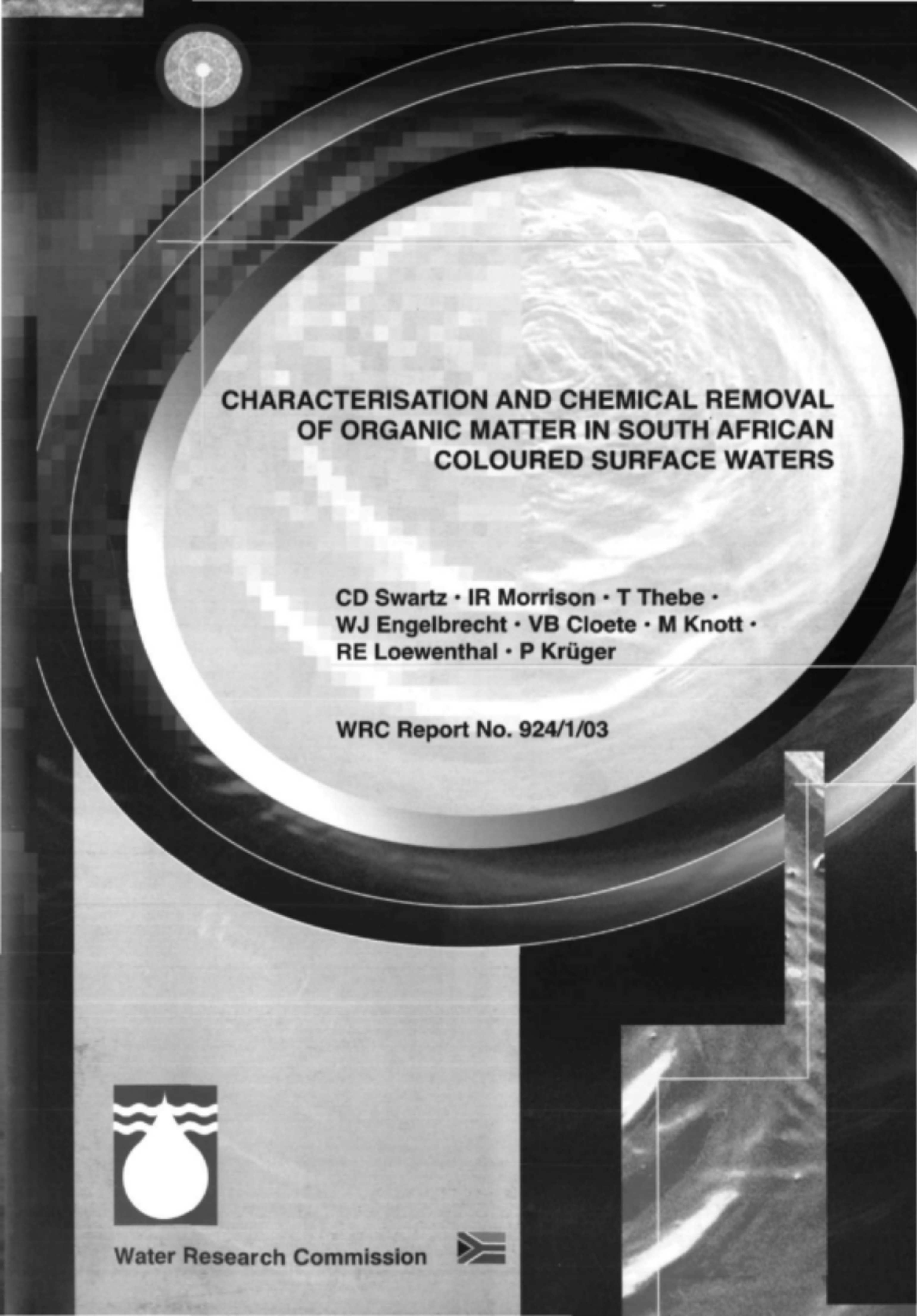

CHARACTERISATION AND CHEMICAL REMOVAL OF ORGANIC MATTER IN SOUTH AFRICAN COLOURED SURFACE WATERS

CD Swartz · IR Morrison · T Thebe ·
WJ Engelbrecht · VB Cloete · M Knott ·
RE Loewenthal · P Krüger

WRC Report No. 924/1/03

Water Research Commission

Characterisation and Chemical Removal of Organic Matter in South African Coloured Surface Waters

Report to the
WATER RESEARCH COMMISSION

by

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EXECUTIVE SUMMARY

By far the highest priority for further research on the treatment of coloured water in South Africa was found to be the need for characterisation and removal of unwanted organic compounds in these waters. Little information is available on the true character and properties of the local coloured waters, and more specifically of its high variability in locality and time (spatial and temporal), as well as the many complexes that it forms with other substances, notably metals. There is also a lack of knowledge on the effect of treatment processes, and in particular coagulation, on the removal of the different constituents of the coloured water. There was, therefore, a need for a more fundamental characterisation of natural organic matter (NOM) in South African coloured waters and classifying the coloured surface water sources, and to use this for establishing the treatability of the different classes of coloured water.

Considerable work on the characterisation of organic matter in coloured waters has been done overseas, notably in the UK (Water Research Centre (Wrc); Severn Trent Water), USA (AWWA Research Foundation), Australia (Australian Water Quality Centre, CSIRO and Monash University) and Norway (Norwegian Institute of Water Research). These included land use (catchment) studies, colour and organic matter characterisation, bench-scale treatability studies and continuous flow studies. A study at the University of Cape Town has, however, shown that South African coloured waters have considerably higher colour levels than in these countries, and that especially in standing waters (such as dams and lakelets), the colour intensity is very high by international standards. The results of the NOM characterisation performed overseas can hence not be applied directly to local waters to assess its treatibility by existing processes or new processes that are being developed.

A project was therefore undertaken to characterise the natural organic matter in South African coloured surface waters and to develop operational coagulation diagrams for the removal of the organic matter, in order to improve the effectiveness and cost-efficiency of treatment of these coloured waters.

The aims of the project were as follows:

- Establishment of a coloured water characterisation and classification approach which is relevant and practical for use by water suppliers and design engineers in South Africa (*i.e.* development of characterisation methods and establishment of appropriate control parameters)
- Characterisation of the natural organic matter according to the adopted approach in each of the major sources (rivers, dams or lakelets) of natural coloured water in the country
- Classification of coloured waters into main types based on the characterisation results
- Performance of extensive bench-scale coagulation tests using ferric and aluminium salts, to determine the extent of removal of natural organic material and to develop operational coagulation diagrams for the main types of raw coloured waters in South Africa
- Application of characterisation data and coagulation diagrams to assess treatability of each of the main coloured water types
- Drawing up a manual on the treatment of South African coloured surface waters

The overall conclusions of this study are that, for the waters of the study area:

- Differences between the waters, apart from turbidity, lie in the amount rather than the nature of the organic content, which appears to be very similar in all the supplies. This finding has resulted in considerable simplification of the whole subject.
- Most of the organic matter has a high UV absorbance, indicating a high aromatic content.
- DOC, UV absorbance, COD and, less accurately, colour can all be used to estimate the amount of humic materials present in the water. Of these, UV measurement is recommended as being the most precise, rapid and convenient.

- Much of the organic matter can be removed by the most commonly used process of coagulation with aluminium or iron salts. There is residual organic content after this treatment, the amount of which, 1.5 to 5 mg/l DOC, is unrelated to that present in the raw water. The percentage residual is therefore generally higher in the low colour waters.

- The amount of disinfection by-products, mainly trihalomethanes, formed when the water is chlorinated is a function of both the concentration of organic matter and the chlorine dose. Generation of the maximum amount requires about 3 mg chlorine per mg of DOC. Measurement of DOC or, more simply, UV absorbance thus provides a good estimate of the potential for formation of disinfectant by-products and is an excellent tool for optimising and monitoring treatment processes.

- To minimise the formation of disinfectant by-products, treatment should aim at reducing UV absorbance to as low a level as possible.

- The required dose of coagulant is proportional to the amount of organic matter present and can be estimated from one of the measures of organic content. The preferred determinand is UV absorbance because of simplicity and rapidity of measurement, provided a UV/VIS spectrophotometer is available, and because it most accurately determines the removable humic fraction.

- A safe reliable dose for iron salts is: mg/l Fe = 30 x UV300/cm.

  For aluminium an equivalent (equimolar) factor applies.

  If filtered water UV254 is low, a lower dose can be considered.

- Optimum coagulation pH values are 4.6 for ferric salts and 5.6 to 5.8 for aluminium sulphate. If settled water turbidity is very high, a higher pH should be tried.

- Ferric chloride is the best coagulant for removal of humic materials, particularly with those waters having a high residual UV254 value. If the UV254 in the filtered water is low, the difference between coagulants is not very great. Aluminium sulphate gives the lowest settled water turbidity. Note that residual UV254 for a given source often varies throughout the year.

- The propensity of floc particles to stick together (sticking factor), one of the factors governing the rate of floc formation, is much the same for all the waters used for the project.

- A second floc formation factor related to water quality is floc volume. If, as mentioned above, a dose proportional to organic content is used, then the floc formation rate will be proportional to the coagulant dose. Floc thus forms more slowly in a light coloured water than in a dark one.

Based on the findings of this study, the following recommendations are made for further research on characterization and treatment of South African coloured surface waters:

a. Investigate the occurrence of metals (iron, manganese and aluminium) in colour removal treatment plants, and draw up guidelines for removal and control of the metals, both at the treatment plant and in the distribution system.

b. Perform desk studies on how alternative non-chemical treatment technologies can be used either together with chemical treatment or on its own to improve the quality of the final water, and be able to do this in a sustainable and affordable manner.

c. Investigate the beneficial use of chemical sludges from colour removal treatment plants (research on management and use of water works sludges generally is currently being carried out by the University of Natal in Pietermaritzburg).

ACKNOWLEDGEMENTS

The research in this report emanated from a project funded by the Water Research Commission and entitled:

" Characterisation and Chemical Removal of Organic Matter in South African Coloured Surface Waters"

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

Dr I M Msibi	Water Research Commission (Chairman)
Ms S G Matthews	Water Research Commission (Secretary)
Dr G Offringa	Water Research Commission
Mr S A Pieterse	Cape Metropolitan Council
Mr D G Devey	Port Elizabeth Municipality
Dr J J Schoeman	CSIR Environmentek
Mr H L Basson	George Municipality
Mr D P Theron	Overberg Water
Prof R E Loewenthal	University of Cape Town
Prof W J Engelbrecht	University of Stellenbosch

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

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

- All the plant managers and operating personnel at the various treatment plants for their assistance in taking the bulk water samples
- Mr Sarel Pieterse of the Scientific Services Department of the Cape Metropolitan Council for his interest in and assistance with the project
- Ms Sara Paarman and Mr David de Villiers of the Chemistry Department of the University of Stellenbosch for their inputs in performing THMFP analyses
- Ms Beth-Marie Robbins of CMC Scientific Services for performing metals analysis of treated water samples from the coagulation studies
- Bridget Fenn for assistance in performing the coagulation beaker tests

PRODUCTS OF THE PROJECT

1. The project led to the undertaking of a PhD research project in the Department of Civil Engineering of the University of Cape Town by Mr Thebe Thebe, under the mentorship of Professor R E Loewenthal. The title of the thesis is:

   "Characterisation and Coagulation of Natural Organic Matter from South African Coloured Surface Waters"

2. A manual is currently being drawn up on treatment of South African coloured surface waters using amongst other the results and findings of this project. The intention is that the manual will be used by design engineers, planners and water utilities as:
   - a diagnostic tool for evaluating and improving/optimising existing coagulation and separation processes
   - a decision making tool to assist with the selection of the most appropriate treatment processes in the design of new treatment plants
   - a working guide for plant operating personnel to efficiently control their coagulation process on a continuous basis with the coagulation diagrams and coagulation control measures.

   The manual will also assist researchers and engineers in developing new processes, technologies and treatment strategies for removal of natural colour from South African raw surface waters.

3. A paper on the project work was presented at the Water Institute of Southern Africa (WISA) Biennial Conference that was held at Sun City during May 2000. The title of the paper was "Characterisation of Natural Organic Matter in South African Coloured Surface Waters" by T Thebe, C D Swartz, I R Morrison, W J Engelbrecht, R E Loewenthal and P Krüger.

4. The data on characterisation of the organic matter in the South African coloured surface waters will be held at the University of Cape Town, and the data on the chemical coagulation beaker tests will be held with Chris Swartz Eng in Mossel Bay.

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CHAPTER 1

INTRODUCTION

1.1 NEED FOR CHARACTERISATION OF ORGANIC MATTER IN SOUTH AFRICAN COLOURED SURFACE WATERS

As a result of a perceived need for information and guidance on treatment of organically coloured surface waters for potable use in the southern coastal zones of South Africa, a project was carried out by CSIR Environmentek to identify any problems or potential problems that are experienced with the treatment of coloured water. This project, which was funded by the Water Research Commission, aimed at drawing up practical guidelines for designers and operating personnel to address the causes of the potential problems with the treatment of local coloured waters.

While the project had achieved its aim of providing practical and useful guidelines to especially plant operating personnel, the extent of the project did not allow any in-depth investigation of the chemical treatability of the South African coloured waters by coagulation/flocculation. At the last Steering Committee Meeting of this project, the Steering Committee indicated that it was necessary to undertake further research on the treatability of the various types of coloured waters that are encountered in the country, with specific emphasis on characterisation of the organic matter in these waters and assessing its removal by chemical coagulation (Swartz and de Villiers, 1998).

To transfer the results of the guidelines project to the end user, a seminar/workshop (jointly organised by the Water Research Commission (WRC), Water Institute of Southern Africa (WISA) and CSIR) was held in Mossel Bay in October 1996 to obtain inputs from all institutions/persons involved in the treatment of coloured water (design engineers; water suppliers; operating personnel; researchers; chemical and equipment suppliers) before finalizing the guidelines document for distribution. During the workshop, at which most of the role players in the treatment of coloured water in South Africa were present, the WRC also facilitated a session to identify research needs in the treatment of coloured waters, and to prioritise these research needs as far as possible (Workshop on Treatment of Coloured Water for Potable Use, Mossel Bay, 1996).

By far the highest priority for further research was found to be the need for characterisation and removal of unwanted organic compounds in coloured waters. Little information is available on the true character and properties of the local coloured waters, and more specifically of its high variability in locality and time (spatial and temporal), as well as the many complexes that it forms with other substances, notably metals. There is also a lack of knowledge on the effect of treatment processes, and in particular coagulation, on the removal of the different constituents of the coloured water. The investigation of existing treatment practices to draw up the guidelines document only entailed once-off basic determination of raw water quality at the plants that were visited, and did not allow any detailed characterisation of the natural organic matter or its spatial or seasonal variation. Treatability studies were also limited to standard beaker tests for determining or confirming optimum coagulant dosages and pH for colur removal and minimising metal residuals in the final water. There was, therefore, a need for a more fundamental characterisation of natural organic matter in South African coloured waters and classifying the coloured surface water sources, and to use this for establishing the treatability of the different classes of coloured water.

Considerable work on the characterisation of organic matter in coloured waters has been done overseas, notably in the UK (Water Research Centre (Wrc); Severn Trent Water)(WRc Environment Reports, (1987)), USA (AWWA Research Foundation), (Owen, D.M. *et al*, (1995), Australia (Australian Water Quality Centre, CSIRO and Monash University)(Newcombe, G. *et al*, (1996) and Norway (Norwegian Institute of Water Research). These included land use (catchment) studies, colour and organic matter characterisation, bench-scale treatability studies and continuous flow studies. A study at the University of Cape Town has, however, shown that South African coloured waters have considerably higher colour levels than in these countries, and that especially in standing waters (such as dams and small lakes), the colour intensity is very high by international standards (Gardener, 1988). The results of the NOM characterisation performed overseas can hence not be applied directly to local waters to assess its treatability by existing processes or new processes that are being developed.

A number of local universities and institutions are currently performing, or have recently completed, research projects on the application and/or development of new treatment processes for colour removal (Van der Walt and Pearson, 1996; Juby and Botha, 1994; Jacobs *et al*, 1996; Cloete *et al*, 1996; Loewenthal, 1997). The results of a characterisation and classification study will also be of value to these research groups in determining process applicability and treatment strategies, and further process development.

1.2 RESEARCH OBJECTIVE

The overall objective of the project was to characterise the natural organic matter in South African coloured surface waters and to develop operational coagulation diagrams for the removal of the organic matter, in order to improve the effectiveness and cost-efficiency of treatment of these coloured waters.

1.3 RESEARCH AIMS

The aims of the research programme were as follows:

a. Establishment of a coloured water characterisation and classification approach which is relevant and practical for use by water suppliers and design engineers in South Africa (i.e. development of characterisation methods and establishment of appropriate control parameters)

b. Characterisation of the natural organic matter according to the adopted approach in each of the major sources (rivers, dams or lakelets) of natural coloured water in the country

c. Classification of coloured waters into main types based on the characterisation results

d. Performance of extensive bench-scale coagulation tests using ferric and aluminium salts, to determine the extent of removal of natural organic material and to develop operational coagulation diagrams for the main types of raw coloured waters in South Africa

e. Application of characterisation data and coagulation diagrams to assess treatability of each of the main coloured water types

f. Drawing up a manual on the treatment of South African coloured surface waters

CHAPTER 2

LITERATURE REVIEW

2.1 NATURE AND OCCURRENCE OF ORGANIC MATTER IN WATER SOURCES

Surface waters containing natural organic matter (NOM) occur in various parts of the world such as many upland sources in Britain, some parts of the United States, Norway and South Africa.

Natural organic matter is a complex matrix of organic material, derived from soil, peat bogs, sediments and plants decay (Gjessing (1976), Owen *et al* (1995) and Kransner *et al* (1996)). It can be divided into two fractions, particulate matter - plant debris, micro-organisms, clay particles - and dissolved organic matter. The latter in turn has been divided into humic and non-humic substances.

Humic substances, largely aromatic in nature, comprise humic and fulvic acids while non-humic substances include proteins, carbohydrates and others. In most terrestrial waters dissolved organic matter constitutes most of the NOM.

2.2 CHARACTERISATION OF ORGANIC MATTER IN SURFACE WATERS

Prior to the 1970s, most studies focussed on the removal of colour from drinking water (Behrman *et al* 1931, Black *et al* 1961, Black *et al* 1963, Black and Christman 1963, Packham 1964 and Hall *et al* 1965). Since then other problems associated with NOM have been identified (Jacangelo *et al* 1995), notably it's involvement as a precursor in the formation of disinfection by-products, believed to be a potential health hazard. Consequently, considerable research efforts have recently been exerted globally in characterising and removing NOM from potable water.

Recently, Korshin and co-workers (1998) have shown that the reduction in UV absorbance that occurs when water containing natural organic matter is chlorinated, correlates directly with total organic halogen, TOX, over a wide range of conditions and can thus be used as an inexpensive means of estimating TOX and as a measure of an important characteristic of the water.

2.3 WORK ON CHARACTERISATION OF ORGANIC MATTER IN SOUTH AFRICA

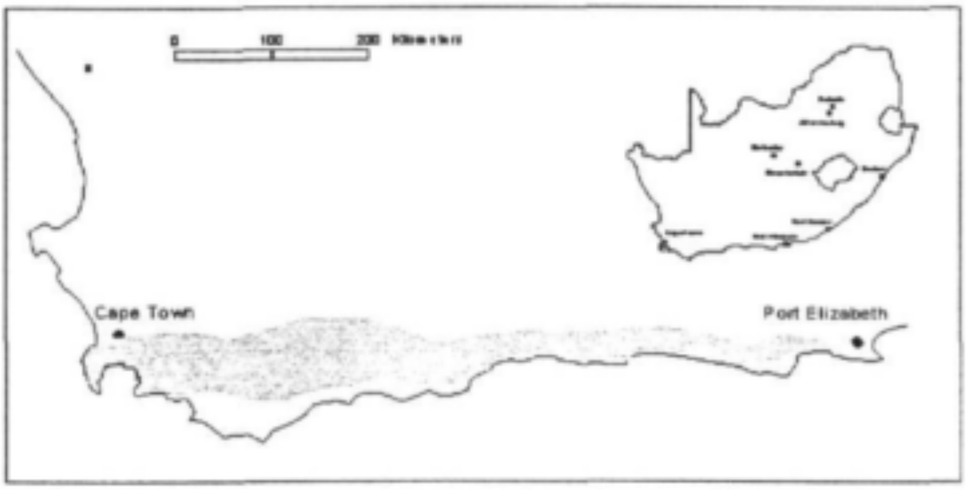
Although the removal of colour from the waters of the south western areas near Cape Town, by means of coagulation with aluminium sulphate and sodium aluminate, has been practised for the past seventy years and a considerable amount of work done on understanding the process, there has been no comprehensive investigation of the characteristics of NOM across the entire area. A workshop of those concerned with the subject, organised on behalf of the WRC, WISA and the CSIR, consequently identified a need for further research, particularly in relation to the formation of disinfection by-products (Workshop on Treatment of Coloured Water for Potable Use, Mossel Bay, 1996). The work reported here was therefore undertaken with these aims in mind.

CHAPTER 3

OCCURRENCE AND DISTRIBUTION OF COLOURED WATERS IN SOUTH AFRICA

3.1 OCCURRENCE OF COLOURED SURFACE WATERS

In South Africa, surface waters all along the Southern Cape coastal belt between Cape Town and Port Elizabeth (Figure 3.1) contain natural organic matter, sometimes in very high concentrations (Swartz and de Villiers, (1998)). Most of the mountain catchments in this coastal belt are sandstone and remote from industrial activities.



3.2 LAND-USE AND CATCHMENT DATA

Data held by the Department of Water Affairs and Forestry on water quality in natural watercourses, rivers and dams, does not include any information of organic material in the water or quality parameters that provide a measure of the level of organic substances (such as UV absorbance, colour or TOC/DOC). It was thus not possible to establish from this data source the distribution of natural coloured water in the country.

It is, however, known and documented that coloured water occurs mainly in the southern coastal zones in the country, stretching from Port Elizabeth in the east to Cape Town in the west. It is found on the southern slopes of the mountain ranges in this area, and is associated with fynbos vegetation and pale-coloured (nutrient-poor) soils.

Discussions with the University of Cape Town (UCT) Freshwater Research Institute revealed that the only other significant sources of coloured water in the country are the swampy areas around Lake Nsese in Northern Natal, but that these are an isolated case and relatively small in extent.

CHAPTER 4

CHARACTERISATION

4.1 CHARACTERISATION AND CLASSIFICATION APPROACH

Because of it's complex nature, detailed identification of all the components of natural organic matter in water is highly expensive, and perhaps not yet completely possible. It was therefore decided to apply a number of standard analytical methods, each measuring some aspect of organic content, to raw waters from the entire area. The effectiveness of the coagulation process, widely used and of low cost, for removal of organic matter, was also assessed by the same methods.

The following parameters, discussed in more detail below, were therefore selected for examination: dissolved organic carbon (DOC), chemical oxygen demand (COD), ultra-violet light absorbance at 254 nm (UV254) and 300 nm (UV300), colour, turbidity and bromide. As measures of disinfection by-product formation: trihalomethane formation potential(THMFP) and differential ultra-violet light absorbance at 272 nm (DUV272), before and after chlorination, were used. Additionally, various other routine measurements such as pH, conductivity, calcium, magnesium, etc, were made.

DOC gives the carbon content of organic matter, while COD is a measure of the amount of oxygen required for its oxidation. The latter figure includes a requirement for the oxidation of hydrogen, sulphur and some other elements but is reduced by the amount of oxygen already present in the organic matter. Therefore the correlation between these two parameters is, to some extent, an indication of degree of similarity of composition.

The COD determination is widely carried out in connection with wastewater treatment and provides an possible alternative measure of DOC content for smaller institutions which cannot afford the capital cost of DOC analyzers, provided the correlation between the two values is reasonably constant and known. Black and Christman (1963), Gjessing (1976) and De Haan et al (1982) made some attempts in this regard. Loewenthal et al (1997) have recently described a Gran titration procedure for the determination of COD at low levels.

The absorption of light by coloured waters is far higher at ultra-violet wavelengths than in the visible region, and is caused by aromatic compounds and other organic substances containing conjugated double bonds. It increases with decrease in wavelength, with no obvious peaks. Provided a spectrophotometer is available, it is a rapid and sensitive determination, and has been used for the past 30 years as a measure of the required dose of metal coagulants and the effectiveness of removal of humic materials from the raw waters of the Western Cape. Edzwald *et al* (1985) have shown that UV254 correlates well with DOC in some American waters. The ratio of UV254 to DOC, referred to as specific UV absorbance (SUVA), (Krasner *et al* 1995, Li *et al* 1998, and Vrijenhoek *et al* 1998 and Childress *et al* 1999), is thus a measure of aromatic content.

In the present study, UV absorbance measurements were carried out at 254 nm, because this has become the wavelength most reported in the literature, and at 300 nm because this allows comparison with a considerable amount of earlier work done on coloured waters in the Western Cape. Additionally, the ratio of the absorbances at the two wavelengths provides a measure of the similarity of organic content.

Chlorination of water although necessary for disinfection purposes also results in the formation, by reaction between chlorine and the organic matter in the water, of an assortment of compounds containing chlorine and other halogen atoms. Trihalomethanes (THM, ie chloroform, bromoform and other related compounds) are amongst the most commonly found such compounds. The total of all organically bound halogens is termed TOX.

There are concerns about the health effects of these compounds and limits of between 10 and 200 μg/l have been placed on THM's by various countries, but the full effects of the many halogenated compounds involved are not known.

Minimisation of TOX formation is therefore to be aimed at in water treatment. The amount of TOX formed depends, amongst other things, on the concentration of chlorine added and on the amount and nature of the organic matter present. Some quantification of the latter, as THM formation potential (THMFP) therefore forms part of the characterisation procedure.

Recently, a differential UV absorbance method (DU272) has been introduced as a measure of the formation of chlorination by-products. The essence of this procedure is that a reduction in UV absorbance occurs when a water is chlorinated, and this has been shown (Korshin et al, 1997) to be proportional to the TOX produced. Instead of measuring the product, one is measuring the disappearance of the precursor. As the humic acid precursor, in the present case, is not notably volatile or unstable and, as the measurement is a simple one, given a suitable spectrophotometer, reproducible results can be expected.

Part of the characterisation procedure is the estimation of the amount and nature of the organic matter left after treatment by the traditional process of coagulation with ferric iron, carried out under near-optimum conditions. As further removal of this residual organic matter would require the use of other, probably more expensive, processes, the identification of those water sources where this might be justified is a useful exercise.

4.2 SELECTION OF SOURCE WATERS FOR CHARACTERISATION

Ten sources of coloured water were chosen for the study, representative of the full range of NOM levels, and spread as evenly as possible over the area from Cape Town to Port Elizabeth, with some bias towards high population density. Western Cape supplies were however under-represented because these had been better studied in the past.

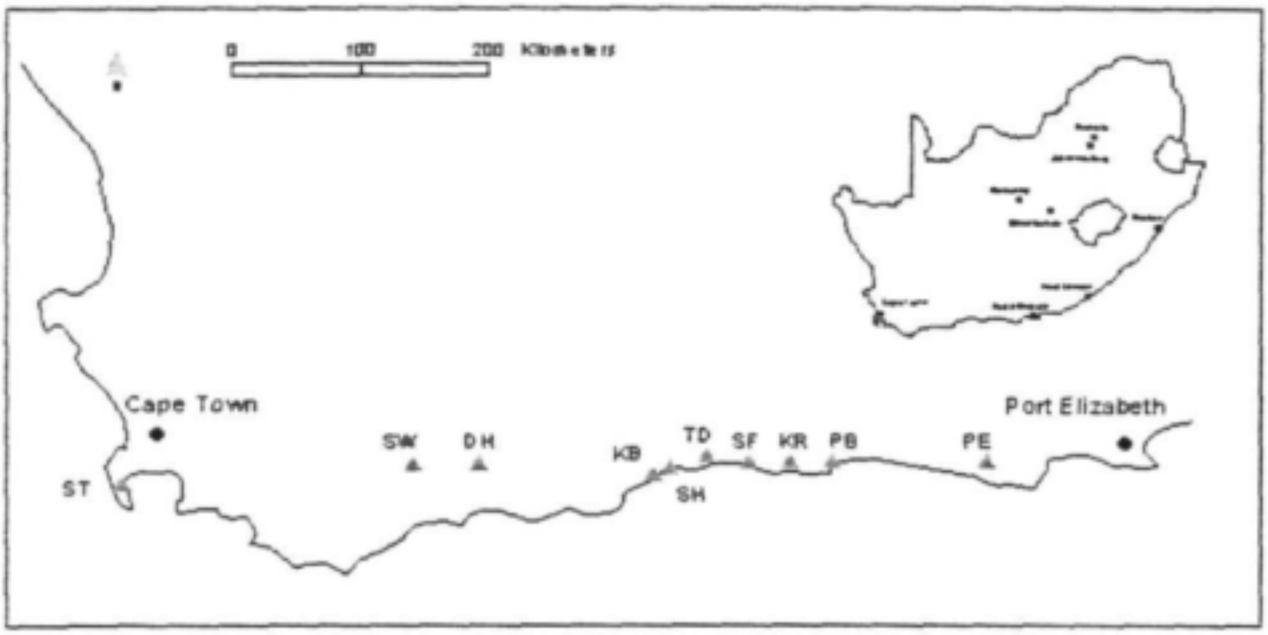
The location of the coloured water sources where the samples were taken for this project are shown in Figure 4.1, and described in Table 4.1, which also provides information on the quality of the raw water.

Figure 4.1 **LOCATION OF SAMPLING POINTS**

Legend to sampling locations (*abbreviations in parentheses are those used in Chapter 7*):

ST - Simons Town *(ST)*

TD - Tuinroete Dam (George) *(George)*



SW - Swellendam *(Swell)*

DH - Duivenhoks River (Heidelberg) *(Duiv)*

KB - Klein Brakrivier *(KB)*

SH - Sandhoogte *(SH)*

SF - Sedgefield *(Sedg)*

KR - Knysna River (Knysna) *(Kny)*

PB - Plettenberg Bay *(Plett)*

PE - Churchill Dam (Port Elizabeth) *(P.E.)*

Table 4.1 WATER SOURCES CHOSEN FOR THE STUDY

No	Code	Water source	Name of treatment plant	Supplying water to	Raw water quality				
					Colour (mg/ℓ Pt)	Turb. (NTU)	pH	Alk. (mg/ℓ as $CaCO_3$)	Fe (mg/ℓ as Fe)
1	KB	Klipheuwel Dam	Kleinbrak	Mossel Bay	200 - 750	7 - 45	3,8 - 7,7	0 - 52	0 - 9,2
2	SH	Ernest Robertson Dam	Sandhoogte	Mossel Bay	350 - 950	0,5 - 2,2	3,2 - 5,3	0 - 0,8	0,3 - 0,8
3	TD	Tuinroete Dam	George	George	400-1000	0,1 - 10	3,8 - 4,5	0	1,0 - 1,5
4	PB	Keurbooms River	Plettenberg Bay	Plettenberg Bay	45 - 390	0,8 - 25	5,2		< 0,1
5	PE	Churchill Dam	Churchill	Port Elizabeth	150 - 350	5 - 100	6,5 - 7,5	< 5	1,5 - 2,0
6	SW	Grootkloof (Langeberg)	Swellendam	Swellendam	160	8,5	5,8	3,0	1,4
7	ST	Lewis Gayle Dam	Simons Town	Simons Town	170 - 370		4,9 - 6,8	0 - 4,5	
8	KR	Knysna River	Knysna	Knysna	20 - 400		5,2		
9	DH	Duivenhoks River	Duivenhoks	Overberg Water	160 - 650	2 - 400	4,1 - 6,5	2 - 28	0,5 - 1,4
10	SF	Karatara River	Sedgefield	Sedgefield	100 - 350	0,5 - 2,0	5,2 - 6,5		

4.3 SAMPLING OF BULK WATER SAMPLES AND ANALYTICAL SCHEDULE

Four sets of samples were taken from the selected raw water sources. Each sampling round covered all the sample points over a three week period, in order to spread the load on the laboratories while minimising the need for storage before analysis.

Starting dates for the sampling rounds were

1. 15 November 1998
2. 23 March 1999
3. 28 September 1999
4. 19 April 2000 (4 sources only)

Three or four samples, at a time, were delivered to the University of Cape Town's Department of Civil Engineering (UCT) on Mondays, mostly within a day of sampling.

Measurement of pH, UV300 and UV254 (on membrane filtered samples) was done on the afternoon of receipt. On the following day aliquots were flocculated with analytical grade ferric sulphate, at a dose of 45 mg/l Fe times the UV300 absorbance and a pH of 4.8. pH adjustment was by means of a solution of analytical grade sodium hydroxide. After slow stirring, for 30 minutes, followed by 30 minutes of settlement, the water was filtered through pre-washed 0.45 μm membrane filters.

Measurement of DOC, required for calculating the required chlorine dose, was completed between Tuesday morning and Wednesday evening and was repeated later in the week.

Delivery to the University of Stellenbosch, Department of Physical Chemistry, was effected on Thursday mornings, where duplicate aliquots of raw(membrane filtered) and treated waters were immediately dosed with chlorine followed by analysis for THM's, 7 days later.

Other analyses were carried out as convenient, within this schedule. All analyses except turbidity were carried out on membrane filtered samples of the raw and treated waters.

Round 4 samples were not subjected to all tests but were used for the comparison of ferric sulphate and ferric chloride coagulants in respect of effect on TMH formation potential and differential UV absorbance.

4.4 ANALYTICAL METHODS

DOC: Measurement of DOC was carried out in duplicate at the UCT Civil Engineering Department using an SGE Anatoc carbon analyser. The performance of the instrument was first optimised by continuously recording the output during runs and tracking down and minimising the sources of error revealed by plots of these values. These included leaking septa, short and variable integration times and baseline drift. The standard deviation for the mean of duplicate determinations on treated samples was about 0.22 mg/l and for raw samples the relative standard deviation was about 8%.

UV Absorbance: Measurements were made by UCT by means of a Unicam 8625 UV/VIS spectrophotometer fitted with a 10 mm cell.

COD: Measurements were made by UCT, using a Gran titration method (Loewenthal *et al*, 1997).

Bromine, calcium, magnesium and aluminium: Analyses were carried out by the UCT Geochemistry Department using a Perkin-Elmer ICP/MS instrument. Good recoveries of bromide were obtained for samples of distilled water and of water of high humic content which had been spiked with potassium bromide.

Manganese and iron: Measurements were made by the UCT Chemistry Department using an Jobin ICP/FE spectrophotometer - standard deviations were 0.001 and 0.006 mg/l respectively.

THMs and THM Formation Potential: These were determined at the University of Stellenbosch (US) Physical Chemistry Department by chlorination under controlled conditions followed by destruction of excess chlorine by means of addition of ascorbic acid, solid phase micro-extraction(SPME) and determination of the extracted THMs on a Fisons gas chromatograph with MD800 quadrapole mass spectrometer as detector. Dichloro-methane was added before the extraction step, as an internal standard. A considerable amount of work was done in setting up this fairly complex procedure.

Various conditions for the SPME stage were tested and adjusted so as to give linear calibration curves for all four THMs over a wide concentration range. Use of added salt to give increased sensitivity was tested and abandoned because of implementation difficulties. It was shown that the high concentrations of humic materials expected in samples did not interfere in the determination.

It was confirmed that a chlorine dose of 3 times the DOC gave a maximum in THM concentration. A pH value of 9.2 was adopted for the chlorination stage, being a little above that likely to be used for many of the treated waters in the study area. A seven day contact period was chosen as being near the maximum residence time likely in water distribution systems.

During the first two sampling rounds, the standard deviation for chloroform (mean of two determinations) near the blank level was about 20 ug/l and at higher concentrations was about 13% of the concentration. For dichloromonobromomethane the corresponding figures were about 5 ug/l and 14%.

The protocol finally adopted for the determination is given in Appendix A.

During the third sampling round, considerable trouble was experienced with the GC/MS instrument and results were rejected as being unreliable.

For the fourth sampling round a capillary GC with an FID detector, and an isothermal program, was employed. Sensitivity was less than with the GC/MS instrument, but was adequate for chloroform and dichloromonobromomethane. The remaining two compounds are normally present in non-significant amounts insofar as the objectives of the fourth round experiments are concerned.

Differential UV absorbance: The method was generally as described by Korsin (1997) and Li (1998). Chlorine was added as a standardised solution of sodium hypochlorite (BDH AnalaR) to samples, buffered at pH 9.2 with sodium tetraborate (Merck), contained in brown glass-stoppered bottles; except where otherwise indicated the dosing rate was 3.2 times the DOC value. The bottles were stored in the dark at 20 °C in a constant temperature room. At the end of the reaction period, residual chlorine was quenched by means of sodium sulphite (Saarchem) and the absorbance at 272 nm measured as above. A further portion of the water, treated in the same manner except that no chlorine was added, was used as the comparison sample. Absorbance values were corrected for volume changes and the difference between un-chlorinated and chlorinated portions calculated. More detail is given in Appendix B.

Turbidity: Measured on a Orbeco-Helige turbidimeter.

Colour: Determined on a Lovibond comparator.

CHAPTER 5

OPTIMISATION OF THE COAGULATION TREATMENT FOR CHARACTERISATION PURPOSES

5.1 OBJECTIVE

This part of the work was intended to allow the selection of a near-optimum set of conditions, of application to all the test waters, for the removal of NOM by flocculation with metal salts. The residual organic fraction could then be classified as non-removable, by this treatment. This limited requirement does not include maximum reduction in turbidity, other than to ensure that it is not so high as to interfere with the main aim. Conditions required for routine treatment are dealt with in Chapter 7.

5.2 PRELIMINARY EXPERIMENTS

It was known, from experience gained by the Scientific Services Branch of the Cape Town City Engineer's Department in the treatment of coloured waters, that the UV absorbance of raw water is a good measure of the required dose of coagulant, and that the absorbance of the treated water is an indication of the residual organic matter. Ferric salts were also known to give a greater degree of removal than those of aluminum, because they permit the use of a lower coagulation pH, down to about pH 4.3.

Figures 5.1a and 5.1b, which summarise examples of past experience with ferric sulphate, show settled water turbidity and UV absorbance at 300 nm in 1 cm cells (UV300), plotted against the coagulant dose expressed as the ratio: Fe/UV300. It can be seen that a dosing ratio of 30 gives reliable results for both UV300 and turbidity. For the characterisation exercise a preliminary choice was made of an overdose with ratio 45 mg Fe/ℓ / UV300 at a pH of 4.5.

Preliminary tests were then carried out on one dark water (Sandhoogte) and a light-coloured water (Swellendam), using ferric chloride and ferric sulphate, to establish that these conditions would be suitable for all waters.

Experiments with Sandhoogte water and ferric chloride confirmed that a pH of 4.5 gave the lowest possible UV300 in the filtered water.

However, when the same conditions were used on a sample of Swellendam water (low UV300) it was found that the settled water turbidity increased to quite high values at high doses (Figure 5.1c). At even more extreme doses all floc disappeared and the water had a clear yellow-brown colour, which appeared to be very finely divided floc as it could be filtered out on a 0.45 micron membrane filter to give a low UV300 filtrate.

However, filtration under these conditions became a lengthy operation and further work showed that, by using ferric sulphate at a slightly higher pH, a low turbidity could be obtained with both waters (Figure 5.1d). The final conditions chosen were pH 4.8, a reasonable compromise for all waters, with a dose ratio of 45 mg Fe / ℓ / UV300.

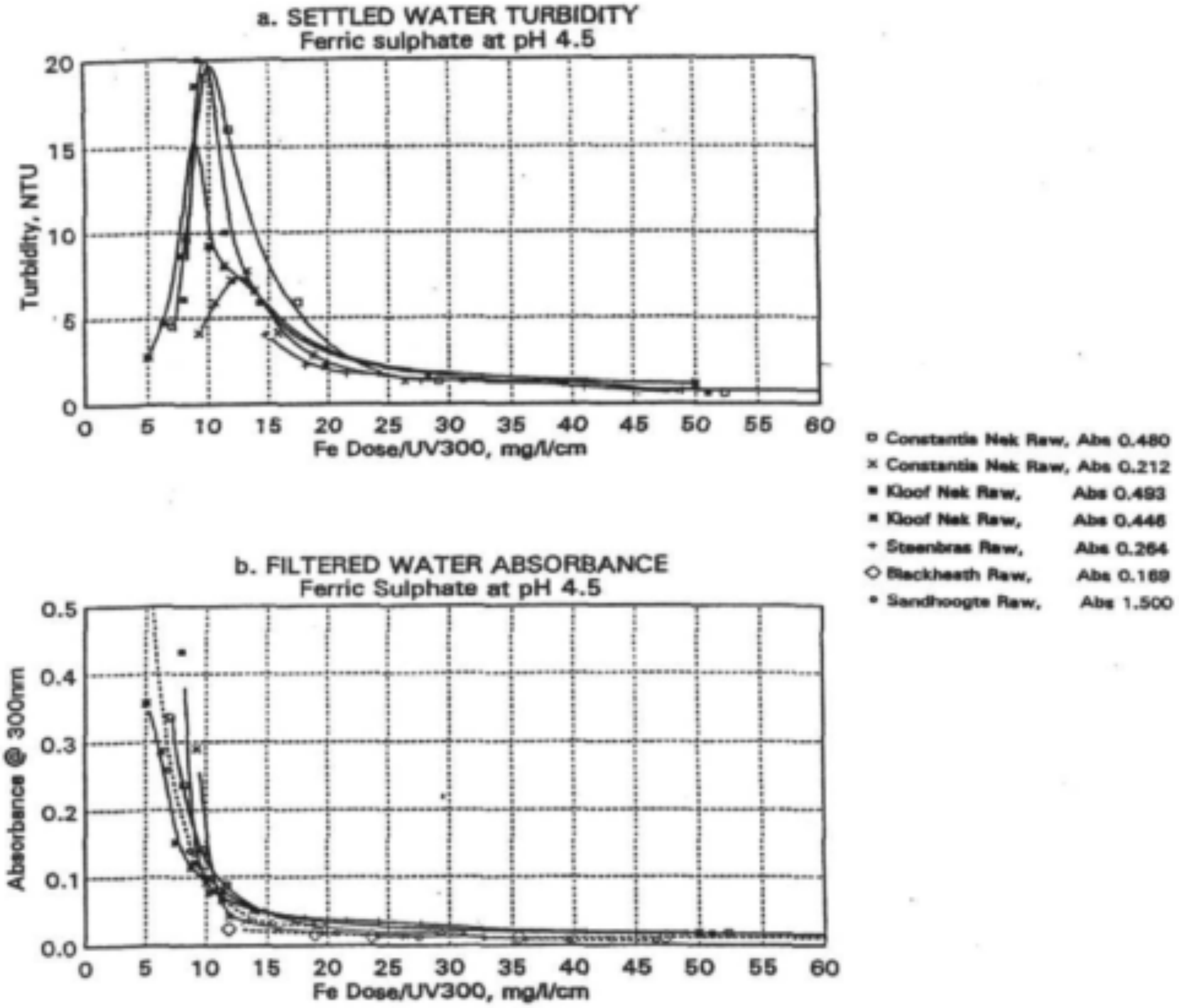
Because high coagulant doses were to be used, sodium hydroxide reagent was considered more suitable for pH adjustment than calcium hydroxide, as it could be prepared in more concentrated solution form, thereby minimising volume changes. Comparison with lime showed that the difference, for UV254 in the treated water, was less than 0.003 cm^{-1}, lime giving the lower result.

5.3 PROTOCOL FOR COAGULATION FOR CHARACTERISATION

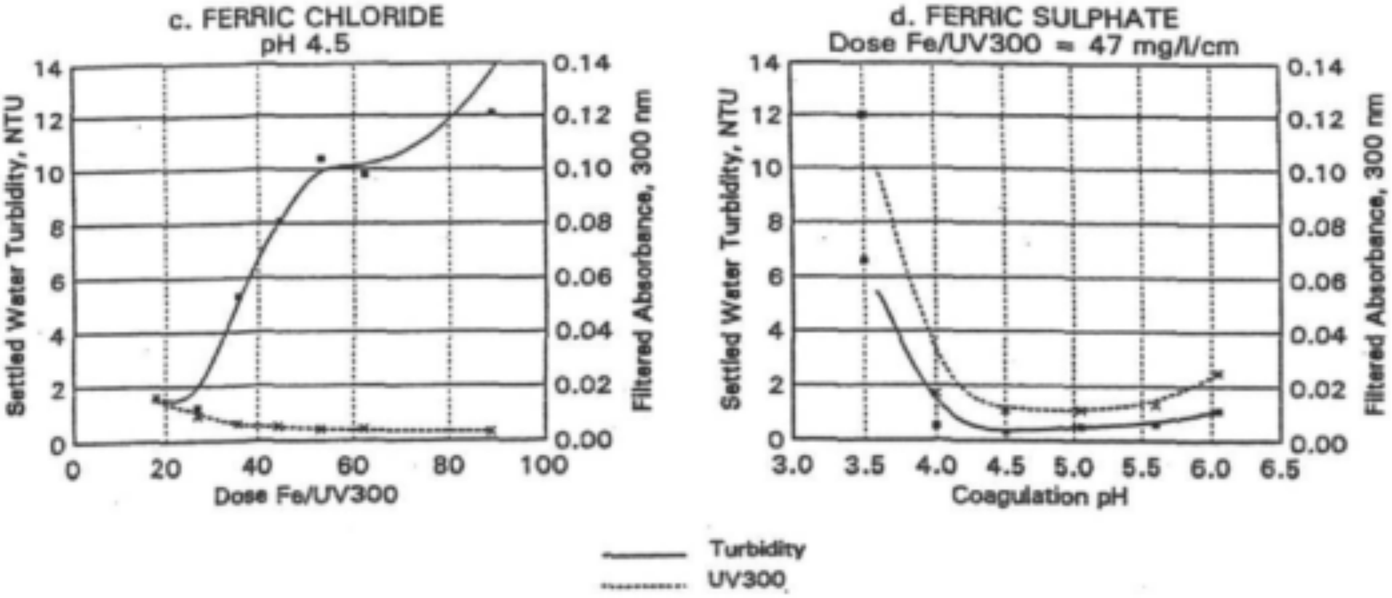
Raw water aliquots of 2 ℓ were treated with analytical grade ferric sulphate, at a dose of 45 mg/ℓ Fe times the UV300 absorbance and a pH of 4.8. pH

FIGURE 5.1

OPTIMISATION OF COAGULATION FOR CHARACTERISATION



SWELLENDAM RAW WATER



adjustment was by means of a solution of analytical grade sodium hydroxide. After slow stirring, for 30 minutes, followed by 30 minutes of settlement, the water was filtered through 0.45 μm membrane filters for analysis.

CHAPTER 6

RESULTS OF CHARACTERISATION OF RAW AND TREATED WATERS

Detailed analytical values are tabulated in Appendix C, plotted in Figures 6.1 to 6.7, and further discussed below.

6.1 UV ABSORBANCE AND DOC

Figures 6.1a and 6.2a show UV254 and UV300 to be highly correlated, for both raw and treated waters (r^2 0.998 and r^2 0.73 respectively, slopes 0.631 and 0.493). The equations for the lines allow either wavelength be used interchangeably. Similarly, UV272 for raw waters was also closely related to UV254 (r^2 0.997, slope 0.934).

The UV254 remaining after treatment, in contrast (Figure 6.1e), correlates poorly with that in the raw water (r^2 0.25), showing that residual material after treament, ie fulvic acids and other soluble compounds, is not necessarily related to the amount of organic matter in the raw water. This is in agreement with previous experience. For example the UV absorbance of the raw water from Steenbras dam gradually declines during the summer while the residual absorbance of the treated water rises, presumably a result of the effect of sunlight on the organic matter.

Raw water UV254 was also well correlated with DOC (r^2 0.979), as shown in Figure 6.1b. The best fit line extrapolates to a DOC value of about 1.5 mg/ℓ for zero absorbance, representing non-absorbing substances.

There are two ways of calculating specific UV absorbance, from these figures. Firstly, dividing UV254 by DOC for each water gives values ranging from 4.4 to 6.8 ℓ/mg-m, and secondly, calculation of the slope of the best fit line in Figure 6.1b gives a value of 7.0 ℓ/mg-m. The differences between these two estimates largely arise from the 1.5 mg/ℓ residual DOC at zero absorbance. When the raw water DOC is low this has a much larger influence on the ratio than with high-DOC waters.

Hence, the slope of the regression line can be considered to give the specific absorbance of the humic acid portion of the organic matter present, which appears to be about the same in all the waters tested, while the individual ratios for each water differ from 7.0 to the extent that non-aromatic substances are also present.

For the treated waters, the regression line slope was 2.8 (r^2 0.42), while the individual ratios were in the range 0.8 to 3.7.

Edzwald *et al* (1985) list ratios of 3.9 to 4.6 for some American, Norwegian and Dutch raw waters, which however had rather lower DOC values than those in the present study. The figures given for American treated waters were between 2.6 and 3.1.

Consistent with other studies (Kranser and Amy 1995; Vrijinhoek *et al* 1998 and Childress *et al* 1999), these figures show much more complete reduction in UV254 than DOC, because of the relative ease of removing humic acids compared to fulvic acids and other more soluble compounds. The high dose of coagulant used in this study means that the residual DOC of the treated water can be taken to provide an estimate of the non-removable DOC present in the raw water.

