University of Southern Queensland

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Treatment of Mine Water with Colloidal Suspensions

A dissertation submitted by

Kristine Leigh Johnston

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Abstract

Groote Eylandt Mining Company (GEMCO) mines manganese from leases of land with Arhnem Land's traditional owners. The open cut mining operation requires dewatering of quarries, with some of the quarries being located in areas of montmorillonite (commonly known as smectite) clay.

Through the action of groundwater infiltration through, and stormwater runoff over the exposed clay surface surrounding the quarry, the clay becomes finely dispersed which results in highly turbid quarry water. This colloidal suspension of clay in the water is attributed to the surface of the clay particles carrying a negative surface charge leading to a stable colloidal system of ultra fine particles. The particles do not settle out over time.

When the quarry fills with water, mining activities must cease. In order for mining to continue, the water must be pumped to a discharge point or for reuse. There are several negative impacts from the turbid water, namely visual impact on the local river system (which is unacceptable to the traditional owners); detrimental effects on ecological aquatic systems; and finely dispersed particles blocking nozzles and screens should the water ever be reused at the ore concentrator.

The aim of the project is to examine treatment of the water prior to discharge/reuse using a reagent to promote flocculation and settling of colloidal suspended material. The appropriate dosage for the concentration of material in the mine water along with a treatment methodology is to be established.

On conclusion of this research project it is envisaged that GEMCO will be able to effectively manage discharge of mine water by treating mine water with colloidal suspension based on the recommendations made which will achieve suitably clarified water that has no detrimental effects on the environment that it is discharged to.

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Certification

I certify that the ideas, designs and experimental work, results and 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.

Kristine Leigh Johnston

Student Number: Q94 206 284

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Signature

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Date

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1   INTRODUCTION

1.1   GROOTE EYLANDT

1.1.1   LAND USE AND TRADITIONAL OWNERS

Groote Eylandt is situated on the western side of the Gulf of Carpentaria forming the eastern border of the Arnhem Land Aboriginal Reserve (Figure 1.1). Most inhabitants are Aboriginals who live in the townships of Angurugu and Umbakumba or small outstations around the island. Alyangula houses employees of Groote Eylandt Mining Company (GEMCO) or people who are indirectly related to the mining operation.

Apart from the mining operations on the west coast, the land is used for traditional purposes by its Aboriginal owners. *(Pietsch, Rawlings et al, 1997, p.1)*
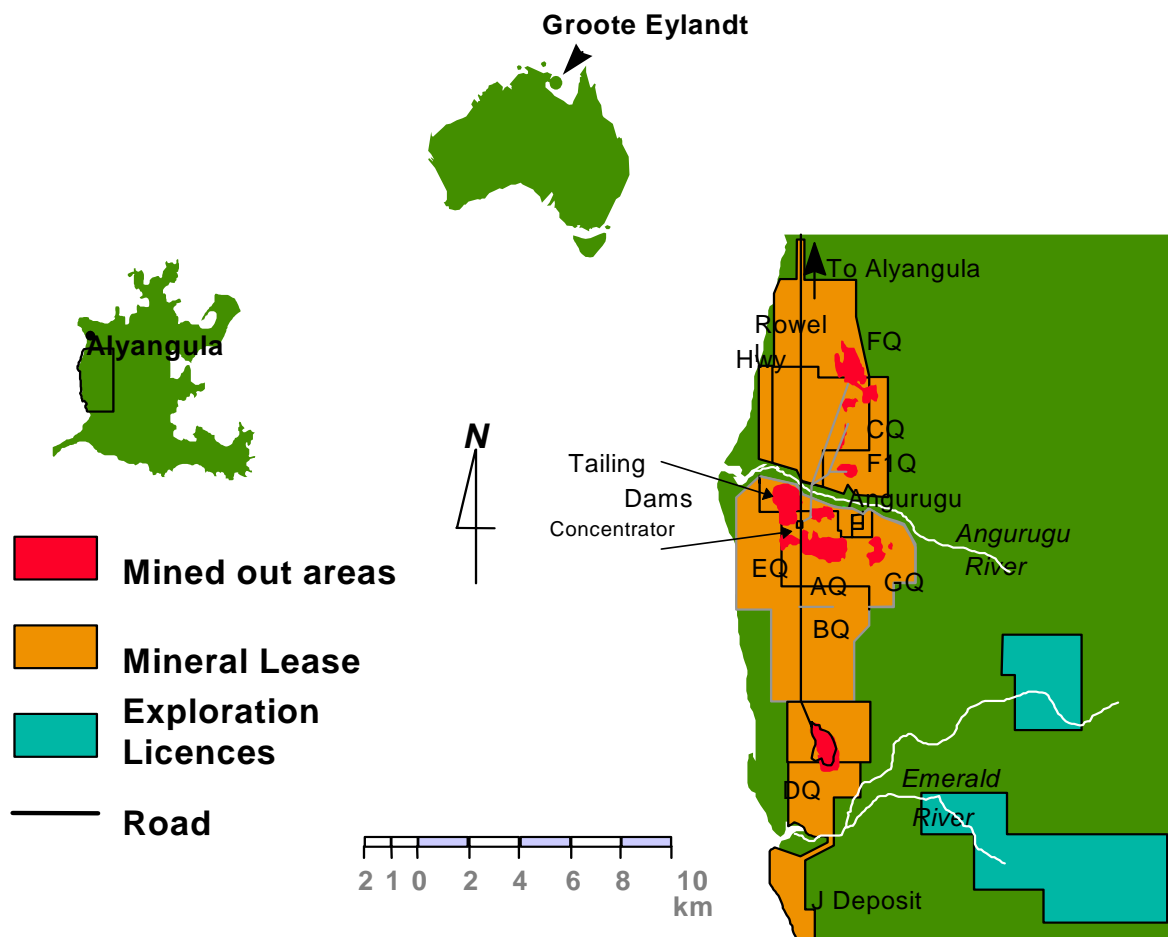
Figure 1.1: Groote Eylandt Mining Company Locality Plan

Groote Eylandt belongs to the Anindilyakwa Aboriginal people. The local township of Angurugu was established by Anglican missionaries in 1942 and it lies in the middle of the Groote Eylandt manganese deposit.

Manganese is mined from leases with traditional owners which extend over an area of approximately 50 square kilometres on the western side of the island.

GEMCO has a responsibility to maintain a high standard of operation to ensure the best outcome its stakeholders which includes the traditional owners in the local indigenous community of Angurugu.

1.1.2   EXPLORATION HISTORY AND MINING OPERATION

The presence of manganese on Groote Eylandt was noted firstly in 1803 by explorer Captain Mark Flinders. Manganese is also evident in the historical art work of the traditional owners of Groote Eylandt. Visiting geologists and missionaries also recorded the occurrence of manganese outcrops before a major exploration program took place in the early 1960's. The exploration program concluded that the reserves were sufficiently large to explore and develop the deposits. *(Pietsch, Rawlings et al, 1997, p.2)*

Manganese is used primarily as a strengthening agent in steel. It hardens the steel and improves its capacity to be worked. At the time of the major exploration program, BHP was importing significant quantities of manganese from overseas. The Groote Eylandt manganese deposit is of high grade and is one of the largest single accumulations of economic manganese in the world. BHP formed GEMCO and mining operations commenced in 1966. *(Pietsch, Rawlings et al, 1997, p.2)*

Mining operations at GEMCO involve the removal of manganese ore by open-cut strip mining. Areas from which ore has been extracted are backfilled with overburden from the next strip to be mined (pre-stripping). This pre-stripping method results in the mine quarries moving across the ore body, with pits being as deep as the ore body

in that particular location. This varies from fairly shallow (approximately 5m) to quite deep (approximately 20m). *(Pietsch, Rawlings et al, 1997, p.25)*

The recovered manganese ore is then beneficiated to specified qualities through a concentrator at the mine site before being transported 16 kilometres north to the ship loading area at Milner Bay in Alyangula.

GEMCO recognises that the traditional owners wish to return the land to its pre-mining state. The Health, Safety, Environment and Community department (HSEC) is responsible, among many other things, for ensuring that measures are taken to reduce the impact to water quality, ecosystems and therefore people due to site operations and water discharge. This is regulated by maintaining full compliance with the wishes of the traditional owners as well as all other regulatory requirements, in order to appropriately treat all discharged water streams to minimise the potential for turbid water leaving the lease boundaries.

1.1.3   MINE WATER

The tropical monsoonal climate of Groote Eylandt consists of two distinct seasons, the wet season and dry season. The average rainfall for the region is approximately 1275mm per annum. The strip mining method results in quarries that fill with water during the wet season from stormwater runoff. Year round, seepage from groundwater movement fills quarries. When the quarries fill with water, mining activities must cease. The water subsequently needs to be pumped out to continue the mining operation.

The mine site (refer to the site plan in Appendix B) falls generally towards Angurugu River from both the north and the south and ultimately towards the coast. Quarry water is pumped from sumps in the southern quarries (such as A South) to an open channel called 'the gash' adjacent the dams area. This water is then pumped from a sump in 'the gash' into the slimes dam. It is then pumped through a series of pumps and dams until it reaches Dam 1. Water is then taken off Dam 1 for use through the concentrator.

The northern quarries (such as C and F1) which are located north of the Angurugu River require pumping to a point where fall is found towards the ocean. There is currently a zero discharge policy to the Angurugu River due to the risk of turbid water entering the river.

1.1.4   MINE WATER WITH COLLOIDAL SUSPENSIONS

Aside from the manganese ore, various types of clay are the most common mineral in the ore deposit. They cover extensive areas and cover the ore body as overburden *(Prajecus, 1989, p.43)*. This overburden is disturbed when pre-stripping the quarries with dozers.

Deposits of montmorillonite were originally recorded in the A South area. The rocks are clay to silt sized and show white and pink colours *(Prajecus, 1989, p.43)*. More recently, a deposit of montmorillonite has been found in C Quarry. The montmorillonite clay is a dioctahedral mineral known commonly as smectite *(Newman and Brown, 1987, p.49)*. These quarries are typified by mine water which is highly turbid compared with other quarries which contain clear water.

In the case of C Quarry, the turbid water with colloidal suspensions has been sitting in situ since approximately 2000. The long range plan for the mine presently indicates that mining will again commence in C Quarry in 2008. Prior to this happening, the water will need to be clarified and then discharged. Once mining activities commence, a treatment procedure will need to be in place for the on going dewatering of C Quarry.

A photograph which highlights the visual impact turbid water has on the Angurugu River is shown below in Figure 1.2. A tribal elder took this photo on an incoming flight to Groote Eylandt in January 2006 after a particularly heavy rainfall event. As mentioned above, when A South Quarry is dewatered, the water drains to an open channel adjacent the slimes dam called 'the gash'. From 'the gash' this water is pumped into the dam for eventual reuse at the concentrator.

This particular incident occurred when water was pumped into the swamp on the ocean side of 'the gash' as a temporary measure due to construction work on the dam wall. The rainfall event carried turbid water from A South quarry into 'the gash' which then in turn ended up in the swamp and flowed into Angurugu River.

This resulted in GEMCO recording a significant incident and following up with an investigation. The result of the investigation was that there is now a zero discharge policy into the Angurugu River.

The traditional owners believe that turbid water is resulting in a delta forming at the river mouth which is affecting their traditional activities such as crabbing and fishing.

It is widely accepted when the turbid water meets saline water in an estuary, the suspended material will settle. Incidents such as this and dewatering quarries with colloidal suspensions require a management procedure to be put in place to avoid potentially negative downstream consequences.

Figure 1.2: Highly Turbid Water Enters Angurugu River, 2006

A significant amount of water is used at the ore concentrator as part of the beneficiation process. Water is used in the concentrator to help the crushed ore flow through each process and for washing, scrubbing and screening processes. Presently,

approximately 700l/s *(Dospisil, P 2005, pers. comm. 21 Dec)* of water is required to run the ore concentrator.

Water is sourced from bore fields which pump water continuously from aquifers on the mine site directly into Dam 1. Some of the southern quarries are dewatered via pumps into channels which run towards 'the gash' adjacent the slimes dam for reuse at the concentrator. These channels also pick up stormwater runoff from the surrounding catchments.

The slimes dams recycle water from the concentrator as well as from dewatering operations. Refer to the site plan in Appendix B for an overview of the water flow around the mine site.

The mine is potentially going to embark on an expansion project in a bid to increase its annual ore production. This will increase the requirement for water in the concentrator.

Water sourced from the bore fields comes at a considerable expense as the pumps are run off generator sets which consume diesel fuel. The bores pump water from approximately 65m underground.

Recycling water from quarry dewatering is a sustainable and cost effective source of water that could partially replace usage of the bore fields. Infrastructure would need to be provided from the northern quarries to harvest stormwater and quarry dewatering runoff and get it across the river to the Dams area.

Highly turbid water entering the concentrator to be used in the beneficiation process is of concern due to the potential for the fine nozzles for spraying water and screens in the scrubbing process becoming blocked. Currently, the volume of turbid water from A South entering the dams is not significant and becomes diluted with the clear water from the bore fields and this is not currently a problem. However, this may not always be the case. Should mine water be recycled at the concentrator thus reducing the

amount of water sourced from the bore fields, then any turbid water must firstly be clarified.

1.2   PROBLEM STATEMENT

The relationship between GEMCO and the local community is an important one. *(Millgate, J 2006, pers. comm., 17 Jan)*. Turbid discharge into Angurugu River is considered totally unacceptable by the local community and by GEMCO. During the wet season, large amounts of rainfall lead to a requirement for dewatering quarries. Dewatering C and F1 Quarries can discharge into the Angurugu River catchment area and result in turbid waters entering the river. Dewatering A South quarry discharges eventually to Dam 1. Highly turbid water could lead to problems at the ore concentrator.

The current dewatering practice in C and F1 Quarries is to pump the water to inactive quarries nearby. The water is then contained in the new location until mining operations must commence there and then the process is repeated. This transfer of water around the C and F1 area is an inefficient practice that is necessitated by the zero discharge policy into Angurugu River.

Turbid water in A South and C Quarries containing montmorillonite clay suspensions should be dewatered either to the environment or for reuse at the concentrator. Therefore, clarification of the water is necessary prior to either of these options taking place.

A procedure for treatment of highly turbid mine water needs to be in place at GEMCO. The procedure should be of a technical nature with managerial guidelines. To this end, the project work will examine treatment methods that are viable for the operation at GEMCO. A final recommendation will be made based on the most cost effective and practicable method to implement.

1.3   OBJECTIVES OF THE WORK

The aim of the project is that the proposed treatment will result in effective destabilisation and flocculation of the colloidal suspensions on a laboratory scale. The clarified water should be of acceptable turbidity for discharge to the environment or for reuse in the concentrator. This dissertation will discuss the findings of the investigation and make certain recommendations for field scale treatment.

To achieve this aim the project objectives are:

- Research information on montmorillonite clay and how the clay goes into suspension, colloidal systems, available reagents for aiding in treatment of the water, effects of turbid and treated water on the environment
- Critically review the literature available that covers the above topics
- Determine which reagents are feasible for the operation at GEMCO
- Determine an appropriate methodology for testing the chosen reagents and complete laboratory testing of samples
- Design a treatment approach for field operation based on laboratory test results and from a cost effectiveness and ease of application point of view
- Recommend a treatment procedure that is compatible with GEMCO's operations.

1.4   RISK ASSESSMENT

Any activity conducted on the mine site must be in accordance with BHP's Fatal Risk Control Protocols. The work for this project was subject to preparation of a Job Hazard Analysis (JHA) and Take 2 ('Take 2 minutes for safety'). In the research and testing phases of this project, there were tasks which involved preparation of a JHA prior to the task taking place. Take 2's were performed as necessary or where the scope of the task was similar to the JHA sheet, but slightly varied.

The JHA that was prepared for this project included the water sampling and water testing tasks. The JHA sheet can be found in Appendix C.

Prior to undertaking laboratory testing, a full laboratory induction was undertaken with the Supervisor of this work area. A copy of the induction sheet is also contained in Appendix C.

The outcome of this project work is the development of a water treatment procedure which will be adopted at the GEMCO site for future treatment purposes. Written into the procedure will be a job hazard analysis which will apply in the implementation of the treatment procedure.

2 LITERATURE REVIEW

In order to have an understanding of how to treat colloidal suspensions, it is important to understand the structure of clays, how they go into suspension, colloidal systems, clarification of turbid water through the processes of coagulation and flocculation and finally sedimentation. The purpose of the literature review was to develop an understanding of these mechanisms.

2.1 WATER QUALITY INDICATORS - TURBIDITY AND pH

Turbidity is a measure of water clarity. Suspended particles in the water cause light rays to be scattered. This imparts a 'false' colour to the water *(USQ, 2004)*. The suspended particles are usually the result of clays, silt or other colloidal suspended matter *(USQ, 2004)*. Measured in nephelometric turbidity units (NTU), turbidity is an indicator of the quality of water in rivers *(EPA, 1997)*.

High turbidity has a number of detrimental effects on aquatic ecosystems. The reduction of light penetration and visibility can limit plant growth and fish movements *(EPA, 1997)*. Suspended solids can stress fish and other aquatic fauna by clogging gills and causing abrasive injuries to respiratory passages *(EPA, 1997)*. Settled sediments from turbid water smother organisms living on the bottom of water ways therefore altering aquatic habitats *(EPA, 1997)*.

Tazaki et al *(2003)* examined the effects of flushed dam sediments on down-stream bottom dwelling aquatic habitats in Toyama Bay, Honshu, Japan.

Controlled exposure experiments with rainbow trout were carried out using smectite suspensions to examine the effect of expanding clays on the gills of fish *(Tazaki et al, 2003, p.244)*. Even for a small amount of smectite suspension in the water (0.5g/l), 2 out of 9 trout died after 18 hours in the water. Examination by optical microscopy revealed that the gill area was reduced because of the smectite *(Tazaki et al, 2003,*

p.250). The gills with smectite suspensions show both damage to the body tissue and changes in the chemistry (*Tazaki et al, 2003, p.250)*.

Flatfish were also collected from Toyama Bay after upstream dams were flushed and their gills examined. Thin films of clay mineral sediments of smectite were found on their gills.

It was concluded from the study that particles <75µm were fine enough to pass through the gill membranes and cover the spaces of the gill tissue. This was thought to induce mucus production thus reducing the rate of oxygen diffusion from the surrounding water in to the fishes blood (*Tazaki et al, 2003, p.250)*. Coarser particles (750-250µm) were large enough to cause mechanical abrasion of the gill (*Tazaki et al, 2003, p.250)*.

Dam flushing also corresponded to drastic declines in yearly flatfish catches. Wakame seaweed production was also reduced (*Tazaki et al, 2003, p.252)*. The seaweed provides important spawning ground for flatfish.

The Environmental Protection Agency *(EPA, 1997)* lists the following levels of NTU as a guide to river water quality:

- good (< 5 NTU)
- fair (5-50 NTU)
- poor (> 50 NTU)

The EPA suggests that turbidity below 50 NTU is suitable for protecting aquatic animals and plants.

The pH of an aquatic environment is also important water quality indicator. pH is a measure of acidity or alkalinity of water. pH 7 is neutral and values above this tend towards alkalinity and below this tend towards acidity *(USQ, 2004)*. All animals and plants are adapted to specific pH ranges, generally between 6.5 and 8.0 *(Waterwatch*

Australia, 2002). If the pH of a waterway or waterbody is outside the normal range for an organism it can cause stress or even death to that organism *(Waterwatch Australia, 2002).*

Table 2.1 below gives guidelines pH levels as they relate to water quality in rivers.

	Excellent	Good	Fair	Poor	Degraded
pH Range	6.0-7.5	5.5-6 or <8.0	8.0-8.5	5.0-5.5 or 8.5-9.0	<5.0 or >9.0

Table 2.1 Water Quality Guidelines (pH) for Rivers (Waterwatch Australia, 2002)

2.2 COLLOIDAL SYSTEMS

Colloids are dispersions of small particles of one material in another *(Atkins, 1990, p.706).* Colloids are defined by size and the colloidal range can extend from 1 nanometer (10^{-9}m) to 1 micrometer (10^{-6}m) *(Shaw, 1991, p.1).* Particles are not able to be seen with optical microscopes and can pass through most filter papers *(Atkins, 1990, p.706).*

Figure 2.1 shows the size of colloids as they relate to other matter found in water.
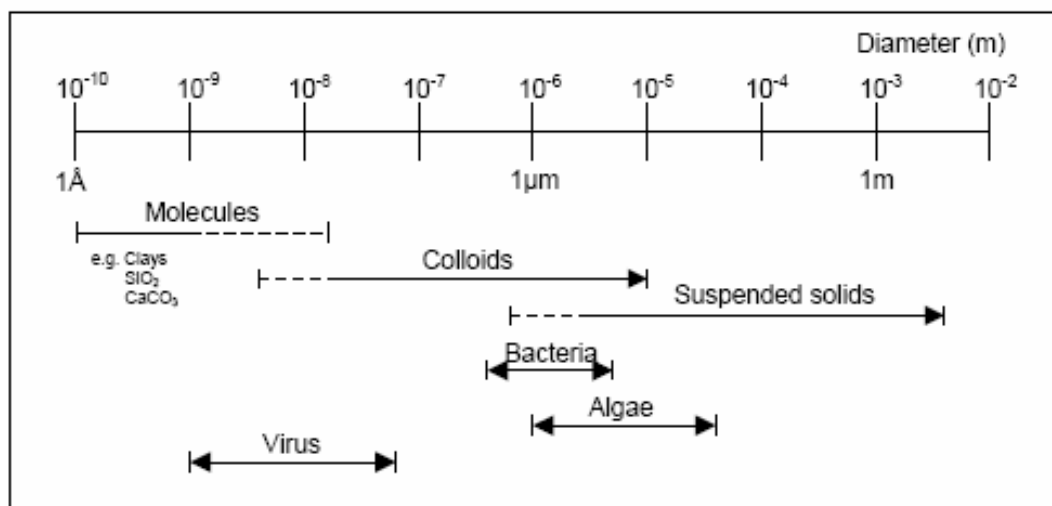
Figure 2:1: Size Spectrum of Waterborne Particles (Benefield et al, 1982, p.182)

Colloids have a large surface area in the dispersed phase compared with the same amount of ordinary material. To explain this, imagine a 1cm cube with a surface area of 6cm^2. Say the cube becomes dispersed as 10^{18} small 10ηm cubes, the total surface area increases substantially to 6 x 10^6cm^2 *(Atkins, 1990, p.707)*. This important feature means that surface chemistry of the solids along with the composition of the aqueous solution dominates the nature of the colloidal system *(Atkins, 1990, p.707)*.

