC column with a perforated support plate near the base. The column was filled to a depth of 663 mm with limestone pebbles, approximately +12 -15 mm in size, which resulted in a void space in the limestone of about 45 %. The continuous flow rate through the column was initially set at 100 L/h, giving a contact time of 5 minutes. The flow rate was later increased to 200 L/h to decrease the contact time in the limestone bed to 2.5 minutes, and to consequently reduce the degree of stabilisation. This was designated Limestone Column 1 (L/S 1).

Tank No. 3: ***A more stabilised water.***

This water was similarly prepared by passing the decolourised water from the water treatment plant, as used in tank 1, upwards through a 255 mm diameter, 2000 mm high clear PVC column with a perforated support plate near the base. The column was filled to a depth of 1632 mm with limestone pebbles approximately +12 -15 mm in size, which resulted in a void space in the limestone of about 45 %. The continuous flow rate through the column was set at 100 L/h, giving a contact time of 20 minutes in the limestone bed. This was designated Limestone Column 2 (L/S 2).

Tank No. 4: ***A fully stabilised water.***

This water was prepared by treating the water from the second limestone column (as used in Tank 3) with additional alkali to increase its pH and to achieve an approximate CCPP of 5mg/L. This was done by feeding the analytical results of the water into the Stasoft4 programme, which calculated the quantity of alkali (1M Na_2CO_3 solution) to be added.

5.4 EXPERIMENTAL PROCEDURE

5.4.1 Initial Start-up

The two limestone columns (L/S 1 and L/S 2) were thoroughly flushed with the water from the treatment plant until all fines had been removed. The columns were then put on line, running continuously for the duration of the experiment.

Tank No.1 was filled with 120 L of the water from the treatment plant sump. A 250 mL sample of the water was taken and the stirrer started. The water sample was tested on site for the following parameters: pH, temperature, total alkalinity (Gran Function titration) and calcium (EDTA titrimetric method).

For tanks No. 2 and 3, a similar procedure was followed, but using the water from limestone columns 1 and 2 respectively. Samples were taken as above.

Tank No.4 was filled with 120 L of water from limestone column 2. Then, using the results of the analyses obtained from the sample taken after filling tank No. 3, the Stasoft4 programme was employed to determine the required dose of 1M Na_2CO_3 solution to obtain a CCPP of approximately 5 mg/L $CaCO_3$. Using the standard prepared 1M Na_2CO_3 solution and noting that the tank contains 120 L of water, the required quantity of the sodium carbonate solution was added. This procedure ensured that the water in this tank was fully stabilised w.r.t. $CaCO_3$. After allowing the water to mix thoroughly, with the stirrer running, a small sample was taken for on site analysis as for the other three tanks.

5.4.2 Routine Sampling Procedure (Every 3rd Day)

To save time when performing the sampling procedure and start a new cycle every third day (72 hours), a special routine was established so that the analyses could be performed while the tanks were being filled or drained. Two samples were collected from each tank, one for analysis on site and one to be taken to the CSIR laboratory at Stellenbosch for analysis, to confirm the accuracy of the on-site analysis. The on-site tests were for: pH, temperature, total alkalinity (Gran Function titration) and calcium (EDTA titration). When a tank had been drained, it was rinsed and then refilled to the 120L mark with the appropriate "new" water. A sample of this "new" water was taken and analysed on site. The polystyrene and plywood cover was correctly relocated on the water surface and the stirrer restarted.

When Tank No. 4 had been filled to the 120 L mark, a calculated quantity of Na_2CO_3 solution (based on Stasoft4 calculation on analytical results from sample from Tank No. 3, obtained from L/S column 2) was added. After allowing the water to mix thoroughly, with the stirrer running, a small sample was taken for on site analysis as for the other three tanks, to get a "new" water analysis for the fully stabilised water.

It was necessary to clean the limestone columns after operating for 2 to 3 weeks, as a heavy algal growth had formed in the lower part of these columns. The limestone had to be renewed as well. This caused a slight fluctuation in the water quality, but it soon settled down to its usual standard.

5.5 RESULTS

The results obtained are shown in Figures 5.2 to 5.6.

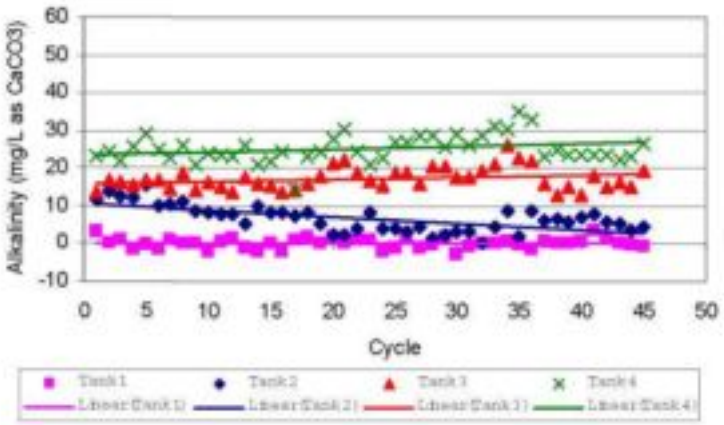

Figure 5.2 Total alkalinity of the initial water.

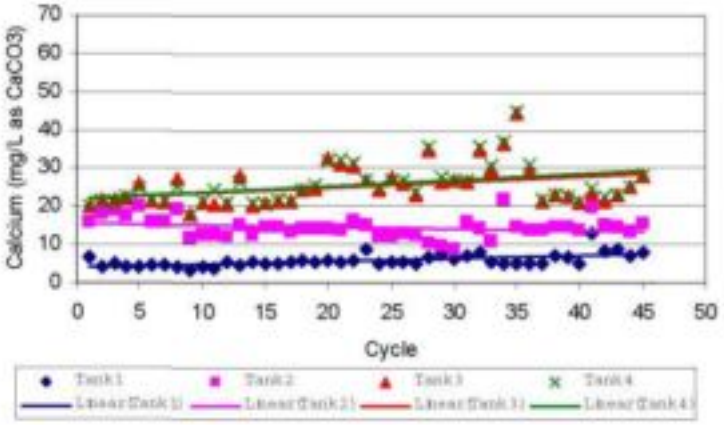

Figure 5.3 Calcium of the initial water.

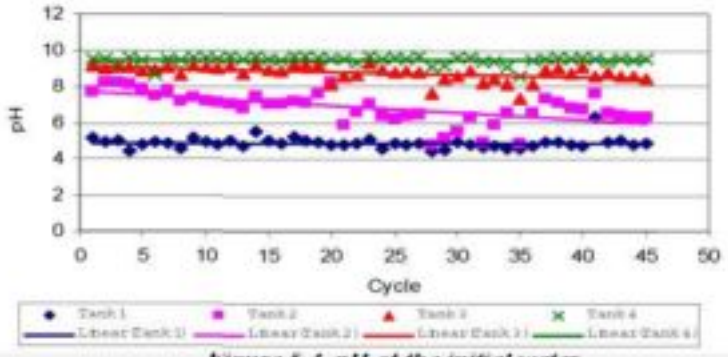

Figure 5.4 pH of the initial water.

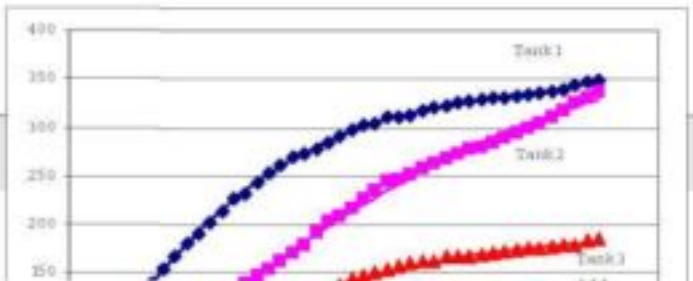

Figure 5.5 Cumulative uptake of total alkalinity in the four respective tanks.

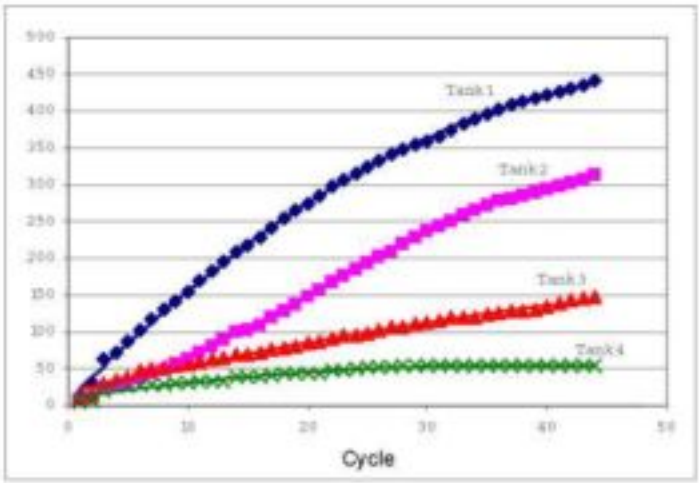

Figure 5.6 Cumulative uptake of calcium in the four respective tanks.

5.6 DISCUSSION OF RESULTS

Figures 5.2 to 5.4 show the total alkalinity, calcium and pH of the initial water placed in the four test tanks at the beginning of each 3-day cycle. From the respective trend lines shown for each of these analyses it is clear that the quality of the water remained fairly constant throughout the test period. The reduction in pH, calcium and total alkalinity for the water fed to Tank No. 2 is as a result of the decrease in the retention time in limestone column No. 1 from 5 minutes to 2.5 minutes (so as to increase the degree of aggression).

Figure 5.5 and 5.6 show the cumulative increase in total alkalinity and calcium, both expressed as calcium carbonate, of water samples collected at the end of a 3-day cycle. These results show that there is a considerable difference in the aggressiveness of the three water types, as indicated by changes in the calcium/total alkalinity of the water after exposure of three days to the cement concrete samples.

- The unstabilised water fed to Tank No. 1 leached out calcium and total alkalinity from the samples at a significantly greater rate than both the partially stabilised water (Tank No. 3) or fully stabilised water (Tank No. 4). This confirms the expected

observation that stabilisation provides protection from aggressive attack.

- Comparison of the partially stabilised water (Tank No. 3) with the fully stabilised water (Tank No. 4) indicates that: In both cases, greater dissolution of alkali's existed. The total alkalinity curve includes the dissolution of all alkali's (i.e. calcium and other alkali's), whereas the calcium curve only records dissolution of calcium mineral. Therefore, total alkalinity is the more important measure of the rate of aggressive attack.
- At the end of the experiment, calcium mineral dissolution had slowed down significantly for the fully stabilised water and was slowing down for the partially stabilised water.
- Whilst the trendlines of "total attack" (leaching of calcium and other alkali's from the cement matrix - indicated by the total alkalinity curves) for both the partially stabilised and fully stabilised waters indicate that a decreasing rate of attack was occurring, the curves had not yet settled down at the end of the experiment. However, Figure 5.5 clearly indicates that the rate of attack for both the partially stabilised and fully stabilised waters is very similar and that the curves are tending towards settling.

- Furthermore, Figure 5.5 shows a constant difference (delta total alkalinity) between the partially stabilised and fully stabilised waters. This result suggests that the relative degree of protection against aggressive attack offered by effective limestone mediated partial stabilisation is similar to a fully stabilised water.

5.7 CONCLUSIONS

Wrt aggression mitigation, it has been shown that:

- The unstabilised water is very aggressive towards cement concrete, leaching out calcium and total alkalinity from the samples at a significantly greater rate than both the partially stabilised water or fully stabilised water.
- Comparison of the partially stabilised water with the fully stabilised water indicates that:
  - In both cases, greater dissolution of alkali's existed. The total alkalinity curve includes the dissolution of all alkali's (i.e. calcium and other alkali's), whereas the calcium curve only records dissolution of calcium mineral. Therefore, total alkalinity is the more important measure of the rate of aggressive attack.
  - At the end of the experiment, calcium mineral dissolution had slowed down significantly for the fully stabilised water and was slowing down for the partially stabilised water.
  - Whilst the trendlines of "total attack" (leaching of calcium and other alkali's from the cement matrix - indicated by the total alkalinity curves) for both the partially stabilised and fully stabilised waters indicate that a decreasing rate of attack was occurring, the curves had not yet settled down at the end of the experiment. Results, however, clearly indicate that the rate of attack for both the partially stabilised and fully stabilised waters is very

similar (constant difference - delta total alkalinity) and that the curves are tending towards settling. This result suggests that the relative degree of protection against aggressive attack offered by effective limestone mediated partial stabilisation is similar to a fully stabilised water.

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CHAPTER 6

Investigation to Determine the Effect of Partial Limestone Stabilisation on Corrosion

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6.1 INTRODUCTION

Chapter Two provided basic information relating to soft water corrosion and the mitigation thereof. It was noted that the predominant corrosion control measure utilised in most parts of the world by water utilities is so-called "stabilisation", where pH adjustment for calcium carbonate saturation control is practised. Water chemistry should be adjusted such that the following corrosion mitigation criteria are satisfied:

With regards to minimising iron corrosion:

Guideline 1: The bulk water should be saturated, or slightly supersaturated, with respect to $CaCO_3$.

Guideline 2: Calcium and total alkalinity values should not be less than 50 mg/L (as $CaCO_3$).

Guideline 3: The Corrosivity Ratio (chloride + sulphate)/total alkalinity (where species concentration are expressed on an equivalent scale) must be less than 0.2.

With regards to corrosion of copper and brass (1):

Guideline 1 : The bulk water should have pH in the range 7.1 to 8.0.

Guideline 2 : The bulk water should have a low carbon dioxide concentration.

It was also noted in Chapter Two that for the smaller volume user or more remote site, such stabilisation processes are not feasible but that limestone mediated partial stabilisation is possible.

The aim of this part of the investigation was to gather data from existing drinking-water distribution systems, and determine the effect of limestone mediated partial stabilisation on iron and copper corrosion. By partial stabilisation is meant the reduction of calcium carbonate dissolution potential (CCDP) to a level which is still positive, but lower than 5 mg/L. With soft, acidic waters this usually results in concomitant pH increase to between 7.5 and 9.0.

6.2 CORROSION MITIGATION IN SMALL USER SYSTEMS

Making use of simple limestone contactors does not provide full stabilisation, but partial stabilisation is effected, and in most cases, this is sufficient to prevent copper corrosion and greatly reduce corrosion of any ferrous material in the water system. Where there were previously considerable corrosion problems, and typically severe cases of "blue" and "red" water, subsequent to the installation of limestone based partial stabilisation systems, the "blue" and "red" water problems were eliminated. Tables 6.1 and 6.2 show typical results obtained from private small holdings/farms, and clearly indicate effective corrosion mitigation being achieved by partial stabilisation.

The results from Table 6.1 are for a limestone based groundwater treatment system on a farm in the Western Cape. The results from Table 6.2, are for a limestone contactor on a small holding treating mountain stream water. In both cases significant corrosion was occurring prior to the installation of a limestone contactor. After the limestone contactors had been commissioned, these problems were effectively eliminated.

Table 6.1: Corrosion Mitigation by Limestone Treatment of Groundwater.

	Prior to Limestone Stabilisation		*After Limestone Stabilisation*		
	Supply	*Cold Tap*	*Supply*	*Product*	*Cold Tap*
Calcium as Ca (mg/L)	0.3	0.3	0.9	20.9	18.8
Alkalinity as $CaCO_3$ (mg/L)	1.5	2.5	2	51	50
pH	5	5.3	5	7.5	7.7
Conductivity (mS/m)	6	6	5.5	14.5	17.1
CCDP as $CaCO_3$ (mg/L)	96	65.1	115	6.92	4.51
Copper as Cu (mg/L)	< 0.02	2.5	< 0.02	< 0.02	< 0.02
Iron as Fe (mg/L)	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05

Table 6.2: Corrosion Mitigation by Limestone Treatment of Mountain Stream.

	Prior to Limestone Stabilisation		*After Limestone Stabilisation*	
	Cold Tap	*Hot Tap*	*Cold Tap*	*Hot Tap*
Calcium as Ca (mg/L)	0.5	0.7	5.5	5.4
Alkalinity as $CaCO_3$ (mg/L)	0.8	11.8	12.8	14.2
pH	4.7	6.5	7	7.1
Conductivity (mS/m)	6.5	7	6.7	6.4
CCDP as $CaCO_3$ (mg/L)	159	20.5	9.08	8.43
Copper as Cu (mg/L)	0.1	14.9	< 0.02	< 0.02
Iron as Fe (mg/L)	14.9	16.9	< 0.05	< 0.05

6.3CASE STUDY: CORROSION MONITORING AT BREDASDORP

6.3.1 Background

The effectiveness of partial stabilisation in the Bredasdorp network on iron and copper corrosion mitigation was investigated via monitoring of iron and copper levels at various points in the Bredasdorp drinking water distribution network. This section presents background information on

implementation of limestone stabilisation at the Bredasdorp treatment works, and in the following section the investigation and results are discussed.