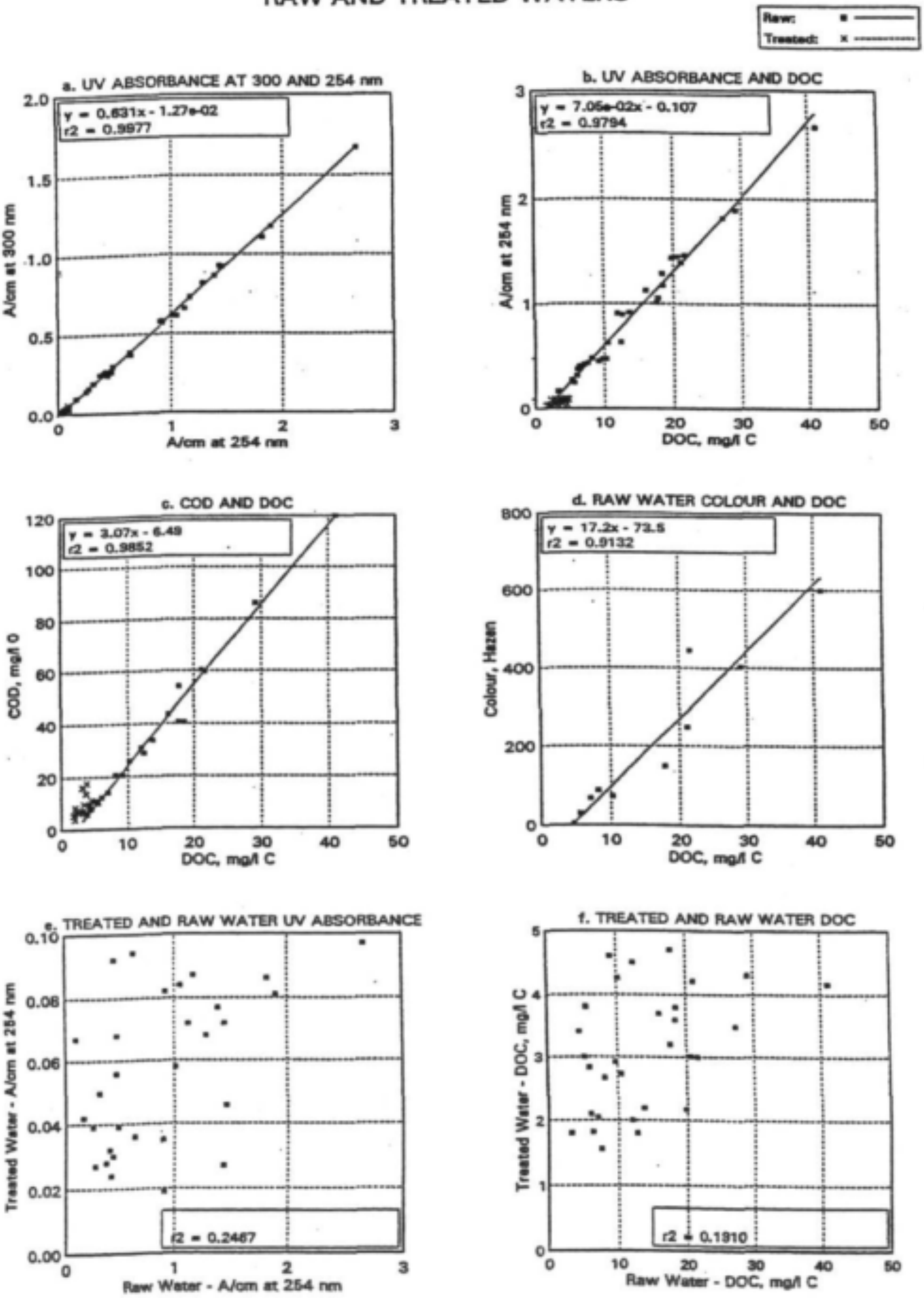
6.2 DOC AND COD

Raw water COD and DOC are also well correlated (r^2 0.985) as shown in Figure 6.1c, with a slope of 3.07 mol O per mol C.

FIGURE 6.1

CORRELATIONS BETWEEN MEASURES OF ORGANIC MATTER

RAW AND TREATED WATERS



There is more scatter visible in treated water plot (Figure 6.2c), partly because of the different scale used and partly because, in contrast to most determinations, the precision of COD measurements at low concentrations is about the same as at high levels, because a back titration is employed.

6.3 COLOUR

As expected, colour in the raw waters was also related to DOC (Figure 6.1d). The plot reveals one of the limitations of colour in this kind of work, namely that it is only when the DOC is above about 5 mg/ℓ that colour becomes visible.

6.4 TURBIDITY

The turbidity of raw water samples varied between 0.5 and 44 NTU. The coagulation conditions used were not always suitable for producing settled water with the lowest possible turbidity .

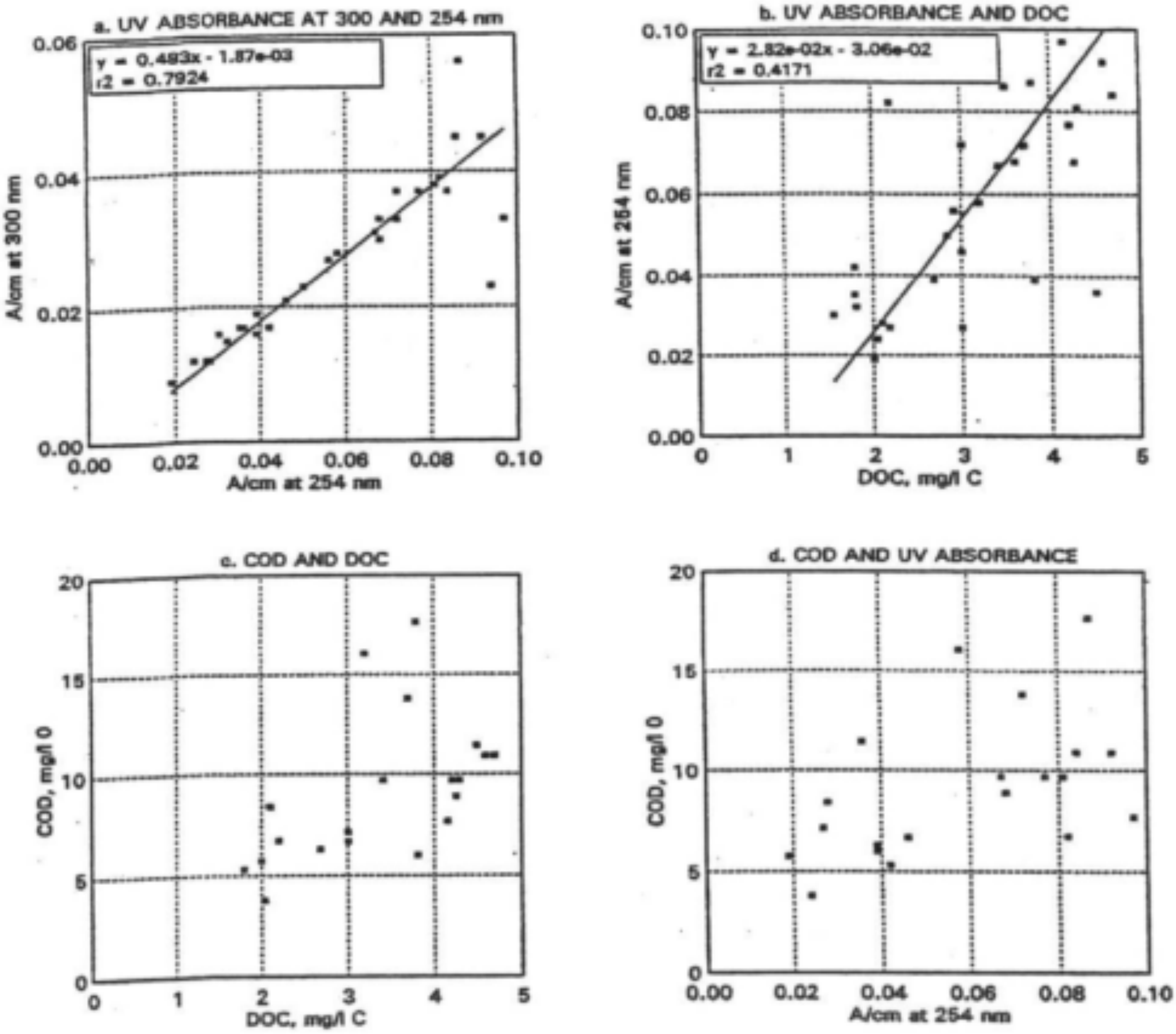
6.5 BROMIDE

Bromide in water is oxidised by disinfectants such as chlorine and ozone, to bromine, which in turn reacts with organic matter to produce brominated disinfection by-products (DBP) (Crozes *et al* 1995). The concentration of bromide in the raw water has an influence on the relative proportions of DBP's produced and on the reaction rates.

Bromine was determined in the raw and treated waters by an ICP/MS method and the concentrations found therefore represent total bromine, though it is likely that the major portion was in the form of bromide. As the coagulation treatment brought about a reduction of about 30 μg/ℓ in all samples (Figure 6.4a), a small amount may have been organically bound.

FIGURE 6.2

CORRELATIONS BETWEEN MEASURES OF ORGANIC MATTER
TREATED WATER



A marked correlation between bromine and magnesium was noted (Figure 6.4b), with a Br/Mg ratio of 0.050. The corresponding ratio in sea water is also 0.050 and as these supplies originate within 30 km or less of the coastline it is reasonable to assume a marine origin for most of the bromine. As a first approximation and in the absence of direct determination, this relationship can be used to estimate the bromine content of raw waters in the coastal zone studied.

6.6 THM FORMATION POTENTIAL

Preliminary work on one sample of raw water showed that, up to the point at which the chlorine dose was sufficient to give a residual (3 x DOC), the THM concentration was approximately proportional to chlorine dose (Figure 6.3d).

Figures 6.3a to 6.3c show that total THM was fairly well correlated with the measures of organic matter, although there was more scatter than in Figure 6.1, because of the greater variability of the THM values.

There is one complete outlier in the raw water total THM values, namely that for the second raw water sample from Sandhoogte, which had a much lower concentration than expected. As the measures of organic matter agree well with each other, the THM value must be considered to be suspect although there were no obvious indications of analytical problems in this case.

The treated water THM's appear to lie on more or less the same line as those for the raw waters when correlated with DOC (Figure 6.3b). Seemingly the fulvic acids and other more soluble materials remaining after the treatment react to about the same extent with chlorine as the more easily removed humic acids.

Figure 6.4c indicates that essentially all the bromide in the raw and treated water was incorporated in the THM's. The average molar percentages of the various THM's, for all the Round 1 and 2 waters were:

FIGURE 6.3

CORRELATIONS RELATED TO THM FORMATION

EFFECT OF ORGANIC MATTER IN WATER BEING CHLORINATED

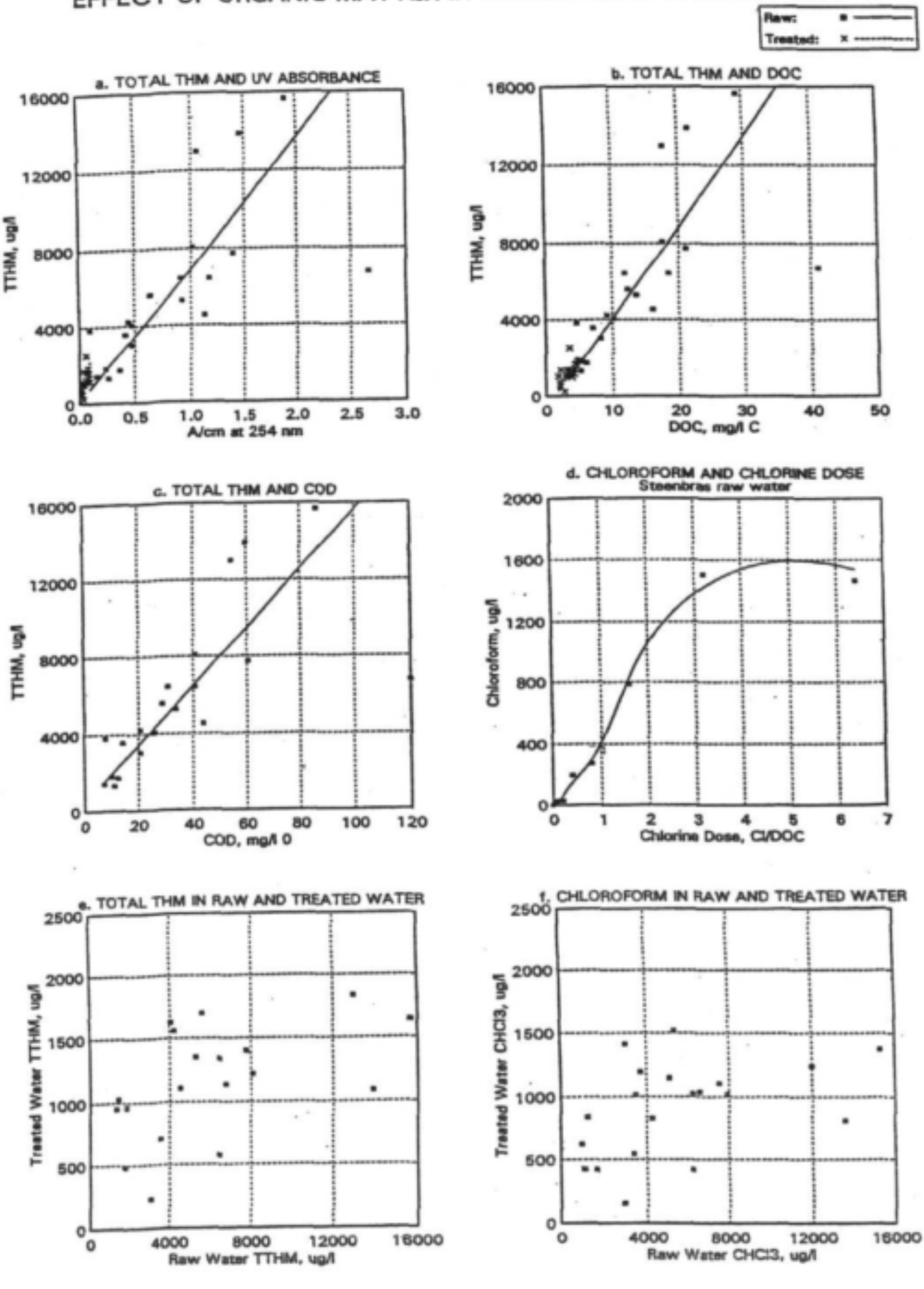


FIGURE 6.4

CORRELATIONS RELATED TO THM FORMATION
EFFECT OF BROMIDE IN WATER BEING CHLORINATED

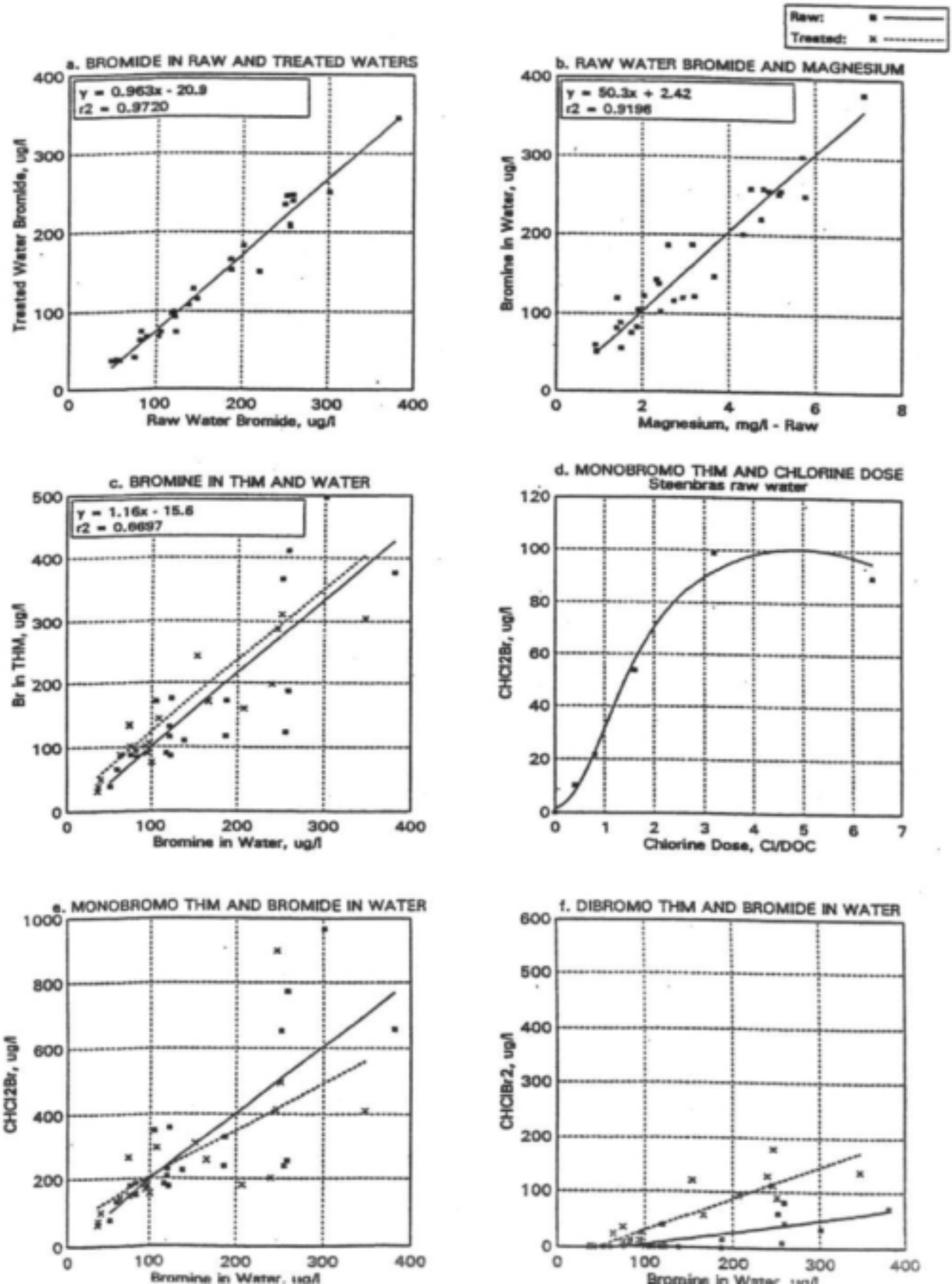


Table 6.1 RELATIVE PROPORTIONS OF THM COMPOUNDS

Compound	Molar Percentage	
	Raw Water	Treated Water
$CHCl_3$	95.6	80.5
$CHCl_2Br$	4.2	16.8
$CHClBr_2$	1.3	2.4
$CHBr_3$	0.0	0.16

The higher percentage of the brominated compounds in the treated water is a consequence of the fact that while their combined concentration is about equal in raw and treated waters, it is being expressed as a percentage of a lower total THM.

The average percentage of the applied chlorine dose incorporated into the THM's, over all the Round 1 and 2 samples was: Raw water 12% Treated Water 10%. In these calculations all the THM's were converted to an equivalent mass of chlorine.

6.7 DIFFERENTIAL UV ABSORBANCE

6.7.1 Effect of Chlorine Dose:

The effect, on DUV272, of varying the Chlorine/DOC ratio, was determined for several raw (Figure 6.5a) and treated waters (Figure 6.5b) from the second sample round, for a 1 day reaction time at pH 9.2.

For ratios of 0 to 2 the differential UV absorbance was nearly proportional to the dose, higher doses having a much smaller incremental effect. The ratio of 3.2 chosen for the final tests on the waters from the third sampling round, can be seen to provide an adequate dose to achieve near maximum DBP formation.

6.7.2 Reaction Time

Figure 6.6a shows the increase in DUV272 with reaction time (log scale), for a raw water with DOC of 41 mg/ℓ (pH 9.2, total time, 7 days). Figure 6.6b gives the corresponding relationship for the same water after treatment (DOC 4.1 mg/ℓl).

The slopes of the two lines are 0.34 and 0.015, respectively. When expressed as a fraction of the original UV272, these figures become 0.15 and 0.20 respectively, in reasonable agreement in view of the fact that the DUV254 values for the treated water are close to the limit of detection of the method. If the raw water figure is taken to be the more accurate of the two, an approximate expression for calculating the differential absorbance for this water, as a function of time, is:

DUV272 = UV272 (0.30 + 0.15 log(t))   where t is in hours

For a time of 168 hours, 1 week, this reduces to:

DUV272 = 0.63 x UV272

The constants in this equation are based on a single experiment carried out one raw water and too much weight should not be placed on them. Use of a log time scale to obtain a straight line fit obscures the fact that nearly half the 7-day DUV272 occurs in the first day and 70% in two days.

6.7.3 Relationship Between DUV272 and DOC and UV272:

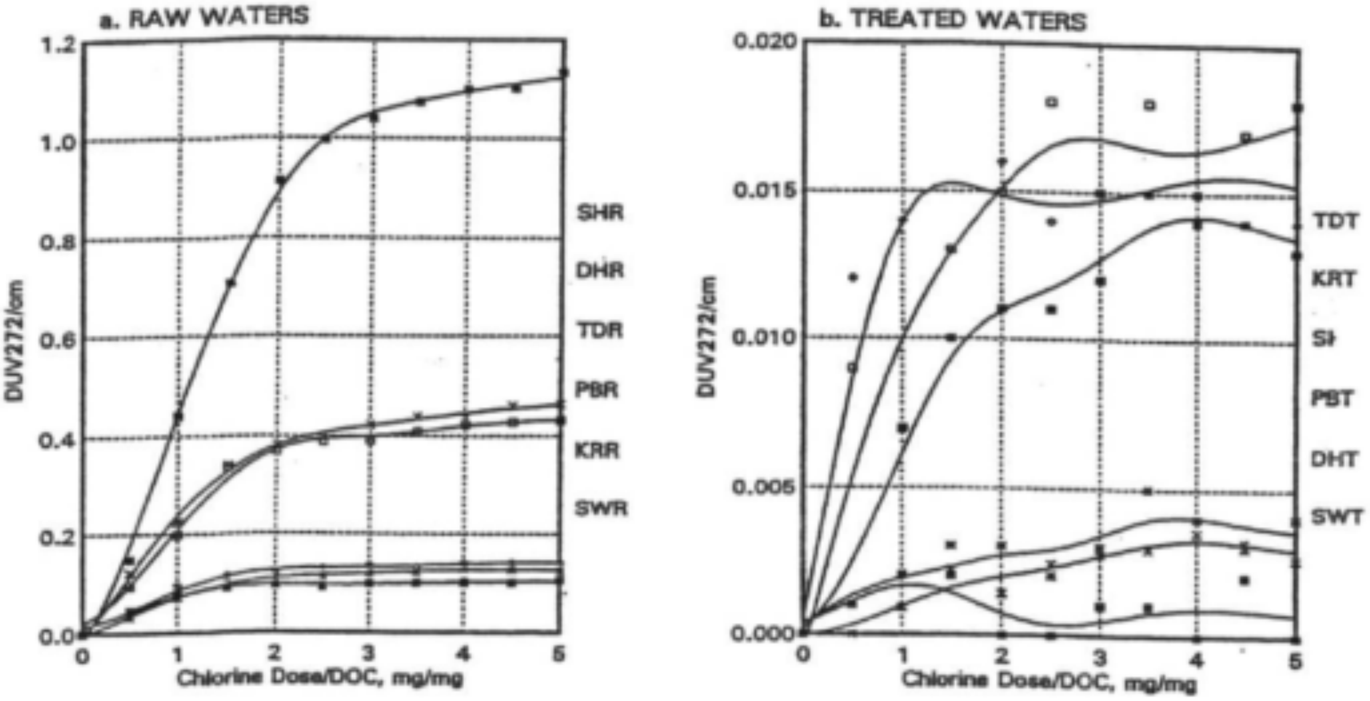
Figures 6.7d and 6.7f show the differential UV absorbance of the ten raw and ten treated waters from sample round 3, plotted against DOC (reaction time 7 days, pH 9.2, temperature 20 °C). There is a high degree of correlation for both sets of water. The best-fit line for treated waters has a lower slope than that for raw waters, 0.011 as against 0.036, and the raw water line cuts the DOC axis at 2.5 mg/ℓ.

FIGURE 6.5

DIFFERENTIAL ABSORBANCE AFTER CHLORINATION

CHLORINE DOSE

1 Day Reaction Time



CHLORINE DOSE WITH DUV NORMALISED

DUV adjusted to 1.0 at dose 3.2 x DOC

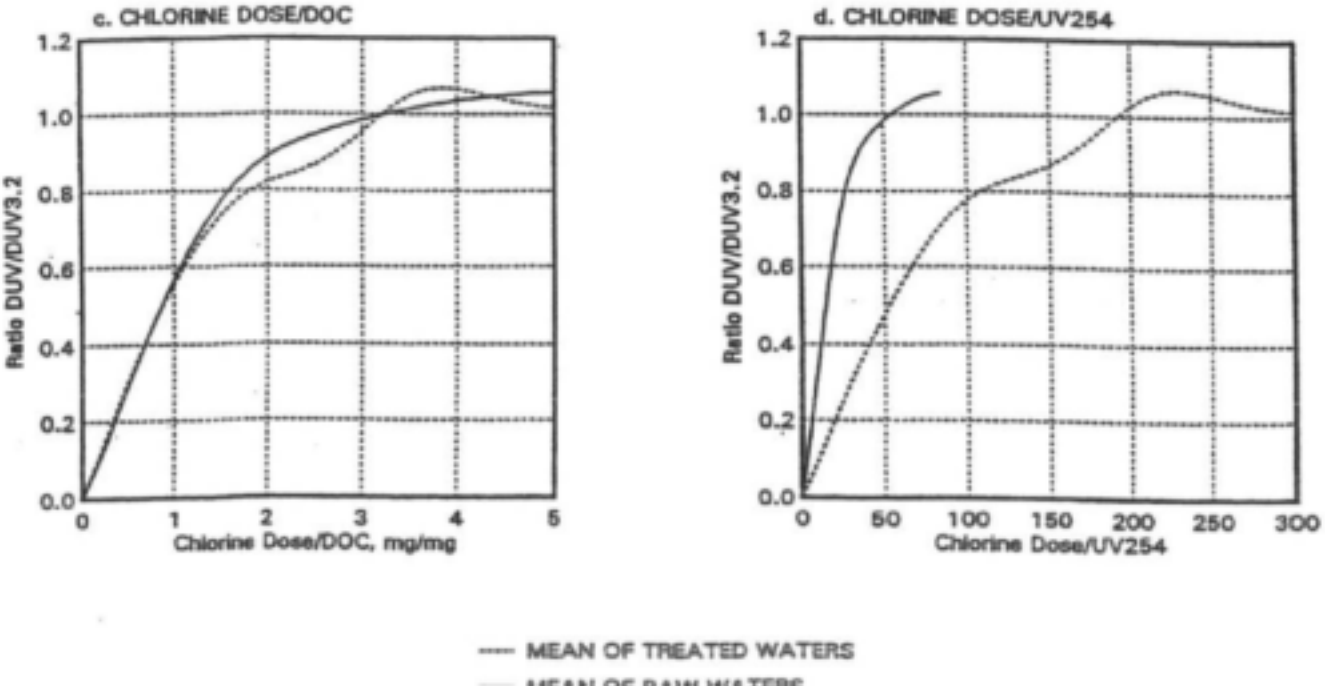
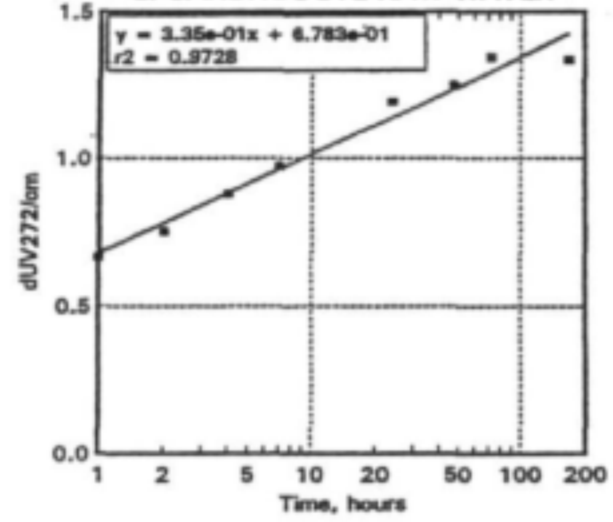


FIGURE 6.6

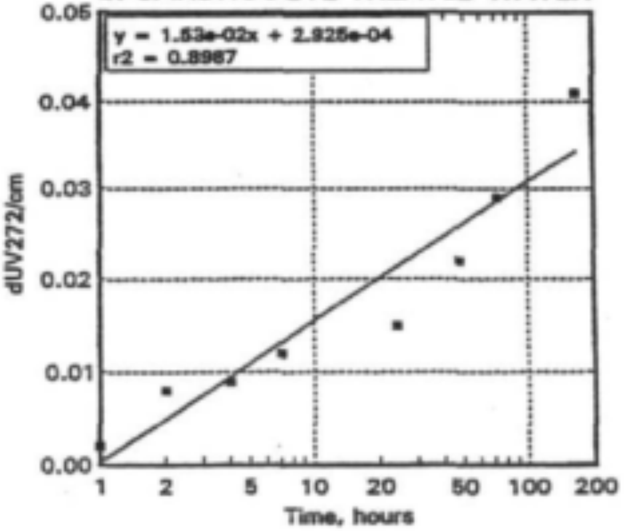
DIFFERENTIAL ABSORBANCE AFTER CHLORINATION

EFFECT OF REACTION TIME

DOSE 3.2 x DOC



a. SANDHOOGTE RAW WATER



b. SANDHOOGTE TREATED WATER

The corresponding plots for the relationship between DUV272 and UV272 are given by Figures 6.7c and 6.7e In this case the treated water values lie nearly on the same line as those for the raw waters, having a slope of 0.43 as against 0.55. Although more extensive work might show this difference to be significant, to a first approximation a single equation could be use to relate the two variables.

DUV272 = 0.55 x UV272 - 0.02

The slope of this line, 0.55 can be compared with that obtained in the reaction time experiment discussed above, namely 0.63 for a 7 day period. Further determinations on the effect of reaction time would be required to improve the agreement.

6.7.4 DUV272 and TOX

The factor connecting TOX formation to DUV272 is reported by Korsin *et al* to be about 10000 ug/*ℓ* TOX/cm, for a number of American and French waters, over a wide range of pH values, reaction times and chlorine doses.

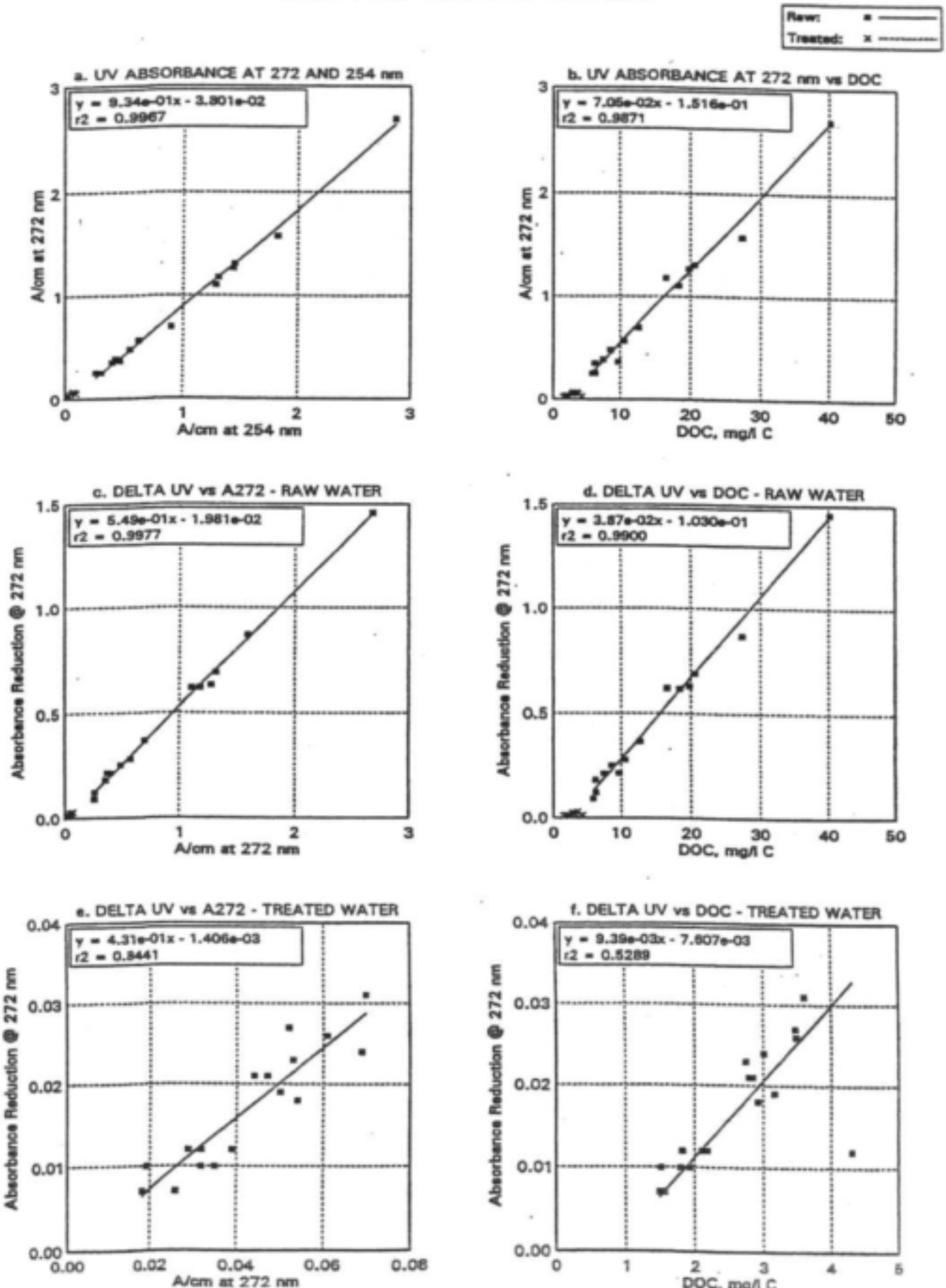
Assuming that this factor is valid for the waters of the present study one obtains TOX values with a range of 910 to 8700 for the raw waters and 70 to 310 for the treated waters. These are estimates of the formation potential of the water ie they were obtained by the use of high chlorine doses, a high pH and a long reaction time. Under normal water treatment conditions, lower values can be expected.

These TOX estimates, when expressed as a percentage of the applied chlorine dose, averaged over all the samples, give the following values: Raw water 10%, Treated water 2%. For the THM determinations, as noted above, the corresponding values were 12 and 10%.

FIGURE 6.7

DIFFERENTIAL ABSORBANCE AFTER CHLORINATION

RAW AND TREATED WATERS



It may be that the DUV272 method underestimates TOX formation in these treated waters as it assumes that the only precursor is UV-absorbing humic materials. Although this is probably a valid assumption in the case of the raw waters it may no longer be true when most of the humic materials have been removed by the treatment, as other soluble substances then form a greater proportion of the remaining DOC, and some of these may also be THM precursors.

6.8 COMPARISON OF FERRIC SULPHATE AND FERRIC CHLORIDE FOR REMOVAL OF DBP

In the course of the preliminary work, there were indications that there might be differences between ferric sulphate and ferric chloride in respect of the degree of removal of organic matter. Samples were therefore taken from four of the sources, Port Elizabeth, Sandhoogte, Duivenshok and Swellendam (Round 4), for comparison of the effect of the treatments on the two disinfection byproduct indicators.

Table 6.2, below, shows the results. In general, ferric chloride gives lower values for UV254, DOC, THMFP and DUV272.

These differential UV results are plotted against DOC in Figure 6.7f, along with the Round 3 values, and are consistent with the latter, except for the Swellendam ferric sulphate treatment result which appears as an outlier. The anomalous results for this sample should perhaps be ignored as it is not at all clear where the problem lies - the THMFP value is consistent with the DOC but both are higher than the UV272 would indicate, suggesting some source of organic matter that does not absorb at ultra-violet wavelengths. However, this effect is not evident when the same water was treated with ferric chloride.

A more comprehensive comparison of treatment chemicals, at various pH values and doses, is given in Chapter 7 of this report, although determination of disinfection by-products was not attempted.

TABLE 6.2 COMPARISON OF TREATMENTS

(Round 4 samples, pH 4.8, Fe dose 45 x UV300, 10 mm cells)

Source	Ferric Sulphate				Ferric Chloride			
	UV254	DOC	THMFP	DUV	UV254	DOC	THMFP	DUV
Sandhoogte	0.050	3.17	420	0.019	0.017	1.93	220	0.010
Port Elizabeth	0.053	3.48	820	0.027	0.047	2.79	500	0.021
Swellendam	0.032	4.32	780	0.012	0.017	1.49	170	0.007
Duivenhoks	0.032	2.11	150	0.012	0.014	1.51	110	0.010

6.9 MANGANESE AND IRON

There was little or no relationship between any two of iron, manganese and DOC in the raw waters.

The treatment process brought about an increase in manganese concentration in nearly every case. As the increase was proportional to the ferric sulphate dose, the manganese must have been present in the analytical grade ferric sulphate used.

Although of no consequence in the present project, it serves as reminder that treatment with ferric iron solutions is likely to give rise to manganese problems even when the raw water manganese content is low. The appropriate remedy is to increase the pH before filtration, in order to precipitate the manganese as MnO_2. Effective removal of ferrous iron by filtration also has a similar requirement.

CHAPTER 7

COAGULATION STUDIES AND COAGULATION DIAGRAMS

7.1 AIMS OF APPROACH TO THE COAGULATION DIAGRAMS

Beakers tests were done on each of the ten selected raw water sources to draw up coagulation diagrams for each source. The aims of the coagulation diagrams are to determine the treatability of each of the selected raw waters with coagulation, under different treatment conditions, and to indicate the effective reduction areas for the control parameters, with specific attention also to the levels of metal residuals in the treated water.

The coagulation diagrams contain the following information:

- Chemical treatability of the raw waters, as measured by
  - UV absorbance at 254 nm
  - turbidity
  - residual metal concentration
- Optimum treatment conditions for each of the water sources, in terms of type of coagulant, coagulant dosage and pH

For each of the raw waters tested, it is possible to establish from the coagulation diagrams the extent to which coagulation can cost-effectively

- remove natural organic matter
- reduce the production of undesirable disinfection by-products

7.2 EXPERIMENTAL PROTOCOL FOR COAGULATION BEAKER TESTS

7.2.1 Raw water sources

Bulk raw water samples were collected one at a time from the ten selected sources and extensive beaker tests carried out at the laboratory in Mossel Bay. These raw water samples were collected over the period October 1999 to January 2001 and were not the same samples taken earlier for the characterization studies reported on in Chapter 4.

7.2.2 Chemicals used

Analytical grade ferric chloride, ferric sulphate and aluminium sulphate were used as coagulants in the beaker tests. Analytical grade lime was used for pH adjustment.

7.2.3 Apparatus

a. Phipps and Bird 6 beaker flocculation stirrer
b. Magnetic stirrer
c. Multipipette
d. Filtration equipment with vacuum pump
e. HACH DR 4000 UV/VIS Spectrophotometer
f. HACH Turbidimeter 2100A
g. Schott Handylab pH meter with Orion glass and reference electrodes

7.2.4 Beaker test procedures

a. 1 litre circular glass beakers were used for performing the beaker tests.

b. The glass beakers were filled with sample up to the 800 mℓ mark. The beaker was placed on the magnetic stirrer and the pH probe inserted into the beaker. Rapid mixing was induced at about 300 rpm (to form a well defined vortex).

c. The coagulant was added first at the predetermined coagulant dose, and thereafter gradually the lime until the target pH was reached (in about 1 to 2,5 minutes).

d. Stirring at high speed was continued for another 30 seconds on the magnetic stirrer, after which the beaker was removed and placed under the Phipps and Bird flocculation stirrer (lamp was switched off during the experiments).

e. Slow mixing at 20 rpm was induced for 20 minutes on the flocculation stirrer. At the end of the flocculation period, the beaker was removed from the stirrer and allowed to settle for 30 minutes.

f. Using plastic syringes (50 - 100 mℓ) supernatant was withdrawn just below the surface of the water in the beaker. A total of 500 mℓ of sample was withdrawn to give a representative sample of the supernatant and to be consistent.

g. The pH and turbidity of the unfiltered supernatant sample were determined.

h. The remainder of the sample was filtered through a 0.45 μm membrane filter and the following done on the filtrate:
   - determine the UV254 of the sample
   - selected samples were preserved by acidification to 0.1 M with nitric acid, and submitted to the CMC Scientific Services for determination of iron, manganese and aluminium (using a Varian ICP-OCS).

i. During the performance of beaker tests on the third of the ten samples, it was decided that for the analysis of residual metals, the pH of the unfiltered supernatant sample would be raised to 7.5 by the addition of lime, before filtration through the membrane filter. This was done in order to simulate plant conditions where the pH is often raised before the sand filters to precipitate iron.

7.2.5 Preliminary investigative tests

Beaker tests were firstly done on two raw waters, one dark (Sandhoogte) and one light (Swellendam), to compare coagulants and alkalis, and to determine treatment ranges for coagulant dosage and pH. The experimental protocol for subsequent detailed tests on all 10 raw water sources was established after processing and interpreting of the results of the preliminary investigative tests.

Coagulant doses were adjusted to be in fixed ratios to the UV300 values of the raw waters. Equimolar amounts of ferric iron and aluminium were used.

7.2.6 Experimental protocol

a. Optimisation of coagulation pH

For ferric chloride and ferric sulphate, tests were done at the following pH values:

4.2 4.6 5.0 5.4 5.8 6.2

For aluminium sulphate, a higher range of pH values were used, as follows:

4.6 5.0 5.4 5.8 6.2 6.6

b. Optimisation of coagulant dose

The following dosages (in mg/ℓ Fe), based on the UV300 absorbance of the raw water, were used for ferric chloride and ferric sulphate:

UV300 x 10
UV300 x 13
UV300 x 17
UV300 x 23
UV300 x 30
UV300 x 40

For alum, the dosages (in mg/ℓ $Al_2(SO_4)_3.12H_2O$) (containing the same molar concentrations of aluminium as in the case of the ferric salts) were as follows:

UV300 x 10 x 5
UV300 x 13 x 5
UV300 x 17 x 5
UV300 x 23 x 5
UV300 x 30 x 5
UV300 x 40 x 5

7.3 RESULTS

7.3.1 Coagulation diagrams

The coagulation diagrams, drawn up for each of the 10 raw water sources from the results of the coagulation beaker tests, are given in Appendix D. Analytical results appear in Appendix E, and include residual metal concentrations after coagulation, settlement and filtration.

7.3.2 Coagulation pH

Figures 7.1 to 7.6 show the effect, for all the waters, of coagulation pH on filtered water UV254 and settled water turbidity, at ferric iron doses of 23 and 30 mg Fe/ℓ/UV300 respectively and the equivalent aluminium sulphate doses.

For both iron salts, filtered water UV254 usually decreased as the pH was reduced, in line with expectations. The minimum was either at pH 4.2/4.6, except for Knysna raw water where it was in the range 4.6/5.0.