Clay particles suspended in water are a common type of colloidal system called a clay suspension. The clay suspension imparts turbidity to the water because the tiny clay particles scatter light in all directions *(van Olphen, 1963, p.1)*.

The dispersed particles collide frequently due to Brownian motion *(van Olphen, 1963 p.9)*. The suspended particle is constantly and randomly bombarded from all sides by molecules of the liquid. If the particle is very small, as in colloids, the hits it takes from one side will be stronger than the bumps from other side, causing it to jump *(Shaw, 1991, p.24)*. These small random jumps are what make up Brownian motion *(Shaw, 1991, p.24)*. Extraneous sources such as mechanical vibrations, convection currents and agitation have no effect on the particles movements and the particles seem to move independently *(Russel et al, 1989, p.65)*.

The stability of a colloidal system is based on the sum of repulsion and attraction energies present. A prevailing repulsive energy means the system will remain in a dispersed state. If attraction energy prevails, the system will flocculate *(Evangelou, 1998, p.373)*.

Smectite clays are known to carry a negative surface charge and when they are immersed in water, a phenomenon known as an electric double layer forms at the clay water interface which leads to a stable colloidal system *(Zhou et al, 1994, p.747)*. In these systems, this energy barrier which exists retards the process of coagulation *(Hogg, 2005, p.807)*. The system may remain virtually unchanged for a considerable period of time.

2.3   ELECTRIC DOUBLE LAYER

As has been discussed above, the stability characteristics of the clay suspension are a result of interactions between the clay particles within the suspension. A major source of stability is the existence of an electric charge on the surface of a particle. Ions in the medium of an equivalent and opposite charge cluster nearby the particle and a layer of rigid ionic atmosphere is formed *(Atkins, 1990, p.708)*.

This rigid layer is surrounded by a diffuse ionic cloud which extends into the bulk solution as the charged unit attracts an oppositely charged ionic atmosphere *(Atkins, 1990, p.708)*. This layer is called the diffuse layer. The two layers make up the electric double layer or diffuse double layer *(Atkins, 1990, p.708)*.
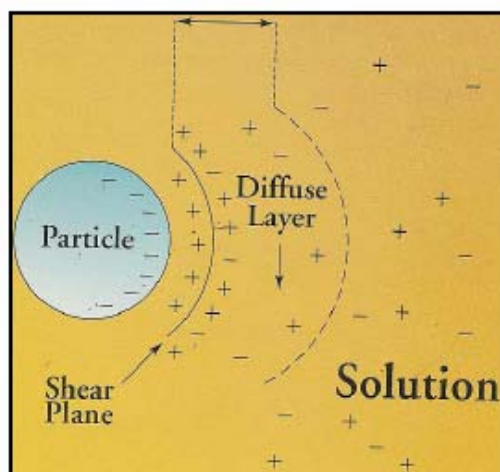
Figure 2.2: Electric Double Layer

The electric potential at the shear plane (refer to Figure 2.2) is relative to its value in the distant, bulk medium and is called the zeta potential. The electric potential decays across the double layer *(Atkins, 1990, p.709)*.

The electric double layer is ionic in character and changes to the nature of the ionic species in solution has direct effects on the layer and therefore impacts on the zeta potential of the colloidal suspension *(Velde, 1995, 178)*.

In a solution of low ionic strength, the electric double layer will be wide and the zeta potential high. At high ionic strengths, the atmosphere is dense and the potential of the particle is low *(Velde, 1995, 178)*. Figure 2.3 demonstrates this change in the electric double layer due to ionic strength of the solution. At high ionic strengths, there is little electrostatic repulsion to hinder the close approach of two colloid particles, flocculation can readily occur as a consequence of Van der Waals forces *(van Olphen, 1963 p.37)*.
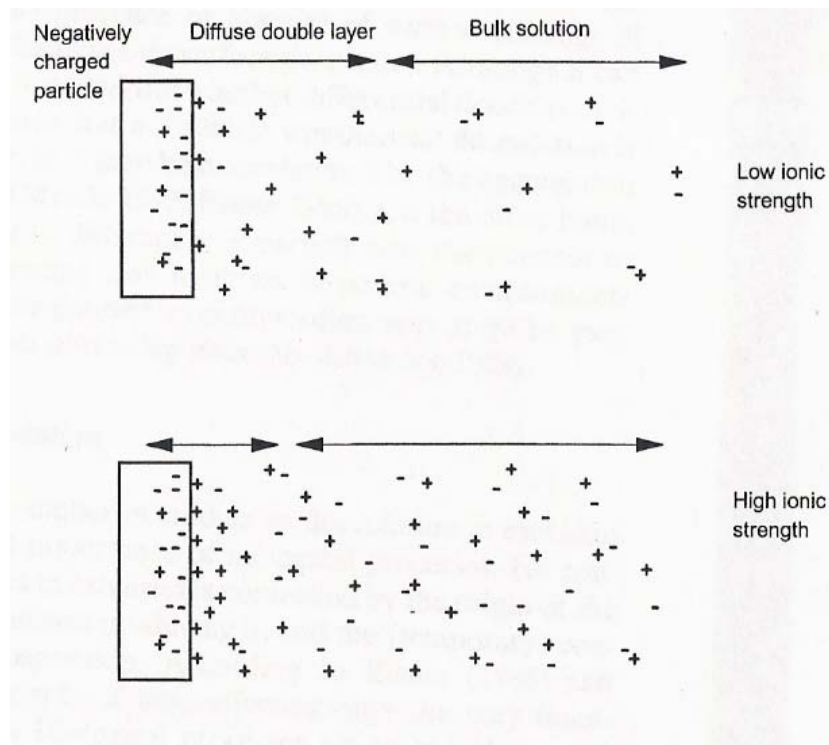
Figure 2.3 Changes to Electric Double Layer due to Ionic Strength (Velde, 1995)

2.4 CLAYS

Clays are defined based on their crystal size. Minerals with particles less than 2μm are defined as clays *(Velde, 1995, p.9)*. The minerals most commonly called clays are sheet-shaped and are called phyllosilicates. Their particles are plate like, being much thinner than wide or long *(Velde, 1995, p.17)*.

The basic building elements of any clay mineral are two-dimensional arrays of silicon-oxygen tetrahedra and two-dimensional arrays of aluminium- or magnesium-oxygen-hydroxyl octahedra *(van Olphen, 1963 p.59).*

Most clay structures have tetrahedral and octahedral layers linked together in the sheet structure. This is done through sharing an oxygen atom *(van Olphen, 1963 p.62).* This sharing occurs in the z direction of the structure. When layers are linked, the upper oxygens of the octahedral units are shared with tetrahedra *(Grim, 1962, p.16).*

Unlike tetrahedra, in the octahedral linkages the number of cations can vary between two and three. For example, there could be 3 Mg^{2+} (magnesium) ions present or 2 Al^{3+} (aluminium) ions in the octahedral sites *(van Olphen, 1963 p.62).* When three ions are present, the structure is called trioctahedral and when two cations are present, the structure is called dioctahedral *(van Olphen, 1963 p.64).* This forms the fundamental classification scheme for clay minerals.

Montmorillonite is dioctahedral and its structure is represented in Figure 2.4 below. There is an octahedral sheet sandwiched between two tetrahedral sheets and thus montmorillonite is called a 2:1 structure *(Newman, 1987 p.49).*

Al (yellow octahedra) and Mg (blue octahedra) can form the octahedral layer. The charged double layers are held together by interlayer cations Ca and Na *(Newman, 1987 p.48).* These cations are represented by purple spheres in Figure 2.4.
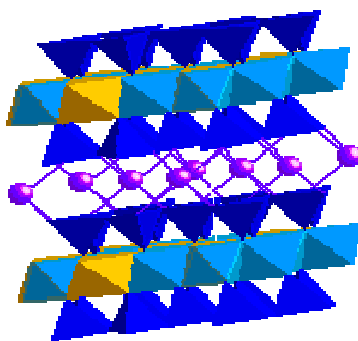
Figure 2.4: Structure of Montmorillonite Clay

The layer thicknesses are the fundamental means of identifying clay mineral species *(Velde, 1995, p.20)*. The layer thickness dimension can be measured by X-ray diffraction analysis (XRD). The unit layer thickness of montmorillonite is 10A (Angstroms) *(Velde, 1995, p.17)*.

Variable amounts of water can be held between the layers of montmorillonite clay and the layer spacing can expand and contract depending on the available hydration.

2.5 MONTMORILLONITE CLAY AND WATER

When in the presence of water, cations on the clay layer surfaces can be easily exchanged with other cations that are available in the solution *(van Olphen, 1963 p.66)*. The water molecules penetrate between the unit layers resulting in inter-layer swelling *(van Olphen, 1963 p.66)*. Montmorillonites are particularly susceptible to this swelling mechanism. Their interlayer spacing can increase to 20A in the presence of water *(van Olphen, 1963 p.67)*. Hence, they are also known as expanding or swelling clays *(Velde, 1995, p.12)*. In the presence of enough water due to various swelling mechanisms, disintegration of the clay into a dispersion can lead to a colloidal system.

2.6 CLARIFICATION OF TURBID WATER

Clarification of water is achieved by the process of coagulation and flocculation which is facilitated by the addition of reagents to the turbid water. The resulting agglomeration of particles leads to solid liquid separation by sedimentation *(Hogg, 2005, p.838)*.

There are a number of techniques by which clarification can be achieved. The most common is dosing the water after the event that imparts turbidity to the water (ie stormwater runoff event). Dosing with gypsum is common as is using aluminium sulphate *(Robinson, 2001)*.

When gypsum is used, the water needs to stand for a few days so that the particles can settle out before the water is discharged. This approach requires large volumes of gypsum and has the disadvantage that an additional storm event can result in overflow into the environment before proper settling can occur *(Robinson, 2001)*.

This is partially overcome by the newer polymer based settling materials. Polymers require less material and settling is rapid however, they can be expensive and require careful processing *(Robinson, 2001)*.

2.6.1   COAGULATION AND FLOCCULATION

The words flocculation and coagulation tend to be used interchangeably in texts relating to colloid chemistry to describe the aggregation process. However, in minerals processing where synthetic polymers are used, there is a distinct difference between the two mechanisms.

Coagulation describes the destabilisation of colloidal dispersions by adding ions which cause a reduction in the mutually repulsive electrical double layer forces present at the solid liquid interface *(Nalco, 2004)*.

Flocculation is the aggregation of colloidal suspensions by the action of high molecular weight polymers soluble in the continuous phase by means other than charge reduction *(Nalco, 2004)*.

In order for aggregation to occur two things must happen, particles must approach each other close enough to interact and they must stick together as a result. Three physical processes are responsible for bringing the particles together. Brownian motion, velocity gradients due to laminar and turbulent shear and differential settling. *(Nalco, 2004)*.

The repulsive forces responsible for the stability of colloidal dispersions are usually of electrical origin and result from the development of electrical charges on particle surfaces. *(Nalco, 2004)*.

2.6.2 POLYMER TECHNOLOGY

Polymers are used in large-scale industrial effluent treatment *(Krentz et al, 2003, p.423-430)*. Synthetic polymers are versatile and can be tailored to a specific application *(Nalco, 2004)*.

A polymer is a chain of sub-units called monomers *(Nalco, 2004)*. The total number of units in a synthetic polymer can be varied producing materials of differing molecular weights (chain length). The polymer chains can be linear, branched or cross-linked *(Nalco, 2004)*.

If the polymer contains ions such as carboxyl or amino, the polymer is called a polyelectrolyte. These polyelectrolytes can be termed cationic (contains positive ions) or anionic (contains negative ions). Polymers without ionisable groups are called non-ionic or polyacrylamides *(Nalco, 2004)*.

Polyelectrolytes function primarily by charge neutralisation and offer the advantage of large and robust floc structure *(Nalco, 2004)*. Polymer flocculation involves the following phases *(Nalco, 2004)*:

- Dispersion of polymer solution into the solution
- Absorption of polymer segments onto particle surface
- Collision of particles partially covered with polymer loops to form polymer bridges

The selection of polymer type is generally based on the pH of the solution and the surface charge of the colloidal suspension. Figure 2.5 provides a general guideline to polymer selection.

pH RANGE	POLYMER TYPE
<1-6.5	Cationic (salt form)
3-9.5	Quaternary Cationic (better charge stability)
<1-14	Nonionic (relatively insensitive to pH
6.5-8.5	Slightly anionic
7.5-14	Strongly anionic
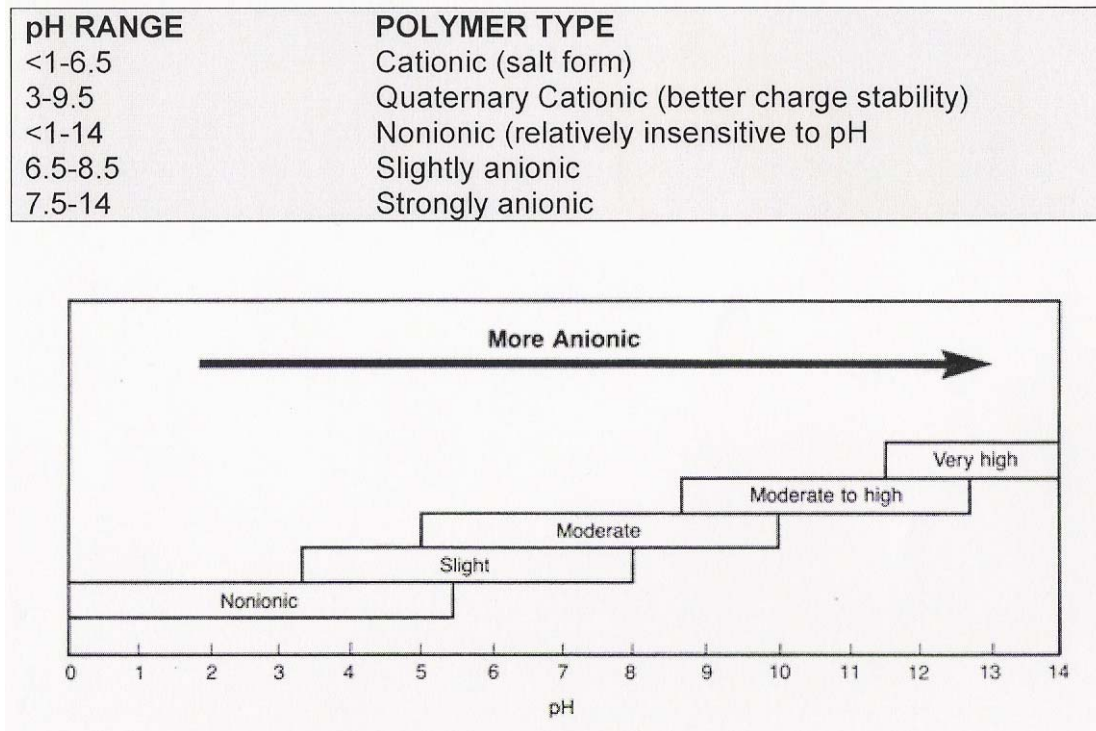
Figure 2.5: Guideline to Polymer Selection (Nalco, 2004).

An important aspect of using polymers is that there needs to be a uniform distribution of the polymer molecules through the water being treated. Polymer to particle contact is vital for the success of using polymer technology. Conversely, excessive agitation can leads to polymer breakdown *(Nalco, 2004)*.

Polymers can also be sensitive to overdosing. Water that is overdosed can remain turbid and become very hard to treat *(Citiwater Laboratories, 2000)*. Most synthetic polymers have a moderate toxicity to fish *(Haslam, 2004)*.

There are concerns about the use of polyacrylamides relating to toxicity of the acrylamide molecule. It is known as a peripheral nerve toxin and may disrupt sensory, motor and autonomic function in peripheral nerves *(Smith, 1995 cited in Cleaves, 2002)*.

2.6.3   GYPSUM

Gypsum is a naturally occurring mineral or can be synthetic, produced as a by-product from some refining processes, particularly fertilizers *(Zhou et al, 2003, p.746)*. Gypsum is widely used in the building industry and is an economical resource. Gypsum can be readily dissolved into solution.

Zhou et al *(2003)* examined the settling characteristics of solids in coal mine effluent using gypsum to destabilize colloidal suspensions.

The fine particles suspended in the effluent water at the study site were mostly dioctahedral smectite *(Zhou et al, 2003, p.746)*. The suspended solids were colloidal size particles that formed a stable suspension *(Zhou et al, 2003, p.746)*.

Gypsum was pre dissolved in deionised water and its concentrations were controlled over a range of dosages *(Zhou et al, 2003, p.749)*. The suspension was poured into graduated settling tubes. After the clays had flocculated and settled in the settling tube, a boundary appeared between the clay flocs and the supernatant water *(Zhou et al, 2003, p.749)*. The boundary moved downward as settling progressed.

Settling curves were plotted from the above test and could be divided into two portions: an initial nearly linear portion with a steep slope, and a second flatter portion. The former represented a free settling process, and the latter represented a hindered settling process within a mass of flocculated clays *(Zhou et al, 2003, p.750)*.

It was concluded that gypsum could be used to flocculate the suspended solids. Even a small amount of gypsum flocculated the system and caused the clays to settle *(Zhou et al, 2003, p.750)*.

2.6.4   SEAWATER

It is commonly known that when turbid water meets saline water in estuaries, suspended clays settle out forming deltas at river mouths *(Twidale, 1993, p.152)*. This is the process of salt flocculation. Salt flocculation occurs between fine grained particles that are charged. The charge may originate from substitutions within the mineral structure or from surface reactions *(Velde, 1995, p.178)*.

Ion exchange from the saline solution into the crystal structure of the clay may destabilise the charge. Conversely, a pH change may affect the surface chemistry of the particle in suspension. In a solution of high ionic strength, the diffuse double layer around the particle can become so compressed that as the particles approach each other due to Brownian Motion or otherwise, the van de Waals attraction between them stick the particles together *(Velde, 1995, p.179)*.

After collision due to Brownian Motion the particles usually separate again. However, when a small amount of salt is added to the clay dispersion, the particles stick together upon collision. Agglomerates (also known as flocs) grow in the suspension and these flocs settle rather quickly. In this way, a bottom sediment forms, leaving a clear, particle free supernatant liquid *(van Olphen, 1963, p.10)*.

The sticking together of particles upon collision means that there are attractive forces between the particles. These attractive forces are attributed to the van der Waals attraction forces where all the atoms of one particle are attracted to all the atoms of another particle. In a suspension, there are also repulsive forces operating due to the similarly charge particles and both the attractive and repulsive forces operate simultaneously. This repulsion decreases with increasing salt concentration *(van Olphen, 1963, p.12)*.

In surface waters of the open oceans, salinity ranges from 33 to 37 *(Brown et al, 1989, p.30)*. The average concentrations of the principle ions in seawater are listed in the following Table 2.2 below (in parts per thousand by weight).

Ion	% by weight		
chloride, Cl-	18.980		
sulphate, SO42-	2.649		
bicarbonate, HCO3-	0.140	}	negatives ions (anions) total = 21.861%
bromide, Br-	0.065		
borate, H2BO3-	0.026		
fluoride, F-	0.001		
sodium, Na+	10.556		
magnesium, Mg2+	1.272		
calcium, Ca2+	0.400	}	positive ions (cations) total = 12.621%
potassium, K+	0.380		
strontium, Sr2+	0.013		
		overall salinity	= 34.482%

Table 2.2 Principle Ions in Seawater (Brown et al, 1989, p.30)

Even though the weight of the negative ions exceeds that of the positive ions, the seawater does not carry a net negative charge *(Brown et al, 1989, p.30)*.

Average salt content in the ocean is 35 grams per kilogram of seawater, composed mostly of the free ions: sodium (Na^+), chloride (Cl^-), sulphate (SO_4^{2-}), magnesium (Mg^{2+}), calcium (Ca^{2+}), and potassium (K^+) *(Brown et al, 1989, p.30)*.

Electrical conductivity of water gives a direct indication of the salinity of water. Electrical conductivity can be measured in milliSiemens per centimetre (mS/cm) or microSiemens per centimetre (µS/cm), which is equal to mS/cm x 1000.

Table 2.3 *(Waterwatch Australia, 2002)* shows some typical electrical conductivity ranges for various water types.

Water type	Electrical Conductivity (µS/cm)
Deionised water	0.5-3
Pure rainwater	<15
Freshwater rivers	**0-800**
Marginal river water	800-1600
Brackish water	1600-4800
Saline water	>4800
Seawater	**51 500**
Industrial waters	100-10 000

Table 2.3 Typical electrical Conductivity Ranges (Waterwatch Australia, 2002)

2.7 SEDIMENTATION

Sedimentation is the separation of suspended particles from water by gravitational settling. The primary purpose is to produce a clarified effluent *(Nalco, 2004)*.