Bredasdorp drinking water supply is drawn from an earth dam, which is fed by mountain streams and boreholes. The water is treated in a conventional water purification works comprising:

- pre-dosage with lime,
- flocculation,
- settling,
- sand filtration,
- chlorination, and
- limestone contact.

The works provides about 4.8 ML/day through a drinking-water reticulation network consisting almost entirely of cement type or cement lined pipes. The raw water is soft and acidic with a pH of 6.2 to 6.5. The use of a floc agent results in a further decrease in pH, further increasing the need for stabilisation. Principle problems being experienced included high household copper levels, and attack of cement concrete pipes. Lime stabilisation was being practised, but was proving problematic and costly.

Partial stabilisation through limestone contact was introduced in 1996. Data obtained from initial pilot plant tests was used in conjunction with theoretical considerations, and other chemical analyses, to design a 4.8 ML/day (200 m^3/h) limestone contactor for Bredasdorp. The limestone contactor is the standard CSIR design (see Chapter 3) comprising two identical reactor units each containing a bed of graded limestone particles, through which water flows in an upward direction. The unit is positioned so that chlorination takes place before limestone contact. The full-scale limestone contactors were commissioned in December 1996. The following water samples were collected during commissioning:

- raw feed to the water purification works,
- post flocculation, settling and filtration,
- post chlorination water, and
- post limestone contact.

Results are shown in the following table.

Table 6.3: Water quality data collected from the Bredasdorp water purification works at time of commissioning of the limestone contactor - 1996.

	Raw Feed	*Filtered*	*Chlorinated*	*Post-stabilised*
pH (field)	7.5	5.9	5.1	9.0
Ca (mg/L $CaCO_3$)	11.8	20.0	11.8	11.0
Alkalinity (mg/L $CaCO_3$)	7.5	1.6	0.8	15.0
CCDP (mg/L $CaCO_3$)	8.0	13.8	51.2	1.8
Turbidity (NTU)	4.5	0.47	0.47	0.40

From the data set out in the above table, it is evident that water purification practises decrease pH and total alkalinity significantly, thereby increasing the CCDP and need for stabilisation. It is further evident that the limestone stabilisation process was operating successfully. Limestone contact reduced the CCDP significantly from ~ 51 mg/L to an acceptable level of ~ 2 mg/L as $CaCO_3$, and increased pH from 5.1 to 9.0. The expectation that such effective partial stabilisation will virtually eliminate aggressive attack of cement concrete, significantly reduce corrosive attack of iron piping and completely eliminate corrosive attack of copper is tested in this investigation.

In a site visit after commissioning, the quality of the water emerging from the contactor was again checked and samples were also collected through the drinking water reticulation network, the latter to provide an indication as to the stability of the water through the reticulation network. These results are shown in Table 6.4 below.

Table 6.4: Limestone Mediated Stabilisation at Bredasdorp – Sept 1997 (After Passing Through a Conventional Colour Removal Plant).

	Prior to Limestone Stabilisation		*After Limestone Stabilisation – 26 Sept 1997*			
	After Treatment	*Hotel Sample*	*After Limestone*	*Network Sample #1*	*Network Sample #2*	*Hotel Sample*
Calcium as Ca (mg/L)	4.7	N/A	13.1	13	14.4	12.9
Alkalinity as $CaCO_3$ (mg/L)	0.8	N/A	15.5	17.8	19.8	16.3
pH	5.1	N/A	8.8	8.9	9.2	8.3
Conductivity (mS/m)	50	N/A	52	49	53	48
CCDP as $CaCO_3$ (mg/L)	52.7	N/A	1.9	1.4	-0.6	2.9
Copper as Cu (mg/L)	< 0.02	2.5	< 0.02	N/A	N/A	0.09

N/A: Not Analysed

The sampling was repeated recently, to check the efficiency of limestone stabilisation in the network, approximately four years after commissioning. These results are shown in Table 6.5 below:

Table 6.5: Limestone Mediated Stabilisation at Bredasdorp – March 2001 (After Passing Through a Conventional Colour Removal Plant).

	Prior to Limestone Stabilisation		*After Limestone Stabilisation – 15 March 2001*			
	After Treatment	*Hotel Sample*	*After Limestone*	*Network Sample #1*	*Network Sample #2*	*Hotel Sample*
Calcium as Ca (mg/L)	4.7	N/A	13.4	13.6	13.4	13.4
Alkalinity as $CaCO_3$ (mg/L)	0.8	N/A	13.8	14.3	14	14
pH	5.1	N/A	8.6	8.6	8.5	7.6
Conductivity (mS/m)	50	N/A	48	48	48	47
CCDP as $CaCO_3$ (mg/L)	52.7	N/A	2.0	2.7	3.0	4.7
Copper as Cu (mg/L)	< 0.02	2.5	< 0.05	<0.05	<0.05	0.09

N/A: Not Analysed

The data in both tables shows the quality of the water leaving the treatment works prior to and after implementation of limestone stabilisation. It shows the quality directly after treatment, as well as at three points of usage in the drinking-water reticulation network. In Table 6.4 (two weeks after commissioning), network samples #1 and #2 were taken near the furthest points in the reticulation network; sample #1 was taken at a household, and sample #2 at the sewage treatment works. In Table 6.5 (recent sampling), samples #1 and #2 were household samples, taken in the centre of town; sample #1 at the dry cleaners near the traffic department offices, and #2 at "All Saints". Inspection of the chemical characteristics of all of these samples shows that the limestone contactor was operating well, both shortly after commissioning as well as recently. The CCDPs of all the samples taken after implementation of limestone stabilisation were acceptably low, and the pH values were generally greater than 8.3. The results illustrate the effectiveness of the limestone stabilisation process in providing well-buffered, stabilised water.

Of particular interest to corrosion mitigation discussions is that samples were collected from the hotel both before and after introduction of partial stabilisation. Whereas significant copper corrosion had previously been observed, it was seen that partial stabilisation brought about effective copper corrosion mitigation within two weeks subsequent to commissioning. Anecdotal accounts thereafter have confirmed that "blue water" episodes ceased after introduction of limestone mediated partial stabilisation.

It is also interesting to note is that, although the contactor was out of commission for a number of months during the year 2000, stabilisation levels in the network increased again to levels similar to those measured fours years ago when the network was shortly after commissioning of the contactor.

6.3.2 Monitoring corrosion in the Bredasdorp reticulation network

The Bredasdorp network was monitored during the period April 2000 and November 2000; a period during which the limestone contactors were out of commission as a result of upgrading. During this period, manual post-lime dosage was practiced. (Subsequently, the limestone contactors have been re-commissioned, and the results shown in Table 6.5 again confirm the effectiveness of partial stabilisation.) The dosage of lime was done manually and could therefore not be controlled very accurately. As a result, the stabilisation level of the "post-stabilised" water varied considerably during the monitored period. This provided the project team with the opportunity to study the influence of variable efficiency lime based stabilisation of a typical soft, acidic water on corrosion mitigation. This variance in stabilisation level (as quantified by the CCDP) resulted in useful data revealing the effect of varying stabilisation levels on metal corrosion.

Parameters monitored

The following points within the distribution network were monitored: the raw feed to the treatment works, the post-chlorinated water (the treated water prior to post-dosage with lime), the "post-stabilised" water, and at nine sampling points distributed through the network. Analysis of the following parameters was undertaken:

- pH

- Calcium
- Total alkalinity
- Electrical conductivity
- Iron
- Aluminium (only for the first two months)
- Copper
- Turbidity
- CCDP (calculated from pH, calcium and total alkalinity, using Stasoft4 (2)).

The Bredasdorp drinking-water reticulation network consists almost entirely of cement type or cement lined pipes. Hence, iron and copper corrosion products originate from household plumbing, network valves and fittings. So the presence of levels of these metals above the detection limit gives a qualitative indication of corrosion occurrence; whereas consistently low levels of corrosion products give a qualitative indication of effective corrosion mitigation.

Results

Figure 6.1 shows the calcium level of the raw untreated water over the monitoring period, as well as that of the post-chlorinated and "post-stabilised" water and water for a network sampling point (Carnation). Lime was dosed at two points, namely before coagulation treatment (pre-treatment lime dosage) and after chlorination (post-treatment lime dosage). The variability of the post-chlorination calcium level indicates that pre-lime dosage levels varied considerably (e.g. on 4 October 2000, there was no pre-lime dosage, due to equipment failure).

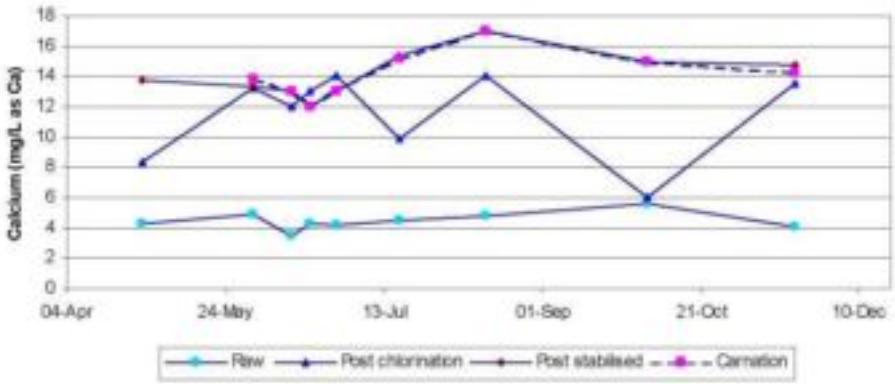

Figure 6.1: Calcium levels in the raw, untreated; post-chlorinated; post-stabilised water; and at "Carnation" (a point in the network).

Iron corrosion

Figure 6.2 shows iron levels of the raw (untreated) water and of the treated water, after post-lime dosage. Iron levels in the raw water ranged between 0.56 and 1.20 mg/L. Treatment reduced iron levels to below the detection limit of 0.05 mg/L.

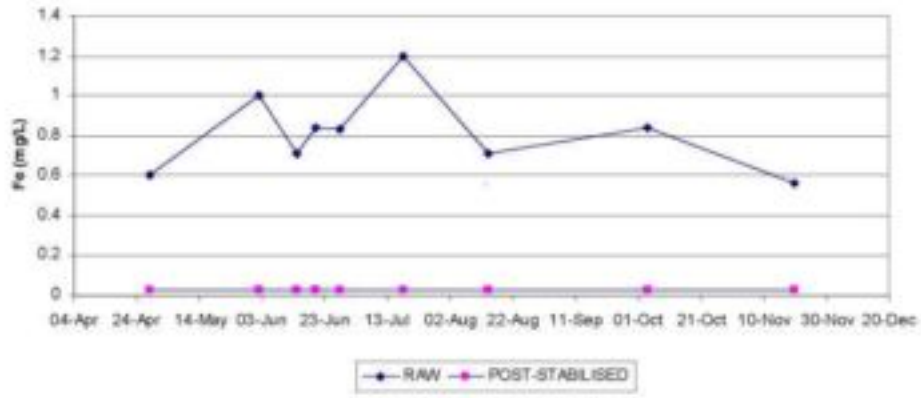

Figure 6.2: Iron removal by the treatment process.

Next, time-series plots of CCDP and iron for each respective network monitoring point were studied. Generally, iron levels in the network were below 0.10 mg/L. The sampler allowed the tap to run for a minute before taking a sample (a standard practice). The possibility should therefore be considered that in some cases corrosion products might have been rinsed out of the system when the samples were taken, if the point of corrosion was close to the sampling tap. Nevertheless, a number of samples did have raised iron levels: among a total of 88 samples, 11 had iron levels >0.10 mg/L, four of these >0.20 mg/L.

Relationship between iron and CCDP levels in the network

In time-series plots with combined data from all the monitored network points, the peaks in network iron levels correspond with peaks in CCDP. Figures 6.3 and 6.4 show that, generally, iron levels were below 0.10 mg/L when CCDP levels were below 6.0 mg/L.

There was one exception to the above observation, namely on 14 August, when raised iron levels (of between 0.10 and 0.20) were observed at two sampling points, although CCDP levels were low at the time (between 0 and 2.0 mg/L). These raised levels can be explained if taken into account that increased CCDP levels had been experienced in the network for a period of 12 days, ending two weeks prior to taking the sample on 14 August. The reason for these raised CCDP levels was a defective pre-lime dosage pump, which prevented pre-lime dosage from 19 to 30 June. To compensate for the period when pre-dosage of lime had not taken place, higher than normal pre-dosage levels were maintained for a while after the pump had been repaired. Iron corrosion products caused by the period of increased CCDP levels are likely to have originated from the raised CCDP.

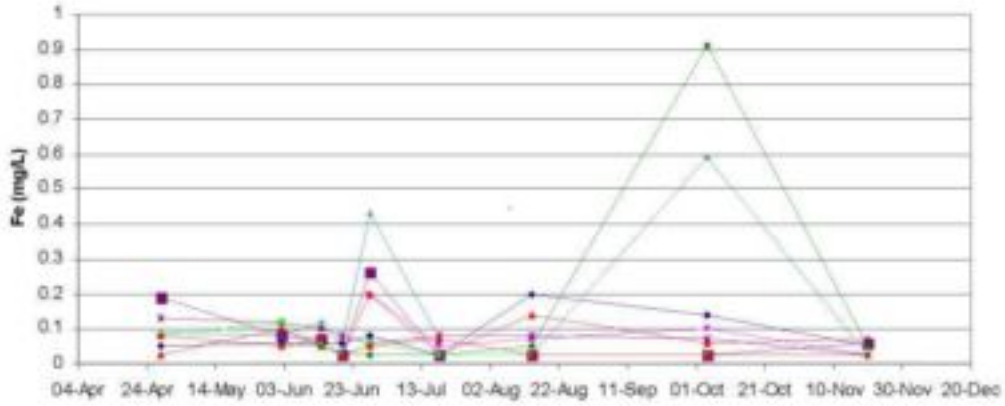

Figure 6.3: Iron levels in the network.

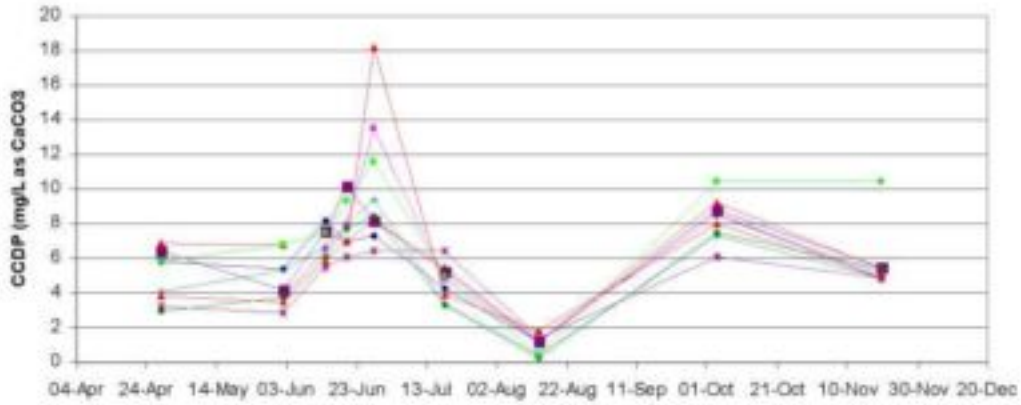

Figure 6.4: CCDP levels in the network.

Figure 6.5 shows the relationship between CCDP and iron levels in samples from nine monitoring points in the network. This scattergram confirms the observation that iron levels were generally lower than 0.10 mg/L when the CCDP of the water was lower than 6.0 mg/L. The two data points indicated by squares (bottom left) represent the two samples that were taken on 14 August and which are discussed in the previous paragraphs.

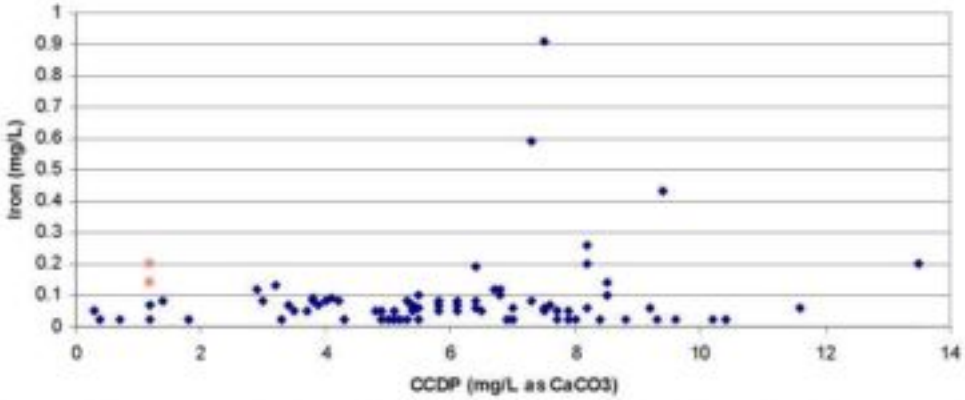

Figure 6.5: Scattergram showing relationship between CCDP and iron levels of samples from nine network monitoring points.