The minimum turbidity for most of the waters was also in the range pH 4.2/4.6 with the exception of Knysna, Duivenshok and Port Elizabeth waters where the turbidity tended to rise slightly with decrease in pH and the minimum was usually in the pH range 5.0/6.2

FIGURE 7.1

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH COAGULANT DOSE OF UV300 x 30

Ferric Chloride

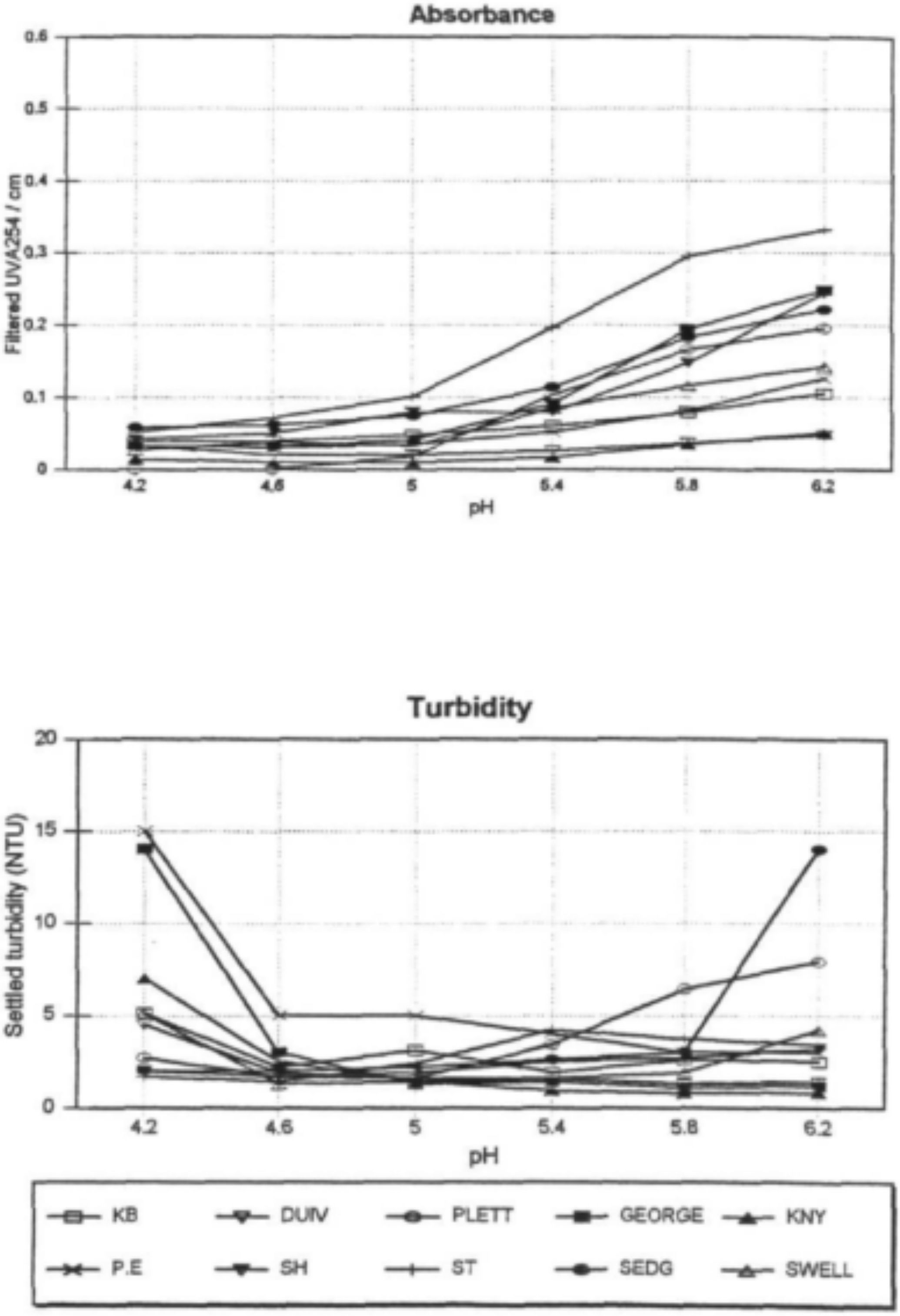


FIGURE 7.2

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH COAGULANT DOSE OF UV300 x 30

Ferric Sulphate

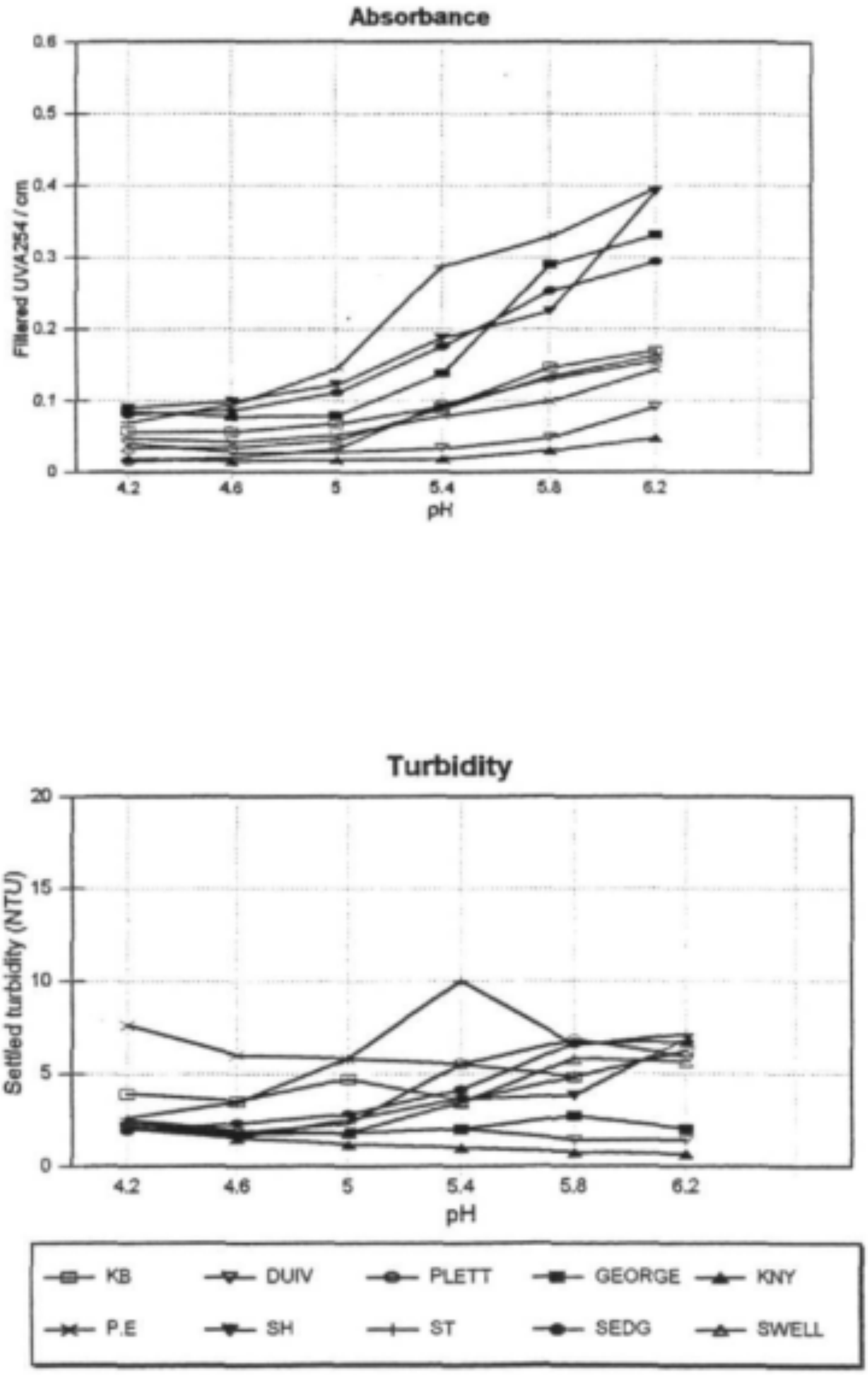


FIGURE 7.3

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH COAGULANT DOSE OF UV300 x 30

Aluminium Sulphate

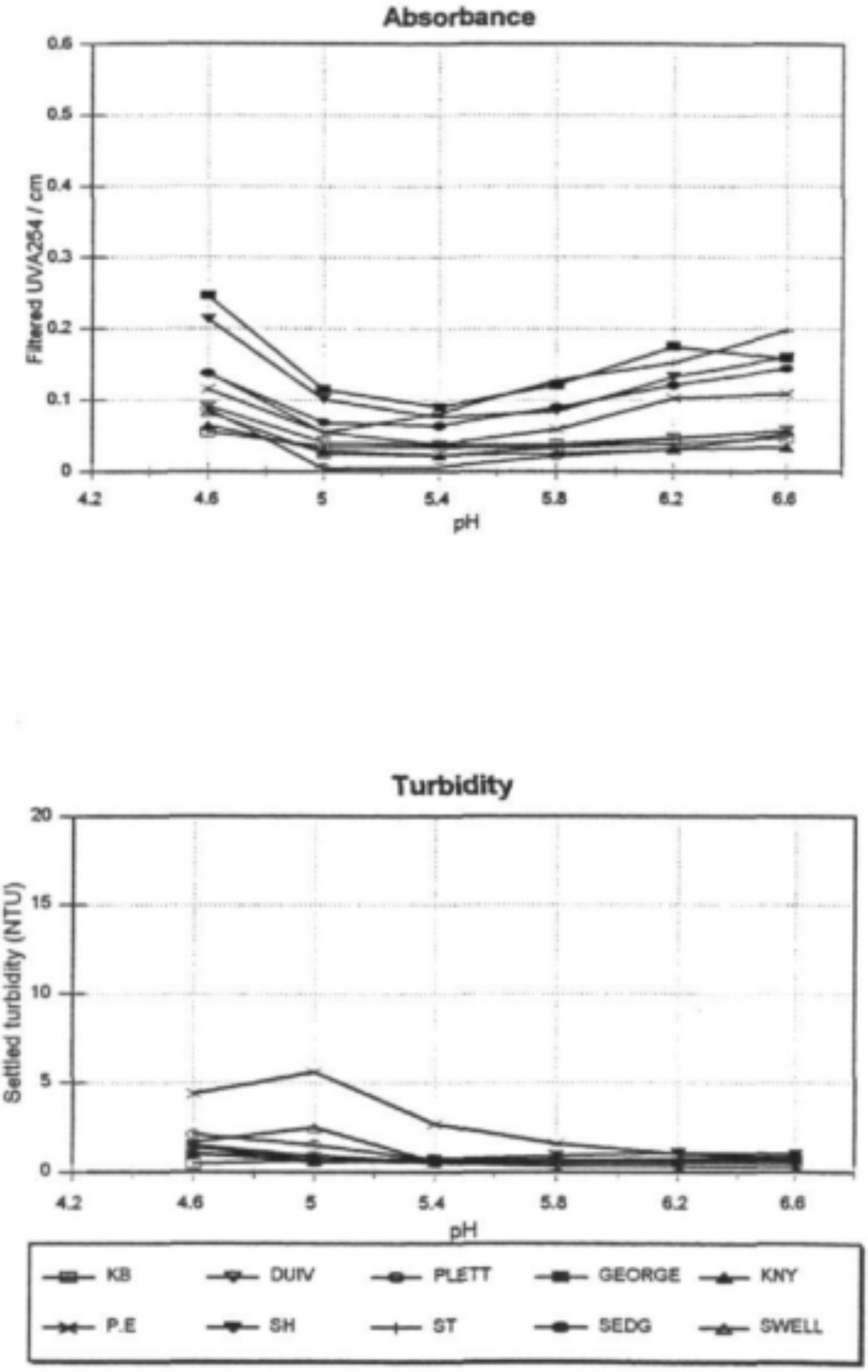


FIGURE 7.4

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH COAGULANT DOSE OF UV300 x 23

Ferric Chloride

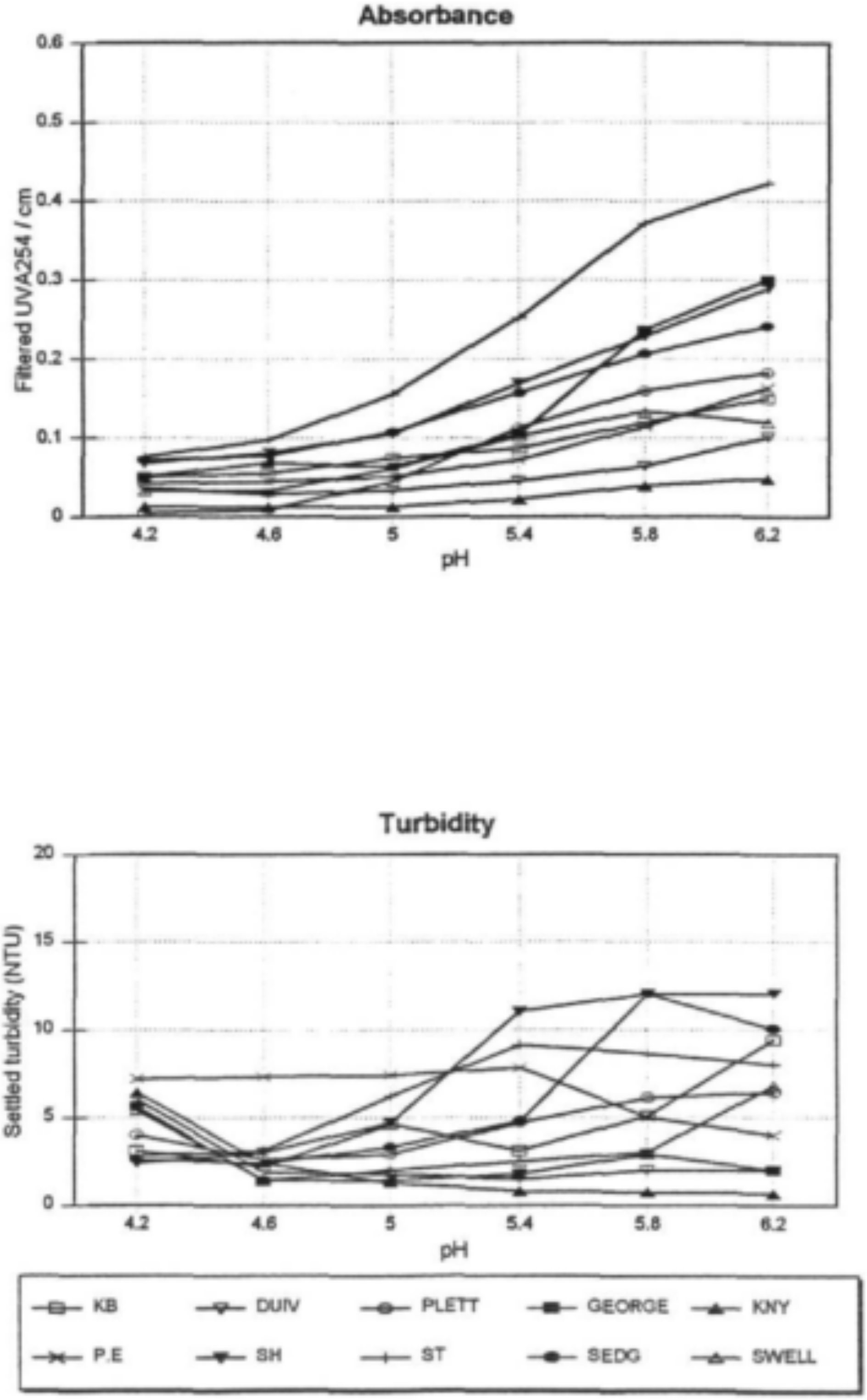


FIGURE 7.5

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH COAGULANT DOSE OF UV300 x 23

Ferric Sulphate

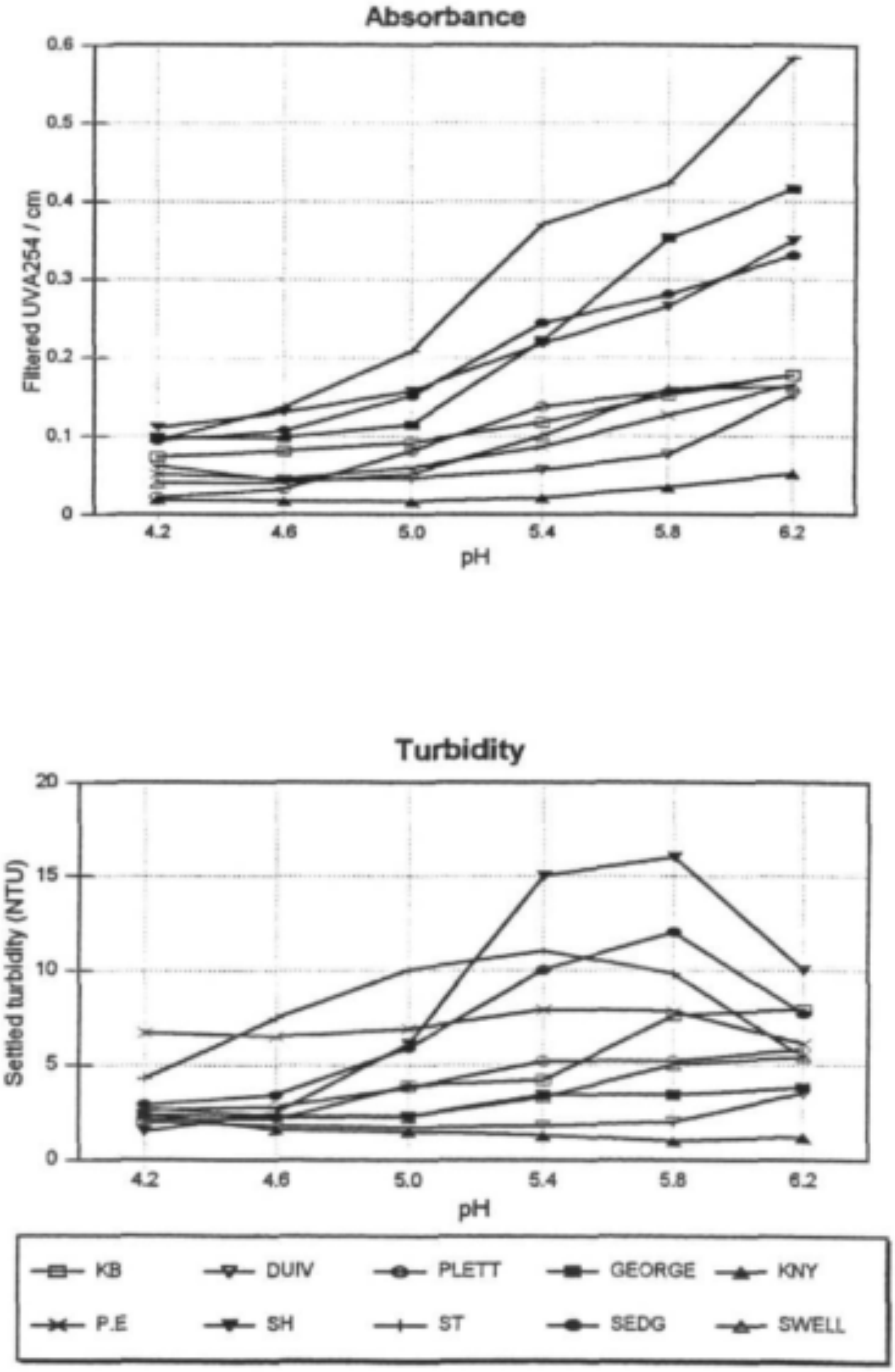
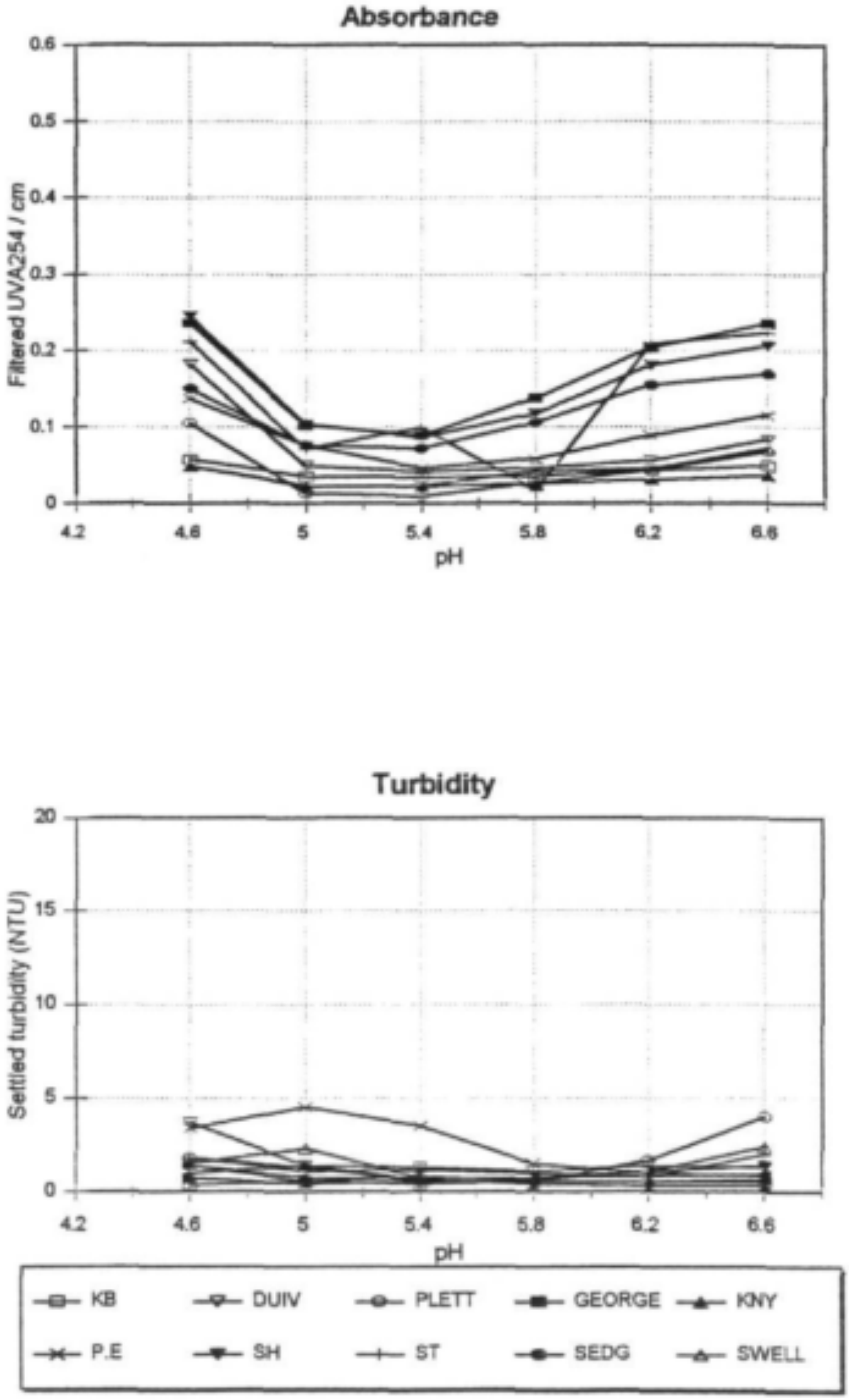


FIGURE 7.6

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH COAGULANT DOSE OF UV300 x 23

Aluminium Sulphate



For aluminium sulphate, the absorbance minimum was at pH 5.4 except in the case of Simons Town where it was at pH 5.0. The turbidity minimum ranged from 5.0 to 6.6, but the turbidity was generally much lower and less variable than with iron salts.

7.3.3 Coagulant Dose

The effect of ferric iron dose, at pH 4.6 and 5.0, is shown in Figures 7.7, 7.8, 7.10 and 7.11.

With ferric chloride, for concentrations above 20 mg Fe/ℓ/UV300, UV254 declined gradually with increase in dose in much the same fashion for all waters, at both pH values. The main difference between samples was the amount of residual UV254, which varied quite considerably. The rate of decline with dose was roughly proportional to UV254 itself. Sedgefield raw water had the highest residual UV254. Dose increases with Port Elizabeth raw water had a small effect; pH 4.6 gave the lowest values.

The curves for settled turbidity, at doses greater than 20 mg Fe/ℓ/UV300 were roughly parallel to each other for all waters except Knysna and Duivenhoks, which increased with dose; these two waters had low UV254 values and the use of a higher pH obviated this problem. Port Elizabeth water was fairly turbid.

At concentrations of less than 20 mg Fe/ℓ/UV300, there was often no floc and the differences between the waters were much greater.

With ferric sulphate the situation was similar, but both UV254 and turbidity were higher in all cases. Kleinbrak water had no floc at a dose of 20 mg Fe/ℓ/UV300.

Aluminium sulphate gave similar results but UV254 was substantially higher than with the ferric coagulants; pH 5.8 gave better removals than pH 6.2. In contrast, settled water turbidity was much lower than with iron.

FIGURE 7.7

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH FERRIC CHLORIDE AT pH 4.6

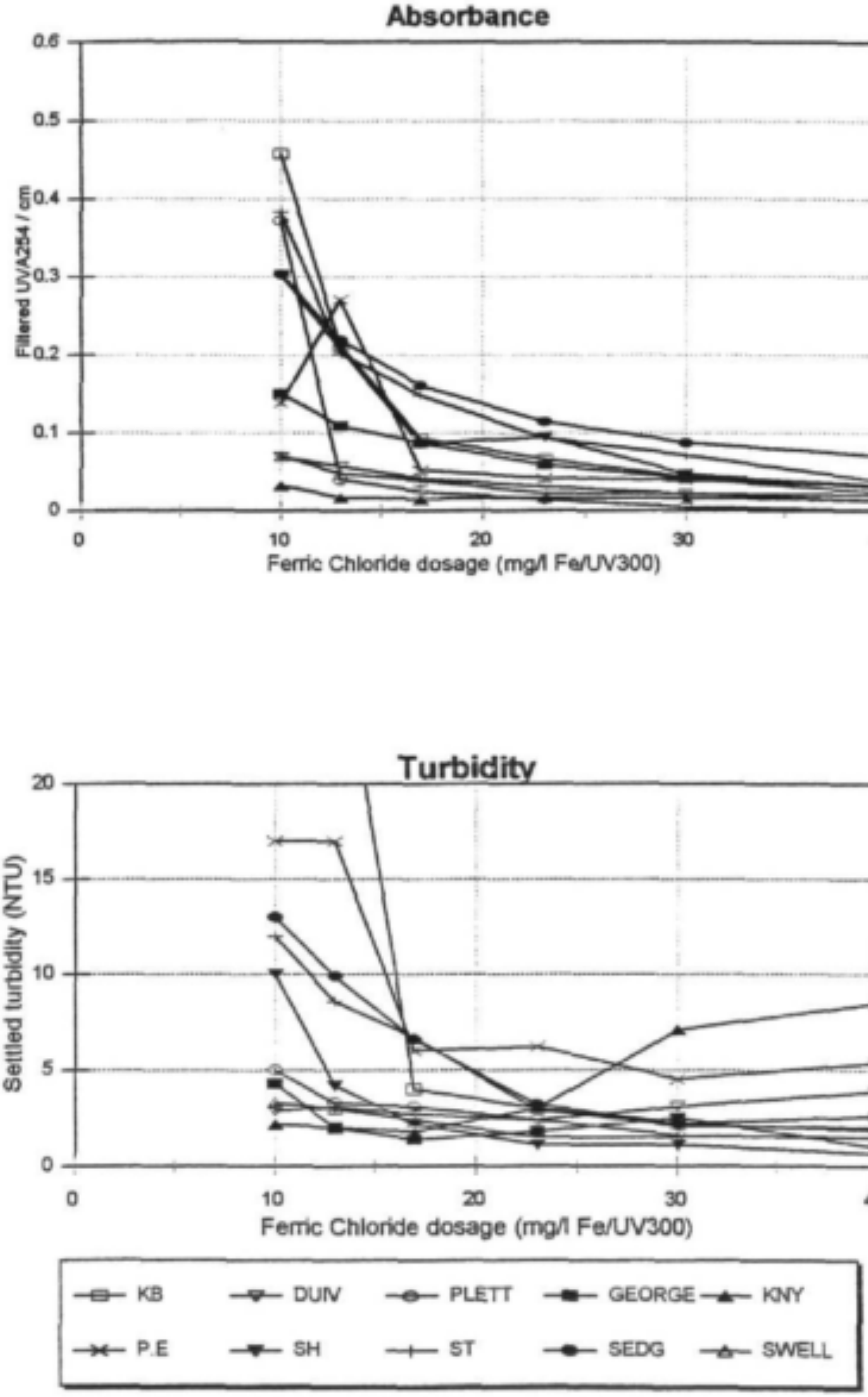


FIGURE 7.8

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH FERRIC SULPHATE AT pH 4.6

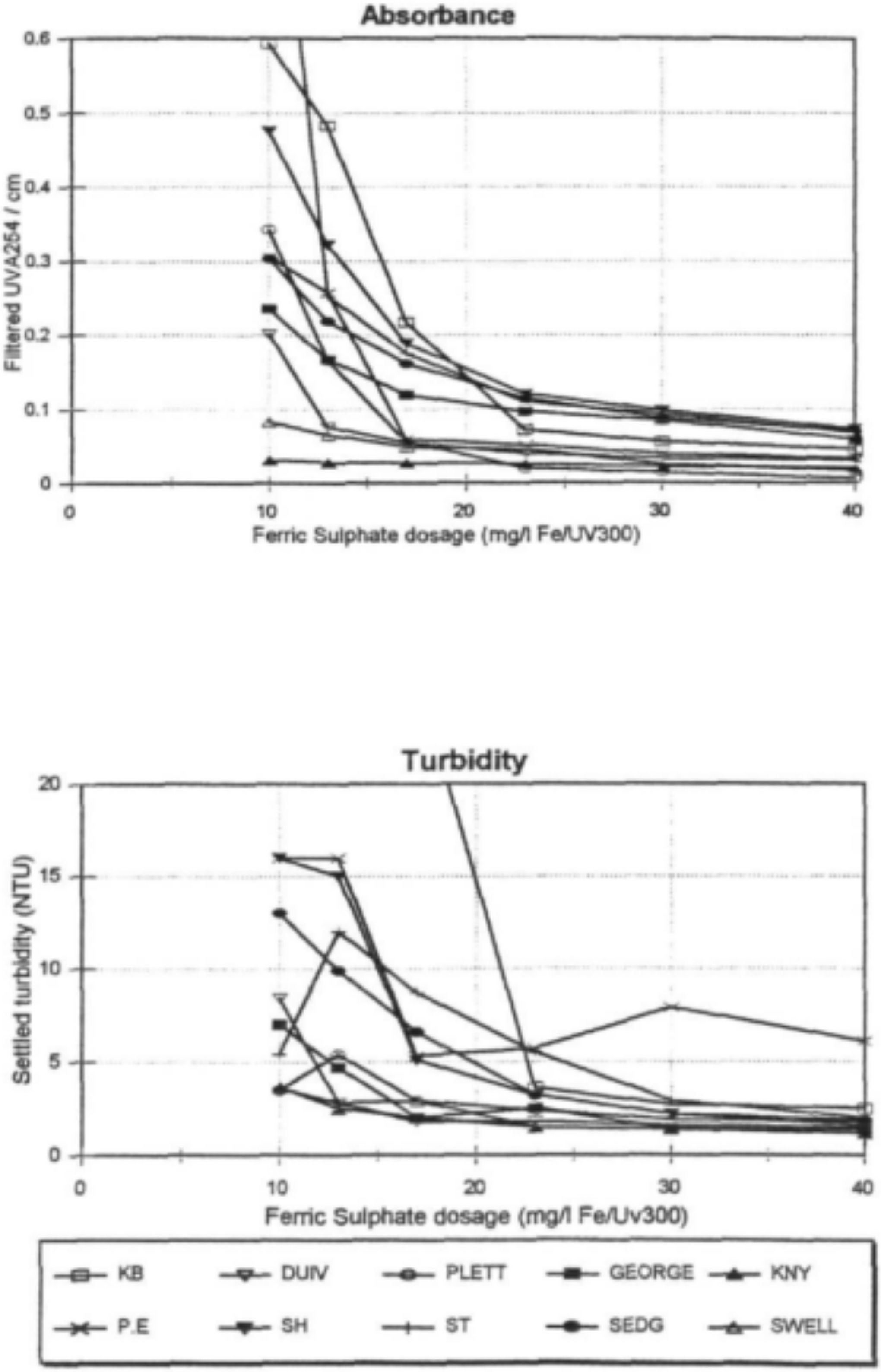


FIGURE 7.9

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH ALUMINIUM SULPHATE AT pH 5.8

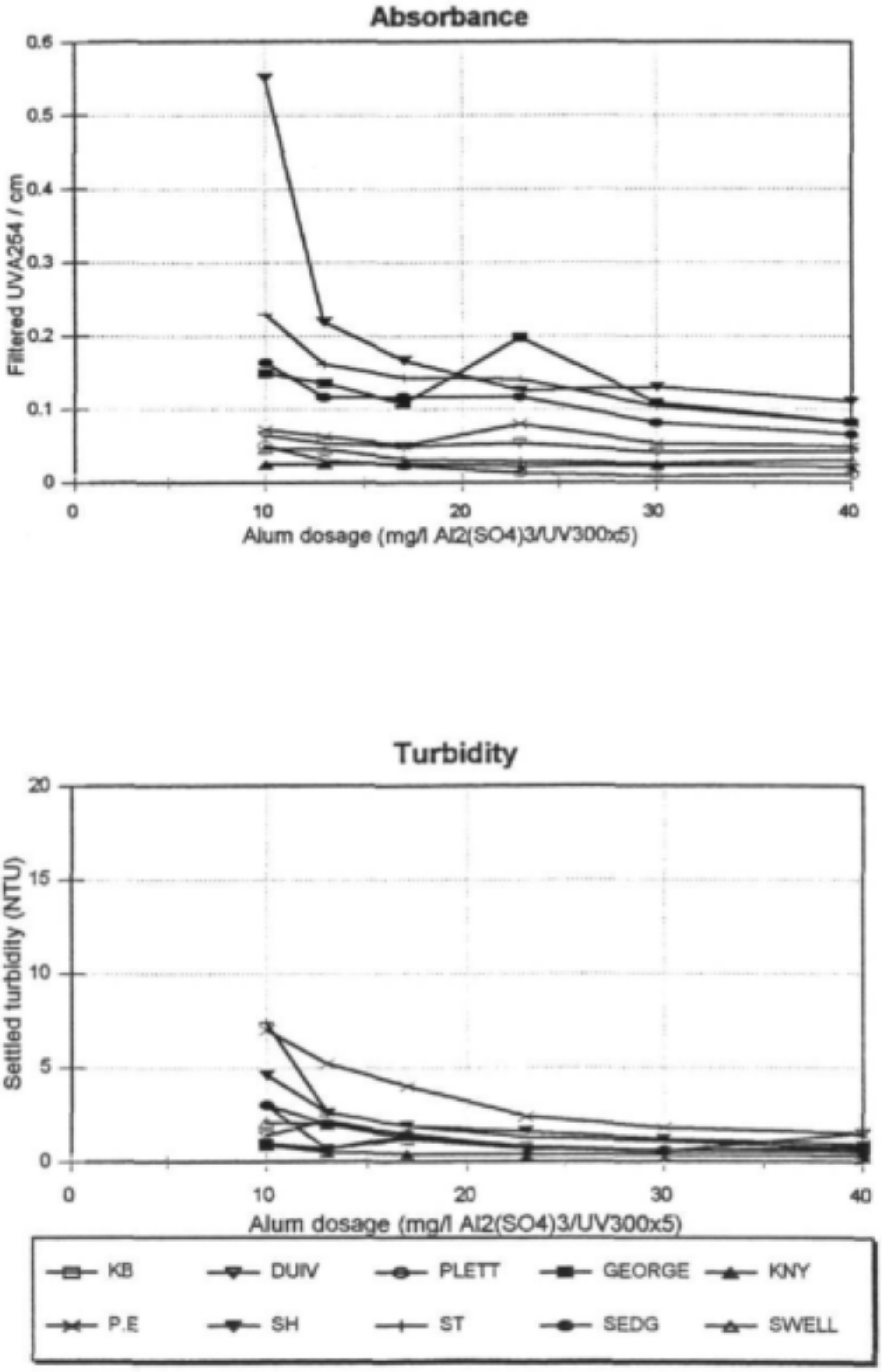
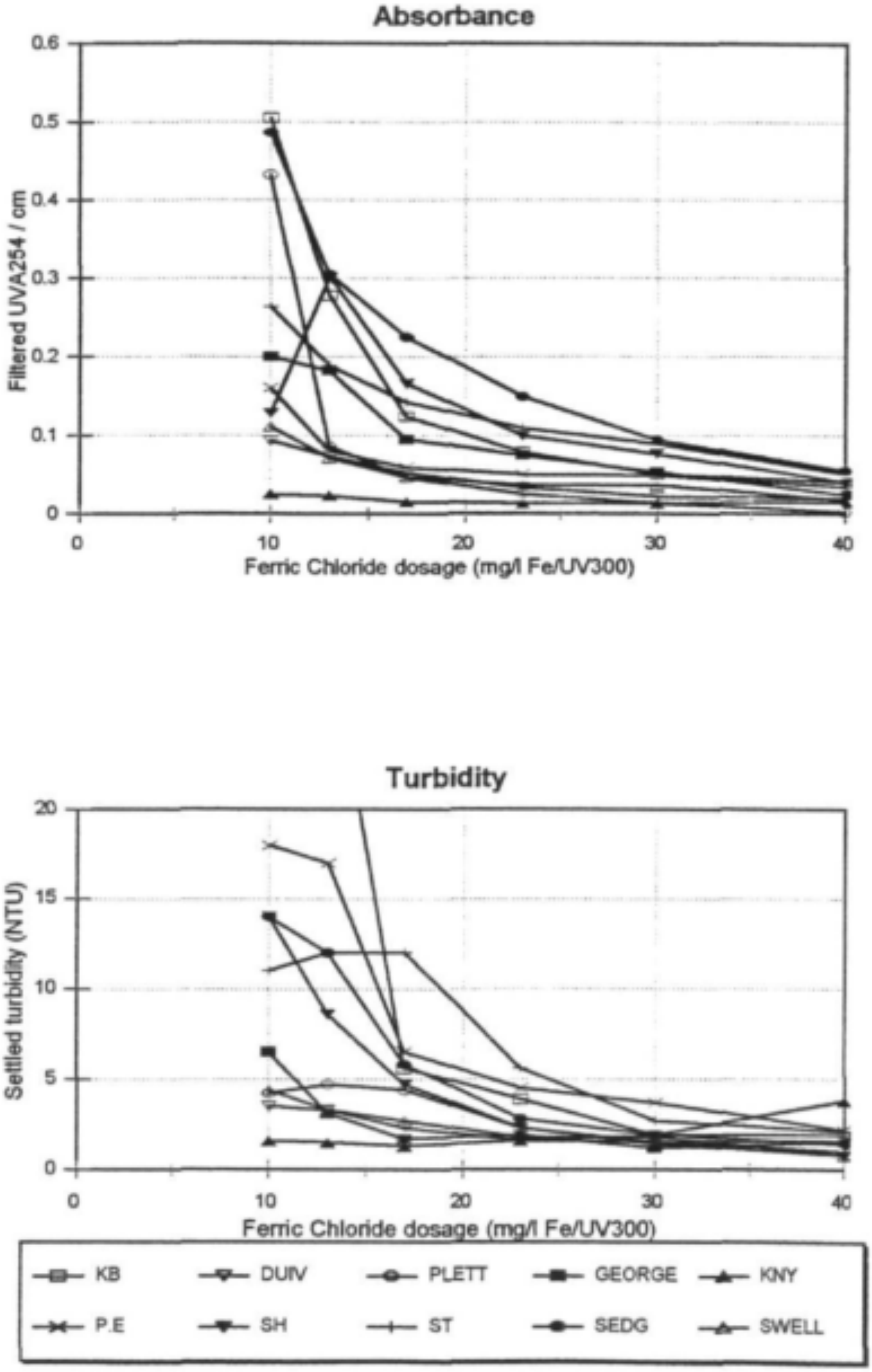


FIGURE 7.10

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH FERRIC CHLORIDE AT pH 5.0



Absorbance

Turbidity

FIGURE 7.11

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH FERRIC SULPHATE AT pH 5.0

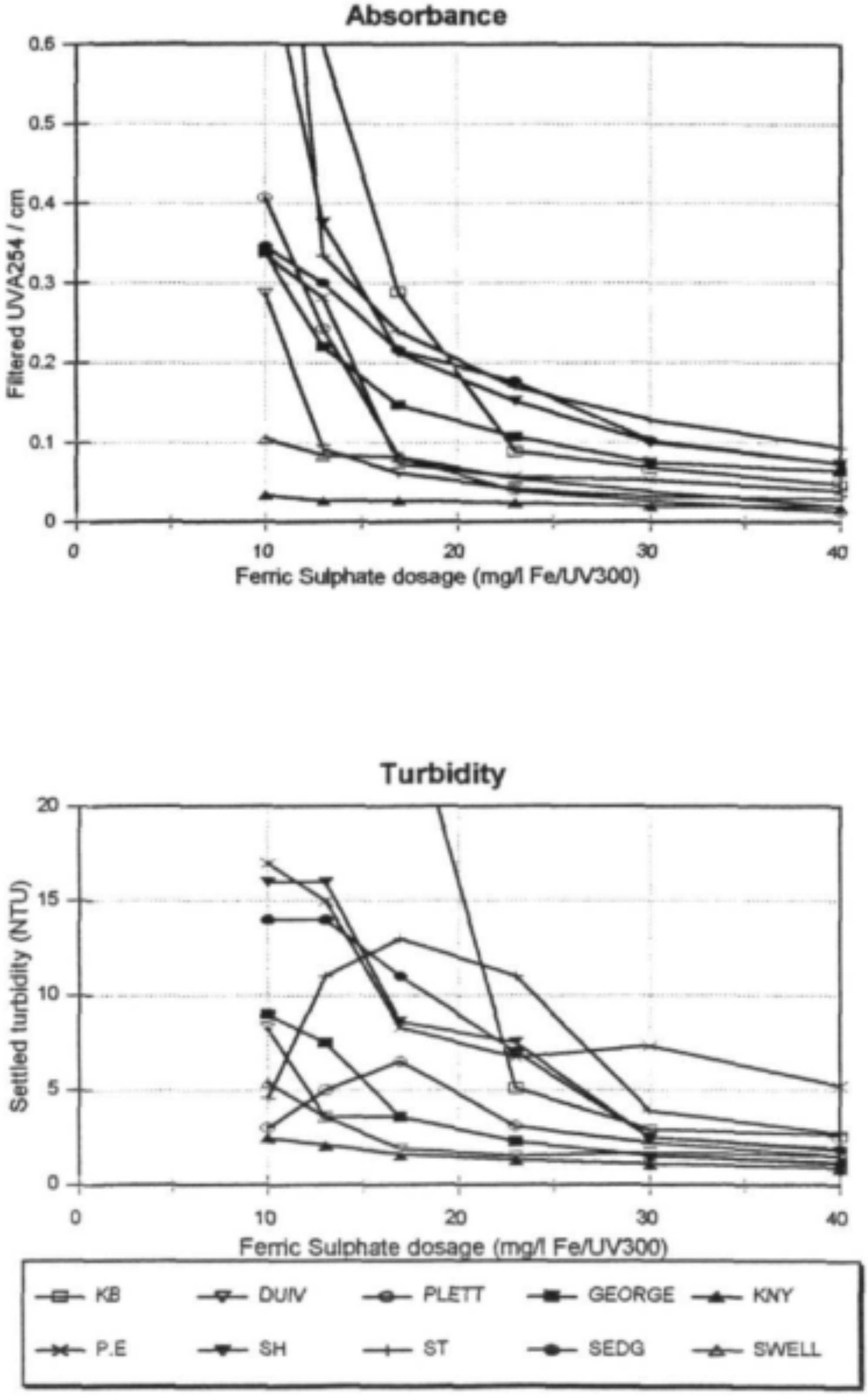
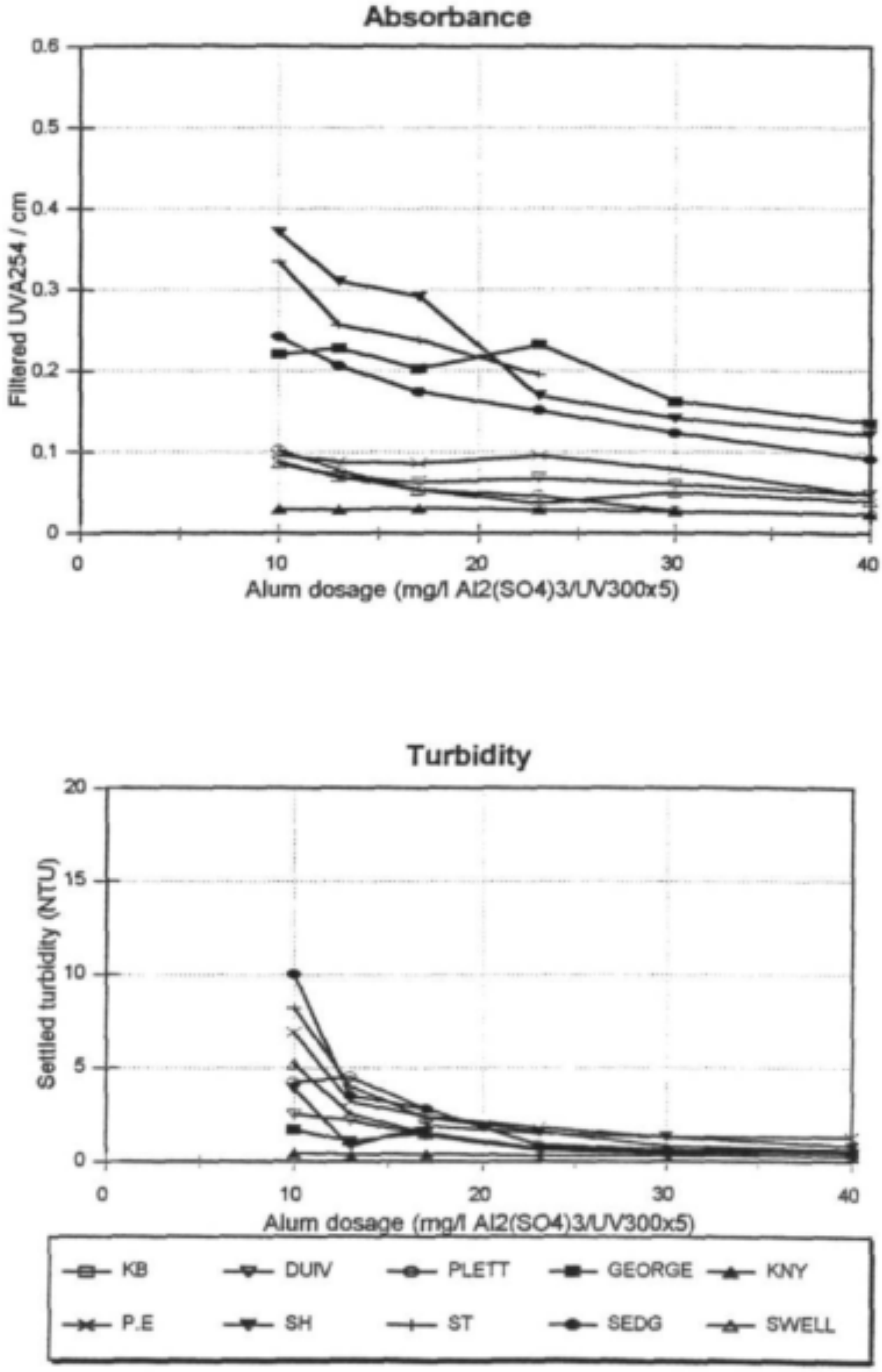


FIGURE 7.12

COAGULATION CURVES FOR 10 WATER SOURCES TREATED WITH ALUMINIUM SULPHATE AT pH 6.2



7.3.4 Residual Metals

A thorough investigation of the removal of aluminium, iron and manganese has not been attempted in this project, although a subset of settled waters were filtered and analysed. In most cases, the pH was raised to 7.5 before filtration. Detailed results are given in Appendix D.

The solubility of aluminium is at a minimum at about 6.2, and increases very rapidly as the pH is reduced below about 5.3 or 5.4. The aluminium residuals measured in the filtered water were in agreement with these figures. With an aluminium sulphate coagulant, the mean aluminium concentrations at pH 5.0, 5.8 and 6.6 were 1.4, 0.25 and 0.51 mg/ℓ respectively. A coagulation pH of 5.0 is thus not suitable for use with aluminium sulphate.

With the iron coagulants, mean aluminium residuals at pH 4.2, 4.6 and 5.0 were 0.17, 0.09 and 0.06 respectively, being limited by the aluminium available in the raw water.

Ferric hydroxide solubility is very low above about pH 4.2. With the ferric coagulants, iron residuals, much the same for both coagulants, were 0.28, 0.14 and 0.11 at pH 4.2, 4.6 and 5.0 respectively. This is more than the expected solubility of ferric hydroxide, probably due to the presence of some ferrous iron in the raw water.

With aluminium sulphate, where the main source of iron was the raw water, the average residual was 0.04 mg/ℓ, about the same at all three pH values.

Manganese present as soluble Mn^{2+} is not expected to be removed by the flocculation process but organically bound manganese may be. Manganese residuals obtained with ferric chloride and aluminium sulphate were much the same for both and represent the contribution of the raw water.

Six of the waters contained 0.01 mg/ℓ Mn or less. Sedgefield, Duivenhoks and Knysna waters contained about 0.02 mg/ℓ, while George had about 0.045 mg/ℓ, enough to give dirty water problems. Ferric sulphate generally gave higher results than for the other two coagulants, probably because of manganese in the reagent solution.

These manganese values were lower than those found in the raw waters during the characterisation phase of the project, suggesting that a large portion was usually removable, a conclusion that requires confirmation.

CHAPTER 8

FLOC FORMATION RATES

8.1 INTRODUCTION

This section summarises the most relevant features of some additional work done by T Thebe in connection with a PhD thesis in Civil Engineering at UCT. While not an official part of the present project, this work is described with his permission. It was carried out on the samples obtained for the project and illustrates one aspect of the character of the water, namely the rates at which floc formation and break-up take place.

8.2 THEORY

Three main mechanisms are considered to play a part in the build-up of floc after the initial formation of very small insoluble particles by the reaction of iron and aluminium salts with hydroxide and humic materials. This build-up is a consequence of the tendency of destabilised particles to stick together when they come into contact with each other. Initially Brownian movement is the main source of contacts but, as the particle size increases, turbulent currents caused by stirring take over and, finally, differential settling of large particles comes to have the major effect. Of these, gentle stirring of the water after the addition of coagulants is the process generally used to promote floc formation at water treatment plants.

Mathematical modelling of the aggregation process, first attempted by Smoluchowsky (1917) and since extended by others, is based on estimation of the contact opportunity for particles, for given energy inputs, stirrer geometry, floc volume and floc 'sticking factor' (the fraction of contacts that result in aggregation). Also included in more recent equations are attempts to allow for

n_i / n_0 is the fraction of initial turbidity remaining after stirring and settlement.

Ka is the aggregation coefficient.

Kb is the breakup coefficient.

G is the root mean square velocity gradient, a measure of the turbulent energy dissipation.

m is the breakup rate exponent, usually 2, but other values have been used.

t is the stirring time in seconds.

In the original equations *n* represented the number of primary particles in the water. In this work, turbidity has been used as an approximate measure of this quantity.

The second term of Equation 8.1 gives a measure of the turbidity remaining as it declines exponentially with increase in stirring time, while the first term sets a lower limit to that decline, after extended stirring, at a level where floc formation and breakup are in dynamic equilibrium..

8.3 EXPERIMENTAL

The work discussed in the present report was focussed on estimating the constants *Ka* and *Kb*, for the waters of the study.

Batch flocculation experiments were carried out on each water at a number of stirring rates, for varying times and the turbidity of the settled water measured. These values were then fitted to Equation 8.1 for batch flocculation, at first visually using Excel, and then by means of a computer program which minimised the root mean square deviation of the experimental values from the

the simultaneous break-up of floc caused by stirring. Although bedevilled by the fact that accurate mathematical description of turbulence is one of the unresolved problems of physics, the approximate equations so far derived do seem to account for many of the observed aspects of the flocculation process.

The relevant differential equation, containing terms for floc formation and break-up rates, as detailed by Argaman and Kaufman (1970), and Parker, Kaufman and Jenkins (1972), can be integrated in several ways, depending on the process configuration used. The following two equations are for plug flow/batch reactors and completely-mixed flow-through (CST) reactors respectively, and have here been expressed in a form which allows them to be applied successively to a number of reactors in series, each with a different stirring intensity and residence time.

Batch and Plug Flow reactors

$$\frac{n_i}{n_o} = \frac{Kb}{Ka} G^{m-1}.(1-e^{-KaGt}) + \frac{n_{i-1}}{n_o} e^{-KaGt} \qquad 8.1$$

CST Reactors

$$\frac{n_i}{n_o} = \frac{n_{i-1} + n_o.Kb.G^m.t}{n_o.(1+Ka.G.t)} \qquad 8.2$$

where

n_0	is the turbidity of the flocculated water after coagulant addition and initial rapid mixing, with no settlement allowed.
n_{i-1}	is the turbidity (after settlement) of water leaving reactor *i - 1* and entering reactor *i*
n_i	is the turbidity (after settlement) of water leaving reactor *i*

theoretical line. *Ka* mostly influences the slope of the downward part of the curve and *Kb* the near constant turbidity after long stirring.

A total of 60 experiments were carried out. Half of these were conducted at three different G values, 30, 20 and 15 s^{-1}, on each of the ten waters. The remainder were done with Simonstown, Sandhoogte and Port Elizabeth waters and included two each at G values of 50 and 100 s^{-1}. Some of the latter tests were carried out on diluted samples. Ferric chloride was used for all tests - except for two with ferric sulphate - at a dosing rate of 30 mg/ℓ Fe per UV300 and pH 4.8. Figures 8.1 to 8.6 show the results obtained.

It was possible to fit the calculated curve to the experimental points remarkably well in most cases, considering that turbidity is not an exact measure of the number of primary particles, depending, as it does, on particle size and colour as well as number. The root mean square deviations ranged from 0.01 to 4.8%, with a median of 0.6%.

The results for nine experiments were excluded from further consideration for the following reasons:

1. Port Elizabeth water had a combination of high turbidity and low colour. The coagulant dose used was therefore low and floc formation slow. Even at the maximum stirring time of 30 minutes the turbidity was still high (2.4 to 4.9 NTU) and not yet reached constancy and it was therefore not possible to derive an accurate value for *Kb*, which is very much affected by the equilibrium turbidity. Furthermore, the low pH used was not really suitable for the flocculation of suspended matter such as clay. It was therefore considered that this water was not really representative of a brown water in respect of floc formation rate.

2. Two experiments with Plettenberg Bay water were also rejected because of non- equilibrium at the end of the experiment. Other experiments with this water were satisfactory.

3. The turbidity of the Klein Brak samples was very high, 21 and 44 NTU, possibly because of sampling problems. Some of the suspended matter was flocculant, and may have consisted of accumulated pipe deposits.

8.4 FLOC FORMATION RATE COEFFICIENT, *Ka*

The coefficient *Ka* is the product of the floc volume, the sticking factor and a constant, dependent on the geometry of the containing vessel and the stirrer. The first two of these are of greatest interest in this report as they are relate to the composition of the water and the chemistry of the treatment.

In the present experiments, the floc volume can be taken to be proportional to coagulant dose because the coagulant and the organic matter, which are the main contributors to the floc volume, were kept in fixed ratio to each other (30 mg/ℓ Fe per UV300). A graph of *Ka* against *Dose* (mg Fe/l) should therefore give a straight line with deviations from the line being influenced by differences between the waters in respect of sticking factor.

The plot in Figure 8.7, suggests that the assumption of a straight line relationship is a valid one. The best fit straight line, forced to pass through the origin, has a slope of 0.232×10^{-4} s^{-1} per mg/ℓ Fe. Whether the deviations from the line are due to differences between the waters or to experimental variability is less clear and is further considered below.

Firstly, Table 8.1 shows that *Ka/Dose* is not significantly affected by variations in *G*, at least in the range tested.

Secondly, other sources of variability in *Ka/Dose* were explored. The experiments were conducted in batches, each on one water sample at two or three *G* values. A single value for n_0, the initial turbidity, was used for the batch. Potential sources of variability can therefore be considered to be: within-batch, between-batch-within-sample-source, and between-sample-source.

Table 8.1 EFFECT OF *G* ON *Ka*

G	Number of Values	Mean Ka/Dose Fe $x 10^4$	Std Dev (Pooled) $x 10^4$
15	16	0.256	0.036
20	18	0.252	
30	10	0.237	
50	2	0.288	
100	2	0.233	

Table 8.2 shows some statistics for *Ka/Dose* which allow estimation of the magnitude of these effects. If there is a significant between-batch effect the standard deviation for Group 2 should be significantly higher than that for Group 1. This can be tested by calculating the variance ratio and comparing it with the expected values as listed in statistical tables. Similarly, the presence *of a between-sample-source effect can be evaluated by comparing Group 3* with Group2.