For successful solids-liquids separation the settling rate of particles should be increased such that gravitational are sufficient to provide adequate separation. The settling rate of particles is affected by their size, shape and weight, as well as by the density of the liquid they are settling through *(Nalco, 2004)*.

Stokes Law equates this settling velocity (*v*) with the physical characteristics of the particle and the medium in which it is settling *(Nalco, 2004)*.

$$v = \frac{2ga^2(d_1 - d_2)}{g\eta}$$

where v = settling rate

α = radius of settling particle

d_1 = density of particle

d_2 = density of fluid

η = coefficient of fluid viscosity

g = gravitational constant

Thus, according to Stokes law, the particle radius has the most influence on the settling rate. Increases in floc size through coagulation and flocculation will influence the settling rate accordingly.

Treatment of water in a clarification pond is recommended. In situ treatment such as in dams (or in the case of this project, in the quarry) is not always satisfactory. The settled sludge from such treatment may be redispersed by slight disturbances of the water due to wind action. Further inflow of the untreated water also counteracts the effect of earlier treatment *(Department of Agriculture, 2004)*.

Where a clarification pond is protected and further inflow can be diverted, treatment can be satisfactory, particularly if a floating take-off is used to pump out the clear water *(Department of Agriculture, 2004)*. This take-off can be made to always remain a certain distance above the bottom so that sludge is not picked up *(Department of Agriculture, 2004)*.

As soon as the clear water has been removed, the sludge should be removed to waste. Sludge left in the clarification pond can prevent satisfactory treatment of the next fill *(Department of Agriculture, 2004)*.

2.8   OTHER CLARIFICATION METHODS

2.8.1   ELECTROFLOCCULATION

Water runoff from building sites can result in considerable pick up of clay particles. This can result in silting up of waterways leading to environmental problems. Environmental guidelines now require that the water must have a value of less than 50 mg/L for general discharge or less than 30mg/L for discharge into environmentally sensitive areas *(EPA, 1997).*

Electro flocculation is a technique in which water is electrolytically treated with sacrificial electrodes, generating the metal flocculating ions and gas bubbles in the same reaction. Suspended material is destabilised and carried to the surface in the gas bubbles where they can be separated from the water. Aluminium electrodes are placed in a reaction tank. The water is pumped into the tank until it reaches the appropriate level, at which stage the electrodes are activated. A current passes between the anodes and cathodes effectively introducing flocculating aluminium cation into the water without any anions being introduced *(Robinson, 2001).*

2.8.2   FLOCCULANT BLOCKS

Flocculant blocks are solid blocks of slow release flocculant which work by releasing into the water stream trace amounts of anionic polymer chain molecules which act to bind together clay fines so that they will settle out rapidly leaving clear water for disposal or re use *(Environmental Warehouse, 2003).*

A secure dosing point should be prepared such as a mesh cage in the flow channel. The blocks should be placed just prior to the flow entering a settling pond and the results observed. To increase dosage, more flocculant blocks are used per volume of water. The optimum number must be determined by trial and will depend on flow volume, solids content and solids type *(Environmental Warehouse, 2003).*

The carrier polymer is non toxic and the solids settle rapidly due to the chain molecules binding together with the clay particles to form large flocs *(Environmental Warehouse, 2003)*.

Clarified water can then be discharged. Figure 2.6 shows the schematic treatment method for flocculant blocks.
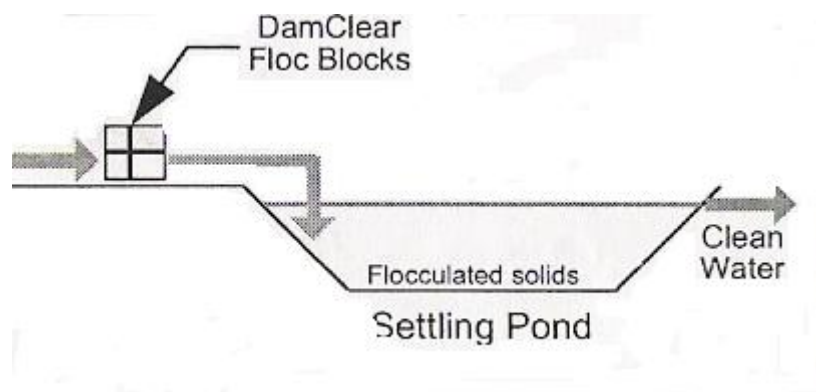
Figure 2.6: Flocculant Block Treatment Method (Environmental Warehouse, 2003)

2.8.3   CONSTRUCTED WETLANDS

Braskerud *(2001)* investigated the influence of vegetation on sedimentation of suspended particles using constructed surface flow wetlands (CWs).

The hypothesis for the effect of increased sedimentation due to vegetation was a combination of reduced turbulence and reduced water velocity *(Braskerud, 2001, p.1447)*. The mechanisms thought to produce increased sedimentation were i) particles flowing into plant stems and leaves ii) particles sticking to the biofilm on macrophytes and iii) random processes moving particles to immersed surfaces *(Braskerud, 2001, p.1447)*.

Vegetation was also thought to shelter trapped sediments from iv) resuspension. It was also considered possible that aggregates were formed through v) flocculation in CWs via a) small scale turbulent water to increase particle interaction and b) organisms producing sticky organic matter to stimulate flocculation *(Braskerud, 2001, p.1447)*.

After six years of investigations, results showed that the retention of clay particles in the CWs exceeded model estimates by a factor of 2.5 to 8.2 *(Braskerud, 2001, p.1447)*. Also, the study found that vegetation did not have any influence on the clay concentration in the sediment *(Braskerud, 2001, p.1447)*. Thus, the clay suspensions are not removed from the water by the filtration of the water through vegetation.

3 RESEARCH METHODOLOGY

3.1 PREVIOUS STUDIES

Previous to this project work, turbid mine water had been sent away to external laboratories for testing to seek advice on treatment options.

3.1.1 CITIWATER LABORATORIES

Citiwater Laboraties of Townsville City Council undertook testing of C Quarry Water samples in August, 2000. A ten litre sample of water was jar tested to ascertain the best method of clarification of the water.

3.1.2 GEMCO HSEC DEPARTMENT

GEMCO Environmental Officers from the Health, Safety, Environment and Community (HSEC) Department undertook testing on flocculant blocks in 2000 however results from the trials were not able to be located.

Dosing is controlled by the slow release mechanism of the flocculant block. Based on evidence of previous work and the fact that the blocks appeared to be easy to apply in the field, flocculant blocks were sourced for testing as part of this project.

3.1.3 CIBA SPECIALTY CHEMICALS

Ciba Specialty Chemicals undertook testing on C Quarry water samples in June, 2004. Based on this previous test work, Ciba Specialty Chemicals were contacted and samples of their products used in bench top testing.

3.2 X-RAY DIFFRACTION (XRD) ANALYSIS

Confirmation of the nature of the colloids in the water was investigated to obtain an understanding of the cause of the turbidity. In the case of the C Quarry water, smectite

clay was thought to be the cause *(Keen, R 2005, pers. comm., 15 Dec)*. Smectite or more specifically, montmorillonite clay had been identified in some areas around the mine site during the exploration program in the 1960's.

A sample of clay from C Quarry was taken and the mineralogical composition of the sample was measured by XRD analysis performed in the metallurgy laboratory.

3.3   PARTICLE SIZE DISTRIBUTION

The particle size distribution was outsourced to Microns to Measure in order to determine if the turbid water was caused by fine particles which were within the range that would classify them as a colloidal suspension. A 1 litre sample of C Quarry water was collected and sent for testing.

3.4   COLLECTING SAMPLE WATER

Water collected from C Quarry for testing was undertaken in accordance with the Job Hazard Analysis (JHA) which can be found in Appendix C. Water was collected with a bailer and transferred into water sample bottles. Figure 3.1 shows water collection being undertaken.

Figure 3.1: Collection of Sample Water

Batches of water were collected and stored in 10 litre buckets at the laboratory as required. The temperature of the storage area was equivalent to the outdoor temperature and water was not stored for more than three days at a time.

3.5 PHASE 1 - PRELIMINARY LABORATORY TEST WORK

A range of reagents from various chemical companies were received at the laboratory. Seawater was also collected from Milner Bay to be used as a reagent. The objective of the preliminary tests was to screen the reagents by investigating their effectiveness in treating the colloidal suspensions of montmorillonite clay in the sample water.

In total, nine (9) reagents were sourced for the screening tests. Table 3.1 on the following page lists the reagents that were used in the screening tests with a brief description of each.

No.	Reagent Name	Description	Source
1	Aluminium Sulphate (Liquid)	Alum Liquid, clear non-viscous liquid	Coogee Chemicals
2	Ciba Magnasol 589 Coagulant	Aqueous solution of inorganic salts and cationic polymer	Ciba Specialty Chemicals
3	Ciba Magnasol 576	Aqueous solution of inorganic salts	Ciba Specialty Chemicals
4	Nalcoag 3268	Polyquaternary Amine in aqueous solution	Nalco Australia
5	Ultrion 8187 (Water Clarification Aid)	Aluminium Salts Water	Nalco Australia
6	Ultrion 83697 (Potable Coagulant)	Polyquaternary amine, polyaluminium chloride, water	Nalco Australia
7	Micro-Gyp	Off white powder form with major elements of Calcium, Sulphur and gypsum	Gypsum Products Australia
8	DamClear Flocculant Block	Flocculant in 3kg block form	Environmental Warehouse
9	Seawater		Collected from Milner Bay Boat Ramp

Table 3.1: Available Reagents for Preliminary Laboratory Test Work

During the preliminary test work phase, tests for each reagent were conducted over a range of dosages in 100mL beakers to assess the approximate optimum dosage (Figure 3.2). This was done by choosing the dosage that gave a visually clarified supernatant at the minimum dosage.

In some cases, suggested dosing rates and results of the previous studies were used as a guide for the products that had been previously tested. The polymers generally had to be diluted with distilled water to achieve the dosage rate as they came in a concentrated, viscous form.

Reaction of the colloidal suspension to the addition of each of reagent was visually observed and this information was recorded onto test report forms. A template test report form can be found in Appendix F.

Figure 3.2: Preliminary Laboratory Test Work

3.5.1   FLOCCULANT BLOCK TEST

The flocculant block was initially tested on sample water by cutting a small cube from the larger block and adding it to a flask with sample water. The water was then agitated so that the flocculant block would contact the sample water.

The flocculant block was also tested in the field in an area where turbid water was discharging through a pipe culvert with supercritical flow (creating an area of turbulence) into a relatively flat and shallow area with slow laminar flow (creating an area where particles could settle).

3.5.2   PHASE 1 SUMMARY

The observations made during the screening tests are described Chapter 4. Five (5) reagents appeared to achieve the desired results.

- ULTRION 83679
- CIBA Magnasol 589
- Aluminium Sulphate
- Microgyp
- Seawater

3.6   PHASE 2 – LABORATORY TEST WORK

3.6.1   EQUIPMENT

The following equipment was used for conducting the test work:

- Several 2000mL graduated beakers (matched)
- Several pipettes and one syringe for reagent addition
- Stop watch to measure settling time
- Reagent solutions prepared in flasks
- Turbidity meter (YSI 6920 SONDE)
- Mixing paddle and sprayer
- Distilled water for dilution, cleaning and rinsing
- Test report forms for recording data (sample in Appendix F)

3.6.2 TURBIDITY METER – SONDE DEVICE

The SONDE device (Figure 3.3) was used to record Turbidity (NTU), pH and electrical conductivity for all turbid water samples and supernatant fluids and these were recorded onto the test report forms for later analysis. The device was operated by suspending the lens in the beaker and an LCD results screen showed the output for the water properties.

Figure 3.3: SONDE Device

3.6.3 PROCEDURE

The following procedure was followed for Phase 2 of the test work.

1. Obtain a suitable quantity of untreated mine water.
2. Prepare reagent solutions as determined from either previous studies or as per the manufacturers' specifications. Solution to be prepared in flasks just prior to conducting test work.
3. Conduct tests in multiples to give a good spread of results. The tests were repeated five (5) times.
4. Fill beakers to the 2000mL level with the turbid water.
5. Determine pH, NTU, temperature and electrical conductivity of the turbid water using the SONDE device and record this on the test report form.
6. Use optimal reagent dose of made up solution.

7. Transfer the optimal dose of reagent solution to the beaker using either a pipette when small quantities of solution are required or a large syringe for larger quantities of solution.

8. Agitate the water by using a mixing paddle. Note the number of rpm's of the paddle and degree of agitation for further evaluation. Other application methods can be used such as spraying to the surface of the water sample. Note the application method on the test report form.

9. Observe the water sample for floc formation and settling characteristics and make notes on the test report forms.

10. Observe sediment interface level (beaker graduations) versus time (minutes/seconds) by using a stop watch and visual observation. Record onto test report forms. Later, prepare a settling curve by plotting the beaker graduations versus time for each reagent.

11. For the purposes of clarification pond sizing, determine the settling rate over the initial linear section of the curve. Convert this to m/hr. This step was outside the scope of the project, however could be used in future work for clarification pond sizing.

12. Determine pH, NTU, temperature and electrical conductivity of the supernatant fluid using the SONDE device after a nominal amount of time and record this on the test report form.

13. Determine amount of settled solids in the water by either filtration or oven drying the settled material.

14. Convert reagent dose to a unit cost/m^3 (or tonne of solids) of turbid water for cost analysis.

15. After analysis of tested reagents, select those suitable for the operation at GEMCO and further optimise the dose rate for improved cost effectiveness.

3.6.4 TEST WORK DESCRIPTION

Once the optimum dosage was determined (from Phase 1 - Preliminary Test Work) solutions were made up and stored in flasks. Tests were undertaken on the sample water in 2000mL beakers. This was so the SONDE device, which is quite large, could be immersed in the clarified supernatant to measure the properties of the clarified

water. Properties such as turbidity, pH and salinity could have substantial effect on the downstream environment. This data was recorded on the test report form. The Phase 2 tests were repeated five times over several days to give a range of results for eventual collation and analysis.

The beakers were lined up from left to right on the bench as shown in the following photo (Figure 3.4). Each beaker was assigned a particular reagent as listed below.

- ULTRION 83679 (No.1 Beaker)
- CIBA Magnasol 589 (No. 2 Beaker)
- Aluminium Sulphate (No.3 Beaker)
- Microgyp (No.4 Beaker)
- Seawater (No.5 Beaker)

The reagents were added to the 2000mL beakers at the optimum dosage.
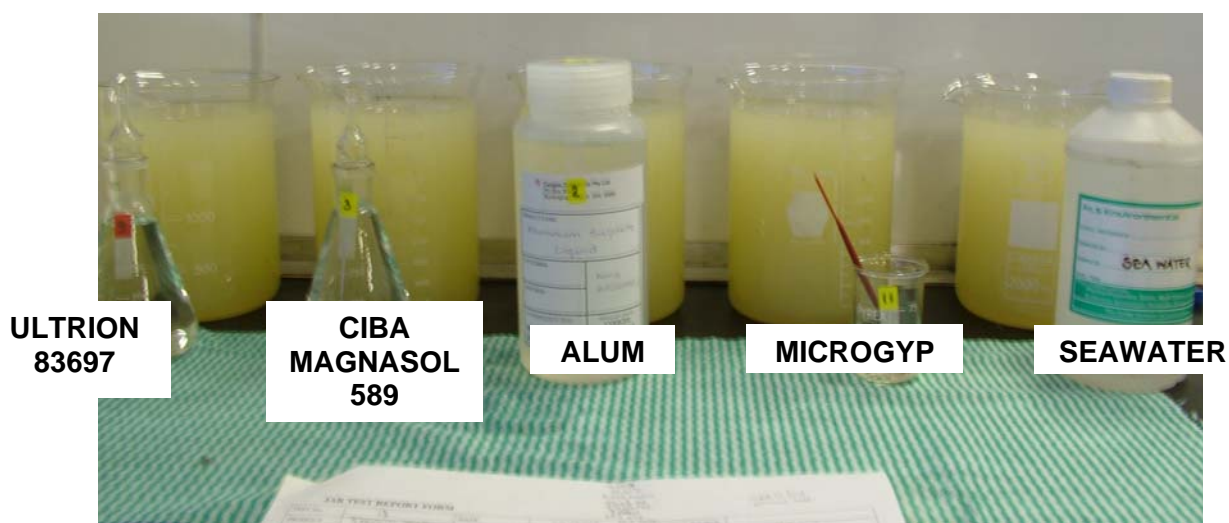
Figure 3.4: Reagents and Untreated Sample Water Prior to Testing

3.7   SUITABLE REAGENTS FOR GEMCO

Following Phase 2 testing of the five reagents, it became apparent that only two types of reagent were suitable for field application at GEMCO. Further tests were

undertaken using only Microgyp and seawater to check the effects of dosing application and to further optimise the dosage. The purpose of the optimisation testing was to closely examine the flocculation process and to determine the absolute minimum dosage required to achieve clarification to enable a cost analysis to be performed.

3.8   APPLICATION TEST WORK

3.8.1   THOROUGH MIXING

Using the optimum dosage rate obtained from the preliminary test work for Microgyp in solution and seawater, the reagents were added to 2000mL beaker containing C Quarry water and stirred vigorously with a paddle for 2 seconds (4 revolutions). The settling characteristics were then observed.

This type of application was to represent a good mix between the mine water and the added reagents if this can be achieved in the field.

3.8.2   SPRAY APPLICATION

For a spray application, a plastic spray nozzle was used to apply the Microgyp in solution and seawater to the surface of the C Quarry Water in 2000mL beakers. The settling characteristics were then observed.

This type of application was to represent a hydromulcher being used to spray the reagent over the surface of the water in the field with good coverage over the turbid water surface.

3.8.3   PARTIAL SPRAY APPLICATION

For the partial spray application, the beaker was covered with an impermeable membrane and approximately 25% of the surface area of the C Quarry water was exposed and sprayed with the Microgyp in solution and seawater (Figure 3.5). The settling characteristics were then observed.

This type of application was to represent a hydromulcher to spray the surface of the turbid water, with a poor coverage being achieved in the field.

Figure 3.5: Spray Application Method

3.8.4   ADDITION OF SOLUTION – NO MIXING

Due to the positive results obtained by the partial spray application, the Microgyp in solution and seawater were then added to the C Quarry water samples by gently pouring the solutions into the beaker. The solutions could be seen to enter the surface of the water and then 'dribble' down the side of the beaker. No agitation was applied to the samples and in the case of the Microgyp, the 'yellowish' coloured solution fell to the bottom of the beaker. The settling characteristics were then observed.

This application was to represent very poor contact between colloidal suspensions and reagent should this situation arise in the field.

3.9   SUSPENDED SOLIDS

A graduated 1000mL glass beaker was used to measure the amount of suspended material in the water in both volume (beaker graduations) and weight (g/L) for reference. The test involved using Magnasol 589, Microgyp and seawater at optimum dosages to settle out the suspended matter and the resulting volume of settled material was measured in the beaker by the beaker graduations.

Two methods were employed for measuring the weight of suspended solids.

1. Clear supernatant was carefully drained and then syringed off the top of the settled material and the remainder was put on fine filter paper and the remaining moisture removed with a compressed air vacuum device. The sludge left on the filter paper was then dried in drying ovens and then weighed to give a g/L amount of suspended material.

2. The second method involved oven drying the settled material after syphoning off supernatant fluid with no prior filtration.

3.10 SLIMES

In the event that the water will be treated with a reagent and then discharged to the slimes dam for the particles to settle out, the effects of the settled material combining with the slimes in the dam was tested. The concern was that the settled material would 'coat' the top of the slimes dam and make its way towards the intake pipeline and eventually get into the ore concentrator.

Slimes were collected from the pipeline that discharges directly to the slimes dam. Settled material with some clear supernatant fluid was collected from tests with Microgyp for this test work.

Three 2000mL were used for this test. The first beaker had the slimes in the beaker and the settled material was poured on top of the slimes. This was to represent treated water being discharged onto the surface of the slimes dam.

The second beaker had the slimes and settled material poured into the beaker at the same time. This was to represent treated water being discharged into the slimes dam at the same time as discharge of slimes from the concentrator.

The third beaker had settled material on the bottom and the slimes were poured over the top. This was to represent the action of slimes discharge occurring on top of settled material from Microgyp treatment.

3.11 RESUSPENSION OF SETTLED MATERIAL

After the colloids settled from the turbid water and there was a clear line between the supernatant fluid and the settled material, the liquid was agitated by stirring with a paddle to try and resuspend the colloids. This was performed for all tests, at their completion.

3.12 RATE OF SETTLEMENT

Using the glass beakers, the rate of settlement was determined as a function of time by recording the time for the settled material to pass certain graduations on the beaker. These tests were performed in the 2000mL beakers.

3.13 DEVELOPMENT OF IFD CURVES FOR ANGURUGU

The purpose of developing Intensity Frequency Duration (IFD) curves for Angurugu was to aid in estimation the volume of water that is likely to be treated each wet season should C Quarry become an active mining site. The volume of water to be treated will need to be known in order to ascertain the cost associated with mining in C Quarry during the wet season.

There is also the potential for treated water from C Quarry to be pumped to the dams area near the ore concentrator for reuse. A detailed catchment analysis should be undertaken to estimate the amount of water that could be sourced, in order to determine if a stormwater harvesting project could be viable. The detailed catchment study was outside the scope of this project. The IFD Curves and the stormwater runoff estimation can be found in Appendix H.