Relationship between iron and pH levels in the network

Figure 6.6 shows the relationship between pH and iron levels in samples from the nine monitoring points in the network. Elevated iron levels (>0.2mg/L) were detected only in samples with pH levels less than 7.5. Generally, iron levels in the network were below 0.1 mg/L at pH levels >7.3.

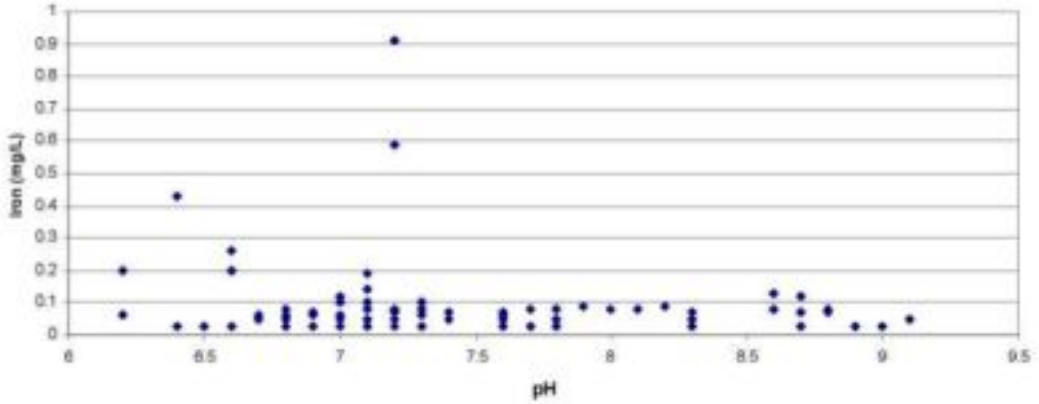

Figure 6.6: Scattergram showing relationship between pH and iron levels of samples from nine network monitoring points.

Concluding Comments

- The Bredasdorp drinking-water reticulation network consists almost entirely of cement type or cement lined pipes; accordingly, iron and copper corrosion products originate from household plumbing, network valves and fittings.
- The presence of iron above the detection limit gives a qualitative indication of iron corrosion occurrence; whereas consistently low levels of corrosion products give a qualitative indication of effective corrosion mitigation.

- A base-line presence of iron is apparent – between 0 and 0.1 mg/L.
- Where the CCDP is kept below 6 mg/L (and pH above 7.3), iron levels stay within the base-line range. This indicates a meaningful reduction in corrosion of iron in the network.

Copper corrosion

Copper levels in the raw water feed to the treatment plant were generally below the CSIR laboratory detection limit of 0.05 mg/L, and remained below the detection limit throughout the network, barring a few exceptions. Values lower than the detection limit are displayed as 0.025 mg/L (half the detection limit). Figures 6.7 and 6.8 show network copper and pH levels over time.

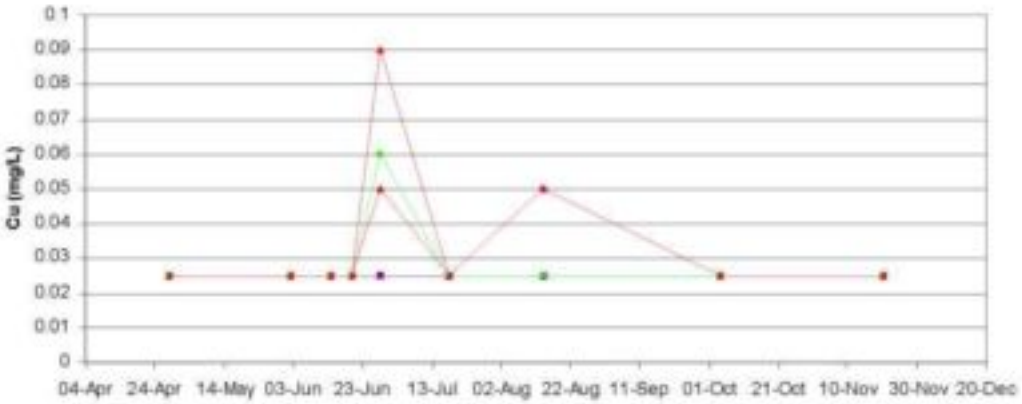

Figure 6.7: Copper levels at network monitoring points.

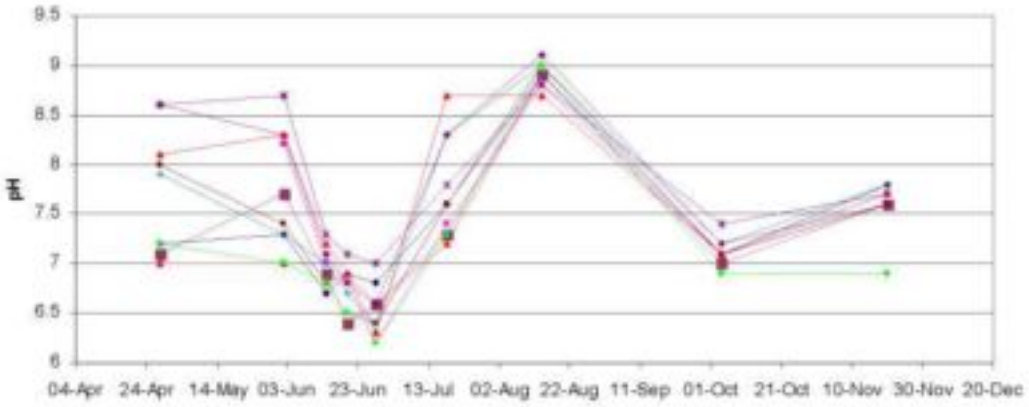

Figure 6.8: pH levels at network monitoring points.

In soft, low salinity water such as this, copper corrosion is not expected at pH above about 7.1. Figures 6.7 and 6.8 above confirm this, with the exception of data on 14 August, when raised copper levels were observed in the network, even though pH levels were above 8.5. It is likely that these raised levels resulted from a period during which the pre-lime dosage equipment failed (19 to 30 June). To compensate for the lack of lime-dosage resulting from the failure,

plant operators maintained a higher pre-lime dosage rate for a few days after the equipment had been repaired. This explains the high pH levels (up to 9.0) recorded on 14 August 2000.

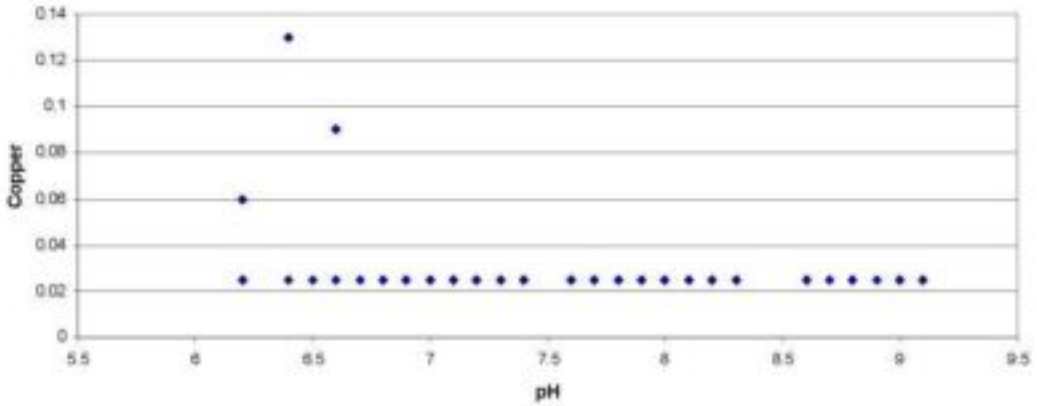

Figure 6.9: Scattergram showing relationship between copper and pH levels in the network.

Figure 6.9 shows the relationship between copper and pH levels in the network. Only three samples had raised copper levels. All three of these samples had pH levels below 7.1, confirming that copper corrosion is not expected at pH above 7.1.

Concluding Comments

- The Bredasdorp drinking-water reticulation network consists almost entirely of cement type or cement lined pipes; accordingly, iron and copper corrosion products originate from household plumbing, network valves and fittings.
- The presence of copper above the detection limit gives a qualitative indication of copper corrosion occurrence; whereas consistently low levels of corrosion products give a qualitative indication of effective corrosion mitigation.
- Where the pH is above 7.1 copper is not detectable. This indicates a meaningful elimination of corrosion of copper in the network.

6.4CASE STUDY: CORROSION MONITORING AT STELLENBOSCH

Stellenbosch Municipality receives water from three sources; namely, treated water from Wemmershoek, Theewaterskloof raw water that is treated in a conventional water purification works at Paradyskloof, and raw Jonkershoek mountain catchment water which is abstracted from the upper ranges of the Eerste River. Wrt the latter, the so-called "Jonkershoek water" is of a particularly high physico-chemical and microbiological quality. Historically, this water underwent minimum treatment comprising only disinfection by chlorination. However, this water is soft and acidic, with pH ranging between 5.0 and 6.5, and total alkalinity and calcium levels not exceeding 5 mg/L as $CaCO_3$. Hence, the Jonkershoek water is a weakly buffered water, and rendered even

more aggressive and corrosive by chlorine addition. Accordingly, Stellenbosch historically experienced significant aggressive attack of both cement concrete pipes, and metal pipes, conduits and containers in the areas where the Jonkershoek water is distributed. (Treatment has since been upgraded to include filtration and stabilisation).

To address the aggression and corrosion problems originating from the Jonkershoek water, limestone contact units were installed to partially stabilise the Jonkershoek water. Considering the complex nature of the distribution network this required that separate limestone contact units were commissioned at the Jonkershoek (2 ML/day) and Rozendal (6 ML/day) reservoirs at the start of 1995, and at the Idas Valley filtration works (12 ML/day) in mid-1997. As a result of pipe network alterations, flow through the Idas Valley units rapidly exceeded the design flow by about 50%, and in February 2001 an upgraded limestone contactor was commissioned at Idas Valley (18 ML/day). All of the limestone contactors are of the standard CSIR design, comprising a minimum of two identical reactor units each containing a bed of graded limestone particles, through which water flows in an upward direction. The units are positioned such that chlorination takes place before limestone contact.

The Stellenbosch drinking-water reticulation network consists mainly of cement type or cement lined pipes; accordingly, iron and copper corrosion products originate from household plumbing, network valves and fittings. From records between the years 1995 and 2000, the iron level of the raw water from Eerste River shows variability between no-detection and 0.10 mg/L, and the level in the water after slow sand-filtration between no-detection and 0.27 mg/L. (Slow sand filtration on its own is not expected to considerably reduce total iron levels.) This considerable variation in iron made it impossible to detect any long-term trends in iron levels in the network as a result of decreased CCDP levels in the network.

With regards to copper corrosion, data collected from the Stellenbosch network since 1995 provides clear evidence of the effect of partial stabilisation on mitigation of copper corrosion. Figures 6.10 and 6.11 shows pH and copper levels at a household sampling point in the centre of the town, which receives blended water originating via the Jonkershoek, Rozendal and Idas Valley limestone contactors.
Regarding stabilisation efficiency, from Figure 6.10 it can be seen that:

- pH adjustment (or stabilisation efficiency) was variable and poor until both the Jonkershoek and Rozendal limestone contactors were functional (pH <7.0 , period before April 1997).
- pH adjustment (or stabilisation efficiency) remained variable; but at an improved, albeit not ideal level, once both the Jonkershoek and Rozendal limestone contactors were functional (pH >7.0, period after April 1997). pH remained variable as a result of influence of variable blend of non-stabilised Idas Valley water.
- It can be noted that since the upgrading of the Idas Valley limestone contactor (i.e. all three reservoirs contributing to water in the centre of town are effectively partially stabilised), the pH of the water has increased to approximately 8 (not shown on graph).

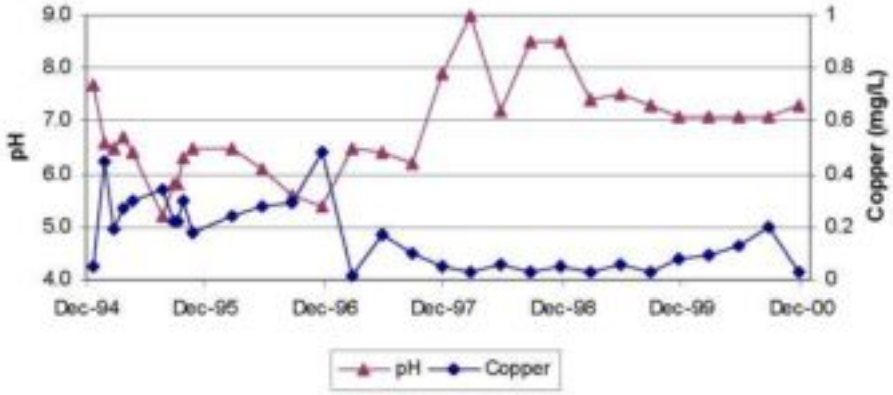

Figure 6.10: pH and copper levels at a household sampling point in Stellenbosch.

Figure 6.11 below shows the relationship between pH and copper levels in the network.

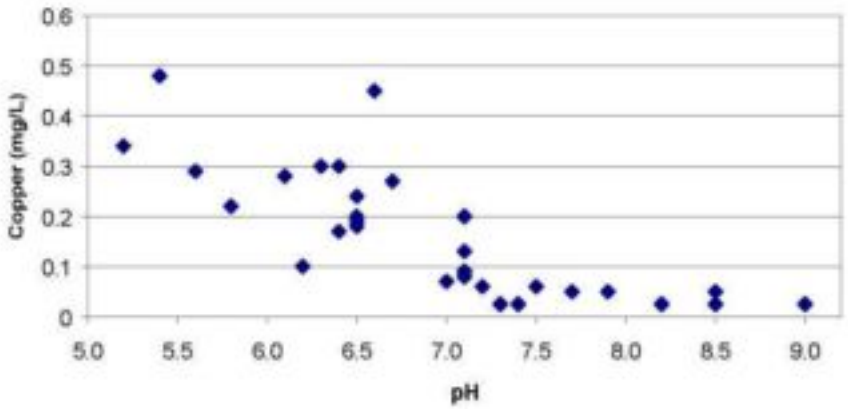

Figure 6.11: Copper versus pH at Stellenbosch network sampling point.

Regarding copper corrosion mitigation, from Figures 6.10 and 6.11 it can be seen that:

Copper corrosion was influenced by variable efficiency of partial stabilisation/pH adjustment. The area of sensitivity for copper corrosion mitigation appears to be at the area between 7.0 and 7.3. Considering the sensitivity of observations to both accurate pH measurement and copper measurement (close to the detection limit), it is suffice to note that at pH's above 7.3 copper corrosion was terminated in the Stellenbosch network.

6.5 CONCLUSIONS

It has been shown that partial stabilisation using limestone contactors can significantly reduce corrosive attack of iron and copper by soft, acidic waters. Data collected from the Bredasdorp network showed that maintaining a CCDP of below 6.0 mg/L, and pH above 7.5, throughout the distribution network effectively eliminated incidences of high rates of iron corrosion. Similarly,

maintaining the pH above 7.1 throughout the network eliminated incidences of high rates of copper corrosion.

Data collected from the Stellenbosch network showed copper corrosion was influenced by variable efficiency of partial stabilisation/pH adjustment, and that at pHs above 7.3 copper corrosion was terminated.

It has been shown that partial stabilisation can achieve the stabilisation levels described above, hence, limestone contactors provide a viable and attractive means of corrosion prevention for the many small holdings, farms, country hotels and rural villages receiving soft, acidic waters.

6.6 REFERENCES

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Chapter 7

Report on Operation of "Spraystab" Units

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7.1 INTRODUCTION

Soft ground waters found in many parts of South Africa are usually acidic, having low pH values owing to their very high dissolved carbon dioxide content. When pumped to the surface, the difference in partial pressure of the CO_2 in the water and the atmosphere results in the expulsion of CO_2 from the water. When a soft ground water has to be stabilised, it is absolutely critical to consider the effect of this unstable excess CO_2 on the process. When stabilisation has to be achieved by means of contact with limestone, the temporarily high calcium carbonate dissolution potential (CCDP) created by the presence of unstable excess CO_2 can result in significant supersaturation with respect to calcium carbonate ($CaCO_3$) when CO_2 is released from the water. The consequent deposition of solid $CaCO_3$ scale on surfaces in contact with the water can be very problematical and frequently has significant financial implications.