Table 8.2 shows that two main sources of variability are within-batch and between-batch, and that between-sample-source effects are insignificant compared with the other two. This does not mean that there were no differences between sample sources in respect of *Ka/Dose*, merely that they were too small to be estimated in the presence of the other sources of variability.

The main source of the between batch effect is probably the n_0 determination.

Table 8.2 VARIABILITY IN Ka/Dose

Data Groups Used for Calculation of Standard Deviation	Std Dev x 10^4	Degrees of Freedom	Variance Ratio F	Significance
1. Within-batch, pooled for all batches	0.014	29		
2. Within-water-source, pooled for all sources	0.035	42	6.25	High
3. All results, grouped together	0.037	49	1.12	Low

The present work therefore suggests that, at least for preliminary design work, a single *Ka/Dose* value can be used for all the waters of the study area, provided that the sample turbidity is not high relative to the organic content. Although more extensive investigation might reveal some differences between water sources, they are not likely to be large.

8.5 BREAKUP COEFFICIENT, *Kb*

In contrast to *Ka*, it was found that the best-fit values for *Kb* were not independent of G. Higher G values gave rise to significantly lower estimates of *Kb* ie the equation was over-compensating for the effect of G on floc break-up. The effect of *m*, the exponent of G in the break-up part of Equation 8.1 was therefore examined. Initially this had been set to a value of 2, which is that usually reported for clay-bearing waters.

The best-fit *Ka* and *Kb* were recalculated for *m* values between 1.2 and 2.0 in steps of 0.1. *Ka* was found to be essentially unaltered by the changes in *m* but, as can be predicted by inspection of the Equation 8.1, *Kb* increased as *m* was reduced, by different amounts for each G value.

Two statistical tests were used in the selection of the most suitable value for *m*:

1. The pooled within-batch relative standard deviation (%RSD) of all the *Kb* values. This can be expected to be at a minimum if *G* has no effect but, as there are more sources of variability in *Kb* than *G*, this statistic is not very sensitive to changes in *m*.

2. The, non-parametric, sign test. For this test, in each batch, *Kb* for the lowest *G* was compared with that for the highest *G*, and the number of increases and decreases were counted. If *G* has no effect, the increases and decreases can be expected to be equal. As the total number of batches was 19, the expected number will be 9.5 each. Table 8.3 shows the results obtained.

Table 8.3 SELECTION OF *m*

m	***Kb***	
	%RSD Within-Batch	**Number of Increases in Kb with higher *G* (Expect 9.5)**
1.2	12.4	12
1.3	11.7	11
1.4	11.8	9
1.5	12.8	6
1.6	14.5	3
1.7	16.6	2
1.8	18.9	2
1.9	21.5	2
2.0	24.2	1

Taking both tests into account, a value of 1.4 for m was chosen as being the most suitable for the brown waters of this study and was used in all other calculations.

As with *Ka/Dose*, the possibility that different water sources have different *Kb* values was explored. The following %RSD values were obtained:

Table 8.4. VARIABILITY IN *Kb*

Data Groups Used for Calculation of Standard Deviation	**Rel Std Dev %**	**Degrees of Freedom**	**Variance Ratio F**	**Signifi-cance**
1. Within-batch, pooled for all batches.	11.8	29		
2. Within-water-source, pooled for all sources.	26.0	42	4.85	High
3. All results, grouped together	27.3	49	1.10	Low

The only significant effect is the between-batch-same-supply variability, the main component of which is probably, as previously, n_o.

The %RSD for *Kb* is higher than for *Ka/Dose*, perhaps not surprising as the calculated values for *Kb* are dependent on *Ka* and on one or two low turbidity readings at the end of a run, whereas *Ka* is mainly derived from several higher turbidity readings which will be less affected by constant errors in turbidity measurements.

8.6 CONCLUSIONS

1. Equations 8.1 and 8.2 can be used to model the turbidity of the settled water after flocculation if a value of 1.4 is used for m, the break-up rate exponent.

2. The aggregation and breakup rate coefficients, *Ka/Dose* and *Kb* (0.232×10^{-4} per mg/l Fe dose and 13.0×10^{-6} s, respectively), are much the same for all waters of the study area with the possible exception of those which contain a large amount of suspended matter relative to the organic content, such as Port Elizabeth. If suitable flocculation conditions are used for the latter, the above constants might apply there too.

3. This means that the floc formation rate will be dependent mainly on the amount of humic materials in the water, provided that a suitable pH is used and that the coagulant dose is proportional to the organic content. Floc in a dark-coloured water can thus be expected to form more rapidly than in a light-coloured one. It should be noted that what is important here is the rate of incorporation of the very small particles into larger flocs of settleable size, and not necessarily the growth of the latter to a very large size.

8.7 REFERENCES

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Parker, D.S., Kaufman, W.J., and Jenkins, D. (1972) Floc Break-up in Turbulent Flocculation Processes. Proc. ASCE, J. Sanitary Engineering Division, 98 (SA1), 79-99.

Von Smoluchoski, M. (1917) Versuch einer Mathematischen Teorie der Koagulations-kinetik Kolloid Losungen. Z. Physik. Chem., 92, 155.

FIGURE 8.1

FLOCCULATION RATE

RATE MODELLING

Points are experimental. Lines are calculated

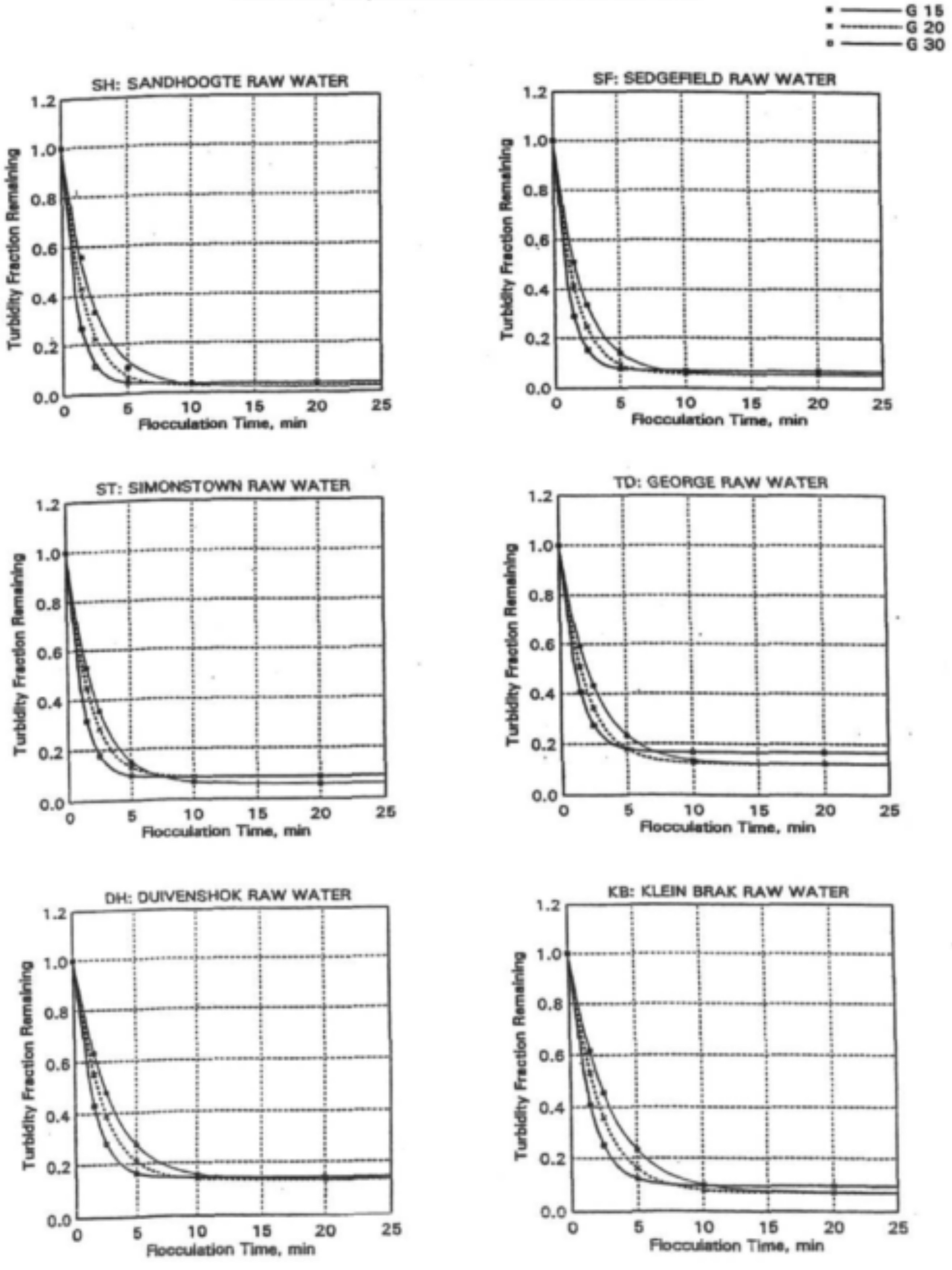


FIGURE 8.2

FLOCCULATION RATE

RATE MODELLING

Points are experimental. Lines are calculated

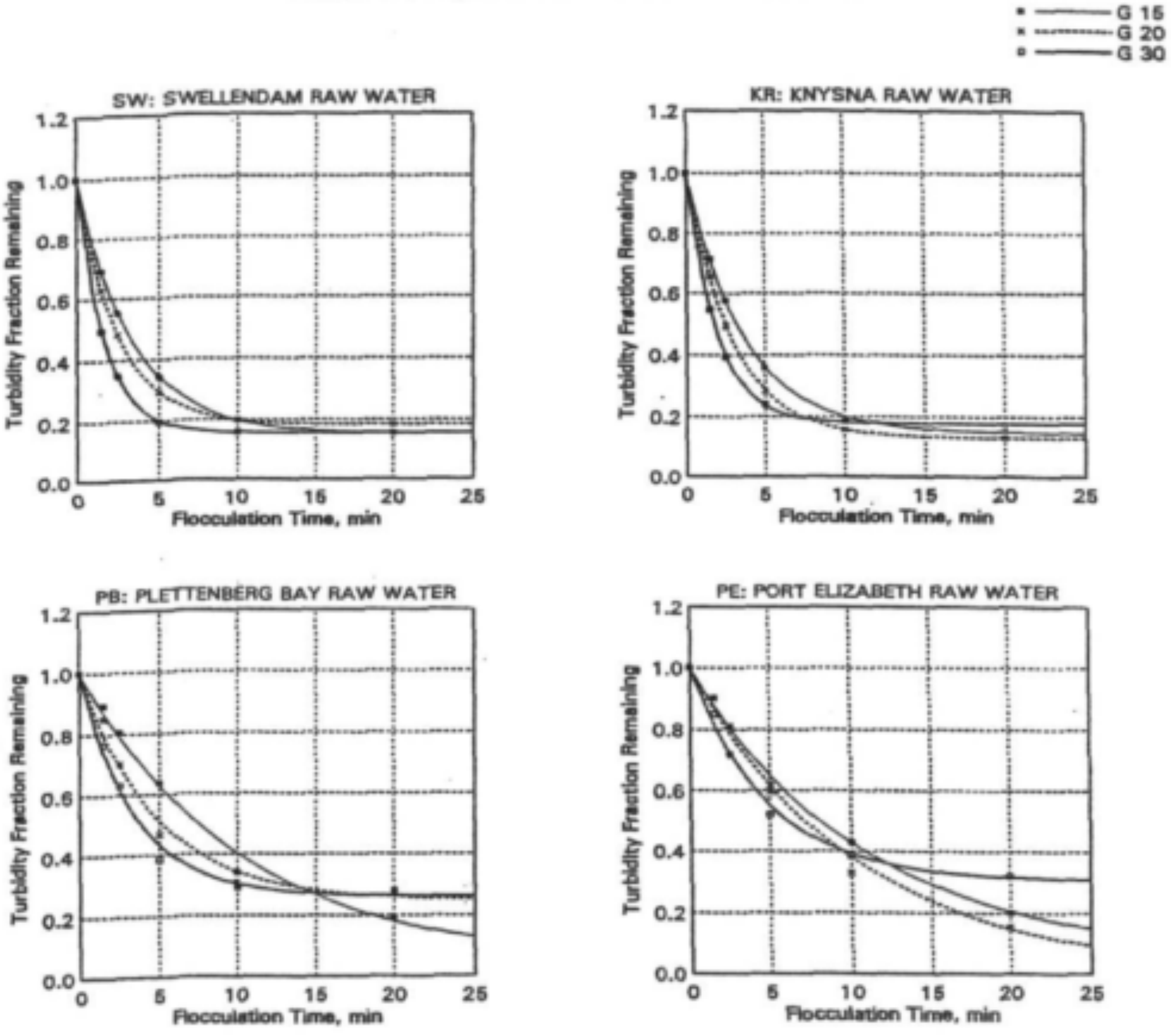


FIGURE 8.3
FLOCCULATION RATE
RATE MODELLING

Points are experimental. Lines are calculated

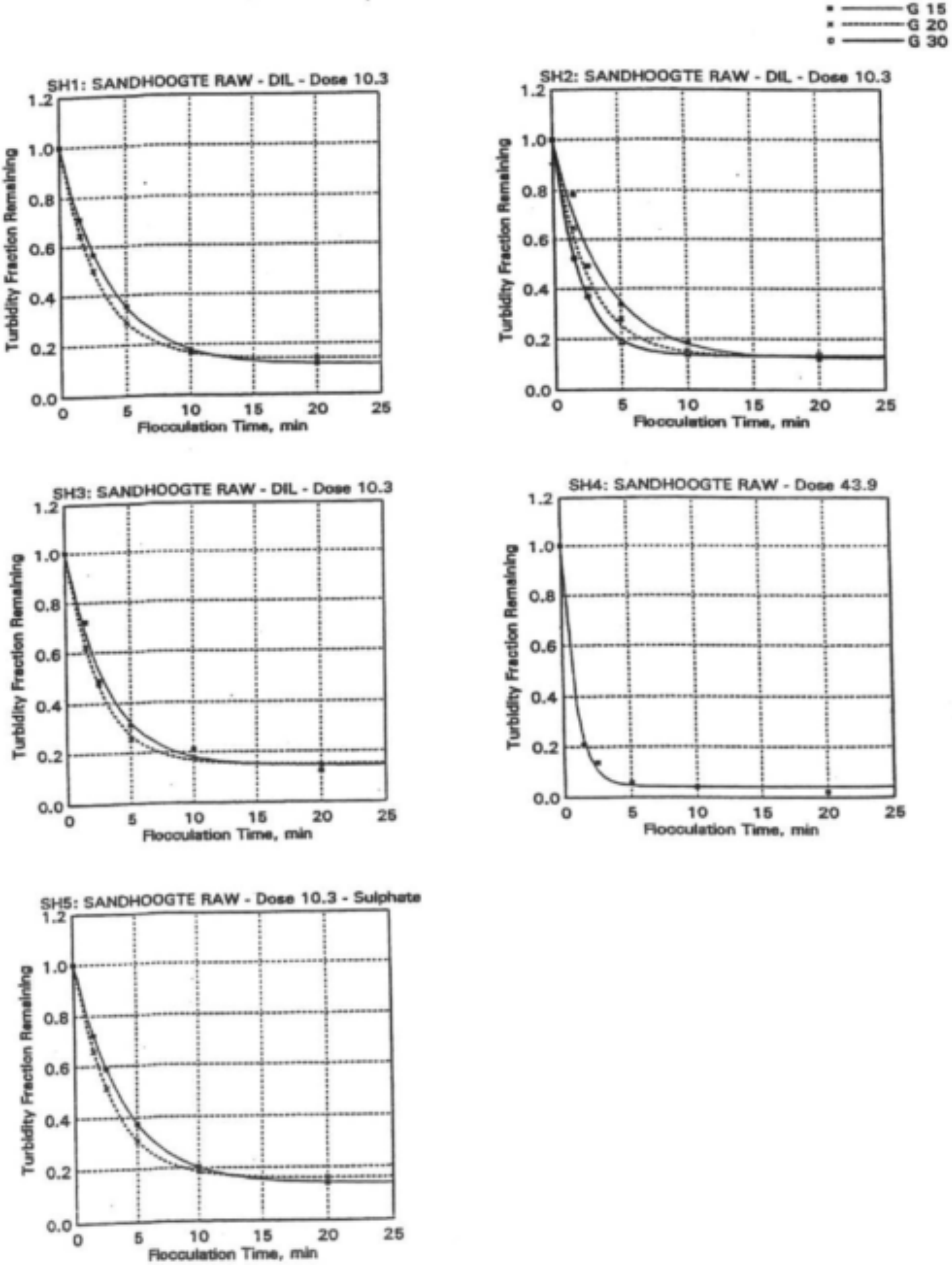


FIGURE 8.4

FLOCCULATION RATE

EXAMPLES OF RATE MODELLING

Points are experimental. Lines are calculated

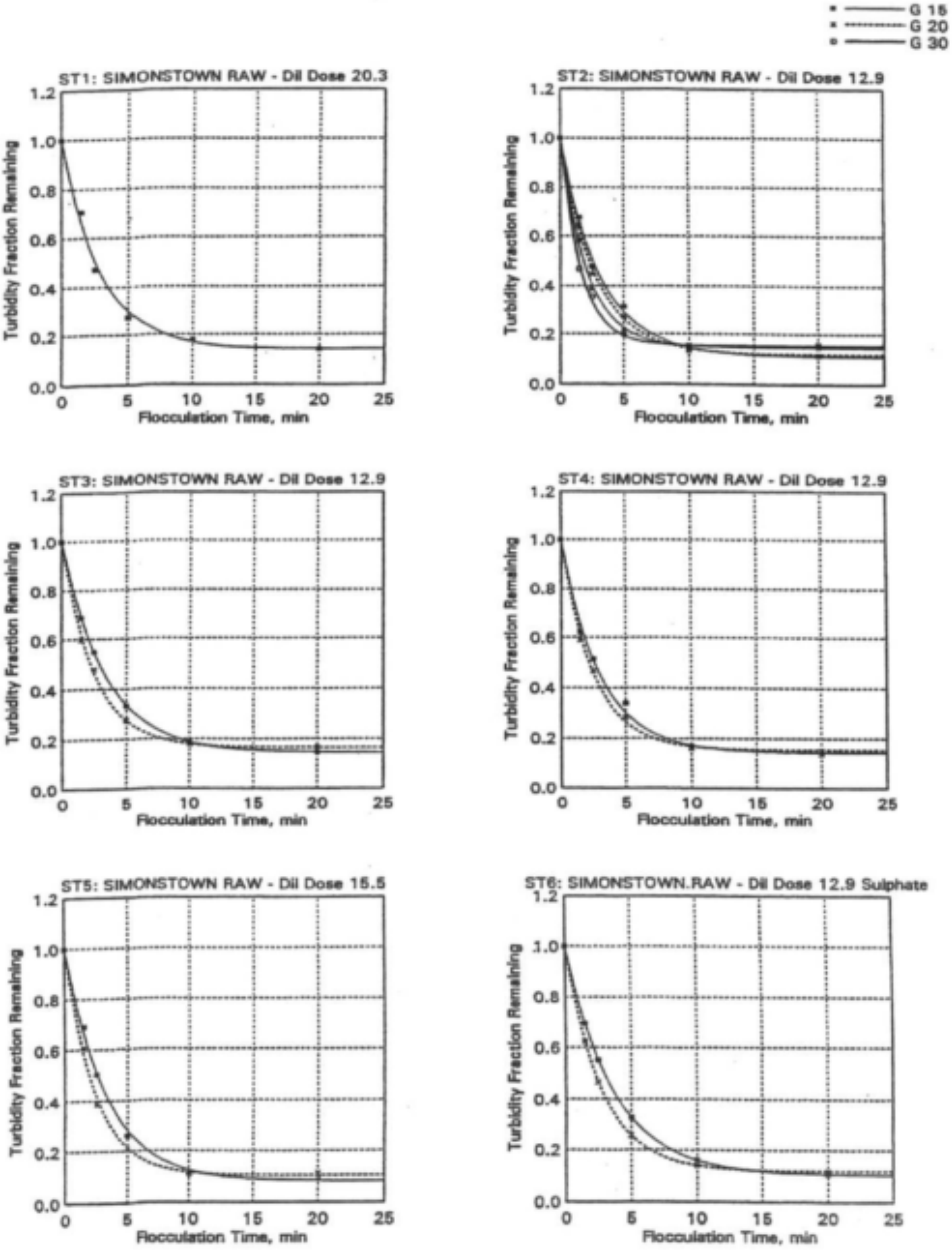


FIGURE 8.5

FLOCCULATION RATE

RATE MODELLING - HIGH G

Points are experimental. Lines are calculated

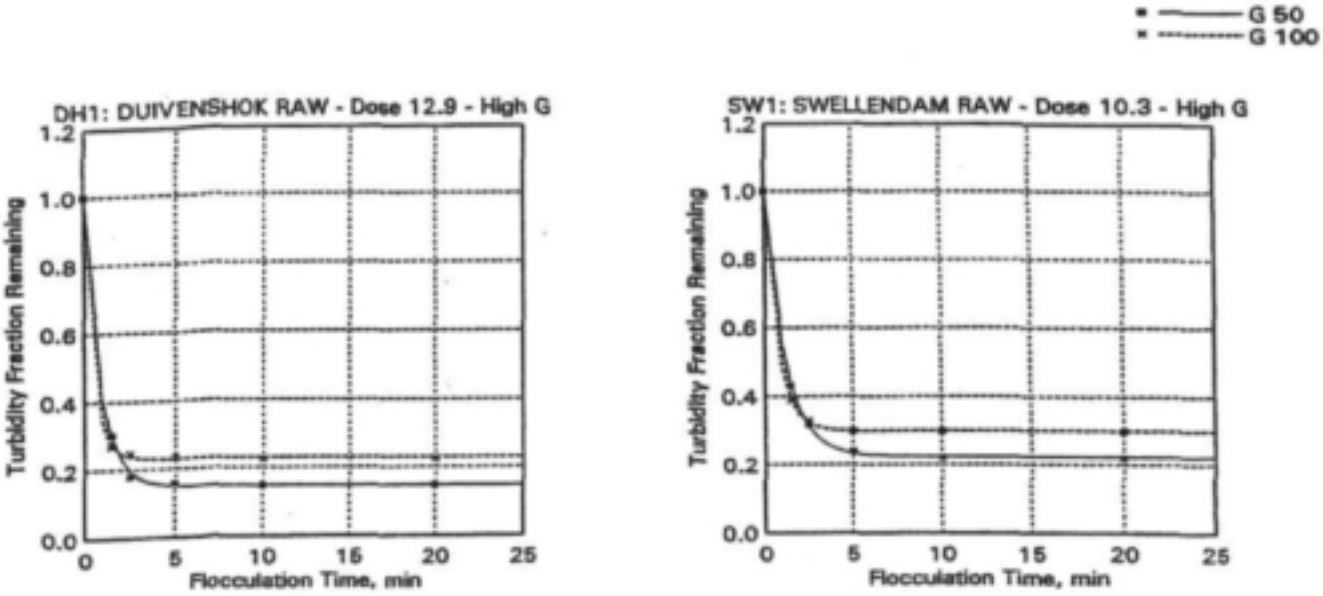


FIGURE 8.6

FLOCCULATION RATE
RATE MODELLING

Points are experimental. Lines are calculated

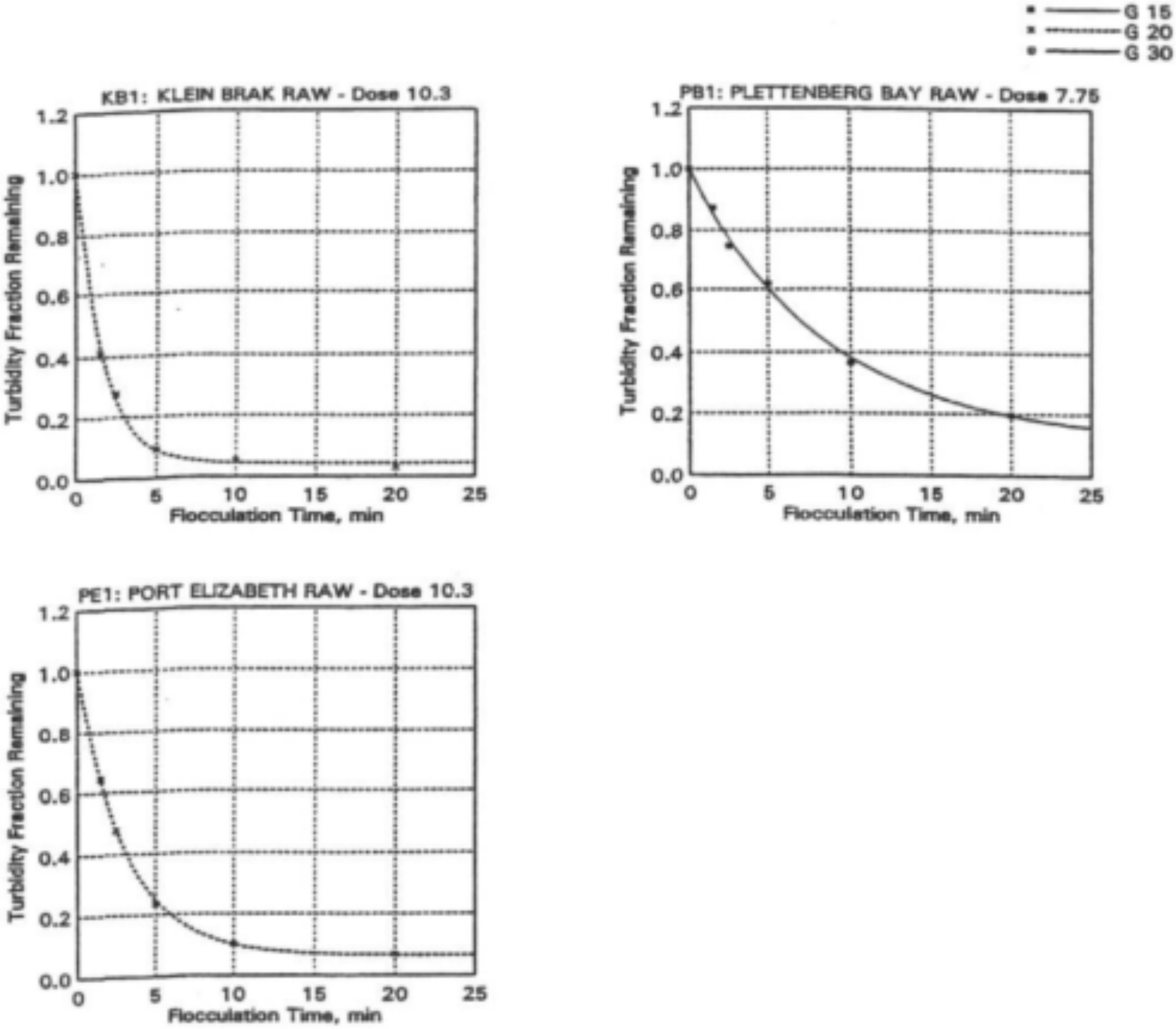
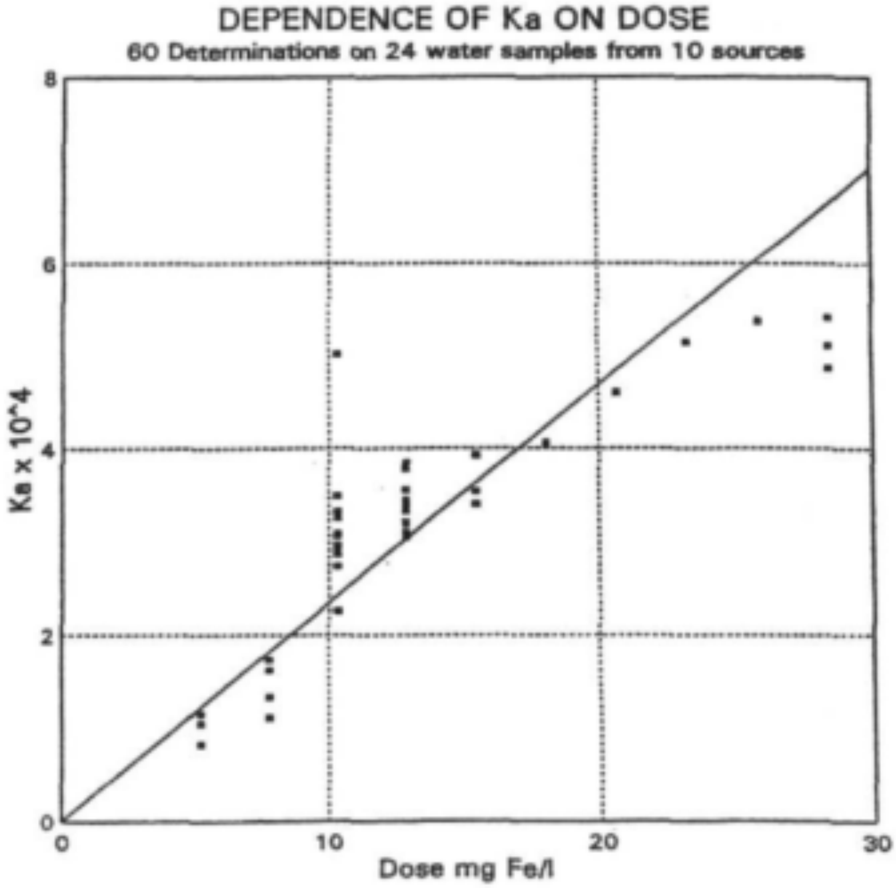


FIGURE 8.7

FLOC FORMATION RATE



CHAPTER 9

DISCUSSION OF RESULTS

9.1 CHARACTERISATION OF ORGANIC MATTER

The natural organic content of many of the waters of the Southern Cape coastal region would seem to be amongst the highest in the world and, judging by UV absorbance, a large proportion of that organic matter, particularly in the darker waters, is aromatic humic material.

That the DOC, UV254, UV272, UV300 and COD values for all the supplies studied are highly correlated, suggests a large degree of similarity in this organic material. The greatest differences found were in the amount present.

A substantial amount, but not all, of the organic matter can be removed by coagulation with ferric salts at low pH. The remaining portion has a lower specific UV absorbance than that in the raw water, implying a smaller residual aromatic content. There is also evidence, based on the correlations with DOC and DUV272, of the presence of non-removable compounds with a low aromatic content. The proportion of this non-removable material is likely to some extent to be seasonal and site specific, but a more detailed examination of this issue has not been carried out.

9.2 MEASUREMENT OR PREDICTION OF DISINFECTION BY-PRODUCT FORMATION POTENTIAL

It must be borne in mind that the conditions chosen for chlorination were intended to show the effect of the organic content of the water ie the THM formation potential. The chlorine doses used were therefore well in excess of those applied in normal water treatment, in order to satisfy the chlorine demand of the water and give a residual free chlorine content after 7 days. For treated waters, they were in the range 5.5 to 14 mg/l Cl and for raw waters 10 to 125 mg/l Cl. The pH chosen for the chlorination stage, 9.2, favours the formation of THMs relative to other chlorinated organic compounds.

The raw waters proved to have a large THM formation potential, which was highly correlated with DOC, UV absorbance and COD. When these waters are chlorinated, the amount of THM's generated is likely to be limited only by the chlorine dose employed, up to a limit of 3 mg chlorine per mg DOC.

The formation potential was much reduced by coagulation with iron salts. The correlation with DOC and UV absorbance was still present but whereas the slope of line linking THMFP to DOC was about the same as with the raw water, that for THMFP and UV254 was much greater in the treated than the raw water. It would seem that organic matter with a lower aromatic content made a larger contribution to THM formation.

Measurement of differential UV absorbance has proved to be useful as an alternative method of estimating the potential for formation of disinfection by-products and for investigating the controlling factors. It is a much simpler and possibly more precise procedure than direct measurement of halogenated compounds.

For the waters of the study, DUV272 has proved to be highly correlated with both DOC and UV272 absorbance - UV254 or UV300 can also be used in the correlation as all are closely related to each other. The regression line intercepts the DOC axis at a concentration of 2.5 mg/l.

Verification of the applicability of Korsin's factor, linking DUV272 to TOX, to the waters of this study has not been attempted but there is some indication, from estimates of the percentage of applied chlorine that is incorporated in the chlorinated organic matter, that a higher factor should be used for treated water than with raw water. This is similar to the finding for THMFP.

9.3 COAGULATION STUDIES AND COAGULATION DIAGRAMS

It should be noted that only one sample of each water was tested in this study. Some of these waters were significantly different in composition to those used for the characterisation study, and the results should not be taken as representing the character of any given source at all times.

It is fairly clear that the use of a coagulant dose proportional to the UV absorbance is a valuable tool for obtaining a consistent treated water quality, in spite of large changes humic acid content.

With the possible exception of Port Elizabeth water, in all cases and for all three coagulants, dosage factors of at least 23 mg/ℓ Fe/ UV300 (or the equivalent amount of aluminium salt) gave a settleable floc and a large degree of removal of organic matter, when used at the optimum pH. What differed from water to water was the residual organic content and the settled water turbidity.

Dosage factors of 30 and 40 mg/ℓ Fe/ UV300 (or the equivalent amount of aluminium salt) always gave lower residual UV254 values than a factor of 23, the improvement between 23 and 30, in particular, was significant.

The final choice of factor will depend on a number of things. With a water of low residual UV254, one can afford to use a lower factor without sacrificing much quality. A large factor gives a more robust treatment in the face of raw water quality changes.

All in all, a factor of 30 mg/ℓ Fe/ UV300 (or the equivalent amount of aluminium salt) is recommended as the norm, but one of 40 is considered to be not cost effective in most cases (Sedgefield and Simons Town might be exceptions). A factor of 23 can be considered if the increased residual organic matter can be tolerated. Anything less requires special investigation.

Selection of the optimum coagulation pH requires a compromise between residual humic acid, and turbidity, aluminium or iron in the settled water. It is not wise to choose a pH which is at the lower limit below which the metal concentration starts to rise, as control of pH at a treatment plant is never exact. One requires a safe band in which to operate.

With the ferric salts, UV254 is usually lowest at pH 4.2, but is little, if any higher at pH 4.6, especially with a dose factor of 30 mg/ℓ Fe/ UV300. Iron and aluminium residuals are also lower at pH 4.6 than 4.2. Turbidity is usually at it's lowest at pH 4.6 but in some cases it rises at lower pH values and the optimum coagulation pH for iron coagulants is therefore considered to be 4.6, or occasionally 5.0.

With aluminium sulphate, UV254 and settled water turbidity were usually at a minimum at pH 5.4, below which value dissolved aluminium concentrations rise very rapidly. Allowing a safety factor, pH 5.6 (or 5.8) is therefore considered the optimum.

Table 9.1 compares results for the three chemicals, at the optimum pH (pH 4.6 for Fe_2Cl_3 and $Fe_2(SO4)_3$ and pH 5.6 for $Al_2(SO4)_3$).

Table 9.1 COMPARISON OF COAGULANTS

WATER	UV254, cm^{-1}			TURBIDITY, NTU		
	$FeCl_3$	$Fe_2(SO4)_3$	$Al_2(SO4)_3$	$FeCl_3$	$Fe_2(SO4)_3$	$Al_2(SO4)_3$
KB	0.042	0.056	-	2.2	3.1	-
SH	0.049	0.098	0.091	1.4	1.8	0.9
TD	0.036	0.080	0.102	2.7	1.6	0.6
PB	0.003	0.016	0.010	1.7	1.9	0.6
PE	0.035	0.040	0.047	4.7	7.0	2.3
SW	0.030	0.030	0.026	1.4	1.6	0.6
ST	0.071	0.094	0.099	1.8	3.1	0.9
KR	0.014	0.019	0.024	4.8	1.5	0.5
DH	0.021	0.030	0.038	2.5	1.7	0.6
SF	0.060	0.086	0.075	2.0	2.3	0.6
Mean:	**0.036**	**0.055**	**0.057**	**2.5**	**2.6**	**0.8**

Ferric chloride can be seen to give the lowest residual UV254 value. The improvement compared with the other two chemicals is most marked and worthwhile in the case of the darker waters. Ferric sulphate and aluminium sulphate gave much the same result. Settled water turbidity was always lowest with aluminium sulphate. The two ferric salts gave essentially the same turbidity.

In a few cases the settled water turbidity was unusually high, but could mostly be reduced by use of a slightly different pH.

Port Elizabeth water had an unfortunate combination of requirements. Ferric salts gave a high turbidity at all pH values, while aluminium sulphate required a high pH for low turbidity, which meant that UV254 was rather high.

CHAPTER 10

CONCLUSIONS

The overall conclusions of this study are that, for the waters of the study area:

1. Differences between the waters, apart from turbidity, lie in the amount rather than the nature of the organic content, which appears to be very similar in all the supplies. This finding has resulted in considerable simplification of the whole subject.

2. Most of the organic matter has a high UV absorbance, indicating a high aromatic content.

3. DOC, UV absorbance, COD and, less accurately, colour can all be used to estimate the amount of humic materials present in the water. Of these, UV measurement is recommended as being the most precise, rapid and convenient.

4. Much of the organic matter can be removed by the most commonly used process of coagulation with aluminium or iron salts. There is residual organic content after this treatment, the amount of which, 1.5 to 5 mg/l DOC, is unrelated to that present in the raw water. The percentage residual is therefore generally higher in the low colour waters.

5. The amount of disinfection byproducts, mainly trihalomethanes, formed when the water is chlorinated is a function of both the concentration of organic matter and the chlorine dose. Generation of the maximum amount requires about 3 mg chlorine per mg of DOC. Measurement of DOC or, more simply, UV absorbance thus provides a good estimate of the potential for formation of disinfectant by-products and is an excellent tool for optimising and monitoring treatment processes.

6. To minimise formation of disinfectant by-products, treatment should aim at reducing UV absorbance to as low a level as possible.

7. The required dose of coagulant is proportional to the amount of organic matter present and can be estimated from one of the measures of organic content. The preferred determinand is UV absorbance because of simplicity and rapidity of measurement, provided a UV/VIS spectrophotometer is available, and because it most accurately determines the removable humic fraction.

8. A safe reliable dose for iron salts is: mg/l Fe = 30 x UV300.

   For aluminium an equivalent (equimolar) factor applies.

   If filtered water UV254 is low, a lower dose can be considered.

9. Optimum coagulation pH values are 4.6 for ferric salts and 5.6 to 5.8 for aluminium sulphate. If settled water turbidity is very high, a higher pH should be tried.

10. Ferric chloride is the best coagulant for removal of humic materials, particularly with those waters having a high residual UV254 value. If the UV254 in the filtered water is low, the difference between coagulants is not very great. Aluminium sulphate gives the lowest settled water turbidity. Note that residual UV254 for a given source often varies throughout the year.

11. The propensity of floc particles to stick together (sticking factor), one of the factors governing the rate of floc formation, is much the same for all the waters.

12. A second floc formation factor related to water quality is floc volume. If, as mentioned above, a dose proportional to organic content is used, then the floc formation rate will be proportional to the coagulant dose. Floc thus forms more slowly in a light coloured water than in a dark one.

CHAPTER 11

RECOMMENDATIONS FOR FURTHER RESEARCH

Based on the findings of this study, the following recommendations are made for further research on characterization and treatment of South African coloured surface waters:

1. Investigate the occurrence of metals (iron, manganese and aluminium) in colour removal treatment plants, and draw up guidelines for removal and control of the metals, both at the treatment plant and in the distribution system.

2. Perform desk studies on how alternative non-chemical treatment technologies can be used either together with chemical treatment or on its own to improve the quality of the final water, and be able to do this in a sustainable and affordable manner.

3. Investigate the beneficial use of chemical sludges from colour removal treatment plants (research on management and use of water works sludges generally is currently being carried out by the University of Natal in Pietermaritzburg).

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APPENDIX A

PROTOCOL FOR DETERMINATION OF TRIHALOMETHANE FORMATION POTENTIAL

PROTOCOL FOR DETERMINATION OF TRIHALOMETHANE FORMATION POTENTIAL

1. Pre-analysis Check List
2. Cl_2 water Preparation
3. Chlorination Process
4. SPME Adsorption Process
5. SPME Desorption Process and GC/MS Analysis
6. THM Concentration Determination
7. Addendum A1
8. Addendum A2
9. Addendum A3
10. Addendum A4

1. PRE-ANALYSIS CHECK LIST

Free active chlorine

Test distilled and deionised water for the presence of free active chlorine by means of the DPD titration method.

THMs

Test distilled, deionised and raw water to be used in analysis for the presence of THMs by means of SPME and GC/MS analysis.

2. CHLORINE WATER PREPARATION

Fill an amber glass bottle with distilled water and bubble Cl_2 (g) through it for a few seconds. Use the DPD-titration method (MERCK) for the determination of free active chlorine:

Reagents (See Addendum A1 for preparation):

Ammonium iron (II) sulfate solution
DPD reagent solution
Phosphate buffer solution

Calculation:

1 mℓ ammonium iron (II) sulfate solution ≅ 0.1 mg free active chlorine

$$\text{mg/ℓ free active chlorine} = \frac{a \times 0.1 \times 1\,000}{b} \qquad (1)$$

a = mℓ of ammonium iron (II) sulfate solution consumed
b = mℓ of test water used
Remember to incorporate the dilution factor in the b factor in equation (1).

Procedure:

Introduce 100 mℓ of test water into a narrow-necked flask of about 150 mℓ capacity and add 5 mℓ DPD reagent solution and 5 mℓ phosphate buffer solution. Insert a magnetic stirrer rod with Teflon coating, and titrate the solution in a magnetic stirrer with ammonium iron (II) sulfate solution until the solution becomes colourless or an unchanging faint pink. For this purpose use a micro burette with injection tube and nozzle, thereby passing in the ammonium iron (II) sulfate solution directly under the surface of the liquid. If the consumption is above 3 mℓ, start with a smaller volume of water which has been made up to 100 mℓ with double-distilled water. Because the Cl_2 water prepared by means of the above method has a high free active chlorine concentration, the following dilution should result in a consumption of less than 3 mℓ of ammonium iron (II) sulfate solution:

300µℓ Cl_2 water diluted to 100 mℓ with distilled water.

Carry out determination in triplicate.

3. CHLORINATION PROCESS

Reagents (See Addendum A2 for preparation):

Nessler's reagent
Borate buffer
Cl_2 water

Calculations:

$$Cl_2(mg/\ell) = 3 \times TOC(mg/\ell) + 7.6 \times NH_3\text{-}N(mg/\ell) \qquad (2)$$

$$C_1V_1 = C_2V_2 \qquad (3)$$

C_1: Cl_2 (mg/ℓ) from titration of the stock solution
V_1: to be calculated
C_2: answer of equation (1)
V_2: 20.5mℓ

Procedure:

Test each treated water sample with Nessler's reagent for the presence of ammonium salts by adding a few drops of reagent to the test water. An orange-brown precipitate will form to give a positive test. The amount of ammonium salts can be determined quantitatively by means of a method described by MERCK. If the test is negative, equation (2) simplifies to

$$Cl_2(mg/\ell) = 3 \times TOC\ (mg/\ell)$$

Introduce 20 mℓ treated water in an amber glass bottle equipped with a hole cap, teflon septum and a magnetic stir bar. Add 0.5 mℓ borate buffer to adjust the pH to 9.2. Calculate by means of equation (1) and (2) the volume Of Cl_2 water necessary to disinfect the treated water samples.

Place sample bottles in a thermoregulated water bath at 25°C on a non-electric magnetic stirrer for a period of 7 days to allow for the process of THM formation.

4. SPME ADSORPTION PROCESS

Reagents (See Addendum A3 for preparation):
30% Ascorbic acid solution
Methylene chloride solution

Calculations:
Volume of Ascorbic Acid (mℓ) = 1.2 X Cl_2 (mg/ℓ) + 1.1 (4)
Cl_2 (mg/ℓ): value calculated from equation (2)

Procedure:

Remove sample bottles from the water bath. Use equation (4) to calculate the volume of 30% ascorbic acid solution necessary to react with any remaining free active Cl_2 in solution. Add the calculated volume of ascorbic acid by means of a micro syringe. Then add 40μλ of CH_2Cl_2 solution as internal STD to each sample bottle by means of a micro syringe. Place the amber glass sample bottle on a magnetic stirrer. Allow for an equilibration time of 10 minutes on the magnetic stirrer before continuing with the extraction of THMs.

Use the red hub (100μm PDMS) fibre for the SPME analysis. Insert the septum-piercing needle through the teflon septum and push the plunger down to expose the PDMS fibre to the headspace of the bottle. Adsorption conditions are as follows:

Adsorption time	20min
Adsorption	headspace
Adsorption temp	20°C
Stir Speed	500 rpm

5. SPME DESORPTION PROCESS AND GC/MS ANALYSIS

Retract the plunger to withdraw the PDMS fibre into the septum-piercing needle. Remove SPME unit from the sample bottle. Use $C0_2$ (dry) to cryo trap the volatiles at the beginning of the column. Insert the SPME into the injector of the GC/MS. See GC temperature program and MS program below. Push the plunger down to expose the fibre to the high temperature of the injector block for desorption of VOCs. Desorption conditions:

Desorption temp	200°C
Desorption time	2min
Cryo trapping	2min

GC temperature program:

Temp.1	45°C
Duration	4 min
Rate	9°C/min
Temp2	120°C
Duration	3 min

MS scan program:

Mass range	50-255

Peaks are integrated electronically.

Column specifications:

40 m 0.32 mm bore PS 255 stationary phase; 1.2 µm film thickness; 4 mℓ He per second

6. THM CONCENTRATION DETERMINATION

Reagents (See Addendum A4 for preparation):

Standard THM solution: Chloroform
Bromodichloromethane
Dibromochloromethane
Bromoform

Methylene chloride

Calculations:

$$\text{THM conc. } (\mu g/\ell) = \frac{\text{Peak Area (sample)}}{\text{Peak Area (std)}} \times \frac{\text{Peak Area } (CH_2Cl_2/\text{std})}{\text{Peak Area } (CH_2Cl_2/\text{sample})} \times \text{THM conc. (std)} \qquad (5)$$

THM conc. ($CHCl_3$) = 75 μg/ℓ
THM conc. ($CHCl_3$) = 200 μg/ℓ
THM conc. ($CHCl_3$) = 250 μg/ℓ
THM conc. ($CHCl_3$) = 30 μg/ℓ

Procedure:

For the determination of the concentration of each THM species, it is necessary to perform a standard THM analysis as well. 20 mℓ of a standard THM mixture are therefore introduced into an amber glass sample bottle together with 40μℓ methylene chloride (internal standard) as well as 0.5 mℓ borate buffer. Analysis for THMs in this standard mixture is according to procedure (4) and (5) in the protocol.

Chromatograms of both the unknown sample and the standard are integrated electronically. The resulting peak areas, together with the concentration of the standard THM under investigation, are subsequently substituted into equation (5) for the calculation of the unknown concentration.

ADDENDUM A1

Ammonium Iron (Ii) Sulfate Solution:

Dissolve 1.106g ammonium iron (II) sulfate GR in freshly boiled and cooled deionised water. Add 2mℓ 1 mol/ℓ sulfuric acid, and make up to 1000 mℓ with the above-mentioned water.

DPD reagent solution:

Dissolve 0. 1 1 g N,N-Diethyi-1,4-phenylenediammonium sulfate GR in deionised water with 2 mℓ mol./ℓ sulfuric acid and 2.5 mℓ 0.02mol/l Titriplex III solution, and make up to 100 mℓ. Store the solution protected from light in a brown bottle. It is unusable if a discolouration develops.

Phosphate buffer solution:

Dissolve 46 g Potassium dihydrogen phosphate GR and 24 g tri-Sodium phosphate 12-hydrate (LAB) in 1000 mℓ deionised water.

Sulfuric acid 1 mol/L:

Make the contents of one ampoule of 0.5mol/ℓ Sulfuric acid Titrisol concentrated solution for preparation of 1 litre of 1 N solution up to 500 ml with deionised water.

Titriplex III solution 0.02mol/L:

Make 200 mℓ 0.l mol/ℓ Titriplex III metal (pM) indicator up to 1000 mℓ with deionised water.

ADDENDUM A2

Nessler's reagent (Quantitative Inorganic Analysis):

Dissolve 35 g of Potassium iodide in 100 mℓ of water, and add 4% Mercuric chloride solution, with stirring or shaking, until a slight red precipitate remains (about 325 mℓ are required). Then introduce, with stirring, a solution of 120 g of Sodium hydroxide in 250 mℓ of water, and make up to 1 litre with distilled water. Add a little more Mercuric chloride solution until there is a permanent turbidity. Allow the mixture to stand for one day and decant from sediment. Keep the solution stoppered in a dark-coloured bottle.

Borate buffer (Standard Methods):

Dissolve 30.9 g anhydrous Boric acid (H_3BO_3) and 10.8 g Sodium hydroxide (NaOH) in 1 litre organic-free water. Refrigerate and prepare fresh weekly.

Chlorine water

See chlorine water preparation, above.

ADDENDUM A3

30% Ascorbic acid

The solubility of ascorbic acid in water is recorded as being approximately 30% $(^{m}/_{v})$. To ensure no contamination of the treated water sample, ascorbic acid (MERCK, pro analysis) was used. Add 30 g ascorbic acid to 70 mℓ distilled water.

Methylene chloride

Prepare a 50mg/ℓ methylene chloride solution by diluting .0367ml mℓ of methylene chloride to 1 litre with distilled water.

ADDENDUM A4

Environmental standard solutions (SUPELCO) are used for the preparation of standard solutions of THMs. Each ampoule contains 1 mℓ 5000 µg/mℓ of the specific THM in methanol. A dilution of one ampoule to 100 mℓ with distilled water would therefore result in a 50 mg/ℓ THM solution.

