University of Southern Queensland

Faculty of Engineering and Surveying

Urban Stormwater Treatment Using Chitosan

A dissertation submitted by

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ABSTRACT

The need to study the treatment of urban stormwater was identified as Toowoomba Regional Council in partnership with the University of Southern Queensland investigates the feasibility of a stormwater harvesting scheme. Urban runoff would be captured, treated to a non-potable standard and reused for local irrigation and industrial applications. The study tests chitosan as a coagulant to remove suspended solids from the captured stormwater. Reduced inflows to Toowoomba's three major reservoirs and the depletion of basalt bores have emphasized the need to utilise urban stormwater. The presence of contaminants including suspended solids, heavy metals, hydrocarbons and nutrients combined with a history of proven alternatives has seen stormwater harvesting projects generally overlooked. The study tested the performance of chitosan against more traditional coagulants. Chitosan is a biodegradable chemical compound produced from the pulverisation and dissolution of crustacean shells. FlocClear BioPolymer™ has been sourced from Los Angeles, USA for the project. FlocClear is a solution containing 2% chitosan acetate by weight. Chitosan will be compared to Magnasol 589, the chemical of choice at Toowoomba's Mt Kynoch water treatment plant. Samples were taken from a variety of urban catchments to ensure a representative range of stormwater turbidity, pH and particle size characteristics were tested. Jar testing was employed using a rapid mixing speed of 100 rpm for 2 minutes. Flocculation followed at 30 rpm for 20 minutes. Settling time was 30 minutes. The initial and final turbidity were measured. Total suspended solids (TSS) tests were also conducted. A relationship between turbidity and TSS was plotted to validate the results. The results were analysed for compliance with the Queensland Water Recycling guidelines for non-potable class-A water. Chitosan proved effective in the removal of suspended solids from urban stormwater particularly from high turbidity stormwater. The maximum efficiency was achieved using a 5.0mg/L chitosan acetate dose. The turbidity of the stormwater was reduced from 260.0 NTU to 8.9 NTU. Chitosan is also capable of treating less turbid water which is seen by reducing a 19.5 NTU influent to 2.5 NTU using a 3.5 mg/L dose. A form of sand filtration is required to further reduce turbidity below 2 NTU, to comply with the Queensland Water Recycling Guidelines.

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Limitations of Use

Professor Frank Bullen
Dean
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CERTIFICATION

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Michael Stuart Shellshear

Student Number: 0050026220

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Signature

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Date

ACKNOWLEDGMENTS

This research project would not have been possible without the assistance and supervision of Dr Ian Brodie. The topic was born out of Ian's keen interest in the field of stormwater. Ian's involvement in the project included assisting in the search of literature, materials and equipment. He also suggested improvements to the testing methodology and proof read assessment items. I thank Ian sincerely for giving freely of both his time and expertise throughout the project.

Secondly I would like to give thanks Joe Gannon of Clear Creek Systems in the United States for donating a 250mL sample of chitosan and postage costs to the project. Joe's correspondence also helped achieve the best possible results using the product his company kindly supplied.

Acknowledgement must also go to the project sponsor Toowoomba Regional Council. Provision of a testing laboratory, equipment and chemicals made the testing run smoothly. I would like to make mention of Toowoomba Regional Council personnel that contributed to the project. Mr Alan Klienschmidt helped organise laboratory space and testing equipment in the initial stages. On a recommendation from Alan, Graham McKeon at Wetalla Wastewater Treatment Plant was consulted. Graham's knowledge of water treatment was drawn upon to improve the test methodology. Justin Holzhiemer also offered wise advice relating to time management and compilation of the dissertation. Without the support of the TRC and its staff the project would not have been a success. I am truly grateful for their input.

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NOMENCLATURE

The following abbreviations have been used throughout the text:-

TSS	Total Suspended Solids (mg/L)
NTU	Nephelometric Turbidity Units
Alum	Aluminium Sulphate
HCl	Hydrochloric Acid
Rpm	Revolutions per Minute
TRC	Toowoomba Regional Council
USQ	University of Southern Queensland
EPA	Queensland Government - Environmental Protection Agency
WWTP	Wastewater Treatment Plant
mV	Millivolt

CHAPTER 1

INTRODUCTION

1.1. Outline of the Study

The need to study the treatment of urban stormwater was identified as Toowoomba Regional Council in partnership with the University of Southern Queensland investigates the feasibility of an urban stormwater harvesting scheme. Under the proposal urban runoff would be captured, treated to a non-potable standard and reused for local irrigation and industrial applications.

The broader study will investigate methods of removing suspended solids from harvested stormwater from urban areas. The focus this project is the use of chitosan as a coagulant in the sediment removal process. Chitosan is a chemical compound produced from the pulverisation and subsequent dissolution of crustacean shells. Chitosan is used in the same manner as conventional coagulants but has the distinct advantage of being biodegradable.

1.2. Background

1.2.1. Stormwater Harvesting

Reduced inflows to Toowoomba's three major reservoirs and the depletion of basalt bores have emphasized the need to utilise urban stormwater. Urban stormwater has the potential to ease the stress upon both these water resources. Research in stormwater harvesting will suggest methods of treating urban runoff to current standards. The focus will be on meeting non-potable standards in terms of both turbidity and suspended solids concentration.

Very few examples of urban stormwater harvesting schemes exist, particularly in Australia. The presence of contaminants including suspended solids, heavy metals, hydrocarbons and nutrients, combined with a history of proven alternatives has seen stormwater harvesting projects generally overlooked. The investigation of more complex forms of water supply including stormwater harvesting and wastewater recycling highlights the challenges researchers, planners and engineers face. Coupled with the problem of pollutant removal is the capture and storage of stormwater. This lies beyond the scope of this project but will be critical in determining the initial and ongoing viability of stormwater harvesting.

There is little published evidence of the use of chitosan in water treatment in Australia. It is hoped this study will replicate results of testing conducted abroad. Chitosan has been used successfully in Asia, Europe and North America to remove sediment from water. Research indicates that chitosan removes suspended solids effectively from stormwater up to a turbidity of 1000 NTU (Washington State Department of Ecology, 2008). Proving the above studies under Australian conditions will provide a renewable and biodegradable alternative to traditional coagulants.

1.2.2. The Problem

The characteristics of urban stormwater differ greatly from more traditional water sources such as surface and ground water. The contaminants in stormwater vary from catchment to catchment, depending largely upon the land use in that catchment. Similarly the concentration of the contaminants will fluctuate due to the intensity, frequency and duration of rainfall events. Thus, a treatment facility must be designed to rapidly adapt to a highly variable incoming water quality.

A representative selection of raw stormwater from urban areas will be sampled and tested. Water will be collected from creek systems, drainage structures and roadways throughout the research period. Records from the Toowoomba Regional Council will also be used. These records provide historical data of water quality in each of Toowoomba's six major stormwater catchments. Effective use of this data avoids the need to sample each catchment in detail. Direct correlation between the prevailing water quality and the test data will also indicate which locations are more suitable to chitosan treatment.

1.2.3. Water Treatment Principles

Coagulants and the process of flocculation are critical elements in conventional water treatment plants for removal of suspended matter. In conventional water treatment facilities, extended retention time removes much of the particulate matter before water reaches the plant. A stormwater harvesting plant must be able to process water with higher levels of suspended solids. Conditions will be similar to those experienced in water treatment plants following periods of heavy rain and large inflows to reservoirs where water contains higher concentrations of suspended solids. These conditions often require a preliminary sedimentation tank to remove heavy sediments (USQ, 2007).

1.2.4. Coagulation

A coagulant is the chemical used to remove the suspended matter that will not settle after prolonged hydraulic retention time and or preliminary treatment. Coagulants react with the colloidal particles to provide an absorbent precipitate. Traditional coagulation with aluminium based chemical hydrolyses metal ions to form hydroxide floc and hydrogen ions (Gebbie, 2005). Hydroxide floc is positively charged heavier-than-water. The hydroxide attracts the negatively charged colloidal particles. Coagulation is rapid and usually occurs in less than ten seconds from the time the coagulant is added (USQ, 2007).

1.2.5. Flocculation and Sedimentation

Flocculation is the process of agglomeration of the initial particles to form larger particles. This occurs via collisions of the particles and subsequent aggregation. Depending upon the water characteristics, the coagulant used and the dose, flocculation can take 20-45 minutes (USQ, 2007).

Following flocculation most of the particles can be removed from the water via sedimentation. Sedimentation settles the agglomerated suspensions by gravity. This is achieved by passing water through a series of tanks at very low velocity. Predicting settling time is complex and is a function of the tanks surface overflow rate (Flow Rate/Surface Area), particle size and density and water viscosity. The settled material that remains is known as sludge.

1.2.6. Chitin and Chitosan

Chitin and chitosan are nitrogenous polysaccharides that are made up of acetylglucosamine and glucosamine units. (Benavente, 2008). Chitin is the second most abundant polymer in nature. It occurs naturally as ordered crystalline microfibrils forming structural components within the exoskeleton of arthropods (Rinaudo, 2006). The primary source of chitin is seafood crustaceans (crab, shrimp, prawn and lobster shells) that are usually disposed of as waste material (Jang et al., 2004). Chitin is a hard, white, inelastic and inert solid and is not soluble in natural solvents. Chitin is however soluble under mild acidic and basic conditions and is thus obtained as the residue after decomposition with acid and alkali (Bade, 1997). This process involves first treating the shells with dilute hydrochloric acid to remove metal salts. The shells are then ground, heated to about 100°C in 1-2 mol/L of sodium hydroxide to decompose proteins and pigments. On drying, the off-white flakes that remain is known as chitosan (Sannan et al., 1976). Global chitosan production was estimated to have reached 2,000 tonnes in the year 2000. Other products capable of being produced from chitin include glucosamine and oligosaccharides (Kurita, 2006). Chitin based products are available commercially as dietary supplements, plant enhancers and water treatment chemicals.

1.3.Research Objectives

This project seeks to test chitosan against Magnesol 589. Magnesol 589 is the primary coagulant in use at Toowoomba's Mt Kynoch water treatment plant. Magnasol 589 is an aluminium based polymer coagulant. The research project will compare the coagulant performance of chitosan with that of a more conventional product (Magnasol 589) for the treatment of urban stormwater.

1.4.Summary

As can clearly be seen this project will test the feasibility of treating urban stormwater to non-potable standards using chitosan as a coagulant. There is a clear and present need for this study as Toowoomba Regional Council searches for supplementary water sources in a time of unprecedented shortages. It is hoped this research will offer an alternative to traditional coagulants.

CHAPTER 2

LITERATURE REVIEW

2.1. Introduction

The literature review for the project will focus on three major areas. The initial investigation will reveal the scope of the broader stormwater harvesting research and water quality requirements for non-potable reuse in Toowoomba. Secondly, historical data from the Toowoomba Regional Council will be drawn upon to predict levels of turbidity and suspended solids that can be expected. Lastly, a comprehensive review of literature pertaining to water treatment using chitosan will be undertaken. Conducting this research will provide an excellent platform from which to conduct laboratory testing. The aim of the testing will be to validate much of the information contained in the literature review.

2.2. Background

The broader research in stormwater harvesting aims to develop a stormwater storage and treatment system that captures the first 15mm of polluted runoff from urban areas for re-use. The system requires the integration of an innovative storage system with an advanced fast-rate treatment process normally used in the wastewater industry (Development of a Fast-Rate Stormwater Re-Use System, 2006).

2.2.1. Current Stormwater Harvesting Practices

Current urban stormwater treatment is classified as a slow-rate system. Examples of slow-rate systems include sedimentation ponds, constructed wetlands and infiltration basins. Treatment of polluted urban runoff is achieved in these systems through natural processes including settling and filtration. They are known as slow-rate systems as the physical and biologically based processes described above require lengthy detention times. The time associated with treatment requires large storage volumes and output water quality varies greatly based on the flow through such storages. Thus, there is a need to produce a system that can deliver consistent water quality and is independent of detention time and or the amount of rainfall (Development of a Fast-Rate Stormwater Re-Use System, 2006).

2.2.2. Target Runoff

The projects to develop a fast-rate stormwater re-use scheme focuses upon urban runoff from sealed surfaces. Of major significance is runoff generated from roads, car parks, driveways and rooves. These impervious surfaces generate runoff during almost all rainfall events and usually contain a high concentration of pollutants. The construction of efficient drainage systems has meant these pollutants enter creeks and other waterways very quickly. In a pre-urban state this of little concern as infiltration reduces the runoff, particularly during minor rainfall events (Development of a Fast-Rate Stormwater Re-Use System, 2006).

To reflect the above runoff and infiltration characteristics of urban landscapes, the first 15mm of each event is stormwater of most interest. Observation and research has revealed that runoff begins from a precious surface after 15mm of rainfall. This is an arbitrary value as it is known that infiltration will vary depending on rainfall intensity, and duration. Soil characteristics and vegetation coverage will also impact heavily on runoff from pervious surfaces (Development of a Fast-Rate Stormwater Re-Use System, 2006).

2.2.3. Potential Scales of Fast-Rate Systems

The above stormwater harvesting principles can be applied on a variety of scales. The Department of Local Government, Planning, Sport and Recreation propose three scales of possible operation (Development of a Fast-Rate Stormwater Re-Use System, 2006).

Small-scale harvesting would capture runoff from a road. The storage and treatment volumes would be small and the treatment technology could be tailored to the specific nature of road runoff. Such a scale necessitates numerous small-scale systems distributed throughout an urban area to provide a viable supply (Development of a Fast-Rate Stormwater Re-Use System, 2006).

Capturing the runoff from a subdivision is an example of a medium scale operation. Greater volumes will be available for treatment and stormwater characteristics will also differ as the runoff will be contributed from surfaces other than roads. The Department of Local Government, Planning, Sport and Recreation suggest water quality may improve due to a diluting effect from roof water (Development of a Fast-Rate Stormwater Re-Use System, 2006).

The feasibility of a large-scale treatment plant must also be considered. A large scale system would potentially capture stormwater from a creek downstream of an urban catchment. Predictably the quantity of this runoff will increase. Water could also be expected to contain an increased concentration of suspended solids due to the erosion of unlined creek banks. This may cause a higher treatment load to the system (Development of a Fast-Rate Stormwater Re-Use System, 2006).

None of these systems have a clear advantage as the economy of operating a central large-scale plant is offset by reticulation costs and deficiencies in water quality as the runoff travels further from its source. This proves the need to conduct testing to determine the water quality from each style of catchment. Future studies will be required to test the feasibility of operating various sized plants (Development of a Fast-Rate Stormwater Re-Use System, 2006).

2.3. Recycled Water Quality Standards

The standard to which recycled water must be treated in Toowoomba is governed by the *Queensland Water Recycling Guidelines*. The primary purpose of the guidelines is to encourage and support water recycling that is safe, environmentally sustainable and cost-effective under Queensland conditions (Queensland Water Recycling

Guidelines, 2005). The guidelines are geared toward recycling from wastewater treatment plants; however the same principles and standards can be applied to stormwater harvesting projects.

2.3.1. Recycled Water Quality Classes

The Queensland Water Recycling Guidelines classify water based on a series of categories ranging through classes A to D. The water quality corresponding to each of these classes has been derived following a quantitative health risk assessment (Queensland Water Recycling Guidelines, 2005). Class A is the highest quality water, and class D, the poorest. The following table shows clearly the classes of water and acceptable levels for each contaminant.

Table 2.1 Recommended water quality specifications for class A-D recycled water (EPA, 2005)

Class	*E. coli* (median) cfu/100mL[2]	BOD5 mg/L median	Turbidity NTU 95% ile (max.)	SS, mg/L median	TDS, mg/L or EC, µS/cm medians TDS / EC[3]	pH
A	< 10	20	2 (5)[4]	5	1000/1600	6-8.5
B	< 100	20	—	30	1000/1600	6-8.5
C	< 1000	20	—	30	1000/1600	6-8.5
D	< 10,000	—	—	—	1000/1600	6-8.5

[1] Use of any of these classes of recycled water should involve development and implementation of a Recycled Water Management Plan incorporating risk management. The location of the sampling point for these parameters will depend on the outcome of the Recycled Water Management Plan (see Chapter 4 of these guidelines).

[2] As these values are medians, for each of these guideline values a response value should be set (e.g. 50% above the guideline value). If the response value is exceeded, another sample should be immediately taken. If this exceeds the response value again, the supply of recycled water should be suspended, and the non-conformance and corrective action process implemented, with supply not being re-established until conforming product can be guaranteed.

[3] For sustainable irrigation, salinity should be kept as low as possible. For example, if TDS >1000 mg/L or EC >1600 µS/cm, a salinity reduction program should be implemented. However, there may be some uses where salinity reduction is not required, or where other salinity management options are more practical. This should be determined during the risk assessment.

[4] Turbidity would generally be measured before the disinfection point at the treatment plant as this is the point at which low turbidity is essential. Monitoring at the treatment plant should be continuous with an alarm activated at an NTU of 2, and automatic shut-off of supply at an NTU of 5. If disinfection of Class A recycled water is achieved partly through processes that are less dependent on turbidity, an indicator other than turbidity should be used. For example, extended lagooning would use detention time in the storage as the critical limit (typically 40 days), rather than turbidity. Ozonation may use an oxidation-reduction potential (ORP) sensor, with the critical limit (in millivolts) determined by the quality of the feed water.

The primary reason the guidelines stipulate an acceptable level of suspended solids is for disinfection requirements. It has been noted that the presence of suspended material in recycled water is crucial to the effectiveness of most forms of disinfection (Queensland Water Recycling Guidelines, 2005).

2.3.2. Irrigation with Recycled Water

Recycled water may be used for irrigation of public open spaces including parks, road verges, sports grounds, schoolyards, racecourses and cemeteries as well as pasture, agricultural, horticultural and silvicultural crops. Table 2.2 shows that irrigation of public space that has uncontrolled access is required to utilise class-A recycled water. Lesser standards apply to sub-surface irrigation and irrigation of areas with controlled access. To commercially and legally satisfy Toowoomba Regional Council and its customers, class-A water is essential. Irrigation for food crops intended for direct human consumptions falls under the A+ classification. This level far exceeds Toowoomba's Regional Council's requirements and will not be considered in this study.

2.3.3. Recycled Water for Industrial Purposes

Like recycled water for irrigation the standard for industrial purposes is based on the likelihood of human contact with the water. Industrial uses for recycled water may include wash down, dust control on construction sites and quarries, boiler feed, process water, industrial cooling and mining as well as a broad range of other uses. Most industrial activities require class-C water. Works on roads and other construction however requires class-A water as there is the possibility of human contact particularly from workmen and bystanders. Works on roads and the use of quarry materials form the majority of projects undertaken directly by Toowoomba Regional Council. Similarly, the council supply's an increasing number of customers with non-potable water from the cities bores. Thus, we will consider class-A standard water as the benchmark for the study as it clearly satisfies all council's requirements. As seen in Table 2.1 the target turbidity and TSS for class A recycled water is 2 NTU and 5mg/L respectively. The pH of treated water must be between 6 and 8.5.

Table 2.2 Recycled water uses, recommended classes and recommended monitoring (EPA, 2005)

Recycled water use	Class[1]	Recommended monitoring
Domestic and commercial property use		
• toilet *flushing*, outdoor hosing and washdown, above ground garden watering	A+	See Table 6.2a
Irrigating public open space and golf courses		
• above ground open space irrigation, uncontrolled access	A	*E. coli* weekly, turbidity[2] continuous, disinfection[3] continuous, pH weekly
• controlled access or subsurface irrigation	C	*E. coli* weekly, SS monthly, disinfection[3], pH monthly
Irrigating food crops and retail nurseries		
• food crops consumed raw or minimally processed	A+	See Table 6.2a
• sugar cane and grapes for wine production	C	*E. coli* weekly, SS weekly, pH weekly
• other above ground food crops with above ground irrigation	A+ [4]	See Table 6.2a
• other above ground food crops with below ground irrigation	C	*E. coli* weekly, disinfection[3] weekly, SS weekly, pH weekly
• root crops	A+ [4]	See Table 6.2a
• retail nurseries irrigating ready to eat crops	A+	See Table 6.2a
Irrigating pasture/fodder and agricultural washdown		
• pasture/fodder for dairy animals without withholding period	B	*E. coli* weekly, disinfection[3] weekly, SS weekly, pH weekly
• pasture/fodder for dairy animals with withholding period of five days	C	*E. coli* weekly, disinfection[3] weekly, SS weekly, pH weekly
• pasture/fodder for other grazing animals except pigs with withholding period of four hours	C	*E. coli* weekly, disinfection[3] weekly, SS weekly, pH weekly
• washdown of hard surfaces in agricultural industries	B	*E. coli* weekly, disinfection[3] weekly, SS weekly, pH weekly
Irrigating non-food crops		
• retail nurseries not irrigating ready to eat products	A	*E. coli* weekly, turbidity[2] continuous, disinfection[3] continuous, pH weekly
• silviculture, turf, cotton, wholesale nurseries with controlled access and other safeguards to protect the health of workers or neighbours	D	*E. coli* monthly, pH monthly
Industrial purposes		
• open system (potential for high human contact) e.g. car wash or quarry where aerosol generation is constant	A+	See Table 6.2a
• open system (potential for occasional human contact, but with safeguards in place)	A	*E. coli* weekly, turbidity[2] continuous, disinfection[3] continuous, pH weekly
• closed system (low human contact) • irrigation of "no public access" areas	C	*E. coli* weekly, disinfection[3] weekly, pH weekly
• fire fighting	A+	See Table 6.2a
Supplementing drinking water supplies		
• surface water or direct injection to aquifer	N/A[5]	See section 7.6 of these guidelines
Recreational purposes		
• fountains and water features (no primary or secondary contact recreation)	A[6]	*E. coli* weekly, turbidity[2] continuous, disinfection[3] continuous, pH weekly
• water features for amenity purposes only (controlled access) • natural or artificial wetlands	C	*E. coli* weekly, disinfection[3] weekly, pH weekly Site specific, depending on the environmental values and water quality objectives of the receiving waterway

[1] In this table a recommendation for use of any particular class of recycled water includes higher classes as well. In other words, if Class C is recommended, Classes A and B could also be used, but Class C is the minimum recommended standard.
[2] See footnote 4 to Table 6.2b. Turbidity should be monitored at the stage in the production process for recycled water that is most relevant. In other words, if turbidity levels are important to the disinfection process, turbidity should be measured immediately before disinfection.
[3] See comments on chlorine disinfection in section 6.6.3 of these guidelines.
[4] See section 7.3.6 of these guidelines for exceptions to this recommendation.
[5] Not applicable, as no specific recycled water quality has yet been determined for this use. See section 7.6 of these guidelines.
[6] An alternative class of recycled water may be used depending on the outcome of the Recycled Water Management Plan (see section 7.7 of these guidelines).

2.4. TRC Water Quality Monitoring

Historical Toowoomba Regional Council stormwater quality data will provide vital information in the study. The water quality records date back to November 2001. These records contain detailed pollutant levels in each of Toowoomba's six major stormwater catchments. Of interest in the study are levels of pH, turbidity and TSS

(Total Suspended Solids). Other pollutants including conductivity, dissolved oxygen, temperature, nitrates, nitrites, nitrogen, phosphorus, biochemical oxygen demand, faecal coliform, enterococcus and chlorophyll-a are also recorded. The above contaminants are not relevant to this project, but must be considered in later research. Figure 2.1 is shows Toowoomba's major stormwater catchments. TRC data does not include readings from the escarpment zone or the Dry Creek catchment.