To alleviate this problem, the CSIR developed a ground water treatment process termed "Spraystab", which has been found to be very effective for both stabilising and for removing dissolved iron from ground water. The original units were designed to treat from 1 to 3 m^3/h, which would be adequate for typical small users, such as farming communities. The development of the unit and examples of the process efficiency is well documented in an earlier WRC report No 613/1/98 entitled *Stabilisation of Soft, Acidic Waters with Limestone.*

7.2 SPRAYSTAB PROCESS

The Spraystab system consists of three main processes with the following specific functions:

- *Aeration unit*, to strip excess carbon dioxide from the water and dissolve oxygen in the water to enable dissolved iron to be oxidised to its insoluble form.
- *Stabilisation unit*, to increase total alkalinity, pH and calcium content of the water such that its CCDP is significantly reduced. This partial stabilisation is achieved by providing sufficient contact time with a suitable limestone aggregate.
- *Filtration unit*, to remove limestone fines and other insoluble matter such as iron floc. The filter is usually a dual media filter, with a hydro-anthracite upper and a filter sand lower layer. The filter bed is divided by a splitter partition into two separate compartments to allow more efficient backwashing, half the filtration area being backwashed at a time, using the available, generally low volume, supply to the aeration unit.

The Spraystab system differs from other air stripping limestone stabilisation plants in that the spray aeration/stripping occurs directly over the limestone contact bed, the aerated water cascading through the limestone bed, onto the dual media filter. Other similar processes employ a separate aeration/

stripping/settling stage, followed by a flooded bed limestone contact stage, which is sometimes followed by a filtration stage.

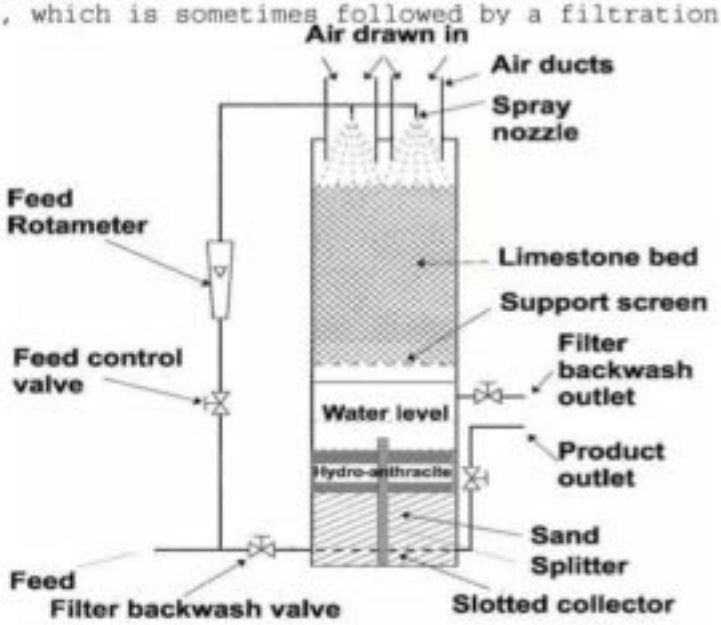

Figure 7.1: Configuration of the Spraystab unit.

Figure 7.2: Installed production Spraystab unit.

Three Spraystab units have been constructed by the CSIR, all three according to the original specification. The first is operating at a farm near Stellenbosch, stabilisation only. The second is operating at a farm near Caledon, where it treats ground water containing iron (1.6 mg/L). The third unit was purchased by Umgeni Water for experimental trials on water with iron levels ranging between 2 and 3.3 mg/L and manganese between 0.2 and 0.3 mg/L.

The first two units are operating satisfactorily, significantly reducing the aggressiveness of the borehole water at both sites as well as effectively removing the iron at the second site. Results of samples taken at the two sites are shown in the table below.

Table 7.1: Raw and treated water quality of two Spraystab units.

Determinant	Site A		Site B			
	1995		1996		1997	
	Raw	Final	Raw	Final	Raw	Final
pH	6.0	8.5	4.7	8.2	4.9	7.1
Calcium mg/l as $CaCO_3$	6.5	26.3	1.9	40	1	15.5
Total alkalinity mg/l as $CaCO_3$	19	39	6	39.8	2	32
Conductivity mS/m	22.5	26	18	24	20	20
CCDP mg/l as $CaCO_3$	80.3	1.4	191	1.6	189	15.6
Iron as mg/L Fe	<0.05	<0.05	1.55	0.05	1.8	0.05

The results showed that the Spraystab unit at Site A was very effective in reducing the aggressive nature of the water, reducing the CCDP from about 80 down to 1.4 mg/L as $CaCO_3$, and increasing the pH from 6.0 to 8.5. This unit was operating at a flow rate of 2 m^3/h, giving a retention time of approximately 3 minutes in the limestone reactor.

The Spraystab unit at Site B gave very good iron removal, reducing the feed water iron levels of 1.55 and 1.8 mg/L to 0.05 mg/L, while effecting a large reduction in the CCDP.

The third Spraystab unit at Umgeni Water, which was used for trials on water with iron content ranging between 2 and 3.3 mg/L and manganese between 0.2 and 0.3 mg/L, gave inconsistent results. Final product iron levels were reported as ranging between 0.1 and 1.6 mg/L and manganese between 0.1 and 0.35 mg/L. This was probably caused by the high turbidity of the feed water (20 to 80 NTU) and problems with the backwash pump, which resulted in poor filtration. Aeration was also not adequate owing to wrong nozzle sizing. Although further trails were envisaged with this unit, Umgeni Water has been unable to carry these out as a result of manpower shortages.

Following the construction of these three Spraystab systems, commercial manufacture of standard Spraystab units (with a treatment capacity of 2.5 m^3/h) has commenced. It is envisioned that these units will be available "off-the-shelf" at distributors supplying "Aquastab pebbles", the limestone used for stabilisation purposes.

7.3 Scale-up of the Spraystab unit

It had been proposed that the CSIR should collaborate with consulting engineers to obtain information for the implementation of the Spraystab process at a scale of 1 ML/day or more. A number of Spraystab-type processes that had subsequently been built by

consultants have been visited (the checklist used during the visits is included in Appendix E), but in the light of the general poor functioning of these plants, which was mostly due to poor design and operation, it was decided to limit the design of a scaled up unit to twice the capacity of the original Spraystab unit. This would be large enough to supply 5 m^3/h (120 m^3/day) for stabilisation only (i.e. where the iron concentration in the feed is less than 1 mg/L), or 2.5 m^3/h (60 m^3/day) for iron removal and stabilisation (i.e. where the iron concentration in the feed exceeds 1 mg/L but is less than 4 mg/L). These larger units would still be manageable, for servicing and limestone addition, by one or two persons and would not require special equipment such as bag lifts, front end loaders etc.

Three of these larger units would be able to produce 0.15 to 0.3 ML/day if used in parallel (depending on the level of dissolved iron in the feed water). A battery of units such as this has the advantage of always having one or two units on-line while the others are being serviced (backwashing the filters, flushing the limestone bed, adding limestone, etc.).

7.4 COMPARISON OF ORIGINAL SPRAYSTAB UNIT WITH LARGER SCALED-UP UNIT

The following table (Table 7.2) shows comparative dimensions of the original Spraystab (capable of treating 2.5 m^3/h) with the scaled-up Spraystab (capable of treating 5 m^3/h).

Table 7.2: Comparison of original Spraystab unit with larger scaled-up unit.

	Original	***Scale up***
Production capacity		
- Stabilisation only	2.5 m^3/h	5.0 m^3/h
- Stabilisation and iron removal	1.25 m^3/h	2.5 m^3/h
Aeration Unit		
Pressure at spray nozzles	300 kPa	300 kPa
Spray nozzles - stabilisation only	2 x 1/2 HH SS 25	2 x 3/4 HH SS 4
Spray nozzles - stabilisation & iron removal	2 x 3/8 HH SS15	2 x 1/2 HH SS 25
PVC air ducts	2 x 250 mm O.D	2 x 300 mm O.D.
Air outlets, in lid with screen	980 cm^2	1420 cm^2
Limestone contact unit		
Internal diameter	600 mm	850 mm
Wall height	1100 mm	1100 mm
Limestone bed depth	800 mm	800 mm
Limestone size grading	-15 +12 mm	-15 +12mm
Total limestone bed volume	0.226 m^3	0.453 m^3
Mean void ratio	45 %	45 %

Multi-media filter		
Internal diameter	600 mm	850 mm
Wall height	1000 mm	1000 mm
Total filter area	0.283 m^2	0.567 m^2
Total bed depth above manifold	600 mm	600 mm
Sand depth	400 mm	400 mm
Sand grading	0.35 to 0.5 mm	0.35 to 0.5 mm
Hydro-anthracite depth	200 mm	200 mm
Hydro-anthracite grading	0.8 to 1.6 mm	0.8 to 1.6 mm
Backwash head clearance	200 mm	200 mm
Maximum filtration rate		
- Stabilisation only	8.8 m/h	8.8 m/h
- Iron removal and stabilisation	4.5 m/h	4.5 m/h
Minimum backwash rate		
- Half filter section at time	28 m/h	28 m/h
Backwash flow rate	4.0 m^3/h	8.0 m^3/h

7.5 LARGER GROUNDWATER STABILISATION/IRON REMOVAL SYSTEMS

Scaling up of the process to handle larger flow rates is feasible, but not in the single unit configuration as was developed for the smaller units described above. Larger systems would use separate aeration units, incorporating settling tanks in the case of water containing iron, followed by upflow reactor vessels, limestone contact units and multi-media filters or membrane filters. These larger systems would have to be custom designed to suit the requirements of the specific application. A number of these larger custom Spraystab-type units that were designed by CSIR have been in operation for a number of years and all are still operating very successfully. However, a number of others designed by reputable consultants have been generally troublesome, owing to not conforming to the proper design parameters. Some of these plants are discussed below.

7.6 ON-SITE INVESTIGATIONS: CUSTOM DESIGNED SPRAYSTAB - TYPE PLANTS OF LARGER CAPACITY

7.6.1 Plant "A" - 2 m^3/hr

Description of plant:

This plant, which was designed by the CSIR, provides water for a small community at a nature reserve. Some existing large galvanized steel storage tanks were adapted and included in the plant. The plant treats approximately 2 m^3/h of borehole water, which contains between 1 and 2 mg/L iron and approximately 0.1 to 0.15 mg/L manganese. The plant has been operating since 1992, and was serviced by the CSIR twice yearly (until 1999).

The plant uses the same process chain as the original Spraystab system, but has separate unit processes for spray aeration/settling, clarification, filtration and stabilisation. The system has proven to be very robust, producing an acceptable product and requiring very little maintenance.

Figure 7.4: Plant "A" stabilisation/iron removal system

The borehole water is fed directly to the four stainless steel spray nozzles located in two vertical rectangular galvanised steel ducts, fitted to the top of a large water tank. Air exit vents in the top of the tank and the top of the spray ducts are covered with wire mesh to prevent contamination. Some iron sludge precipitates on the tank bottom and is occasionally flushed out.

From the aeration/settling tank, the water, which still contains a small amount of suspended oxidised iron, passes to the upflow reactor tank. The water passes upwards though the shallow media, comprising stone chips and largish limestone lumps, to an outlet manifold, from where it gravitates to a pressure multi-media (hydro-anthracite and sand) filter. The filtered water then passes upwards through a limestone bed in the stabilisation tank and overflows directly into a large storage tank.

The water is disinfected by passing through a Klorman in-line chlorinator, before gravitating down to the users. Water can also be pumped to a higher storage reservoir.

Results obtained from a typical sample analysis are shown in Table 7.4.

Table 7.4: Analyses of samples from Plant "A".

Determinant	Feed	Product
Calcium (as mg/L Ca)	3.6	19.2
Total alkalinity (as mg/L $CaCO_3$)	2.0	35.5
Iron (as mg/L Fe)	1.4	0.15
Manganese (as mg/L Mn)	0.10	< 0.05
Turbidity (NTU)	0.35	1.8
PH	4.8	7.9
Electrical Conductivity (mS/m)	75	80
CCDP (as mg/L $CaCO_3$)	172	4.2

In general, the plant produces final water with satisfactory increases in pH, calcium, and total alkalinity, with acceptable removal of iron and manganese. The reduced CCDP indicates that a reasonable degree of stabilisation has been reached. However, the increased level of turbidity indicates that the plant requires servicing. This sample was taken just before a four-monthly routine service, so the results should indicate the worst quality that the plant produces.

7.6.2 Plant "B"- 125 m^3/h

Description of plant:

This plant was designed by a sizeable civil consulting firm and is located at a large estate development. The plant operates on water from a number of boreholes and has a capacity of 125 m^3/h. The borehole water is soft, aggressive and contains 5 to 12 mg/L iron. The entire plant is built on a steep slope.

The plant consists of a large open horizontal settling basin with a sloping bottom and overflow weir at the deep end. At the inlet end the water cascades over about five shallow "step", affording some aeration. This unit was retro-installed when the original plant proved troublesome. From the settling basin the water gravitates to four limestone tanks, with the water dribbling from a number of slotted filter nozzles (as is normally used on the bottom of a sand filter) onto the limestone bed. From the limestone units, the water passes to self -backwashing sand filters and to a storage reservoir.

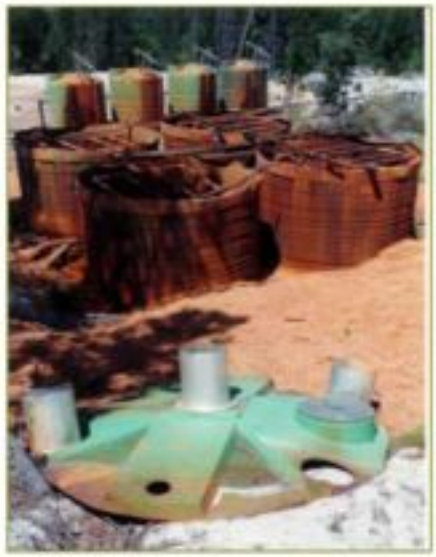

Figure 7.3: Plant "B" stabilisation/iron removal system.

Samples were taken at the plant and the results of analyses of these samples are shown in Table 7.3 below. These results clearly show that the feed water is soft and acidic with a very low pH.

Table 7.3: Analyses of samples from Plant "B".

Determinant	***Feed***	***Post aeration settling***	***Final product (tap in kitchen)***
Calcium (as mg/L Ca)	4.5	7.3	21.0
Total alkalinity (as mg/L $CaCO_3$)	29	20	50
Iron (as mg/L Fe)	9.5	3.0	0.97
Manganese (as mg/L Mn)	2.5	2.3	0.87
Copper (as mg/L Cu)	N/A	N/A	0.65
Turbidity (NTU)	2.6	20	8.1
pH	6.1	6.6	7.0
Electrical Conductivity (mS/m)	19.8	19.4	25.4
CCDP (as mg/L $CaCO_3$)	94.8	24.4	21.2

N/A: Not Analysed

Comments:

The plant is hydraulically under designed relative to the operationally proven Spraystab units designed by the CSIR. The aeration system is totally inadequate and the way it is implemented, i.e. cascading water ahead of an open settling tank, results in subsequent blockage of the "slotted filter nozzles" provided on the four limestone tanks, which were intended to fulfil the function of aeration nozzles. This has caused endless problems for the operators. The aeration is totally inadequate to oxidise the iron, or the manganese. It is also unlikely that the manganese will precipitate out at the low pH (7.3 after settling tank), even if the aeration was sufficient for this purpose.

It is not clear whether the open topped limestone tanks operate in "cascade" or "flooded" mode. Operational experience has shown that it is essential that the limestone bed operates in the "cascade" mode if iron is present. The limestone beds appear to be almost totally clogged with iron. It must be noted that the original Spraystab units were designed to treat water containing iron not in excess of 4 mg/L, and the iron load on these units far exceed this level. These limestone beds would prove to be impossible to clean adequately by simple spraying with a hose, as is routinely used for cleaning proper Spraystab units.

The overall treatment, as indicated by the water quality in the kitchen, manages to increase the pH to 7.0, reduce the iron to 0.97 mg/L and the manganese to 0.87 mg/L, while the turbidity is 8.1 NTU. The copper level of 0.65 mg/L indicates that corrosion of the copper piping, geysers and fittings is occurring. The results indicate that the final treated water fails SABS 241-1999 Class 0 (Ideal) and Class 1 (Acceptable) requirements in terms of iron, manganese and turbidity, and fails SABS 241-1999 Class 0 (Ideal) in terms of copper.

This plant should be completely redesigned using accepted water treatment design principles, as the iron and manganese levels far exceed those recommended for use with Spraystab plants.

7.6.3 Plant "C"- 18 m^3/h

Description of plant:

This plant was designed by a sizeable civil consulting firm to treat 18 m^3/h borehole water for a local district council. The water reputedly has an iron content of about 5 mg/L. The borehole water is first pumped into a reservoir and then pumped to a limestone tank located on top of the reservoir, at a rate of 18 m^3/h. The limestone tank is a cylindrical steel CONN 60 unit, 900 mm in diameter, which stands 1500 mm high. The limestone (Aquastab pebbles) rests on a perforated plate, leaving a space below the plate above the base of the tank. The height of the limestone bed is 1000 mm above the support plate.