Chloroform

Dilute one environmental standard $CHCl_3$ ampoule with distilled water to 100 mℓ in a volumetric flask.

Bromodichloromethane

Dilute one environmental standard $CHCl_2Br$ ampoule with distilled water to 100 mℓ in a volumetric flask.

Dibromochloromethane

Dilute one environmental: standard $CHClBr_2$ ampoule with distilled water to 100 mℓ in a volumetric flask.

Bromoform

Dilute one environmental standard $CHBr_3$ ampoule with distilled water to 100 mℓ in a volumetric flask.

Standard THM mixture

From the above THM solutions the following amounts are used for a 1 litre dilution mixture:

$CHCl_3$: 1.5 mℓ 50 mg/ℓ solution
$CHCl_2Br$: 4.0 mℓ 50 mg/ℓ solution
$CHClBr_2$: 5.0 mℓ 50 mg/ℓ solution
$CHBr_3$: 0.6 mℓ 50 mg/ℓ solution

Methylene chloride

See Addendum A3.

APPENDIX B

PROTOCOL FOR
DETERMINATION OF DIFFERENTIAL UV ABSORBANCE

DETERMINATION OF DIFFERENTIAL UV ABSORBANCE

This method is generally as described by Korshin (1997) and Li (1998), with modifications to suit the present study.

The reaction was carried out at pH 9.2, as the brown waters of the study area are soft and generally have to be rendered less aggressive to cement and concrete by raising the alkalinity and pH.

1. Samples

1.1 Samples were filtered through pre-rinsed 220 or 450 nm membrane filters.

1.2 Sample aliquots of 40 mℓ were measured into 50 mℓ glass stoppered brown glass reaction bottles.

2. Reagents

2.1 Buffer - pH 9.2: 38 g Sodium borate decahydrate, $Na_2B_4O_7.10H_20$, analytical grade, was dissolved in 1 litre distilled water. The following pH values were obtained for various amounts of buffer added to combinations of hypochlorite and a very acidic raw water (Sandhoogte raw water, with DOC of 41 mg/ℓ C). Temperatures were 17.0 - 18.4 °C. A buffer volume of 2 mℓ per 40 mℓ sample gave adequate control of pH and was used in subsequent work.

	pH for Various Buffer Volumes							
Buffer - mℓ/40 mℓ sample:	**0.0**	**0.4**	**0.8**	**1.2**	**1.6**	**2.0**	**2.4**	**2.8**
Hypochlorite - 200 mg/ℓ Cl_2:	10.4	9.37	9.29	9.26	9.25	9.24	9.24	9.24
Sandhoogte Raw:	4.10	8.93	9.09	9.14	9.17	9.18	9.20	9.21
Sandhoogte + 200 mg/l $Cℓ_2$	7.00	9.11	9.18	9.20	9.21	9.21	9.22	9.23

2.2 Sodium Hypochlorite Solution: Analytical grade sodium hypochlorite solution (BDH) was standardised, at regular intervals, by means of a potassium iodide/thiosulphate titration, and was then diluted to give a chlorine dosing solution, as discussed below.

In order: 1) to minimise volume changes, 2) not to overfill the 50-mℓ reaction bottle, and 3) to achieve a reasonable accuracy in dispensing the chlorine dosing solution, the volume of hypochlorite solution added to samples was usually limited to the range 1 to 2mℓ, (although, in experiments where the chlorine dose was varied, volumes down to 0.2 mℓ were used).

Thus, to accommodate the wide range of doses required for raw and treated waters (about 6 to 200 mg/ℓ) the concentration of the chlorine dosing solution differed for each water.

For example: With a water of DOC 20 mg/ℓ and a dosing rate of 3.2 x DOC the required dose would be 64 mg Cl_2/ℓ. To a sample volume of 40 mℓ, 64x40/1000, or 2.56 mg chlorine would have to be added. If the volume of chlorine dosing solution added was 2 mℓ, it's concentration would need to be 2.56 x 1000 / 2, or 1280 mg/ℓ. Other combinations of volume and concentration are possible.

2.3 Sodium Sulphite Solution: The solution was freshly prepared for each experiment at a concentration such that the volume required to quench the full chlorine dose was equal to the volume of chlorine solution added. Thus, if 2 mℓ of chlorine solution was added to a sample, then 2 mℓ of sodium sulphite solution was also added at the end of the reaction period. 1780 mg sodium sulphite reacts with 1000 mg chlorine and, to continue the previous example, the concentration in that case would be 1280 x 1.78, or 2278 mg/ℓ.

The absorbance of a 1765 mg/ℓ solution of sodium sulphite in a 1 cm cell was measured to be:

254 nm	0.288
272 nm	0.014
300 nm	0.002

The maximum absorbance error arising from the presence of sodium sulphite at 272 nm is therefore:

1. Raw water, DOC 40 mg/ℓ, chlorine dose 200 mg/ℓ:
   $0.014 \times 200 \times 1.78 / 1765 = 0.003\ \text{cm}^{-1}$

2. Treated water, DOC 4 mg/ℓ, chlorine dose 20 mg/ℓ
   $0.014 \times 20 \times 1.78 / 1765 = 0.0003\ \text{cm}^{-1}$

These errors are negligible and in practice will be even smaller because the chlorine doses will usually be lower and chlorine remaining after the reaction period will further reduce the sulphite concentration.

3. Procedure

3.1 40.00 mℓ of filtered sample was pipetted into a 50 mℓ brown glass bottle, followed by 2.00 mℓ of buffer and the desired volume (usually in the range 1.00 to 2.00 mℓ) of chlorine solution, with gentle mixing.

3.2 A comparison solution for each different sample water was prepared at the same time and further treated in the same manner except for the omission of chlorine and sulphite.

3.3 After complete mixing, the bottles were stoppered and stored in a box in a room maintained at 20 °C. The temperature was checked by means of a thermometer kept in a bottle containing water.

3.4 After the desired reaction period, freshly prepared sodium sulphite solution was added, the volume being equal to that of the chlorine. No sulphite was added to the comparison sample.

3.5 The absorbance of the solutions, after mixing, was measured in 1 cm cells at 272 nm. Longer cells would have been preferable for treated waters and would have been used, had they been available.

3.6 All absorbances were corrected for volume changes, by multiplying by the factor:
(40 + volume buffer + volume chlorine dosing solution + volume sulphite solution) / 40

3.7 Differential UV Absorbance was calculated by subtracting the corrected absorbance from that of the unchlorinated comparison sample.

APPENDIX C

ANALYTICAL DATA FOR CHARACTERISATION OF RAW AND TREATED WATERS

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 1

ANALYTICAL DATA

WATER SOURCE: Klipheuwel Dam, Kleinbrak (Mossel Bay)

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-16	1999-03-23	1999-09-26	1998-11-17	1999-03-16	1999-10-28
Coagulant Dose mg/l Fe	-	-	-	10.47	2.2	18.1
pH Raw/Coagulated	7.05	5.43	6.20	4.8	4.8	4.8
Turbidity Raw/Settled	34.5	27.7	44.0	23.7	19.9	3.7
MEASURES OF ORGANIC CONTENT:						
Colour	-	5	-	-	-	-
Absorbance/cm 254nm	0.446	0.098	0.623	0.092	0.067	0.094
Absorbance/cm 272 nm	-	-	0.569	-	-	0.053
Absorbance/cm 300nm	0.254	0.048	0.382	0.045	0.031	0.023
DOC mg/l C	9.1	4.53	10.5	4.6	3.41	2.74
COD mg/l O	20.6	8.0	-	10.9	9.7	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide µg/l Br	381	259	256	347	247	210
Aluminium mg/l Al	2.78	0.16	1.15	0.03	0.03	0.03
Iron mg/l Fe	3.74	26.00	2.82	0.233	0.740	0.172
Manganese mg/l Mn	0.095	0.513	0.056	0.066	0.458	0.080
Calcium mg/l Ca	5.82	3.74	3.85	5.84	2.89	4.13
Magnesium mg/l Mg	7.11	4.52	5.21	6.95	4.14	5.44
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ µg/l	3491	3006	-	1015	1414	-
$CHCl_2Br$ µg/l	660	774	-	409	898	-
$CHClBr_2$ µg/l	72	44	-	136	179	-
$CHBr_3$ µg/l	0	0	-	0	23	-
Total THMFP µg/l	4223	3824	-	1560	2514	-
Delta UV 272 nm	-	-	0.282	-	-	0.023

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 2

ANALYTICAL DATA

WATER SOURCE: Ernest Robertson Dam, Sandhoogte (Mossel Bay)

	RAW WATER			**TREATED WATER**		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-16	1999-03-23	1999-09-26	1998-11-17	1999-03-02	1999-10-28
Coagulant Dose mg/l Fe	-	-	-	24.4	73.3	41.3
pH Raw/Coagulated	4.67	3.90	4.34	4.8	4.8	4.8
Turbidity Raw/Settled	1.3	1.4	1.5	3.3	4.6	1.4
MEASURES OF ORGANIC CONTENT:						
Colour	-	600	-	-	-	-
Absorbance/cm 254nm	0.906	2.670	1.437	0.019	0.097	0.027
Absorbance/cm 272 nm	-	-	1.275	-	-	0.039
Absorbance/cm 300nm	0.579	1.667	0.931	0.009	0.033	0.012
DOC mg/l C	12.0	41.1	19.8	2.0	4.16	2.18
COD mg/l O	30.6	120	-	5.74	7.7	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide µg/l Br	120	76	89	100	41	68
Aluminium mg/l Al	0.34	0.86	0.48	0.06	0.12	0.08
Iron mg/l Fe	0.596	0.695	0.655	0.140	0.811	0.241
Manganese mg/l Mn	0.034	0.036	0.021	0.093	0.207	0.128
Calcium mg/l Ca	1.15	1.23	0.93	1.17	1.28	0.99
Magnesium mg/l Mg	1.42	1.74	1.49	1.39	1.70	1.54
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ µg/l	6228	6564	-	419	1036	-
$CHCl_2Br$ µg/l	207	178	-	156	100	-
$CHClBr_2$ µg/l	41	0	-	0	0	-
$CHBr_3$ µg/l	0	0	-	0	0	-
Total THMFP µg/l	6435	6742	-	575	1136	-
Delta UV 272 nm	-	-	0.629	-	-	0.012

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 3

ANALYTICAL DATA

WATER SOURCE: Tuinroete Dam, George

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-15	1999-03-23	1999-09-26	1998-11-17	1999-03-02	1999-10-28
Coagulant Dose mg/l Fe	-	-	-	31.4	38.4	36.2
pH Raw/Coagulated	5.91	4.90	5.95	4.8	4.8	4.8
Turbidity Raw/Settled	17.4	3.3	8.0	2.5	5.9	1.6
MEASURES OF ORGANIC CONTENT:						
Colour	-	250	-	-	-	-
Absorbance/cm 254nm	1.173	1.392	1.287	0.087	0.077	0.068
Absorbance/cm 272 nm	-	-	1.107	-	-	0.070
Absorbance/cm 300nm	0.730	0.865	0.817	0.056	0.037	0.033
DOC mg/l C	18.5	21.1	18.4	3.8	4.21	3.60
COD mg/l O	40.6	60.4	-	17.7	9.7	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide μg/l Br	186	138	143	166	108	129
Aluminium mg/l Al	0.59	0.53	0.41	0.15	0.09	0.08
Iron mg/l Fe	4.60	1.510	2.050	1.180	0.300	0.240
Manganese mg/l Mn	0.090	0.068	0.036	0.165	0.174	0.140
Calcium mg/l Ca	3.59	2.75	2.63	3.56	2.74	2.88
Magnesium mg/l Mg	2.61	2.39	2.33	2.58	2.30	2.47
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ μg/l	6200	7522	-	1023	1106	-
$CHCl_2Br$ μg/l	239	225	-	257	295	-
$CHClBr_2$ μg/l	0	0	-	59	0	-
$CHBr_3$ μg/l	0	0	-	0	0	-
Total THMFP μg/l	6439	7747	-	1339	1401	-
Delta UV 272 nm	-	-	0.615	-	-	0.031

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 4

ANALYTICAL DATA

WATER SOURCE: Keurbooms River, Plettenberg Bay

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-19	1999-03-23	1999-09-28	1998-11-24	1999-03-09	1999-10-05
Coagulant Dose mg/l Fe	-	-	-	3.5	10.5	10.3
pH Raw/Coagulated	6.31	5.92	-	4.8	4.8	4.8
Turbidity Raw/Settled	0.9	1.0	4.7	2.8	5.3	5.7
MEASURES OF ORGANIC CONTENT:						
Colour	-	70	-	-	-	-
Absorbance/cm 254nm	0.163	0.416	0.430	0.042	0.024	0.030
Absorbance/cm 272 nm	-	-	0.393	-	-	0.026
Absorbance/cm 300nm	0.095	0.263	0.239	0.017	0.012	0.016
DOC mg/l C	3.2	6.99	7.49	1.8	2.04	1.56
COD mg/l O	7.34	14.3	-	5.31	3.8	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide µg/l Br	83	82	56	75	64	39
Aluminium mg/l Al	0.07	0.18	0.21	0.02	0.03	0.04
Iron mg/l Fe	0.218	0.316	0.405	0.680	0.178	0.361
Manganese mg/l Mn	0.024	0.031	0.046	0.046	0.050	0.047
Calcium mg/l Ca	2.05	1.44	1.21	1.58	1.44	1.30
Magnesium mg/l Mg	1.87	1.40	1.51	1.84	1.37	1.57
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ µg/l	1236	3374	-	842	544	-
$CHCl_2Br$ µg/l	154	186	-	150	142	-
$CHClBr_2$ µg/l	12	4	-	36	24	-
$CHBr_3$ µg/l	0	0	-	0	0	-
Total THMFP µg/l	1402	3564	-	1028	710	-
Delta UV 272 nm	-	-	0.213	-	-	0.007

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 5

ANALYTICAL DATA

WATER SOURCE: Churchill Dam, Port Elizabeth

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-19	1999-03-23	1999-09-28	1998-11-24	1999-03-16	1999-10-05
Coagulant Dose mg/l Fe	-	-	-	7.0	7.0	7.75
pH Raw/Coagulated	6.50	6.5	-	4.8	4.8	4.8
Turbidity Raw/Settled	11.6	12.6	35.5	11.9	14.7	17.0
MEASURES OF ORGANIC CONTENT:						
Colour	-	30	-	-	-	-
Absorbance/cm 254nm	0.270	0.246	0.310	0.027	0.039	0.050
Absorbance/cm 272 nm	-	-	0.257	-	-	0.044
Absorbance/cm 300nm	0.156	0.140	0.190	0.012	0.016	0.023
DOC mg/l C	5.2	5.49	5.90	3.0	3.81	2.84
COD mg/l O	11.1	10.2	-	7.15	6.0	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide µg/l Br	259	252	250	240	246	235
Aluminium mg/l Al	1.28	1.31	1.94	0.01	0.02	0.03
Iron mg/l Fe	3.75	1.930	1.310	1.85	0.108	0.132
Manganese mg/l Mn	0.042	0.043	0.012	0.042	0.054	0.034
Calcium mg/l Ca	2.47	2.58	2.81	2.56	2.86	2.88
Magnesium mg/l Mg	4.81	5.17	5.77	4.90	5.12	5.86
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ µg/l	966	1084	-	625	423	-
$CHCl_2Br$ µg/l	255	654	-	202	412	-
$CHClBr_2$ µg/l	83	63	-	129	112	-
$CHBr_3$ µg/l	0	0	-	23	17	-
Total THMFP µg/l	1304	1801	-	956	964	-
Delta UV 272 nm	-	-	0.091	-	-	0.021

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 6

ANALYTICAL DATA

WATER SOURCE: Grootkloof (Langeberg), Swellendam

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-23	1999-03-23	1999-10-29	1998-11-24	1999-03-02	1999-10-12
Coagulant Dose mg/l Fe	-	-	-	10.47	14.0	10.3
pH Raw/Coagulated	5.52	5.40	5.55	4.8	4.8	4.8
Turbidity Raw/Settled	10.0	3.6	2.5	7.2	5.2	6.0
MEASURES OF ORGANIC CONTENT:						
Colour	-	90	-	-	-	-
Absorbance/cm 254nm	0.370	0.476	0.400	0.028	0.039	0.032
Absorbance/cm 272 nm	-	-	0.354	-	-	0.032
Absorbance/cm 300nm	0.242	0.296	0.252	0.012	0.019	0.015
DOC mg/l C	6.0	8.10	6.27	2.1	2.68	1.82
COD mg/l O	12.5	20.7	-	8.42	6.3	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide μg/l Br	52	60	51	37	38	37
Aluminium mg/l Al	0.36	0.30	0.22	0.04	0.06	0.04
Iron mg/l Fe	0.535	0.818	0.536	1.26	0.196	0.147
Manganese mg/l Mn	0.037	0.038	0.022	0.058	0.086	0.048
Calcium mg/l Ca	0.55	0.44	0.45	0.67	0.46	0.46
Magnesium mg/l Mg	0.93	0.91	0.93	0.90	0.89	0.95
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ μg/l	1639	2898	-	420	156	-
$CHCl_2Br$ μg/l	79	133	-	64	74	-
$CHClBr_2$ μg/l	0	0	-	0	2	-
$CHBr_3$ μg/l	0	0	-	0	0	-
Total THMFP μg/l	1718	3031	-	484	232	-
Delta UV 272 nm	-	-	0.180	-	-	0.012

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 7

ANALYTICAL DATA

WATER SOURCE: Lewis Gayle Dam, Simons Town

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-23	1999-03-23	1999-10-11	1998-11-24	1999-03-09	1999-10-12
Coagulant Dose mg/l Fe	-	-	-	31.4	27.9	49.1
pH Raw/Coagulated	5.93	5.80	4.96	4.8	4.8	4.8
Turbidity Raw/Settled	1.1	0.8	0.9	6.6	3.6	3.6
MEASURES OF ORGANIC CONTENT:						
Colour	-	150	-	-	-	-
Absorbance/cm 254nm	1.127	1.055	1.822	0.072	0.084	0.086
Absorbance/cm 272 nm	-	-	1.586	-	-	0.061
Absorbance/cm 300nm	0.661	0.614	1.108	0.033	0.037	0.045
DOC mg/l C	16.1	17.8	27.3	3.7	4.70	3.49
COD mg/l O	43.6	54.3	-	13.8	10.9	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide µg/l Br	256	301	220	207	251	151
Aluminium mg/l Al	0.30	0.35	0.57	0.09	0.06	0.14
Iron mg/l Fe	0.537	0.358	1.250	0.270	0.246	0.308
Manganese mg/l Mn	0.047	0.030	0.074	0.118	0.109	0.195
Calcium mg/l Ca	4.46	5.10	3.90	4.93	5.04	4.09
Magnesium mg/l Mg	4.93	5.71	4.76	4.82	5.84	4.96
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ µg/l	4276	11999	-	831	1243	-
$CHCl_2Br$ µg/l	240	966	-	181	495	-
$CHClBr_2$ µg/l	9	34	-	94	90	-
$CHBr_3$ µg/l	0	0	-	7	7	-
Total THMFP µg/l	4525	12999	-	1106	1835	-
Delta UV 272 nm	-	-	0.870	-	-	0.026

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 8

ANALYTICAL DATA

WATER SOURCE: Knysna River, Knysna

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-30	1999-03-23	1999-09-28	1998-12-01	1999-03-09	1999-10-05
Coagulant Dose mg/l Fe	-	-	-	17.5	14.0	12.9
pH Raw/Coagulated	4.94	5.29	-	4.8	4.8	4.8
Turbidity Raw/Settled	1.4	1.4	2.4	8.8	6.6	4.1
MEASURES OF ORGANIC CONTENT:						
Colour	-	75	-	-	-	-
Absorbance/cm 254nm	0.631	0.469	0.464	0.036	0.068	0.056
Absorbance/cm 272 nm	-	-	0.369	-	-	0.054
Absorbance/cm 300nm	0.367	0.273	0.258	0.017	0.030	0.027
DOC mg/l C	12.4	10.2	9.67	4.5	4.26	2.92
COD mg/l O	28.6	25.7	-	11.4	8.9	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide μg/l Br	121	187	201	95	153	183
Aluminium mg/l Al	0.48	0.30	0.28	0.14	0.09	0.09
Iron mg/l Fe	0.587	0.897	0.391	0.094	0.492	0.283
Manganese mg/l Mn	0.069	0.057	0.028	0.105	0.086	0.036
Calcium mg/l Ca	1.67	1.78	2.04	1.64	1.97	2.10
Magnesium mg/l Mg	2.95	3.16	4.33	2.87	3.07	4.34
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ μg/l	5337	3721	-	1522	1199	-
$CHCl_2Br$ μg/l	229	329	-	168	310	-
$CHClBr_2$ μg/l	5	15	-	10	120	-
$CHBr_3$ μg/l	0	0	-	0	0	-
Total THMFP μg/l	5571	4065	-	1700	1629	-
Delta UV 272 nm	-	-	0.215	-	-	0.018

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 9

ANALYTICAL DATA

WATER SOURCE: Duivenhoks River, Duivenhoks

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-30	1999-03-23	1999-10-07	1998-12-01	1999-03-16	1999-10-12
Coagulant Dose mg/l Fe	-	-	-	24.4	41.9	28.8
pH Raw/Coagulated	5.73	5.03	5.67	4.8	4.8	4.8
Turbidity Raw/Settled	6.0	5.3	4.0	5.7	5.0	4.3
MEASURES OF ORGANIC CONTENT:						
Colour	-	445	-	-	-	-
Absorbance/cm 254nm	0.916	1.460	0.896	0.082	0.046	0.035
Absorbance/cm 272 nm	-	-	0.696	-	-	0.032
Absorbance/cm 300nm	0.572	0.922	0.580	0.039	0.021	0.017
DOC mg/l C	13.7	21.6	12.7	2.2	3.00	1.80
COD mg/l O	33.6	59.6	-	6.76	6.7	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide µg/l Br	117	105	148	97	74	116
Aluminium mg/l Al	0.64	0.58	0.32	0.08	0.07	0.07
Iron mg/l Fe	0.916	1.490	1.130	0.200	0.634	0.238
Manganese mg/l Mn	0.075	0.059	0.023	0.129	0.148	0.087
Calcium mg/l Ca	1.13	0.76	1.43	1.28	0.84	1.49
Magnesium mg/l Mg	2.74	1.90	3.66	2.59	1.86	3.70
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ µg/l	5094	13588	-	1151	814	-
$CHCl_2Br$ µg/l	184	350	-	177	265	-
$CHClBr_2$ µg/l	0	0	-	26	8	-
$CHBr_3$ µg/l	0	0	-	0	0	-
Total THMFP µg/l	5278	13938	-	1354	1087	-
Delta UV 272 nm	-	-	0.371	-	-	0.010

CHARACTERISATION OF COLOURED SURFACE WATERS

Table 10

ANALYTICAL DATA

WATER SOURCE: Karatara River, Sedgefield

	RAW WATER			TREATED WATER		
Sampling Round:	1	2	3	1	2	3
Date Sampled/Treated	1998-11-28	1999-03-23	1999-10-07	1998-12-01	1999-03-16	1999-10-12
Coagulant Dose mg/l Fe	-	-	-	27.9	52.4	41.3
pH Raw/Coagulated	4.45	4.56	4.47	4.8	4.8	4.8
Turbidity Raw/Settled	1.7	3.5	2.9	3.3	3.3	4.4
MEASURES OF ORGANIC CONTENT:						
Colour	-	405	-	-	-	-
Absorbance/cm 254nm	1.012	1.897	1.447	0.058	0.081	0.072
Absorbance/cm 272 nm	-	-	1.316	-	-	0.069
Absorbance/cm 300nm	0.616	1.178	0.920	0.028	0.038	0.037
DOC mg/l C	17.6	29.1	20.6	3.2	4.30	3.01
COD mg/l O	40.7	86.1	-	16.1	9.7	-
INORGANIC:						
Alkalinity mg/l CaCO3	-	-	-	-	-	-
Bromide μg/l Br	122	123	103	93	74	68
Aluminium mg/l Al	0.60	0.92	0.69	0.15	0.12	0.14
Iron mg/l Fe	0.878	1.040	0.825	0.196	0.909	0.237
Manganese mg/l Mn	0.059	0.061	0.026	0.124	0.185	0.116
Calcium mg/l Ca	2.02	2.07	1.60	2.01	2.07	1.58
Magnesium mg/l Mg	3.20	2.04	2.43	3.10	2.02	2.51
MEASURES OF FORMATION OF CHLORINATED COMPOUNDS (7-DAY):						
$CHCl_3$ μg/l	7906	15317	-	1017	1375	-
$CHCl_2Br$ μg/l	177	359	-	189	264	-
$CHClBr_2$ μg/l	0	0	-	12	6	-
$CHBr_3$ μg/l	0	0	-	0	0	-
Total THMFP μg/l	8083	15676	-	1218	1645	-
Delta UV 272 nm	-	-	0.689	-	-	0.024

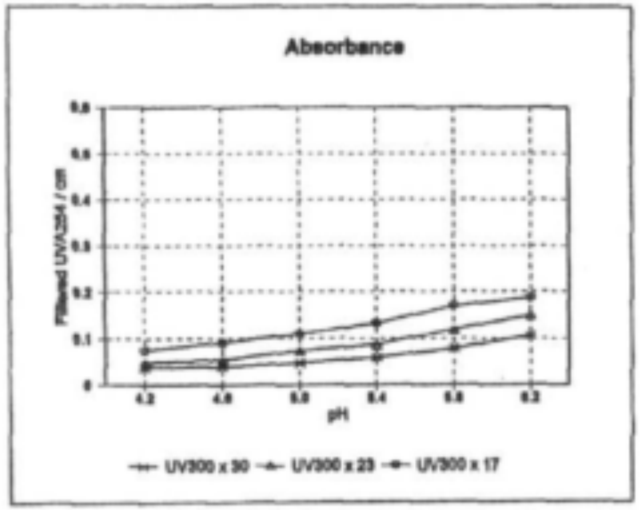
APPENDIX D

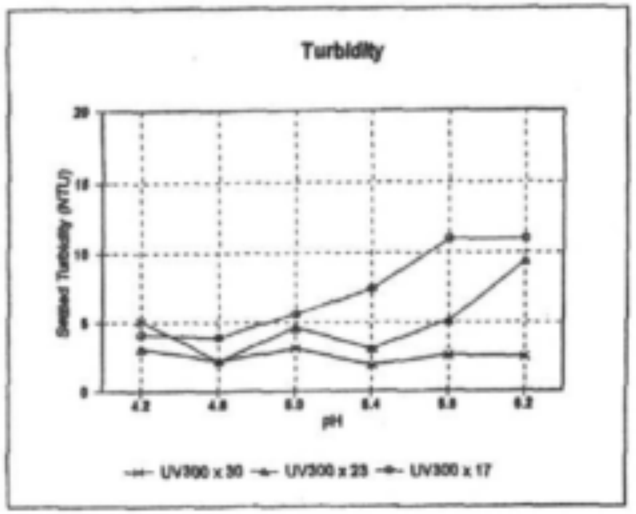
COAGULATION DIAGRAMS

KLEINBRAK RAW WATER

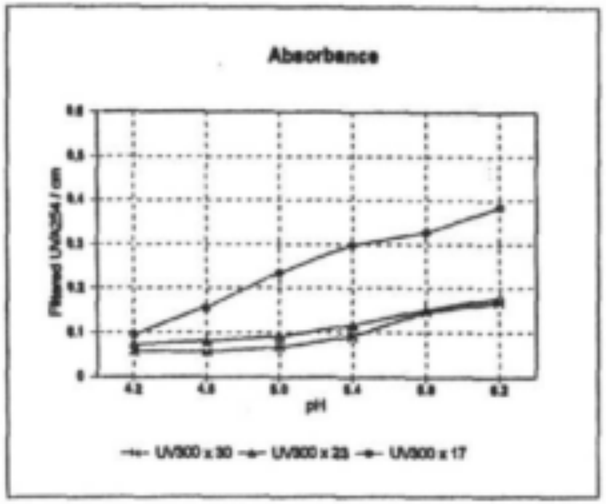
pH Optimisation

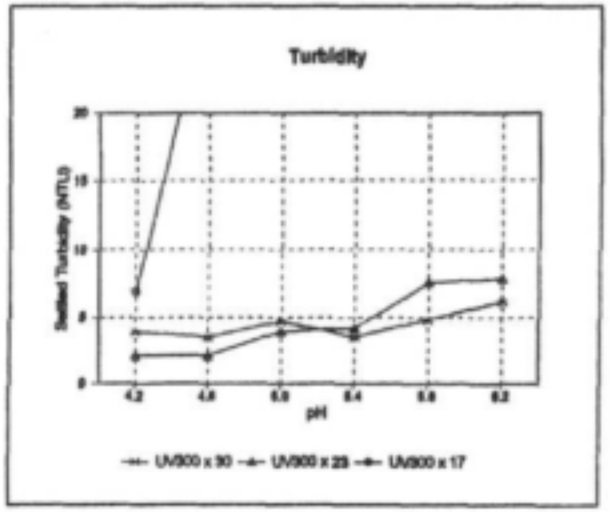
Ferric Chloride





Ferric Sulphate

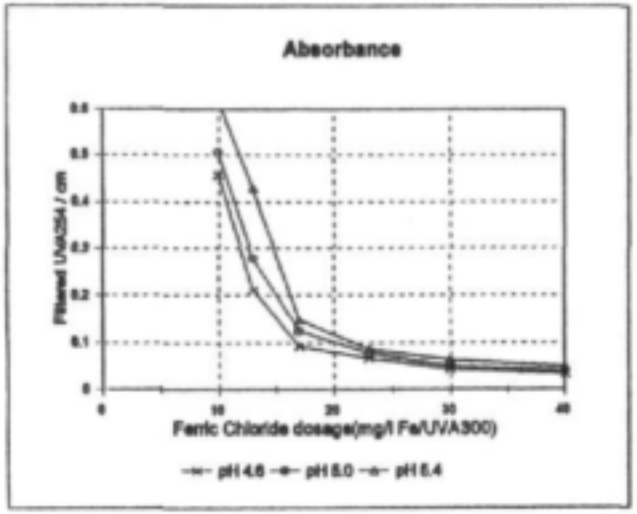




KLEINBRAK RAW WATER

Dose Optimisation

Ferric Chloride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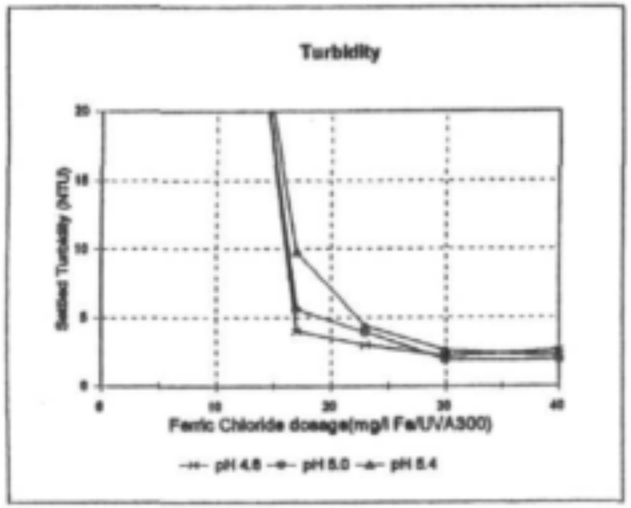
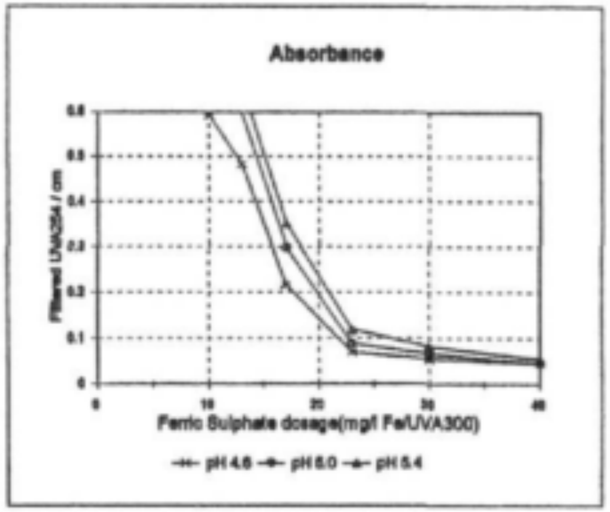

Turbidity

Ferric Sulphate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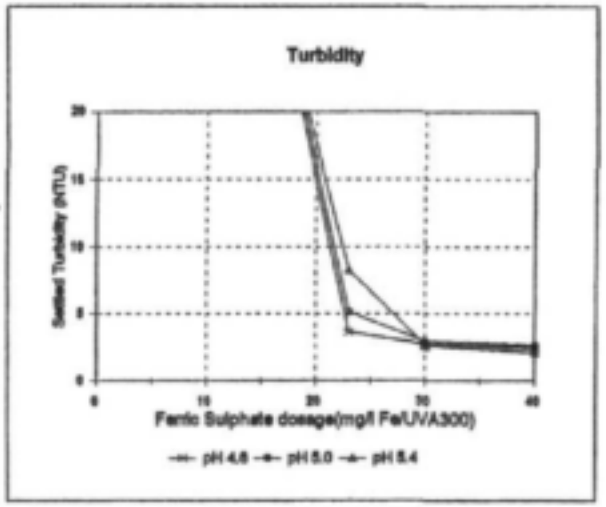
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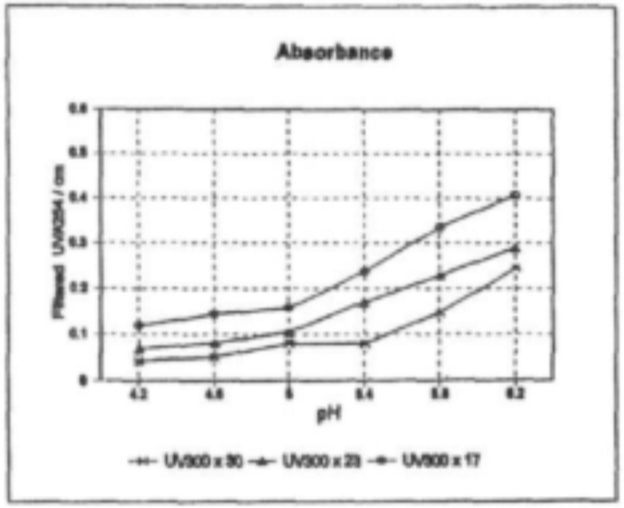
SANDHOOGTE RAW WATER

pH Optimisation

Ferric chloride

Absorbance



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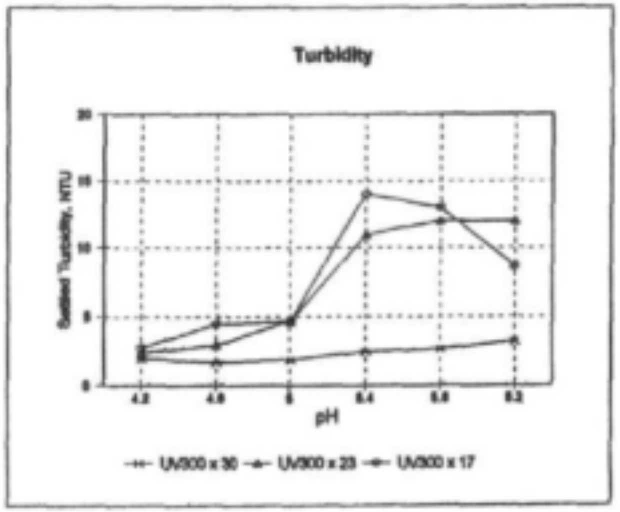
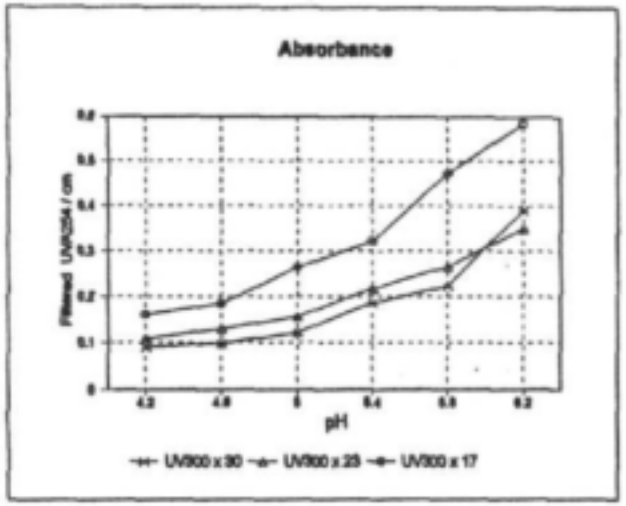


Ferric Sulphate

Absorbance



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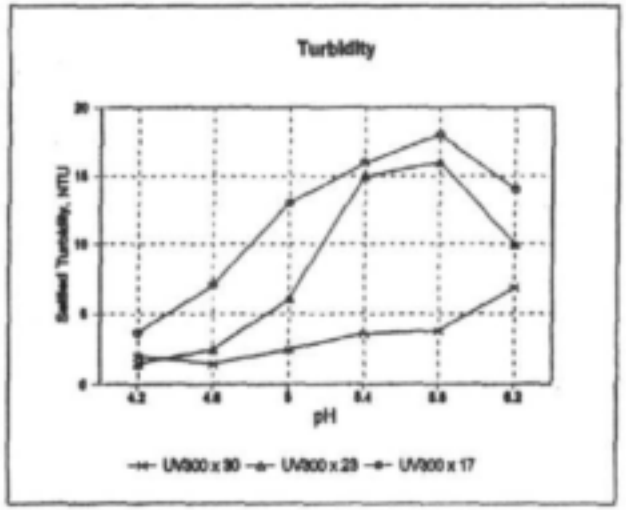
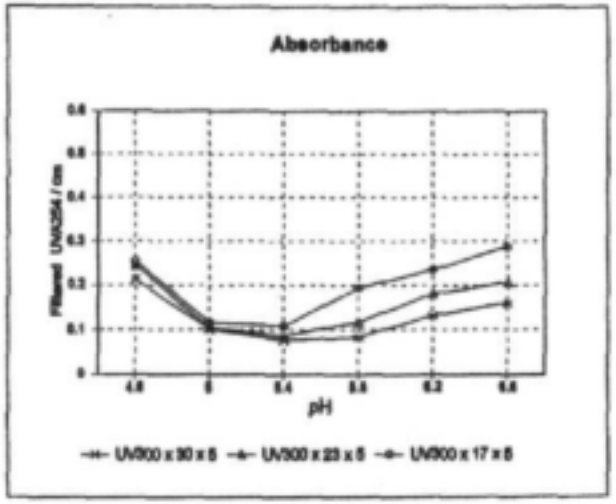
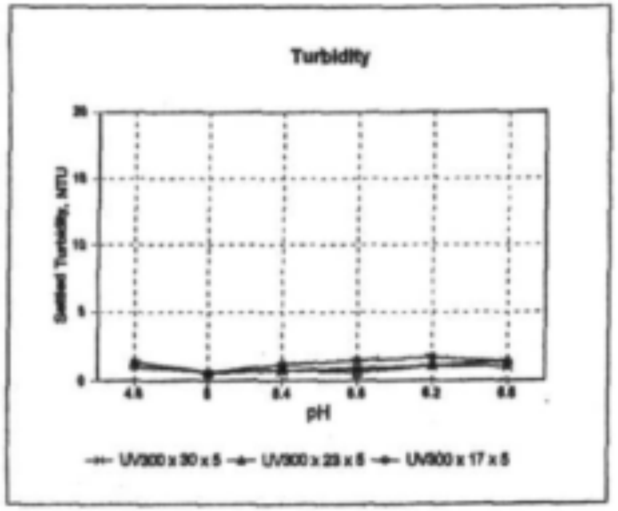


Aluminium Sulphate

Absorbance



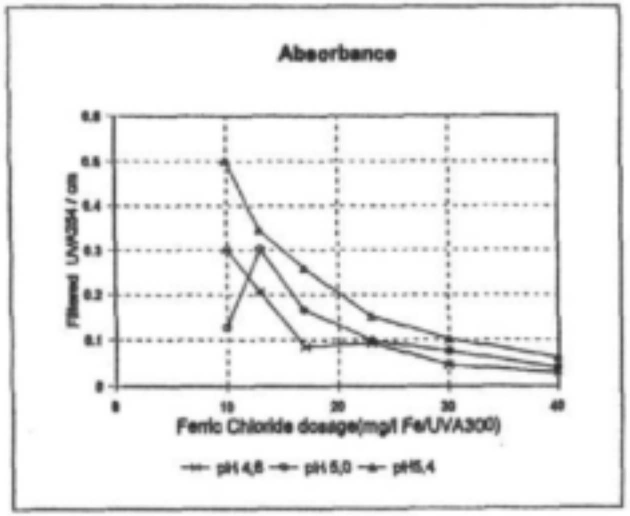
Turbidity

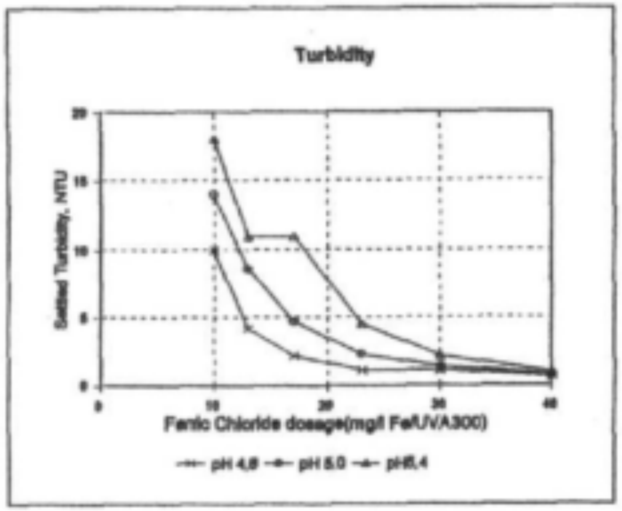


SANDHOOGTE RAW WATER

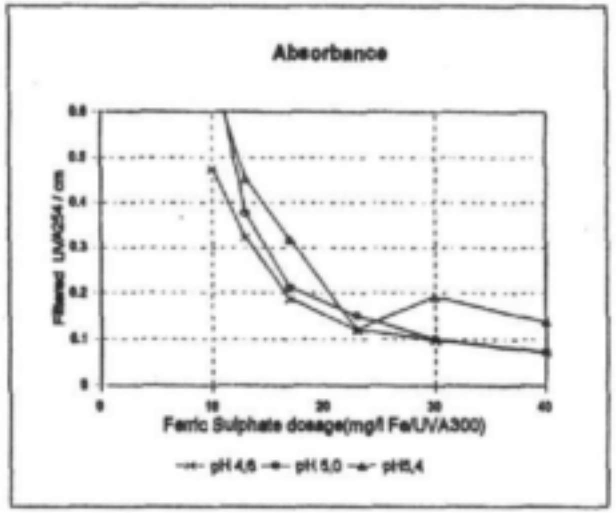
Dose optimisation

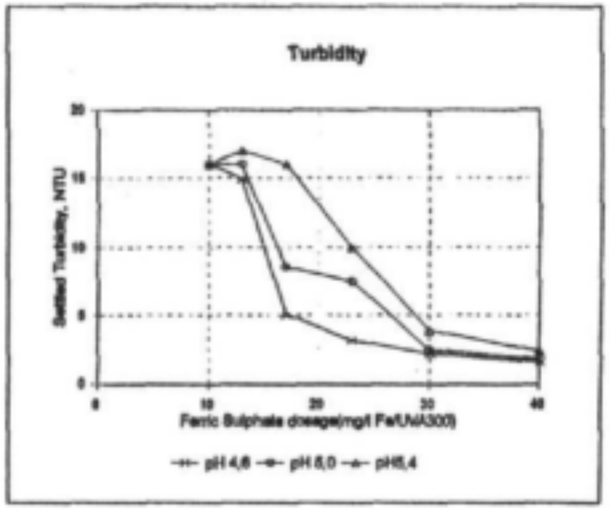
Ferric chloride





Ferric Sulphate





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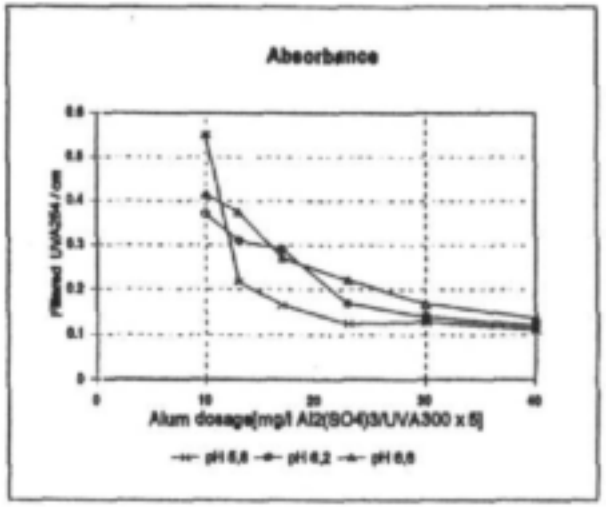
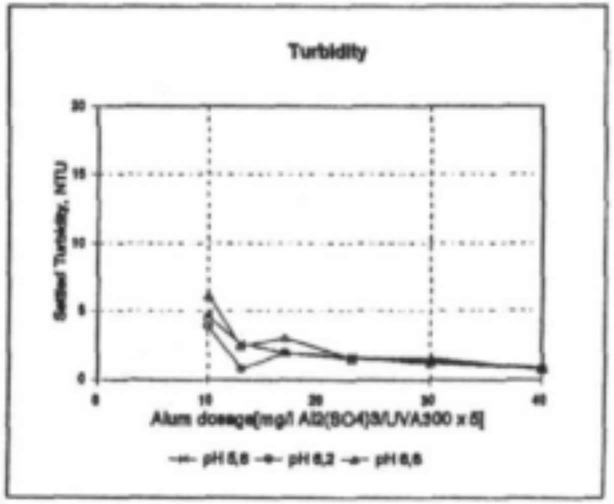
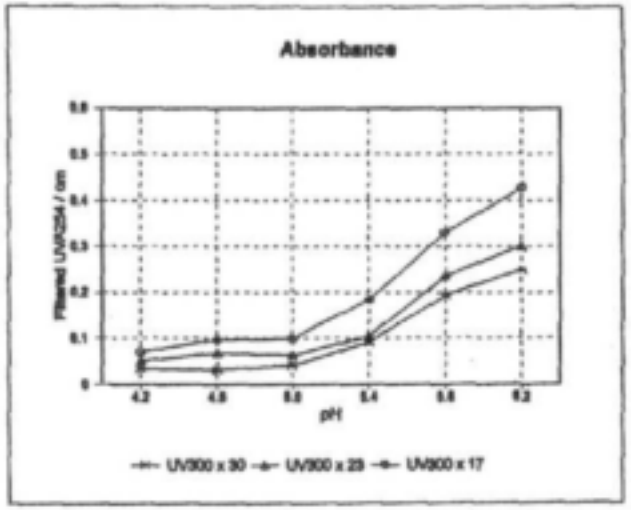




GEORGE RAW WATER

pH Optimisation

Ferric Chloride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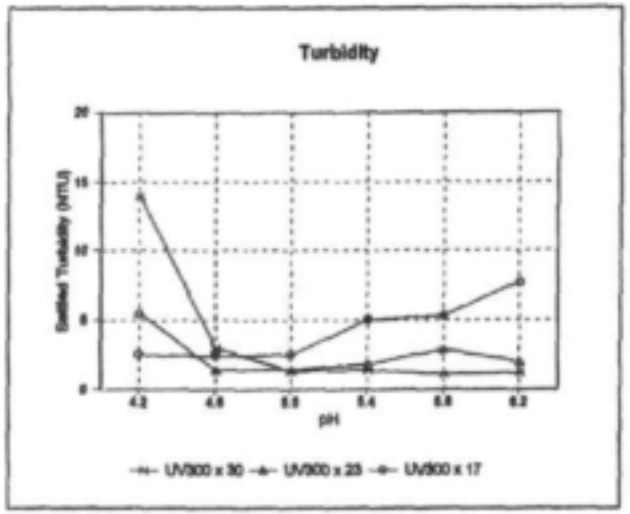
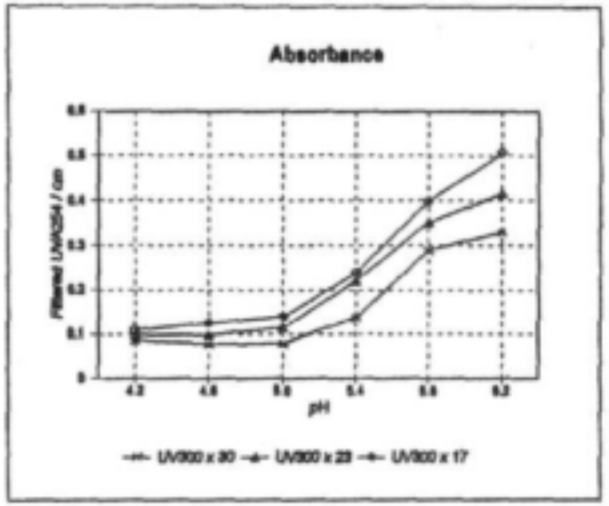