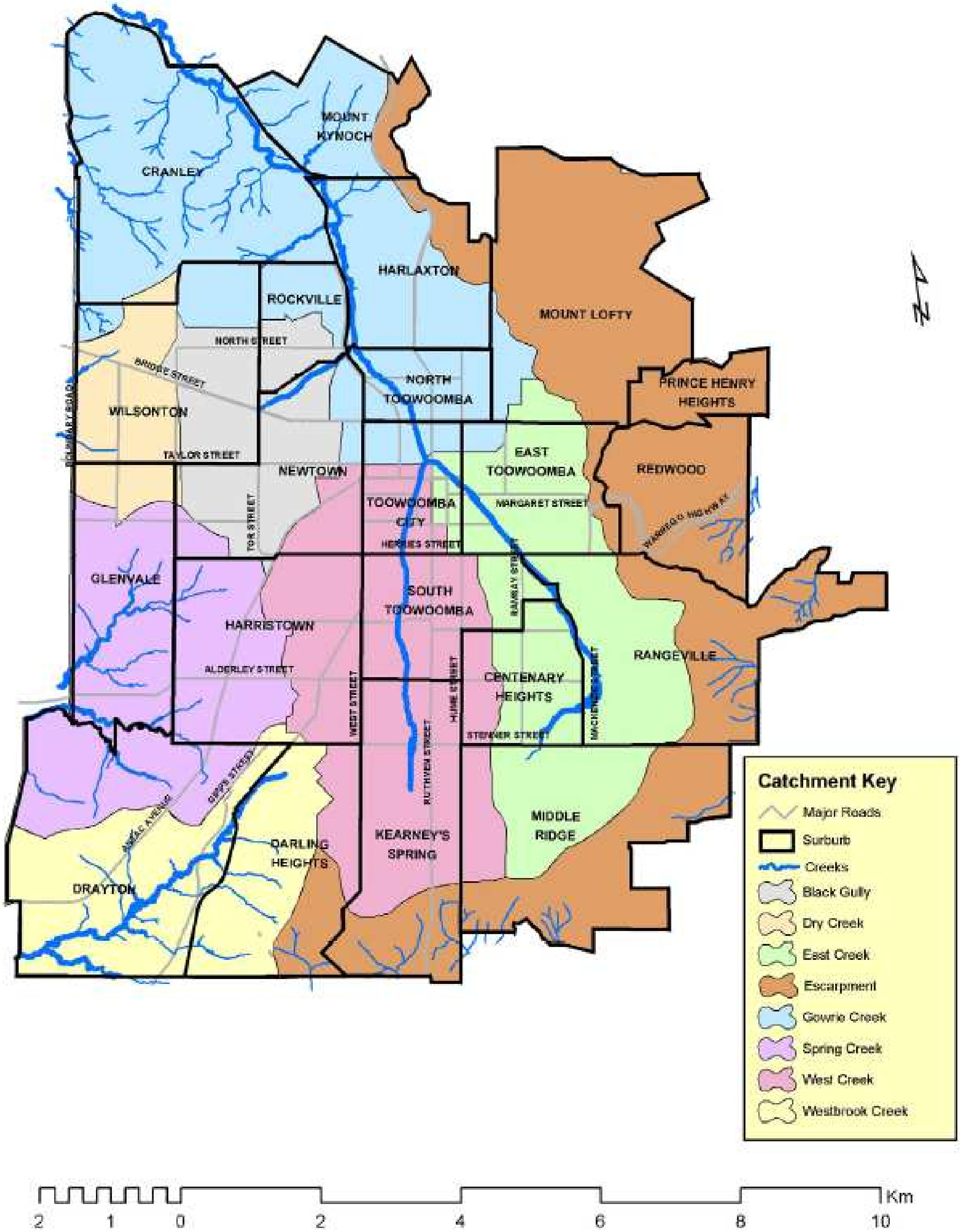


Figure 2.1 Map showing Toowoomba's stormwater catchments (TRC, 2002)

The data will provide clues on potential sites to capture water for the testing. A variety of sites will be selected to ensure representative ranges of suspended solids concentration are covered. The data will also highlight any anomalies in the laboratory testing to be conducted. Effective use of this resource will negate the need to conduct extra testing at all sites suitable for a stormwater treatment plant. The complete stormwater quality graph for each of Toowoomba's catchments is included as appendix D of the dissertation. Shown below is a typical TSS/Turbidity graph that will be used to estimate the stormwater quality that a stormwater harvesting/treatment plant may encounter.

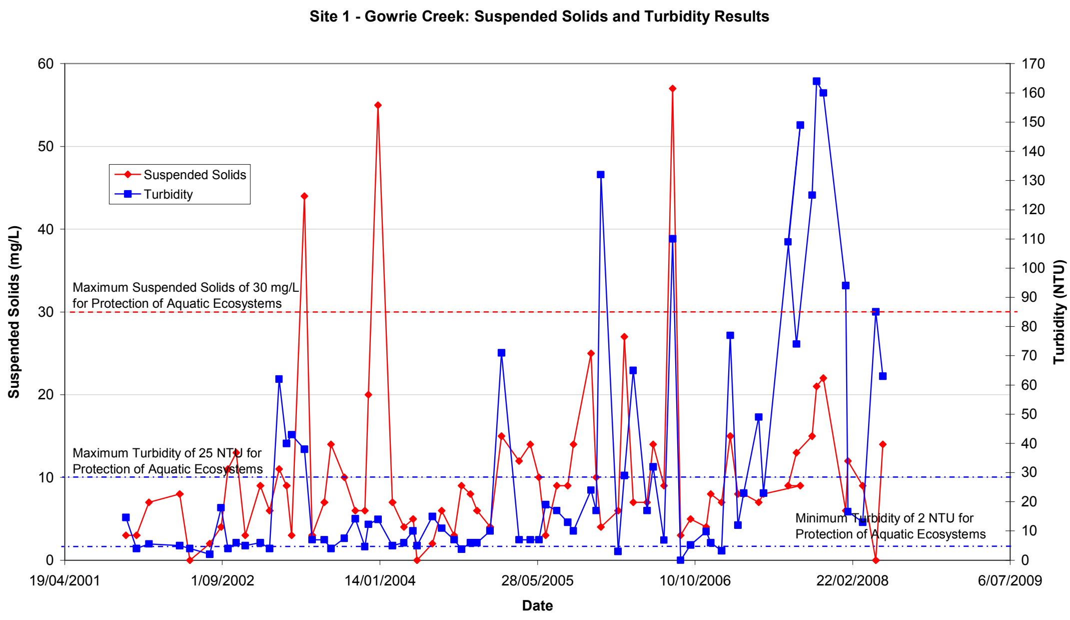


Figure 2 2 Turbidity and TSS concentrations for Gowrie Creek (TRC, 2008)

2.5.Chitosan Research

To determine the initial feasibility of using chitosan as a coagulant to treat urban stormwater, thorough research was required. Many studies existed, predominantly reported in journal articles. Each study produced encouraging results using chitosan to treat various forms of polluted water including stormwater. None of the studies were found to have originated in Australia. Thus, an opportunity was presented to prove the effectiveness of chitosan as a coagulant under Australian conditions.

2.5.1. The Effect of pH on Flocculation

The pH of the raw water has been found to dramatically impact on the efficiency of flocculation. When testing chitison to remove silt suspensions from Indian river water, Divakaran and Pillai (2002) found that maximum turbidity removal was achieved at pH 7. Divakaran and Pillai (2002) tested a range of pH levels from 4.0-9.0 in increments of 0.5. The dose rate was constant at 1.0mg/L and the initial turbidity recorded at 40 NTU. The percentage of turbidity removed diminishes almost linearly to zero at pH 4 from a maximum at pH 7. Similarly, the same occurs as pH 9 water produces no reduction in turbidity.

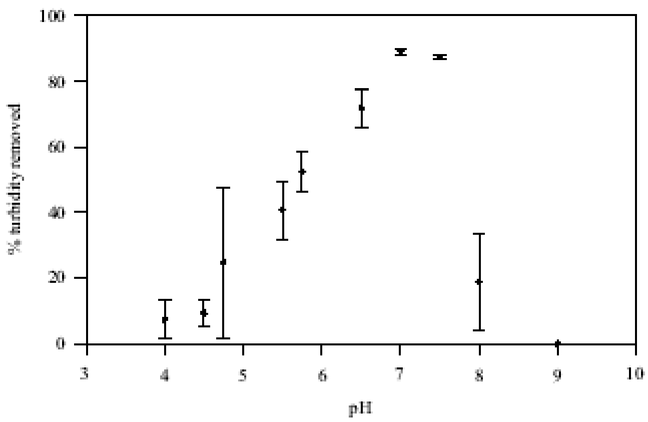


Figure 2.3 Effect of pH on the removal of turbidity in water, due to river silt, using chitosan. Initial turbidity=40NTU, chitosan dosage=1 mg/L. Vertical bars indicate standard deviation from six repetitions (Divakaran and Pillai, 2002).

Similarly, Huang and Chen (1996) proved that pH 6 was the optimum level when using chitosan to treat synthetically produced bentonite suspensions. A chitosan dosage of 2mg/L combined to an influent water of 45 NTU reduced turbidity below 1 NTU. The above research suggests that water in the range of ph 5.0 to 7.0 will give the satisfactory results.

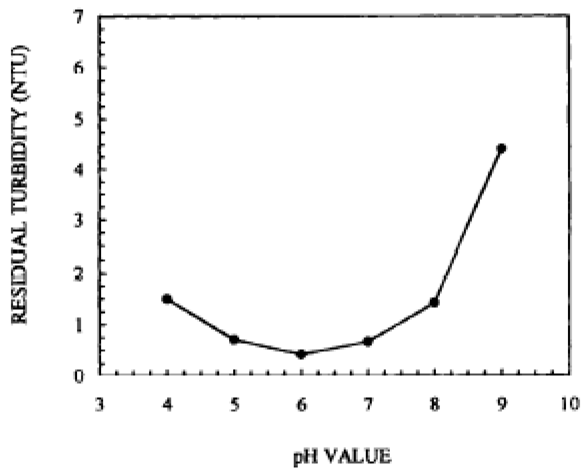


Figure 2.4 The residual turbidity of bentonite suspensions after jar-mixing/settling as function of pH (chitosan dosage = 2.0 mg/L; initial turbidity = 45 NTU) (Huang and Chen, 1996).

2.5.2. Determination of an Optimum Chitosan Dosage

There is a wide selection of research investigations that indicate an optimum chitosan dosage. These studies represent testing of water qualities ranging from surface water at a municipal water treatment plant through to sediment laden runoff in construction sites. As the characteristics of urban stormwater will almost certainly fluctuate, satisfactory performance of chitosan over a range of a range of dosages is paramount. Any chemical that has sensitivity to dose rate will cause inefficiencies in the operational and testing requirements of an urban stormwater harvesting plant.

It must be considered that each study has used chitosan obtained from an alternate source. Discrepancies will exist where chitosan solutions have been prepared in a different manner. The concentration of remnant acetic acid used to dissolve the chitosan and the purity of the chitosan itself is expected to influence results.

Chitosan studies of urban drinking water in Salerno, Italy by Rizzo et al. (2008) revealed key aspects regarding the treatment of relatively low-turbidity water. The study was a comparison between chitosan and metal salts, namely aluminium sulphate and ferric chloride. It was deduced that from a raw water sample at 16.6 NTU, peak performance was achieved at a chitosan dose of 1.0mg/L. Figure 2.5 (a) shows that for pH neutral water (pH 7) there is only a gradual decline in performance as the concentration of chitosan approaches 10 mg/L. When very low turbidity samples were tested a significant difference was detected. When a 1.0mg/L sample of chitosan is applied to 3.3 NTU water, a pH of 5 and 6 is preferable. As the dosage increases the preference reverts to pH 7 and eventually results in better turbidity removal. The above situation is shown in figure 2.5 (b). The theory was extended on by showing the effect of turbidity removal versus initial turbidity as shown in Figure 2.5 (c).

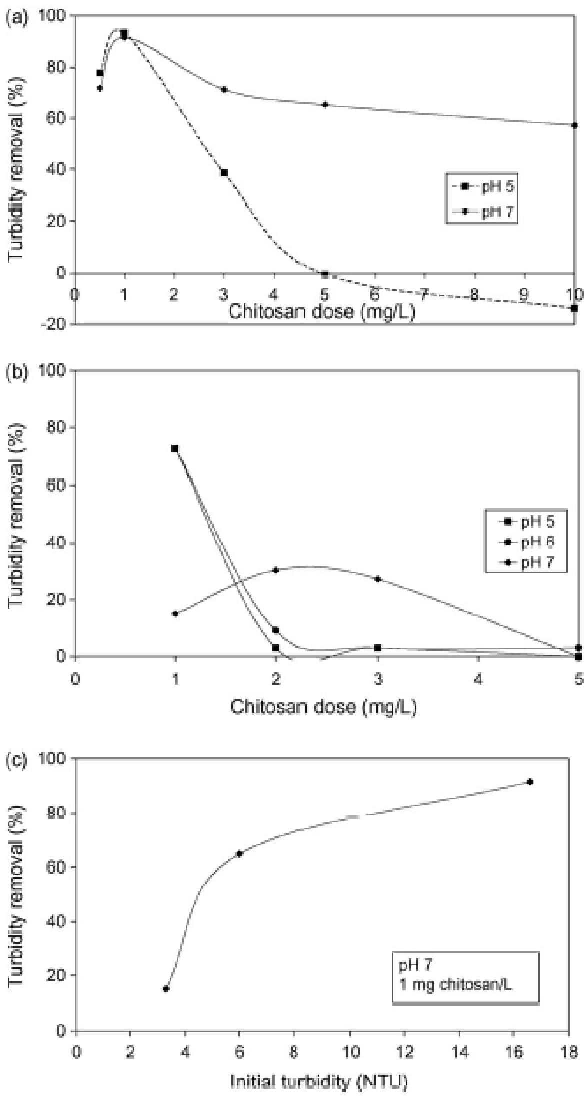


Figure 2.5 Effect of coagulation by chitosan on turbidity removal: (a) effect of chitosan dose and pH in high turbidity (16.6 NTU) sample (b), effect of chitosan dose and pH in low turbidity (3.3 NTU) sample (c), effect of initial turbidity (Rizzo et al, 2008).

TRC records indicate that runoff entering creek systems may be more turbid than those encountered by Rizzo et al. (2008). Huang and Chen (1996) conducted chitosan testing using an initial turbidity range of 25 to 1000 NTU. The test samples were synthetically prepared by the addition of bentonite and kaolinite clays in the form of powder. Huang and Chen (1996) also prepared their own chitosan by crushing crab shells to a powder and deacetylating chitosan from the chitin using sodium hydroxide (NaOH). The results achieved by Huang and Chen (1996) are not far removed from those of Rizzo et al. (2008). In dosing water of an initial turbidity of 30 NTU at both pH 4 and 7, excellent turbidity removal was measured. Figure 2.6 and Figure 2.7 shows average results for pH 4 and pH 7 respectively. This indicates that treatment performance is insensitive to pH, contrary to the findings of Rizzo et al. (2008). Unlike the study of Rizzo et al. (2008), the pH continues to have little impact as dosage increases beyond the optimum.

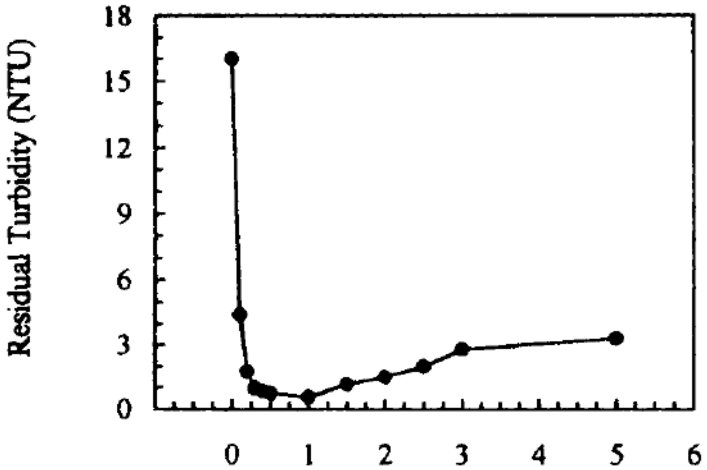


Figure 2.6 The residual turbidity of supernatants after jar mixing/settling of coagulated particles with various chitosan dosages for an initial turbidity of 30 NTU at pH 4 (Huang and Chen, 1996).

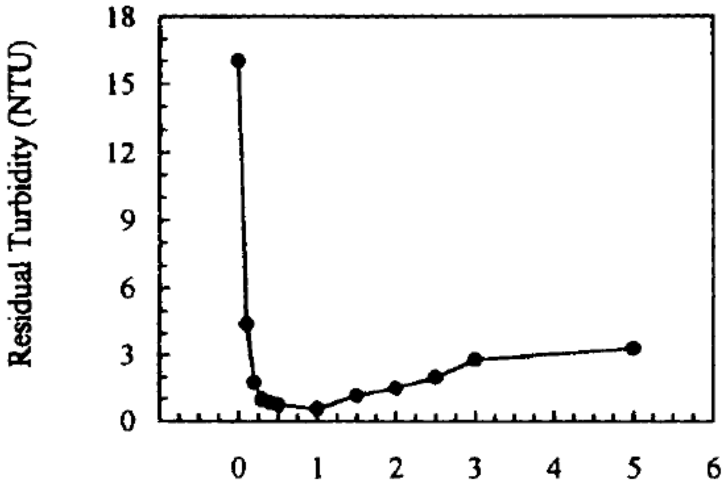


Figure 2.7 The residual turbidity of supernatants after jar mixing/settling of coagulated particles with various chitosan dosages for an initial turbidity of 30 NTU at pH 7 (Huang and Chen, 1996).

Huang and Chen (1996) proceeded to test the optimal chitosan dose upon more turbid suspensions of both their bentonite and kaolinite samples. Interestingly the bentonite is far more easily removed than the kaolinite particles having the same initial turbidity. This prompted Huang and Chen (1996) to add bentonite as a coagulant aid in form of a 100:1, bentonite: chitisan mix. In doing this a dramatic improvement to the removal of kaolinite was achieved. Finally, Huang and Chen (1996) proved a linear relationship between the optimum chitosan dose (combined with the bentonite coagulant aid) and the turbidity of kaolinite. A pictorial representation of the findings of Huang and Chen (1996) is seen in figure 2.8 to 2.11.

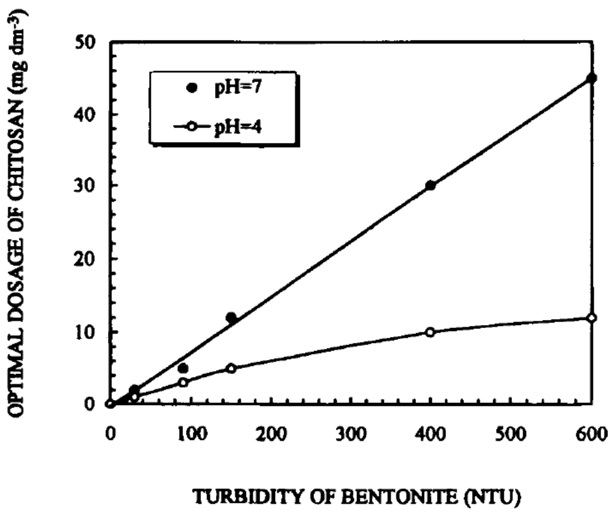


Figure 2.8 Optimal chitosan dosages for bentonite suspensions of various turbidity's in acidic and neutral pH conditions (Huang and Chen, 1996).

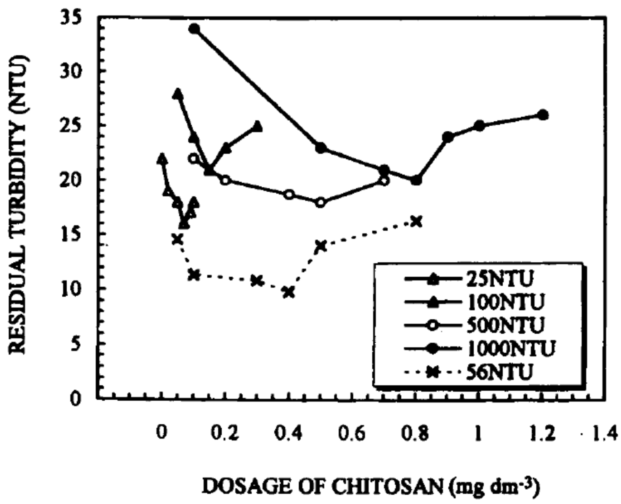


Figure 2.9 The residual turbidity's of supernatant after jar-mixing/settling with various chitosan dosages for the 25, 100, 500 and 1000 NTU kaolinite suspensions and a 56 NTU raw suspension (Huang and Chen, 1996).

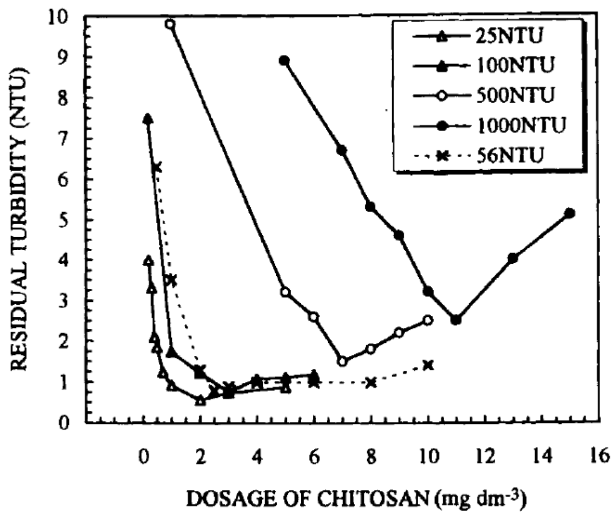


Figure 2.10 The residual turbidity's of supernatant after jar-mixing/settling with various chitosan dosages and bentonite additive for the 25, 100, 500 and 1000 NTU kaolinite suspensions and a 56 NTU raw suspension (Huang and Chen, 1996).

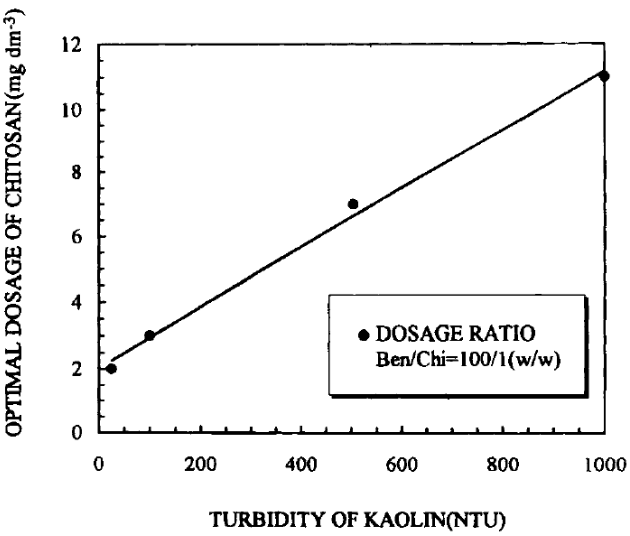


Figure 2.11 The comparison of the optimal chitosan and bentonite dosage with kaolinite suspensions of various turbidity's (Huang and Chen, 1996).