The tank has one spray nozzle above the limestone bed, and two inspection hatches, which are covered by perforated plate to allow air to enter the tank but to prevent debris from entering the tank.

It is not possible to flush the limestone bed in an upwards flow direction as there is no top outlet provided, but it is possible to fill and then flush the tank to waste *via* a central base outlet. From the outlet the water gravitates to two pressure sand filters. These units comprise CONN 60 cylindrical tanks mounted on their sides, with Consol coarse 0.7 grade sand. These filters may be backwashed in a normal upflow manner.

The treated water is stored in two reservoirs.

Comments:

The limestone tank apparently receives very little or no regular attention. It is not regularly flushed or the bed hosed down. The limestone is not topped up regularly and no regular water quality monitoring is performed.

After one year of operation the limestone bed blocked up completely and the tank had to be emptied and the limestone replaced, after which normal operation resumed.

The sand filters are backwashed once a week.

In the absence of water quality analytical data it is unclear how the system is performing. However, with reference to the CSIR units, it appears as though the plant is overloaded and both the iron removal capability and the stabilisation are questionable, especially as the aeration without any induced draught into the tank appears to be inadequate. Replacing the limestone once per year is expensive and it is very likely that the performance will deteriorate and probably become quite poor towards the end of the year.

7.7 SUMMARY AND CONCLUSIONS

During this project, groundwater treatment and/or iron removal sites were visited. Information gathered from these visits was assessed and used to set out guidelines for the design and operation of Spraystab groundwater treatment systems.

It was found that the present Spraystab system can be up-sized to treat approximately 5 m^3 /h (if the feed's iron concentration does not exceed 1 mg/L). Dimensions are given in the report for the upgraded design.

The upper limit for iron in a water to be treated with the Spraystab system is set at 4 mg/L. However, the iron load affects the maximum capacity to which the system can be upgraded. If iron in the feed water exceeds 1 mg/L, the maximum capacity to which the Spraystab can be up-sized is 2.5 m^3/h.

Scaling up of the process to handle larger flow rates than mentioned above is feasible, but not in the single unit configuration as was developed for the smaller units described above. Larger systems would use separate aeration units, incorporating settling tanks in the case of water containing iron, followed by upflow reactor vessels, limestone contact units and multi-media filters or membrane filters. These larger systems have to be designed to suit the requirements of the specific application.

7.8 RECOMMENDATIONS

From inspection and analysis of various groundwater treatment and/or iron removal sites during this project, it is recommended that the following stepwise procedure be followed (on a site specific basis):

- *Step 1*
  Remove CO_2 (aeration via spray nozzles). This unit operation will strip excess CO_2 from the water and dissolve some oxygen into the water to assist in the oxidation of iron and manganese. Settling tanks should be provided if iron is present in the groundwater.

- *Step 2*
  Raise pH, calcium and total alkalinity (partial stabilisation using a suitable limestone aggregate). The associated increase in pH and total alkalinity promotes the oxidation of iron and manganese to their trivalent state, which is insoluble and precipitates to form floc.

- *Step 3*
  Filter iron floc (dual media filter comprising both hydro-anthracite and filter sand or membrane filtration). The filter will also remove limestone fines and any other insoluble matter.

NOTE: If iron is flocculated prior to aeration the spray nozzles will block (see Plant "B") and aeration would be ineffective.

CHAPTER 8

FINAL CONCLUSIONS

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Whilst conventional lime and carbon dioxide stabilisation methods are well documented and understood, control of the process requires well trained staff and reliable equipment - both seldom available in the many small towns and communities receiving such waters. Furthermore, lime mediated stabilisation is expensive, usually comprising more than 50% of the chemical cost of water treatment. An alternative approach that has been successfully implemented at a number of treatment works throughout the Western Cape is partial stabilisation using limestone. Past experience shows that partial stabilisation with limestone has significant advantages over the traditional use of lime and carbon dioxide, including a significant running cost saving of about 75% relative to lime stabilisation.

With this project, limestone mediated stabilisation technology was consolidated, using information gathered through experience of CSIR and various water suppliers that implemented the technology. A number of operational limestone contactor units that treat surface waters have been visited. In all cases the limestone contactors improved the aggressive/corrosive qualities of their feed waters, and in most cases, significantly so. Information gathered from these visits was assessed and used to set out guidelines for the design and operation of limestone contactors. In particular, where shortcomings in the design or operation of a system led to inefficient or sub-optimal performance of the process, these shortcomings were documented, to prevent these mistakes from being repeated. Final design and operational details will be captured in a guidelines document, which will be used to transfer limestone stabilisation technology to potential users.

Particular issues relating to the implementation and design of limestone contactor systems for surface waters, which were identified at the planning stage of the project, were:

(i) the upper limit for colour in the feed water of surface water limestone contactors,
(ii) the effect of limestone mediated, partial, stabilisation on the reduction of aggressive attack of cement materials and corrosion of metals in reticulation networks.

Conclusions *re* the above two issues are given below.

8.1 UPPER LIMIT FOR COLOUR IN THE FEED WATER

The following conclusions were reached w.r.t. limestone stabilisation of coloured surface waters:

- Limestone contactors appear to be capable of partially stabilising acidic coloured waters, with colour ranging from 50 to 450 mg/L Pt, quite readily, provided that the limestone bed is regularly flushed to remove fines and other loose deposits. It should, however, be noted that partial stabilisation of highly coloured waters should be practically limited to smaller limestone contactors. This is a result of the fact that the limestone bed will eventually become "blocked". When this occurs, flushing alone will not clean the bed, and the limestone would need to be replaced. Removal and replacement of limestone for a large contactor would be costly and time consuming. In smaller limestone contact systems, replacement of limestone would not be as problematic.
- Since such effective flushing is not achievable on larger municipal units that treat volumes of 1 ML/day or more, the maximum limit for colour in the feed water to the larger municipal units is set at 30 mg/L Pt. This limit is based on experience on existing municipal units.
- For smaller contact units in which the whole limestone bed can be replaced with relative ease, a higher colour level can be tolerated, bearing in mind that with higher colour levels, the flushing requirement increases.

- Regular flushing (or possibly backwashing in the case of small contactor units), according to a fixed routine, is essential to maintain performance. The cleaning frequency depends on the colour and iron load imposed on the reactor. The insoluble organic and turbidity load will also affect the performance, if regular flushing is not carried out.

8.2 THE EFFECT OF PARTIAL STABILISATION ON CEMENT AGGRESSION

Laboratory aggression tests were initiated, to test the effect of limestone partial stabilisation on the rate of aggressive attack on cast cement concrete samples. The experiment was repeated with fully stabilised water (i.e. with slightly positive calcium carbonate precipitation potential, achieved by means of chemical dosage), so that the effect of partial stabilisation can be compared to that of full stabilisation.

Wrt aggression mitigation, it has been shown that:

- The unstabilised water is very aggressive towards cement concrete, leaching out calcium and total alkalinity from the samples at a significantly greater rate than both the partially stabilised water or fully stabilised water.
- Comparison of the partially stabilised water with the fully stabilised water indicates that:
  - In both cases, greater dissolution of alkali's existed. The total alkalinity curve includes the dissolution of all alkali's (i.e. calcium and other alkali's), whereas the calcium curve only records dissolution of calcium mineral. Therefore, total alkalinity is the more important measure of the rate of aggressive attack.
  - At the end of the experiment, calcium mineral dissolution had slowed down significantly for the fully stabilised water and was slowing down for the partially stabilised water.
  - Whilst the trendlines of "total attack" (leaching of calcium and other alkali's from the cement matrix - indicated by the total alkalinity curves) for both the partially stabilised and fully stabilised waters indicate that a decreasing rate of attack was occurring, the curves had not yet settled down at the end of the experiment. Results, however, clearly indicate that the rate of attack for both the partially stabilised and fully stabilised waters is very similar (constant difference - delta total alkalinity) and that the curves are tending towards settling. This result suggests that the relative degree of protection against aggressive attack offered by effective limestone mediated partial stabilisation is similar to a fully stabilised water.

8.3 THE EFFECT OF PARTIAL STABILISATION ON CORROSION

Data was collected from the Bredasdorp and Stellenbosch reticulation networks, to determine the effect that limestone mediated, partial stabilisation has on iron and copper corrosion in municipal water distribution networks.

It has been shown that partial stabilisation, using limestone contactors, can significantly reduce corrosive attack of iron and copper by soft, acidic waters. Data collected from the Bredasdorp network showed that maintaining a CCDP of below 6.0 mg/L and pH above 7.5 throughout the distribution network effectively eliminated incidences of high rates of iron corrosion. Similarly, maintaining the pH above 7.1 throughout the network eliminated incidences of high rates of copper corrosion.

Data collected from the Stellenbosch network showed copper corrosion was influenced by variable efficiency of partial stabilisation/pH adjustment, and that at pH's above 7.3, copper corrosion was terminated.

It has been shown that partial stabilisation with limestone can achieve the stabilisation levels described above (a CCDP below 6.0 mg/L and pH above 7.5), hence, limestone contact is a viable and attractive means of corrosion prevention for the many small holdings, farms, country hotels and rural villages receiving soft, acidic waters.

8.4 GROUNDWATER CONSIDERATIONS

Special consideration is needed for the stabilisation of groundwaters. The Spraystab unit, developed during the previous WRC project, has been shown to be effective for iron removal for small scale users (1 to 3 m^3/h), where iron is less than 3 mg/L. Importantly, the Spraystab system is able to achieve iron removal with a total retention time of about fifteen minutes; i.e. considerably less than the two to three hours of a conventional system.

During this project, groundwater treatment and/or iron removal sites were visited. Information gathered from these visits was assessed and used to set out guidelines for the design and operation of Spraystab groundwater treatment systems.

Two particular issues relating to the implementation and design of the Spraystab system that were addressed in this project are discussed below.

8.4.1 Treatment capacity of the Spraystab system

It was found that the present Spraystab system can be up-sized to treat approximately 5 m^3/h (if the feed's iron concentration does not exceed 1 mg/L). Dimensions are given in the report for the upgraded design.

8.4.2 Upper limits for iron and manganese removal with the Spraystab type system

The upper limit for iron in a water to be treated with the Spraystab system is set at 4 mg/L. However, the iron load affects the maximum capacity to which the system can be upgraded. If iron in the feed water exceeds 1 mg/L, the maximum capacity to which the Spraystab can be up-sized is 2.5 m^3/h.

Scaling up of the process to handle larger flow rates than mentioned above is feasible, but not in the single unit configuration as was developed for the smaller units described above. Larger systems would use separate aeration units, incorporating settling tanks in the case of water containing iron, followed by upflow reactor vessels, limestone contact units and multi-media filters or membrane filters. These larger systems have to be designed to suit the requirements of the specific application.

APPENDIX A:

CHECKLIST FOR LIMESTONE CONTACTOR DESIGN/OPERATION SITE VISITS

General	*Check*
Location of unit: **Date of visit:**	
Period of operation:	
• Commissioning (month/year)	
• Currently operating?	
• Has it been out of commissioning for extended periods?	
If yes, specify: reason(s)	
When	
Responsibilities: Skill level: Tel no:	
• Overall responsibility:	
• Operator:	
• Other:	
Physical Lay-Out: • Sketch plan	
• Photograph	
General condition (appearance and safety)	
Construction material:	
Access to important points: • Limestone filling/inspection hatch (Y/N)	
• Sampling points FEED (Y/N) PRODUCT (Y/N)	
Any pressure measurement? (Y/N)	
Services on Site • Electricity	
• Water hose	
• Other (specify)	
Hydraulic Design	
Operational flow rate: Maximum flow rate:	
Shape of unit (make sketch if needed):	
Dimensions of bed:	
Operational flow direction:	
Is short-circuiting possible? (Y/N) likely? (Y/N)	

How is bed supported?	
Positioning and size of inlet/outlet:	
Inlet: Position Diameter	
Outlet: Position Diameter	
Under-drain: Position Diameter	
Is top of unit closed? i.t.o. light: i.t.o. access to birds, insects, etc:	
Does the pipe lay-out allow: Down-flow? Flow to waste?	
Complete drainage? Bypassing of bed?	
Flow distribution system:	
Description (sketch if necessary)	
History of problems? Blockage Mechanical Failure	
If yes, more details:	
Were problems rectified? How?	
Operation	
Is there a formal operation procedure? If yes, has a copy been obtained?	
Is there an operation log book? If yes, have you paged through it with the operator?	
Topping up with limestone: How often checked?	
What prompts topping up?	
Topped up at fixed time intervals? If yes, how often?	
Are limestone usage figures available?	
Limestone packaging Bags or Bulk	
Means of transport of limestone	
Is standard Aquastab media (12-15 mm sizing) used?	
Condition of limestone when added (many fines?)	
Is the unit drained... Regularly (specify estimated time intervals) Seldom? Never?	
What prompts drainage operation?	
Indication of drainage flow rate (eg. it takes x min to drain)	
Is the unit run to waste? Regularly (specify time intervals) Seldom? Never?	
What prompts run to waste operation?	
Indication of waste flow rate (is it same as operational flow rate?)	

Is there any warning mechanism indicating blockage of the bed?	
Was the unit ever emptied out?	
If yes, what prompted it?	
Observations made when bed was emptied:	
Size distribution: Cross-sectional	
Vertical	
Any residue forming on particles?	
Is an increase in treatment capacity foreseen? If yes, when?	
What equipment will need upgrading?	
Pre- and post-treatment	
Pre-treatment steps:	
Is there a strainer before the limestone bed?	
Post-treatment steps:	
Method/location of disinfection points:	
Observations on the general efficiency of treatment at the plant:	
How often is water quality monitored? FEED STAB PRODUCT	
RAW WATER SOURCE FINAL WATER	
OTHER (specify)	

WQ Parameters being monitored:	
On-site sampling	
pH **Temperature**	
CALCOSTAB FEED:	
CALCOSTAB PRODUCT (1st UNIT)	
CALCOSTAB PRODUCT (2nd UNIT)	
RAW FEED TO WTP:	
FINAL PRODUCT:	
OTHER (specify):	
Are any pressure drop measurements possible? If yes:	
PRESSURE DROP (1st UNIT)	
PRESSURE DROP (2nd UNIT)	
General Comments	

APPENDIX B:

ANALYTICAL RESULTS OF STABILISATION TESTS ON COLOURED WATERS

Jonkershoek tests (23 November 1999 - 19 October 2000)

Date	11/23/99		6/8/00		7/17/00		8/8/00		9/11/00		10/19/00	
DETERMINANT	Feed	Final	Feed	Final	Feed	Final	Feed	Final	Feed	Final	Feed	Final
Calcium as Ca mg/l	0.5	4.8	0.4	4.6	0.4	4	0.31	4.5	0.27	4.5	0.34	10.9
Alkalinity as $CaCO_3$ mg/l	3	13.3	2.3	13	1.8	10.8	2	13	1.3	11	2	30
Iron as Fe mg/l	0.11	0.09	0.13	0.06	0.1	<0.05	0.07	0.07	0.05	<0.05	0.25	0.36
Conductivity mS/m @25^0	3.6	5.7	3.2	5.2	3	4.8	3.35	5.7	2.9	5	-	-
pH (Lab)	6.4	8.8	6.2	9.1	5.8	8.9	6.1	9.6	6	9.1	6.3	8.4
TurbidityNTU	0.7	0.52	1.9	0.45	1.4	0.55	0.52	0.64	0.43	0.45	0.33	4.8
Colour (Filt) mg/l Pt	15	20	20	20	25	30	10	10	20	20	15	30
Colour (Unfilt) mg/l Pt	20	25	30	30	30	30	15	15	20	20	15	45
CCDP as $CaCO_3$ mg/l	13.7	5.4	13.3	3.5	18.3	4.8	13.9	1.6	14.5	5.3	13.6	2.7

Steenbras tests (28 January 2000 - 22 November 2000)