Turbidity

Ferric Sulphate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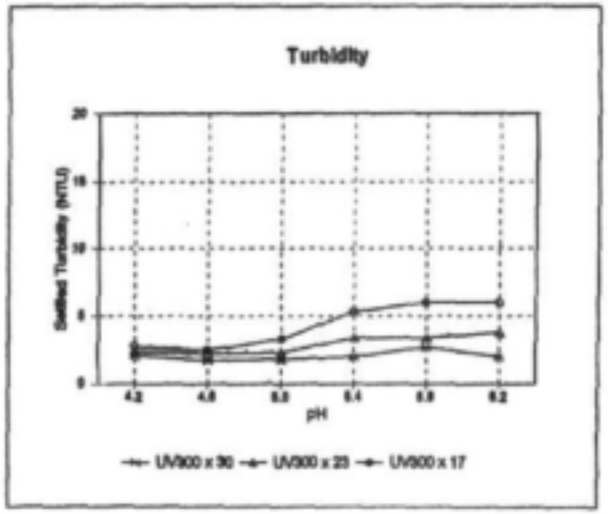
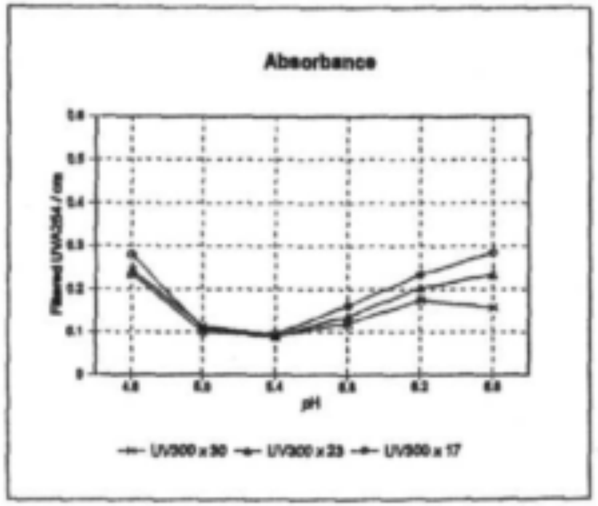

Turbidity

Aluminium Sulphate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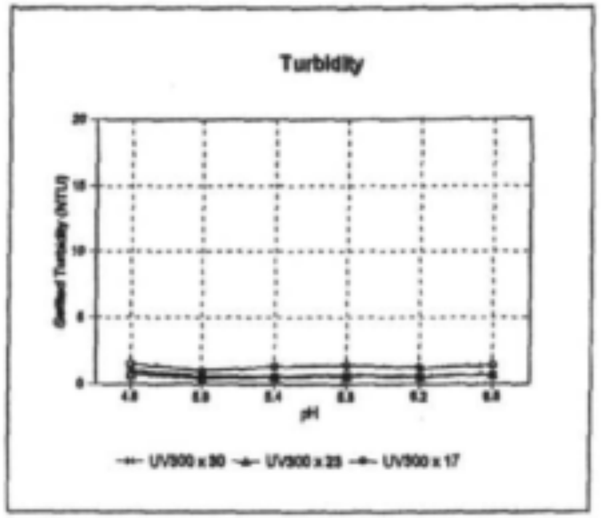
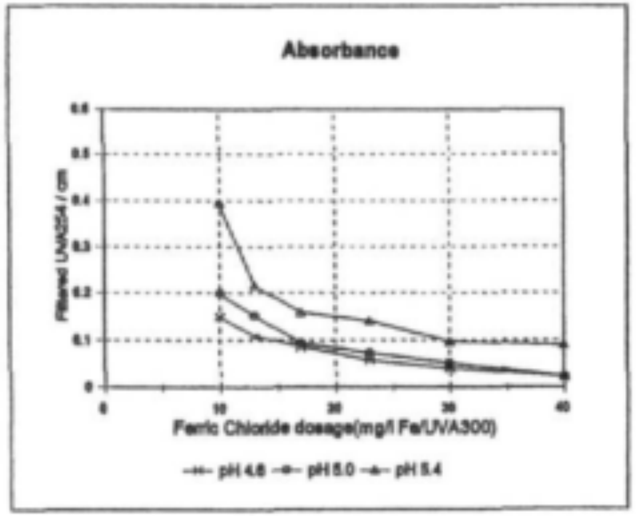
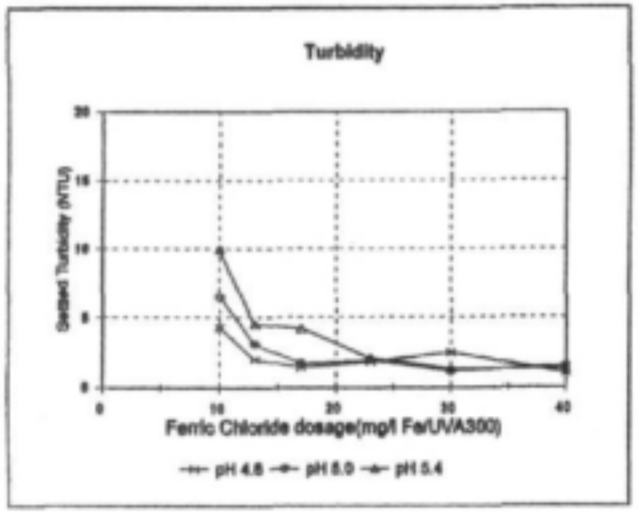

Turbidity

GEORGE RAW WATER

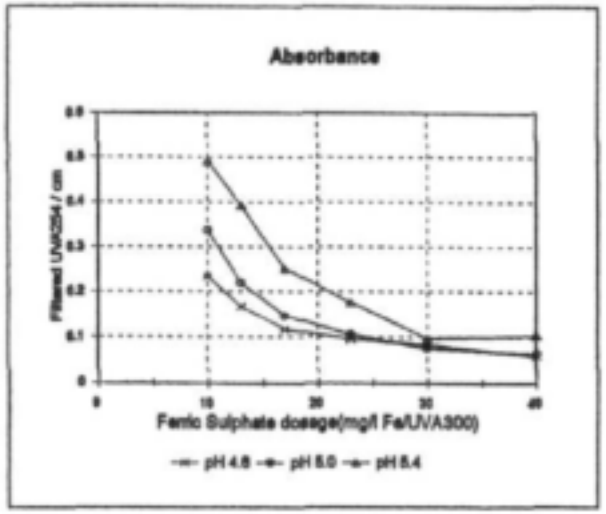
Dose Optimisation

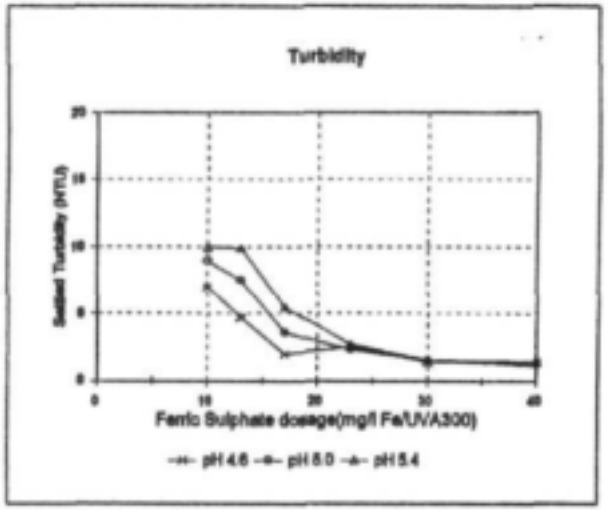
Ferric Chloride





Ferric Sulphate





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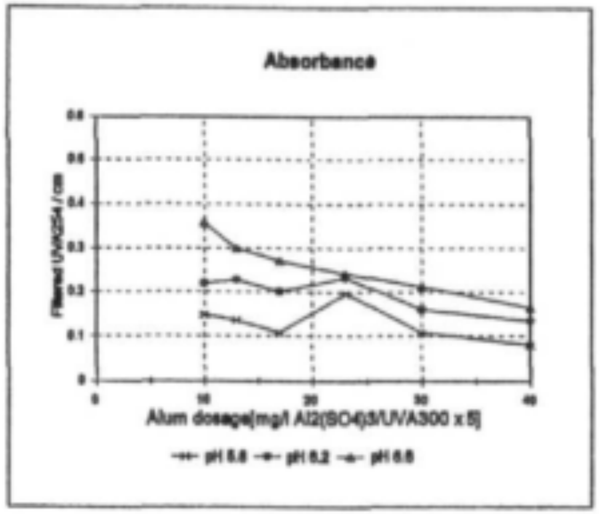
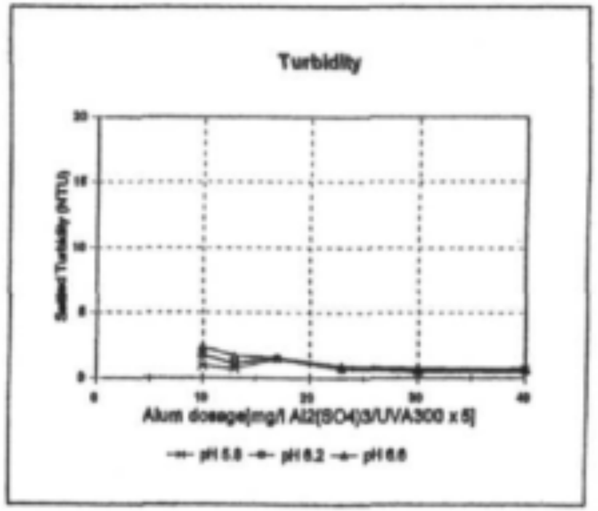
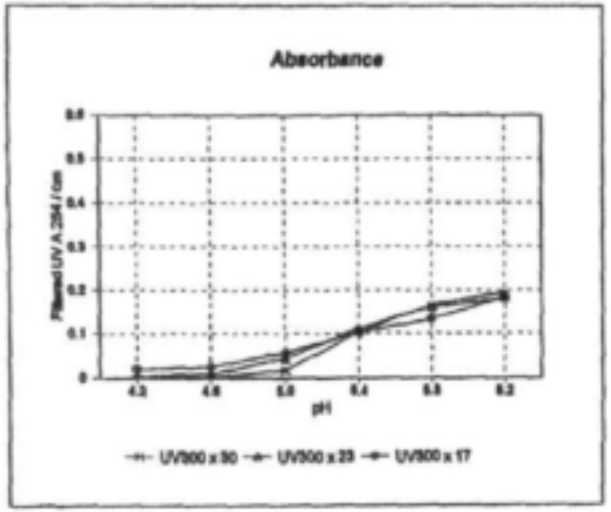


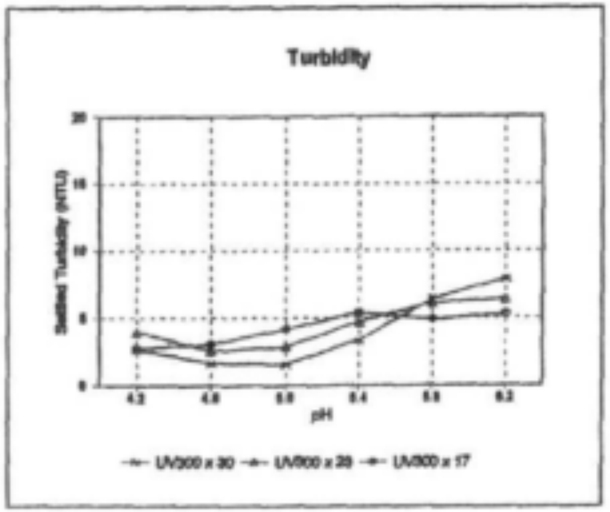


PLETTENBERG BAY RAW WATER

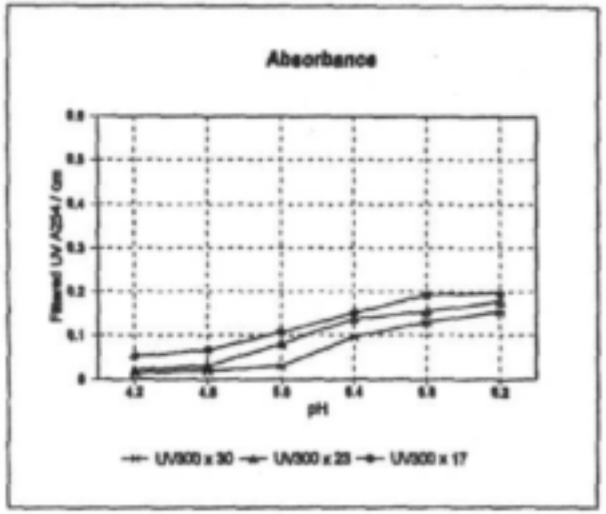
pH Optimisation

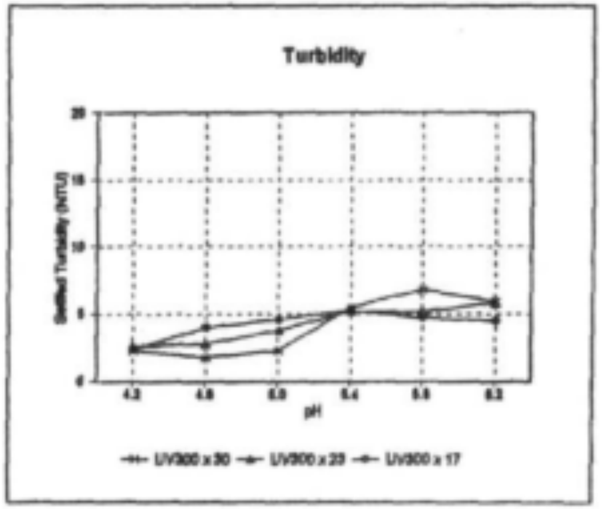
Ferric Chloride





Ferric Sulphate





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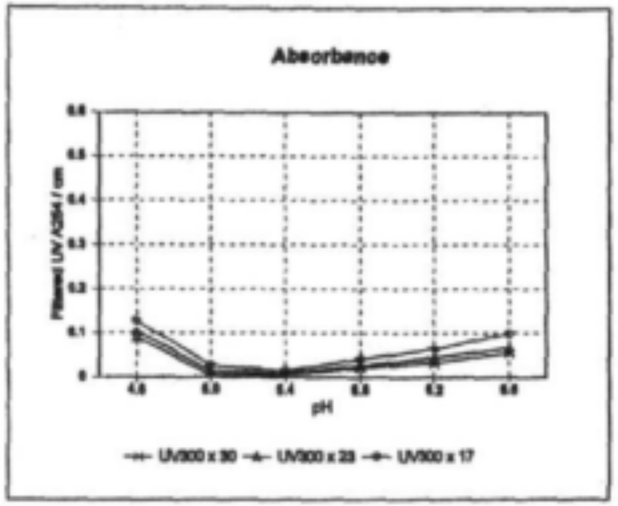
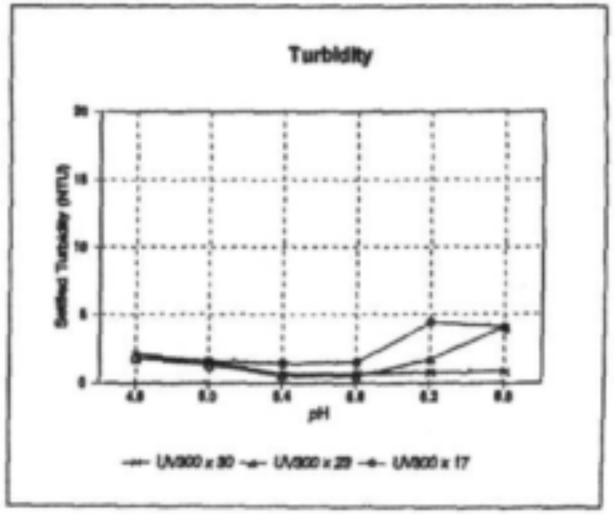
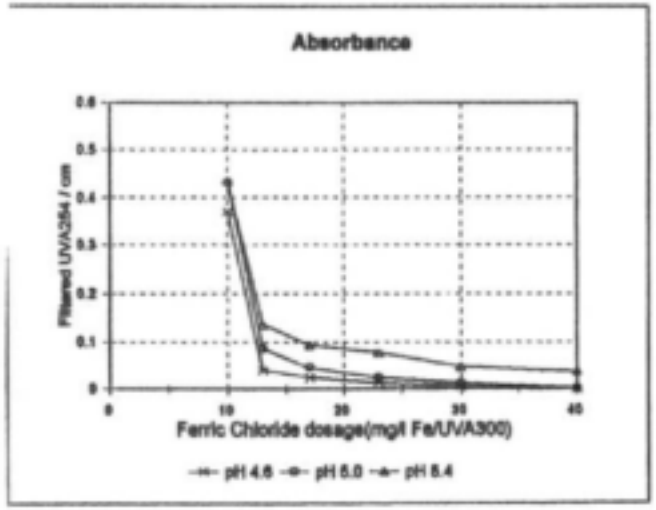




PLETTENBERG BAY RAW WATER

Dose Optimisation

Ferric Chloride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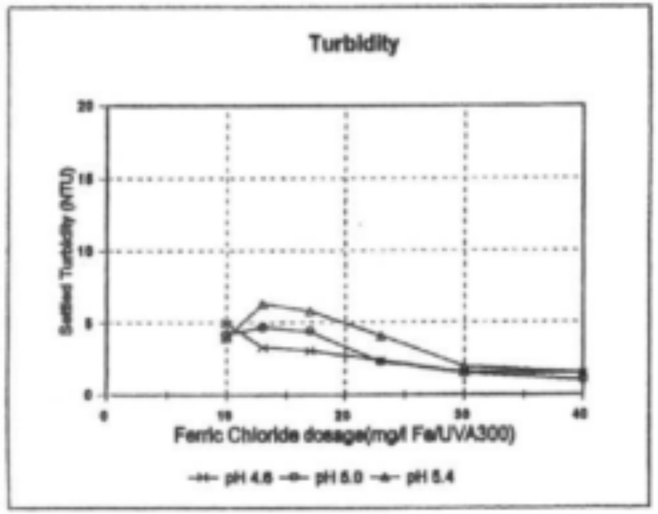
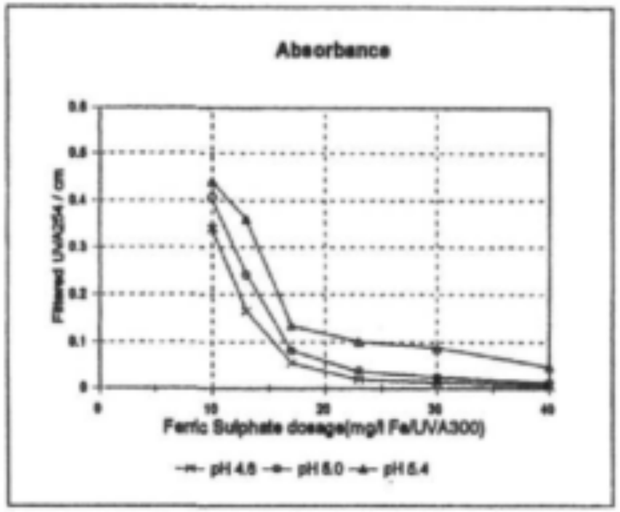

Turbidity

Ferric Sulphate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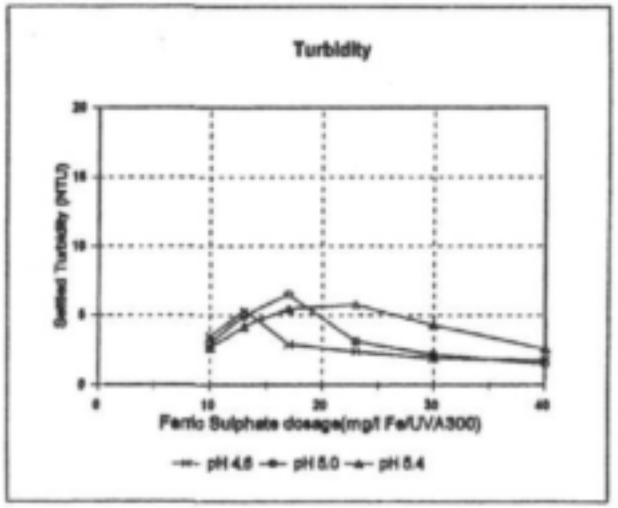
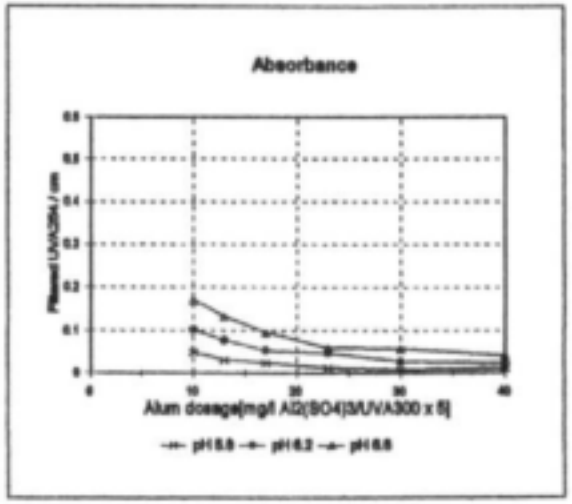

Turbidity

Aluminium Sulphate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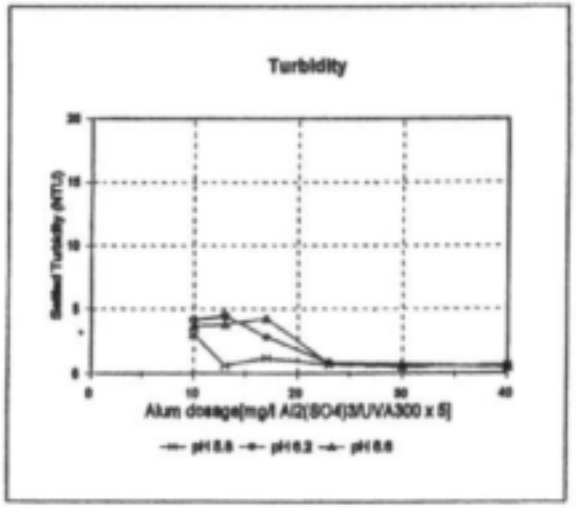
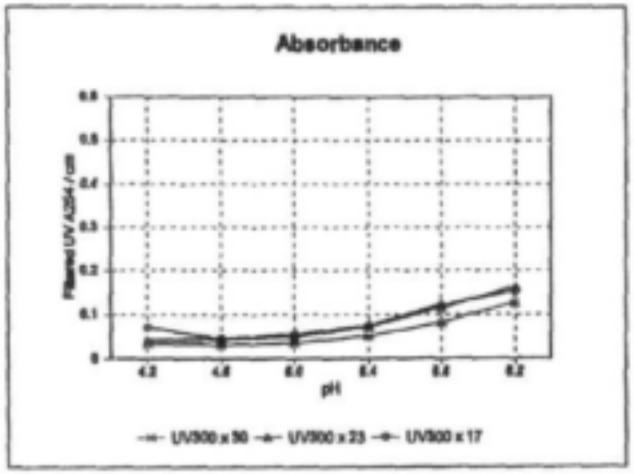
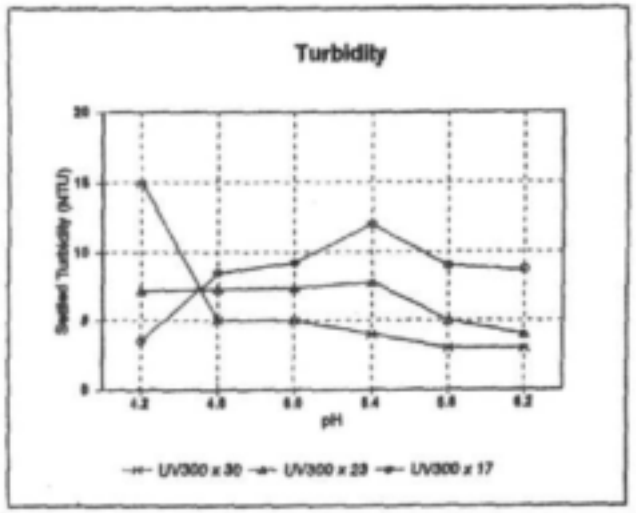

Turbidity

PORT ELIZABETH RAW WATER

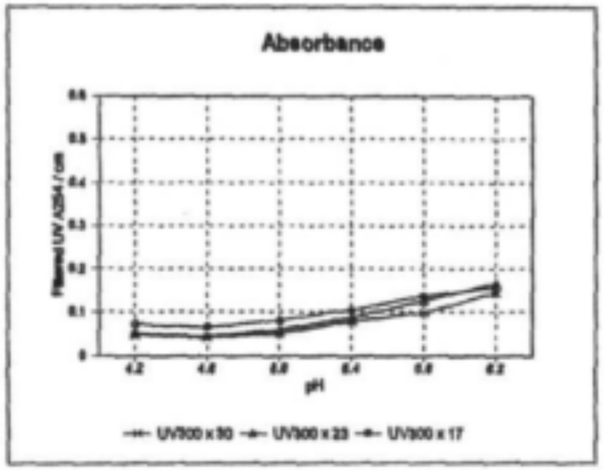
pH Optimisation

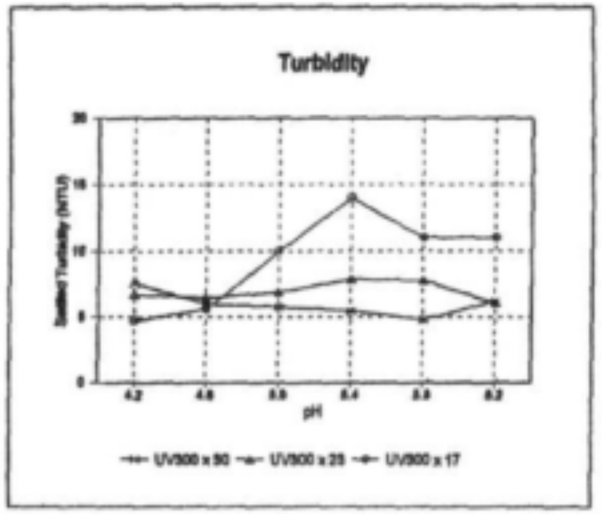
Ferric Chloride


Absorbance

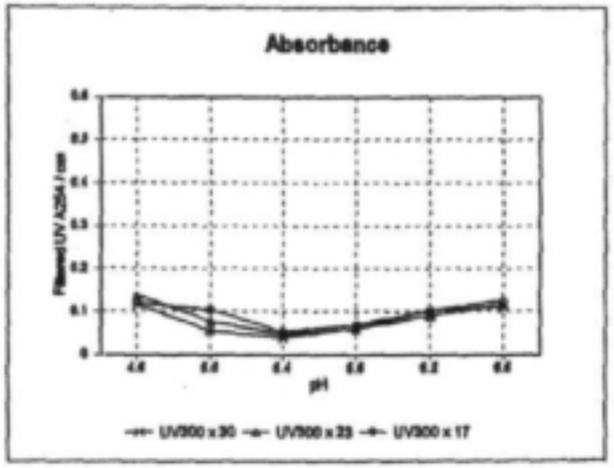

Turbidity

Ferric Sulphate


Absorbance


Turbidity

Aluminium Sulphate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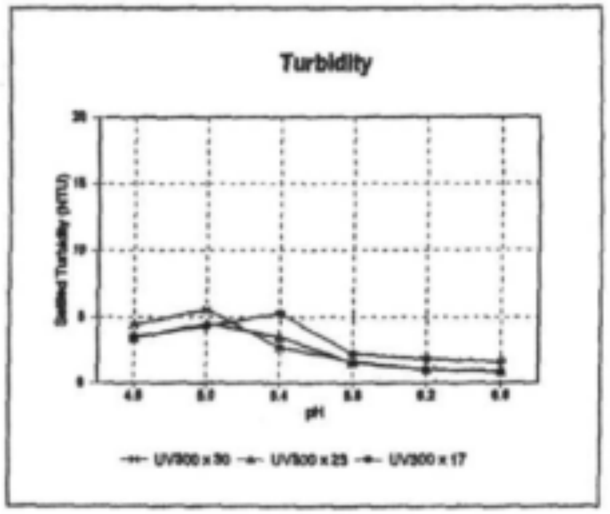
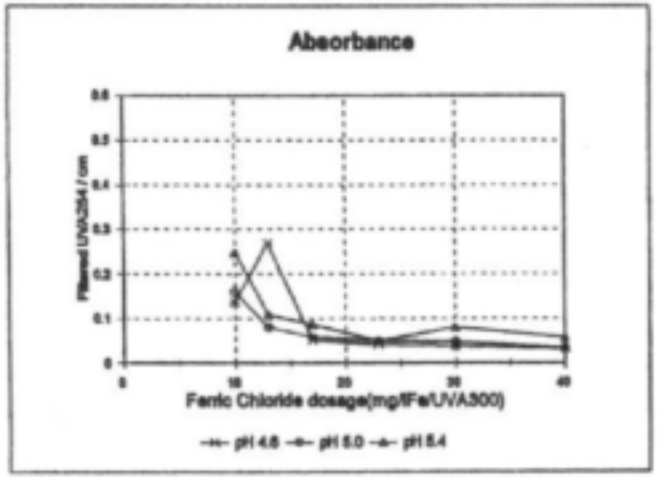
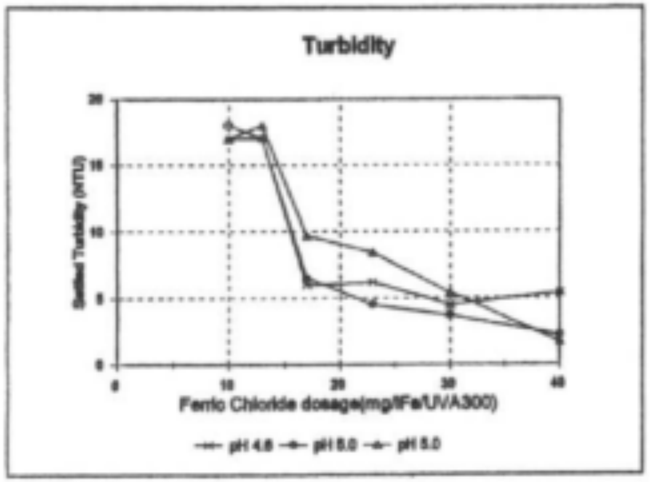

Turbidity

PORT ELIZABETH RAW WATER

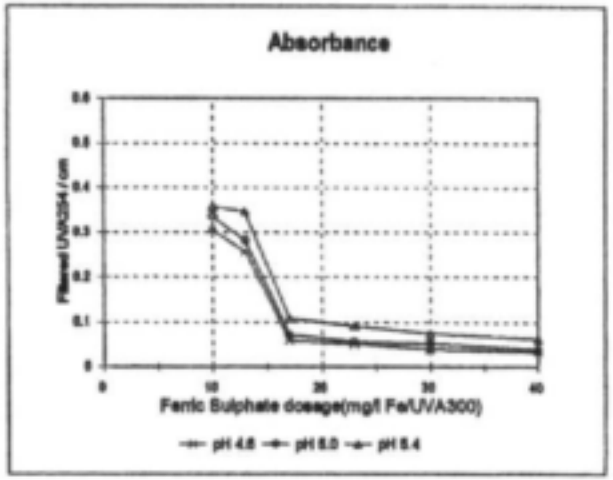
Dose Optimisation

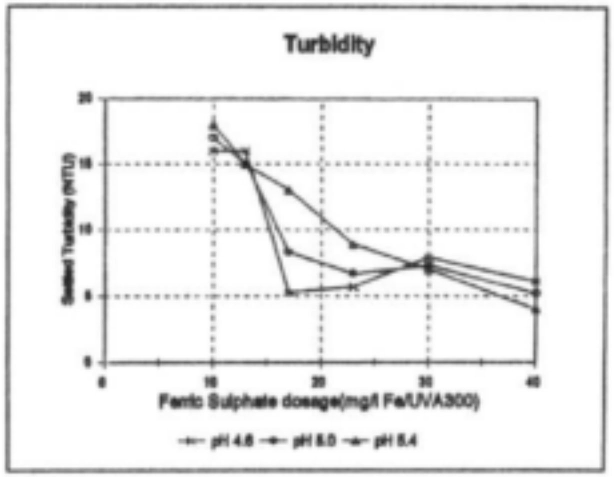
Ferric Chloride



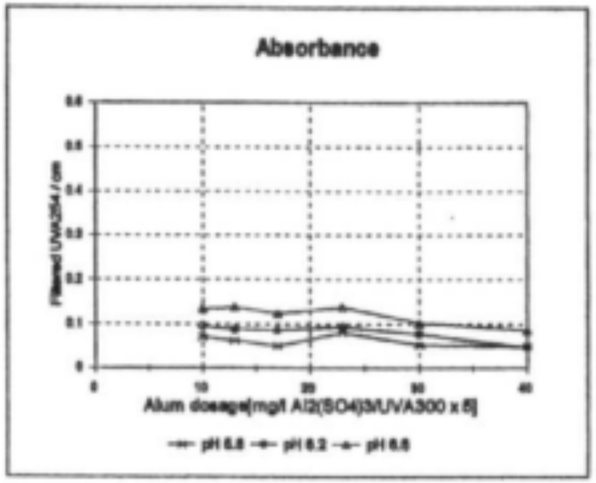


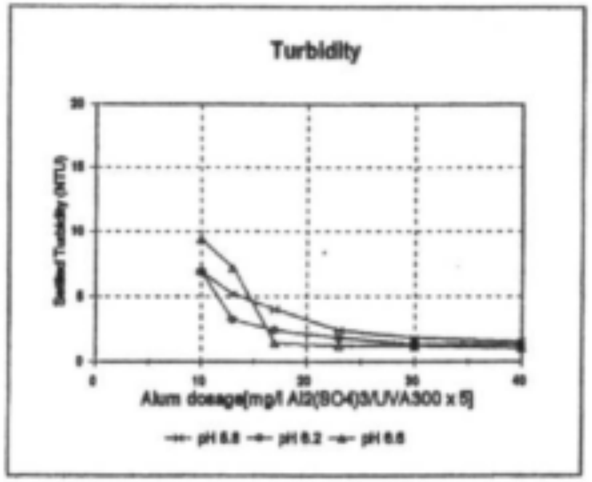
Ferric Sulphate





Aluminium Sulphate

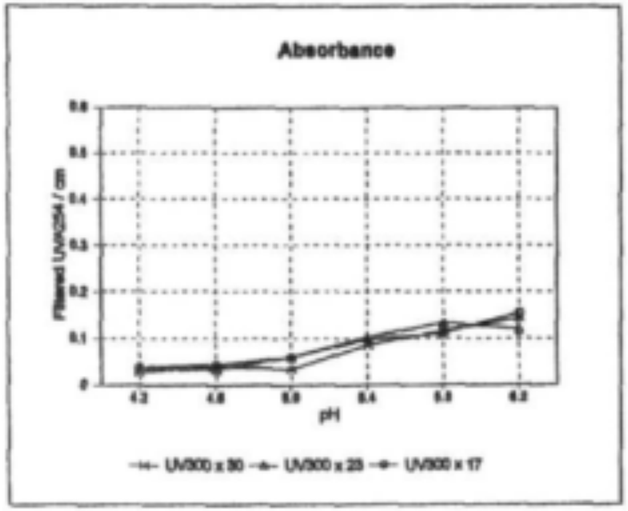


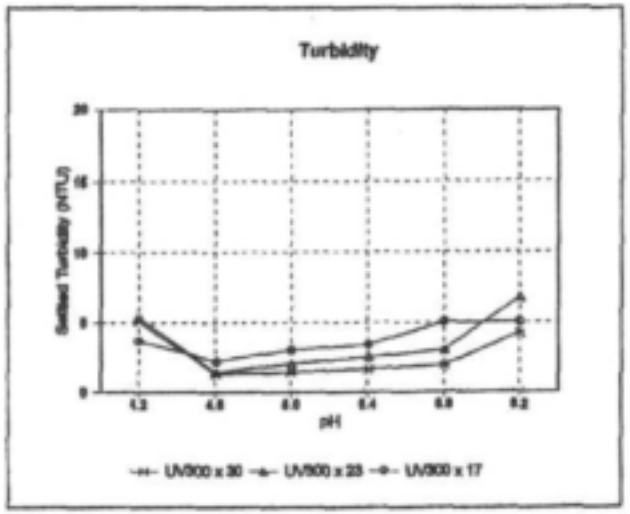


SWELLENDAM RAW WATER

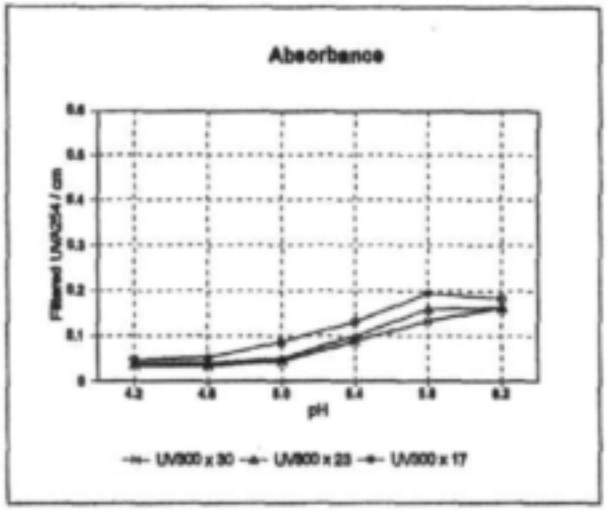
pH Optimisation

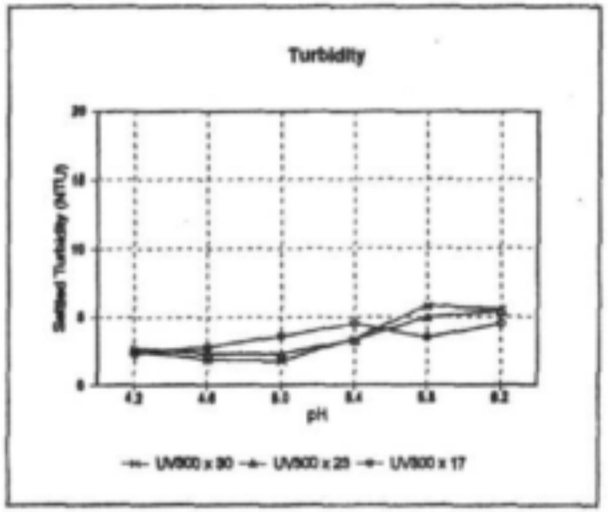
Ferric Chloride



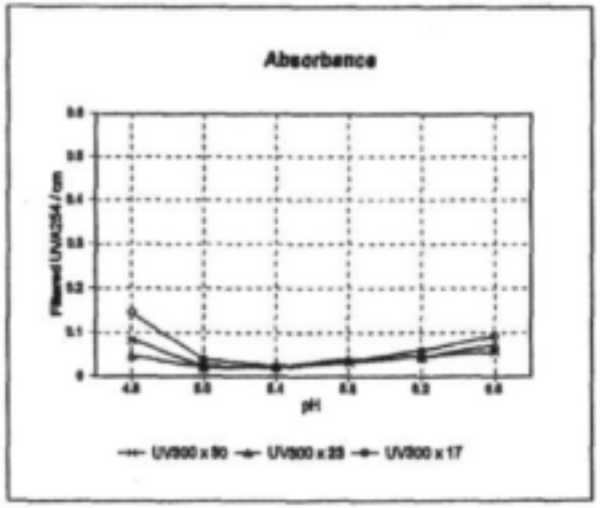


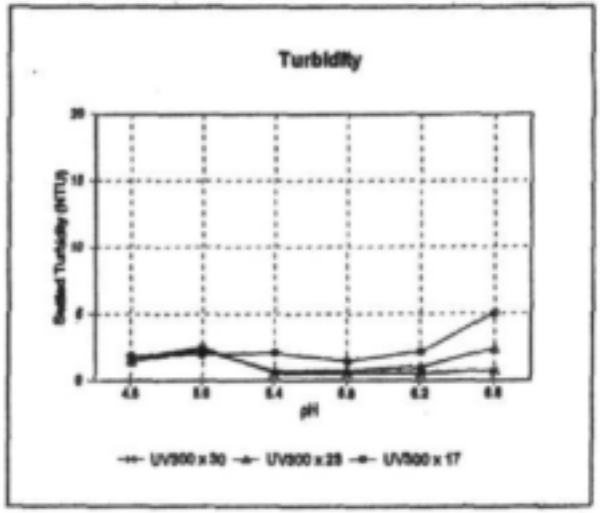
Ferric Sulphate





Aluminium Sulphate

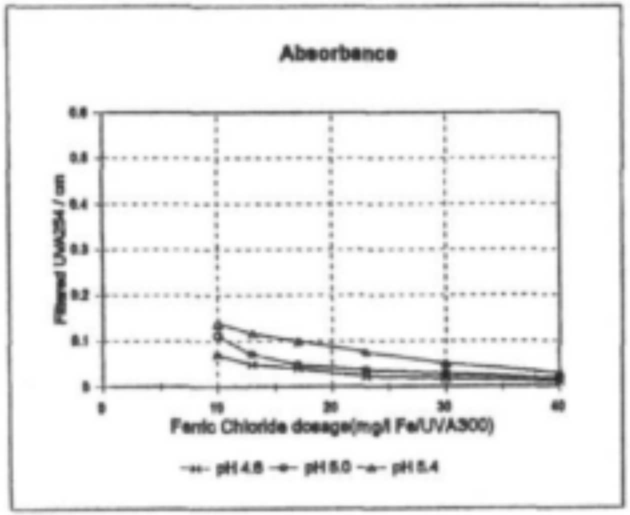


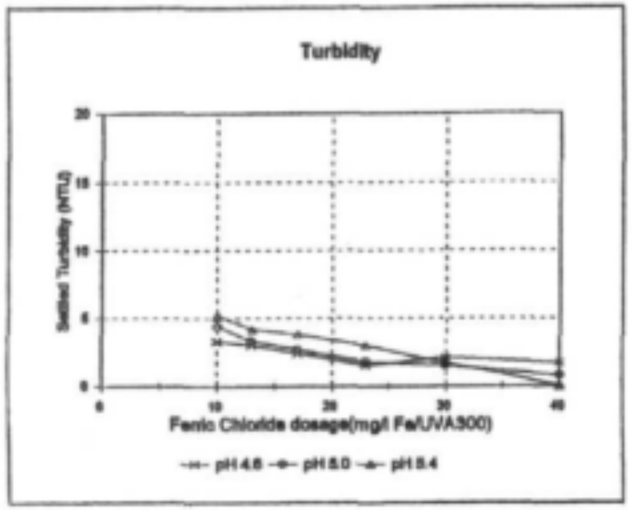


SWELLENDAM RAW WATER

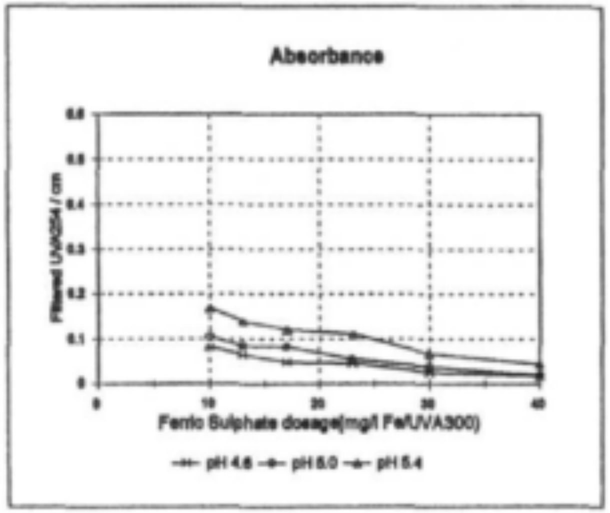
Dose Optimisation

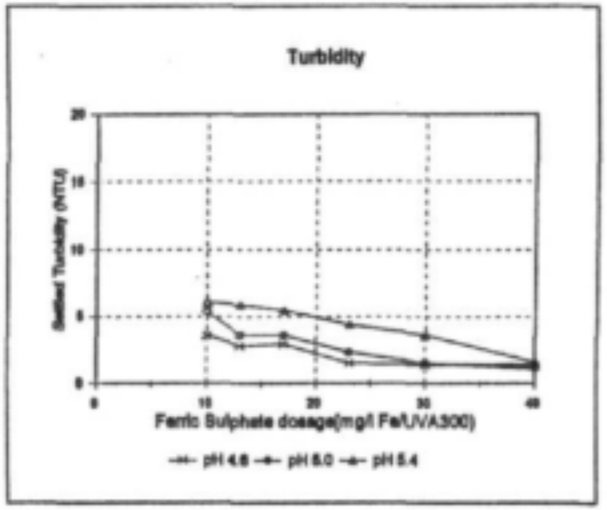
Ferric Chloride



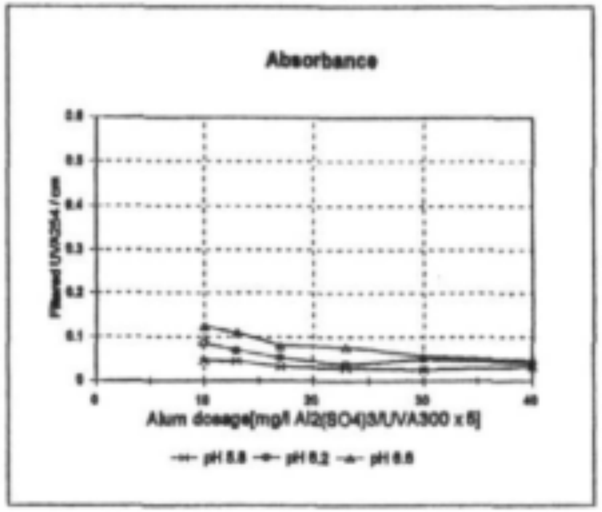


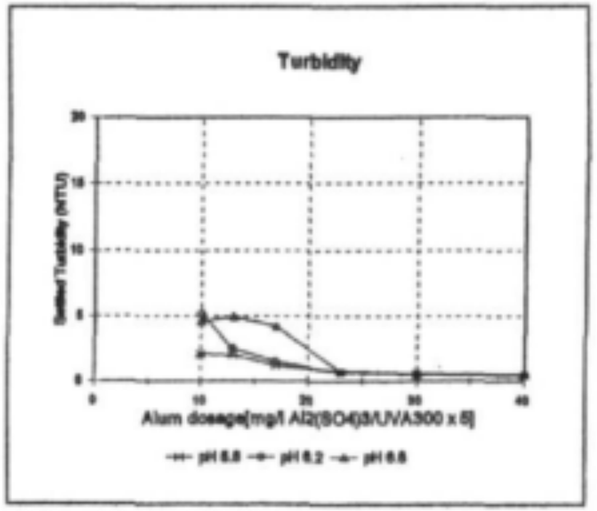
Ferric Sulphate





Aluminium Sulphate

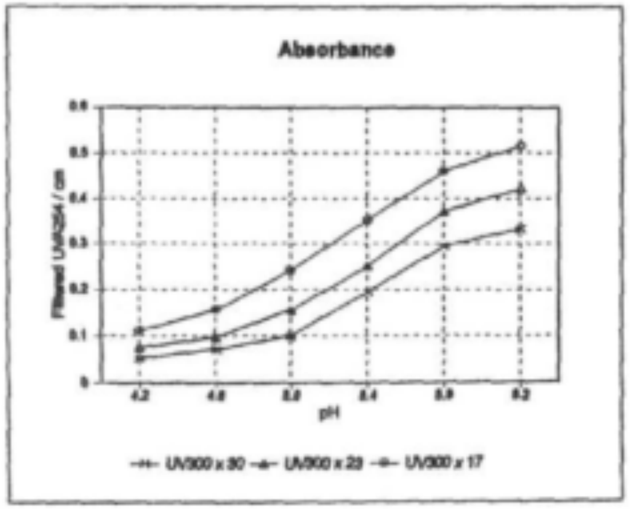


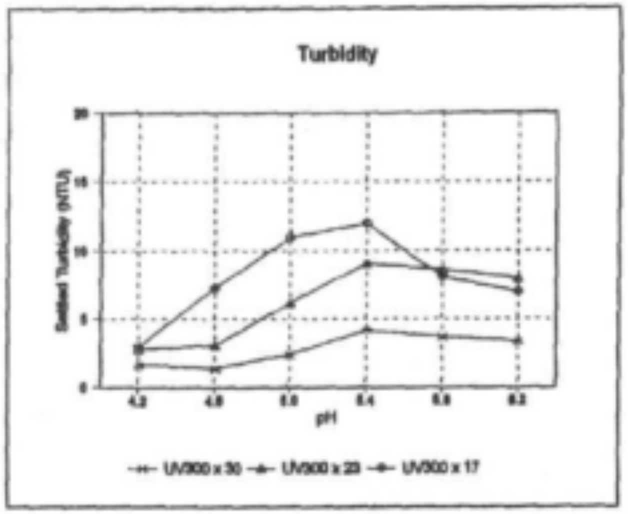


SIMONS TOWN RAW WATER

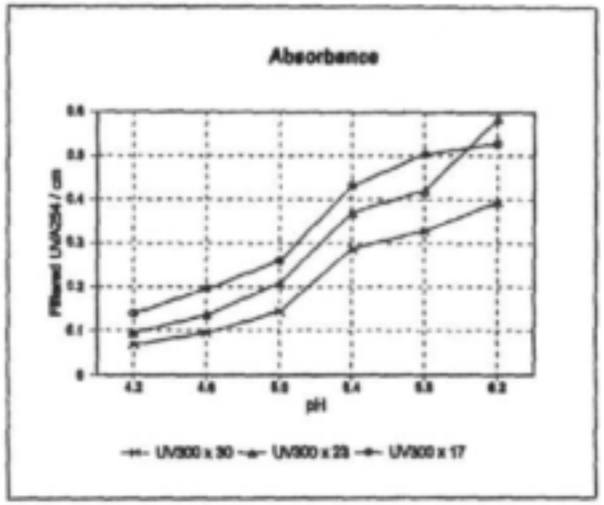
pH Optimisation

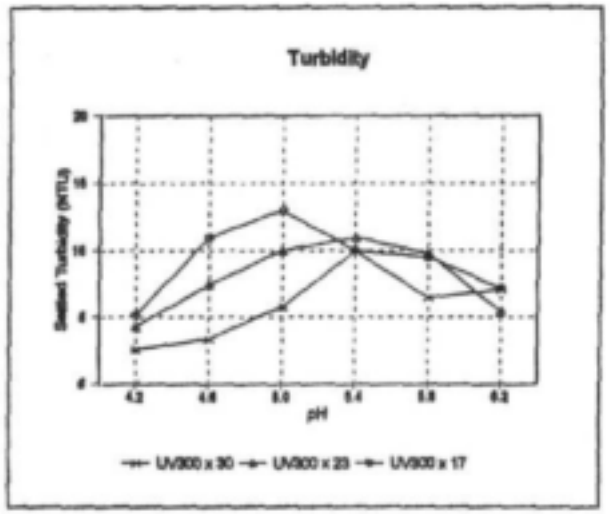
Ferric Chloride


Absorbance

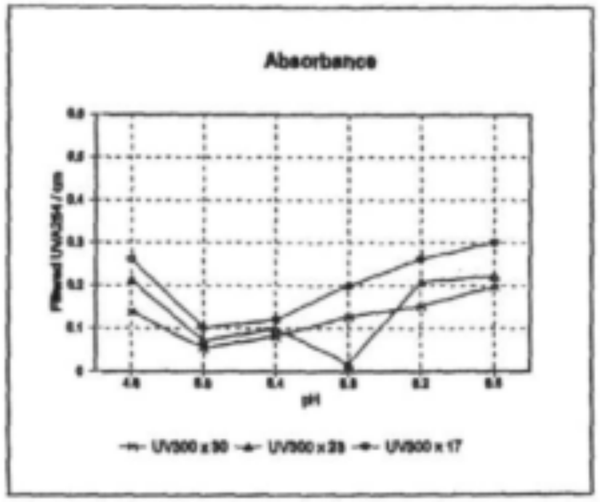

Turbidity

Ferric Sulphate


Absorbance


Turbidity

Aluminium Sulphate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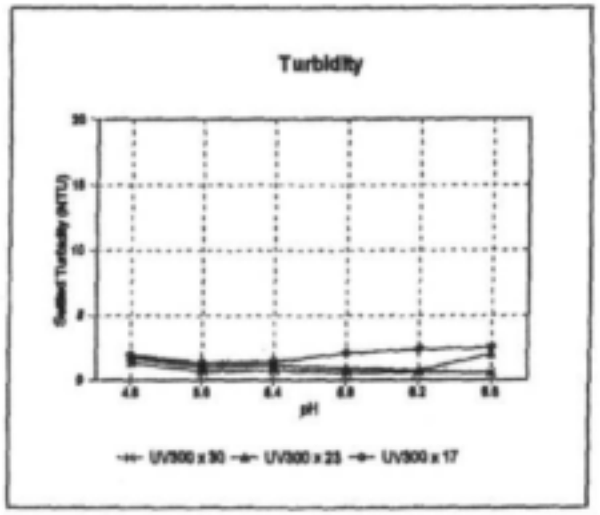
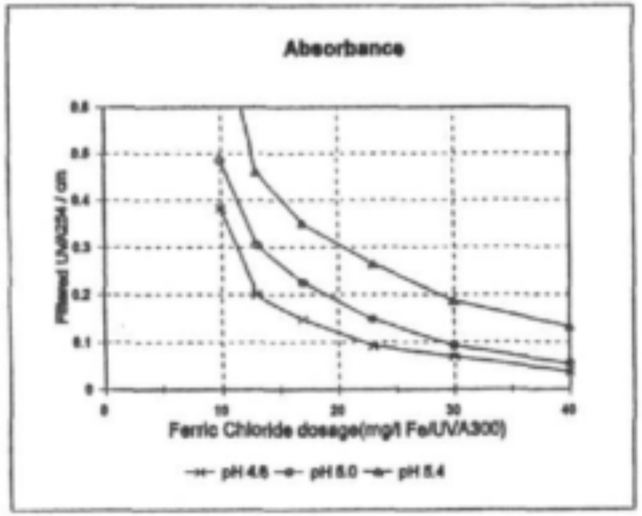
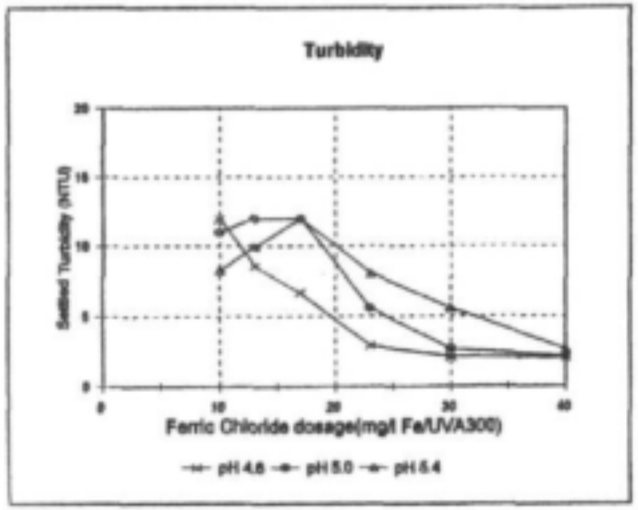