In an approach that best mirrors the levels of turbidity recorded in the TRC water quality monitoring data, Divakaran and Pillai (2002) determine an optimum chitosan dosage to treat river silt. Again Divakaran and Pillai (2002) use a self-prepared chitosan solution created by similar means to Huang and Chen (1996). The tests are conducted on pH neutral water collected from the Periyar River in India with initial silt suspensions from 10-160 NTU. In most instances turbidity removal peaks at a chitosan dose of 0.5 mg/L. Beyond this dose turbidity removal diminishes due to re-stabilisation of the particles. The phenomenon is more pronounced at lower turbidity levels. A summary of the results of Divakaran and Pillai (2002) in terms of optimum chitosan dosage can be seen clearly in Figure 2.12.

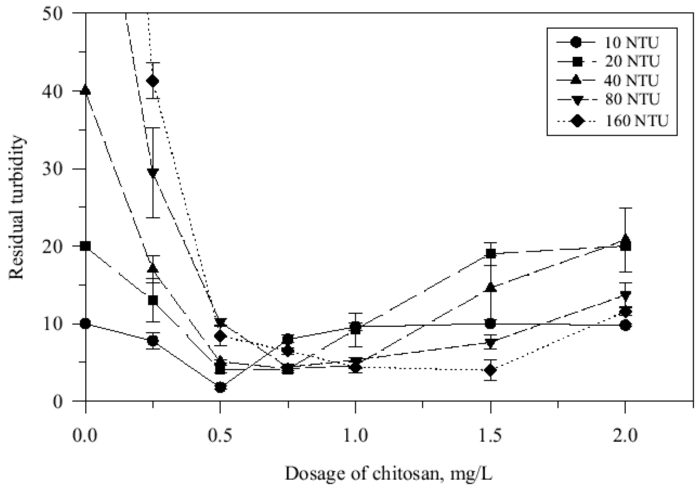


Figure 2.12 Effect of varying chitosan dosage (in mg/L) on the residual turbidity attained, starting with water having and initial turbidity's of 10-160 NTU at a pH of 7. Vertical bars indicate standard deviation from six repetitions (Divakaran and Pillai, 2002).

2.5.3. Particle Re-Stabilisation

In the research of both Huang and Chen (1996) and Divakaran and Pillai (2002) the phenomenon of particle re-stabilisation is exhibited. They recognise it but do not provide detailed explanations for its occurrence. Ng et al. (2006) give a more thorough explanation in their study however. Re-stabilisation occurs due to an overdose of coagulant. The overdose of coagulant causes the normally negatively charged suspended particles to become coated in the positively charged hydroxide ions. The particles then exhibit a net positive charge and repel each other as they did initially as negatively charged particles, thus becoming re-stabilised. A measure of the charge upon the particle is its zeta potential, which is measured in millivolts (mV). Turbid water usually has a negative zeta potential. This is neutralised by the addition of coagulant. Treated water in which re-stabilisation has occurred, will possess a positive zeta potential.

2.5.4. Chitosan-Enhanced Sand Filtration Systems

Technology developments in the field of chitosan enhanced sand filtration have proven effective in treating highly turbid water. Several American companies have adapted practices usually confined to urban drinking water treatment to stormwater treatment. This has applied to de-watering flooded construction sites and the in-situ treatment of polluted waterways. Two such organisations are Natural Site Solutions and Clear Creek Systems, who both develop and recommend chitosan based water treatment services. Each organisation utilises an alternate chitosan product. Examples of commercially available chitosan products targeted at the stormwater treatment market include StormKlear Liquifloc™ from Natural Site Solutions and FlocClear™ Biopolymer from Clear Creek Systems. StormKlear Liquifloc™ is 1% chitosan acetate by weight, whilst FlocClear™ Biopolymer is a 2% solution of chitosan acetate.

Natural Site Solutions' operations centre on the implementation of relatively small-scale chitosan-enhanced sand filtration systems. Natural Site Solutions offer a range of treatment plants ranging up to plants capable of delivering a discharge of 2,900 litres per minute. In the absence of hydrological data it is assumed such systems would prove adaptable to a medium-scale harvesting operation as proposed by the Fast-Rate Stormwater Re-Use Scheme. The operations and maintenance manual (Natural Site Solutions, 2003) supplied with the plants, claim to achieve approximately 50-60 percent efficiency in suspended solids removal in the absence of Liquifloc. Addition of the chemical is claimed to average a 95-99 percent turbidity removal with no change to water pH. After dosing with Liquifloc the colloidal particles are removed by sand filtration. Sludge collected on the filter media is backwashed at time intervals dependant upon the sediment concentration. Little data existed in the manual regarding the mixing and flocculation regime and it was apparent there was no settling in the plant. The manual does however suggest the filters are placed at a minimum of 50 feet (approx. 15 metres) from the chemical injection point. This will propagate a form of rapid mixing given flow conditions are turbulent. Natural Site Solutions claim their plant will adequately treat stormwater up to 1000 NTU and pH from 6.5-8.5. Stormwater outside these parameters will require pre-treatment. Effective turbidity removal occurs when chitosan acetate is dosed between 0.25-1.0 mg/L. Natural Site Solutions' operations and maintenance manual relates dosage to turbidity so 0.1mg/L is added for every 100 NTU increase within the influent stormwater (Natural Site Solutions, 2003). A schematic of the Natural Site Solutions fast rate treatment plant is shown below in figure 2.13.

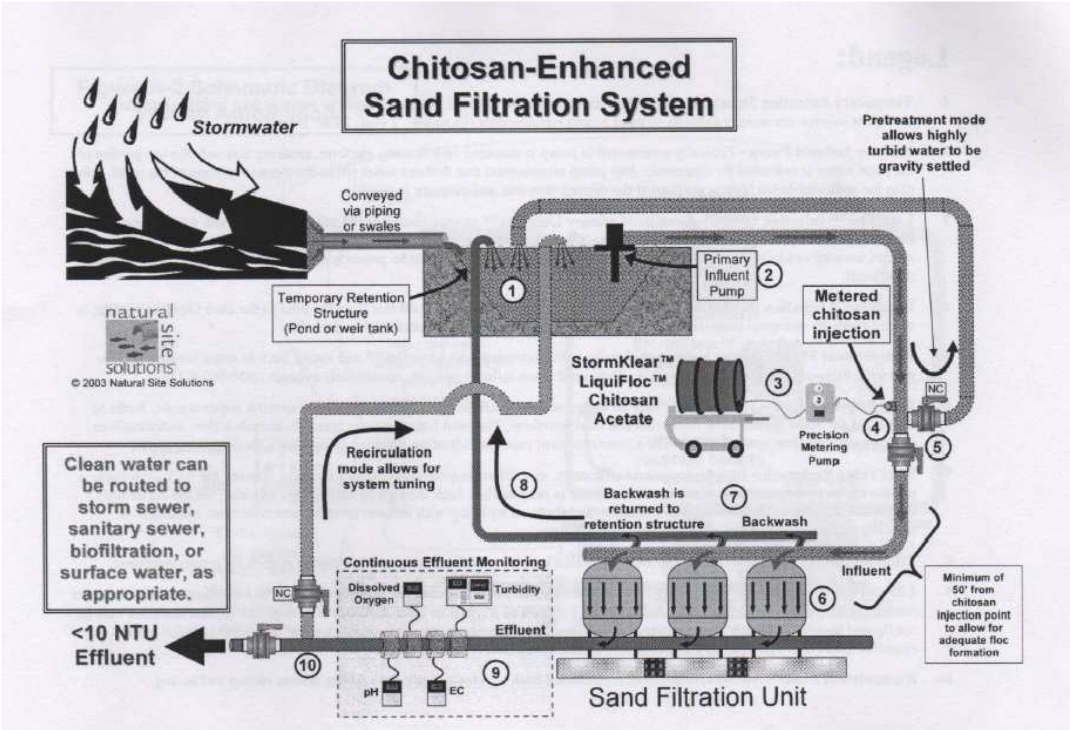


Figure 2.13 A schematic of the Natural Site Solutions Chitosan-Enhanced Sand Filtration System (Natural Site Solutions, 2003).

Like Natural Site Solutions, Clear Creek Systems have developed treatment systems to remove suspended solids from stormwater using the chitosan polymer. Clear Creek Systems approach is similar in that its Chitosan-Enhanced Sand Filtration systems are targeted at treating construction site runoff and other highly polluted industrial stormwater. Clear Creek Systems chemical of choice FlocClear Biopolymer is applied at rates up to at maximum of 1.0 mg/L. A 1.0 mg/L dose is deemed sufficient to treat influent stormwater up to 600 NTU. It must be noted that FlocClear is however a 2% chitosan acetate solution by weight, thus Clear Creek Systems suggest a maximum dose twice that of Natural Site Solutions. Pre-treatment is recommended when turbidity exceeds 600 NTU. FlocClear may be used in the pre-treatment process.

There is also a lower turbidity limit of 50 NTU for influent water suggested by Clear Creek Systems. The Chitosan-Enhanced Sand Filtration system will sound an alarm when the water entering the plant is outside the range specified above. The fact this lower limit exists may pose problems to treating urban stormwater. Thus investigating the performance of chitosan at low turbidity will be essential. Clear Creek Systems suggest jar tests be conducted to determine the optimum coagulant dose at start up. Similarly, jar tests must also be used when influent turbidity readings vary by 20% or greater. The performance of the plant is claimed to produce effluent with a residual turbidity of less than 10 NTU (Washington State Department of Ecology, 2008).

Figure 2.14 Two Clear Creek Systems - Chitosan-Enhanced Sand Filtration Systems treating contaminated runoff at West Park in Roseville, California (www.clearcreeksystems.com, 2005)

2.6. Modified Clay and Activated Carbon Treatment of Urban Runoff

Clear Creek Systems also produce urban stormwater treatment plants that use modified clay and activated carbon filter media for the removal of oil based contaminants. In the modified clay filters, bentonite clay is modified with quaternary amines, rendering it organophillic. These '*organoclays'* have been used effectively to remove mechanically emulsified oil, grease and other sparingly soluble large chlorinated hydrocarbons from urban stormwater in the United States. The other type of filter media is a virgin granular activated carbon made from selected grades of bituminous coal. This product is specifically designed for liquid phase applications where high surface area is needed for maximum absorption. Although not chitosan based processes, the above filtration methods are clear examples of stormwater harvesting schemes. By treating the initial runoff from urban landscapes, a source of non-potable water is provided, whilst dramatically improving the health of creek systems. The above technology will not be investigated as part of the project but the filter media is a great example of what could be incorporated to an urban stormwater recycling plant in Toowoomba (Clear Creek Systems, 2005).

Figure 2.15 Clear Creek Systems – Urban runoff treatment plants utilising modified clay and activated carbon filter media (www.clearcreeksystems.com, 2005)

2.7. Environmental and Health Factors

The environmental and health impacts of introducing a new chemical, such as chitosan must be thoroughly understood prior to being accepted for use in Australia. Chitosan is used in America, which possesses similar environmental protection bodies to Australia. Chitosan being organic and biodegradable, has the potential to solve issues related to the use and disposal of conventional inorganic coagulants. In their research Divakaran and Pillai (2002) noted that the sludge obtained from such treatment poses disposal problems and tends to accumulate in the environment. Divakaran and Pillai (2002) also point to the work of Stauber et al. (1999) and Pontius (2000) who state that there is increasing concern about residual aluminium in drinking water, which may be present as a result of alum treatment. Residusal aluminium has been expressed by the public in connection with Alzheimer’s disease. To date these concerns have not been conclusively proven. Toowoomba’s drinking water supply is no longer treated with aluminium sulphate (alum), however Magnasol 589 is an aluminium based polymer. Further research into these health effects would be invaluable in evaluating preferred coagulants. Despite the lack of evidence regarding the health effects of residual aluminium, there is an obvious advantage in developing biodegradable coagulants such as chitosan where cost and performance are comparable.

CHAPTER 3

RESEARCH AND TEST METHODOLOGY

3.1.Stormwater Capture

Stormwater samples were collected from a variety of sites within Toowoomba during and immediately following rainfall events. Targeted sites included road gully inlets, road kerb and channels, stormwater drainage headwalls, detention ponds and creek systems. A variety of sites was desirable so as to include a representative sample of water quality. This allowed for conclusions to be drawn regarding the position and scale of a stormwater harvesting plant. During the project stormwater samples were collected during four separate rainfall events. Capture sites chosen for each catchment include:

- **West Creek** – Concrete lined channel at Creedon Drive
- **East Creek** – Unlined Creek at Ballin Drive
- **Gowrie Creek** – Just upstream from Wetalla WWTP
- **Westbrook Creek** – Unlined Creek at Smart Drive
- **Road Pavement Runoff** – Road Gully Inlets at Smart Drive and Hoey Street

Unfortunately time did not permit the sampling of the Black Gully and Dry Creek catchments. At each of the above sites stormwater was collected in plastic 20 litre buckets. Although not apparent at the commencement of stormwater sampling, it became clear that 60 litres from each site was the preferable amount. Buckets were clearly marked, indicating the location and date that the stormwater sample was captured. When laboratory facilities and or sufficient time where unavailable samples were stored in the USQ post-harvesting cold room. This aimed to retain the water characteristics at the time of capture by housing the samples in a cool environment. A risk assessment for the capture of the samples has been undertaken and is included later in this chapter.

Figure 3.1 Captured stormwater samples at the Wetalla Wastewater Treatment Plant laboratory

3.2.Contingency Plan for Stormwater Capture

As rainfall is inherently variable, a contingency plan was devised in the event of insufficient rainfall over the study period. Capture of stormwater samples would revert to collection from stagnant creek systems and detention ponds. The possibility of preparing synthetic samples from local clays was also considered. Instead it was decided the stormwater ponded in creeks during dry weather was more representative of urban runoff. The contingency plan was used on three separate occasions during the study period where test days had been organised and there was insufficient samples. Testing of these dry weather samples was compared to samples taken from the same sites during rainfall to determine discrepancies water quality.

3.3.Water Quality Testing

All testing for the project was conducted at Toowoomba Regional Council's Wetalla Wastewater Treatment Plant. The laboratory was chosen primarily due to the range and availability of testing equipment.

3.3.1. Turbidity Measurement

The turbidity of both raw and treated samples was measured using a TPS Model WP-88 turbidity-temperature meter sourced from the USQ. The meter is designed primarily for field work but proved adequate for laboratory work. Prior to testing the meter was calibrated using the synthetic 90 and 900 NTU control samples.

Figure 3.2 Turbidity was measured using a TPS Model WP-88 turbidity-temperature meter

3.3.2. pH Measurement and Adjustment

Prior to each jar test the pH was measured and adjusted where applicable. pH was measured using a Cyberscan 2100 meter at the Wetalla laboratory. The meter was calibrated when display on the meter requested it using the manufacturer's instructions. In tests to determine the optimum pH, hydrated lime and 0.01 Molar hydrochloric acid (HCl) was used to adjust the pH. Hydrated lime was sourced directly from the silo at the Wetalla facility. When adjusting pH, care was taken to ensure the reading on the meter had stabilised before adding more acid or lime.

Figure 3.3 pH measurements using a Cyberscan 2100 pH meter

3.3.3. TSS (Total Suspended Solids) Test Procedure

Total Suspended Solids (TSS) testing was conducted as per the Toowoomba Regional Council quality plan (Toowoomba Regional Council, 2008). TSS testing was used primarily to validate the readings received from the turbidity meter. Due to TSS testing taking an extended period to conduct, the test was conducted on selected, representative samples. A major consideration when testing raw water was ensuring grass clippings and submerged agglomerates were excluded from the sample prior to testing.

TSS testing was conducted using the following apparatus:

- Filter holder
- Vacuum pump
- Filter flask, 1000mL
- Drying oven 103ºC-105ºC
- Analytical balance
- Glass fibre disc (Watman GF/C 47-50mm)
- Desiccator and desiccant
- Graduated measuring cylinders 25mL, 50mL, 100mL, 500mL
- Tweezers
- Filter rack

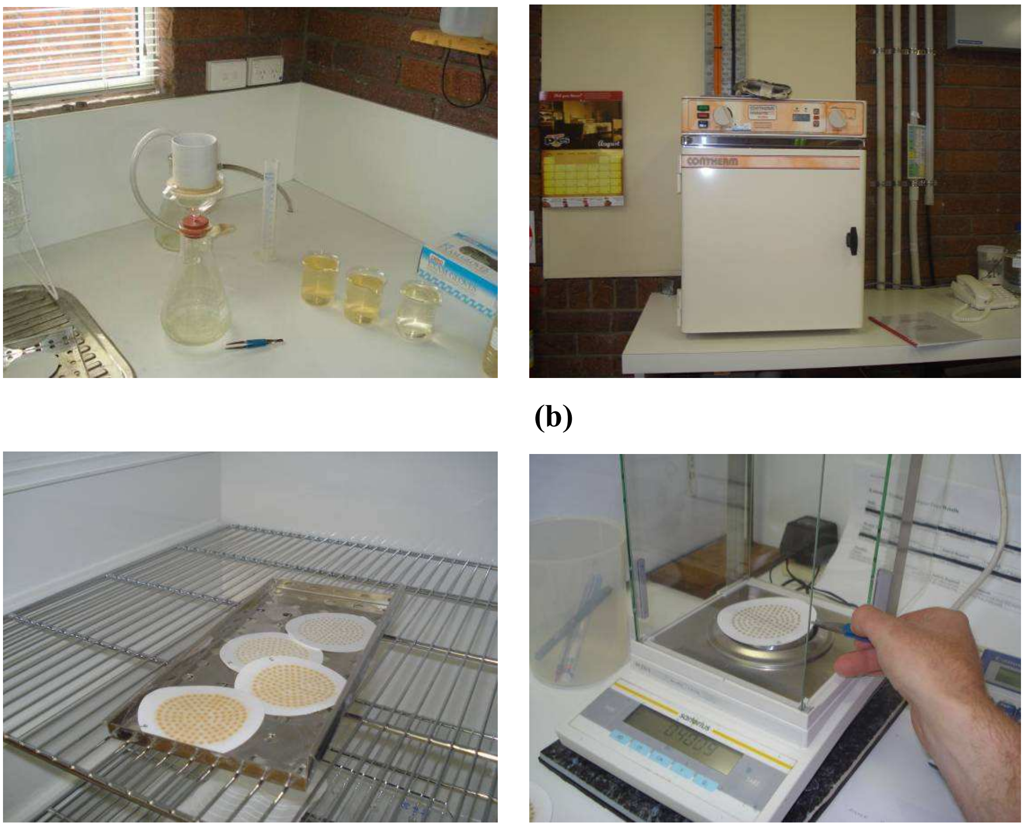
The TSS test procedure is as follows:

1. Place the glass filter disc on top of the filter apparatus and clamp in place.
2. Apply vacuum and check that the disc is not torn.
3. Wash the disc three times using approximately 20mL of distilled water.
4. Remove the disc from the filter apparatus and place in a drying oven at 103ºC-105ºC for one (1) hour.
5. After one hour remove from the oven and place in the desiccator to cool to room temperature.

6. Immediately before use, remove the filter disc from the desiccator and weigh. The weight of the unused filter disc is called W1 (in grams).
7. Replace the filter disc on the filter apparatus and clamp in place.
8. Apply vacuum and filter a measured volume of sample through the filter disc.
9. Rinse 3 times with distilled water as previously described.
10. Remove the filter disc from the filter apparatus and dry in the oven at 103ºC-105ºC for two (2) hours.
11. Remove from the oven after two hours and cool in a desiccator to room temperature and weigh. The weight of the dry filter disc and residue is W2 (grams).

Calculations:

$$\textbf{Total Suspended Solids (TSS)} = \frac{\textbf{(W2(g)-W1(g)) x 1,000,000}}{\textbf{mL of sample}} \quad \textbf{(mg/L)}$$



(a) **(b)**

(c) **(d)**

Figure 3.4 TSS test procedure showing (a) TSS filter apparatus and samples, (b) Drying oven, (c) Desiccator and samples, (d) Analytical balance

3.4. The Jar Test

To conduct performance trials of chitosan and Magnasol 589 the jar test was employed. A major consideration in the use of the Wetalla laboratory was the availability of a jar tester. At the time of testing the jar tester at Toowoomba's Mt Kynoch water treatment laboratory was unavailable. The USQ model was undesirable also as it was limited to a single test at any one time. The Mt Kynoch tester was the preferred choice as it possessed square jars, whereas the Wetalla apparatus' jars were circular. Square jars are designed to simulate the 'dead spots' experienced in flocculation tanks. This machine had the added advantage of draw-off taps from which to sample the supernatant treated water. The use of circular jars indicates that flocculation will be more efficient as dead spots are effectively eliminated.

3.4.1. Apparatus

A Phipps and Bird Model PB – 700 was used for the testing. The tester has the capacity to conduct six tests simultaneously. Each test jar has a volume of 2000mL. Additional equipment in the laboratory was also utilised for the jar test. This includes a graduated 1000mL beaker and magnetic mixer for preparing the coagulant solution and mixing acid and lime during pH correction. A pipette was used for dosing the coagulant into the 1000mL beaker and from the beaker to the test samples. An electronic timer was used to monitor mixing and settling durations.

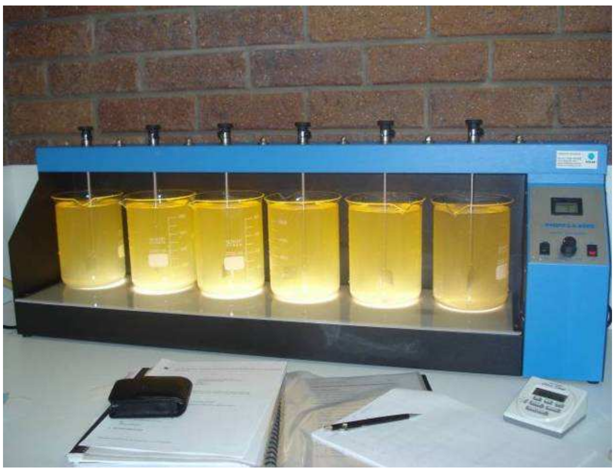


Figure 3.5 A Phipps & Bird Model PB – 700 Jar Tester with six 2000mL samples.

3.4.2. Jar Test Methodology

Like the TSS tests, jar testing was conducted in accordance with the Toowoomba Regional Council's quality plan requirements (Toowoomba Regional Council, 2000). The TRC quality plan for laboratory staff at the Mt Kynoch laboratory is conducted using the following steps:

1. Collect represented samples of water to be dosed.
2. Prepare a solution of the coagulant to be tested by adding 1mL to 1L of distilled water. Mix well for 5 minutes.
3. Clearly label the jars with dose rates being tested.
4. Fill jars with 2L of sample and place in jar tester.
5. Turn the stirrer on and dose jars with the amount marked on the jar.
6. Determine time intervals where samples need to be collected.
7. When the time has expired, collect sample and test immediately.
8. Record results on jar test results form.

Information that was recorded varied from the quality plan requirements as it was developed for municipal water treatment analysis. pH and turbidity were recorded both before and after the test. Iron, manganese, and aluminium concentration were excluded as was colour alkalinity and total hardness. The mixing regime for the tests had not been clearly specified in the TRC work instructions for laboratory staff. In the absence of this vital information the relevant mixing times and corresponding mixing speed was sourced from a previous study. The system of Huang and Chen (1996) was adopted, who incorporated a 2 minute rapid mixing phase at 100 rpm, followed by flocculation at 30 rpm for 20 minutes and a final settling time of 30 minutes.