Date	28/01/00		05/04/00		02/05/00		8/6/00		14/07/00		08/08/00		11/9/00		9/10/00		22/11/00	
DETERMINANT	Feed	Final	Feed	Final	Feed	Final	Feed	Final	Feed	Final	Feed	Final	Feed	Final	Feed	Final	Feed	Final
Calcium as Ca mg/l	1.3	5.9	1.2	4.7	1.3	4.6	1.3	5.7	1.1	3.7	1.2	4.1	1.2	3.2	1.9	4.6	1.8	5.6
Alkalinity as $CaCO_3$ mg/l	2	12	2	10.5	1.8	10	2	12	1	7.3	1.3	8.5	0.25	4.8	2.5	9.3	2	12
Iron as Fe mg/l	0.41	0.31	0.8	0.4	0.61	0.48	0.98	0.81	0.83	0.51	0.42	0.39	0.35	0.34	0.92	0.31	0.34	0.3
Conductivity mS/m @25^0	7.7	9.7	8.4	9.8	8.4	9.7	8.2	9.8	8	8.6	7.7	8.6	7.9	8.2	8.7	9.4	8.6	10.2
pH (Lab)	5.4	7.8	5.6	8.2	5.4	7.7	5.5	7.5	5	6.9	5	7.3	5	6.7	5.6	7.3	5.6	8
TurbidityNTU	2.5	2.2	5.1	3.1	3.9	2.9	7.7	6.6	6	3.4	3.5	3.2	4.4	4.1	9.6	3.2	3.7	2.8
Colour (Filtered) mg/l Pt	55	60	100	100	75	75	100	80	75	50	125	100	100	100	100	100	70	70
Colour (Unfiltered) mg/l Pt	60	60	150	100	75	75	130	110	100	70	150	120	75	75	150	120	75	75
CCDP as $CaCO_3$ mg/l	43.6	6.4	28.6	6.8	40.1	7.5	34	6.1	70.1	9.3	82.3	7.4	39.5	11.2	33.8	8.3	28.5	6.3

Suurbraak tests (7 May 1999 - 20 September 2000)

Date	7/5/99		20/07/99		4/8/99		26/08/99		6/9/99		21/09/99		1/11/99		7/12/99		5/5/00		17/08/00		20/9/00	
Determinant	Raw	Final	Raw	Final	Raw	Final	Raw	Final	Raw	Final	Raw	Final	Raw	Final	Raw	Final	Raw	Final	Raw	Final	Raw	Final
Calcium as Ca mg/l	3.3	24.3	0.2	7.3	0.4	7.9	0.6	9.1	0.48	8.13	0.5	9.7	0.52	3.5	0.7	12.7	0.5	14.1	0.6	9.3	0.49	7.7
Alkalinity as CaCO3 mg/l	0.5	22	0	14	0	17	2.8	23	-	17	-	21	0	5	0	28	0.3	35	0	22	0	17
Conductivity mS/m@25@C	4.3	7	4.6	6.2	4.5	5.8	19.6	23	4.65	6.18	4.84	7.2	4.7	4.3	4.7	8.9	4.8	10.3	5	8	4.5	5.7
pH (Lab)	4.7	8	4.5	7.5	4.5	7.4	4.9	6	4.2	7.2	4.3	7.6	4.3	6.1	4.4	7.6	4.6	7.4	4.5	7.3	4.4	7
Total Dissolved Solids (Calc) mg/l	28	45	29	40	29	37	125	147	30	40	31	46	30	28	30	57	31	66	32	51	29	36
Iron as Fe mg/l	0.53	0.37	0.63	0.56	0.3	0.27	1.9	1.8	0.45	0.28	0.41	0.28	0.34	0.34	0.52	0.28	0.59	0.34	0.55	0.39	0.38	0.28
Saturation pH (pH) (20@C)	11.7	9.2	-	9.5	-	9.4	11.3	9.2	-	9.4	-	9.2	-	-	-	9	12.4	8.8	-	9.2	-	9.4
Turbidity NTU	0.31	0.52	1.2	0.76	0.77	0.76	0.17	7.9	-	-	0.31	34	0.5	0.48	-	-	3.6	1.3	0.35	0.91	0.35	1.4
Colour mg Pt/L(unfilt)							-	-			-	-	250	200	250	250	450	300	300	300	300	250
Colour mgPt/l (filt)							-	-			450	300	-	-	250	200	400	300	250	250	250	200
Hardness as CaCO3 mg/l	17	124	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
CCDP as CaCO3 mg/l	129.3	1.9	200.6	6.3	200.4	6.7	270.8	8.7	465.8	7.7	352.1	5.6	468	21.4	270	5.5	162	14.1	200.7	8.1	270.9	11.1

For all the blank spaces there is no specific surance of filtered or unfiltered its just colour and then with the lines it means there was no colour tested at all

APPENDIX C:

AGGRESSION TRIALS DATA

Aggression Trials Data (15 January 2001 – 24 June 2001)

Tank 1								Tank 2							
		Start of cycle			End of cycle					Start of cycle			End of cycle		
Period (2001)	Cycle	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	Period (2001)	Cycle	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)
15-18 Jan	1	5.13	3.11	6.5	8.22	25.82	19.5	15-18 Jan	1	7.71	11.67	16.0	7.89	25.91	22.1
18-21 Jan	2	4.91	0.29	4.3	8.35	22.40	21.5	18-21 Jan	2	8.24	13.71	18.1	8.30	20.59	24.0
27-30 Jan	3	5.00	1.20	5.0	8.36	32.00	37.0	27-30 Jan	3	8.22	12.30	19.0	8.85	26.86	30.8
30-2 Feb	4	4.46	-1.63	4.4	8.80	14.86	13.4	30-2 Feb	4	8.12	12.16	17.8	8.97	18.58	20.5
2-5 Feb	5	4.80	-0.37	4.2	8.97	13.19	20.0	2-5 Feb	5	7.87	15.47	20.3	8.66	18.71	24.0
5-8 Feb	6	4.91	-1.42	4.8	9.24	16.07	20.1	5-8 Feb	6	7.50	10.04	15.8	8.50	19.94	22.8
8-11 Feb	7	4.90	1.14	4.8	8.61	16.21	18.9	8-11 Feb	7	7.81	10.48	16.1	8.75	17.05	22.6
11-14 Feb	8	4.55	0.20	4.2	8.06	15.17	17.8	11-14 Feb	8	7.21	11.14	19.4	8.97	20.82	24.2
14-17 Feb	9	5.13	-0.01	3.2	8.72	13.33	15.5	14-17 Feb	9	7.41	8.68	11.8	7.98	21.87	19.5
17-20 Feb	10	4.91	-1.87	4.1	8.96	11.03	15.5	17-20 Feb	10	7.20	8.28	12.7	8.87	16.56	18.7
20-23 Feb	11	4.79	0.48	3.9	8.89	10.80	19.0	20-23 Feb	11	7.10	7.62	12.4	9.16	15.04	21.0
23-26 Feb	12	5.04	1.31	5.5	9.63	13.72	19.1	23-26 Feb	12	7.08	7.75	12.3	7.72	23.19	22.0
26-1 Mar	13	4.72	-0.90	4.7	9.36	10.67	18.5	26-1 Mar	13	6.84	5.20	14.9	7.80	16.27	22.8
1-4 Mar	14	5.53	-1.73	5.4	7.54	10.73	18.7	1-4 Mar	14	7.49	9.83	12.4	7.66	17.08	23.3
8-11 Mar	15	5.02	0.09	5.2	8.52	4.87	12.1	8-11 Mar	15	7.08	8.13	14.5	7.21	13.37	17.9
11-14 Mar	16	4.86	-1.95	5.1	9.32	9.86	17.5	11-14 Mar	16	7.09	8.05	14.5	9.29	16.01	21.4
14-17 Mar	17	5.24	1.10	5.5	9.42	10.83	18.5	14-17 Mar	17	7.18	7.41	13.6	9.54	13.92	23.0
17-20 Mar	18	5.03	1.93	5.8	9.37	10.18	17.5	17-20 Mar	18	7.10	8.15	14.4	9.29	15.55	23.2
20-23 Mar	19	4.97	0.08	5.3	8.69	9.40	16.2	20-23 Mar	19	7.66	5.23	14.3	8.86	13.67	23.7
23-26 Mar	20	4.83	1.85	5.7	6.91	4.99	16.1	23-26 Mar	20	8.21	2.30	14.1	8.42	11.78	24.2
26-29 Mar	21	4.82	0.18	5.3	6.93	5.29	14.8	26-29 Mar	21	5.86	2.18	13.8	8.05	14.36	23.3
29-1 Apr	22	4.85	0.88	5.9	7.68	7.61	19.0	29-1 Apr	22	6.64	3.85	16.5	8.56	15.07	28.1

Tank 1								Tank 2							
		Start of cycle			End of cycle					Start of cycle			End of cycle		
Period (2001)	Cycle	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	Period (2001)	Cycle	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)
1-4 Apr	23	5.08	1.23	8.7	8.07	6.43	18.2	1-4 Apr	23	7.02	8.08	15.0	8.77	13.76	23.5
10-13 Apr	24	4.56	-1.75	5.2	7.89	5.64	14.0	10-13 Apr	24	6.43	3.96	12.1	8.48	11.43	19.5
13-16 Apr	25	4.84	-1.08	5.5	7.35	3.13	14.3	13-16 Apr	25	6.25	3.93	12.2	8.01	13.88	21.5
16-19 Apr	26	4.83	1.79	5.4	7.13	4.15	14.2	16-19 Apr	26	6.40	3.26	13.2	7.91	12.84	21.9
19-22 Apr	27	4.87	-1.02	5.0	7.23	4.92	13.3	19-22 Apr	27	6.49	4.27	12.5	7.77	12.87	19.8
29-2 May	28	4.47	-0.11	6.5	5.19	0.60	13.0	29-2 May	28	4.77	1.64	10.5	6.87	4.71	20.5
2-5 May	29	4.53	1.84	7.5	6.40	3.16	14.0	2-5 May	29	5.14	2.38	9.8	7.13	7.01	18.8
5-8 May	30	4.91	-2.60	6.2	5.58	2.11	11.0	5-8 May	30	5.50	3.11	9.0	7.38	9.31	17.0
8-11 May	31	4.82	-0.69	7.0	5.59	3.55	12.5	8-11 May	31	6.32	3.30	16.0	7.55	8.84	21.8
11-14 May	32	4.66	-0.01	8.0	4.90	1.65	18.0	11-14 May	32	4.93	0.06	14.4	6.52	4.46	22.5
14-17 May	33	4.74	0.19	5.5	5.86	3.69	12.5	14-17 May	33	5.87	4.56	11.0	7.55	9.80	20.0
18-21 May	34	4.58	0.77	5.1	5.00	2.10	12.4	18-21 May	34	6.52	8.72	21.8	7.46	13.28	27.2
21-24 May	35	4.56	-0.36	5.1	4.61	1.36	12.4	21-24 May	35	4.87	1.78	14.6	5.24	3.72	21.5
24-28 May	36	4.72	-1.45	4.9	6.10	-0.27	11.6	24-28 May	36	6.56	8.63	14.0	8.06	13.66	19.9
28-31 May	37	4.95	0.49	5.0	6.53	0.94	10.4	28-31 May	37	7.34	6.21	13.8	8.18	11.06	17.4
31-3 Jun	38	4.92	0.16	7.0	6.58	1.45	11.6	31-3 Jun	38	7.11	6.45	14.7	8.32	11.48	18.8
3-6 Jun	39	4.80	0.07	6.6	6.30	1.74	11.1	3-6 Jun	39	6.85	5.49	14.8	7.86	10.10	18.3
6-9 Jun	40	4.70	0.58	5.0	6.49	1.93	9.8	6-9 Jun	40	6.78	6.77	13.8	8.18	11.55	17.9
9-12 Jun	41	6.36	3.52	13.0	7.32	6.05	16.6	9-12 Jun	41	7.63	7.90	19.5	8.44	14.91	23.5
12-15 Jun	42	4.98	1.50	8.2	6.97	2.98	13.2	12-15 Jun	42	6.51	5.77	15.2	8.49	12.92	19.6
15-18 Jun	43	5.00	0.16	8.9	6.76	4.51	13.5	15-18 Jun	43	6.38	5.46	14.5	8.13	12.36	20.3
18-21 Jun	44	4.81	-0.18	7.0	6.43	3.10	13.6	18-21 Jun	44	6.35	3.47	13.3	7.79	9.69	19.6
21-24 Jun	45	4.86	-0.51	8.1	4.82	0.74	10.5	21-24 Jun	45	6.36	4.60	15.3	7.27	10.95	19.0

Tank 3								Tank 4							
		Start of cycle			End of cycle					Start of cycle			End of cycle		
Period (2001)	Cycle	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	Period (2001)	Cycle	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)
15-18 Jan	1	9.17	13.93	20.0	7.94	21.62	29.5	15-18 Jan	1	9.55	22.97	20.0	9.32	28.11	24.2
18-21 Jan	2	9.05	16.69	21.9	7.34	29.94	27.0	18-21 Jan	2	9.56	24.45	21.3	9.05	29.84	24.3
27-30 Jan	3	9.10	16.20	22.0	7.78	36.03	37.9	27-30 Jan	3	9.06	22.00	20.5	8.02	37.88	32.5
30-2 Feb	4	9.06	15.45	22.4	8.25	20.32	27.0	30-2 Feb	4	9.57	25.50	22.5	8.68	29.94	28.9
2-5 Feb	5	8.89	16.91	25.8	7.83	27.06	29.3	2-5 Feb	5	9.43	28.85	24.9	8.51	29.62	25.3
5-8 Feb	6	8.92	16.86	21.5	8.24	20.81	29.9	5-8 Feb	6	8.68	24.91	21.8	8.45	28.55	23.8
8-11 Feb	7	9.08	14.64	21.1	8.54	19.14	23.2	8-11 Feb	7	9.56	22.49	21.5	8.38	26.88	21.5
11-14 Feb	8	8.64	18.93	27.2	8.25	22.74	29.5	11-14 Feb	8	9.44	26.21	25.0	8.77	28.21	25.2
14-17 Feb	9	9.17	14.25	18.0	8.50	18.47	21.0	14-17 Feb	9	9.61	20.88	17.4	9.03	24.83	19.5
17-20 Feb	10	9.09	16.35	21.0	8.19	18.85	23.0	17-20 Feb	10	9.62	24.05	21.3	8.71	26.97	22.0
20-23 Feb	11	9.01	15.19	20.5	8.21	18.18	23.0	20-23 Feb	11	9.56	23.60	24.2	9.13	26.35	25.0
23-26 Feb	12	9.18	13.92	20.5	7.60	28.00	23.9	23-26 Feb	12	9.64	23.12	20.8	8.92	28.40	21.5
26-1 Mar	13	8.70	17.62	28.0	8.18	22.61	30.5	26-1 Mar	13	9.56	26.17	26.6	8.29	30.40	27.0
1-4 Mar	14	9.23	15.76	20.0	8.56	19.86	24.0	1-4 Mar	14	9.69	20.86	20.9	7.91	27.99	26.4
8-11 Mar	15	8.93	15.53	20.9	8.69	19.10	21.9	8-11 Mar	15	9.53	21.67	20.6	8.96	21.81	21.3
11-14 Mar	16	8.90	13.75	21.5	8.80	18.34	24.4	11-14 Mar	16	9.44	24.42	21.9	9.12	26.18	22.4
14-17 Mar	17	9.23	13.98	21.5	8.83	20.48	24.5	14-17 Mar	17	9.70	13.98	21.5	9.08	23.99	22.8
17-20 Mar	18	9.23	15.76	24.5	8.84	19.96	26.3	17-20 Mar	18	9.67	23.26	24.2	9.09	24.10	26.3
20-23 Mar	19	9.23	17.92	24.6	8.80	21.02	27.8	20-23 Mar	19	9.63	24.46	25.5	8.96	27.45	25.8
23-26 Mar	20	8.12	21.42	32.5	8.26	25.92	37.0	23-26 Mar	20	9.53	27.69	32.0	8.74	30.82	32.5
26-29 Mar	21	8.61	22.35	31.2	8.23	24.15	33.7	26-29 Mar	21	9.52	30.12	32.4	8.70	31.00	32.6
29-1 Apr	22	8.67	18.87	30.5	8.29	22.45	34.6	29-1 Apr	22	9.28	24.22	31.3	8.92	27.90	34.6