4   RESULTS AND DISCUSSION

4.1   PREVIOUS STUDIES

The results contained in the previous studies helped initially determine approximate dosage rates for preliminary testing. They also provided some guidance as to the environmental effects of the polymer based flocculants and Aluminium Sulphate.

The clarified water is most likely to be discharged to the river or ocean. The concern is that any residual reagent in the clarified water may harm the aquatic environment. Also, there would be no controls in place should overdosing of the water occur and then discharge proceed unchecked. One of the main parameters for the treatment methodology is that there should be no downstream detrimental effects to the environment.

The risk of overdosing and therefore being unable to further treat the water or harming the environment with a chemical which is known to be toxic to fish is out of the question and the previous studies helped identify where this may be the case.

Another parameter for the treatment methodology is that the field application of the water treatment process must be easy to apply. Thus sophisticated dosing and mixing apparatus, which is needed for some of the reagents, is outside the scope of GEMCO's operations.

4.1.1   CITIWATER LABORATORIES

Aluminium Sulphate was used on the water samples with lime addition for pH correction. It was determined that the Alum was unsuitable because of problems with soluble aluminium at the low pH of the water sample. A cationic polyelectrolyte was also used and satisfactory results were obtained.

The optimum dose was 8mg/l of the 45% active cationic polymer. It was noted that if the cationic polymer was overdosed, it no longer produced clarification of the water

and the water remained turbid and became very hard to treat. A copy of the report can be found in Appendix E.

4.1.2 CIBA SPECIALTY CHEMICALS

The report concluded that the most effective products were Magnasol 589, 576 and LT425. However, the report indicated that these products were potentially toxic to fish should overdosing occur and the water is then discharged into rivers. This was supported by the products materials safety data sheets. The report indicated the dosing levels that were effective for treatment of the water and are summarised in Table 4.1.

Product	Dose Rate of Product as Supplied	Turbidity @ 10 minutes NTU
Magnasol 576	10mL per m3	205
	20mL per m3	19
LT425	10mL per m3	199
	20mL per m3	66
Magnasol 589	10mL per m3	52
	20mL per m3	39

Table 4.1: Results of Citiwater Laboratories Report

The report recommended an underdosing strategy and a spray application of the diluted coagulant onto the surface of the turbid water.

Anionic flocculants were tested on the water samples (Ciba products Magnafloc 5250 and Magnafloc 338) however these offered poor results from which it was concluded that the suspended solids were highly dispersed and therefore responded more favourably to the coagulant (cationic) products. The report can be found in Appendix E.

4.2 XRD ANALYSIS

The XRD analysis was performed to determine if the sample clay matched the mineral concentration of montmorillonite clay. Expected upper and lower values *(Newman, 1987, p.50)* were compared with the results of the XRD analysis. The results are contained in Table 4.2 below.

Compound	Sample Value	Expected Value (Upper)	Expected Value (Lower)	Unit
Mn	0.488	0.03	0.006	%
Fe	3.466	3.35	1.06	%
SiO_2	58.744	64.7	54.07	%
Al_2O_3	16.394	22.48	17.18	%
P	0.0216	0.049	0	%
Na_2O	0.164	3.80	0.92	%
MgO	2.558	4.32	2.09	%
K_2O	1.462	0.07	0.02	%
CaO	0.154	0.15	0.03	%
TiO_2	0.784	0.37	0.00	%

Table 4.2: Results of XRD Analysis and Comparison with Expected Values

The clay sample that was collected came from a quarry edge in a mined out area. The in situ material had been significantly disturbed by dozers as it had been pushed to the side of the quarry as overburden. This would explain the high manganese reading in the sample. Not all the mineral elements fell within the expected values however, the composition matched more closely to the breakdown of montmorillonite clay than any other clay type. The conclusion was that the material found in C Quarry is montmorillonite clay.

4.3 PARICLE SIZE DISTRIBUTION

The report obtained from Microns to Measure stated that the sample had a multimodal particle size distribution (Figure 4.1). About 76% of the sample was in a distribution between 0.04 and 0.9 microns with a maximum at about 0.33 microns. The mean size for this distribution was 0.31 microns.

The remainder of the sample was in a broad distribution between 0.9 and 10 microns with a maximum of about 1.7 microns. The overall mean was 0.82 microns and the median 0.36 microns. Therefore the particles fell into the colloidal size range. The report can be found in Appendix E.
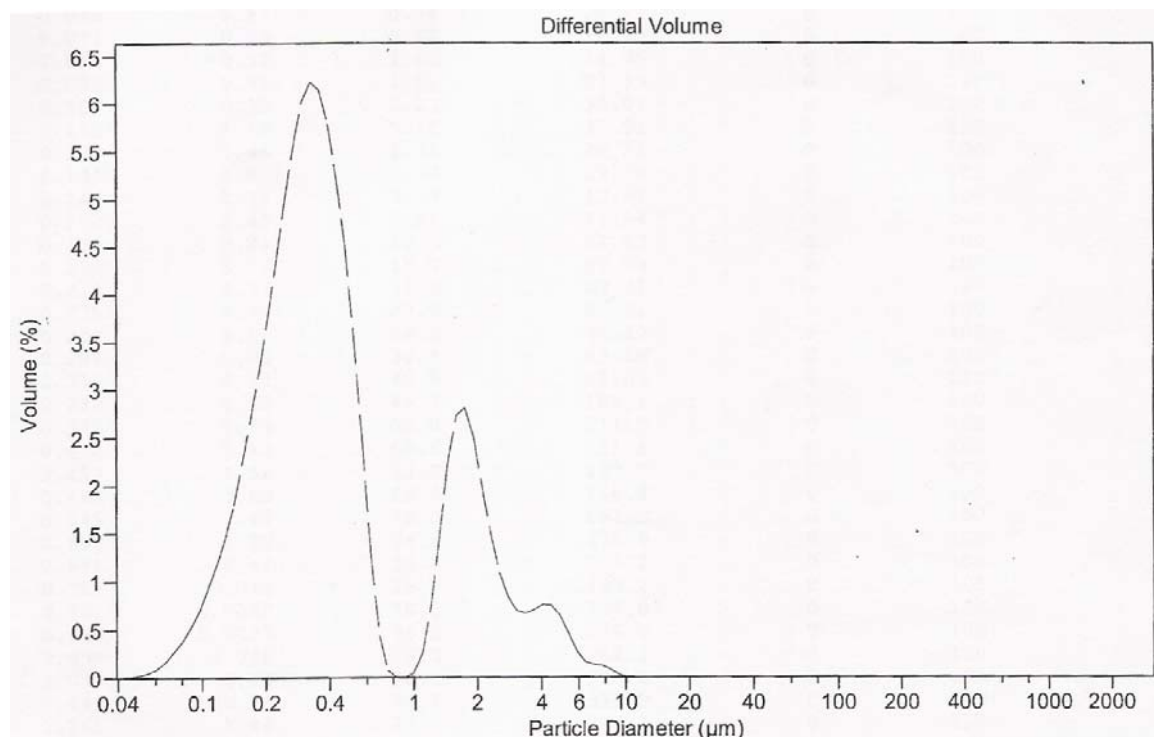
Figure 4.1: Particle Size Distribution

4.4 WATER SAMPLES

Water collected from C Quarry was stored in lidded, ten (10) litre buckets in the oven room of the metallurgy laboratory. The room was not air conditioned and the sample water was not kept for more than three days. Thus, the temperature of the water was

kept consistent with the outdoor temperature. The lids prevented the sample water from being contaminated with manganese dust. The pH of the sample water did not vary in the course of three days and so it was concluded that water stored in this manner was an acceptable representation of the water in C Quarry.

Sample water was tested with the SONDE turbidity meter prior to every test and the properties of the water were recorded. It was found that the properties of the water varied slightly. This was put down to several factors such as:

- Recent heavy rainfall prior to collecting samples may have diluted the turbid water and thus affected the turbidity measurement and pH level
- Collecting water with the bailer may have stirred up sediment from the bottom of the quarry floor as the only accessible point to the water by foot appeared to be shallow. It was hard to tell how deep to allow the bailer as it was impossible to visually determine the bottom of the quarry floor through the turbid water
- Larger particles may have settled in the buckets whilst being stored as the stored sample water was not exposed to the elements.

Due to the slight variance in sample composition, and should the work in this dissertation be used in the future for testing, it will be recommended that the bench top testing method presented in Chapter 3 be followed to determine the optimum dosage for the water to be treated prior to commencing a field scale test.

4.5 PHASE 1 - PRELIMINARY LABORATORY WORK

In the course of the screening test work it became evident that not all the products were suitable for use on C Quarry water. Some of the reagents gave a cloudy supernatant fluid or appeared to be sensitive to overdosing. Other products indicated on their material safety data sheets that there was a chance of causing toxicity to the environment upon discharge and were discounted.

The observations made during the screening tests are summarised in Table 4.3 on the following pages.

No.	Product Name	Test Description	Observation and Optimum Dosage	Continue Testing?
1	Aluminium Sulphate (Liquid)	Aluminium sulphate comes as a 50% solution. A series of 100ml beakers were dosed with 0.2, 0.4, 0.6, 0.8, 1.0, 2.0, and 4.0 of the solution which equates to 1.0, 2.0, 3.0, 4.0, 5.0, 10.0 and 20.0 0ml/L of the pure aluminium sulphate. Solution was stirred into the beakers.	Flocs formed and settled with increasing speed in accordance with increasing dosage. The flocs tended to settle out after approximately 10 minutes. The supernatant fluid showed good clarity. The optimum dosage appeared to be 1ml/L (0.2ml of solution into a 100ml beaker).	✔
2	Ciba Magnasol 589 Coagulant	The coagulant comes in 100% liquid form however the liquid is quite viscous so it was diluted to 0.25% v/v in distilled water. A series of 100ml beakers were dosed with 0.2, 0.4, 0.6, 0.8, 1.0ml of the solution which equates to 5.0, 10.0, 15.0, 20.0, 25.0ml/m^3 of the pure Magnasol 589. Coagulant was stirred rapidly into the samples.	Initially, the Magnasol was made up into a 50% solution and the water dosed with 1000ml/L of product. The water did not flocculate at all and this was in accordance with the Ciba Speacialty Chemicals report that if overdosing occurs, the water remains turbid and will be difficult to treat. With the smaller doses, flocs formed immediately and settled within 3 minutes. The optimum dose is 20ml/m^3.	✔
3	Ciba Magnasol 576	The coagulant comes in 100% liquid form however the liquid is quite viscous so it was diluted to 0.25% v/v in distilled water. A series of 200ml beakers were dosed with 0.4, 0.8, 1.2, 1.6, 2.0, 2.4, 2.8, 3.2, 3.6 and 4.0ml of the solution which equates to 5, 10, 15, 20, 25, 20, 35, 40, 45 and 50ml/m^3 of the pure Magnasol 576. Coagulant was stirred rapidly into the samples.	Flocs did not seem to form very readily and the supernatant fluid appeared cloudy. The optimum dosage appeared to be around 30ml m^3 with higher dosages showing signs of overdosing. The product was discounted due to the cloudy supernatant however this was not consistent with the report from Ciba Specialty Chemicals which listed this product as suitable.	✖

No.	Product Name	Test Description	Observation and Optimum Dosage	Continue Testing?
4	Nalcoag 3268	The coagulant comes in 100% liquid form however the liquid is quite viscous so it was diluted to 0.5% v/v in distilled water. A series of 200ml beakers were dosed with 0.2, 0.4, 0.6, 0.8, 1.0 and 2.0ml of the solution which equates to 5.0, 10.0, 15.0, 20.0, 25.0 and 50ml/m^3 of the pure Nalcoag 3268. Coagulant was stirred rapidly into the samples.	The supernatant fluid isn't as clear as with some of the other reagents. The optimum dosage appeared to be about 25 ml/m^3. The use of this reagent was discounted due to the insufficient clarity of supernatant fluid.	✘
5	Ultrion 8187 (Water Clarification Aid)	The coagulant comes in 100% liquid form however the liquid is quite viscous so it was diluted to 0.5% v/v in distilled water. A series of 200ml beakers were dosed with 0.6, 1.0 and 2.0ml of the solution which equates to 15.0, 25.0 and 50ml/m^3 of the pure Ultrion 8187. Coagulant was stirred rapidly into the samples.	The flocs form in a matter of seconds with a clear supernatant fluid. The optimum dosage appeared to be about 25 ml/m^3.	✘
6	Ultrion 83697 (Potable Coagulant)	The coagulant comes in 10-30% w/w liquid form however the liquid is quite viscous so it was diluted to 0.5% v/v in distilled water. A series of 200ml beakers were dosed with 0.1, 0.2, 0.4, 0.8 and 1.2ml of the solution which equates to 2.5, 5, 10, 20 and 30ml/m^3 of the pure Ultrion 83697. Coagulant was stirred rapidly into the samples.	This reagent seemed to be sensitive to under and overdosing. The flocs formed rapidly with almost instantaneous settlement and extremely clarified supernatant fluid. The optimum dosage appeared to be about 5 ml/m^3.	✔

No.	Product Name	Test Description	Observation and Optimum Dosage	Continue Testing?
7	Micro-Gyp	Gypsum powder added to small amount of distilled water and stirred into water sample	Flocs appear to be about 0.5 to 1mm in diameter. Flocs settle after around 30 minutes. It is noted that small dosages take a little longer to settle out. Optimal dosage is determined to be 0.5g/L	✔
8	DamClear Flocculant Block	A small piece of the flocculant flock was added to a flask containing sample water and agitated to dissolve the flocculant. A field test was also undertaken.	There appeared to be no floc formation or clarification of the water in the field during the field test.	✘
9	Seawater	Seawater was added by syringe. A series of 200ml beakers were dosed with 1, 2, 10.5, 22, 48ml which equates to 0.5, 1, 5, 10 and 20% of the volume of sample water. The seawater was stirred rapidly into the samples.	The larger dosages were showing fair clarity after 20 minutes however, the optimum dosage was determined to be 1% seawater to volume of sample water but settlement of particles took several hours.	✔

Table 4.3: Observations During Preliminary Laboratory Test Work

4.5.1   FLOCCULANT BLOCK TEST

The flocculant block tested in the flask did not destabilise the clay suspension. This was thought to be because the flocculant block is made up of an anionic polymer. The negative charge of the clay suspension means that the colloids were not destabilised by the addition of an anionic polymer. This was supported by the Citiwater Laboratories report which noted that anionic flocculants were ineffective.

The block was also taken to the field for testing. The manufacturer's specifications instruct that the block is to be immersed in the water at a point of turbulence just upstream of a settling pond. The specification stated that flocs would form instantly.

A culvert entrance (point of turbulence) was selected for immersing the block into the flow of turbid water. The block was held in place with a survey peg. Directly downstream of the culvert was a widening of the channel and the flow of water slowed considerably. This would allow for any flocs that form to settle out and it was expected to see some clarification of the water. This did not occur and it was decided that unless the flocculant block contained a cationic polymer, it would not be suitable for treatment of the C Quarry water.

Figure 4.2 shows the field testing of the flocculant block.

Flocculant block is removed from packaging

Flocculant block is held in place with survey peg. Instant clarification is not evident.

Figure 4.2: Flocculant Block Test

4.5.2   PHASE 1 SUMMARY

The reagents were assessed on the following selection criteria (Table 4.4) in order to determine their compatibility with the treatment objectives. This determined which reagents would progress to Phase 2 of testing.

Selection Criteria	Objective
Clarity of supernatant fluid	Turbidity must be less than 50 NTU
Settling time	Must be within 24 hours
Ease of application	The reagent must be able to be readily applied to large quantities of water in the field
Risk of negative impact to environment	MSDS and research on the reagent must show that there is no detrimental effects to the downstream environment

Table 4.4: Selection Criteria for Preliminary Laboratory Test Work

From the abovementioned selection criteria the following five (5) reagents appeared to achieve the desired results:

- ULTRION 83679
- CIBA Magnasol 589
- Aluminium Sulphate
- Microgyp
- Seawater

4.6   PHASE 2 – LABORATORY TEST WORK

After addition of the optimum dosage, the settlement characteristics, times and other comments were recorded on the test report form.

Figure 4.3 shows the sample water just after addition of the reagents. Note that the Ultrion 83697, Ciba Magnasol 589 and Aluminium Sulphate have reacted immediately. Microgyp and seawater do not initially appear to show floc formation.
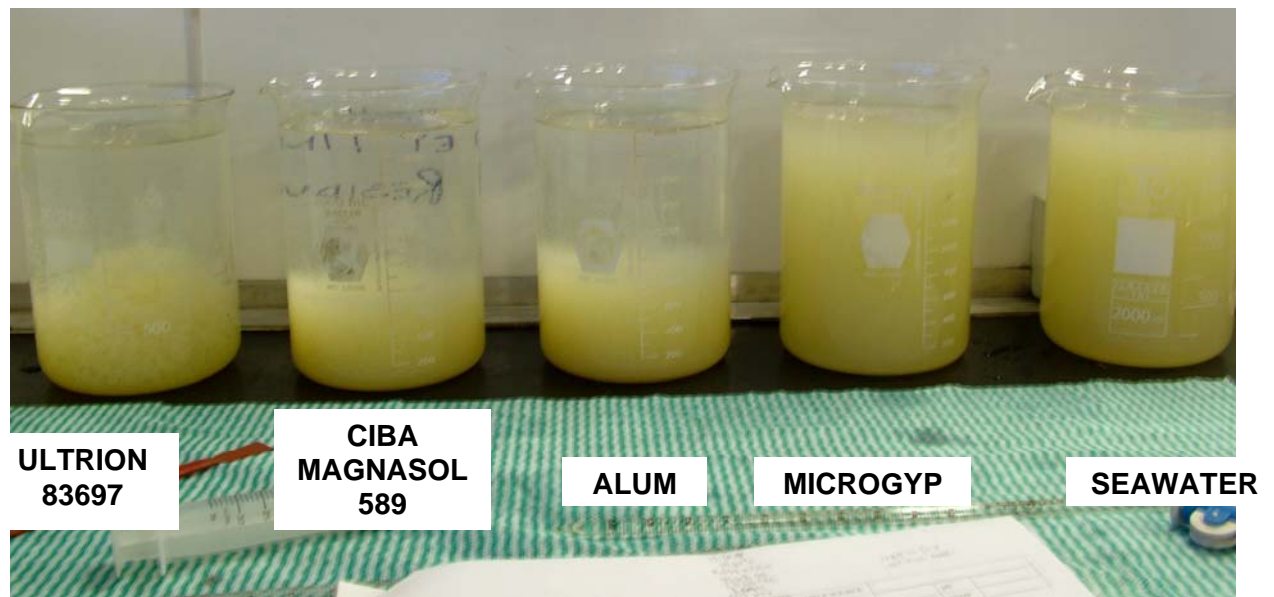
Figure 4.3: 10 Minutes after Addition of Optimum Reagent Dosage

Figure 4.4 shows the same test several hours later. Note that all reagents have satisfactorily settled the suspended material.
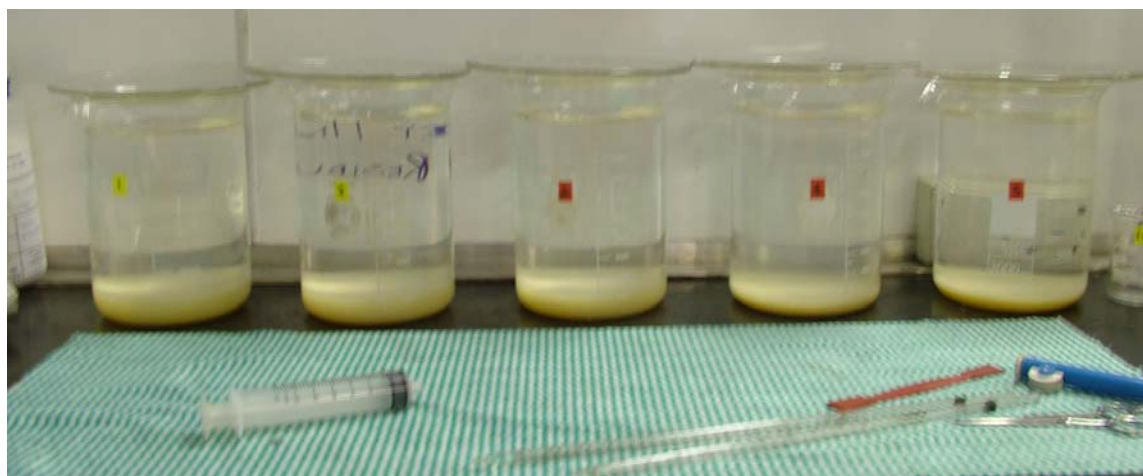
Figure 4.4: Several Hours after Addition of Optimum Reagent Dosage

4.6.1   ULTRION 83697 (BEAKER 1)

The optimum dosage for Ultrion was found to be 5ml/m^3. The reagent had to be made up into a solution with distilled water as only very small quantities were required to treat the water. The Ultrion solution was then added to the sample water with a pipette to control the small dosage required and mixed into the water with a paddle.

The formation of flocs was instantaneous with the floc size being very large which is expected of a polymer flocculant. The flocs would swirl in the clarified supernatant fluid due to the mixing motion of the paddle. When the water stilled, the flocs settled out rapidly and the large floc structure was visible on the bottom of the beaker. The settling time was within minutes.

4.6.2   CIBA MAGNASOL 589 (BEAKER 2)

The optimum dosage of Ciba Magnasol 589 was found to be 20ml/m^3. The reagent had to be made up in solution with distilled water as only very small quantities were required to treat the water. The Ciba Magnasol 589 was then added to the sample water with a pipette to control the small dosage required and mixed into the water with a paddle.