3.5.Risk Assessment

This research like almost all daily activities involves an element of risk. Despite the fact that the chance of injury to oneself or others may be small, a risk assessment must still be carried out. The project will contain numerous risks, some which may be considered a small risk and others a large risk associated to a dangerous activity.

3.5.1. Stormwater Collection Risks

The first and major risk to be analysed is linked to the collection of stormwater samples. The task could be considered as slight (possible but unlikely) in terms of its likelihood. The consequence of the risk becoming reality will encompass all levels of possible consequences ranging from minor equipment damage through to death in the worst case scenario. To control this risk several measures need to be employed including obeying relevant traffic laws, being alert to nearby vehicular movements and wearing a florescent safety vest. A risk also associated to the collecting of stormwater is approaching rapidly flowing creek systems and drainage structures. The task could be seen as a significant risk as it is possible that harm could eventuate. Again it will be a rare risk (only several times yearly) and consequences will again range from minor equipment damage to death. To mitigate this risk a sound footing be gained before attempting to capture samples. Suitable footwear will also be essential, preferably a type with considerable grip.

3.5.2. Laboratory Testing Risks

The other foreseeable risks are attributed to the testing of the samples. The chemicals that are used must be properly managed to ensure safety. Chitosan as per the material safety data sheet (see appendix C) has very few risks, thus the chance of harm is minimal. Even the worst case scenario of constant skin and eye contact will only produce minor irritations. Nonetheless skin and eye contact will be avoided by using the appropriate laboratory equipment to handle the chitosan. The original test plan incorporated the use of aluminium sulphate (alum). There were significant dangers associated with continual direct exposure to alum. Subsequent visits to the Mt Kynoch water treatment facility confirmed Magnasol 589 was the primary coagulant and hence it was selected for use in this project. The use of this chemical avoided some safety precautions as the effects of Magnasol exposure are similar to those of chitosan. Magansol 589 is an irritant to the skin and eyes and exposure should be cotrolled. This is confirmed in the material safety data sheet (see appendix C). The risk of skin and eye contact to hydrochloric acid when adjusting pH was negated through the use of safety goggles. Gloves were not worn as the acid was delivered via a dispenser atop the hydrochloric acid bottle, avoiding any direct skin contact. The project risk assessment is summarised in Appendix B.

CHAPTER 4

DATA AND RESULTS ANALYSIS

The testing took place at the Wetalla Wastewater Treatment Plant over a four month period. Testing was conducted on weekly basis to coincide with the availability of the laboratory. This meant utilising the contingency plan when stores of stormwater collected during rainfall were exhausted. The testing ran relatively smoothly and became more efficient as an understanding of the test procedures was gained. An oversight related to the dosage of chitosan spoiled several early tests. This problem saw chitosan dosed according the volume of FlocClear, not chitosan acetate. After several poor tests and further research it became apparent FlocClear was a 2% chitosan acetate solution by weight. The dosage was adjusted and results improved markedly.

4.1. The Effect of pH Upon Turbidity Removal

In an attempt to determine an optimum pH level for both coagulants, the pH was adjusted according to the aforementioned methodology (section 3.3.2). Problems were experienced early in the study when adjusting the water to a whole pH unit. The reading fluctuated seemingly uncontrollably with the addition of either acid or lime. This problem was avoided by allowing sufficient time for the reading on the meter to stabilise prior to adding more acid or lime. Although taking considerable time, an accuracy of ± 0.05 pH units was achieved using this approach. Interestingly, the addition of hydrated lime also increased the turbidity of the water. This could be clearly seen by eye as the test sample became slightly cloudy and visible amounts of lime sediment accumulated at the base of the jar.

4.1.1. pH and Magnasol 589

Both coagulants were tested for optimum pH using wet weather West Creek stormwater samples captured from the concrete lined channel east of Creedon Drive.

Despite being captured some 20 days apart, the water exhibited a very similar appearance, pH and turbidity. In the first test Magnasol 589 produced excellent results. The results largely indicated a low sensitivity to the pH adjustment as all final turbidity readings were at or below 4 NTU. The maximum turbidity removal was achieved at pH 7.25, with only 1.5 NTU remaining in the supernatant. As mentioned above, the problems pertaining to pH adjustment limited the range that was tested. Nonetheless the range shown in the Figure 4.1 and the test 1 data sheet (Appendix A) covers all probable pH readings of Toowoomba stormwater. TRC stormwater quality data seldom shows a pH reading outside the range of pH 6.5 - 9.0. These results are encouraging from the viewpoint of urban stormwater treatment. A coagulant that performs over a large range of pH levels will eliminate the need for pH correction. This in turn reduces costs by minimising the need for additional materials and testing.

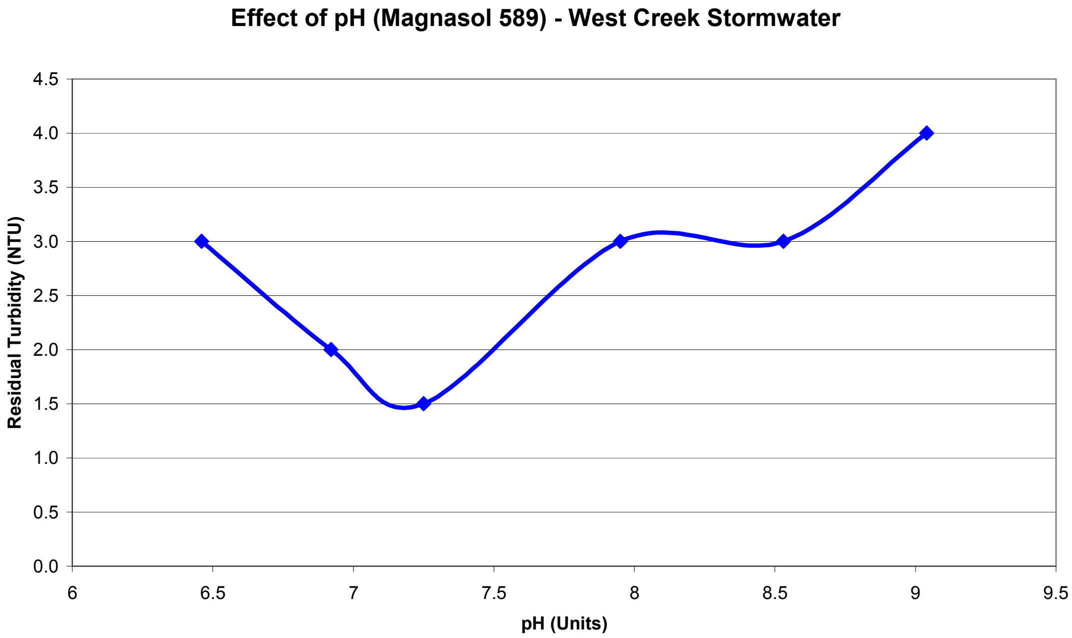


Figure 4.1 The effect of pH upon performance of Magnasol 589. Influent turbidity = 22.5 NTU.

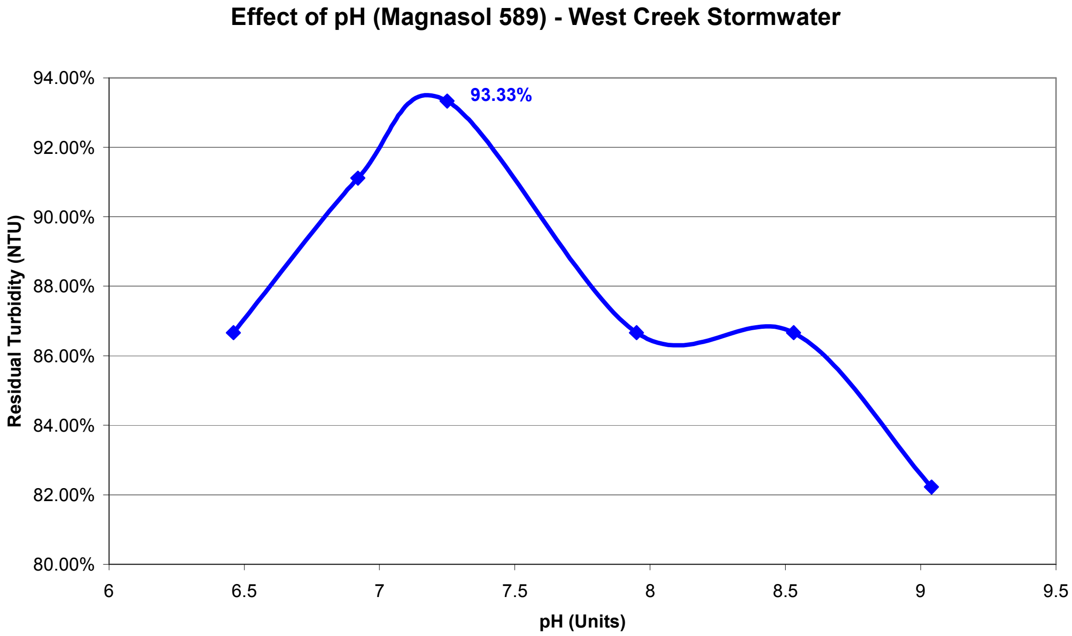


Figure 4.2 The effect of pH upon performance of Magnasol 589 by percentage turbidity removed

4.1.2. pH and Chitosan - FlocClear

The effect of pH upon chitosan performance tests were not finalised until some time after the Mangasol testing due to the problems administering a correct dosage. For the purposes of the research it was decided to broaden the tests to a pH range of 5.0 – 10.0. The improved pH adjustment methodology was implemented and samples were accurately corrected to the desired pH level. The test results again produced encouraging results, however not as effective as those from Magnasol 589. The chitosan tests result in a higher residual turbidty of 3.9 NTU. Maximum turbidty removal was achieved at pH 7.0. Figure 4.3 clearly shows that FlocClear experiences a greater sensitivity to dose than Magnasol 589. This sensitivity is seen below as virtually no reduction in turbidity is achieved below pH 6.0 and above pH 9.0. The increase in turbidity beyond pH 9.0 can be attributed to the addition of hydrated lime in the pH adjustment process. The implications of these results will be discussed further in the following chapter.

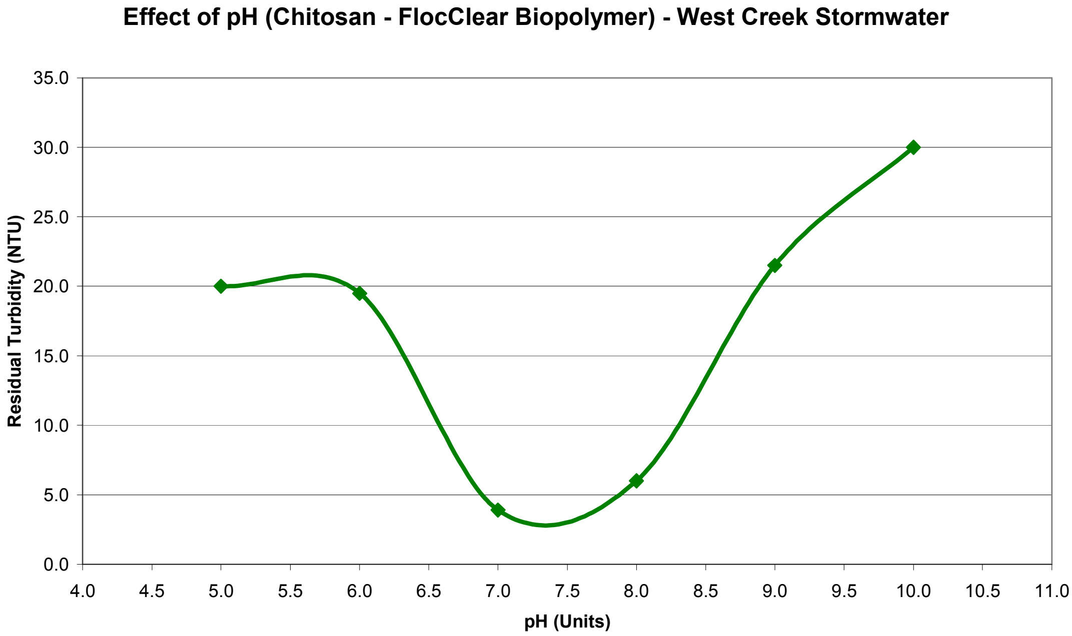


Figure 4.3 The effect of pH upon performance of Chitosan - FlocClear. Influent turbidity = 19.5 NTU.

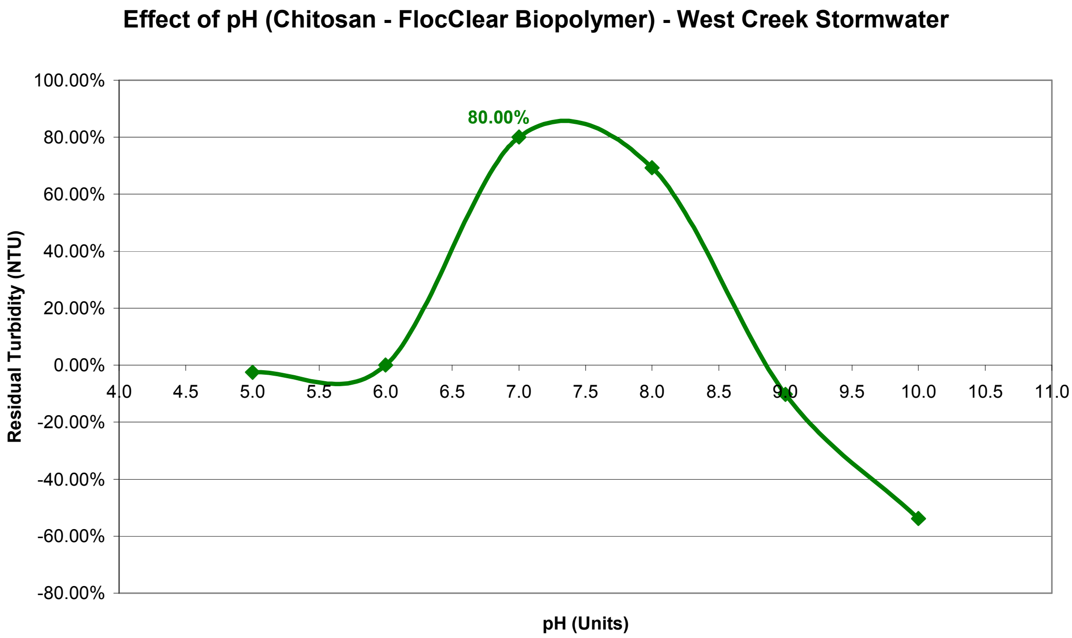


Figure 4.4 The effect of pH upon performance of Chitosan -FlocClear by percentage turbidity removed

The above pH testing demonstrated that an influent water quality exhibiting a pH of between 6.5 and 7.5 would produce good results for both coagulants. Throughout the duration of the study, testing revealed the raw stormwater pH was close to neutral. The minimum pH recorded was 6.73 and the maximum was 7.61. This indicated that the water wouldn't require a pH adjustment to achieve acceptable flocculation. Following this finding, it was decided that most attention be diverted to the determination of an optimum dosage for each chemical.

4.2. Optimum Chemical Dose

The determination of an optimum dose was considered in conjunction with water type and quality. The influent turbidity and the type of surface the captured sample originated from were important considerations. The study will not investigate particle size distribution or the presence of other contaminants due to both time and resource constraints. Visually, a significant difference could be detected between samples collected directly from a road and those collected from creek systems. The road pavement runoff was typically grey to black in colour, whereas the creek water was characterised by being a red/brown, presumably due to clay suspensions. The captured samples also contained varying levels of heavy sediments that settled a short time after capture. It was decided these particles be excluded from testing as they would be effectively settled in a treatment plant by a short detention period prior to treatment. This was achieved when testing by filling the jars using only the water near the top of the buckets and allowing any disturbed heavy particles to settle before filling the next jar.

Selecting a suitable dosage range prior to testing became another consideration. On several occasions the chosen range did not clearly show the optimum dosage. This was evidenced through either minimal flocculation in any samples or a test that did not exhibit some re-stabilisation of the particles. Re-stabilisation occurs when the turbidity removal efficiency diminishes as the dose increases beyond the optimum. Graphically, re-stabilisation is depicted through a 'U' shaped figure. To ensure the optimum dosage was found, secondary tests where carried out using identical stormwater samples with a different range of dosages.

4.2.1. The Optimum Magnasol 589 Dosage

The testing using Magnasol 589 found that dose rate was highly dependant upon influent turbidity. Figure 4.6 clearly shows a relationship between dosage and residual turbidity from three tests.

The 30 NTU West Creek sample captured in wet weather shows a constant rate of turbidity removal at dosages up to 3.5 mg/L. As the dose increases above 3.5 mg/L the efficiency is diminished, however residual turbidity still falls to a minimum at 5.0 mg/L. The final turbidity at 5.0 mg/L is 2.5 NTU. Supplementary tests were not conducted at higher doses as there were no identical samples remaining.

The dry weather sample collected from East Creek at a lagoon on Ballin Drive exhibited an initial turbidity of 62.0 NTU. At the time of capture the water was stagnant and exhibited high concentrations of red clay particles. Reference to TRC stormwater quality data shows this turbidity to be slightly above average for the catchment. The jar test produced excellent results in terms of the relative turbidity removal with over 90% removal at a dosage of 11.0 mg/L. This sample produced very rapid flocculation with flocs appearing immediately after dosing. The flocs were also large and fibrous. A photograph of this jar test is shown below in Figure 4.5. The results follow a similar pattern to those from the West Creek test above. Residual turbidity drops rapidly before stabilising, forming an 'L' shaped graph as seen in figure 4.6. This indicates a lack of sensitivity to dose as the optimum dosage is approached. This clearly proves Magnasol 589 will perform well when treating stormwater captured from creeks during dry weather. Figure 4.5 shows a marked difference in water clarity due to variable dosage during jar tests conducted on East Creek stormwater.

Figure 4.5 Jar testing of East Creek stormwater. Dosages range from 6.0mg/L (far left jar) to 11.0mg/l (far right jar)

The testing using Magnasol 589 found that dose rate was highly dependant upon the source water quality. This is evidenced through the performance of Magnasol 589 on stormwater captured directly from a road pavement at a Hoey St road gully inlet during a storm. The recorded data from the test (Appendix C – Test 7) proves flocculation is very slow and floc size is small when testing road pavement runoff. From a 14.5 NTU initial turbidity, a residual of 3.0 NTU was achieved at a dose of 5.5mg/L of Magnasol 589 by weight. Despite the apparent slow flocculation and settling, the result at optimum coagulant dose was encouraging. A clear finding from the test was the narrow window in which effective flocculation would occur. Unlike creek stormwater there was no gradual increase in efficiency with dose. Between 4.5mg/L and 5.0mg/L there is a sharp increase in performance. Re-stabilisation of the particles is exhibited between 5.5 – 6.5 mg/L and is very rapid.

The results of the Magansol 589 testing were encouraging. It provided a clear representation of what could be achieved using a conventional polymer based coagulant to treat various types of stormwater. The results of the variable dose Magnasol 589 testing are shown in Figure 4.6 as a measure of residual turbidity, in Figure 4.7 as percentage turbidity removed. A summary of the variable dose Magansol 589 testing is also seen in table 4.1 below.

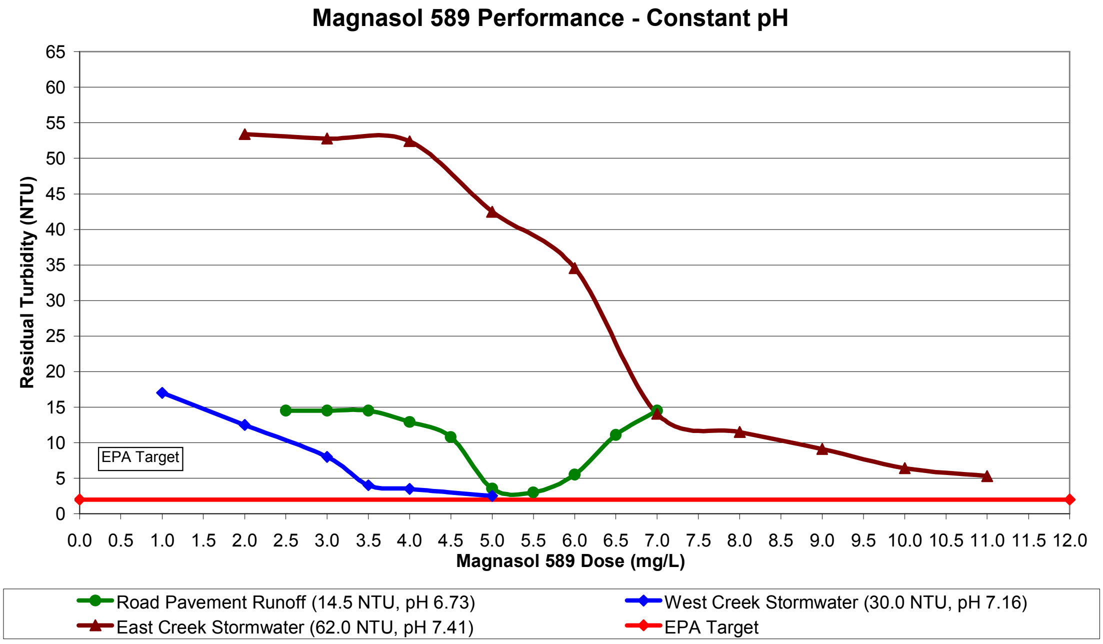


Figure 4.6 The effect of variable dosage upon the performance of Magnasol 589

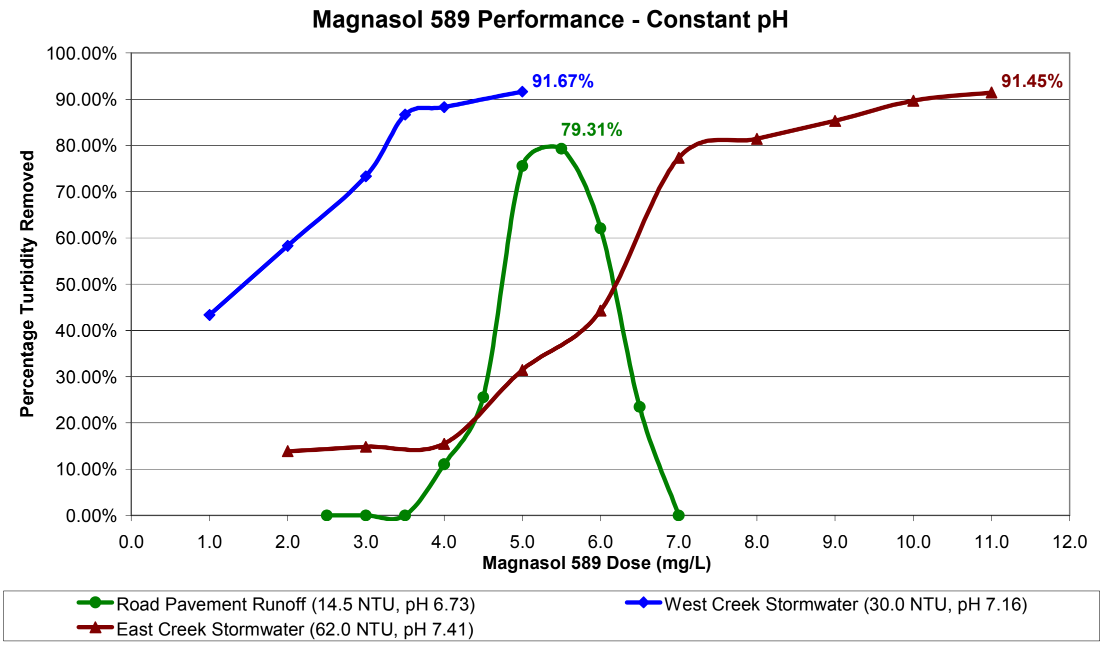


Figure 4.7 Magnasol 589 performance by percentage turbidity removed

Table 4.1 Variable Dose Magnasol 589 Testing Summary

Sample Location	West Creek (Creedon Dr)	East Creek (Ballin Dr)	Road Gully Inlet (Hoey St)
Weather Conditions	Wet	Dry	Wet
pH	7.16	7.41	6.73
Optimum Dose (mg/L)	5.0	5.5	5.5
Initial Turbidity (NTU)	30.0	62.0	14.5
Residual Turbidity at Optimum Dose (NTU)	2.5	5.3	3.0
Maximum % Turbidity Removed	91.67	91.45	79.31

4.2.2. The Optimum Chitosan Dosage

The optimum dosage of chitosan varied depending on the type of stormwater tested. Due to time constraints and a lack of rainfall, three samples were collected in dry weather from creek ponds. To cover a broader range of turbidity, two of these samples were created by mixing stormwater from separate sources. Stormwater was sourced from Gowrie Creek just upstream of the Wetalla plant and mixed with East Creek water. Varying the portions of each sample effectively controlled the turbidity. It must be noted the Gowrie Creek water was very clear (3.9 NTU). It was however alkaline and thus a slight pH correction was undertaken. Throughout the study period variable dosage testing was conducted on five separate samples including:

1. West Creek stormwater 19.5 NTU, pH 7.61 (wet weather)
2. Road pavement runoff 14.5 NTU, pH 6.73 (wet weather)
3. East Creek Stormwater 260 NTU, pH 7.05 (dry weather)
4. Mixture of East and Gowrie Creek stormwater 88.0 NTU, pH 7.61 (dry weather)
5. Mixture of East and Gowrie Creek stormwater 60.0 NTU, pH 7.59 (dry weather)

The typical test patterns were similar to those in the Magnasol 589 tests. Figure 4.8 and 4.9 show flocculation performance increasing gradually with dose to an optimum level. This optimum level is broad and appears to continue at a constant rate of residual turbidity despite the dose still increasing. An exception to this concept is again seen when testing road pavement runoff where rapid re-stabilisation occurs. The road pavement runoff tested using chitosan was an identical sample to that tested above with Magnasol 589. The optimum chitosan dosage for treating this road runoff was found to be 2.0mg/L, which left a residual turbidity of 5.5 NTU. Despite being achieved at less than half the dosage, the residual turbidity is higher than that for Magnasol 589.