Turbidity

SIMONS TOWN RAW WATER

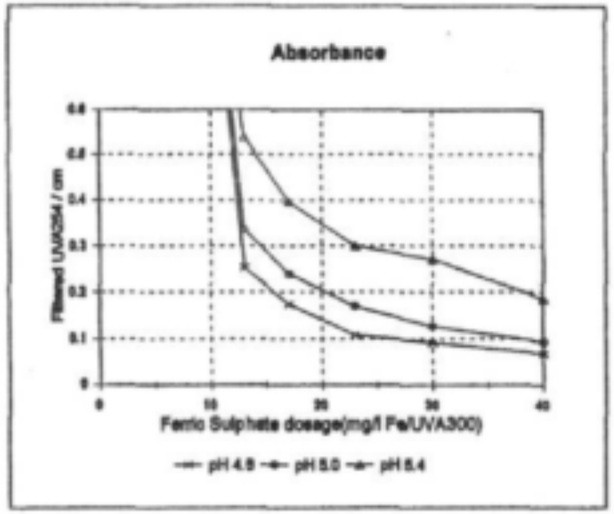
Dose Optimisation

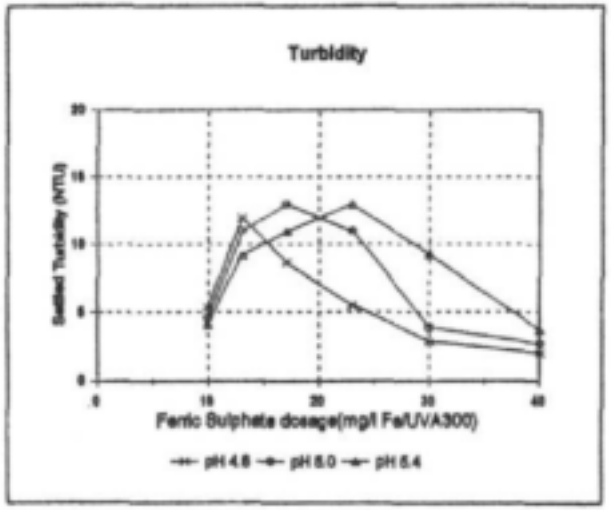
Ferric Chloride



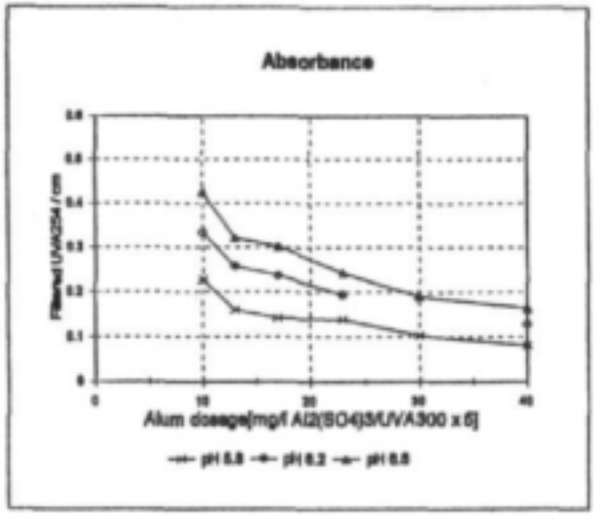


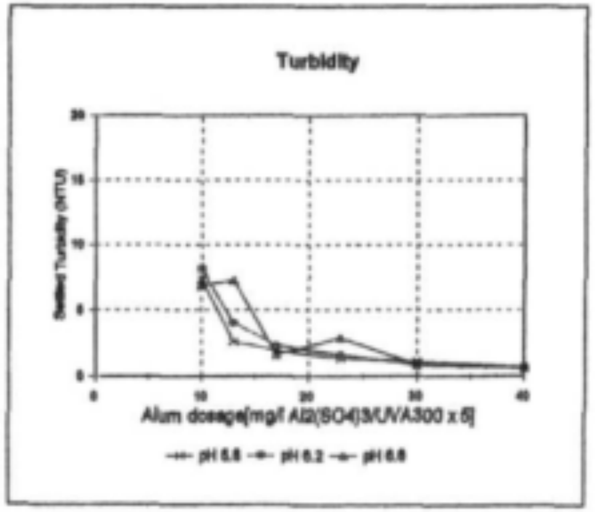
Ferric Sulphate





Aluminium Sulphate

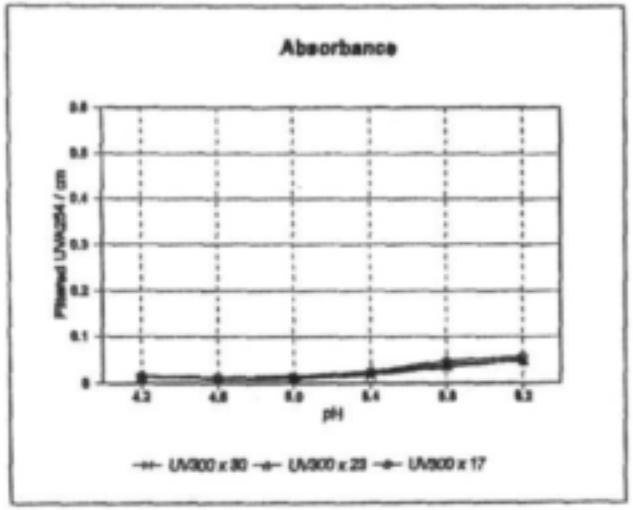


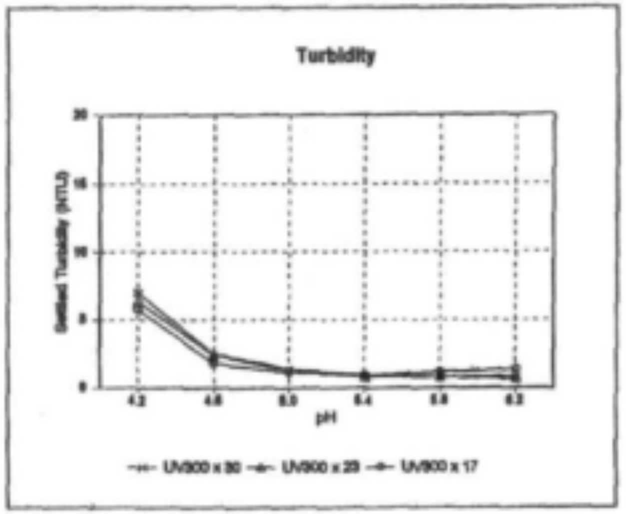


KNYSNA RAW WATER

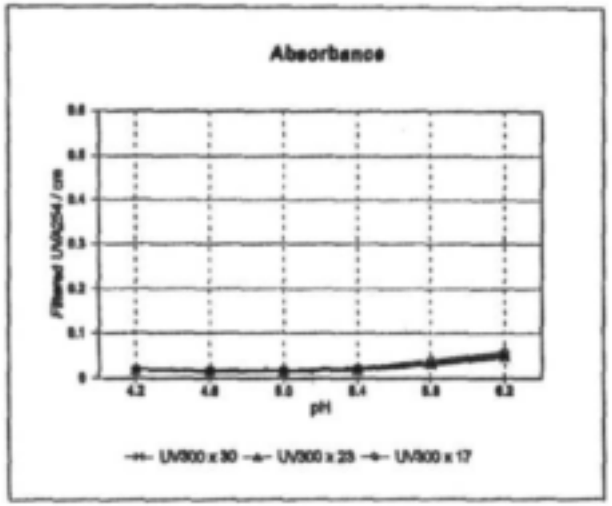
pH Optimisation

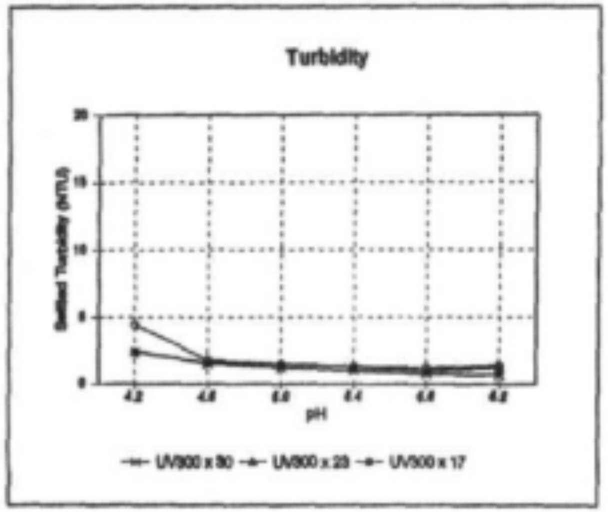
Ferric Chloride





Ferric Sulphate





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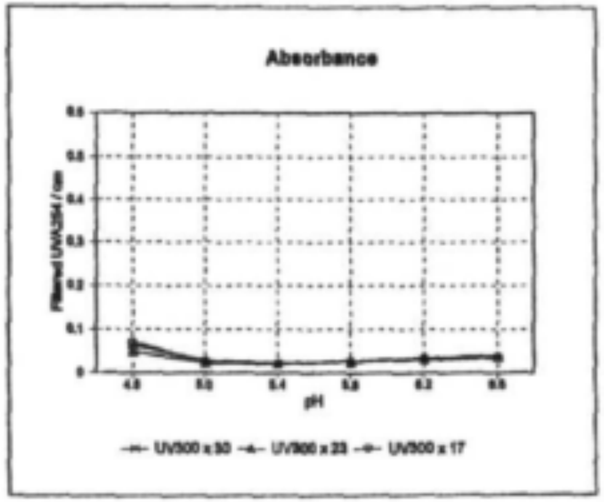
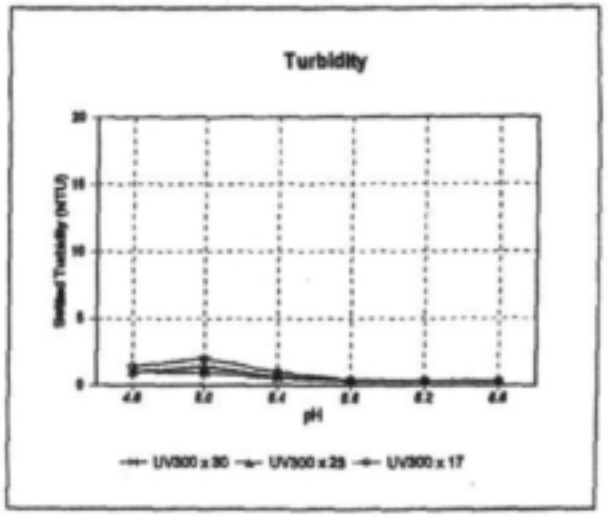
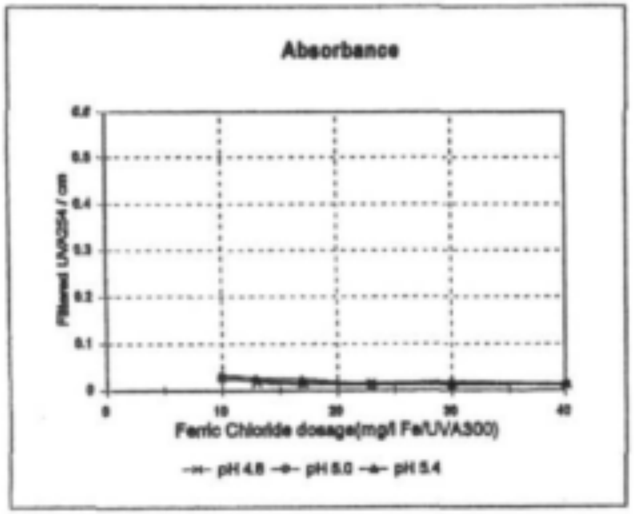


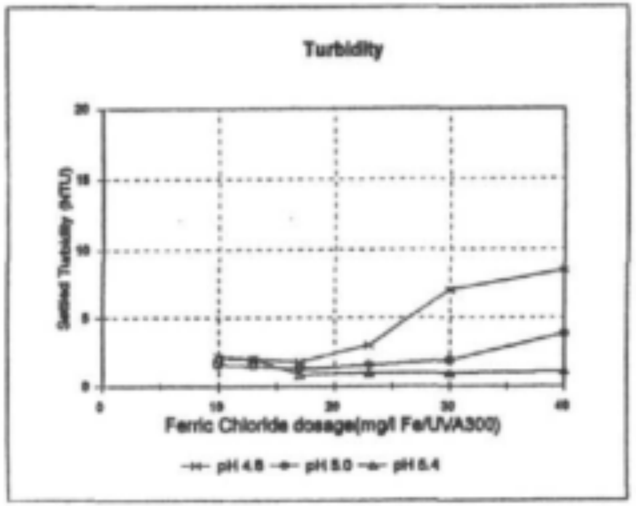


KNYSNA RAW WATER

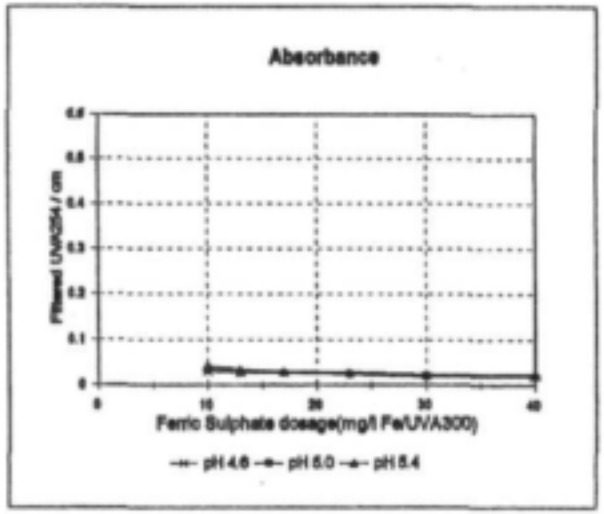
Dose Optimisation

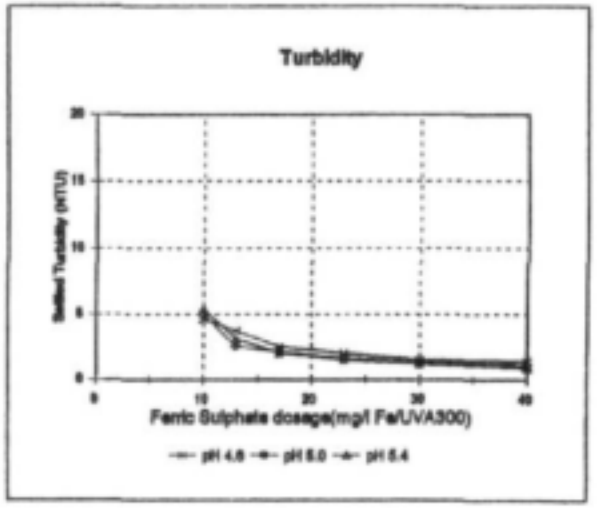
Ferric Chloride



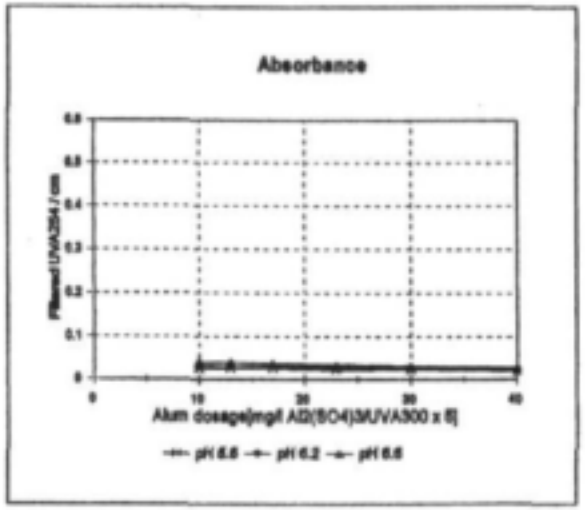


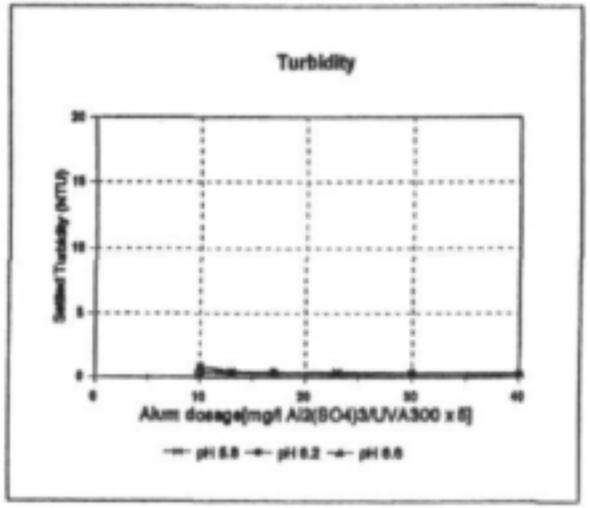
Ferric Sulphate





Aluminium Sulphate

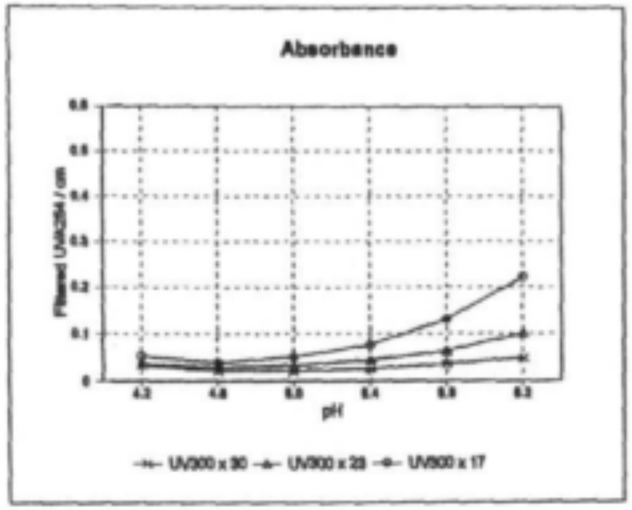


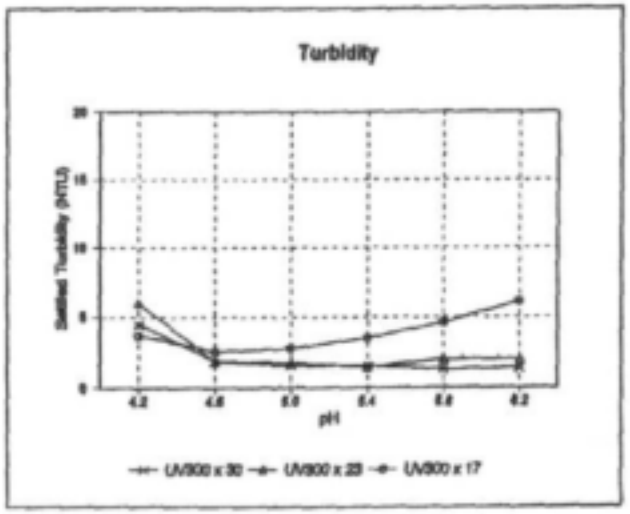


DUIVENHOKS RAW WATER

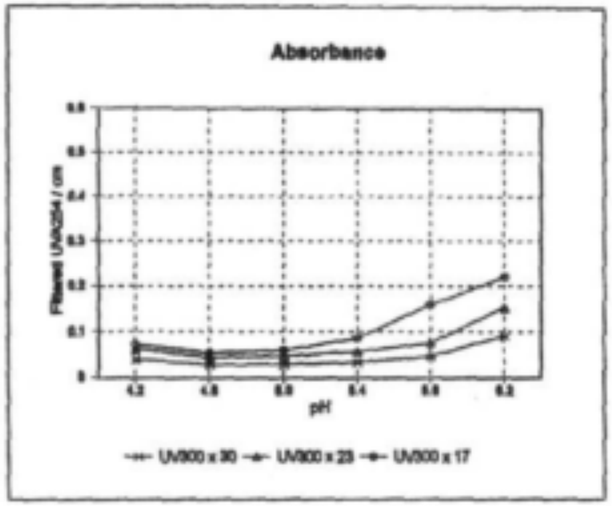
pH Optimisation

Ferric Chloride


Absorbance


Turbidity

Ferric Sulphate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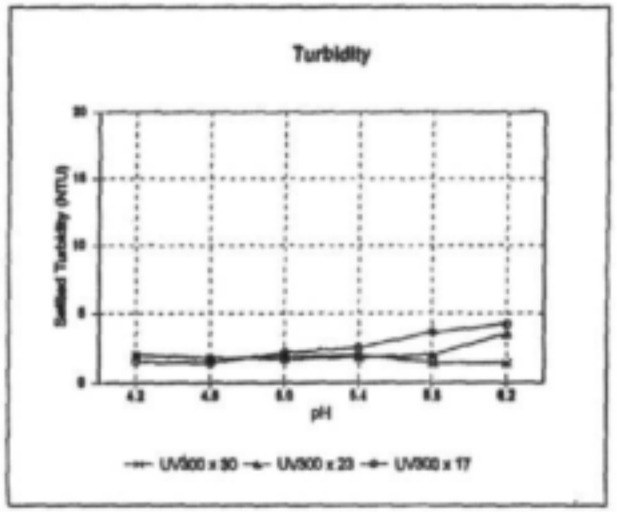
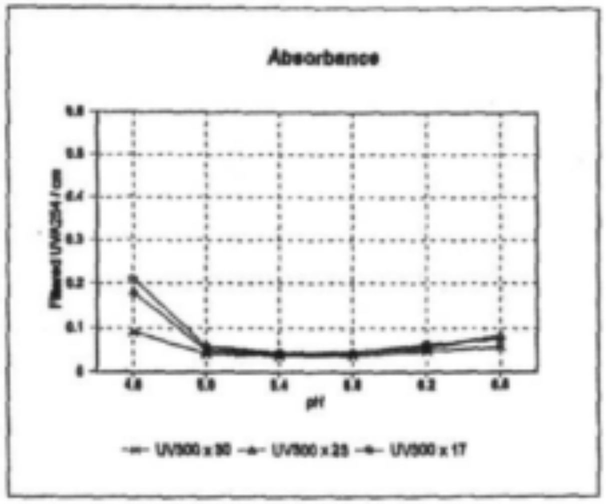

Turbidity

Aluminium Sulphate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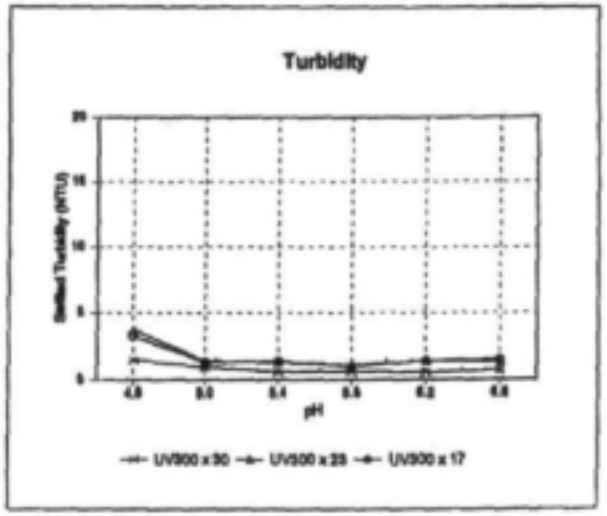
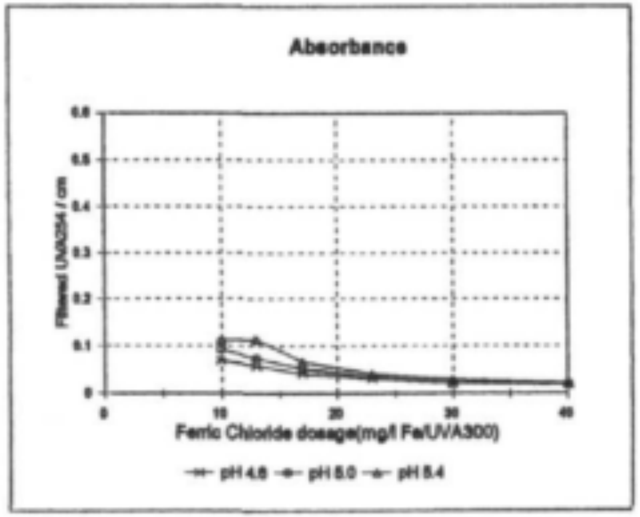
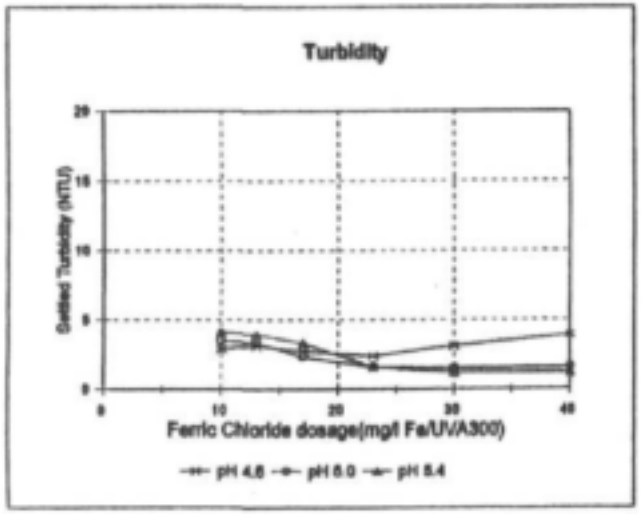

Turbidity

DUIVENHOKS RAW WATER

Dose Optimisation

Ferric Chloride





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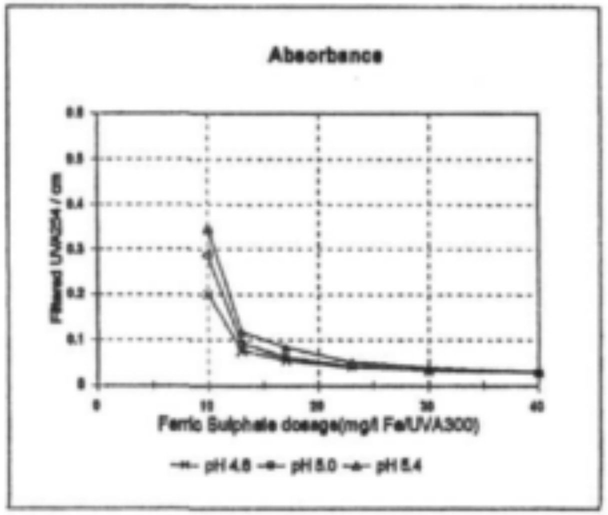
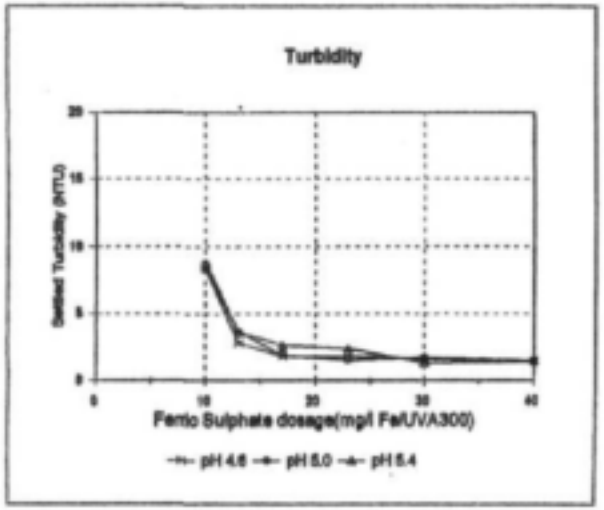
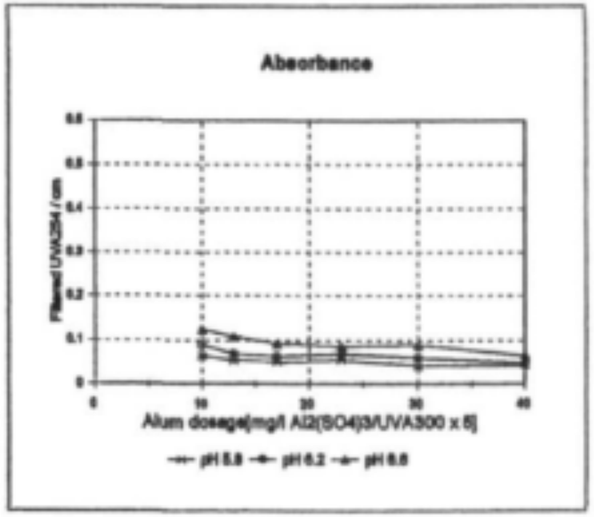
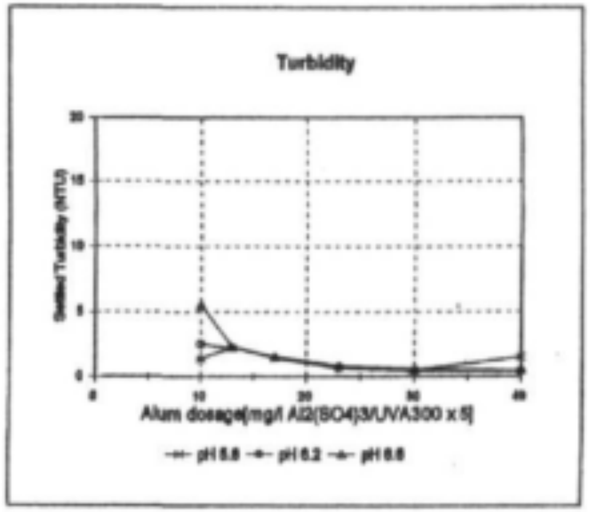




Aluminium Sulphate

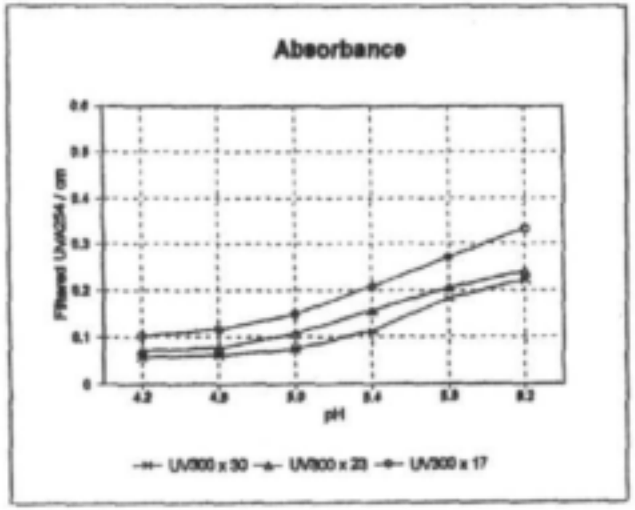


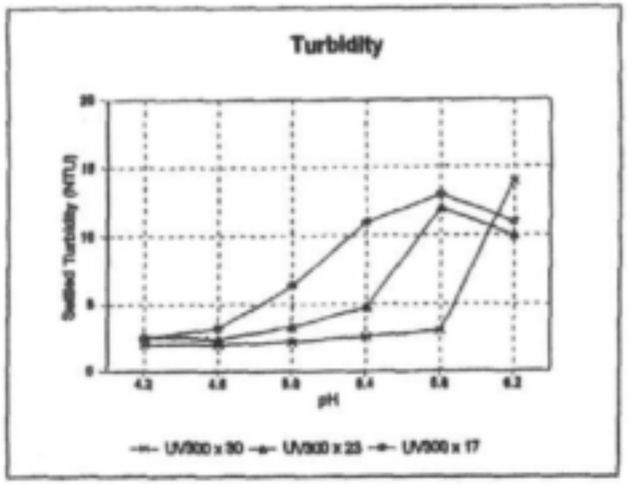


SEDGEFIELD RAW WATER

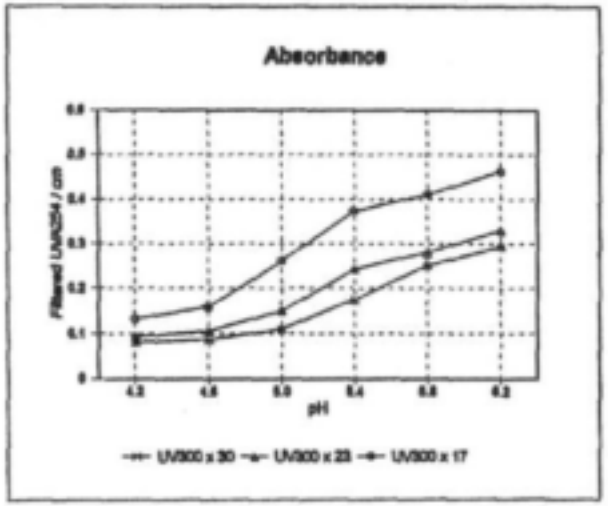
pH Optimisation

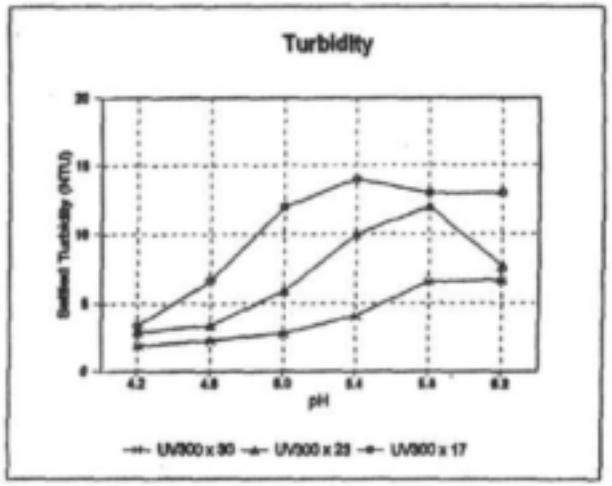
Ferric Chloride



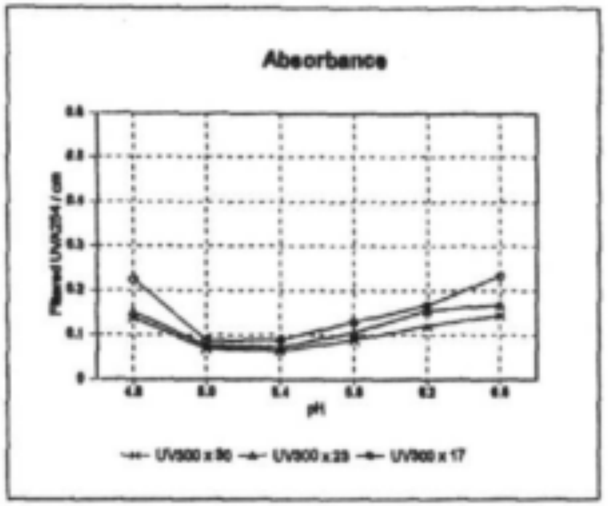


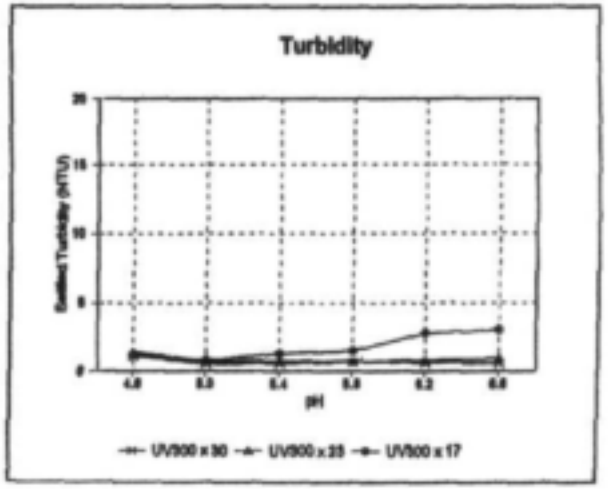
Ferric Sulphate





Aluminium Sulphate

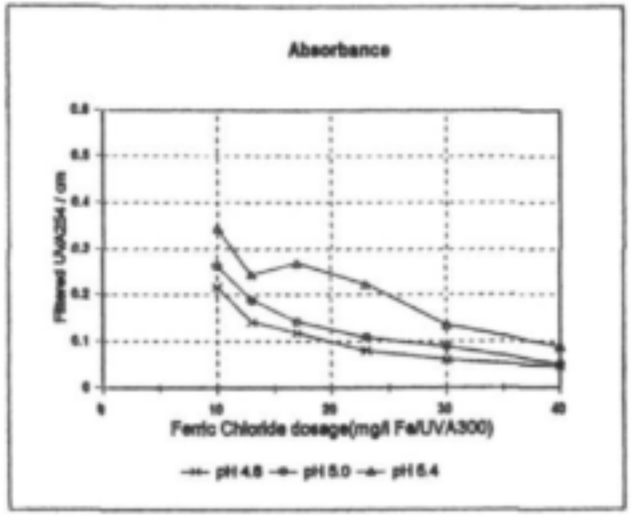


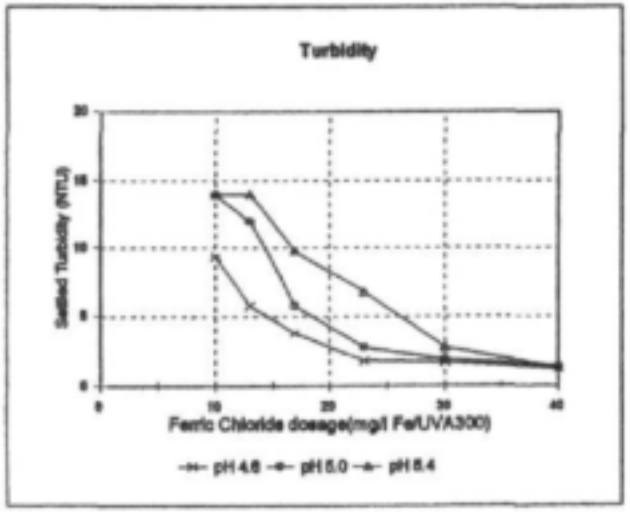


SEDGEFIELD RAW WATER

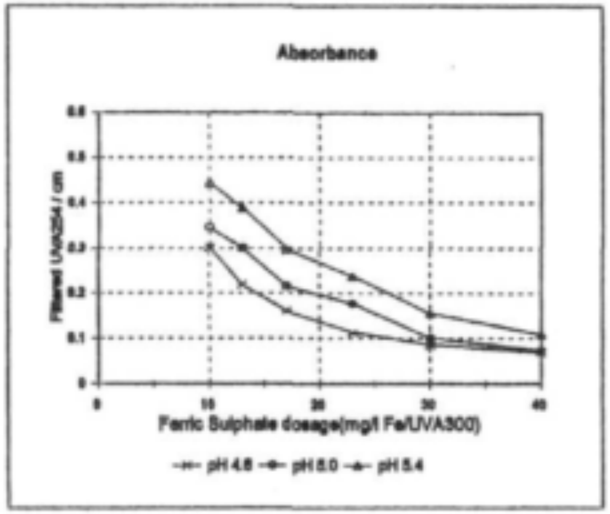
Dose Optimisation

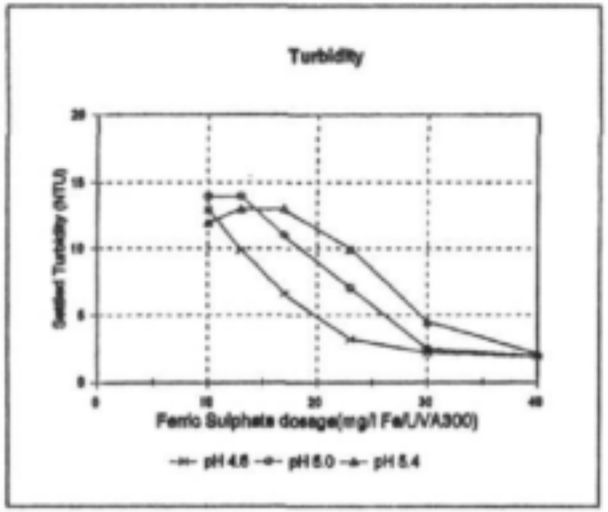
Ferric Chloride


Absorbance

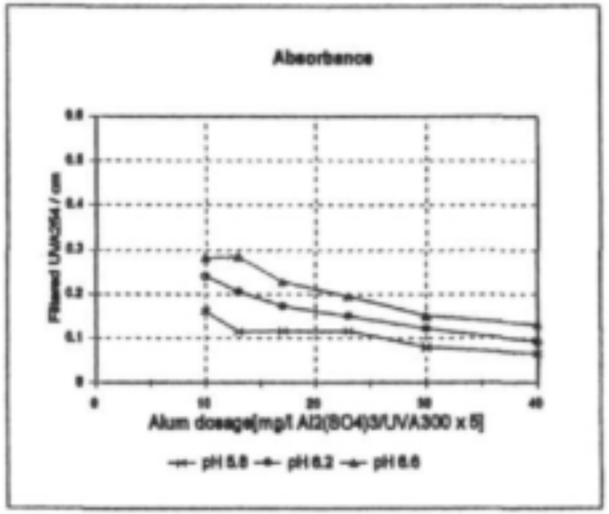

Turbidity

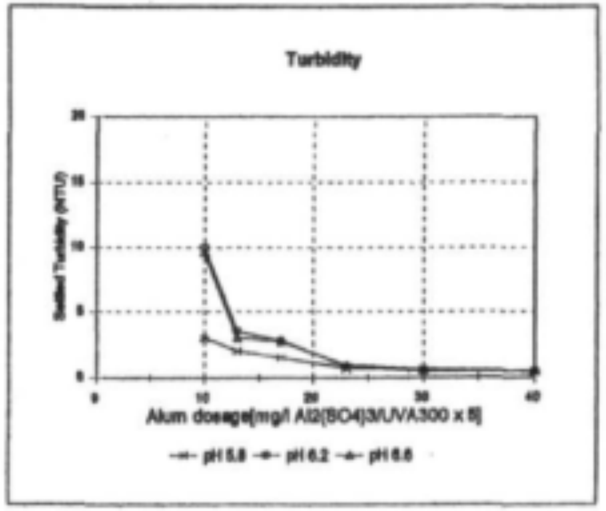
Ferric Sulphate


Absorbance


Turbidity

Aluminium Sulphate


Absorbance


Turbidity

APPENDIX E

ANALYTICAL RESULTS OF COAGULATION STUDIES

KLEINBRAK RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 30
Dosage	14.8 mg/l as Fe

pH	Turb	UV254
4.2	5.1	0.038
4.6	2.2	0.040
5.0	3.1	0.048
5.4	1.9	0.060
5.8	2.6	0.079
6.2	2.5	0.106

Set 2

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 23
Dosage	11.3 mg/l as Fe

pH	Turb	UV254
4.2	3.1	0.050
4.6	2.2	0.055
5.0	4.6	0.074
5.4	3.1	0.086
5.8	5.1	0.119
6.2	9.4	0.149

Set 3

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 17
Dosage	8.4 mg/l as Fe

pH	Turb	UV254
4.2	4.1	0.076
4.6	3.9	0.091
5.0	5.6	0.109
5.4	7.4	0.133
5.8	11	0.170
6.2	11	0.167

Dose Optimisation

Set 7

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 10
Dosage	4.9 mg/l as Fe

pH	Turb	UV254
4.6	28	0.458
5.0	27	0.505
5.4	27	0.620

Set 8

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 13
Dosage	6.4 mg/l as Fe

pH	Turb	UV254
4.6	30	0.212
5.0	30	0.278
5.4	30	0.429

Set 9

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 17
Dosage	8.4 mg/l as Fe

pH	Turb	UV254
4.6	4	0.093
5.0	5.6	0.124
5.4	9.8	0.147

Set 10

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 23
Dosage	11.3 mg/l as Fe

pH	Turb	UV254
4.6	3	0.066
5.0	3.9	0.078
5.4	4.4	0.087

Set 11

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 30
Dosage	14.8 mg/l as Fe

pH	Turb	UV254
4.6	2.2	0.043
5.0	1.9	0.050
5.4	2.6	0.064

Set 12

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 40
Dosage	19.7 mg/l as Fe

pH	Turb	UV254
4.6	2.6	0.033
5.0	1.9	0.040
5.4	2.2	0.049

KLEINBRAK RAW WATER

Coagulation with Ferric Sulphate

pH Optimisation

Set 4
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 14.8 mg/l as Fe

pH	Turb	UV254
4.2	3.9	0.057
4.6	3.5	0.056
5.0	4.7	0.067
5.4	3.5	0.091
5.8	4.8	0.146
6.2	6.2	0.169

Set 5
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 11.3 mg/l as Fe

pH	Turb	UV254
4.2	2.1	0.073
4.6	2.1	0.081
5.0	3.9	0.091
5.4	4.2	0.117
5.8	7.6	0.152
6.2	7.9	0.178

Set 6
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 8.4 mg/l as Fe

pH	Turbidity (NTU)	UV254
4.2	6.9	0.095
4.6	29.0	0.156
5.0	31.0	0.235
5.4	30.0	0.299
5.8	30.0	0.327
6.2	30.0	0.383