The formation of flocs was rapid, although a smaller floc size formed than with the Ultrion. This is possibly due to a different chain length of the polymer. After the water became stationary, the flocs settled rapidly to the bottom of the beaker. The settling time was within minutes and similar to Ultrion 83697.

4.6.3   ALUMINIUM SULPHATE (BEAKER 3)

The optimum dosage for Aluminium Sulphate was found to be 1ml/L. The reagent was supplied in a 50% v/v solution. A pipette was used for the small dosages required. The flocs that formed were less than 1mm in diameter. They formed about 1 minute after addition to the water sample. The flocs took about 10 minutes to settle out unlike

the Ultrion 83697 and Ciba Magnasol 589 which settle rapidly. The resulting supernatant fluid is extremely clear.

4.6.4   MICROGYP (BEAKER 4)

The optimum dosage of Microgyp was determined during the preliminary test work as 0.5g/L. Microgyp had to be dissolved into a small amount of distilled water for addition to the sample water. Not all the Microgyp would dissolve however, the particles of Microgyp would be suspended in the distilled water. Just after addition of the Microgyp in solution, no visible flocs seem to occur. After approximately 10 minutes, it could be seen that flocculation occurred and particles were settling however, the supernatant fluid was still quite turbid. After 30 minutes, the supernatant fluid was extremely clear.

4.6.5   SEAWATER (BEAKER 5)

The optimum dosage of seawater was determined as 1.0% of the volume of water to be treated. Seawater was added to the sample water with a large syringe due to the larger dosage required than the commercial reagents.

Just after addition of the seawater, no visible flocs seemed to occur. After approximately 20 minutes, it could be seen that seawater formed a clear layer on the bottom of the beaker. This was due to the seawater being denser than the sample water. Flocculation appeared to occur from the bottom of the beaker in an upwards direction. After approximately 2 hours, the supernatant fluid had adequate clarity.

4.6.6   SUMMARY OF RESULTS

C Quarry water samples, on average, had the following properties prior to testing.

Property	Measurement
Turbidity	462.5 NTU
pH	7
Temperature	25°C
Electrical Conductivity	0.0325 mS/cm

Table 4.5: C Quarry Water Properties Prior to Treatment

After testing, which was determined when the turbidity reached an acceptable level (ie below 50 NTU), the supernatant fluid had the following properties.

Reagent	Dosage	Turbidity NTU	pH	Temp °C	Electrical Conductivity mS/cm
ULTRION 83697	5ml/m^3	24.7	4.5	25	0.078
CIBA MAGNASOL 589	20ml/m^3	12	4.5	25	0.087
ALUMINIUM SULPHATE	1ml/L	4.3	3.8	25	0.749
MICROGYP	0.5g/L	21.9	5.5	25	0.527
SEAWATER	1.0%	27	5.8	25	0.812

Table 4.6: C Quarry Water Properties after Treatment and Optimum Dosages

All reagents show an acceptable level of clarity and meet with the EPA standard of <50 NTU to ensure that aquatic environments will be protected.

The addition of all reagents tends to drop the pH of the clarified water. In the case of the polymers and aluminium sulphate, the pH level is considered degraded for water entering a riverine system. The pH may stabilise with time, however this was not tested.

The Microgyp and seawater present a pH which is acceptable for release into an aquatic environment.

The electrical conductivity (and therefore the salinity) of the clarified water increases after treatment to varying degrees. The polymers do not significantly increase the electrical conductivity of the clarified water. Aluminium Sulphate, Microgyp and seawater however increase the electrical conductivity. Rivers can have water with electrical conductivity of up to 0.8 mS/cm and still be considered freshwater.

The treatment with 1% seawater brings the electrical conductivity just over this level. If this treatment option is ever considered for treatment of turbid water to then be recycled to the concentrator, dilution with bore fields water would be required. Otherwise, a corrosion study would need to be undertaken.

4.7 SUSPENDED SOLIDS

The following table lists the results from the two methods of measuring the suspended solids. Generally, the clay suspensions settled to approximately the 150mL mark on a 2000mL beaker, however, when this material was syphoned and dried or filtered, the amount of dried material was very small.

Reagent	Filter and dry g/litre	Siphon and oven dry g/litre
Magnasol 589	0.6	0.7
Microgyp	0.8	0.8
Seawater	(filter not working)	2.7

Table 4.7: Suspended Solids

The fact that the amount of solids is so small supports the Microns to Measure report which shows that the colloidal particles are ultra fine.

4.8 SLIMES

In the event that the water will be treated and then discharged to the slimes dam for particles to settle out, the effects of the settled material combining with the slimes in the dam was tested.

After three hours, the slimes and added settled material had settled to the bottom of the beakers leaving a clear supernatant fluid. There was no indication that the three methods had made any difference to the settling characteristics of the slime. The samples were then left sitting for two days. After this time, there was no apparent visual change to the top surface of the settled slimes. It was not evident that the settled material would sit on top of the slimes, as was hypothesised.

Settled material added to slimes by various methods

Settled material

After 3 hours, no indication of settled material coating surface

Figure 4.5: Settled Sludge and Slimes Tests

4.9 RESUSPENSION OF SETTLED MATERIAL

When settled material on the bottom of the test beakers was stirred with the mixing paddle to attempt to resuspend the particles, the particles merely settled back to the bottom of the beaker after a short amount of time. This is because the colloidal system is no longer stable and the particles cannot simply return to their suspended state.

Also, it would appear that the agglomeration of the particles is not reversed with agitation by the mixing paddle and hence, the particles resettle within a short amount of time, in about 10 minutes, unlike when they are first treated in the case of Microgyp and seawater, which can take several hours. Severe agitation of polymer treated flocs can lead to breakdown of the floc structure.

4.10 RATE OF SETTLEMENT

The rate of settlement of the particles is of interest to GEMCO for future work as this will determine how large to make the clarification ponds. The particle settlement rate could be determined from the settling curves and approximating a straight line to give a m/hr rate.

For some reagents, it was not initially clear where the supernatant/turbid water interface line was between the settling material and the clarified water. However this would become apparent after an initial period. In the case of the polymer reagents, due to the extremely fast floc formation, there was an instant separation of the suspensions from the clear supernatant and therefore settlement times were very short.

4.11 COST ANALYSIS

Based on the Phase 2 test work, settlement rate curves were plotted and a cost analysis was performed. Companies supplying products were contacted for pricing information. Ciba Specialty Chemicals was reluctant to give information about the price of their product and as such, this product could not be priced.

The price of seawater is based on the cost to pump the water from the ocean to a point where the turbid water and the seawater can mix and have time for the particles to settle such as a clarification pond.

Pumps at GEMCO were run using diesel fuelled generator sets and a survey was conducted to measure the fuel usage at the bore field pumps to determine the running costs. The bore field pipe lines have flow meters and thus, water pumped per amount of fuel could be measured.

These pumps operate against approximately 65m of head. The seawater pumps would not be pumping against this much head, so the cost determined from the fuel usage survey at the bore fields is a worst case scenario. The result was $0.06/m³ of water pumped and this has been used for the cost analysis.
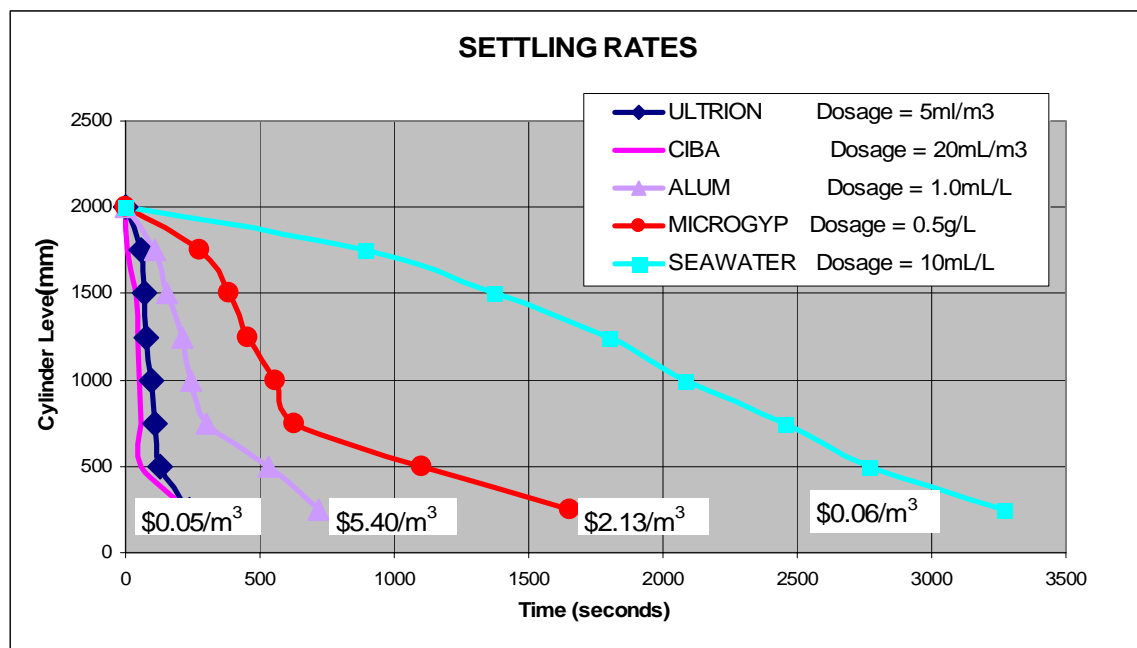
Figure 4.6: Settlement Curves and Treatment Costs per m³

4.12 VIABLE OPTIONS FOR GEMCO

4.12.1 MICROGYP

Microgyp appeared to be the least sensitive method to dosing. Higher dosages caused particles to settle out more quickly. Overdosing causes Microgyp particles to settle to the bottom due to their high density and therefore supernatant fluid is suitable to discharge to the environment.

It is a common flocculant used on building sites to deal with turbid water and is readily available and relatively cheap. Microgyp settling times were quite slow compared with the other commercial reagents, but still gave an exceptionally clarified supernatant. However, for the amounts of water to be treated in C Quarry (not to mention the rest of the mine site) it would appear that this option could be costly. Microgyp tends to clarify the water with enough time so the optimum dosage depends on the required settling time.

As the cost of Microgyp could affect whether this is a suitable reagent for GEMCO an optimisation of the amount of Microgyp required was undertaken. The purpose of this was to establish what the absolute minimum amount of Microgyp is required to clarify the water.

A series of tests were undertaken in 200ml beakers using a sprayer to apply the Microgyp in solution as can be seen in Figure 4.7.

Figure 4.7: Optimisation of Microgyp Testwork

The optimised dosage was 0.2g/L which clarified the water when left to stand overnight. Smaller amounts of Microgyp still clarified the water, however, at an amount less than 0.1g/L, the results started to show poor clarity and thus, 0.2g/L was selected. Refer to figure 4.8.
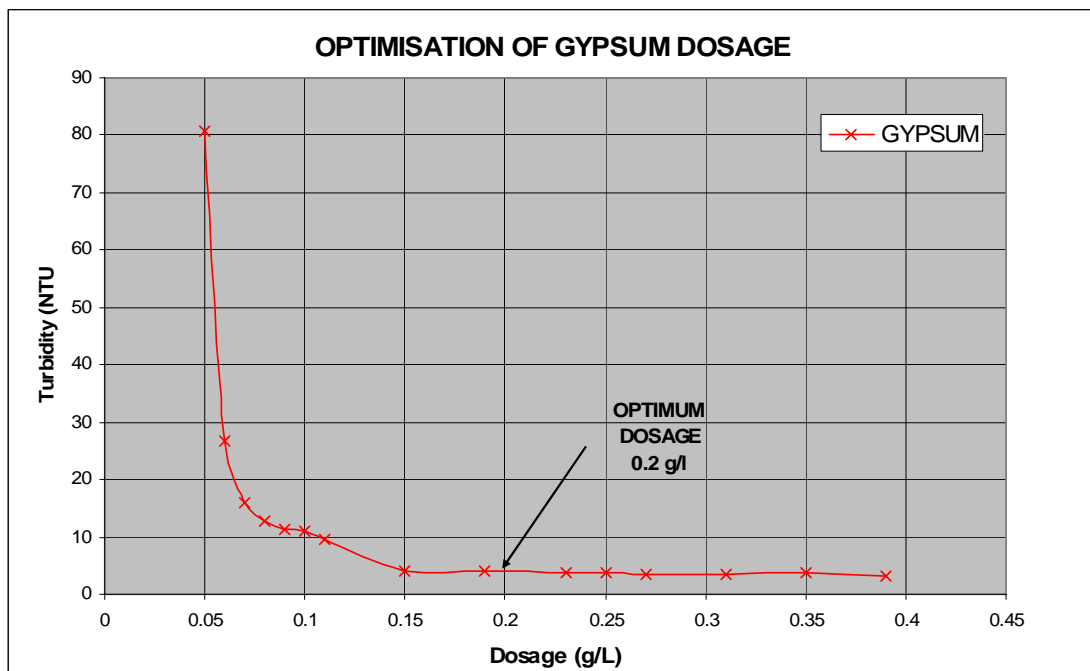
Figure 4.8: Microgyp Optimisation Curve

4.12.2 SEAWATER

The optimum dosage of seawater was readily discovered during the preliminary test work phase and Figure 4.9 illustrates that 1% seawater to the volume of water to be treated is the optimum dose.

Seawater is readily available to GEMCO and by using seawater pumps and a pipeline, water could be pumped for use as the treatment reagent.
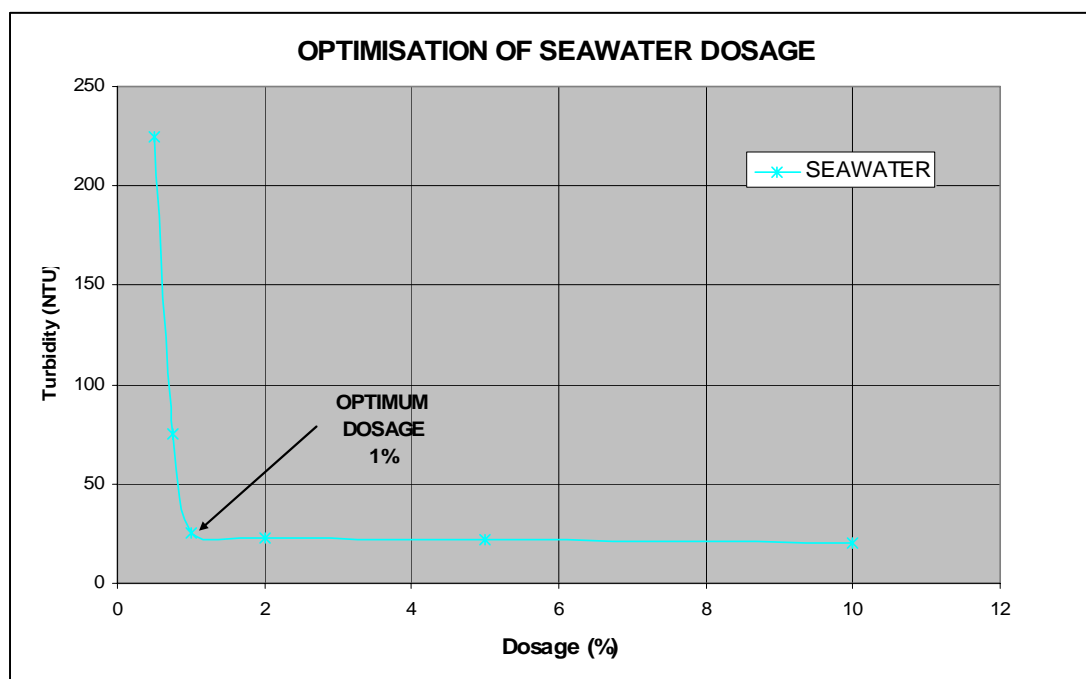
Figure 4.9: Seawater Optimisation Curve

4.13 APPLICATION DISCUSSION

The application tests in the laboratory indicated that both Microgyp and seawater are fairly insensitive to dosing in that they didn't require considerable particle contact to be effective. Whilst the largest test was undertaken in a 2000mL beaker, it was difficult to conclude at a field scale application how much particle contact would be required before settling times became too great or settlement was non existent due to there being too much distance between the reagent and colloids. However, the application of both Microgyp and seawater by pouring the reagents into the beakers

was promising. Both reagents were still effective with this application method and this is promising for field application.

Spraying of Microgyp solution or seawater onto the surface of the quarry water could prove difficult if the quarry is too vast. Pumping the turbid water to a smaller treatment area may be effective and the clarification pond would need to be deep enough to ensure that settled material could be stored until such time as being able to be removed or covered over. Clear supernatant could be pumped out of the clarification pond from a floating takeoff or an overflow weir could be set up.

Problems could occur with resuspension of settled material. The material would not actually go back into suspension, as determined from the laboratory testing, however due to external agitation such as pump vibrations or wind action on the surface of the clarification pond, there could be a risk that settled material could be stirred up and discharged to the river.

In the event of a major rainfall event during the wet season, it is also possible that the settled material could be picked up and overflow to the river, which would pose an environmental hazard.

Ideally, clarification ponds should be deep enough to prevent settled material from being picked up in a major rainfall event and carried to the river or ocean. Removal of the settled material to the dry tip where it could be covered over is an option. Therefore, the treatment method should not stop at just discharging clear water but also deal with the settled material so that it cannot enter the aquatic environment.

Note that when Microgyp was poured down the side of the beaker, the particles still flocculated and settled. (Figure 4.10 left beaker). Seawater forms a clear layer on the bottom of the beaker and settles particles from the bottom of the beaker in an upwards direction. (Figure 4.10 right beaker).
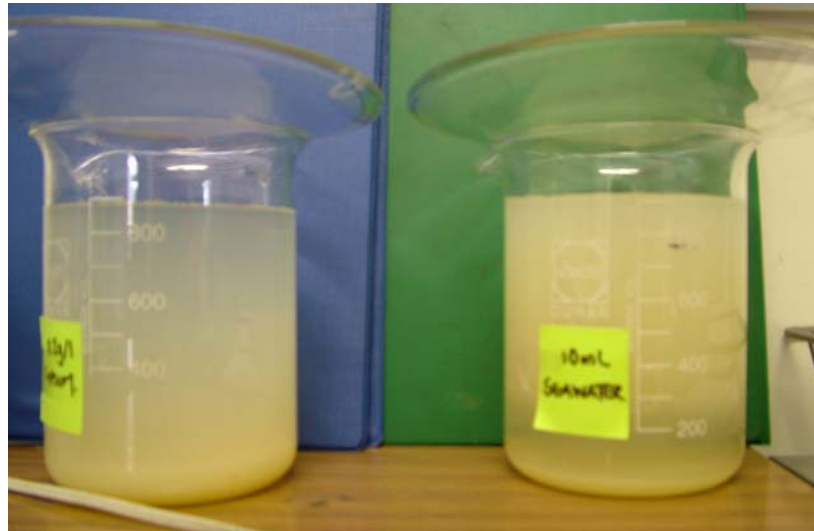
Figure 4.10: Settling Characteristics of Microgyp and Seawater

The Microgyp settles the suspended material faster than seawater (Figure 4.11), but if left to stand for several hours, both reagents leave a clarified supernatant fluid.

Figure 4.11: Settlement Rates of Microgyp versus Seawater

5   RECOMMENDATIONS

The purpose of this section is to outline a procedure for dealing with turbid mine water in C Quarry and to offer some recommendations that can be adapted to other areas of the mine experiencing similar problems.

The following sections break the process down into steps so that Environmental Officers can follow the procedure and effectively manage the mine water prior to discharge.

5.1   TREATMENT PROCEDURE

This section should form the basis for a treatment procedure at GEMCO when dealing with turbid mine water. The procedure can be adapted for any reagent and the optimum dosages given are for the turbid water in C Quarry. Should turbid water be encountered elsewhere on the mine site (such as in A South Quarry), then the procedure can be adapted to suit the turbidity levels of that particular site.

5.1.1   COLLECT WATER SAMPLE

A sample of water should be collected from the site, being careful not to disturb the bottom of the quarry and therefore picking up excess sediment. The bailer should be used so that the sample is from an area giving a representative sample of the water in the quarry.

5.1.2   DETERMINE NATURE OF TURBIDITY

To determine the nature of the suspended material, a sample of the clay material should be taken for XRD analysis. The sample should be as free of organic and other debris as possible to give a representative sample of the clay. The sample should be tested in the XRD machine in the metallurgy laboratory and the chemical composition checked against the standard composition of montmorillonite clay.

5.1.3   LABORATORY TESTWORK

For C Quarry water with a turbidity of 462.5 NTU the dosages in Table 5.1 clarified the water.

Microgyp	Seawater
0.2g/L	1% of sample volume

Table 5.1: Optimised Dosages of Microgyp and Seawater

Select a range of values based on the turbidity in NTU of the collected sample. For a lower turbidity than 462.5, trial a range of values below and up to the optimum levels in Table 5.1. Vice versa for sample water with a higher turbidity level than 462.5.

Using 2000mL beakers in series, fill each beaker with the collected water sample to the 2000mL mark. Apply the range of dosages of the selected reagent and record the settling rate. After a given period of time, test the supernatant fluid with the SONDE turbidity meter to ensure that the turbidity has fallen below the acceptable standard of 50 NTU.

5.1.4   DETERMINE SUITABLE REAGENT

A decision based on cost and application should be made to determine which reagent will be used to treat the water.

The acceptable level of turbidity should be a function of cost, required settlement time, efficiency and environmental considerations.