The stormwater captured from the creeks (both wet and dry weather) showed that the optimum dosage is contained in a wide range. This appears in figure 4.8 as a plateau on the graph. The plateau is again preceded by an almost linear reduction of turbidity. The West Creek test is slightly different in that the reduction appears very gradual at first and is followed by a sudden decrease in residual turbidity. Flocculation was very good at dosages between 2.5 and 4.0 mg/L, peaking at 3.5 mg/L leaving a residual turbidity of only 2.6 NTU.

A sample from East Creek was captured in an attempt to trial chitosan on the same water quality that was used for the Magnasol test some months previously. Unfortunately the turbidity of the water captured from the same source had risen from 62 NTU to 260 NTU. Although an accurate head-to-head comparison could not be made, the water was tested and provided some interesting results. With a minor increase in optimum dose to 5.0mg/L, chitosan effectively reduced the residual turbidity from 260 NTU to 8.9 NTU (96.15%).

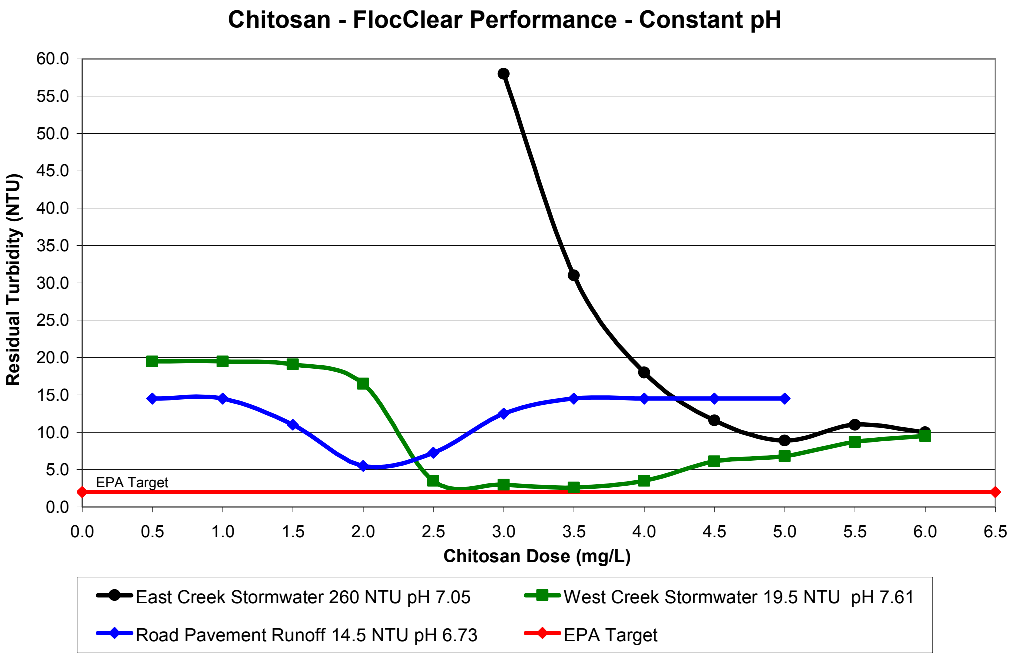


Figure 4.8 The effect of variable dosage upon Chitosan - FlocClear performance

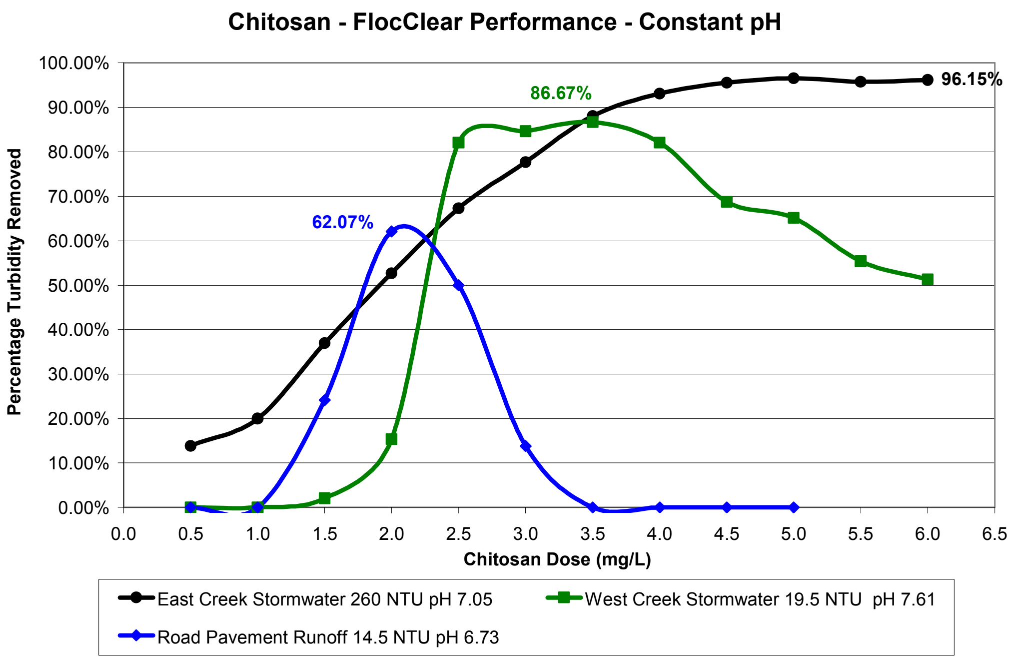


Figure 4.9 Chitosan - FlocClear performance by percentage turbidity removed

The samples prepared by mixing East and Gowrie Creek stormwater produced different results. Flocculation in the test was very slow initially. Over the twenty minute flocculation period flocs eventually grew to a large size. Although the residual turbidity remained relatively high, it was encouraging to note the wide range at which a moderate percentage of the suspended matter was removed. The 88.0 NTU sample reached an optimum level at a 3.5mg/L dosage, leaving 14.0 NTU in the supernatant. The 60.0 NTU sample reduced the turbidity to 14.6 NTU at 4.0mg/L. The test results for each of the five samples can be clearly seen in the two graphs below and the data sheets in Appendix C. A summary of the variable dose Chitosan – FlocClear testing is seen in table 4.2 below.

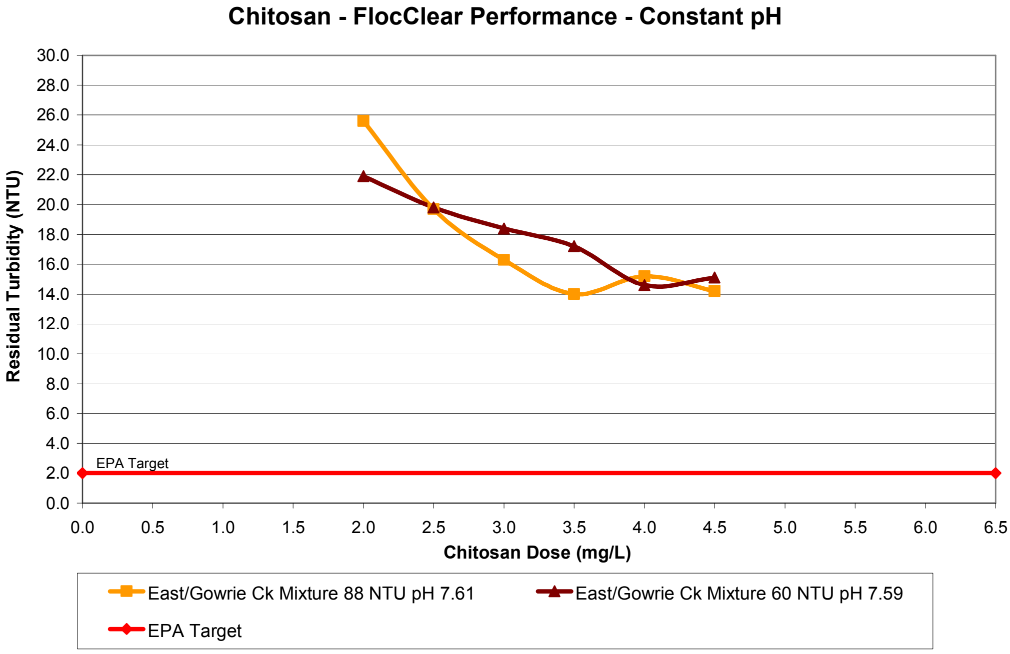


Figure 4.10 The effect of variable dosage upon Chitosan - FlocClear performance (Mixed Samples)

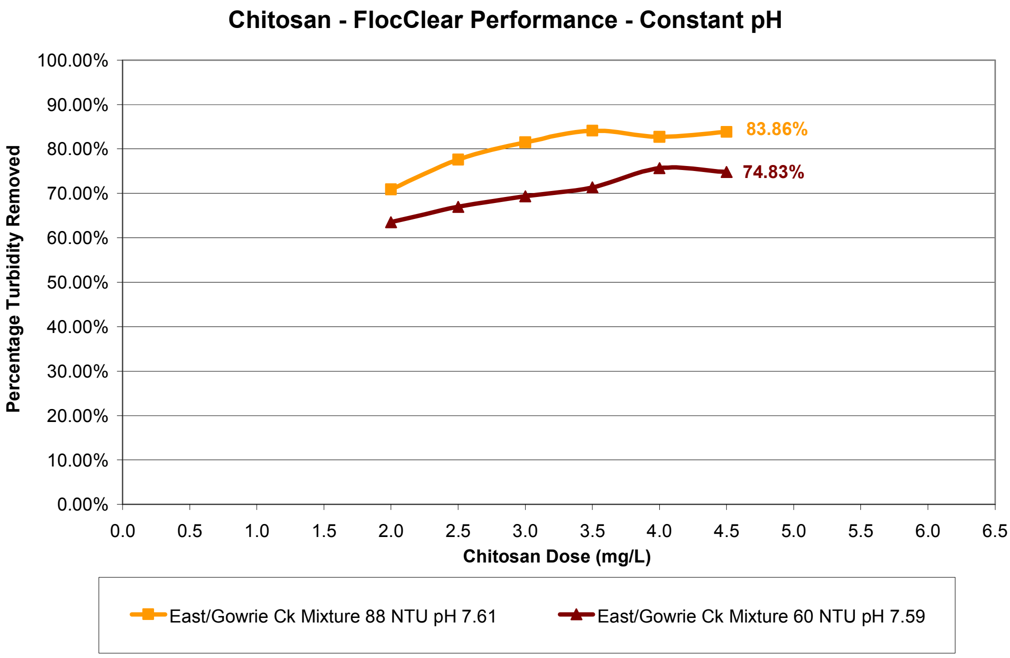


Figure 4.11 Chitosan - FlocClear performance by percentage turbidity removed (Mixed Samples)

Table 4.2 Variable Dose Chitosan - FlocClear Testing Summary

Sample Location	West Creek (Creedon Dr)	East Creek (Ballin Dr)	Road Gully Inlet (Hoey St)	Gowrie/East Creek Mix 1	Gowrie/East Creek Mix 2
Weather Conditions	Wet	Dry	Wet	Dry	Dry
pH	7.61	7.05	6.73	7.59	7.61
Optimum Dose (mg/L)	3.5	5.0	2.0	4.0	3.5
Initial Turbidity (NTU)	19.5	260.0	14.5	60.0	88.0
Residual Turbidity at Optimum Dose (NTU)	2.6	8.9	5.5	14.6	14.0
Maximum % Turbidity Removed	86.67	96.15	62.07	74.83	83.86

4.3. Turbidity and TSS Relationship

The project also aimed to validate the readings from the turbidity meter to results from total suspended solids tests. The relationship will also be compared to data from the Toowoomba Regional Council that contained both a turbidity reading and a TSS from an identical water sample. The tests were conducted upon stormwater captured from East Creek and treated using Magnasol 589 (refer to test 3 results – Appendix C). Even visually it was clear to see a consistent progression of water clarity in the treated samples. This confirms the near linear line exhibited above in figure 4.4 for East Creek stormwater. By plotting both the turbidity and the TSS from this test a linear relationship is again produced. These results are pleasing and they suggest that the more efficient turbidity measurement is an accurate measure of suspended solids.

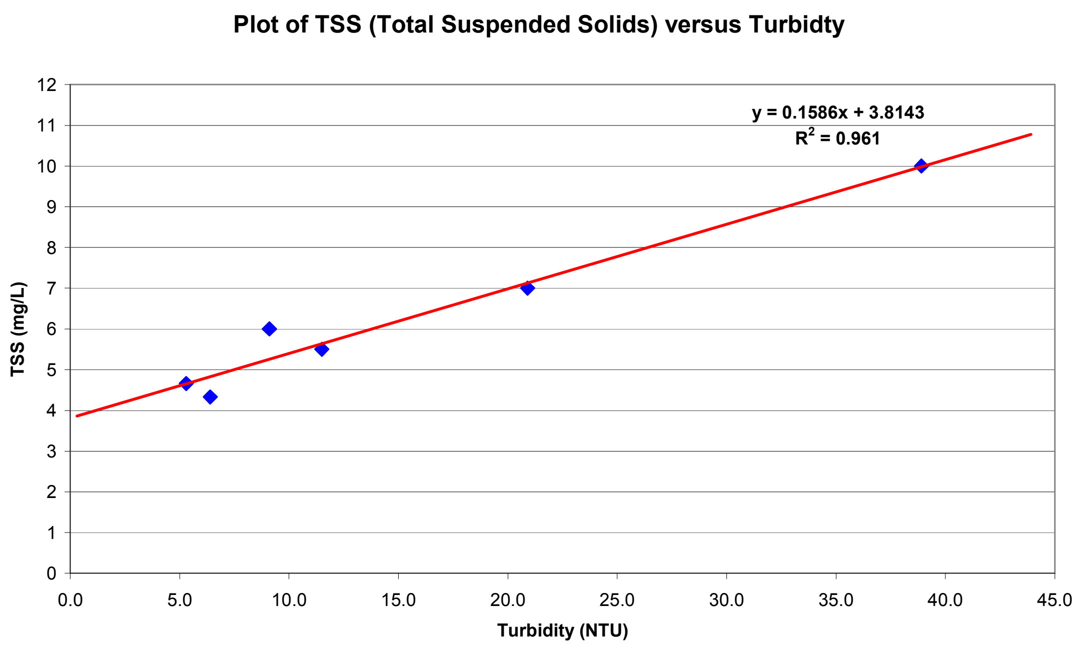


Figure 4.12 The relationship between TSS and Turbidity from treated East Creek Stormwater

The concept of turbidity as a measure of TSS was further investigated using stormwater quality data from the Toowoomba Regional Council. The results gained by plotting TSS against turbidity were less consistent however. Figure 4.6 shows a linear relationship is evident only at high turbidity readings. Below 80 NTU there is an upward trend as indicated by the red line, but there is little consistency in the results. An accurate relationship can not readily be drawn when the turbidity is below

80 NTU. Although not included here the relationship from the other five stormwater catchments produces a similar graph. Without an understanding of how the TRC water samples were captured and tested, the reasons behind these results remains unknown.

The regression equation shows a very similar rate of change of TSS with respect to turbidity in both comparisons. The inaccuracy of the TRC data is highlighted by the intercept on the TSS axis. Theoretically at a zero TSS reading should also translate to zero turbidity. For the purposes of the study the turbidity will be utilised to measure water quality.

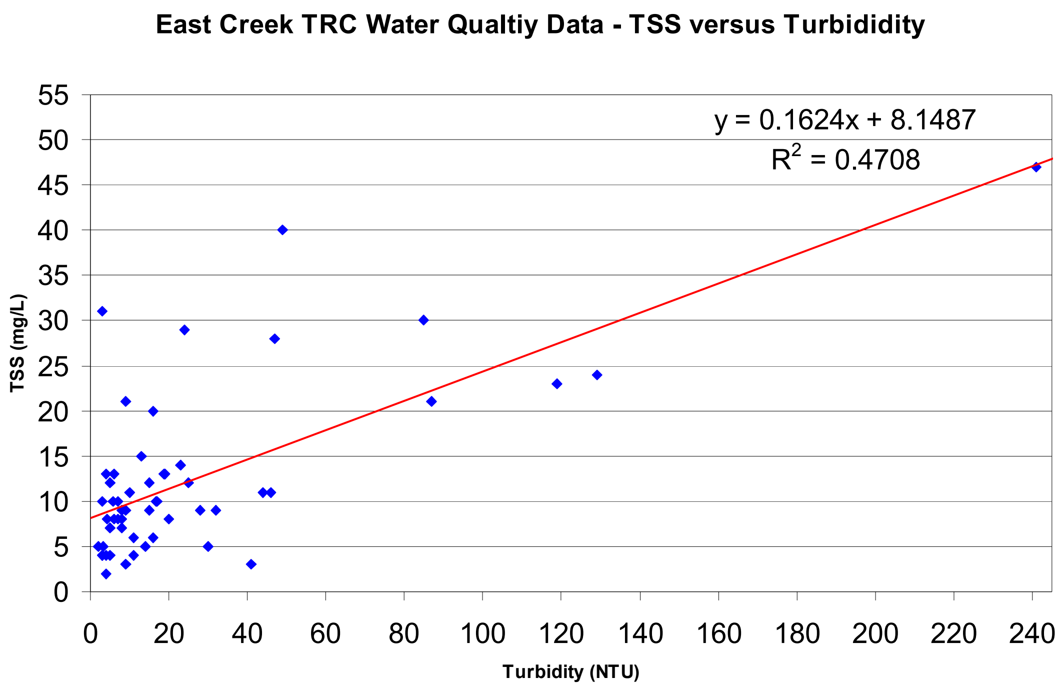


Figure 4.13 The relationship between TSS and Turbidity from TRC water quality data

CHAPTER 5

DISCUSSION AND IMPLICATIONS

5.1. Chitosan Treatment of Creek Water

In the laboratory testing conducted, chitosan proved effective in the treatment of urban stormwater. The performance was seen to be impacted heavily by the type of raw stormwater. The results gained from testing of creek water samples were more encouraging than those from road pavement runoff. The relative turbidity removal percentage indicated a consistent performance regardless of the creek water's initial turbidity. Importantly, the data also showed only moderate differences to the efficiency either side of the optimum dosage. This indifference to dose is a crucial consideration for a stormwater treatment plant as it markedly reduces the equipment and testing requirements. These operational savings undoubtedly make stormwater harvesting from creek systems within Toowoomba a more attractive option.

5.1.1. Expected Turbidity Levels in Toowoomba Creeks

Reference to the TRC water quality data confirms that the historic turbidity levels have seldom risen above 80 NTU. The data also shows that turbidity in all catchments is below 40 NTU for the majority of the year. It shows West and Gowrie Creeks to have higher turbidity levels than the other catchments tested. The results from this project are at odds with this and suggest that East Creek has the higher turbidity, followed by West and Gowrie Creeks. This however is of little significance as the range of turbidity's to be expected was the most important consideration. The test results clearly show chitosan's ability to treat water containing a greater concentration of suspended solids than is usually present in Toowoomba's urban stormwater.

5.1.2. pH Adjustment to Treat Creek Water

As the testing clearly showed, chitosan treatment is dependent upon pH. Inefficiencies were seen in the variable pH tests either side of the preferred pH level. Magnasol 589 showed similar performance at low pH, but was superior to chitosan as the stormwater became more alkaline. This is evidenced by Magnasol 589 still removing in excess of 82% of turbidity at pH 9.0. This trait suits Toowoomba stormwater as the TRC data (figure 5.1) clearly shows a tendency for stormwater in Toowoomba's catchments to be alkaline. East and West Creek were the catchments closest to pH neutral conditions, while Gowrie Creek exhibited an alkaline average of pH 8.3. The samples captured for this study were not as alkaline with most at or around pH 7.0. This may be due to the samples being captured during rainfall events and thus having less time in contact with alkaline landforms. Regardless of the coagulant used, some form of pH adjustment in the form of an acid will be required to produce optimum performance from an urban stormwater treatment plant. Figure 5.1 shows the average pH in each of Toowoomba's stormwater catchments.