Dose Optimisation

Set 13
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 10
Dosage 4.9 mg/l as Fe

pH	Turb	UV254
4.6	21	0.593
5.0	21	0.608
5.4	21	0.695

Set 14
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 13
Dosage 6.4 mg/l as Fe

pH	Turb	UV254
4.6	23.0	0.483
5.0	23.0	0.602
5.4	23.0	0.663

Set 15
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 8.4 mg/l as Fe

pH	Turb	UV254
4.6	26	0.217
5.0	27	0.289
5.4	27	0.350

Set 16
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 11.3 mg/l as Fe

pH	Turb	UV254
4.6	3.6	0.072
5.0	5.1	0.089
5.4	8.3	0.119

Set 17
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 14.8 mg/l as Fe

pH	Turb	UV254
4.6	2.7	0.056
5.0	2.9	0.068
5.4	2.6	0.083

Set 18
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 40
Dosage 19.7 mg/l as Fe

pH	Turb	UV254
4.6	2.5	0.046
5.0	2.6	0.047
5.4	2.1	0.056

KLEINBRAK RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)
4,2	232	6	33	191	36	72			
4,6	74 (71)	7 (5)	27 (19)	91 (89)	37 (43)	25 (25)			
5,0	44 (37)	8 (5)	20 (13)	84 (84)	39 (34)	20 (18)	5	0.3	512
5,8							9	0.1	35
6,6							0	0	81

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

SANDHOOGTE RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 30
Dosage	48.3 mg/l as Fe

pH	Turb	UV254
4.2	2.0	0.042
4.6	1.7	0.050
5.0	1.9	0.060
5.4	2.5	0.080
5.8	2.7	0.147
6.2	3.2	0.245

Set 2

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 23
Dosage	37.0 mg/l as Fe

pH	Turb	UV254
4.2	2.4	0.067
4.6	3	0.081
5.0	4.7	0.105
5.4	11	0.169
5.8	12	0.228
6.2	12	0.289

Set 3

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 17
Dosage	27.4 mg/l as Fe

pH	Turb	UV254
4.2	2.8	0.119
4.6	4.5	0.143
5.0	4.7	0.157
5.4	14	0.237
5.8	13	0.335
6.2	8.6	0.407

Dose Optimisation

Set 7

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 10
Dosage	16.1 mg/l as Fe

pH	Turb	UV254
4.6	10	0.302
5.0	14	0.128
5.4	18	0.501

Set 8

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 13
Dosage	20.9 mg/l as Fe

pH	Turb	UV254
4.6	4.2	0.208
5.0	8.6	0.302
5.4	11	0.343

Set 9

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 17
Dosage	27.4 mg/l as Fe

pH	Turb	UV254
4.6	2.2	0.086
5.0	4.7	0.168
5.4	11	0.260

Set 10

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 23
Dosage	37.0 mg/l as Fe

pH	Turb	UV254
4.6	1.1	0.094
5.0	2.3	0.099
5.4	4.5	0.152

Set 11

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 30
Dosage	48.3 mg/l as Fe

pH	Turb	UV254
4.6	1.1	0.047
5.0	1.4	0.076
5.4	2.2	0.102

Set 12

Coag type	FeCl3 + Lime
Dosage formula	UV300 x 40
Dosage	64.4 mg/l as Fe

pH	Turb	UV254
4.6	0.65	0.029
5.0	0.79	0.040
5.4	1	0.063

SANDHOOGTE RAW WATER

Coagulation with Ferric Sulphate

pH Optimisation

Set 4
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 48.3 mg/l as Fe

pH	Turb	UV254
4.2	2.0	0.090
4.6	1.5	0.099
5.0	2.5	0.122
5.4	3.6	0.187
5.8	3.8	0.224
6.2	6.9	0.391

Set 5
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 37.0 mg/l as Fe

pH	Turb	UV254
4.2	1.5	0.110
4.6	2.5	0.130
5.0	6.1	0.157
5.4	15.0	0.218
5.8	16.0	0.265
6.2	10.0	0.349

Set 6
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 27.4 mg/l as Fe

pH	Turb	UV254
4.2	3.7	0.161
4.6	7.1	0.185
5.0	13.0	0.264
5.4	16.0	0.322
5.8	18.0	0.473
6.2	14.0	0.585

Dose Optimisation

Set 13
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 10
Dosage 16.1 mg/l as Fe

pH	Turb	UV254
4.6	16	0.476
5.0	16	0.740
5.4	16	0.697

Set 14
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 13
Dosage 20.9 mg/l as Fe

pH	Turb	UV254
4.6	15.0	0.322
5.0	16.0	0.376
5.4	17.0	0.453

Set 15
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 27.4 mg/l as Fe

pH	Turb	UV254
4.6	5.1	0.188
5.0	8.6	0.213
5.4	16	0.318

Set 16
Coag type Fe2(SO4)3 + Lime
Dosage formul UV300 x 23
Dosage 37.0 mg/l as Fe

pH	Turb	UV254
4.6	3.2	0.12
5.0	7.5	0.152
5.4	10.0	0.22

Set 17
Coag type Fe2(SO4)3 + Lime
Dosage formul UV300 x 30
Dosage 48.3 mg/l as Fe

pH	Turb	UV254
4.6	2.2	0.098
5.0	2.5	0.100
5.4	3.9	0.192

Set 18
Coag type Fe2(SO4)3 + Lime
Dosage formul UV300 x 40
Dosage 64.4 mg/l as Fe

pH	Turb	UV254
4.6	1.6	0.073
5.0	1.8	0.074
5.4	2.4	0.139

SANDHOOGTE RAW WATER

Coagulation with Aluminiun Sulphate

pH Optimisation

Set 19
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formula UV300 x 5 x 30
Dosage 241.5 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
4.6	1.40	0.213
5.0	0.66	0.101
5.4	0.74	0.076
5.8	0.92	0.084
6.2	1.10	0.133
6.6	1.00	0.160

Set 20
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formula UV300 x 5 x 23
Dosage 185.15 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
4.6	1.4	0.245
5.0	0.57	0.104
5.4	0.82	0.086
5.8	0.62	0.117
6.2	1.1	0.181
6.6	1.4	0.206

Set 21
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formula UV300 x 5 x 17
Dosage 136.85 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
4.6	1	0.255
5.0	0.62	0.118
5.4	1.2	0.108
5.8	1.5	0.194
6.2	1.7	0.235
6.6	1.4	0.287

Dose optimisation

Set 22
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formul UV300 x 5 x 10
Dosage 80.5 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
5.8	4.6	0.551
6.2	3.9	0.370
6.6	6.1	0.415

Set 23
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formul UV300 x 5 x 13
Dosage 104.65 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
5.8	2.6	0.219
6.2	0.8	0.31
6.6	2.4	0.374

Set 24
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formul UV300 x 5 x 17
Dosage 136.85 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
5.8	1.9	0.166
6.2	1.9	0.291
6.6	3	0.270

Set 25
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formula UV300 x 5 x 23
Dosage 185.15 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
5.8	1.6	0.125
6.2	1.5	0.169
6.6	1.5	0.222

Set 26
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formula UV300 x 5 x 30
Dosage 241.5 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
5.8	1.2	0.130
6.2	1.3	0.141
6.6	1.5	0.169

Set 27
Coag type $\mathrm{Al_2(SO_4)_3}$ + Lime
Dosage formula UV300 x 5 x 40
Dosage 322 mg/l as $\mathrm{Al_2(SO_4)_3}$

pH	Turb	UV254
5.8	0.9	0.111
6.2	0.8	0.121
6.6	0.8	0.138

SANDHOOGTE RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)
4,2	530	10	309	436	106	295	▨	▨	▨
4,6	377 (282)	9 (8)	152 (152)	298 (282)	99 (111)	149 (148)	▨	▨	▨
5,0	317 (212)	9 (7)	57 (51)	221 (204)	97 (110)	58 (56)	10	8	2 060
5,8	▨	▨	▨	▨	▨	▨	0	9	49
6,6	▨	▨	▨	▨	▨	▨	0	4	272

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

GEORGE RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 40.53mg/l as Fe

pH	Turb	UV254
4.2	14.0	0.033
4.6	3.0	0.032
5.0	1.3	0.041
5.4	1.4	0.091
5.8	1.1	0.194
6.2	1.2	0.249

Set 2
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 31.073mg/l as Fe

pH	Turb	UV254
4.2	5.6	0.050
4.6	1.4	0.068
5.0	1.4	0.063
5.4	1.8	0.104
5.8	2.9	0.236
6.2	2	0.300

Set 3
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 23.0mg/l as Fe

pH	Turb	UV254
4.2	2.5	0.070
4.6	2.4	0.096
5.0	2.5	0.099
5.4	5	0.183
5.8	5.3	0.331
6.2	7.7	0.427

Dose Optimisation

Set 7
Coag type FeCl3 + Lime
Dosage formula UV300 x 10
Dosage 13.51mg/l as Fe

pH	Turb	UV254
4.6	4.3	0.150
5.0	6.5	0.200
5.4	10	0.396

Set 8
Coag type FeCl3 + Lime
Dosage formula UV300 x 13
Dosage 17.60mg/l as Fe

pH	Turb	UV254
4.6	2	0.109
5.0	3.1	0.182
5.4	4.5	0.217

Set 9
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 23.0mg/l as Fe

pH	Turb	UV254
4.6	1.4	0.087
5.0	1.7	0.095
5.4	4.2	0.159

Set 10
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 31.073mg/l as Fe

pH	Turb	UV254
4.6	1.8	0.059
5.0	1.9	0.074
5.4	2.1	0.141

Set 11
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 40.53mg/l as Fe

pH	Turb	UV254
4.6	2.5	0.041
5.0	1.2	0.053
5.4	1.3	0.098

Set 12
Coag type FeCl3 + Lime
Dosage formula UV300 x 40
Dosage 54.04mg/l as Fe

pH	Turb	UV254
4.6	1	0.023
5.0	1.5	0.024
5.4	1.3	0.090

GEORGE RAW WATER

Coagulation with Ferric Sulphate

pH Optimisation

Set 4
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 40.53mg/l as Fe

pH	Turb	UV254
4.2	2.1	0.085
4.6	1.7	0.077
5.0	1.8	0.079
5.4	2.0	0.137
5.8	2.7	0.289
6.2	2.0	0.33

Set 5
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 31.073mg/l as Fe

pH	Turb	UV254
4.2	2.4	0.097
4.6	2.2	0.098
5.0	2.3	0.114
5.4	3.4	0.221
5.8	3.4	0.352
6.2	3.8	0.415

Set 6
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 23.0mg/l as Fe

pH	Turb	UV254
4.2	2.8	0.108
4.6	2.5	0.125
5.0	3.3	0.139
5.4	5.3	0.24
5.8	6.0	0.399
6.2	6.0	0.507

Dose Optimisation

Set 13
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 10
Dosage 13.51mg/l as Fe

pH	Turb	UV254
4.6	7	0.235
5.0	9	0.338
5.4	10	0.492

Set 14
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 13
Dosage 17.56mg/l as Fe

pH	Turb	UV254
4.6	4.7	0.167
5.0	7.5	0.22
5.4	9.9	0.393

Set 15
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 23.0mg/l as Fe

pH	Turb	UV254
4.6	2	0.119
5.0	3.6	0.147
5.4	5.5	0.252

Set 16
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 31.073mg/l as Fe

pH	Turb	UV254
4.6	2.5	0.096
5.0	2.3	0.107
5.4	2.7	0.176

Set 17
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 40.53mg/l as Fe

pH	Turb	UV254
4.6	1.4	0.084
5.0	1.5	0.075
5.4	1.5	0.098

Set 18
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 40
Dosage 54.04mg/l as Fe

pH	Turb	UV254
4.6	1.4	0.059
5.0	1.2	0.064
5.4	1.4	0.103

GEORGE RAW WATER

Coagulation with Aluminium Sulphate

pH Optimisation

Set 19
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 202.7mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.00	0.246
5.0	0.59	0.115
5.4	0.60	0.090
5.8	0.70	0.121
6.2	0.58	0.175
6.6	0.69	0.158

Set 20
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 23
Dosage 155.37mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	0.74	0.238
5.0	0.43	0.102
5.4	0.56	0.069
5.8	0.6	0.138
6.2	0.55	0.204
6.6	0.69	0.235

Set 21
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 114.84mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.5	0.280
5.0	1	0.109
5.4	1.3	0.095
5.8	1.4	0.162
6.2	1.2	0.234
6.6	1.4	0.286

Dose Optimisation

Set 22
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 10
Dosage 67.55 mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.97	0.149
6.2	1.7	0.220
6.6	2.4	0.357

Set 23
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 13
Dosage 87.82mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.7	0.135
6.2	1.1	0.228
6.6	1.7	0.3

Set 24
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 114.84mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.4	0.108
6.2	1.5	0.202
6.6	1.5	0.270

Set 25
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 155.37mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.7	0.198
6.2	0.7	0.232
6.6	0.9	0.243

Set 26
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 202.65mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.56	0.109
6.2	0.51	0.162
6.6	0.75	0.213

Set 27
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 40
Dosage 270.2mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.8	0.082
6.2	0.5	0.136
6.6	0.7	0.166

GEORGE RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)
4,2	202	44	244	380	131	244			
4,6	122 (104)	43 (49)	146 (224)	171 (154)	128 (123)	179 (177)			
5,0	73 (65)	43 (43)	65 (74)	79 (103)	126 (126)	77 (85)	111	48	-
5,8							84 (31)	35 (37)	74 (69)
6,6							38 (35)	21 (12)	317 (-)

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

PLETTENBERG BAY RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 7.89mg/l as Fe

pH	Turb	UV254
4.2	2.7	0.000
4.6	1.7	0.001
5.0	1.6	0.018
5.4	3.4	0.103
5.8	6.4	0.166
6.2	7.9	0.196

Set 2
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 6.05mg/l as Fe

pH	Turb	UV254
4.2	4	0.004
4.6	2.6	0.009
5.0	2.9	0.044
5.4	4.7	0.112
5.8	6.1	0.159
6.2	6.4	0.162

Set 3
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 4.47mg/l as Fe

pH	Turb	UV254
4.2	2.8	0.020
4.6	3.1	0.025
5.0	4.2	0.058
5.4	5.4	0.102
5.8	4.9	0.131
6.2	5.3	0.164

Dose Optimisation

Set 7
Coag type FeCl3 + Lime
Dosage formula UV300 x 10
Dosage 2.63mg/l as Fe

pH	Turb	UV254
4.6	5	0.371
5.0	4.2	0.432
5.4	4	0.435

Set 8
Coag type FeCl3 + Lime
Dosage formula UV300 x 13
Dosage 3.42mg/l as Fe

pH	Turb	UV254
4.6	3.3	0.04
5.0	4.7	0.086
5.4	6.3	0.136

Set 9
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 4.47mg/l as Fe

pH	Turb	UV254
4.6	3.1	0.024
5.0	4.4	0.046
5.4	5.8	0.094

Set 10
Coag type FeCl3 + Lime
Dosage formul UV300 x 23
Dosage 6.05mg/l as Fe

pH	Turb	UV254
4.6	2.4	0.014
5.0	2.3	0.025
5.4	4.1	0.078

Set 11
Coag type FeCl3 + Lime
Dosage formul UV300 x 30
Dosage 7.89mg/l as Fe

pH	Turb	UV254
4.6	1.6	0.005
5.0	1.5	0.013
5.4	2	0.048

Set 12
Coag type FeCl3 + Lime
Dosage formul UV300 x 40
Dosage 10.52mg/l as Fe

pH	Turb	UV254
4.6	1.5	0.000
5.0	1	0.002
5.4	1.5	0.038

PLETTENBERG BAY RAW WATER

Coagulation with Ferric Sulphate

pH Optimisation

Set 4

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 30
Dosage	7.89mg/l as Fe

pH	Turb	UV254
4.2	2.3	0.015
4.6	1.8	0.02
5.0	2.3	0.032
5.4	5.5	0.095
5.8	6.8	0.13
6.2	5.9	0.155

Set 5

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 23
Dosage	6.05mg/l as Fe

pH	Turb	UV254
4.2	2.6	0.022
4.6	2.8	0.032
5.0	3.8	0.081
5.4	5.2	0.137
5.8	5.2	0.156
6.2	5.8	0.178

Set 6

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 17
Dosage	4.47mg/l as Fe

pH	Turb	UV254
4.2	2.4	0.053
4.6	4.0	0.067
5.0	4.6	0.106
5.4	5.3	0.152
5.8	4.7	0.193
6.2	4.5	0.197

Dose Optimisation

Set 13

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 10
Dosage	2.63mg/l as Fe

pH	Turb	UV254
4.6	3.5	0.342
5.0	3	0.407
5.4	2.7	0.441

Set 14

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 13
Dosage	3.42mg/l as Fe

pH	Turb	UV254
4.6	5.4	0.166
5.0	5.0	0.243
5.4	4.2	0.361

Set 15

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 17
Dosage	4.7mg/l as Fe

pH	Turb	UV254
4.6	2.9	0.056
5.0	6.5	0.082
5.4	5.5	0.135

Set 16

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 23
Dosage	6.05mg/l as Fe

pH	Turb	UV254
4.6	2.4	0.02
5.0	3.1	0.039
5.4	5.8	0.101

Set 17

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 30
Dosage	7.89mg/l as Fe

pH	Turb	UV254
4.6	1.9	0.014
5.0	2.2	0.026
5.4	4.3	0.088

Set 18

Coag type	Fe2(SO4)3 + Lime
Dosage formula	UV300 x 40
Dosage	10.52mg/l as Fe

pH	Turb	UV254
4.6	1.8	0.006
5.0	1.5	0.013
5.4	2.6	0.048

PLETTENBERG BAY RAW WATER

Coagulation with Aluminium Sulphate

pH Optimisation

Set 19
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 39.45mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	2.10	0.087
5.0	1.50	0.004
5.4	0.69	0.006
5.8	0.67	0.021
6.2	0.76	0.031
6.6	0.84	0.053

Set 20
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 23
Dosage 30.25mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.8	0.105
5.0	1.3	0.013
5.4	0.54	0.009
5.8	0.5	0.026
6.2	1.7	0.043
6.6	4	0.067

Set 21
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 22.36mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.8	0.128
5.0	1.6	0.027
5.4	1.4	0.015
5.8	1.5	0.040
6.2	4.4	0.064
6.6	4.1	0.099

Dose Optimisation

Set 22
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 10
Dosage 13.15mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	3	0.050
6.2	4.2	0.102
6.6	3.7	0.170

Set 23
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 13
Dosage 17.10mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.7	0.03
6.2	4.5	0.077
6.6	3.8	0.133

Set 24
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 22.36mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.2	0.024
6.2	2.8	0.053
6.6	4.3	0.095

Set 25
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 30.25mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.7	0.013
6.2	0.9	0.046
6.6	0.8	0.059

Set 26
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 39.45mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.58	0.008
6.2	0.63	0.027
6.6	0.79	0.057

Set 27
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 40
Dosage 52.6mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.7	0.011
6.2	0.6	0.024
6.6	0.5	0.042

PLETTENBERG BAY RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)
4,2	177	2	120	211	8	203			
4,6	83 (187)	2 (2)	102 (344)	86 (137)	10 (7)	72 (87)			
5,0	133 (103)	2 (2)	75 (70)	80 (79)	11 (8)	198 (60)	39	2	1 730
5,8							38 (35)	2 (1)	596 (709)
6,6							43 (40)	1 (1)	1 220 (1 033)

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

PORT ELIZABETH RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 7.1 mg/l as Fe

pH	Turb	UV254
4.2	15.0	0.033
4.6	5.0	0.031
5.0	5.0	0.035
5.4	4.0	0.052
5.8	3.0	0.081
6.2	3.0	0.127

Set 2
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 5.4 mg/l as Fe

pH	Turb	UV254
4.2	7.2	0.042
4.6	7.3	0.044
5.0	7.4	0.050
5.4	7.8	0.072
5.8	5	0.114
6.2	4	0.163

Set 3
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 3.9 mg/l as Fe

pH	Turb	UV254
4.2	3.5	0.071
4.6	8.5	0.046
5.0	9.2	0.066
5.4	12	0.075
5.8	9	0.121
6.2	8.7	0.153

Dose Optimisation

Set 7
Coag type FeCl3 + Lime
Dosage formula UV300 x 10
Dosage 2.4 mg/l as Fe

pH	Turb	UV254
4.6	17	0.138
5.0	18	0.160
5.4	17	0.248

Set 8
Coag type FeCl3 + Lime
Dosage formula UV300 x 13
Dosage 3.1 mg/l as Fe

pH	Turb	UV254
4.6	17	0.271
5.0	17	0.08
5.4	18	0.109

Set 9
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 3.9 mg/l as Fe

pH	Turb	UV254
4.6	6	0.052
5.0	6.5	0.059
5.4	9.7	0.087

Set 10
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 5.4 mg/l as Fe

pH	Turb	UV254
4.6	6.2	0.042
5.0	4.5	0.050
5.4	8.4	0.050

Set 11
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 7.1 mg/l as Fe

pH	Turb	UV254
4.6	4.5	0.039
5.0	3.7	0.049
5.4	5.4	0.081

Set 12
Coag type FeCl3 + Lime
Dosage formula UV300 x 40
Dosage 9.4 mg/l as Fe

pH	Turb	UV254
4.6	5.4	0.032
5.0	2.2	0.034
5.4	1.7	0.057

PORT ELIZABETH RAW WATER

Coagulation with Ferric Sulphate

pH Optimisation

Set 4		
Coag type	Fe2(SO4)3 + Lime	
Dosage formula	UV300 x 30	
Dosage	7.1 mg/l as Fe	
pH	Turb	UV254
4.2	7.6	0.047
4.6	6.0	0.042
5.0	5.8	0.051
5.4	5.5	0.078
5.8	4.8	0.099
6.2	6.2	0.143

Set 5		
Coag type	Fe2(SO4)3 + Lime	
Dosage formula	UV300 x 23	
Dosage	5.4 mg/l as Fe	
pH	Turb	UV254
4.2	6.7	0.051
4.6	6.5	0.045
5.0	6.9	0.059
5.4	7.9	0.086
5.8	7.8	0.126
6.2	6.1	0.166

Set 6		
Coag type	Fe2(SO4)3 + Lime	
Dosage formula	UV300 x 17	
Dosage	3.9 mg/l as Fe	
pH	Turb	UV254
4.2	4.7	0.071
4.6	5.6	0.066
5.0	10.0	0.08
5.4	14.0	0.104
5.8	11.0	0.137
6.2	11.0	0.155

Dose Optimisation

Set 13		
Coag type	Fe2(SO4)3 + Lime	
Dosage formula	UV300 x 10	
Dosage	2.4 mg/l as Fe	
pH	Turb	UV254
4.6	16	0.306
5.0	17	0.336
5.4	18	0.359

Set 14		
Coag type	Fe2(SO4)3 + Lime	
Dosage formula	UV300 x 13	
Dosage	3.1 mg/l as Fe	
pH	Turb	UV254
4.6	16.0	0.257
5.0	15.0	0.282
5.4	15.0	0.347

Set 15		
Coag type	Fe2(SO4)3 + Lime	
Dosage formula	UV300 x 17	
Dosage	3.9 mg/l as Fe	
pH	Turb	UV254
4.6	5.3	0.059
5.0	8.3	0.073
5.4	13	0.109

Set 16		
Coag type	Fe2(SO4)3 + Lime	
Dosage formul	UV300 x 23	
Dosage	5.4 mg/l as Fe	
pH	Turb	UV254
4.6	5.7	0.051
5.0	6.7	0.057
5.4	8.9	0.092

Set 17		
Coag type	Fe2(SO4)3 + Lime	
Dosage formul	UV300 x 30	
Dosage	7.1 mg/l as Fe	
pH	Turb	UV254
4.6	7.9	0.039
5.0	7.3	0.053
5.4	7	0.075

Set 18		
Coag type	Fe2(SO4)3 + Lime	
Dosage formul	UV300 x 40	
Dosage	9.4 mg/l as Fe	
pH	Turb	UV254
4.6	6.1	0.033
5.0	5.2	0.039
5.4	4.0	0.063

PORT ELIZABETH RAW WATER

Coagulation with Aluminium Sulphate

pH Optimisation

Set 19
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 35.25 mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	4.40	0.115
5.0	5.60	0.054
5.4	2.70	0.038
5.8	1.60	0.059
6.2	1.00	0.103
6.6	0.80	0.109

Set 20
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 23
Dosage 27.0 mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	3.4	0.137
5.0	4.5	0.076
5.4	3.5	0.046
5.8	1.5	0.058
6.2	1.0	0.089
6.6	0.67	0.115

Set 21
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 19.9 mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	3.5	0.120
5.0	4.3	0.103
5.4	5.3	0.052
5.8	2.2	0.069
6.2	1.8	0.101
6.6	1.6	0.125

Dose Optimisation

Set 22
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 10
Dosage 11.8 mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	7	0.072
6.2	6.9	0.098
6.6	9.4	0.135

Set 23
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 13
Dosage 15.3 mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	5.2	0.063
6.2	3.2	0.088
6.6	7.2	0.139

Set 24
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 19.9 mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	4	0.051
6.2	2.4	0.086
6.6	1.4	0.124

Set 25
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 23
Dosage 27.0 mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	2.4	0.08
6.2	1.8	0.095
6.6	1.2	0.138

Set 26
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 35.2 mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.8	0.053
6.2	1.3	0.078
6.6	1.2	0.104

Set 27
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 40
Dosage 47 mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.5	0.049
6.2	1.3	0.048
6.6	1.0	0.086

PORT ELIZABETH RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)
4,2	252	1.54	210	302	16	36			
4,6	170 (69)	2 (2)	60 (121)	96 (348)	16 (22)	41 (83)			
5,0	46 (50)	0.7 (1)	44 (25)	54 (58)	16 (22)	28 (77)	11	4	2195
5,8							6 (3)	4 (4)	182 (67)
6,6							7 (4)	2 0.6	591 (267)

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

SWELLENDAM RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 7.8 mg/l as Fe

pH	Turb	UV254
4.2	5.1	0.027
4.6	1.3	0.038
5.0	1.4	0.033
5.4	1.6	0.085
5.8	1.9	0.116
6.2	4.2	0.143

Set 2
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 5.98mg/l as Fe

pH	Turb	UV254
4.2	5.4	0.033
4.6	1.4	0.032
5.0	2	0.060
5.4	2.5	0.102
5.8	3	0.133
6.2	6.8	0.119

Set 3
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 4.42mg/l as Fe

pH	Turb	UV254
4.2	3.7	0.037
4.6	2.2	0.043
5.0	3	0.059
5.4	3.4	0.098
5.8	5	0.109
6.2	5	0.155

Dose Optimisation

Set 7
Coag type FeCl3 + Lime
Dosage formula UV300 x 10
Dosage 2.6mg/l as Fe

pH	Turb	UV254
4.6	3.3	0.070
5.0	4.4	0.111
5.4	5.2	0.137

Set 8
Coag type FeCl3 + Lime
Dosage formula UV300 x 13
Dosage 3.38mg/l as Fe

pH	Turb	UV254
4.6	3	0.046
5.0	3.3	0.071
5.4	4.2	0.116

Set 9
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 4.42mg/l as Fe

pH	Turb	UV254
4.6	2.4	0.039
5.0	2.7	0.047
5.4	3.8	0.099

Set 10
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 5.98mg/l as Fe

pH	Turb	UV254
4.6	1.5	0.022
5.0	1.8	0.036
5.4	3	0.077

Set 11
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 7.8mg/l as Fe

pH	Turb	UV254
4.6	1.5	0.022
5.0	1.8	0.036
5.4	3	0.077

Set 12
Coag type FeCl3 + Lime
Dosage formula UV300 x 40
Dosage 10.40mg/l as Fe

pH	Turb	UV254
4.6	1.7	0.012
5.0	0.78	0.017
5.4	0.75	0.029

SWELLENDAM RAW WATER

Coagulation with Ferric Sulphate

pH Optimisation

Set 4
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 7.8mg/l as Fe

pH	Turb	UV254
4.2	2.5	0.034
4.6	1.9	0.034
5.0	1.8	0.044
5.4	3.4	0.088
5.8	5.8	0.134
6.2	5.6	0.162

Set 5
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 5.98mg/l as Fe

pH	Turb	UV254
4.2	2.7	0.04
4.6	2.3	0.04
5.0	2.3	0.051
5.4	3.3	0.1
5.8	5.0	0.16
6.2	5.4	0.163

Set 6
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 4.42mg/l as Fe

pH	Turb	UV254
4.2	2.3	0.048
4.6	2.8	0.053
5.0	3.6	0.085
5.4	4.5	0.131
5.8	3.5	0.194
6.2	4.5	0.183

Dose Optimisation

Set 13
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 10
Dosage 2.6mg/l as Fe

pH	Turb	UV254
4.6	3.6	0.083
5.0	5.4	0.105
5.4	6.1	0.168

Set 14
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 13
Dosage 3.38mg/l as Fe

pH	Turb	UV254
4.6	2.8	0.065
5.0	3.6	0.084
5.4	5.9	0.138

Set 15
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 4.42mg/l as Fe

pH	Turb	UV254
4.6	2.9	0.049
5.0	3.6	0.082
5.4	5.5	0.120

Set 16
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 5.98mg/l as Fe

pH	Turb	UV254
4.6	1.5	0.045
5.0	2.3	0.055
5.4	4.4	0.11

Set 17
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 7.8mg/l as Fe

pH	Turb	UV254
4.6	1.4	0.025
5.0	1.5	0.038
5.4	3.6	0.067

Set 18
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 40
Dosage 10.40mg/l as Fe

pH	Turb	UV254
4.6	1.4	0.017
5.0	1.1	0.019
5.4	1.6	0.044

SWELLENDAM RAW WATER

Coagulation with Aluminium Sulphate

pH optimisation

Set 19
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 39.0 mg/L as Al2(SO4)3

pH	Turb	UV254
4.6	1.70	0.083
5.0	2.50	0.025
5.4	0.60	0.022
5.8	0.56	0.033
6.2	0.60	0.046
6.6	0.76	0.057

Set 20
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 23
Dosage 29.9 mg/L as Al2(SO4)3

pH	Turb	UV254
4.6	1.5	0.048
5.0	2.3	0.022
5.4	0.75	0.023
5.8	0.77	0.041
6.2	1.1	0.045
6.6	2.4	0.072

Set 21
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 22.1mg/L as Al2(SO4)3

pH	Turb	UV254
4.6	1.9	0.146
5.0	2	0.040
5.4	2.1	0.024
5.8	1.5	0.035
6.2	2.2	0.059
6.6	5	0.093

Dose Optimisation

Set 22
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 10
Dosage 13.0mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	2.1	0.046
6.2	5.2	0.086
6.6	4.6	0.124

Set 23
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 13
Dosage 16.9mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	2.0	0.045
6.2	2.5	0.07
6.6	5.0	0.109

Set 24
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 22.1mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.2	0.032
6.2	1.5	0.053
6.6	4.2	0.080

Set 25
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 29.9mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.7	0.029
6.2	0.7	0.037
6.6	0.8	0.077

Set 26
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 39.0mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.62	0.026
6.2	0.58	0.050
6.6	0.59	0.056

Set 27
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 40
Dosage 52.0mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.5	0.031
6.2	0.5	0.040
6.6	0.6	0.047

SWELLENDAM RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)
4,2	161	2	283	180	8	203			
4,6	66 (90)	3 (4)	298 (106)	84 (71)	13 (13)	87 (264)			
5,0	66 (50)	6 (4)	410 (78)	78 (67)	15 (13)	90 (64)	38	9	2 792
5,8							20 (17)	8 (8)	563 (681)
6,6							202 (22)	11 (10)	1 141 (503)

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

SIMONS TOWN RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 17.25mg/l as Fe

pH	Turb	UV254
4.2	1.7	0.062
4.6	1.4	0.072
5.0	2.4	0.101
5.4	4.2	0.196
5.8	3.7	0.295
6.2	3.4	0.332

Set 2
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 13.23mg/l as Fe

pH	Turb	UV254
4.2	2.8	0.075
4.6	3.1	0.097
5.0	6.2	0.155
5.4	9.1	0.252
5.8	8.6	0.371
6.2	8	0.422

Set 3
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 9.78mg/l as Fe

pH	Turb	UV254
4.2	3	0.111
4.6	7.3	0.155
5.0	11	0.242
5.4	12	0.353
5.8	8.1	0.460
6.2	7	0.515

Dose optimisation

Set 7
Coag type FeCl3 + Lime
Dosage formula UV300 x 10
Dosage 5.75mg/l as Fe

pH	Turb	UV254
4.6	12	0.383
5.0	11	0.486
5.4	8.3	0.803

Set 8
Coag type FeCl3 + Lime
Dosage formula UV300 x 13
Dosage 7.48mg/l as Fe

pH	Turb	UV254
4.6	8.6	0.201
5.0	12	0.305
5.4	10	0.461

Set 9
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 9.78mg/l as Fe

pH	Turb	UV254
4.6	6.7	0.148
5.0	12	0.225
5.4	12	0.350

Set 10
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 13.23mg/l as Fe

pH	Turb	UV254
4.6	2.9	0.093
5.0	5.6	0.149
5.4	8.1	0.265

Set 11
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 17.25mg/l as Fe

pH	Turb	UV254
4.6	2.1	0.071
5.0	2.7	0.094
5.4	5.6	0.188

Set 12
Coag type FeCl3 + Lime
Dosage formula UV300 x 40
Dosage 23.0mg/l as Fe

pH	Turb	UV254
4.6	2	0.037
5.0	2.1	0.055
5.4	2.6	0.133

SIMONS TOWN RAW WATER

Coagulation with Ferric Sulphate

pH optimisation

Set 4
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 30
Dosage 17.25mg/l as Fe

pH	Turb	UV254
4.2	2.6	0.069
4.6	3.4	0.094
5.0	5.8	0.144
5.4	10.0	0.287
5.8	6.5	0.328
6.2	7.1	0.395

Set 5
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 23
Dosage 13.23mg/l as Fe

pH	Turb	UV254
4.2	4.3	0.094
4.6	7.5	0.136
5.0	10.0	0.208
5.4	11.0	0.37
5.8	9.8	0.422
6.2	5.4	0.584

Set 6
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 17
Dosage 9.78mg/l as Fe

pH	Turb	UV254
4.2	5.2	0.139
4.6	11.0	0.196
5.0	13.0	0.26
5.4	10.0	0.432
5.8	9.5	0.503
6.2	7.2	0.528

Dose optimisation

Set 13
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 10
Dosage 5.75mg/l as Fe

pH	Turb	UV254
4.6	5.4	1.026
5.0	4.6	1.093
5.4	4.1	1.107

Set 14
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 13
Dosage 7.48mg/l as Fe

pH	Turb	UV254
4.6	12.0	0.253
5.0	11.0	0.335
5.4	9.2	0.539

Set 15
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 17
Dosage 9.78mg/l as Fe

pH	Turb	UV254
4.6	8.7	0.175
5.0	13	0.239
5.4	11	0.397

Set 16
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 23
Dosage 13.23mg/l as Fe

pH	Turb	UV254
4.6	5.5	0.109
5.0	11.0	0.17
5.4	13.0	0.3

Set 17
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 30
Dosage 17.25mg/l as Fe

pH	Turb	UV254
4.6	2.9	0.093
5.0	3.9	0.128
5.4	9.3	0.271

Set 18
Coag type $Fe_2(SO_4)_3$ + Lime
Dosage formula UV300 x 40
Dosage 23.0mg/l as Fe

pH	Turb	UV254
4.6	2.0	0.068
5.0	2.7	0.094
5.4	3.7	0.186

SIMONS TOWN RAW WATER

Coagulation with Aluminium Sulphate

pH Optimisation

Set 19
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 86.25mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.40	0.138
5.0	0.68	0.054
5.4	0.79	0.081
5.8	0.63	0.128
6.2	0.68	0.152
6.6	0.64	0.198

Set 20
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 23
Dosage 66.13mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.8	0.212
5.0	1.1	0.071
5.4	1.2	0.099
5.8	1	0.017
6.2	0.8	0.209
6.6	2	0.223

Set 21
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 48.90mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	2	0.261
5.0	1.4	0.102
5.4	1.5	0.120
5.8	2.1	0.200
6.2	2.4	0.263
6.6	2.5	0.302

Dose Optimisation

Set 22
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 10
Dosage 28.75mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	7.4	0.230
6.2	8.2	0.334
6.6	6.9	0.425

Set 23
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 13
Dosage 37.38mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	2.6	0.161
6.2	4.0	0.257
6.6	7.3	0.322

Set 24
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 49.0mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.9	0.143
6.2	2.3	0.238
6.6	1.6	0.303

Set 25
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 66.13mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.3	0.141
6.2	1.6	0.195
6.6	2.9	0.244

Set 26
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 86.25mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.1	0.104
6.2	0.83	missing
6.6	0.64	0.190

Set 27
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 40
Dosage 115.0mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.7	0.081
6.2	0.6	0.129
6.6	0.6	0.164

SIMONS TOWN RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)
4,2	128	3	186	220	15	121			
4,6	80 (80)	4 (2)	204 (94)	133 (157)	20 (14)	81 (281)			
5,0	79 (75)	4 (2)	72 (77)	278 (107)	23 (21)	61 (93)	33	4	737
5,8							32 (37)	3 (2)	469 (839)
6,6							32 (50)	2 (5)	1 390 (959)

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

KNYSNA RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 14.64 mg/l as Fe

pH	Turb	UV254
4.2	7.0	0.015
4.6	2.5	0.011
5.0	1.4	0.010
5.4	0.9	0.017
5.8	0.8	0.034
6.2	0.9	0.051

Set 2
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 11.22mg/l as Fe

pH	Turb	UV254
4.2	6.4	0.013
4.6	2.4	0.012
5.0	1.3	0.012
5.4	0.81	0.022
5.8	0.76	0.039
6.2	0.66	0.048

Set 3
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 8.30mg/l as Fe

pH	Turb	UV254
4.2	5.8	0.016
4.6	1.8	0.013
5.0	1.1	0.015
5.4	0.9	0.025
5.8	1.2	0.048
6.2	1.4	0.057

Dose Optimisation

Set 7
Coag type FeCl3 + Lime
Dosage formul UV300 x 10
Dosage 4.88mg/l as Fe

pH	Turb	UV254
4.6	2.2	0.032
5.0	1.6	0.025
5.4	2.1	0.034

Set 8
Coag type FeCl3 + Lime
Dosage formul UV300 x 13
Dosage 6.34mg/l as Fe

pH	Turb	UV254
4.6	2	0.017
5.0	1.5	0.023
5.4	2	0.027

Set 9
Coag type FeCl3 + Lime
Dosage formul UV300 x 17
Dosage 8.30mg/l as Fe

pH	Turb	UV254
4.6	1.8	0.015
5.0	1.3	0.015
5.4	0.87	0.025

Set 10
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 11.22mg/l as Fe

pH	Turb	UV254
4.6	3	0.017
5.0	1.6	0.013
5.4	1	0.014

Set 11
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 14.64mg/l as Fe

pH	Turb	UV254
4.6	7.1	0.016
5.0	1.9	0.013
5.4	0.99	0.020

Set 12
Coag type FeCl3 + Lime
Dosage formula UV300 x 40
Dosage 19.52mg/l as Fe

pH	Turb	UV254
4.6	8.5	0.013
5.0	3.8	0.015
5.4	1.1	0.015

KNYSNA RAW WATER

Coagulation with Ferric Sulphate

pH Optimisation

Set 4

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 30
Dosage	14.64mg/l as Fe

pH	Turb	UV254
4.2	2.5	0.019
4.6	1.5	0.015
5.0	1.2	0.017
5.4	1.0	0.018
5.8	0.8	0.03
6.2	0.7	0.047

Set 5

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 23
Dosage	11.22mg/l as Fe

pH	Turb	UV254
4.2	2.4	0.019
4.6	1.6	0.017
5.0	1.5	0.016
5.4	1.3	0.021
5.8	1.0	0.034
6.2	1.2	0.052

Set 6

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 17
Dosage	8.30mg/l as Fe

pH	Turb	UV254
4.2	4.4	0.021
4.6	1.8	0.02
5.0	1.5	0.02
5.4	1.3	0.024
5.8	1.2	0.04
6.2	1.4	0.059

Dose Optimisation

Set 13

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 10
Dosage	4.88 mg/l as Fe

pH	Turb	UV254
4.6	3.7	0.031
5.0	2.5	0.034
5.4	3.1	0.042

Set 14

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 13
Dosage	6.34mg/l as Fe

pH	Turb	UV254
4.6	2.5	0.028
5.0	2.1	0.027
5.4	2.0	0.034

Set 15

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 17
Dosage	8.30mg/l as Fe

pH	Turb	UV254
4.6	2	0.027
5.0	1.6	0.027
5.4	1.5	0.030

Set 16

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 23
Dosage	11.22mg/l as Fe

pH	Turb	UV254
4.6	1.5	0.026
5.0	1.3	0.024
5.4	1.2	0.029

Set 17

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 30
Dosage	16.64mg/l as Fe

pH	Turb	UV254
4.6	1.4	0.022
5.0	1.1	0.020
5.4	0.9	0.025

Set 18

Coag type	$Fe_2(SO_4)_3$ + Lime
Dosage formula	UV300 x 40
Dosage	19.52 mg/l as Fe

pH	Turb	UV254
4.6	1.2	0.021
5.0	0.9	0.020
5.4	0.7	0.024

KNYSNA RAW WATER

Coagulation with Aluminium Sulphate

pH Optimisation

Set 19
Coag type Al2(SO4)3 + Lime
Dosage formul UV300 x 5 x 30
Dosage 73.2mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.00	0.064
5.0	0.95	0.029
5.4	0.55	0.023
5.8	0.35	0.025
6.2	0.33	0.031
6.6	0.31	0.034

Set 20
Coag type Al2(SO4)3 + Lime
Dosage formul UV300 x 5 x 23
Dosage 56.12mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1	0.048
5.0	1.4	0.023
5.4	0.63	0.022
5.8	0.42	0.025
6.2	0.35	0.031
6.6	0.36	0.036

Set 21
Coag type Al2(SO4)3 + Lime
Dosage formul UV300 x 5 x 17
Dosage 41.48mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.4	0.069
5.0	2	0.026
5.4	1	0.022
5.8	0.41	0.027
6.2	0.35	0.033
6.6	0.36	0.037

Dose Optimisation

Set 22
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 10
Dosage 24.4mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.9	0.025
6.2	0.45	0.030
6.6	0.5	0.040

Set 23
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 13
Dosage 31.72mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.5	0.026
6.2	0.4	0.029
6.6	0.4	0.039

Set 24
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 41.48mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.41	0.026
6.2	0.42	0.031
6.6	0.35	0.037

Set 25
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 56.12mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.4	0.022
6.2	0.3	0.029
6.6	0.4	0.034

Set 26
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 73.2mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.36	0.024
6.2	0.34	0.027
6.6	0.32	0.031

Set 27
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 40
Dosage 97.6mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.3	0.021
6.2	0.3	0.024
6.6	0.3	0.028

KNYSNA RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)
4,2	247	3	73	69	30	77			
4,6	107 (142)	8 (3)	107 (46)	40 (36)	40 (30)	58 (60)			
5,0	167 (61)	20 (17)	50 (33)	35 (36)	47 (40)	43 (38)	44	16	694
5,8							33 (30)	17 (16)	299 (316)
6,6							30 (29)	16 (14)	290 (363)

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

DUIVENHOKS RAW WATER

Coagulation with Ferric Chloride

pH Optimisation

Set 1
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 18.12mg/L as Fe

pH	Turb	UV254
4.2	4.5	0.033
4.6	1.9	0.021
5.0	1.6	0.021
5.4	1.6	0.026
5.8	1.3	0.036
6.2	1.4	0.048

Set 2
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 13.892 mg/l as Fe

pH	Turb	UV254
4.2	6	0.036
4.6	1.9	0.029
5.0	1.8	0.033
5.4	1.5	0.045
5.8	2	0.064
6.2	2	0.101

Set 3
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 10.268 mg/l as Fe

pH	Turb	UV254
4.2	3.7	0.053
4.6	2.6	0.039
5.0	2.8	0.051
5.4	3.5	0.076
5.8	4.6	0.131
6.2	6.1	0.222

Dose Optimisation

Set 7
Coag type FeCl3 + Lime
Dosage formula UV300 x 10
Dosage 6.04 mg/l as Fe

pH	Turb	UV254
4.6	2.9	*0.069*
5.0	3.5	0.093
5.4	4.1	0.113

Set 8
Coag type FeCl3 + Lime
Dosage formula UV300 x 13
Dosage 7.85 mg/l as Fe

pH	Turb	UV254
4.6	3.1	0.057
5.0	3.3	0.073
5.4	3.9	0.114

Set 9
Coag type FeCl3 + Lime
Dosage formula UV300 x 17
Dosage 10.27mg/L as Fe

pH	Turb	UV254
4.6	2.7	0.041
5.0	2.3	0.052
5.4	3.3	0.066

Set 10
Coag type FeCl3 + Lime
Dosage formula UV300 x 23
Dosage 13.89mg/L as Fe

pH	Turb	UV254
4.6	2.4	0.031
5.0	1.6	0.033
5.4	1.6	0.041

Set 11
Coag type FeCl3 + Lime
Dosage formula UV300 x 30
Dosage 18.12mg/L as Fe

pH	Turb	UV254
4.6	3.1	0.021
5.0	1.5	0.022
5.4	1.2	0.029

Set 12
Coag type FeCl3 + Lime
Dosage formula UV300 x 40
Dosage 24.16mg/l as Fe

pH	Turb	UV254
4.6	3.9	0.020
5.0	1.6	0.019
5.4	1.2	0.021

SEDGEFIELD RAW WATER

Coagulation with Ferric Sulphate

pH Optimisation

Set 4
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 21.06mg/l as Fe

pH	Turb	UV254
4.2	1.9	0.08
4.6	2.3	0.086
5.0	2.8	0.111
5.4	4.1	0.175
5.8	6.6	0.252
6.2	6.7	0.293

Set 5
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 16.15mg/l as Fe

pH	Turb	UV254
4.2	2.9	0.094
4.6	3.4	0.106
5.0	5.9	0.161
5.4	10.0	0.244
5.8	12.0	0.28
6.2	7.7	0.33

Set 6
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 11.93mg/l as Fe

pH	Turb	UV254
4.2	3.4	0.132
4.6	6.7	0.159
5.0	12.0	0.262
5.4	14.0	0.374
5.8	13.0	0.412
6.2	13.0	0.462

Dose Optimisation

Set 13
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 10
Dosage 7.02mg/l as Fe

pH	Turb	UV254
4.6	13	0.303
5.0	14	0.346
5.4	12	0.444

Set 14
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 13
Dosage 9.13mg/l as Fe

pH	Turb	UV254
4.6	9.9	0.219
5.0	14.0	0.3
5.4	13.0	0.388

Set 15
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 17
Dosage 11.93mg/l as Fe

pH	Turb	UV254
4.6	6.6	0.161
5.0	11	0.216
5.4	13	0.298

Set 16
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 16.15mg/l as Fe

pH	Turb	UV254
4.6	3.2	0.114
5.0	7.0	0.177
5.4	10.0	0.239

Set 17
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 30
Dosage 21.06mg/l as Fe

pH	Turb	UV254
4.6	2.2	0.087
5.0	2.5	0.102
5.4	4.5	0.157

Set 18
Coag type Fe2(SO4)3 + Lime
Dosage formula UV300 x 40
Dosage 28.08mg/l as Fe

pH	Turb	UV254
4.6	1.9	0.070
5.0	1.9	0.074
5.4	2.1	0.110

DUIVENHOKS RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)	Fe (µg/ℓ)	Mn (µg/ℓ)	Al (µg/ℓ)
4,2	294	20	113	620	52	114			
4,6	143 (175)	19 (17)	91 (91)	210 (188)	50 (49)	102 (116)			
5,0	109 (116)	19 (17)	67 (86)	130 (110)	50 (48)	78 (75)	63	9	1 050
5,8							83 (88)	9 (9)	40 (42)
6,6							73 (40)	11 (7)	56 (142)

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

SEDGEFIELD RAW WATER

Coagulation with Aluminium Sulphate

pH Optimisation

Set 19 .
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 105.3mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.10	0.137
5.0	0.56	0.068
5.4	0.62	0.064
5.8	0.72	0.089
6.2	0.65	0.121
6.6	0.60	0.144

Set 20
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 23
Dosage 80.73mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.4	0.150
5.0	0.78	0.076
5.4	0.75	0.072
5.8	0.79	0.106
6.2	0.82	0.155
6.6	0.96	0.169

Set 21
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 59.67mg/l as Al2(SO4)3

pH	Turb	UV254
4.6	1.2	0.224
5.0	0.82	0.088
5.4	1.3	0.090
5.8	1.5	0.129
6.2	2.8	0.167
6.6	3	0.233

Dose Optimisation

Set 22
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 10
Dosage 35.1mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	3	0.163
6.2	10	0.241
6.6	9.6	0.282

Set 23
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 13
Dosage 45.63mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	2.0	0.116
6.2	3.5	0.208
6.6	3.0	0.284

Set 24
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 17
Dosage 59.67mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	1.5	0.117
6.2	2.8	0.174
6.6	2.7	0.228

Set 25
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 23
Dosage 80.73mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.7	0.117
6.2	0.8	0.151
6.6	1.0	0.196

Set 26
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 30
Dosage 105.3mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.63	0.061
6.2	0.52	0.123
6.6	0.6	0.152

Set 27
Coag type Al2(SO4)3 + Lime
Dosage formula UV300 x 5 x 40
Dosage 140.4mg/l as Al2(SO4)3

pH	Turb	UV254
5.8	0.5	0.066
6.2	0.5	0.092
6.6	0.5	0.132

SEDGEFIELD RAW WATER

Residual metal concentrations after coagulation at optimum dosage of UVA300 x 30 with the three different metal coagulants, at different pH values

pH	Ferric chloride			Ferric sulphate			Aluminium sulphate		
	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)	Fe (μg/ℓ)	Mn (μg/ℓ)	Al (μg/ℓ)
4,2	369	20	247	442	64	230			
4,6	249 (668)	19 (21)	108 (94)	348 (299)	63 (62)	139 (584)			
5,0	214 (712)	19 (22)	53 (166)	580 (262)	62 (61)	63 (345)	86	19	744
5,8							132 (55)	18 (19)	90 (162)
6,6							49 (58)	13 (12)	583 (507)

Values in parenthesis denotes samples from different experimental sets subject to the same coagulation conditions

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