The tests should be repeated to narrow down the optimum dosage according to these requirements.

5.2 NORTHERN QUARRIES (C QUARRY)

The dewatering requirement of C Quarry for mining operations to commence in 2008 is a substantial undertaking due to the shear volume of water to be treated. The treatment procedure will involve the mass treatment of water, followed by a retention time in a settling zone prior to mass discharge of the water.

The application tests involving seawater and Microgyp revealed that consistent particle contact was not required and it was determined that either of these reagents would be suitable depending on the final use of the water.

Water from C Quarry needs to be pumped to a location away from the montmorillonite clay to eliminate the possibility of further rainfall events contributing further colloidal suspensions into the treated water. The location has to have sufficient capacity to act as a permanent settlement basin for ongoing treatment. The location should preferably be deep, and of substantial length to ensure that settlement occurs.

A suitable location could be F1 Quarry, which has been previously mined out and has apparent sufficient depth. The turbid water could be pumped to this location and then treated. Conversely, a clarification pond could be constructed elsewhere on the mining lease.

5.2.1 C QUARRY – DISCHARGE TO RIVER

Discharge of treated C Quarry water to the river is recommended by installing seawater pumps and a pipeline to F1 Quarry. Upon settling of the material, a floating pump could be used to pump off the clarified supernatant fluid for discharge downstream to the river. Refer to Schematic Map 1 in Appendix G.

5.2.2 C QUARRY – REUSE AT CONCENTRATOR

Discharge of treated C Quarry water to Dam 1 for reuse at the concentrator is recommended by the use of Microgyp to treat the turbid water. A hydromulcher could

be used to apply the Microgyp in solution to the surface of the water. Upon settling of the material, a floating pump could be used to pump the clarified supernatant fluid through a pipeline to Dam 1. Refer to Schematic Map 2 in Appendix G.

5.2.3   C QUARRY – DISCHARGE TO OCEAN

Discharge of treated C Quarry water to the ocean is recommended by constructing a clarification pond on the mining lease, close to the ocean. C Quarry water could be pumped north until it can discharge and flow overland to the clarification pond. Seawater pumps and a pipeline could supply the required amount of seawater to the clarification pond to settle the suspended material. Upon settling of the material, a floating pump could be used to pump the clarified supernatant fluid through a pipeline to the ocean. Refer to Schematic Map 3 in Appendix G.

5.3   SOUTHERN QUARRIES (A SOUTH)

Since the commencement of this project, A South Quarry exhibited similar problems with turbid water and from the original geological exploration study, the cause of the turbid water is the presence of montmorillonite clay in this area.

5.3.1   A SOUTH QUARRY – REUSE AT CONCENTRATOR

Turbid water from A South Quarry flow through overland channels towards the Dams area. This water could instead be diverted to a clarification pond constructed on the mining lease. It is recommended that the turbid water be treated with Microgyp. A hydromulcher could be used to apply the Microgyp in solution to the surface of the water. Upon settling of the material, a floating pump could be used to pump the clarified supernatant fluid through a pipeline to the 'gash', where the water would flow overland towards the Dams area. Refer to Schematic Map 4 in Appendix G.

5.3.2   A SOUTH QUARRY – DISCHARGE TO OCEAN

Again, turbid water from A South could be diverted into a clarification pond constructed on the mining lease. It is recommended that seawater pumps and a pipeline be used to supply the required amount of seawater to the clarification pond to settle the suspended material. Upon settling of the material, a floating pump could be used to pump the clarified supernatant fluid through a pipeline to the ocean. Refer to Schematic Map 5 in Appendix G.

5.4   MAINTENANCE OF CLARIFICATION PONDS

Settled material should be occasionally scraped out by an excavator. The material could be transported to the dry dip to be covered over. This should be done annually just prior to the wet season as a large rainfall could pick up the settled material and flush it down stream to the river. In this event, the resuspended material would quickly resettle however, as has been previously discussed, this would cause significant damage to downstream aquatic systems.

Should mining operations need to continue during the set season, the water should be pumped and treated in batches according to the required retention time in the sedimentation area. An area should be sized to ensure that the treatment phase does not mean that quarry water will back up and cause mining operations to cease. The process should allow continuous mining during the wet season.

6 CONCLUSIONS

Future work needs to investigate the effect of using the turbid water through the concentrator. The water may not have any detrimental effects at the concentrator in which case, it may be viable to install a pump line to Dam 1 directly from C Quarry. Relating to the construction of such a pipe line, future work should also include a detailed catchment study to ascertain the potential benefits of stormwater harvesting and a groundwater study in the C and F1 quarry areas. This could lead to an alternate and sustainable supply of water to the concentrator.

The effects of using treated water through the concentrator should be the subject of a separate study. Residual Microgyp in the water may affect the ore beneficiation process and seawater could have a corrosive effect on pipework and fittings. Future work should take the form of a corrosion study.

The project objectives are now addressed.

Information on montmorillonite clay and how it goes into suspension and forms a stable colloidal system was researched. Reagents for aiding in the treatment of the turbid water were sourced and researched. The effects of turbid and treated water on the environment were also researched however, further investigation needs to be done on the effects of treated water in downstream environments, such as at the concentrator.

The available literature on the above topics was critically reviewed.

It was determined that Microgyp and seawater were the most feasible reagents for the operation at GEMCO, depending on the final use of the treated water.

Chapter 3 outlined an appropriate methodology for testing the chosen reagents and laboratory testing of samples was completed in accordance with this methodology.

Chapter 5 outlined treatment approaches for field operation based on the laboratory test results and from a cost effectiveness and ease of application point of view. Several recommended treatment procedures were compatible with GEMCO's operations, depending on the final use of the clarified water. The recommendations made in Chapter 5 should be put forward for further discussion and development.

Finally, seawater offers the best solution to the turbidity problem at GEMCO due to it being freely available year round, having no detrimental downstream effects on the environment and its ease of application.

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APPENDIX A

PROJECT SPECIFICATION

University of Southern Queensland

Faculty of Engineering and Surveying

ENG 4111/2 Research Project
PROJECT SPECIFICATION

FOR: **Kristine Leigh JOHNSTON**
TOPIC: Treatment of Mine Water with Colloidal Suspensions
SUPERVISOR: Mark Porter

SPONSORSHIP: **GEMCO**   bhpbilliton
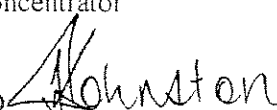
PROJECT AIM: The project aims to provide a solution to the problem concerning the treatment of mine water with clay suspension so that the water may be either discharged to the environment or reused at the concentrator.

PROGRAMME: **Issue A, 6th March 2006**

1. Research information on the clay types in the area, colloidal systems, available chemical products for aiding in treatment of the water, effects of turbid and treated water on the environment
2. Critically evaluate the literature available that cover the above topics
3. Determine which commercial products are economically feasible for the operation at GEMCO
4. Determine an appropriate methodology for testing the chosen products and complete laboratory testing of samples
5. Design a treatment approach for field operation based on laboratory test results and from a cost effectiveness and ease of application point of view
6. Recommend a treatment procedure that is compatible with GEMCOs operations

As time permits:

7. Implement a field scale test of treatment method
8. Feasibility of water reuse based on hydrological and groundwater analyses of the catchment under study
9. Determination of the downstream effects of turbid and treated water at the concentrator

AGREED _Johnston_ (student) _Port_ (Supervisor)
 _20/03/06_ (date)   _27 Mar 06_ (date)

APPENDIX B

SITE PLAN

OCEAN

F QUARRY

C QUARRY

ANGURUGU RIVER

F1 QUARRY

SWAMP

DAMS

THE GASH

PLANT

ANGURUGU

A SOUTH
QUARRY

BORE
FIELDS

LEGEND:
→ SURFACE WATER FLOW
●→ SUMP & PUMP
----- BORE LINE
--- SLIMES LINE

SITE PLAN

APPENDIX C

JOB HAZARD ANALYSIS SHEET, LABORATORY INDUCTION SHEET AND TAKE TWO FORM

GEMCO

Groote Eylandt Mining Company Pty Ltd

- Resourcefully operated by BHP Billiton -

JOB HAZARD ANALYSIS WORKSHEET

Job Description:	Quarry Water Sampling	Job Location:	Quarries	Date of JHA: 15/02/2006
Plant/Equip Number:	Varies	Supervisor:	Emma Keating	*Training / licence Requirements- Light vehicle dams and quarries driving induction.*
Plant/Equip description:	Light Vehicle	Department:	Tech. Services	
Maintenance job #	No	Dig permit ?	No	
Hot Work Permit ?	No	Confined space permit ?	NO	

Special or primary hazards

Manual handling of equipment - Back/Joint/Muscle strains, Hand Injuries

Slip/trip hazards

Vehicle accident – light/heavy vehicle interaction

Vehicle travelling over rough ground or becoming bogged – potential passenger injury or requirement to recover vehicle

Vehicle rollover and visibility to passing traffic – potential collision with passing vehicles or injury to passenger

Pedestrian and vehicle interaction – potential collision

Contact with dangerous fauna

Dehydration, Heat Stress, Sunburn

PPE requirements		Other equipment	
Hard hat	Safety Boots	Water	
Safety glasses	Long Trousers	Sample Bottle and crate for carrying bottles	
Wide brim for hard hat	Long Sleeved Shirt	Light Vehicle	
Sunscreen		Bailer	
Gloves – Rubber and Leather		Hand held radio	

Doc. No: FRM-3843
Approved: Pat McAtackney
JHA Workesheet

Version: 3
Page 1 of 7

Version Date: 26th Oct 2004
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GEMCO

Groote Eylandt Mining Company Pty Ltd

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Guideline for use

1. **Identify the task** — ie what are you going to do?

2. Break the task into **simple steps.**

3. **Identify the existing or potential hazards**, using the following key to determine the hazard type (use **bold** highlighted letter) :

Business	Community	Environment	Health	Quality	Safety
Loss of production	Disturbance of significant site	Oil Spill	Hearing Loss	Contamination	Manual Handling

4. **Conduct initial risk assessment** for each hazard identified using the risk matrix, and put the **severity letter** using the following key (use **bold** highlighted letter)

Low	Moderate	High	Extreme

5. From the Matrix then put in the **number** score in the initial risk score columns.

6. **Develop** and identify the hazard controls, then **repeat** the risk assessment with the controls in place (steps 4 – 5) and fill in **residual/final risk** columns.
For example changing car tyre

Consequence Severity
Refer to Consequence Severity Table

		Low	Minor	Moderate	Major	Critical	FACTOR
Almost Certain	This event has occurred at GEMCO in the last twelve months.	High 100	High 50	Extreme 1000	Extreme 2500	Extreme 7500	10
Likely	This event has occurred at a BHP Billiton site in the last twelve months	Moderate 30	Moderate 30	Extreme 300	Extreme 750	Extreme 3000	3
Possible	This event has occurred in the mining industry in the last 5 years.	Low 10	Moderate 30	High 100	Extreme 300	Extreme 1000	10
Unlikely	I have heard of a similar event occurring in the mining industry in the last 10 years	Low 3	Low 3	Moderate 30	High 90	Extreme 300	3
Rare	I have heard of a similar event occurring in industry in the last 100 years	Low 1	Low 3	Moderate 10	High 30	High 100	1
LIKELIHOOD		1	3	10	30	100	

Simple job steps and hazard table

Simple job steps (Break job into smaller manageable steps)	Existing or potential hazards (" A source that has the potential to cause loss, harm " eg falling object, electricity, entanglement chemicals etc)	Initial Risk score TYPE	Initial Risk score SEVERITY	Initial Risk score No.	Hazard control (Eg Eliminate, substitute, redesign, separate, administrate (i.e. procedures, permits, forms, training), PPE)	Residual / final risk score SEVERITY	Residual / final risk score No.
Park car	Car rolls away-crush injury	S	M	30	Chock wheels, park car on even ground, remove keys from ignition	L	1
	Hit by another vehicle-crush injury	S	E	300	Park out of traffic flow	L	1
Remove spare wheel	Manual handling-strain	S	M	30	Use correct lifting techniques, get help	L	3
Jack the car	Car slips off jack-crush injury	S	E	300	Secure jack, firm base, correct jacking point, place spare wheel under car	L	3
Change wheel	Car slips off jack-crush injury	S	E	300	As above, place spare wheel under car prior to jacking, loosen wheel nuts prior to jacking	L	3
	Manual handling-strain/sprain	S	M	30	Use correct lifting techniques	L	1
Pack up	Manual handling-strain/sprain	S	M	30	Use correct lifting techniques	L	1

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GEMCO

Simple job steps (Break job into smaller manageable steps)	Existing or potential hazards (" A source that has the potential to cause loss, harm " eg falling object, electricity, entanglement chemicals etc)	Initial Risk score			Hazard control (Eg Eliminate, substitute, redesign, separate, administrate (i.e. procedures, permits, forms, training), PPE)	Residual / final risk score	
		TYPE	SEVERITY	No.		SEVERITY	No.
Loading equipment onto vehicle	• Manual handling - strains	S	H	300	• Use correct lifting procedure and stretch before heavy lifting. Lower sides of ute tray to reduce lifting height and share the load if necessary.	L	9
	• Slip/Trip hazards	S	H	300	• Visually inspect the path to vehicle and remove obstacles to ensure it is clear of trip hazards before carrying equipment to vehicle	L	9
	• Hand Injuries	S	H	300	• Wear gloves when handling/carrying equipment	L	9
Travel to sampling location	• Light/heavy vehicle interaction - vehicle accident (mine site)	S	H	90	• Driver of vehicle to be in possession of light vehicle permit and dams and quarries permit. Driver to follow mine site traffic rules at all times. Radio Mike 1 to inform of your destination and to check heavy vehicle movements	L	3
	• Vehicle becoming bogged or moving over rough surfaces	S	H	300	• 4WD is required in order to access sampling locations. Caution to be used if ground is boggy and those areas avoided where possible. If vehicle becomes bogged, radio to Mike 1 for assistance.	L	3

Simple job steps (Break job into smaller manageable steps)	Existing or potential hazards ("A source that has the potential to cause loss, harm "eg falling object, electricity, entanglement chemicals etc)	Initial Risk score			Hazard control (Eg Eliminate, substitute, redesign, separate, administrate (i.e. procedures, permits, forms, training), PPE)	Residual / final risk score	
		TYPE	SEVERITY	No.		SEVERITY	No.
Parking vehicle and walking to sampling location from vehicle	• Vehicle visibility and instability — potential for vehicle roll over or collision with passing traffic	S	M	30	• When parking vehicle, leave beacon light on for high visibility to passing traffic and park on level, stable ground	L	3
	• Pedestrian and vehicle interaction	S	H	100	• Vehicle is to be parked well clear of the road, on same side of road as sampling location so that pedestrian does not have cross the road.	L	3
	• Slip/Trip hazard - walking over clayey and rough surface down incline whilst carrying equipment	S	H	300	• Choose clearest path of least descent and walk carefully when carrying equipment. Hand held radio to be taken by sampler.	L	9
	• Potential for dangerous fauna (eg snakes/spiders/crocodiles)	E	H	300	• Sampling to be conducted during daylight hours when crocodile risk is minimised and visual checking is most effective. Sampling to be conducted in pairs so that one person can watch the water. Bailer to be used for collecting sample so that personnel can maintain a 3m distance from waters edge	M	30

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Simple job steps (Break job into smaller manageable steps)	Existing or potential hazards ("A source that has the potential to cause loss, harm " eg falling object, electricity, entanglement chemicals etc)	Initial Risk score			Hazard control (Eg Eliminate, substitute, redesign, separate, administrate (i.e. procedures, permits, forms, training), PPE)	Residual / final risk score	
		TYPE	SEVERITY	No.		SEVERITY	No.
Collect Water Sample	• Muscle strain associated with using bailer to collect water sample	S	H	300	• Lifting of bailer to be done by bending at knees and keeping back straight and holding rod in correct position (upright). Sample size is small and weight of sample will not cause strain to user	L	9
	• Contact with contaminated waters	E	M	30	• Rubber gloves to be worn whilst transferring sample into bottles in case of contaminated/acidic water	L	3
	• Dehydration, heat stress	S	H	300	• Drink plenty of water, rest as needed	L	3
	• Sunburn	S	H	300	• Apply sunscreen before starting job and wear a widebrim hat	L	9

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GEMCO

Simple job steps (Break job into smaller manageable steps)	Existing or potential hazards ("A source that has the potential to cause loss, harm " eg falling object, electricity, entanglement chemicals etc)	Initial Risk score			Hazard control (Eg Eliminate, substitute, redesign, separate, administrate (i.e. procedures, permits, forms, training), PPE)	Residual / final risk score	
		TYPE	SEVERITY	No.		SEVERITY	No.
Carrying Water Samples back to vehicle	• Muscle strain associated with lifting/carrying samples	S	H	300	• Lifting of sampling bottles to be done by bending at knees and keeping back straight. Sample bottles will be placed into a crate or like for carrying back to vehicle. Weight is not to exceed 10-15 kilos (which equates to 10-15 bottles) depending on personal strength. Sides of ute tray to be lowered when lifting samples into vehicle. Share the load with another person if necessary.	L	9
	• Slip/Trip hazards	S	H	300	• Visually inspect the path to vehicle and remove obstacles to ensure it is clear of trip hazards before carrying equipment to vehicle. Carry bottles in a crate so that they are not cumbersome.	L	9
	• Hand Injuries	S	H	300	• Wear gloves when handling/carrying equipment		
• Travelling back to the office	• Light/heavy vehicle interaction - vehicle accident	S	H	90	• Driver to follow mine site traffic rules at all times.	L	9
	• Vehicle becoming bogged or moving over rough surfaces	S	H	300	• Caution to be used if ground is boggy and those areas avoided where possible. If vehicle becomes bogged, radio to Mike 1 for assistance.	L	3
						L	3

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Groote Eylandt Mining Company Pty Ltd
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Simple job steps (Break job into smaller manageable steps)	Existing or potential hazards ("A source that has the potential to cause loss, harm " eg falling object, electricity, entanglement chemicals etc)	Initial Risk score			Hazard control (Eg Eliminate, substitute, redesign, separate, administrate (i.e. procedures, permits, forms, training), PPE)	Residual / final risk score	
		TYPE	SEVERITY	No.		SEVERITY	No.
• Unloading samples and equipment from vehicle and carrying to office	• Slip/Trip hazards	S	H	300	• Ensure path to office is clear of trip hazards. Carry bottles in a crate so that they are not cumbersome.	L	9
	• Hand Injuries	S	H	300	• Wear gloves when handling/carrying equipment	L	9
	• Muscle strain associated with lifting/carrying samples	S	H	300	• Share the load with another person if necessary and lower sides of ute tray when lifting samples out of vehicle.	L	9

Name of participant	Signature	Name of participant	Signature
Joe Witt	*[signature]*		
KRISTINE JOHNSTON	*[signature]*		

If initial risk score is >10 then please ensure that an entry for this activity and hazard is recorded on the Risk Register

Send completed form to Supervisor for filing

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JHA Worksheet

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APPENDIX 1 – LABORATORY AREA INDUCTION

TO FOLLOW GENERAL INDUCTION FOR VISITORS, CLEANERS & NEW STAFF.

1. Safety glasses are to be worn and no food in all areas beyond the yellow line.

2. Location of hidden rubbish bins.

3. Location and use of broken glassware bin.

4. Operation of "sensor" tap.

5. Location and operation of safety shower and eye-wash.

6. Leave the laboratory if there is a power failure while work is in progress in the fume hoods.

7. Hearing protection to be used in the sample prep. area while work is in progress.

8. Be aware that due to the use of hearing protection and a noisy environment, the operator may not know you are present while work is in progress in sampling areas.

9. Care with laboratory reagents. Some are poisonous, corrosive or carcinogenic. Some react violently with water. Treat everything as dangerous. Wash hands before eating or drinking.

10. Don't use distilled water for general cleaning purposes.

11. Don't use laboratory glassware for drinking vessels.

12. Many pieces of equipment are delicate and some need to be set up after being disturbed, so don't move or bump instruments. Laboratory personnel are responsible for gear on benches and sink areas.

13. Equipment used around the fusion machine can be VERY hot without visible indication.

14. Keep water away from balance benches.

Signed _Johnston_ (Operator)   _Jay._ (Senior Laboratory Coordinator)

Name _KRISTINE JOHNSTON_   _Rod Jones._

Date _20 / 03 / 06._

GEMCO

Take 2 record

IDENTIFY

Job Location: Quarry
Job Description: Pipe Inventory

Legend: Checklist - Tick the appropriate box

Yes No

☑ ☐ Check the environment – is it normal (rain, slippery conditions, spilled oil)?

☑ ☐ Check the equipment condition. Is it safe to use? - Am I authorised and trained to use it for this job?

☑ ☐ Do I know how to safely use this material/substance? Have I consulted the MSDS for the material?

☑ ☐ Can I do this job safely without straining or over exerting myself?

☑ ☐ Has the system been de-energised and isolated?

☑ ☐ Have I ensured that I cannot be burnt/electrocuted while undertaking this task?

☑ ☐ Is the air ok to breathe where I am going (Gas, Fume, Dust)? Consider if an air test is required?

☑ ☐ Have I ensured that nothing may fall on me or strike me?

☑ ☐ Have I ensured that I cannot fall more than 2 meters? (If a fall is possible - Working at Heights permit)

☑ ☐ Can I do this job/task safely without assistance?

☑ ☐ Have I ensured that there is no chance I can or may spill or pollute something?

IF YOU TICK NO OR ARE CONCERNED ABOUT ANY OF THE ABOVE YOU
MUST EITHER COMPLETE THE JOB WITH A STANDARD GEMCO WORK
INSTRUCTION FOR THAT TASK OF IF NOT AVAILABLE COMPLETE A JHA.