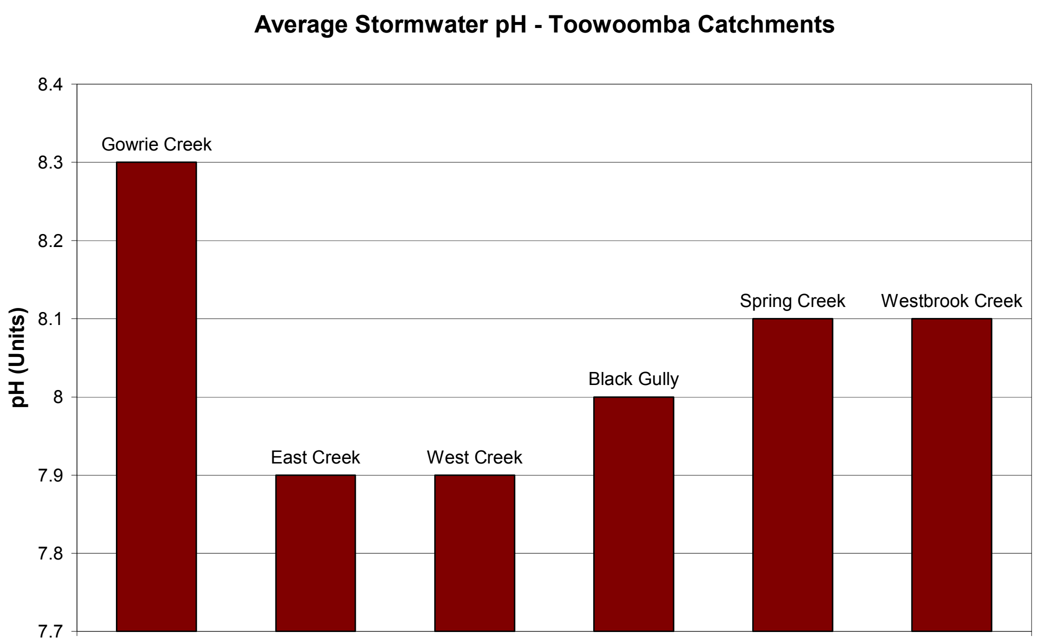


Figure 5.1 The Average pH of Stormwater in Toowoomba's Catchments (Toowoomba Regional Council)

5.1.3. Comparison to Magnasol 589

The performance of chitosan is comparable to that of Magnasol 589. Despite Magnasol 589 consistently outperforming chitosan in head to head testing, the margin was very small on each occasion. The speed of flocculation and the size of the floc were also very similar. Consultation with TRC laboratory staff added weight to this conclusion. They revealed that in recent polymer trials to select a replacement coagulant for aluminium sulphate to treat Toowoomba's drinking water supply, there was little difference amongst the polymer based chemicals. The decision to use Magnasol 589 at the Mt Kynoch plant was heavily influenced by the chemicals ability to reduce the quantity of sludge being produced. The study does not investigate this concept, but it will again be an important consideration in a stormwater treatment context.

5.2. Chitosan Treatment of Road Pavement Runoff and Particle Re-stabilisation

A very interesting result of the testing is the effect of re-stabilisation. Although this phenomenon is seen in the test results from some creek samples, it is far more pronounced in road pavement runoff. This effect is present in the test results of both FlocClear and Magnasol 589. When treating urban runoff with both chemicals re-stabilisation was so dramatic the turbidity removal percentage reduced to zero by adding only 1.5mg/L (Magnasol 589 or chitosan acetate) more than optimum dose. A graphic representation is seen below in figure 5.1. The small window for effective treatment is undesirable as it leaves little margin for error in the calibration of a stormwater treatment plant. As the turbidity of the road pavement runoff is initially low, flocculation may be replaced by filtration. Further tests using various forms of filter media will be required to gauge the feasibility of this method.

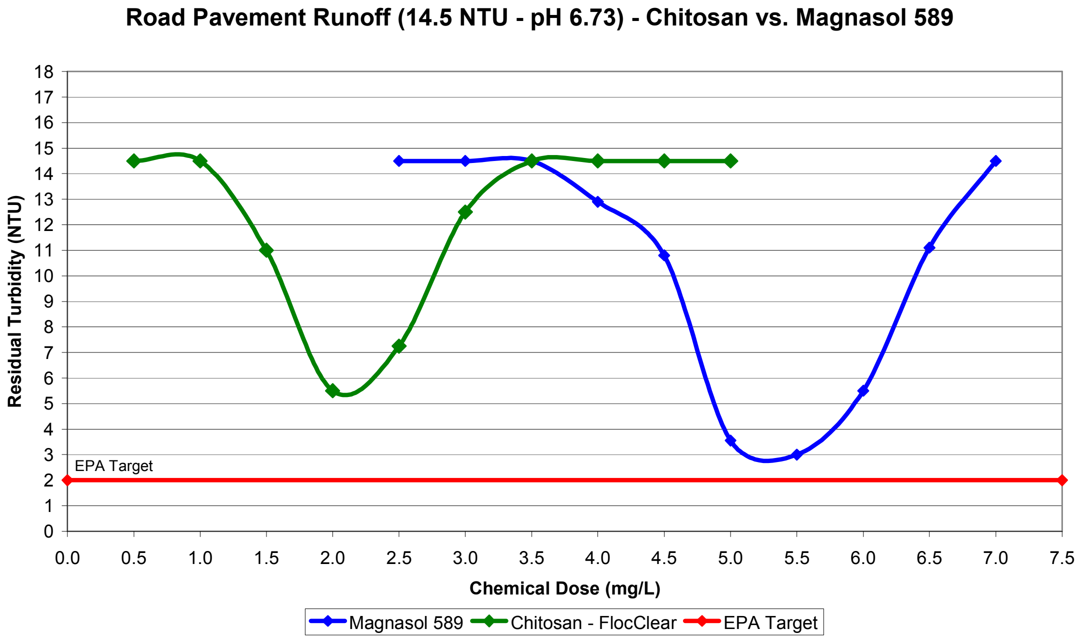


Figure 5.2 The effect of re-stabilisation of road pavement runoff

5.3.Compliance with EPA Guidelines

From the 15 successful jar tests recorded, only one jar from one test met the EPA target of 2 NTU. By flocculation alone a reduction in turbidity of Toowoomba's urban runoff below 10 NTU is very feasible. To produce class-A water for non-potable reuse, a form of filtration must be adopted. The above literature review has suggested several methods of filtration that may be applicable. These include modified clay, activated carbon and rapid sand filtration. Either of these alternatives will produce effluent below the 2 NTU threshold. Like turbidity, meeting the target for pH is also very achievable. The target of 6.5 - 8.0 is the range in which effective flocculation occurred for both coagulants. Tests on the supernatant from each jar test confirmed this requirement was met.

5.4.Location and Scale of Urban Stormwater Harvesting

The study has revealed several findings pertaining to the positioning and scale of potential stormwater harvesting plants. The preference to a particular coagulant is seen as a minor factor when analysing possible locations for such a plant. More critical considerations include hydrological analysis, other pollutant levels, available space, storage and reticulation requirements. TRC data shows similar but inherently variable, characteristics in each stormwater catchment. FlocClear and Magnasol 589 adequately removed suspended solids from all creek water tested. Further analysis to determine the ability of each coagulant to remove contaminants not covered in this study may influence the positioning of a treatment facility.

5.4.1. Stormwater Harvesting and Environmental Impacts

Decisions must also be made from an environmental standpoint. Harvesting the best quality water or that which is most readily treated may pose environmental impacts. This will be seen by concentrating poorer quality stormwater in the creek system after the better quality water is harvested. The development of a fast-rate stormwater re-use system study focuses upon improving the health of the creek systems, whilst providing a supplementary water supply. Clearly a balance needs to be sought between these two factors. This may mean positioning treatment plants in locations that cause cost both economic and operational inefficiencies in a stormwater recycling plant for the purpose of meeting environmental objectives.

5.4.2. The Effect of Scale upon Stormwater Harvesting Feasibility

An issue more closely linked to this project is the potential scales of a stormwater harvesting operation as defined by the Department of Local Government, Planning, Sport and Recreation. During the project samples were drawn from sites corresponding to each of the suggested scales of operation. From each type of site, key conclusions can be drawn regarding the water quality and treatability. Small scale operation proved an unattractive option for chitosan treatment. The narrow range available in which to deliver the optimum dosage will make treatment very difficult as influent water quality varies. Low turbidity from sealed surfaces such as roads lends itself to filtration treatment alone. Large scale operation by treating high turbidity stormwater from creeks presents the most viable option for chitosan treatment. Very effective flocculation was seen in creek water tests with various levels of turbidity up to 260 NTU.

CHAPTER 6

CONCLUSIONS

6.1. Future Research

This dissertation forms only a small part of the broader study to investigate the feasibility of stormwater harvesting in Toowoomba. Further study remains in the areas of chitosan treatment, stormwater treatment by other coagulants and alternate treatment methods.

6.1.1. Further Chitosan Research

The study provides much information regarding the use of FlocClear Biopolymer by Rocklin Products. It does not investigate the use of other known chitosan based products including StormKlear, nor does it trial the use of pure chitosan acetate. Research and testing of these chemicals will provide more conclusions on the viability of chitosan based stormwater treatment. Time and financial constraints also meant the presence of other contaminants was not tested. The ability of chitosan to remove metals and other contaminants must be tested and analysed for compliance with the Queensland Water Recycling Guidelines. The work of Benavente (2008) suggests metallic ions are absorbed by chitosan during the coagulation process.

6.1.2. Conventional Coagulants to Treat Stormwater

Work also remains to research and test stormwater with other conventional coagulants. Magnasol 589 is one of a multitude of polymer based coagulants currently available. Metal salts are another type of coagulant that must be considered. Further trials must be undertaken to determine which of the above coagulants is the most suitable for treating urban runoff.

6.1.3. Other Treatment Methods

This study has outlined several alternate methods of treatment. The contaminant removal capability of each was not investigated. Many of these methods are currently utilised in the tertiary treatment of wastewater. Examples of these systems include air flotation, micro-filtration, ultra-filtration, reverse osmosis, UV disinfection and chlorine disinfection. These treatment methods have the potential to be used in conjunction with the chitosan treatment of urban stormwater.

6.2. Chitosan as Coagulant to Treat Urban Stormwater

Freight and storage requirements are a noticeable drawback pertaining to the use of FlocClear. As FlocClear is 2% chitosan acetate solution by weight, 50 times the amount of the sloution is required to obtain the same amount of the active ingredient (chitosan acetate) as is currently available using Magnasol 589. This is offset slightly by the optimum dosage of chitosan acetate being approximately half that of Mganasol 589. The additional shipping will include sourcing chitosan from known suppliers outside Australia. Until a local supplier or chitosan acetate becomes commercially available, widespread chitosan use may be unfeasible.

From an operational standpoint, chitosan has the potential to be dosed in the same manner as all liquid coagulants. It is anticipated the current style of doing pumps and equipment would be capable of dosing chitosan in a stormwater treatment plant. This characteristic makes it very simple to alternate between liquid-based coagulants.

As can be seen clearly throughout the study, chitosan has the ability to remove suspended solids from urban stormwater. By producing very similar results to those from Magnasol 589, it is proved to be a competitive product in terms of performance. Unfortunately, additional information relating to the cost and availability of FlocClear were not forthcoming from the supplier. These considerations combined with sludge production, safety and environmental considerations will inevitably determine the viability of using chitosan to treat urban runoff.

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APPENDICES

Appendix A – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

<u>Eng 4111/4112 Research Project</u>
PROJECT SPECIFICATION

FOR: **MICHAEL SHELLSHEAR**

TOPIC: URBAN STORMWATER TREATMENT USING CHITOSAN

SUPERVISOR: Dr Ian Brodie

ENROLMENT: ENG 4111 – S1, 2008
ENG 4112 – S2, 2008

PROJECT AIM: To determine the water properties of urban stormwater runoff and trial the substance chitosan as a coagulant to treat the water to a non-potable standard suitable for irrigation and industrial purposes within Toowoomba.

SPONSORSHIP: Toowoomba City Council / Toowoomba Regional Council

PROGRAMME: **(Issue A, 13 March 2008)**

1. Research background information regarding the present use of chitosan in the United States to treat stormwater.
2. Select various sites within Toowoomba city from which stormwater samples will be collected. The selection of sites will depend greatly upon the land use activities in the area. A variety of catchments will be selected on this basis.
3. Research water quality standards for irrigation in urban areas (eg. parks and sporting fields).
4. Conduct laboratory testing of the stormwater samples to determine both the most effective dosage of chitosan to be used and the performance of chitosan compared to conventional water treatment processes.
5. Evaluate the above research testing and results of the water treatment.
6. Submit an academic dissertation on the research.

As time permits:

7. Analyse the effects of extended detention time on stormwater quality.

AGREED: _________________ (student) ___/___/___
_________________ (supervisor) ___/___/___

Examiner/Co-examiner: _________________________________

Appendix B – Project Risk Assessment

Table B-1 Risk assessment matrix for collecting stormwater from roads

	Likelihood	**Consequence**	**Risk Priority**
Risk; Capturing stormwater samples from road pavements	Slight	Possible Death	High (Unacceptable)
Controls;	**New Risk Scores**		
6. Florescent safety vest to be worn when collecting samples. 7. Be alert to nearby vehicular movements	Very Slight	Possible Death	Low (Acceptable)

Table B-2 Risk assessment matrix for collecting stormwater from creeks

	Likelihood	**Consequence**	**Risk Priority**
Risk; Capturing stormwater samples from swollen creek systems	Significant	Major Injury	High (Unacceptable)
Controls;	**New Risk Scores**		
1. Florescent safety vest to be worn when collecting samples. 2. Sound footing to be gained prior to collecting sample. 3. Footwear with grip to be worn.	Slight	Major Injury	Low (Acceptable)

Table B-3 Risk assessment matrix for using chemicals during laboratory tests

<table>
<tr><th></th><th>Likelihood</th><th>Consequence</th><th>Risk Priority</th></tr>
<tr><td>Risk;

Exposure to chemicals including Magnasol 589, Chitosan and Hydrochloric acid during laboratory testing</td><td>Occasional</td><td>Minor Injury / Illness</td><td>High (Unacceptable)</td></tr>
<tr><td rowspan="2">Controls;

1. Pipette to be used when measuring quantities of Magnasol and Chitosan.
2. Hydrochloric acid dispenser to be near sample when dispensing to avoid splashing
3. Safety goggles to be worn</td><td colspan="3">New Risk Scores</td></tr>
<tr><td>Very Slight</td><td>Minor Injury / Illness</td><td>Low (Acceptable)</td></tr>
</table>

Appendix C – Jar Test Result Sheets

Table C-1 Test 1 Results

JAR TEST : Constant Dosage; Variable pH						DATE : 31/07/08	
DESCRIPTION : West Ck Stormwater (Stenner St)						TIME : 10:00am	
CHEMICALS & RAW WATER QUALITY	**UNITS**	**A**	**B**	**C**	**D**	**E**	**F**
Magnasol 589	mg/L	3.5	3.5	3.5	3.5	3.5	3.5
pH	UNITS	6.46	6.92	7.25	7.95	8.53	9.04
Turbidity	NTU	22.5	22.5	22.5	22.5	22.5	22.5
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	10	8	5	6	8	10
FLOC SIZE	A-E	C	C	A	A	B	C
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	3.0	2.0	1.5	3.0	3.0	4.0
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:							

Table C-2 Test 2 Results

JAR TEST : Constant pH; Variable Dosage							DATE : 31/07/08	
DESCRIPTION : West Ck Stormwater (Stenner St)							TIME : 2:00pm	
CHEMICALS & RAW WATER QUALITY	**UNITS**	**A**	**B**	**C**	**D**	**E**	**F**
Magnasol 589	mg/L	1.0	2.0	3.0	3.5	4.0	5.0
pH	UNITS	7.16	7.16	7.16	7.16	7.16	7.16
Turbidity	NTU	30.0	30.0	30.0	30.0	30.0	30.0
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	N/A	N/A	N/A	N/A	N/A	N/A
FLOC SIZE	A-E	N/A	N/A	N/A	N/A	N/A	N/A
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	17.0	12.5	8.0	4.0	3.5	2.5
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	At the time of testing there was insufficient water from the above site to conduct further testing at dose rates greater than 5.0 mg/L. Results are encouraging nonetheless.						

Table C-3 Test 3 Results

JAR TEST : Constant pH; Variable Dosage							DATE : 13/08/08
DESCRIPTION : East Ck Stormwater (Ballin Dr) - Not Flowing							TIME : 9:00apm
CHEMICALS & RAW WATER QUALITY	**UNITS**	**A**	**B**	**C**	**D**	**E**	**F**
Magnasol 589	mg/L	2.0	3.0	4.0	5.0	6.0	7.0
pH	UNITS	7.41	7.41	7.41	7.41	7.41	7.41
Turbidity	NTU	62.0	62.0	62.0	62.0	62.0	62.0
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	N/A	N/A	N/A	N/A	N/A	N/A
FLOC SIZE	A-E	N/A	N/A	N/A	N/A	N/A	N/A
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	53.4	52.8	52.4	42.5	30.2	7.2
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	The sample was more turbid than in previous test and contained suspended matter that appeared to be red clay. The performance of the chemical appeared to still be increasing at the highest dosage used. Further Tests conducted on the same water. See test 3A.						

Table C-4 Test 3A Results

JAR TEST : Constant pH; Variable Dosage						DATE : 13/08/08	
DESCRIPTION : East Ck Stormwater (Ballin Dr) - Not Flowing						TIME : 11:30am	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F
Magnasol 589	mg/L	6.0	7.0	8.0	9.0	10.0	11.0
pH	UNITS	7.41	7.41	7.41	7.41	7.41	7.41
Turbidity	NTU	62.0	62.0	62.0	62.0	62.0	62.0
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	N/A	N/A	N/A	N/A	N/A	N/A
FLOC SIZE	A-E	N/A	N/A	N/A	N/A	N/A	N/A
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	38.9	20.9	11.5	9.1	6.4	5.3
TSS (If Conducted)	mg/L	10	7	5.5	6	4.33	4.66
NOTES:	Again the performance of the chemical appeared to still be increasing at the highest dosage used. Final turbidity's seem out. Can't see any problem with test methods. TSS testing conducted to validate turbidity readings.						

Table C-5 Test 4 Results

JAR TEST : Constant pH; Variable Dosage						DATE : 20/08/08	
DESCRIPTION : West Ck Stormwater (Creedon Dr) - Not Flowing						TIME : 9:00am	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F
Chitosan - FlocClear	mg/L	0.5	1.0	1.5	2.0	2.5	3.0
pH	UNITS	7.61	7.61	7.61	7.61	7.61	7.61
Turbidity	NTU	19.5	19.5	19.5	19.5	19.5	19.5
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	N/A	N/A	N/A	15	10	5
FLOC SIZE	A-E	E	E	E	C	B	A
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	19.5	19.5	19.1	16.5	3.5	3.0
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	Adjustments were made to the testing method with flocclear found to be a 2% chitosan acetate, which explained very poor results in previous chitosan testing. These results have not been tabled as there was vitually no flocculation. New doseage reflects chitosan aceate concentration						

Table C-6 Test 4A Results

JAR TEST : Constant pH; Variable Dosage						DATE : 20/08/08	
DESCRIPTION : West Ck Stormwater (Creedon Dr) - Not Flowing						TIME : 10:35am	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F
Chitosan - FlocClear	mg/L	3.5	4.0	4.5	5.0	5.5	6.0
pH	UNITS	7.61	7.61	7.61	7.61	7.61	7.61
Turbidity	NTU	19.5	19.5	19.5	19.5	19.5	19.5
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	2	3	4	8	10	15
FLOC SIZE	A-E	A	B	B	B	C	C
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	2.6	3.5	6.1	6.8	8.7	9.5
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	These test results are very encouraging. It was noted that the a dosage of 3.5mg/L chitosan produced very similar results to magnasol testing at 3.5mg/L on water from the same source.						

Table C-7 Test 5 Results

JAR TEST : Constant Dosage; Variable pH						DATE : 20/08/08	
DESCRIPTION : West Ck Stormwater (Creedon Dr) - Not Flowing						TIME : 1.00pm	
CHEMICALS & RAW WATER QUALITY	**UNITS**	**A**	**B**	**C**	**D**	**E**	**F**
Chitosan - FlocClear	mg/L	3.5	3.5	3.5	3.5	3.5	3.5
pH - (Raw-7.61)	UNITS	5.0	6.0	7.0	8.0	9.0	10.0
Turbidity	NTU	19.5	19.5	19.5	19.5	19.5	19.5
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	N/A	N/A	7	5	N/A	N/A
FLOC SIZE	A-E	E	E	B	A	E	E
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	20.0	19.5	3.9	6.0	21.5	30.0
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	These test results are also very encouraging. Chitosan was most effective when pH was 7.0 (neuteral). Most of the samples collected were around this mark. For further testing I will neglect pH adjustment providing the raw water pH is close to 7. It is noted that adding lime to increase pH actually increased the turbidity of 2 samples.						

Table C-8 Test 6 Results

JAR TEST : Constant pH; Variable Dosage							DATE : 10/09/08	
DESCRIPTION : Road Runoff (Hoey St Road Gully)							TIME : 10.00am	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F	
Chitosan - FlocClear	mg/L	2.5	3.0	3.5	4.0	4.5	5.0	
pH	UNITS	6.73	6.73	6.73	6.73	6.73	6.73	
Turbidity	NTU	14.5	14.5	14.5	14.5	14.5	14.5	
MIXING								
RAPID TIME	min	2	2	2	2	2	2	
RAPID SPEED	rpm	100	100	100	100	100	100	
FLOCCULATION TIME	min	20	20	20	20	20	20	
FLOCCULATION SPEED	rpm	30	30	30	30	30	30	
SETTLING								
SETTLING TIME	min	30	30	30	30	30	30	
FLOC TIME TO FORM	min	12	15	N/A	N/A	N/A	N/A	
FLOC SIZE	A-E	C	C	N/A	N/A	N/A	N/A	
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A	
SUPERNATANT								
TURBIDITY	NTU	6.0	10.5	14.5	14.5	14.5	14.5	
TSS (If Conducted)	mg/L	5.5	6.5	10.5	9	10	9	
NOTES:	Flocculation was very slow and floc size was small. Another test will be conducted as it appears the minimum turbidity is outside this range.							

Table C-9 Test 6A Results

JAR TEST : Constant pH; Variable Dosage							DATE : 10/09/08	
DESCRIPTION : Road Runoff (Hoey St Road Gully)							TIME : 11.00am	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F	
Chitosan - FlocClear	mg/L	0.5	1.0	1.5	2.0	2.5	3.0	
pH	UNITS	6.73	6.73	6.73	6.73	6.73	6.73	
Turbidity	NTU	14.5	14.5	14.5	14.5	14.5	14.5	
MIXING								
RAPID TIME	min	2	2	2	2	2	2	
RAPID SPEED	rpm	100	100	100	100	100	100	
FLOCCULATION TIME	min	20	20	20	20	20	20	
FLOCCULATION SPEED	rpm	30	30	30	30	30	30	
SETTLING								
SETTLING TIME	min	30	30	30	30	30	30	
FLOC TIME TO FORM	min	N/A	N/A	N/A	N/A	N/A	N/A	
FLOC SIZE	A-E	N/A	N/A	D	C	D	E	
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A	
SUPERNATANT								
TURBIDITY	NTU	14.5	14.5	11.0	5.5	8.5	14.5	
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	
NOTES:	Again flocculation was very slow and floc size was small.							