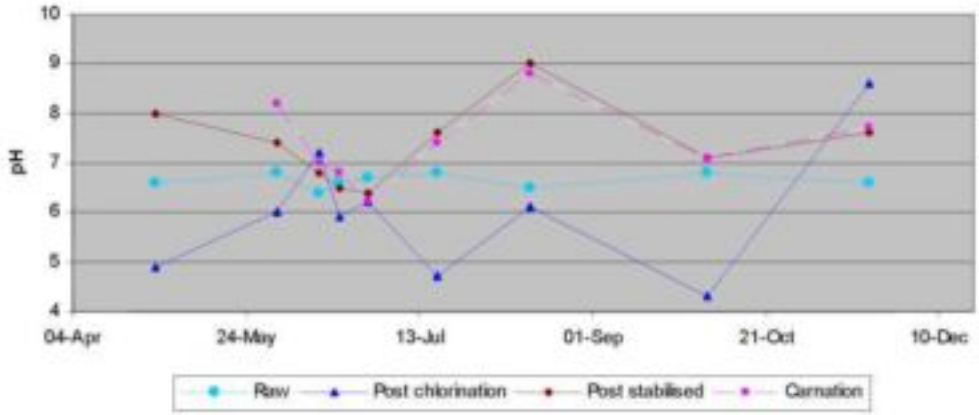
Tank 3								Tank 4							
		Start of cycle			End of cycle					Start of cycle			End of cycle		
Period (2001)	Cycle	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	Period (2001)	Cycle	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)	pH	Alkalinity (mg/L as $CaCO_3$)	Calcium (mg/L as $CaCO_3$)
1-4 Apr	23	9.32	16.55	26.8	8.15	21.24	30.0	1-4 Apr	23	9.65	21.18	26.9	8.98	24.76	28.2
10-13 Apr	24	8.98	15.35	24.5	8.48	21.97	26.0	10-13 Apr	24	9.54	22.48	25.0	7.91	29.44	27.3
13-16 Apr	25	8.81	18.82	27.5	8.47	21.41	28.9	13-16 Apr	25	9.58	26.77	27.0	8.93	28.33	27.5
16-19 Apr	26	8.84	18.68	26.0	8.21	23.04	30.9	16-19 Apr	26	9.55	26.73	26.7	7.85	27.00	27.8
19-22 Apr	27	8.80	15.72	23.0	8.25	18.98	26.2	19-22 Apr	27	9.69	28.68	23.9	8.77	28.88	24.3
29-2 May	28	7.66	20.75	35.0	7.99	23.30	36.0	29-2 May	28	9.07	28.63	35.5	7.92	32.19	36.0
2-5 May	29	8.46	20.65	26.5	8.35	23.64	30.0	2-5 May	29	9.16	25.62	27.5	8.84	30.02	27.5
5-8 May	30	8.57	17.45	27.0	8.22	18.91	29.0	5-8 May	30	9.57	29.03	27.0	8.81	29.68	27.0
8-11 May	31	8.87	17.38	26.5	8.48	17.93	29.0	8-11 May	31	9.60	26.09	27.0	9.25	26.17	27.0
11-14 May	32	8.23	19.18	35.0	7.87	23.79	40.5	11-14 May	32	9.35	28.78	35.5	8.88	29.46	35.5
14-17 May	33	8.46	20.91	29.9	8.70	20.92	30.0	14-17 May	33	9.39	31.11	30.5	8.96	31.12	30.5
18-21 May	34	8.12	25.93	36.5				18-21 May	34	9.09	30.33	37.0	8.25	32.94	37.0
21-24 May	35	7.38	22.60	44.5	7.62	24.93	47.0	21-24 May	35	8.60	35.17	45.0	7.65	36.16	46.0
24-28 May	36	8.17	21.83	29.2	8.28	23.49	31.4	24-28 May	36	9.47	32.87	30.9	8.09	34.30	30.9
28-31 May	37	8.95	15.86	21.5	8.49	17.30	23.5	28-31 May	37	9.56	23.02	21.7	7.80	24.61	21.8
31-3 Jun	38	9.01	12.71	23.0	8.48	14.11	24.4	31-3 Jun	38	9.63	24.65	23.0	7.75	27.40	23.0
3-6 Jun	39	8.73	14.83	22.7	8.24	15.93	25.0	3-6 Jun	39	9.50	23.61	22.7	8.04	25.80	22.7
6-9 Jun	40	9.07	13.12	21.1	8.80	13.95	25.5	6-9 Jun	40	9.60	23.36	21.2	7.53	25.93	21.8
9-12 Jun	41	8.60	17.79	23.5	7.78	19.25	27.4	9-12 Jun	41	9.50	23.55	24.8	8.72	26.01	24.8
12-15 Jun	42	8.81	14.82	21.4	8.45	15.88	25.2	12-15 Jun	42	9.36	23.37	22.8	9.13	25.58	22.9
15-18 Jun	43	8.56	16.23	23.0	8.31	17.77	25.2	15-18 Jun	43	9.56	22.27	23.0	9.17	24.02	23.0
18-21 Jun	44	8.61	15.15	25.0	8.13	19.10	27.4	18-21 Jun	44	9.47	23.08	25.3	9.14	25.08	25.4
21-24 Jun	45	8.47	19.15	28.0	7.87	21.10	28.0	21-24 Jun	45	9.55	26.61	28.0	8.85	26.66	28.2

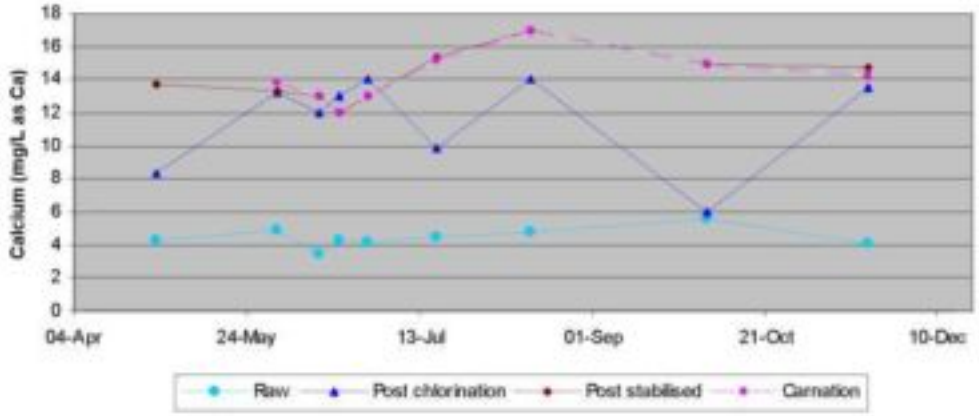
APPENDIX D:

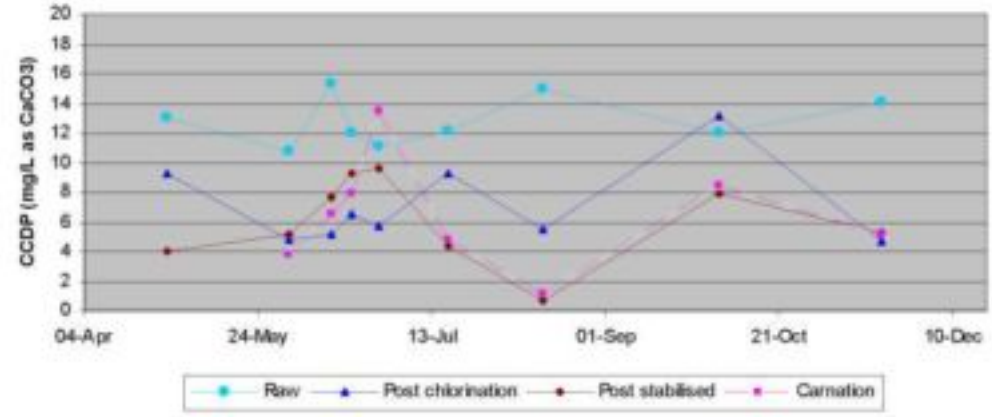
CORROSION INVESTIGATION DATA

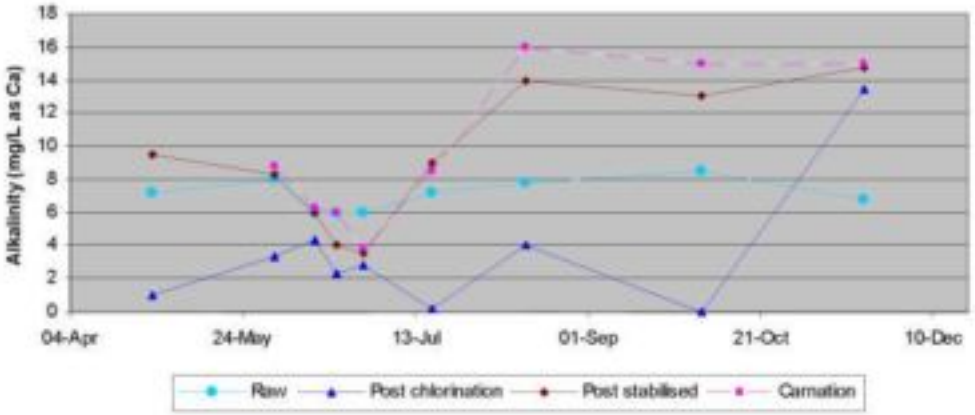
WATER QUALITY BEFORE, DURING AND AFTER TREATMENT, AND AT ONE NETWORK MONITORING PLANT

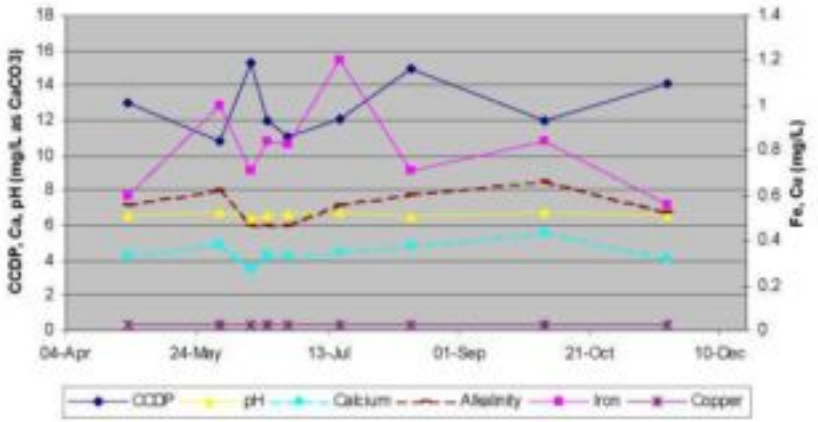
Water quality before, during and after treatment, and at one network monitoring point:



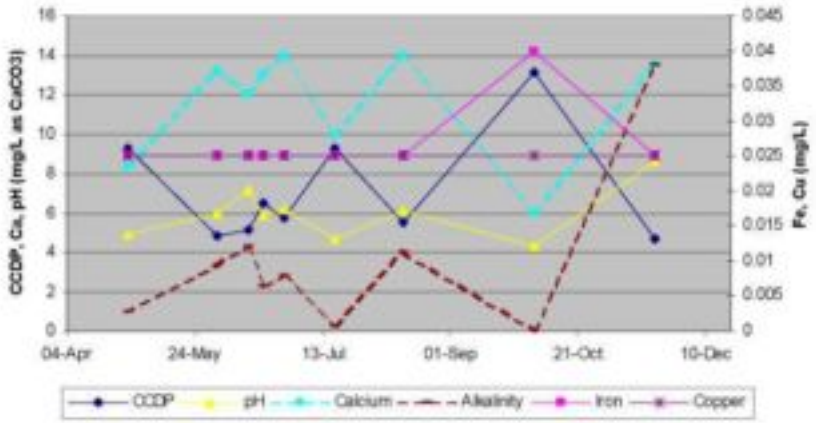




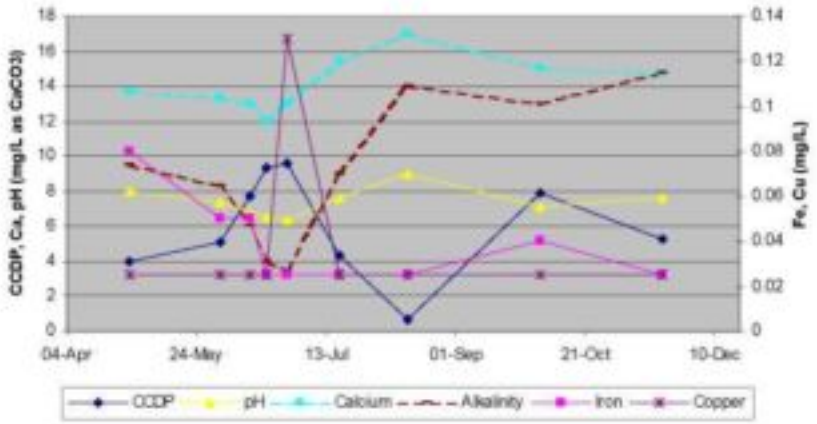




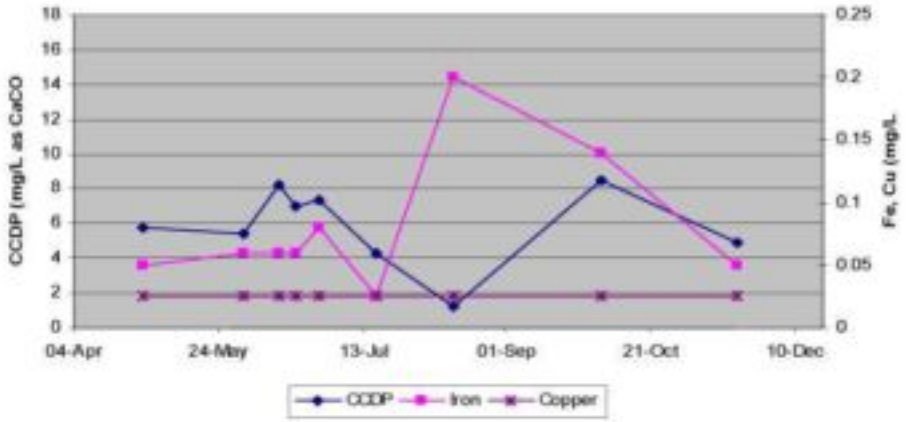
Raw water



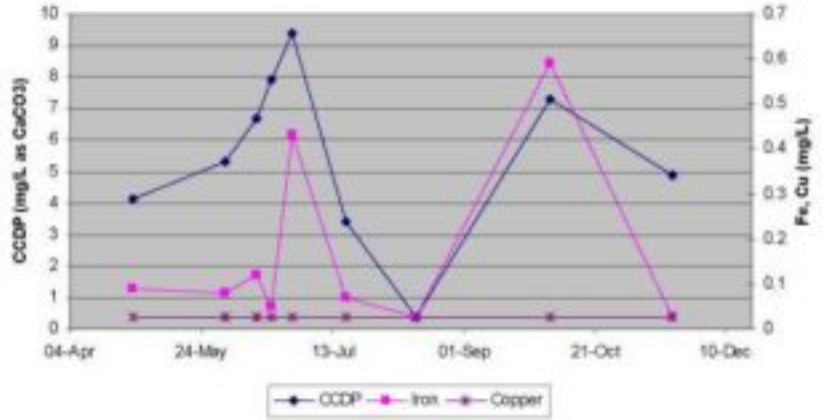
Post chlorination



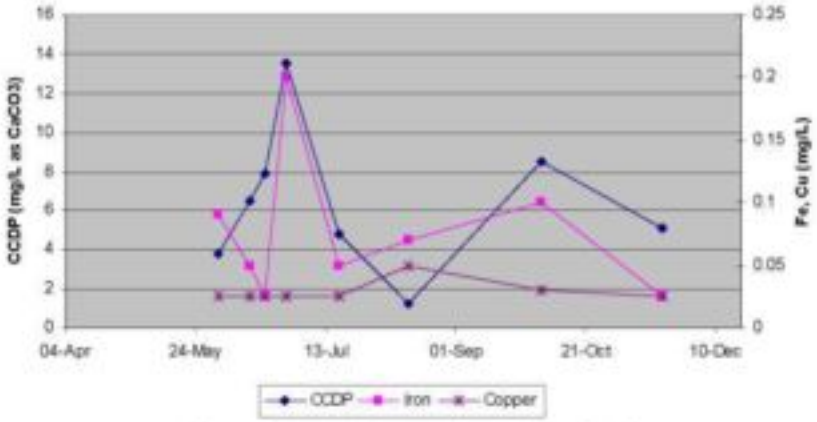
Post-stabilisation



Network monitoring point: "All Saints"



Network monitoring point: "Plakkers"



Network monitoring point: "Carnation"