V.2.

Job/Shift Notes

DATE: 14/12/05 .... SHIFT: D/N

Stay away from
edges apply cuts

Adequate eye protection
has been applied.
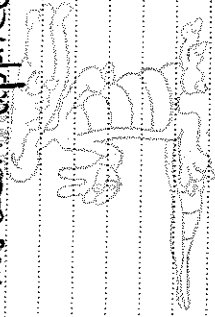
Participants:
Crew member/s Chris/Kris
Supervisor Chris .... Time <11.52

V.2.

APPENDIX D

X-RAY DIFFRACTION ANALYSIS AND PARTICLE SIZE DISTRIBUTION REPORT

O.3y/69.

All %, × 2

Philips Analytical

Results on-line

Type:	Routine
Archive:	AA_MnOre 40-60%
Application:	AA_MnOre 40-60%
Sample:	001 KJ 2703
Sum (%):	100.0000
Init weight:	0.6 g
Flux weight:	6 g
Final weight:	6.6 g
LOI (%):	57.838

Compound	Value	Unit	Status
Mn	0.244	%	
Fe	1.733	%	
SiO2	29.372	%	
Al2O3	8.197	%	
P	0.0108	%	
Na2O	0.082	%	
MgO	1.279	%	
K2O	0.731	%	
CaO	0.077	%	
SrO	0.006	%	
BaO	0.038	%	
TiO2	0.392	%	

Channel	Status	Raw (kcps)	Net (kcps)
SrBg1		18.7985	
Sr		18.3940	1.3455
SrBg2		15.3130	
Fe		94.9434	
Mn		17.8163	
Ti		4.0670	
Ba		0.7607	0.2228
BaBg1		0.5423	
CaBg1		0.3542	
Ca		1.0160	0.7056
CaBg2		0.3078	
KBg1		0.3615	
K		6.0411	5.8799
PBg1		0.0410	
P		0.1175	0.0837
Si		31.5960	
Al		8.1373	
Mg		4.7085	4.7681
MgBg1		0.3843	

ALS Environmental

SUB-CONTRACT LABORATORY
RESULTS COVERSHEET
for ALS WORKORDER EB0601941

Client Details

Client	:	GEMCO

Project	:	C Quarry Water
Order number	:	E27370
C-O-C Number	:	- Not provided -
Site	:	- Not provided -
Sampler	:	Kristine Johnston

Comments

The attached report contains sub-contracted components of ALS Environmental work order EB0601941. This report has been electronically stored for ALS record purposes and has not been altered in any way.

FOR LABORATORY USE ONLY
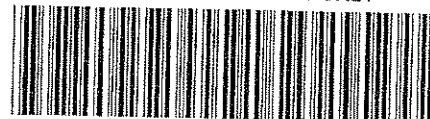
ALSE - QUALITY, SERVICE and TECHNOLOGY provided GLOBALLY   A Campbell Brothers Limited Company

ANALYSIS REPORT

Report No: 736

Job No: A640

Michael Heery
ALS Environmental
32 Shand Street
STAFFORD QLD 4053

Report Date: 1 March 2006
Samples Submitted: 1 March 2006
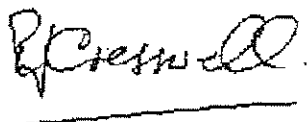
Sample ID: EB0601941-001

Report:

The sample has a multimodal particle size distribution. About 76% lies in a distribution between 0.04 and 0.9 microns with a maximum at about 0.33 microns; the mean size for this distribution is 0.31 microns. The remainder lies in a broad distribution between 0.9 and 10 microns with a maximum at about 1.7 microns. The overall mean is 0.82 microns and the median 0.36 microns.

A detailed report is attached.

$1 \text{ micron} = 10^{-6} \text{ m}$

Dr Pearson Cresswell

Notes: The measurements were made using a Coulter LS230 instrument. The sample was dispersed in water using sonication to aid dispersion. The distribution was calculated using a Mie Theory optical model (RI 1.55/0.01) which is suitable for quartz, clays and other common soil minerals.

File name:	A640.$12	Group ID:	A640
Sample ID:	ALS EB0601941-001		
Run number:	12	Operator:	pjc
Comments:	GEMCO BHP C QUARRY 21/02/06		
Optical model:	Soil1.rfd PIDS included		
LS 230	Small Volume Module		
Start time:	12:44 1 Mar 2006	Run length:	96 seconds
Obscuration:	3%	PIDS Obscur:	63%
Fluid:	Water		
Software:	3.01	Firmware:	2.02 0

Differential Volume
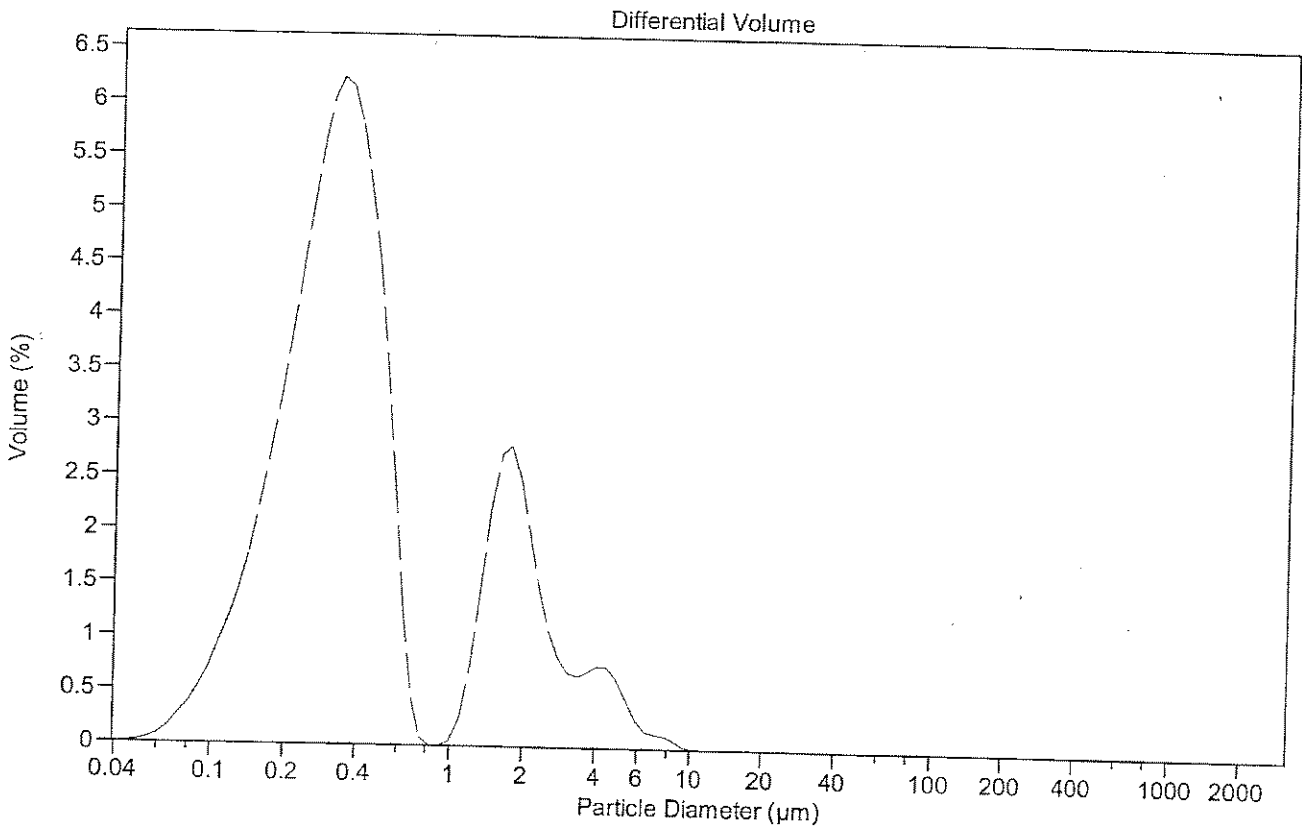
Volume Statistics (Arithmetic)   A640.$12

Calculations from 0.0400 µm to 2,000 µm

Volume:	100%			
Mean:	0.817 µm	S.D.:		1.113 µm
Median:	0.360 µm	C.V.:		136%
D(3,2):	0.317 µm			
Mode:	0.326 µm			

% <	10	25	50	75	90
µm	0.163	0.241	0.360	0.622	2.100

A640.$12

Channel Diameter (Lower) μm	Diff. Volume %	Cum. < Volume %	Channel Diameter (Lower) μm	Diff. Volume %	Cum. < Volume %
0.040	0.0062	0	11.83	0	100
0.044	0.012	0.0062	12.99	0	100
0.048	0.022	0.018	14.26	0	100
0.053	0.045	0.040	15.65	0	100
0.058	0.089	0.085	17.18	0	100
0.064	0.17	0.17	18.86	0	100
0.070	0.27	0.34	20.71	0	100
0.077	0.39	0.61	22.73	0	100
0.084	0.52	1.00	24.95	0	100
0.093	0.71	1.52	27.39	0	100
0.102	0.93	2.23	30.07	0	100
0.112	1.18	3.16	33.01	0	100
0.122	1.46	4.34	36.24	0	100
0.134	1.80	5.79	39.78	0	100
0.148	2.22	7.59	43.67	0	100
0.162	2.69	9.81	47.94	0	100
0.178	3.21	12.5	52.62	0	100
0.195	3.77	15.7	57.77	0	100
0.214	4.37	19.5	63.41	0	100
0.235	4.99	23.9	69.61	0	100
0.258	5.58	28.8	76.42	0	100
0.284	6.03	34.4	83.89	0	100
0.311	6.24	40.5	92.09	0	100
0.342	6.15	46.7	101.1	0	100
0.375	5.79	52.8	111.0	0	100
0.412	5.23	58.6	121.8	0	100
0.452	4.52	63.9	133.7	0	100
0.496	3.60	68.4	146.8	0	100
0.545	2.49	72.0	161.2	0	100
0.598	1.29	74.5	176.9	0	100
0.656	0.44	75.8	194.2	0	100
0.721	0.075	76.2	213.2	0	100
0.791	0.0050	76.3	234.0	0	100
0.868	0.0037	76.3	256.9	0	100
0.953	0.046	76.3	282.1	0	100
1.047	0.26	76.3	309.6	0	100
1.149	0.74	76.6	339.9	0	100
1.261	1.49	77.3	373.1	0	100
1.384	2.23	78.8	409.6	0	100
1.520	2.73	81.1	449.7	0	100
1.668	2.81	83.8	493.6	0	100
1.832	2.50	86.6	541.9	0	100
2.011	2.00	89.1	594.8	0	100
2.207	1.49	91.1	653.0	0	100
2.423	1.09	92.6	716.8	0	100
2.660	0.83	93.7	786.9	0	100
2.920	0.70	94.5	863.9	0	100
3.205	0.67	95.2	948.3	0	100
3.519	0.71	95.9	1,041	0	100
3.863	0.76	96.6	1,143	0	100
4.240	0.76	97.3	1,255	0	100
4.655	0.65	98.1	1,377	0	100
5.110	0.46	98.7	1,512	0	100
5.610	0.27	99.2	1,660	0	100
6.158	0.16	99.5	1,822	0	100
6.760	0.13	99.6	2,000		100
7.421	0.12	99.8			
8.147	0.082	99.9			
8.943	0.024	99.97			
9.818	0.0028	99.997			
10.78	0	100			

CHAIN OF CUSTODY

From: ALS Environmental
32 Shand St
Stafford QLD 4053
PH: 07 3243 7222
FAX: 07 3243 7259

To: Microns to Measure
42 Ramsden Street
CLIFTON HILL VIC 3068
Ph: (03) 9481 3451
Fax: (03) 9481 3451

Att:

Due Date: 7/03/2006

Purchase Order #: 241245

ALS Batch #: EB0601941

ALS (logo)

SAMPLE ID.	SAMPLE IDENTIFICATION	CONTAINER DATA #			LABORATORY PARAMETERS	COMMENTS
		DATE	TYPE	NO.	PSD by Laser Light Scattering (0.04 - 2000um)	
1	C Quarry	21/02/06	W	1	✓	

NOTES:

1. Please ensure that a signed copy is faxed back immediately to ALS Brisbane acknowledging receipt.

2. Contact Michael Heery if the requested TAT cannot be met.

RELINQUISHED BY (SIGN / PRINT):	RECEIVED BY (SIGN / PRINT):	DATE: 28/02/06
OF: ALS Brisbane	OF: Microns to Measure	TIME: 1400
RELINQUISHED BY (SIGN / PRINT):	RECEIVED BY (SIGN / PRINT): P. Cresswell	DATE: 1-3-06
OF:	OF:	TIME: 0900

(ARRIVAL TEMP: deg. C)   (ARRIVAL TEMP: deg. C)

AUSTRALIAN LABORATORY SERVICES P/L   Page: 1 of

APPENDIX E

PREVIOUS REPORTS

CITIWATER TOWNSVILLE

A BUSINESS UNIT OF
TOWNSVILLE CITY COUNCIL

LABORATORY SERVICES

DELIVERY ADDRESS: Douglas Water Plant, Angus Smith Drive, Douglas, Qld 4814
POSTAL ADDRESS: P.O. Box 1268, Townsville, Qld 4810 Ph 07 47755891 Fax 07 47255 387
e-mail pcm@townsville.qld.gov.au

ATTENTION: JAMIE McCORKELL

FROM: PETER MOCKERIDGE

DATE: 6/09/00

TEST RESULTS	
Client: GEMCO	**Sample Description, Quantity**
Address: Groote Eylandt Mining Co P/L	Water samples
Alyangula	**Date Received:** 28/08/00
Groote Eylandt NT 0885	**Date Commenced:** 28/08/00
	Date completed: 5/09/00

A ten litre sample of water was jar tested to ascertain the best method of clarification of the water. The original pH of the sample was 5.3 as measured at Groote Eylandt and also in the Citiwater laboratory.

Two methods of clarification were used. One method using alum with pH correction using lime. The other using a Floerger product FL45CLV which is a cationic polyelectrolyte, polydiallyldimethylammoniumchloride which is 45% active. A similar product can be bought from Nalco or Calgon. The cationic polyelectrolyte was found to give best results. The alum was found to be unsuitable because of problems with soluble aluminium at the low pH of the water. The optimum dose for clarification was found to be 8 mg/L of the 45% active polydiallyldimethylammoniumchloride polymer.

1. Use of alum as clarification agent.

Because of the low pH of the water sample, pH correction was necessary when alum was used. Good results were obtained using an addition of 50 milligrams per litre alum and 10 milligrams per litre lime. However the pH of the resultant water was 5.6. Aluminium is relatively soluble at this pH so the use of this method of clarification could lead to the discharge of soluble aluminium with the clarified water.

Alum mg/L	Lime mg/L	pH	Turbidity NTU
40	10	5.75	25
50	10	5.6	10
60	10	5.3	26
50	20	6.2	110

Signatory .... Peter Mockeridge Chemist	This document may not be reproduced except in full.
Page 1 of 2	Reference No. gemco090600

A BUSINESS UNIT OF
TOWNSVILLE CITY COUNCIL

CITIWATER T O W N S V I L L E

LABORATORY SERVICES

DELIVERY ADDRESS: Douglas Water Plant, Angus Smith Drive, Douglas, Qld 4814
POSTAL ADDRESS: P.O. Box 1268, Townsville, Qld 4810 Ph 07 47755891 Fax 07 47255 387
e-mail pcm@townsville.qld.gov.au

2. Use of cationic polyelectrolyte

Good clarification was obtained using the cationic polyelectrolyte. The optimum dose for clarification was found to be 8 mg/L of the 45% active catfloc. Concentrations of 9 and 10 milligrams per litre produced similar results. The dose rate of cationic polyelectrolyte should be carefully monitored and changes made slowly. It is to be noted that if cationic polymer is overdosed it no longer produces clarification of water. The water will remain dirty and will be very hard to treat.

Cationic mg/L	pH	Turbidity NTU
6	5.95	21
7	5.98	15
8	5.98	8.2
9	6.04	8.0
10	5.98	8.4

COMMENTS: Ten one litre bottles of the water to be treated were supplied to the lab. The samples were combined, the resultant composite mixed and the analysis performed.

Signatory .... Peter Mockeridge Chemist	This document may not be reproduced except in full.
Page 2 of 2	Reference No. gemco090600

From:	McCorkell, Jamie A
Sent:	Friday, 25 November 2005 12:30 AM
To:	Rose, Brian J
Subject:	RE: Greetings and Query

Emailed Jamie on 20th Jan 2006.

Hey Champ,

Sorry I haven't got back sooner...been doing the travel thing and the remote network access has been really dodgy!

The best (easiest) product to use was called a "Flocc Block" from CIBA chemicals. It was a poly flocc product in a solid block a bit bigger than a house brick. From memory the optimum dose was around 2mg/l (I think!). Overdosing however didn't casue a problem which is lucky cos the delivery system isn't real precise. Just to clarify (no pun intended) we were using it on the C Quarry discharge. The method was to run the discharge from C quarry to e quarry(?...next to the airport). Basically you dump the flocc block in the open drain in an onion bag, it dissolves and doses the water as it flows passed and the particles theoretically drop out prior to being re-lifted out of e quarry and into the drain line to the river. If the drainage network doesn't run that way, I'd get CIBA to re-run the flocc trials and size up a sedimentation basin that can be excavted in the drain line so the particles are removed before hitting the river.

Not stressing over the dolphins...busy organising controls to exclude critters for an underwater drill and blast program for construction of a new 3rd berth. Using fixed sonar array with time of arrival range and bearing algorithms for passive detection of whales and dolpins and possibly an unmanned isreali army remote piloted vehicle with forward looking infrared radar so we can detct in all conditions to be able to D&B 24/7...COOL!

Cheers

Jamie

From:	Rose, Brian J
Sent:	Wednesday, 23 November 2005 1:58 PM
To:	McCorkell, Jamie A
Subject:	Greetings and Query
Importance:	High

Hey Jamie

How goes it? Haven't heard from you in ages, not that I am any better at maintaining contact.

If you hadn't heard, I joined the "Dark side" about a year & a half ago so I shake rattle and roll every day in the concentrator.

Quick question, do you remember anything about the flocculants you trailed up here to try and drop the clays out of the quarry runoff? Where you sourced them and which one worked the best. I remember a couple seemed to work fairly well, but don't remember any of the details as to brand or product info.

Hope you aren't getting too stressed monitoring the Dolphins etc.

Thanks

Brian Rose
Production Metallurgist
GEMCO
Ph - (08) 8987-4488
Fax- (08) 8987-4301

1

GEMCO ⊕

Alyangula
Groote Eylandt   NT   0885
AUSTRALIA

Telephone +618 8987 4444
Facsimile   +618 8987 4499

Facsimile

To:	Matt Leach- Ciba Chemicals	**From:**	Jamie McCorkell
Fax:	08 8941 8246	**Pages:**	5
CC:		**Date:**	17 January 2006

Re: "Magnasol Floc Blocs"

Matt,

As (briefly) discussed, we are interested in trialing flocculants to improve the quality of discharge water from one of our quarries. To this end, we had samples of the quarry water flocc tested by Citiwater Laboratories in Townsville. The recommendation from this analysis was the addition of 8mg/l of 45% active catfloc (see attached lab report).

As an initial trial, we were intending to flash-mix the required dose in a hydromulcher, and apply the mixture to the water surface using the pump and spray nozzle on the equipment. One of the potential problems with this batch treatment type scenario, is that the suspended material is colloidal smectite clay. The concern is that after successful application and "drop out", as the quarry is subsequently pumped down the intruding groundwater will carry an additional load of clay particles into the pit which will remain in suspension.

Our plant metallurgist is currently investigating thickening options for the beneficiation plant tailings discharge, and came across an old Allied Colloids flyer regarding the floc blocs (also attached FYI). This product would appear to suit our needs (as it may be placed in the discharge stream allowing for continuous pump-down instead of batching), however we would like to trial the product to determine it's suitability.

Please advise if it is possible to obtain a sample of the product for a field trial, and costs for future supplies if a trial shows promise. Additionally, could you provide any available information on the relationship between flow and dose provided by the product (ie a channel of given x-section and flow rate will receive a dose of approximately ? mg/l).
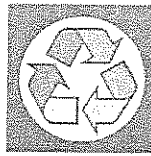
Any questions regarding the above, please contact me on phone 08 8987 4397, or e-mail jmccorkell@billiton.com.au .

Regards

Jamie McCorkell
**Environment Officer**

Environmental Warehouse

DamClear Flocculant Blocks

Product Description

DamClear Flocculant Blocks are a simple, convenient method for applying flocculant to water requiring clarification.

Flocculant Blocks consist of fine granules of powder grade flocculant dispersed in a solid, but readily water soluble polymer. The carrier polymer is non toxic. As water flows over the Block, flocculant is released which reacts with sediment. The solids settle rapidly leaving a clear treated water.

Typical Applications
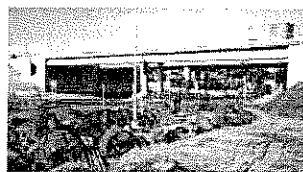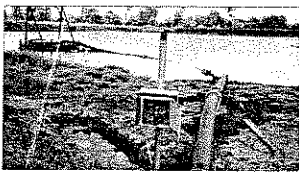
Flocculant blocks are ideal for dosing flocculant in remote locations such as storm water drains & detention dams and in situations where regular supervision of dosing is not practical. They have found application in many situations, some of these include ......