Table C-10 Test 7 Results

JAR TEST : Constant pH; Variable Dosage							DATE : 10/09/08	
DESCRIPTION : Road Runoff (Hoey St Road Gully)							TIME : 12.00pm	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F	
Magnasol 589	mg/L	2.5	3.0	3.5	4.0	4.5	5.0	
pH	UNITS	6.73	6.73	6.73	6.73	6.73	6.73	
Turbidity	NTU	14.5	14.5	14.5	14.5	14.5	14.5	
MIXING								
RAPID TIME	min	2	2	2	2	2	2	
RAPID SPEED	rpm	100	100	100	100	100	100	
FLOCCULATION TIME	min	20	20	20	20	20	20	
FLOCCULATION SPEED	rpm	30	30	30	30	30	30	
SETTLING								
SETTLING TIME	min	30	30	30	30	30	30	
FLOC TIME TO FORM	min	N/A	N/A	N/A	N/A	16	12	
FLOC SIZE	A-E	N/A	N/A	N/A	N/A	D	C	
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A	
SUPERNATANT								
TURBIDITY	NTU	14.5	14.5	14.5	12.9	8.0	2.1	
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	
NOTES:	Not experiencing large flocs as in creek water. Looked very similar to chitosan testing in terms of time to form floc and floc size. Slightly more effective. Another test will be required with higher Magnasol concentrations.							

Table C-11 Test 7A Results

JAR TEST : Constant pH; Variable Dosage								DATE : 10/09/08
DESCRIPTION : Road Runoff (Hoey St Road Gully)								TIME : 1.00pm
CHEMICALS & RAW WATER QUALITY	**UNITS**	**A**	**B**	**C**	**D**	**E**	**F**	
Magnasol 589	mg/L	4.5	5.0	5.5	6.0	6.5	7.0	
pH	UNITS	6.73	6.73	6.73	6.73	6.73	6.73	
Turbidity	NTU	14.5	14.5	14.5	14.5	14.5	14.5	
MIXING								
RAPID TIME	min	2	2	2	2	2	2	
RAPID SPEED	rpm	100	100	100	100	100	100	
FLOCCULATION TIME	min	20	20	20	20	20	20	
FLOCCULATION SPEED	rpm	30	30	30	30	30	30	
SETTLING								
SETTLING TIME	min	30	30	30	30	30	30	
FLOC TIME TO FORM	min	9	10	10	12	15	N/A	
FLOC SIZE	A-E	D	C	C	C	D	E	
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A	
SUPERNATANT								
TURBIDITY	NTU	13.6	5.0	3.0	5.5	11.1	14.5	
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A	
NOTES:	Results OK							

Table C-12 Test 8 Results

JAR TEST : Constant pH; Variable Dosage						DATE : 08/10/08	
DESCRIPTION : East Creek Stormwater (Ballin Dr)						TIME : 8.30am	
CHEMICALS & RAW WATER QUALITY	**UNITS**	**A**	**B**	**C**	**D**	**E**	**F**
Chitosan - FlocClear	mg/L	0.5	1.0	1.5	2.0	2.5	3.0
pH	UNITS	7.05	7.05	7.05	7.05	7.05	7.05
Turbidity	NTU	260.0	260.0	260.0	260.0	260.0	260.0
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	N/A	15	5	4	3	2
FLOC SIZE	A-E	E	D	B	B	A	A
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	224.0	208.0	164.0	123.0	85.0	58.0
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	Happy with results						

Table C-13 Test 8A Results

JAR TEST : Constant pH; Variable Dosage							DATE : 08/10/08	
DESCRIPTION : East Creek Stormwater (Ballin Dr)							TIME : 9.30am	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F
Chitosan - FlocClear	mg/L	3.5	4.0	4.5	5.0	5.5	6.0
pH	UNITS	7.05	7.05	7.05	7.05	7.05	7.05
Turbidity	NTU	260.0	260.0	260.0	260.0	260.0	260.0
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	<1min	<1min	<1min	<1min	<1min	<1min
FLOC SIZE	A-E	A	A	A	A	A	A
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	31.0	18.0	11.6	8.9	11.0	10.0
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	Happy with results						

Table C-14 Test 9 Results

JAR TEST : Constant pH; Variable Dosage							DATE : 08/10/08	
DESCRIPTION : Mixture of East Ck and Gowrie Ck Stormwater							TIME : 10.30am	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F
Chitosan - FlocClear	mg/L	2.0	2.5	3.0	3.5	4.0	4.5
pH	UNITS	7.61	7.61	7.61	7.61	7.61	7.61
Turbidity	NTU	88.0	88.0	88.0	88.0	88.0	88.0
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	8	7	5	6	7	7
FLOC SIZE	A-E	C	B	B	A	A	A
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	25.6	19.7	16.3	14.0	15.2	14.2
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	Gowrie Ck water was mixed with East Creek Stormwater to produce a different mixture and turbidity. (East Ck 260 NTU, pH 7.05) - (Gowrie Ck 3.9 NTU pH 8.56). pH correction was required to bring into optimum range. Flocculation was not a rapid as in previous tests. Floc size was small at first but grew at a consistant rate during flocculation.						

Table C-15 Test 10 Results

JAR TEST : Constant pH; Variable Dosage							DATE : 08/10/08	
DESCRIPTION : Mixture of East Ck and Gowrie Ck Stormwater							TIME : 11.45am	
CHEMICALS & RAW WATER QUALITY	UNITS	A	B	C	D	E	F
Chitosan - FlocClear	mg/L	2.0	2.5	3.0	3.5	4.0	4.5
pH	UNITS	7.59	7.59	7.59	7.59	7.59	7.59
Turbidity	NTU	60.0	60.0	60.0	60.0	60.0	60.0
MIXING							
RAPID TIME	min	2	2	2	2	2	2
RAPID SPEED	rpm	100	100	100	100	100	100
FLOCCULATION TIME	min	20	20	20	20	20	20
FLOCCULATION SPEED	rpm	30	30	30	30	30	30
SETTLING							
SETTLING TIME	min	30	30	30	30	30	30
FLOC TIME TO FORM	min	8	7	5	6	7	7
FLOC SIZE	A-E	C	B	B	A	A	A
TIME TO FORM PIN FLOC	min	N/A	N/A	N/A	N/A	N/A	N/A
SUPERNATANT							
TURBIDITY	NTU	21.9	19.8	18.4	17.2	14.6	15.1
TSS (If Conducted)	mg/L	N/A	N/A	N/A	N/A	N/A	N/A
NOTES:	Gowrie Ck water was again mixed with East Creek Stormwater to produce a different mixture and turbidity. (East Ck 260 NTU, pH 7.05) - (Gowrie Ck 3.9 NTU pH 8.56). pH correction again required to bring into optimum range. Similar results to previous test. Note similar flocculation over all dosages.						

Appendix D – Toowoomba Regional Council Stormwater Quality Data

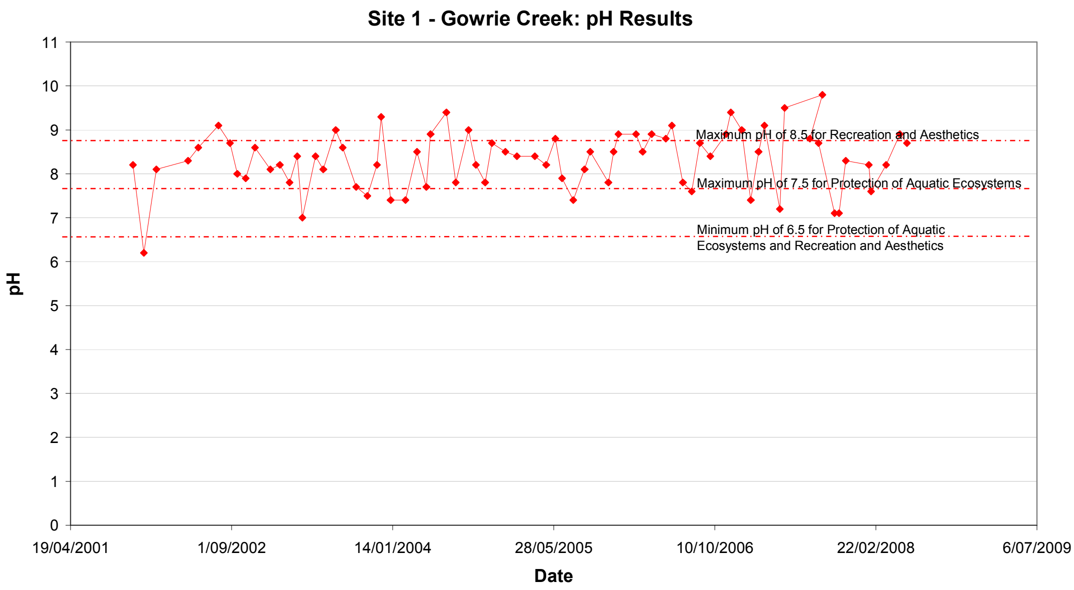


Figure D-1 Gowrie Creek pH (Toowoomba Regional Council)

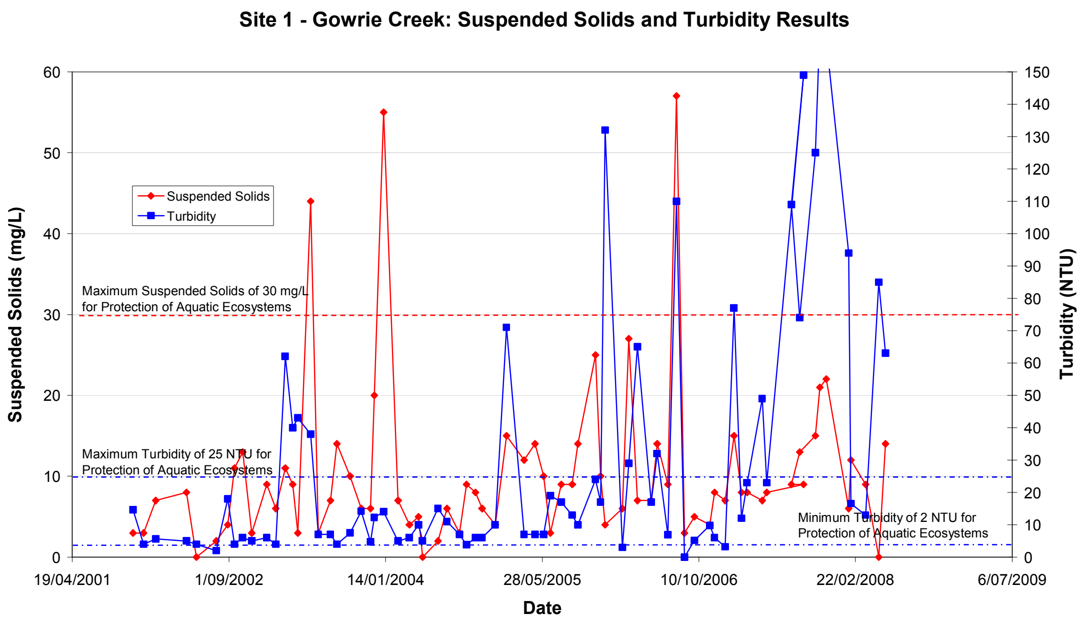


Figure D-2 Gowrie Creek Turbidity and TSS (Toowoomba Regional Council)

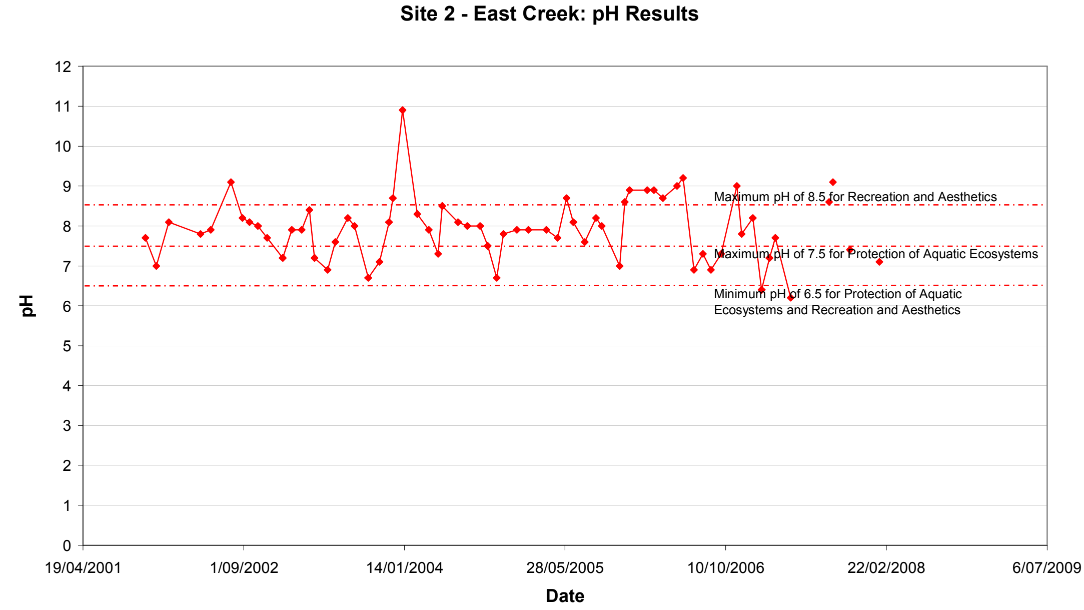


Figure D-3 East Creek pH (Toowoomba Regional Council)

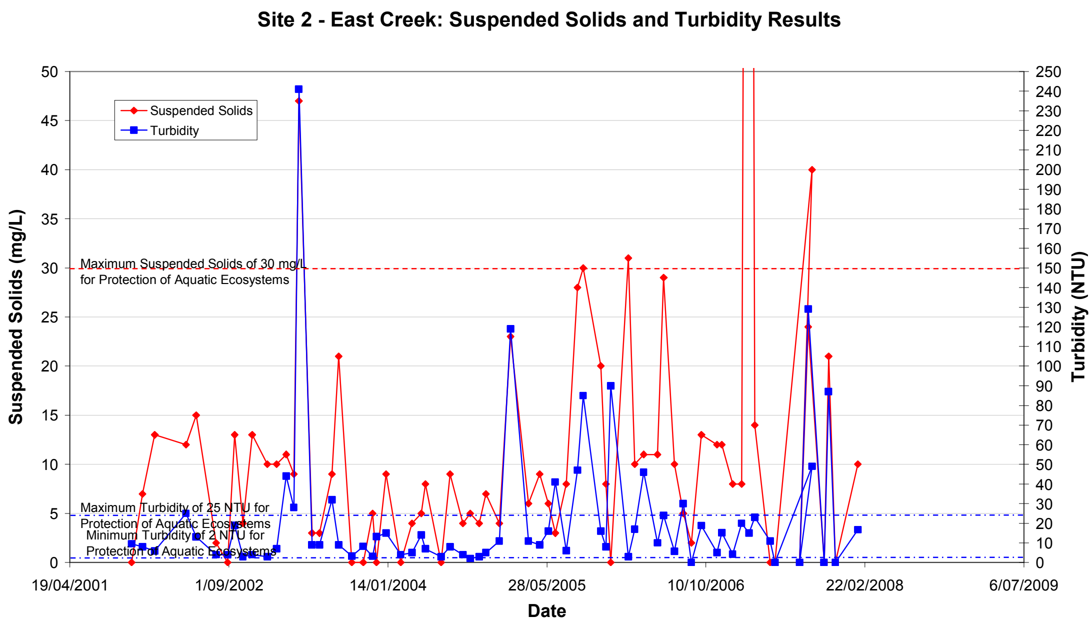


Figure D-4 East Creek Turbidity and TSS (Toowoomba Regional Council)

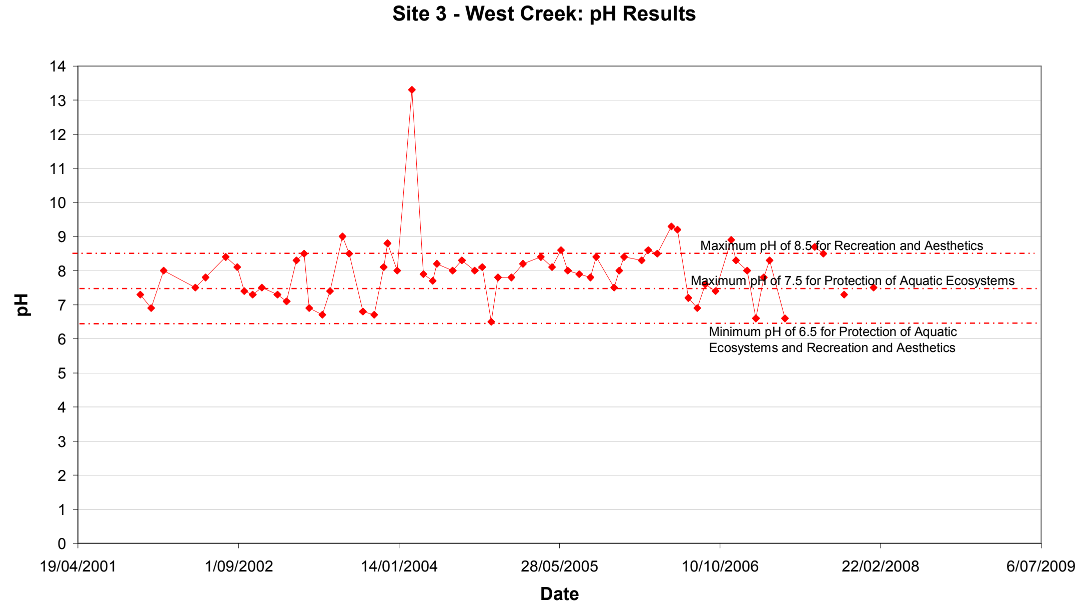


Figure D-5 West Creek pH (Toowoomba Regional Council)

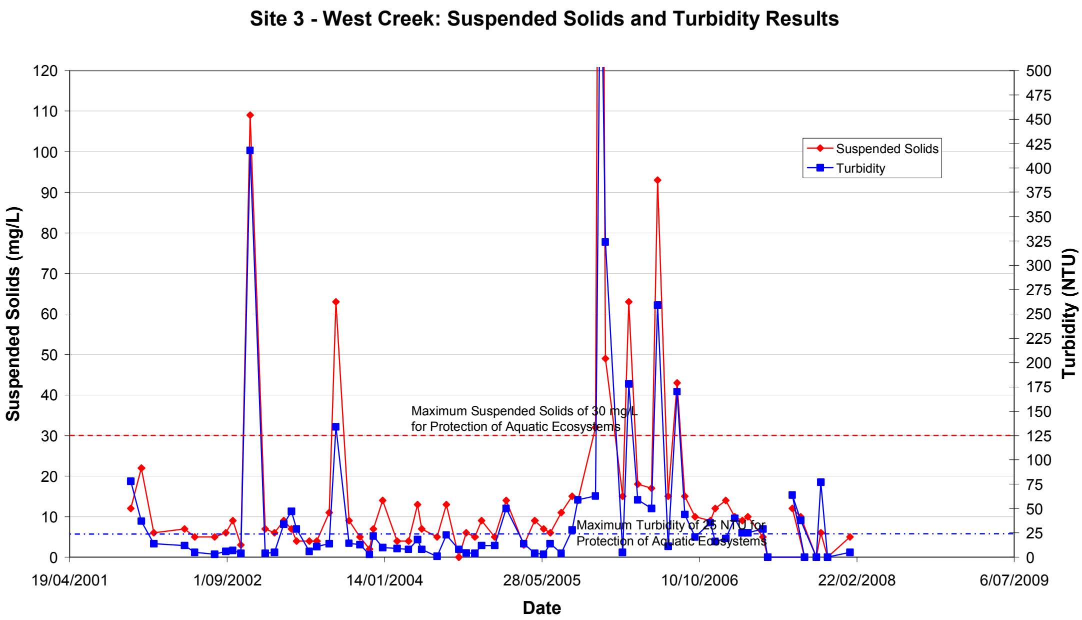


Figure D-6 West Creek Turbidity and TSS (Toowoomba Regional Council)

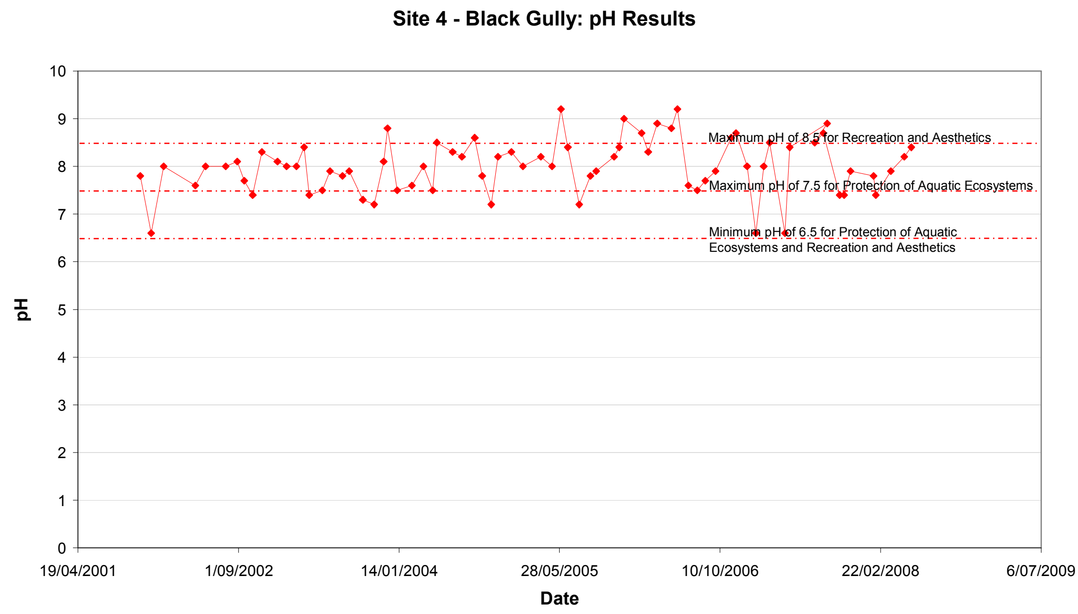


Figure D-7 Black Gully pH (Toowoomba Regional Council)

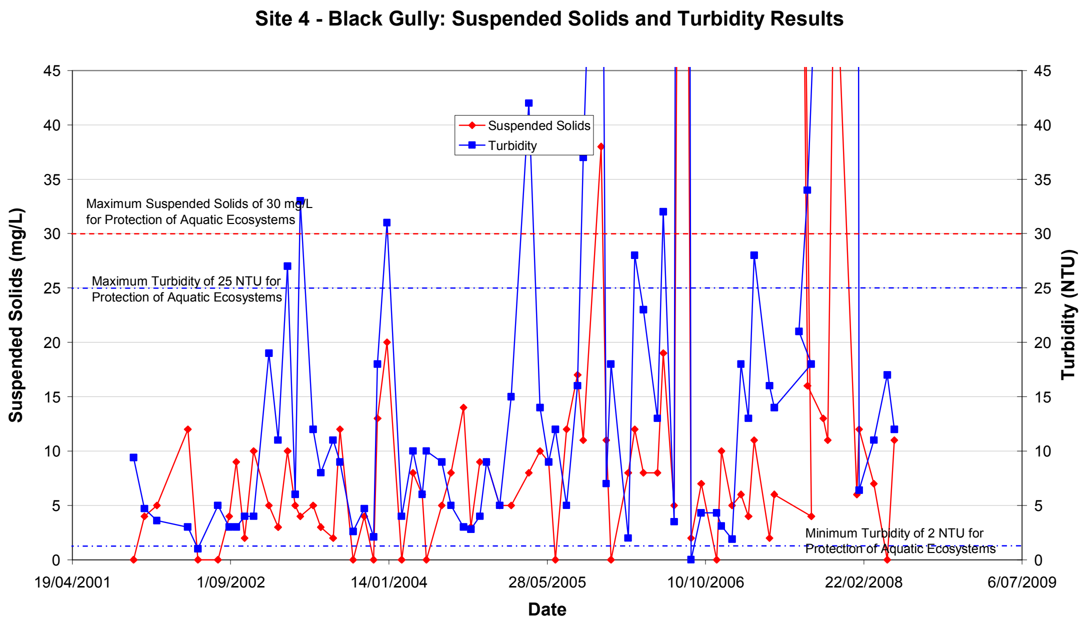


Figure D-8 Black Gully Turbidity and TSS (Toowoomba Regional Council)