Dates	*28-Apr*	*02-Jun*	*14-Jun*	*20-Jun*	*28-Jun*	*18-Jul*	*14-Aug*	*04-Oct*	*20-Nov*
RAW									
pH	6.6	6.8	6.4	6.6	6.7	6.8	6.5	6.8	6.6
CCDP as $CaCO_3$ mg/l	13	10.8	15.3	12	11.1	12.1	15	12	14.1
Ca as Ca mg/l	4.3	4.9	3.5	4.3	4.2	4.5	4.8	5.6	4.1
Alk as $CaCO_3$ mg/l	7.2	8	6	6	6	7.2	7.8	8.5	6.8
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.02	<0.05
Iron as Fe mg/l	0.6	1	0.71	0.84	0.83	1.2	0.71	0.84	0.56
Conductivity mS/m	43	41	36	40	39	39	36	37	38
Aluminium mg/L Al	0.71	1.6	1.14	1.25	1.3	-	-	-	-
Turbidity NTU				6.7	7	17	5.4	8.4	5.3
POST-CHLORINATION									
pH	4.9	6	7.2	5.9	6.2	4.7	6.1	4.3	8.6
CCDP as $CaCO_3$ mg/l	25.6	5.1	6.1	17.1	13	23.6	19.3	30.9	3
Ca as Ca mg/l	8.3	13.2	12	13	14	9.9	14	6	13.5
Alk as $CaCO_3$ mg/l	1	3.3	4.3	2.3	2.8	0.25	4	0	13.5
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.04	<0.05
Iron as Fe mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.04	<0.05
Conductivity mS/m	47	44	42	46	45	43	42	42	43
Aluminium mg/L Al	0.1	0.09	<0.05	<0.1	0.14	-	-	-	-
Turbidity NTU				0.2	0.34	0.19	0.54	0.19	0.21
POST-STABILISATION									
pH	8	7.4	6.8	6.5	6.4	7.6	9	7.1	7.6
CCDP as $CaCO_3$ mg/l	4	5.1	7.7	9.3	9.6	4.3	0.7	7.9	5.3
Ca as Ca mg/l	13.7	13.3	13	12	13	15.4	17	15	14.7
Alk as $CaCO_3$ mg/l	9.5	8.3	6	4	3.5	9	14	13	14.8
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	0.13	<0.05	<0.05	0.02	<0.05
Iron as Fe mg/l	0.08	0.05	0.05	<0.05	<0.05	<0.05	<0.05	0.04	<0.05
Conductivity mS/m	47	45	44	46	45	44	44	42	44
Aluminium mg/L Al	0.19	<0.05	<0.05	0.1	<0.1	-	-	-	-
Turbidity NTU				0.28	0.31	0.28	0.27	0.63	0.23
OFFICE									
pH	8.6	8.7	7.3	7.1	7	7.8	8.8	7.4	7.7
CCDP as $CaCO_3$ mg/l	3.2	2.9	5.5	6.1	6.4	6.4	1.4	6.1	4.9
Ca as Ca mg/l	13.8	14.2	13	13	13	14.9	18	15	15.1
Alk as $CaCO_3$ mg/l	10	9.8	8	6.3	5.8	9.3	14	15	18
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.02	<0.05
Conductivity mS/m	47	45	44	47	45	44	43	43	44
Aluminium mg/L Al	0.14	<0.05	<0.05	0.1	<0.1	-	-	-	-
Iron as Fe mg/l	0.13	0.12	0.1	0.08	0.06	0.08	0.08	0.07	<0.05
Turbidity NTU				0.35	0.3	0.41	0.35	0.52	0.22

Dates	*28-Apr*	*02-Jun*	*14-Jun*	*20-Jun*	*28-Jun*	*18-Jul*	*14-Aug*	*04-Oct*	*20-Nov*
UITKYK									
pH	8.1	8.3	7.2	6.9	6.3	8.7	8.7	7.1	7.7
CCDP as $CaCO_3$ mg/l	3.8	3.5	5.8	7	18.2	3.9	1.8	8	4.9
Ca as Ca mg/l	13.8	14.1	13	13	13	15.1	17	15	14.9
Alk as $CaCO_3$ mg/l	9.8	9.8	7.5	6	7.2	10	14	13	15.5
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	0.05	<0.05	0.05	0.02	<0.05
Iron as Fe mg/l	0.08	0.05	0.07	<0.05	0.05	0.07	<0.05	0.04	<0.05
Conductivity mS/m	47	45	44	47	46	44	44	43	44
Aluminium mg/L Al	0.16	<0.05	<0.05	<0.1	<0.1	-	-	-	-
Turbidity NTU				0.25	7.5	0.37	0.29	0.48	0.23
DU PREEZE									
pH	7.1	7.7	6.9	6.4	6.6	7.3	8.9	7	7.6
CCDP as $CaCO_3$ mg/l	6.4	4.2	7.6	10.2	8.2	5.2	1.2	8.8	5.5
Ca as Ca mg/l	12.8	14.3	13	12	13	14.5	17	14	13.7
Alk as $CaCO_3$ mg/l	8	9.8	7.8	3.8	4	7.8	14	12	13.8
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.02	<0.05
Iron as Fe mg/l	0.19	0.08	0.07	<0.05	0.26	<0.05	<0.05	0.04	0.06
Conductivity mS/m	47	45	44	46	45	44	44	42	44
Aluminium mg/L Al	0.16	0.06	<0.05	<0.1	0.11	-	-	-	-
Turbidity NTU				0.27	1.5	0.28	0.26	0.83	0.2
SHAMEENS									
pH	8.6	8.3	7.1	6.8	6.6	8.3	9.1	7.2	7.6
CCDP as $CaCO_3$ mg/l	3	3.7	6.1	7.7	8.4	3.3	0.3	7.5	5.4
Ca as Ca mg/l	14.5	13.8	13	12	13	15.5	17	15	13.9
Alk as $CaCO_3$ mg/l	10	9	7	5.5	4.3	9.3	14	15	14.3
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.02	<0.05
Iron as Fe mg/l	0.08	0.05	0.05	<0.05	<0.05	<0.05	0.05	0.91	0.05
Conductivity mS/m	48	45	44	46	45	45	44	42	44
Aluminium mg/L Al	0.1	0.18	<0.05	<0.1	<0.1	-	-	-	-
Turbidity NTU				0.28	0.31	0.28	0.26	4.6	0.25
PLAKKERS									
pH	7.9	7.3	7	6.7	6.4	8.3	9	7.2	7.8
CCDP as $CaCO_3$ mg/l	4.1	5.3	6.7	7.9	9.4	3.4	0.4	7.3	4.9
Ca as Ca mg/l	13.9	13.9	13	12	13	14.7	17	15	13.9
Alk as $CaCO_3$ mg/l	9	8	7	4.5	3.3	9.8	14	14	14.5
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.02	<0.05
Iron as Fe mg/l	0.09	0.08	0.12	0.05	0.43	0.07	<0.05	0.59	<0.05
Conductivity mS/m	48	44	44	46	45	44	44	42	44
Aluminium mg/L Al	0.1	0.13	0.16	<0.1	0.21	-	-	-	-
Turbidity NTU				0.24	2	0.3	0.31	3.6	0.2

Dates	*28-Apr*	*02-Jun*	*14-Jun*	*20-Jun*	*28-Jun*	*18-Jul*	*14-Aug*	*04-Oct*	*20-Nov*
TRAFFIC									
pH	7.2	7	6.8	6.5	6.2	7.3	9	6.9	-
CCDP as $CaCO_3$ mg/l	5.8	6.8	7.5	9.3	11.6	5	0.4	10.4	-
Ca as Ca mg/l	13.7	13.3	13	12	13	15.4	18	15	-
Alk as $CaCO_3$ mg/l	8.5	7.5	5.5	4	3	8	15	13	-
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	0.06	<0.05	<0.05	0.02	-
Iron as Fe mg/l	0.08	0.12	0.06	<0.05	0.06	<0.05	<0.05	0.04	-
Conductivity mS/m	48	45	44	46	45	44	44	42	-
Aluminium mg/L Al	0.14	0.09	0.13	<0.1	0.14	-	-	-	-
Turbidity NTU				0.25	0.5	0.34	0.31	1.2	-
ALL SAINT									
pH	7.2	7.3	6.7	6.9	6.8	7.6	8.9	7.1	7.8
CCDP as $CaCO_3$ mg/l	5.8	5.4	8.2	7	7.3	4.3	1.2	8.5	4.9
Ca as Ca mg/l	13.3	13.3	12	13	13	15.5	17	15	13.7
Alk as $CaCO_3$ mg/l	7.8	7.5	5	6	5	8.5	14	15	14
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.02	<0.05
Iron as Fe mg/l	0.05	0.06	0.06	0.06	0.08	<0.05	0.2	0.14	0.05
Conductivity mS/m	47	44	44	46	45	44	44	43	44
Aluminium mg/L Al	0.17	0.13	0.13	<0.1	<0.1	-	-	-	-
Turbidity NTU				0.27	0.34	0.29	0.68	1.4	0.2
DRY CLEAN									
pH	7	7	6.8	6.9	6.6	7.2	8.9	7	7.6
CCDP as $CaCO_3$ mg/l	6.9	6.8	7.5	7	8.2	5.5	1.2	9.2	5.4
Ca as Ca mg/l	12.9	13.7	13	12	14	15.1	17	14	14.2
Alk as $CaCO_3$ mg/l	7.8	7.8	5.5	3.8	4.3	7.8	14	13	14.8
Copper as Cu mg/l	<0.05	<0.05	<0.05	<0.05	0.09	<0.05	<0.05	0.02	<0.05
Iron as Fe mg/l	<0.05	0.1	0.05	<0.05	0.2	<0.05	0.14	0.06	0.07
Conductivity mS/m	47	44	44	46	45	44	44	42	44
Aluminium mg/L Al	0.17	0.09	0.13	<0.1	0.11	-	-	-	-
Turbidity NTU				0.2	1.7	0.3	0.58	1.4	0.41
CARNATION									
pH		8.2	7	6.8	6.2	7.4	8.8	7.1	7.7
CCDP as $CaCO_3$ mg/l		3.8	6.5	7.9	13.5	4.8	1.2	8.5	5.1
Ca as Ca mg/l		13.8	13	12	13	15.2	17	15	14.2
Alk as $CaCO_3$ mg/l		8.8	6.3	6	3.8	8.5	16	15	15
Copper as Cu mg/l		<0.05	<0.05	<0.05	<0.05	<0.05	0.05	0.03	<0.05
Iron as Fe mg/l		0.09	0.05	<0.05	0.2	0.05	0.07	0.1	<0.05
Conductivity mS/m		44	44	46	45	44	44	43	44
Aluminium mg/L Al		<0.05	0.14	<0.1	0.19	-	-	-	-
Turbidity NTU				0.23	1.4	0.31	0.34	1.1	0.25

APPENDIX E:

1. *CHECKLIST OF SPRAYSTAB DESIGN/OPERATION SITE VISITS*

2. *FLOW DIAGRAMME OF STABLISATION/IRON REMOVAL SYSTEM*

E1: Checklist for Spraystab design/operation site visits

General	Check
Location of unit: **Date of visit:**	
Period of operation:	
•• Commissioning (month/year)	
•• Currently operating?	
•• Has it been out of commissioning for extended periods?	
If yes, specify: reason(s)	
when	
Responsibilities: Skill level: Tel no:	
•• Overall responsibility:	
•• Operator:	
•• Other:	
Physical Lay-Out: •• Sketch plan (if necessary)	
•• Photograph	
General condition (leaks, appearance and safety)	
Construction materials:	
Services on Site •• Electricity	
•• Water hose	
•• Other (specify)	
General Design	
Operational flow rate: Maximum flow rate:	
Shape of unit (make sketch if needed):	
Dimensions of the system, and sub-units:	
Does the pipe lay-out allow: Hosing down the limestone bed: Flow to waste?	
Backwashing of the filter?	
Complete drainage? Bypassing of the unit?	
Visual inspection possible (eg. clear PVC strips), or are inside of beds only visible when the system is taken	
apart?	
Aeration	
General design of aeration section adequate?	
Spraynozzles - fine spray produced? If not, checked for blockage?	

Number Type Size Specified flow	
Specified pressure	
Are pump characteristics known? Is pump curve available?	
Min flow Delivery pressure at min flow	
Max flow Delivery pressure at max flow	
Mesh screens to prevent leaves, etc?	
Are aeration nozzles readily accessible?	
Limestone contact section	
How is limestone bed supported?	
Bed dimensions Bed depth on arrival	
Is backwashing of bed possible?	
Sizing of inlet and outlet	
Can bed be hosed down?	
Topping up with limestone: How often checked?	
What prompts topping up?	
Topped up at fixed time intervals? If yes, how often?	
Are limestone usage figures available?	
Limestone packaging Bags or Bulk	
Means of transport of limestone	
Is standard Aquastab media (12-15 mm sizing) used?	
Condition of limestone when added (many fines?)	
Check condition of limestone in unit: Discolouration? Iron-sludge build-up?	
Multi-media filter	
Media used: Sand grading: Sand depth:	
Hydro-anthracite grading: Hydro-anthracite depth:	
Dimensions of filter-bed:	
Bed depth above manifold:	
Backwash head clearance:	
Type of collector manifold:	
Sizing of inlet outlet	
Is filter bed sectional? If yes, can sections be backwashed separately?	
Specifications of pump for backwashing:	
How often is media replaced? What prompts replacement?	

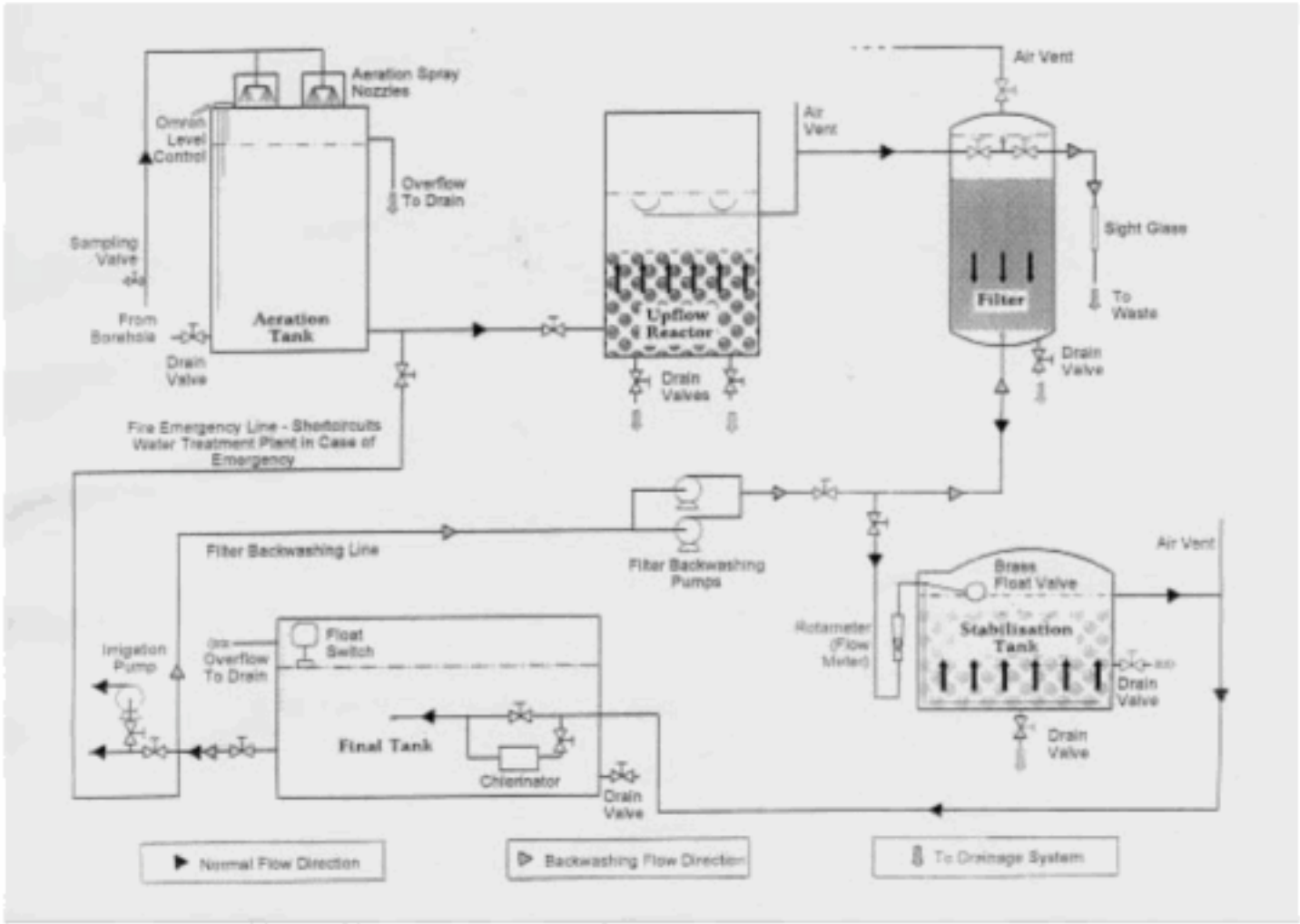
Operation	
Is there a formal operation procedure? If yes, has a copy been obtained?	
Is there an operation log book? If yes, have you paged through it with the operator?	
Is there any warning mechanism indicating blockage of the limestone bed and/or filter?	
Is an increase in treatment capacity foreseen? If yes, when?	
What equipment will need upgrading?	

Pre- and post-treatment	
Pre-treatment steps (if any)	
Post-treatment steps:	
Method/location of disinfection points:	
Observations on the general efficiency of treatment at the plant:	
How often is water quality monitored? FEED TO S'STAB S'STAB PRODUCT	
RAW WATER SOURCE FINAL WATER	
OTHER (specify)	
WQ Parameters being monitored:	

On-site sampling			
	pH	**Temperature**	
SPRAYSTAB PRODUCT WATER:			
POST LIMESTONE CONTACT BED:			
POST AERATION:			
FEED TO SPRAYSTAB:			
RAW FEED TO THE TREATMENT FACILITY (if different to the above):			
AFTER DISINFECTION (if applicable):			

General Comments	

E2: Flow Diagram of Stabilisation/Iron Removal System



Flow Diagram of Stabilisation/Iron Removal System