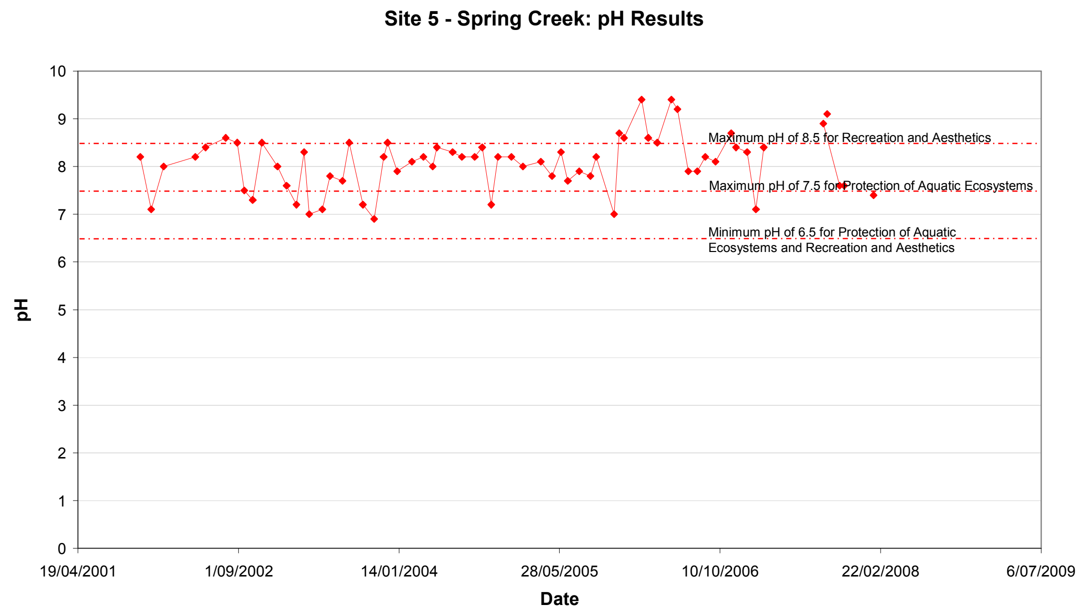


Figure D-9 Spring Creek pH (Toowoomba Regional Council)

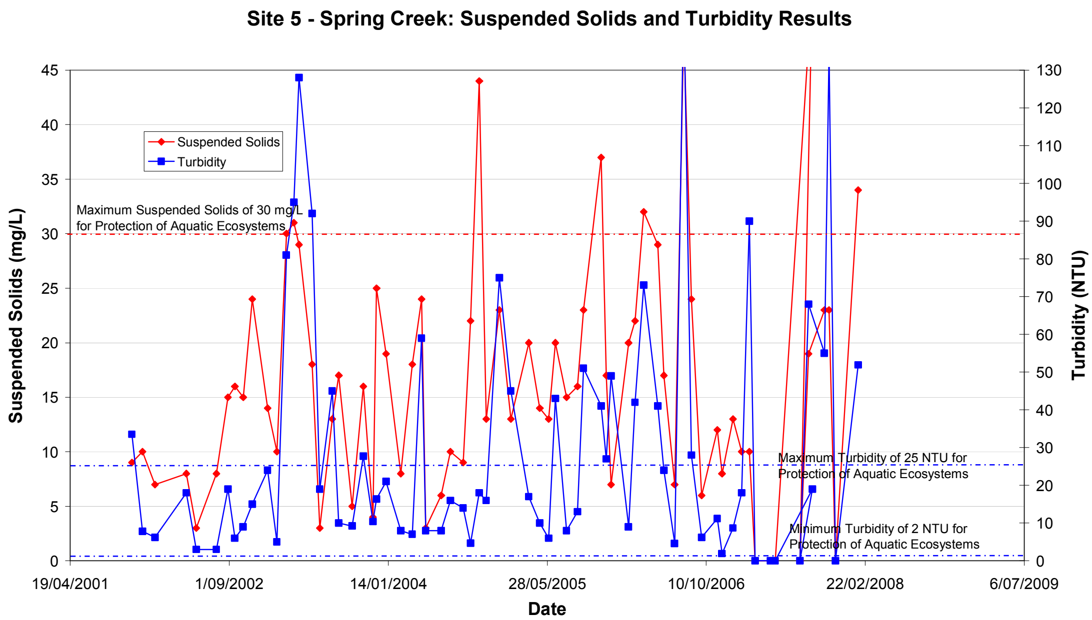


Figure D-10 Spring Creek Turbidity and TSS (Toowoomba Regional Council)

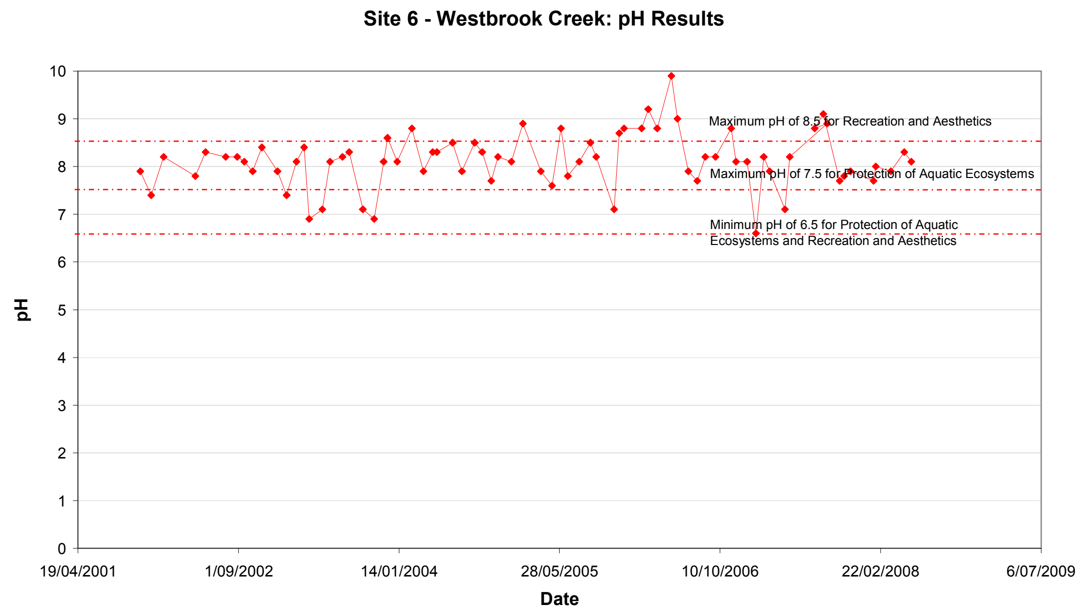


Figure D-11 Westbrook Creek pH (Toowoomba Regional Council)

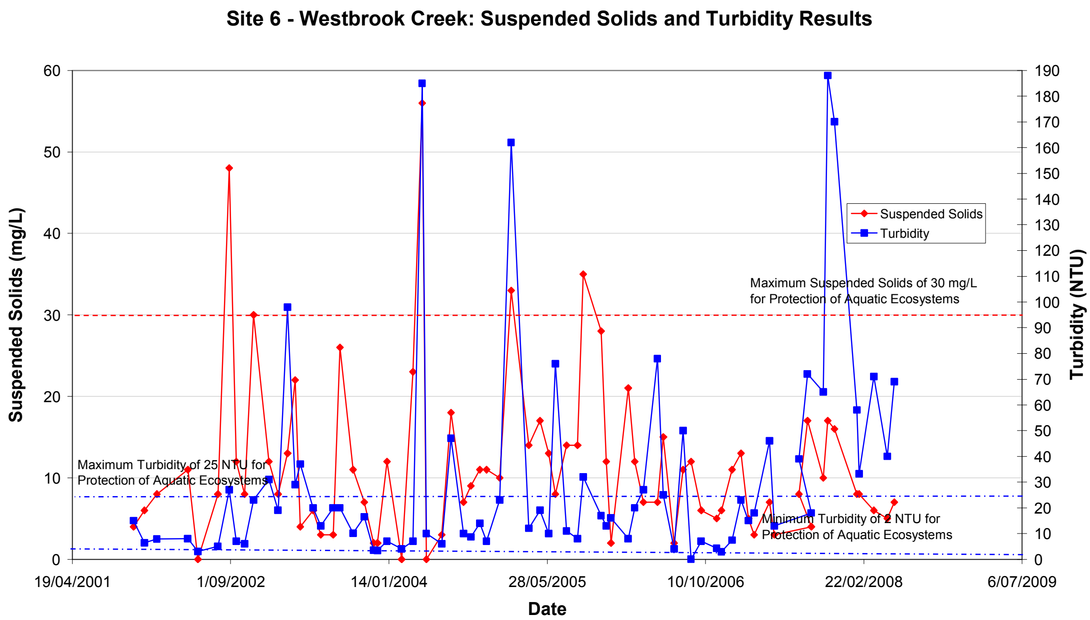


Figure D-12 Westbrook Creek Turbidity and TSS (Toowoomba Regional Council)

Appendix E – Chemical Material Safety Data Sheets

Safety Data Sheet

May not comply with national legislation; shall be used only as a source of information.

Ciba

1. Identification of the Substance/Preparation and of the Company/Undertaking

Designation/Trade Name:	MAGNASOL 589
Use:	Coagulant.
Company:	Ciba Spezialitätenchemie AG Klybeckstrasse 141 CH-4002 BASEL Schweiz Tel +41 61 636 1111 Fax +41 61 636 1212
Emergency contact:	+41 61 632 0779

2. Composition/Information on Ingredients

Chemical nature:

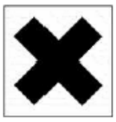
Aqueous solution of inorganic salts and cationic polymer

Hazardous ingredients		Classification*	Content (%)
CAS-No.: 26062-79-3	2-Propen-1-aminium, N,N-dimethyl-N-2-propenyl-, chloride, homopolymer	R 52/53	>= 4 - <= 40
CAS-No.: 1327-41-9 EC-No.: 215-477-2	Aluminum chloride, basic	Xi R 36/38	>= 10 - <= 75

*) The wording of the hazard symbols and R-phrases is specified in chapter 16 if dangerous ingredients are mentioned.

3. Hazards Identification

Classification required according to EU



Irritant.

R phrase(s):

R52/53	Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
R36/38	Irritating to eyes and skin.

Hazards:

May cause irritation to the gastrointestinal tract if swallowed.
Repeated skin exposure may cause contact dermatitis
Spilled product is slippery underfoot.
May cause irritation to the respiratory system, if mists or sprays maybe inhaled.

4. First-aid Measures

If inhaled:

If conscious place in a safe sitting or recovery position. Keep the casualty at rest. Move to fresh air. Seek medical attention if you feel unwell or if exposure prolonged.

On skin contact:

Remove contaminated clothing. Wash affected skin with plenty of water, shower if necessary. If skin irritation or dermatitis commences or persists seek medical attention.

On contact with eyes:

Rinse immediately with plenty of water for at least 10 minutes taking care to wash under the eyelids. If irritation persists, seek medical attention.

On ingestion:

Do not induce vomiting. Never give anything by mouth to an unconscious person. Check breathing and pulse. Place victim in the recovery position, cover and keep warm. Loosen tight clothing such as a collar, tie, belt or waistband. Seek medical attention. Rinse mouth and then drink plenty of water.

5. Fire-fighting Measures

Suitable extinguishing media:

dry powder, carbon dioxide, water spray, foam

Unsuitable extinguishing media for safety reasons:

No restrictions.

Combustion products:

Carbon oxides., Sulphur oxides, Hydrogen chloride, Nitrogen oxides

Exposure hazards:

Do not release chemically contaminated water into drains, soil or surface water. Sufficient measures must be taken to retain the water used for extinguishing. Dispose of contaminated water and soil according to local regulations.

Special protective equipment:

Chemical protection suit, suitable gloves, boots and self contained breathing apparatus.

6. Accidental Release Measures

Personal precautions:

Wear suitable personal protective clothing and equipment. Breathing apparatus is only required in a fire situation.

Environmental precautions:

Prevent entry into sewage systems, ground and surface waters.

Methods for cleaning-up or taking-up:

Soak up with inert absorbent material (e.g. sand, silica gel, acid binder, universal binder, sawdust).
Scoop into marked containers for disposal as chemical waste.
Large spillages should be neutralised with a suitable alkali, such as sodium carbonate
Contain washwater and dispose of in accordance with local regulations.

7. Handling and Storage

Handling

Safety showers and eyewash facilities should be provided in areas where accidental exposure is foreseeable.
High risk of slipping due to leakage/spillage of product.
Keep away from steel, copper, zinc and silver

Storage requirements:
Safety showers and eyewash facilities should be provided in areas where accidental exposure is foreseeable.
Do not store above 40°C.
Keep only in the original container.
Protect from frost.

8. Exposure Controls and Personal Protection

Technical measures/precautions:
Ensure adequate ventilation, especially in confined areas.

Respiratory protection:
Respiratory protection in case of vapour/aerosol release.

Hand protection:
Chemical resistant protective gloves (EN 374)

Eye protection:
Tightly fitting safety goggles (chemical goggles).

Skin and body protection:
Lightweight protective clothing.

9. Physical and Chemical Properties

Form:	liquid
Colour:	amber
Odour:	solvent-like
pH value:	approx. 2
Melting point:	Not applicable
Boiling point:	approx. 100 °C
Flash point:	> 100 °C
Self-ignition temperature:	Not tested
Explosion hazard:	Not applicable
Fire promoting properties:	Not tested
Vapour pressure:	approx. 12,3 kPa (50 °C)
Density:	approx. 1,2 g/cm3
Relative vapour density (Air):	Not tested
Solubility in water:	miscible
Solubility:	Not tested
Partitioning coefficient n-octanol/water (log Pow):	Not applicable
Viscosity, dynamic:	Not tested
Evaporation rate:	Not tested

10. Stability and Reactivity

Conditions to avoid:
Avoid temperatures above 40°C.

Materials to avoid:
acids, oxidizing agent, With sodium hypochlorite solution, an explosive reaction occurs with the formation of chlorine gas., This product will react with metals to liberate highly flammable H2 gas.

Hazardous decomposition products:
No decomposition expected under normal storage conditions.

11. Toxicological Information

Acute oral toxicity:
rat/LD50: > 2.000 mg/kg
By analogy with a product of similar composition

Acute dermal toxicity:
Not tested

Acute inhalation toxicity:
Not tested

Skin irritation/corrosion:
Irritant. (Conventional method)

Eye irritation/corrosion:
Irritant. (Conventional method)

Skin Sensitization:
Not tested

12. Ecological Information

Toxicity to fish:
96 h/LC50: > 10 mg/l
For the polymer component of this product

Toxicity to aquatic invertebrates:
48 h/EC50: > 10 mg/l
For the polymer component of this product

Toxicity to aquatic plants:

Not tested

Toxicity to microorganisms:

Not tested

Assessment of aquatic toxicity:
Polyaluminium chloride
The unneutralised product is expected to be toxic to fish.

Biodegradation:

Not tested

13. Disposal Considerations

Waste from residue/unused products:
Observe all local regulations.

Contaminated packaging:
Contaminated packaging should be emptied as far as possible and disposed of in the same manner as the substance/product.
Clean packaging material should be subjected to waste management schemes (recovery recycling, reuse) according to local legislation.

14. Transport Information

Land transport (ADR):

Not classified as a dangerous good under transport regulations.

Land transport (RID):

Not classified as a dangerous good under transport regulations.

Sea transport (IMDG):

Not classified as a dangerous good under transport regulations.

Air transport (ICAO/IATA):

Not classified as a dangerous good under transport regulations.

15. Regulatory Information

Regulations of the European Union (Labelling) / National legislation/regulations

Classification required according to EU

Hazard symbol(s):

Xi Irritant.

R phrase(s):

R52/53	Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment.
R36/38	Irritating to eyes and skin.

S phrase(s):

S28.1	After contact with skin, wash immediately with plenty of water and soap.
S36/37/39	Wear suitable protective clothing, gloves and eye/face protection.
S61	Avoid release to the environment. Refer to special instructions/safety data sheets.
S26	In case of contact with eyes, rinse immediately with plenty of water and seek medical advice.

16. Other Information

Use:

Restricted use: THIS MATERIAL IS NOT INTENDED FOR USE IN PRODUCTS FOR WHICH PROLONGED CONTACT WITH MUCOUS MEMBRANES, BODY FLUIDS OR ABRADED SKIN, OR IMPLANTATION WITHIN THE HUMAN BODY, IS SPECIFICALLY INTENDED, UNLESS THE FINISHED PRODUCT HAS BEEN TESTED IN ACCORDANCE WITH NATIONALLY AND INTERNATIONALLY APPLICABLE SAFETY TESTING REQUIREMENTS. BECAUSE OF THE WIDE RANGE OF SUCH POTENTIAL USES, CIBA IS NOT ABLE TO RECOMMEND THIS MATERIAL AS SAFE AND EFFECTIVE FOR SUCH USES AND ASSUMES NO LIABILITY FOR SUCH USES.

R phrases and hazard symbols:

R52/53 **Harmful to aquatic organisms, may cause long-term adverse effects in the aquatic environment.**

R36/38	Irritating to eyes and skin.
Xi	Irritant.

Vertical lines in the left hand margin indicate an amendment from the previous version.

This product should be stored, handled and used in accordance with good industrial hygiene practices and in conformity with any legal regulation. The information contained herein is based on the present state of our knowledge and is intended to describe our products from the point of view of safety requirements. It should not therefore be construed as guaranteeing specific properties.

MATERIAL SAFETY DATA SHEET
FLOCCLEAR - BIOPOLYMER

ROCKLIN PRODUCTS, INC. • WWW.ROCKLINPRODUCTS.COM • (866) 349-3562

RP

SECTION 1. MATERIAL IDENTIFICATION

PRODUCT NAME: FlocClear - BioPolymer
CHEMICAL FAMILY: Chitosan
CAS REG. NO.: None-mixture
EMERGENCY PHONE NO.: (866) 349-3562
REVISED DATE: 02/10/05
SUPERCECES: N/A

SECTION 2. HAZARDOUS INGREDIENTS

Acetic Acid, CASRN 64-19-7

SECTION 3. PHYSICAL DATA

Appearance: Amber liquid
pH: 3.0 – 5.0
Specific Gravity: 0.993

SECTION 4. REACTIVITY DATA

Stable: X **Unstable:**
Hazardous Combustion or Decomposition Products: Oxides of nitrogen and carbon
Incompatibility: Basic compounds may precipitate chitosan; strong oxidants
Hazardous Polymerization: Will not occur

SECTION 5. FIRE AND EXPLOSION DATA

Flash Point (method used): Not Known, non-flammable
Special Fire Fighting Procedures: None
Extinguishing Media: Water or foam

SECTION 6. EMERGENCY AND FIRST AID PROCEDURES

Ingestion: If victim is conscious and alert, give 2-4 cupfuls of milk or water.
Inhalation: Get medical aid immediately. Remove to fresh air immediately. If not breathing, give artificial respiration. If breathing is difficult, give oxygen.
Skin: Flush skin with plenty of soap and water .
Eye: Flush eyes with plenty of water for at least 15 minutes, occasionally lifting the upper and lower lids. Get medical aid if irritation persists.

SECTION 7. HEALTH HAZARD INFORMATION

OSHA Permissible Exposure Limit: For acetic acid, 10 ppm
ACGIH Threshold Limit Value: For acetic acid, 10 ppm
Primary Route(s) of Exposure/Entry: Eye, Skin
Acute Effects of Overexposure:
- **Ingestion:** None known
- **Inhalation:** None known
- **Skin:** May cause irritation
- **Eye:** Mildly irritating

Chronic Effects of Overexposure: None known
Listed as Carcinogen or Potential Carcinogen: No

SECTION 8. PROTECTION INFORMATION

Respiratory Protection: Should not be required. Avoid misting.
Ventilation: Should not be required.
Protective Gloves: Rubber gloves recommended
Eye Protection: Safety glasses, goggles recommended
Other Protective Equipment: Eye washing equipment, safety shower recommended
Other Control Measures: None should be needed

SECTION 9. SPILL, LEAK AND DISPOSAL PROCEDURES

In Case of Spill or Leak: Pick up and wash down
Waste Disposal Method: Dispose of in a manner consistent with federal, state, and local regulations.
EPA Registry Number: None
Environmental Toxicity Data: None known. Biodegradable

SECTION 10. SPECIAL PRECAUTIONS

Precautions to be taken in Handling and Storing: Keep container closed.

SECTION 11. REGULATORY INFORMATION

Status on Substance Lists: The concentrations shown are maximum or ceiling levels (weight %) to be used for calculations for regulations. Trade Secrets are indicated by "TS."

FEDERAL EPA

COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT OF 1980 (CERCLA): requires notification of the National Response Center of release of quantities of Hazardous Substances equal to or greater than the reportable quantities (RQ's) in 40 CFR 302.4. Components present in this product are at a level which could require reporting under the statute are:

Substance	CAS No.	Percent
None		

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 (SARA) TITLE III: requires emergency planning based on Threshold Planning Quantities (TPQ's) and release reporting based on Reportable Quantities (RQ's) in 40 CFR 355. Components in this product at a level which could require reporting under the statute are:

Substance	CAS No.	Percent
None		

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 (SARA) TITLE III:, Section 311 and 312, requires reporting to certain authorities of hazardous chemicals under the Occupational Safety and Health Act of 1970 (29 CFR 1910.1200). This product should be considered as having Acute Health Effects.

SUPERFUND AMENDMENTS AND REAUTHORIZATION ACT OF 1986 (SARA) TITLE III requires submission of annual reports of release of toxic chemicals that appear in 40 CFR 372 (for SARA 313). This information must be included in all MSDS's that are copied and distributed for this material. Components present in this product at a level which could require reporting under the statutes are:

Substance	CAS No.	Percent
None		

TOXIC SUBSTANCES CONTROL ACT (TSCA) Status: This product is a mixture and cannot be assigned a CAS number. All components of this product are listed in TSCA inventory.

SECTION 12. SHIPPING REGULATIONS

U.S. DEPARTMENT OF TRANSPORTATION

Proper Shipping Name (49 CFR 172.101-102): Not Regulated
Hazard Classification (49 CFR 172.101-102): N/A
Labels Required (49 CFR 172.101-102): N/A
Placards Required (49 CFR 172.504): None
Poison Constituent (49 CFR 172.203(k): No