- **Construction Sites**
  Clarification of storm water on building sites & construction sites.

- **Mines & Quarries**
  Clarification of storm water run-off from mining operations & stock piles at rock, sand & gravel quarries.

- **Road Construction**
  Clarification of storm water run-off at road, rail & tunnelling construction sites.

- **Trade Wastewater**
  Clarification of trade wastewater to remove solids and sludge.

- **Farm Dam Water**
  Clarification of clay contaminated water storage dams on farms.

Application & Benefits

DamClear Flocculant Blocks are rectangular in shape, dimensions are 210 x 170 x 80 mm. Each block weighs 3 kg and will treat between 100,000 - 300,000 litres of water.

The most common method for applying Flocculant Blocks is to place 1 or more Blocks in a 25 mm aperture wire mesh cage. The cage is positioned at a point of turbulence that will ensure contact with most of the water flow. A point of turbulence may have to be created if one does not exist.

The turbulent flow across the Blocks releases the flocculant into the water stream. Flocculation of sediment and suspended solids occurs immediately.
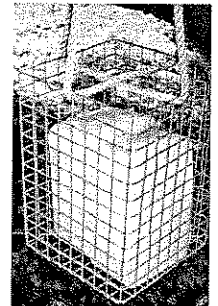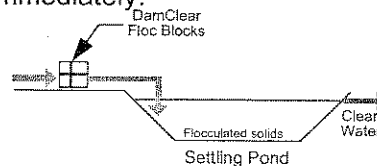
Product benefits include........
- Suitable for use in locations where electrical power is not available.
- No dosing equipment to maintain or monitor.
- Low capital cost.
- Stable product with a long shelf life.
- Simple visual method for monitoring usage.
- Addition rate approximates flow proportional dosing. As water flow rate varies the rate of block dissolution changes.

DamClear Flocculant Blocks do not contain aluminium or iron and will not affect water pH.

Ordering Information

DamClear Flocculant Blocks are supplied in boxes of 8, net weight 24 kg, or are available as individual Blocks, packed in a plastic container.

Also available are heavy duty wire mesh baskets and hand-held clarity meters to measure water quality.

For additional information regarding this product consult your local agent, Environmental Warehouse or visit our website.

Printed in Australia

Ciba Specialty Chemicals

COAGULANT AND FLOCCULANT SCREENING TESTWORK CONDUCTED UPON DIRTY PIT-WATER SAMPLES, JUNE 2004

FOR

GEMCO PTY LTD

Technical Report

Prepared by: *Mark Haslam*
Date: *8th June, 2004*
Revision: *1*

TECHNICAL REPORT NO: MH012
TO: Jeff Millgate
FROM: Mark Haslam

COMPANY: GEMCO Pty Ltd

SUBJECT: TREATMENT OF DIRTY PIT-WATER SAMPLES

CONFIDENTIALITY

All documents and data supplied by Ciba Specialty Chemicals shall be regarded as confidential and shall not be used by the Contractor or Principal, or disclosed to a third party, for purposes other than the preparation or evaluation of a tender or as necessary for the performance of the Contract.

1.0 SUMMARY

A request was received from Mr Jeff Millgate as to whether Ciba Specialty Chemicals could offer a treatment solution for some dirty water contained within mining areas at GEMCO Pty Ltd's Groote Eylandt operations. As the treated water is to be discharged into local waterways, an environmentally benign process was requested.

Several products were tested, the most effective being Magnasol 589. However Magnasol 576 and LT 425 were also effective. LT425 is used for the processing of potable drinking water and is therefore of low toxicity.

There is however a possible risk to fish if overdosing of the water occurs and the water is discharged into rivers or streams (refer to MSDS sheets).

Other more benign chemicals, including anionic powder flocculants and guar were ineffective due to the highly dispersed nature of the suspended fines.

2.0 EXPERIMENTAL DETAILS

2.1 Flocculant and Coagulant Solution Make Up

1. Flocculants and coagulants were prepared at 0.25%w/v and 0.25% v/v respectively in Perth tap water (the flocculant being prepared from powder form and the coagulant being a liquid product).

2. 100 mL subsamples of the water samples supplied by GEMCO were then treated with 0.4 mL and 0.8 mL additions of the 0.25% solutions prepared previously and mixed..

3. After 10 minutes a sample of the water was then taken and the turbidity measured using a Hach Turbidity Meter.

3.0   RESULTS and DISCUSSION

The following Turbidity readings were obtained on the samples as received.

	pH	Turbidity
Site 1	7.2	232 NTU
Site 2	6.7	59 NTU
Site 3	6.5	76 NTU

— this must be (Quarry)

Site 1 was obviously the worst sample visually, the appearance of which indicated the presence of highly dispersed fine particulates, possibly some form of clay mineral. The other samples did not appear to be particularly dirty.

Testwork was initiated on Site 1 samples and performance compared for Site 2 and Site 3 samples.

Site 1 Results

Product	Dose Rate of Product As Supplied	Turbidity @ 10 mins (NTU)
Magnasol 576	10 mL per m3	205
	20 mL per m3	19
LT425	10 mL per m3	199
	20 mL per m3	66
Magnasol 500	10 mL per m3	229
	20 mL per m3	212
Magnasol 589	10 mL per m3	52
	20 mL per m3	39
Magnafloc 5250	20 g per m3	220
Magnafloc 338	20 g per m3	220
Guar	20 g per m3	215

Subject: GEMCO PTY LTD DIRTY PIT-WATER TREATMENT

Site 2 Results

Product	Dose Rate of Product As Supplied	Turbidity @ 10 mins (NTU)
Magnasol 576	10 mL per m3	30
	20 mL per m3	31
LT425	10 mL per m3	22
	20 mL per m3	28
Magnasol 589	10 mL per m3	23
	20 mL per m3	25

Site 3 Results

Product	Dose Rate of Product As Supplied	Turbidity @ 10 mins (NTU)
Magnasol 576	10 mL per m3	26
	20 mL per m3	23
LT425	10 mL per m3	20
	20 mL per m3	24
Magnasol 589	10 mL per m3	25
	20 mL per m3	24

These results clearly demonstrate the effectiveness of Magnasol 576, Magnasol 589 and LT 425 in being able to improve the water clarity. The poor results obtained using the guar and anionic flocculants Magnafloc 5250 and Magnafloc 338 indicate that the suspended solids are indeed very highly dispersed and respond more favourably to the coagulant products.

A possible treatment methodology would be by spraying the diluted coagulant onto the surface of the dirty water and allowing several days for the solids to settle. It may be more effective to recirculate the water by pumping it out of the pit and dosing the coagulant and returning the water to the pit, but this would depend on equipment availability and access.

The coagulant products could possibly result in harm to fish if overdosed water is discharged into rivers etc. This risk is significantly reduced if an under-dosing strategy is employed, i.e. by leaving the water slightly dirty (within environmental discharge limitations of course). When applied, the coagulant itself is irreversibly absorbed onto the particulate surfaces and the presence of some suspended solids indicates insufficient quantities of the coagulant have been added. Therefore no excess coagulant will be present, and because the coagulant that has been added will not be available in an active form in water, the water will be suitable for discharge.

In order to ensure an excess of coagulant is not added, reliable estimates of water volumes to be treated are therefore required before commencing treatment.

4.0 RECOMMENDATIONS

It is recommended that GEMCO satisfy themselves as to the effectiveness of the recommended products Magnasol 576, Magnasol 589 and Magnafloc LT425 on site by following the test procedure described previously. Samples of the products can be provided upon request.

Based on the testwork results indicating an estimated required dose rate of about 15 mL per m3 and based upon a total water volume requiring treatment of 539,000 m3, the required volume of coagulant would be 8,100 litres.

Currently we have the following quantities available for immediate delivery:

- Magnasol 576:   2,500 kg available in 1300 kg (1,000 L) IBC's.
  - Price = $ 2.50 per kg (excluding GST), ex works, Wyong NSW
- Magnasol 589:   2,000 kg available in 240 kg (200 L) drums
  - Price = $ 2.50 per kg (excluding GST), ex works, Wyong NSW
- Magnafloc LT425: 3,000 kg available in 200 L drums
  - Price = $ 3.75 per kg (excluding GST), ex works, Wyong NSW

Additional supplies would be available subject to manufacturing schedules.

APPENDIX F

TEST REPORT FORM TEMPLATE

TEST REPORT FORM

TEST No.	DATE	SAMPLE SOURCE
DESCRIPTION	COMMENTS	
	SALINITY	pH
	ELECT CONDUCT	TEMP

BEAKER No.		1	2	3	4	5	6
REAGENT							
MIXING METHOD	Flask Solution						
DOSAGE	mg/L						
SAMAPLE VOLUME	mL						
SETTLING TIME	min						
SUSPENDED SOLIDS AFTER SETTLING	mg/l						
TURBIDITY	NTU						
pH							
ELECT CONDUCT	mS/cm						
TEMP	C						
COMMENTS							

APPENDIX G

SCHEMATIC RECOMMENDED
TREATMENT MAPS

OCEAN

F QUARRY

C QUARRY

PUMP TO F1

PUMP SEA WATER TO F1

ANGURUGU RIVER

F1 QUARRY

PUMP CLARIFIED WATER TO RIVER

SWAMP

DAMS

THE GASH

PLANT

ANGURUGU

A SOUTH QUARRY

BORE FIELDS

SCHEMATIC 1
C QUARRY
DISCHARGE TO RIVER

LEGEND:
- → SURFACE WATER
- ⊶ SUMP & PUMP
- ····· BORE LINE
- ─·─ SLIMES LINE
- ⊶ SEA WATER PUMP
- --- SEA WATER LINE
- ⊶ FLOATING TAKE OFF
- ─·─ CHANNEL FLOW

OCEAN

F QUARRY

C QUARRY

PUMP
TO F1

APPLY MICROGYP
WITH
HYDROMULCHER

F1 QUARRY

ANGURUGU RIVER

PUMP CLARIFIED
WATER TO DAM 1

SWAMP

DAMS

THE GASH

PLANT

ANGURUGU

A SOUTH
QUARRY

BORE
FIELDS

SCHEMATIC 2
C QUARRY
REUSE AT CONCENTRATOR

LEGEND:
→ SURFACE WATER
○▻ SUMP & PUMP
------ BORE LINE
SLIMES LINE

○▻ HYDROMULCHER FOR
MICROGYP
○▻ FLOATING TAKE OFF
—·— CLARIFIED WATER LINE

F QUARRY

PUMP SEA WATER TO
CLARIFICATION POND

PUMP TO
CHANNEL
FLOW

OCEAN

PUMP CLARIFIED
WATER TO OCEAN

C QUARRY

ANGURUGU RIVER

F1 QUARRY

SWAMP

DAMS

THE GASH

PLANT

ANGURUGU

A SOUTH
QUARRY

BORE
FIELDS

SCHEMATIC 3
C QUARRY
DISCHARGE TO OCEAN

LEGEND:
- → SURFACE WATER
- ⊶ SUMP & PUMP
- ⋯⋯ BORE LINE
- — SLIMES LINE

- ▨ CLARIFICATION POND
- ⊶ SEA WATER PUMP
- – – – SEA WATER LINE
- ⊶ FLOATING TAKE OFF
- —·— CHANNEL FLOW

OCEAN

F QUARRY

ANGURUGU RIVER

C QUARRY

F1 QUARRY

SWAMP

DAMS

THE GASH

PLANT

ANGURUGU

PUMP TO
CHANNEL
FLOW

A SOUTH
QUARRY

BORE
FIELDS

APPLY MICROGYP
WITH
HYDROMULCHER

SCHEMATIC 4
A SOUTH
REUSE AT CONCENTRATOR

LEGEND:
→ SURFACE WATER
o→ SUMP & PUMP
······ BORE LINE
—·— SLIMES LINE

CLARIFICATION POND
HYDROMULCHER FOR
MICROGYP
o→ FLOATING TAKE OFF
—·— CHANNEL FLOW

OCEAN

F QUARRY

C QUARRY

ANGURUGU RIVER

F1 QUARRY

SWAMP

DAMS

THE GASH

PLANT

ANGURUGU

A SOUTH
QUARRY

PUMP SEA WATER TO
CLARIFICATION POND

BORE
FIELDS

PUMP CLARIFIED
WATER TO OCEAN

SCHEMATIC 5
A SOUTH
DISCHARGE TO OCEAN

LEGEND:
→ SURFACE WATER
o▷ SUMP & PUMP
····· BORE LINE
····· SLIMES LINE

▨ CLARIFICATION POND
o▷ SEA WATER PUMP
— — SEA WATER LINE
o▷ FLOATING TAKE OFF
—·— CLARIFIED WATER LINE

APPENDIX H

INTENSITY FREQUENCY DURATION
CURVES FOR ANGURUGU
AND
STORMWATER RUNOFF ESTIMATION
FOR NORTHERN QUARRIES

REPORT

INTENSITY-FREQUENCY-DURATION

CHARTS

and

STORMWATER RUNOFF ESTIMATION FOR C AND

F1 QUARRY CATCHMENTS

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1. INTRODUCTION

As part of the Northern Quarries Water Recycle Pipe Line project feasibility study, a hydrologic analysis has been performed on the catchment and is contained herein this report.

The report contains the computation of temporally and spatially consistent, intensity-frequency-duration (IFD) design rainfall curves for Angurugu, Groote Eylandt, Northern Territory. The IFD curves can be used for design flood models, hydrological and environmental studies.

This report uses the graphical procedure presented in Australian Rainfall and Runoff (AR&R), Book 2.

The report then goes on to calculate the stormwater runoff that the catchment can supply for stormwater harvesting purposes.

2. DEVELOPMENT OF IFD CURVES

2.1. Basic Information

The Design Rainfall Isopleths, Regional Skewness and Geographical Short Duration Maps can be found in Appendix A.

2.1.1. Basic Rainfall Intensities

From the Design Rainfall Isopleth Charts (AR&R Maps 1-6) the following rainfall intensities are read off:

Table 2.1.1
Basic Rainfall Intensities

$^{2}I_{1\ hour}$ (mm/hr)	$^{2}I_{12\ hour}$ (mm/hr)	$^{2}I_{72\ hour}$ (mm/hr)	$^{50}I_{1\ hour}$ (mm/hr)	$^{50}I_{12\ hour}$ (mm/hr)	$^{50}I_{72\ hour}$ (mm/hr)
68	10.8	3	123	19.4	7

2.1.2. Skewness Factor

From the Regional Skewness Map (AR&R Map 7) the Skewness Factor, G, is obtained.

Table 2.1.2
Skewness Factor

G
0.24

2.2. Geographical Short Duration Factors

From the Geographical Short Duration Map (AR&R maps 8-9), F2 and F50 are determined.

Table 2.2
Geographical Short Duration Factors

F2	F50
3.94	16.4

2.2.1. 6 Minute Rainfall Intensities

Using the above Short duration Factors, the 6 minute rainfall intensities were calculated from formulas and are listed in the Table below.

- $$^2I_{6\ minute} = F2 \times (^2I_{1\ hour})^{0.9}$$

- $$^2I_{6\ minute} = F50 \times (^{50}I_{1\ hour})^{0.6}$$

Table 2.2.1
6 Minute rainfall Intensities

$^2I_{6\ minute}$ (mm/hr)	$^{50}I_{6\ minute}$ (mm/hr)
175.7	294.3

2.3. Log Pearson III Intensities

The procedure for finding LP III intensities was followed according to the graphical method outoined in AR&R. The following steps resulted in the Log Pearson III Interpolation diagram for Standard ARI in Appendix B.

- Construct G Line from skewness factor
- Plot basic data at the 2 and 50 year lines
- Draw in the 6 minute, 1, 12 & 72 hour lines
- Draw vertical lines from the intersection of the G Line and the sloping frequency lines. The vertical lines give the modified LP III intensity values.

Table 2.3
Log Pearson III Intensities
Adjusted for Angurugu

$^{2}I_{6\ minute}$ (mm/hr)	$^{2}I_{1\ hour}$ (mm/hr)	$^{2}I_{12\ hour}$ (mm/hr)	$^{2}I_{72\ hour}$ (mm/hr)
174	67.5	10.5	3
$^{5}I_{6\ minute}$ (mm/hr)	$^{5}I_{1\ hour}$ (mm/hr)	$^{5}I_{12\ hour}$ (mm/hr)	$^{5}I_{72\ hour}$ (mm/hr)
210	82	13.2	4
$^{10}I_{6\ minute}$ (mm/hr)	$^{10}I_{1\ hour}$ (mm/hr)	$^{10}I_{12\ hour}$ (mm/hr)	$^{10}I_{72\ hour}$ (mm/hr)
232	92.1	14.8	4.5
$^{20}I_{6\ minute}$ (mm/hr)	$^{20}I_{1\ hour}$ (mm/hr)	$^{20}I_{12\ hour}$ (mm/hr)	$^{20}I_{72\ hour}$ (mm/hr)
265	110	17	5.5
$^{50}I_{6\ minute}$ (mm/hr)	$^{50}I_{1\ hour}$ (mm/hr)	$^{50}I_{12\ hour}$ (mm/hr)	$^{50}I_{72\ hour}$ (mm/hr)
305	129	20	7
$^{100}I_{6\ minute}$ (mm/hr)	$^{100}I_{1\ hour}$ (mm/hr)	$^{100}I_{12\ hour}$ (mm/hr)	$^{100}I_{72\ hour}$ (mm/hr)
334	143	22.5	8.5

2.4.1 Year Intensities

The 1 Year intensities were then calculated from the following formula:
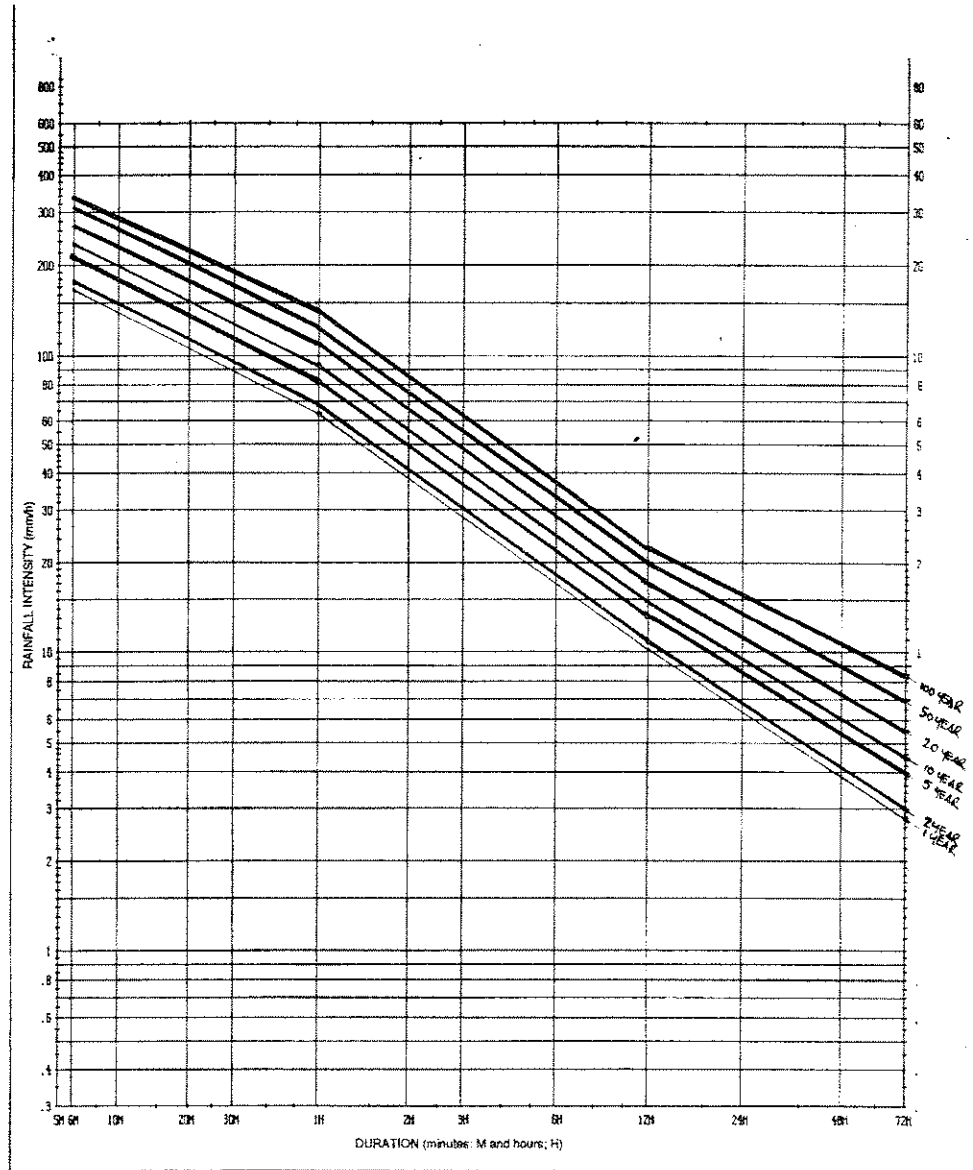
$$^{1}I_{D} = \frac{^{2}I_{D}}{1 + 0.4046 \times \log 1.13 \times \left(\frac{^{50}I_{D}}{^{2}I_{D}} \right)}$$

Table 2.4
Log Pearson III 1 Year Intensities
Adjusted for Angurugu

$^{1}I_{6\ minute}$ (mm/hr)	$^{1}I_{1\ hour}$ (mm/hr)	$^{1}I_{12\ hour}$ (mm/hr)	$^{1}I_{72\ hour}$ (mm/hr)
167.7	64.8	10.1	2.8

The above intensities were used to create the Intensity Frequency Duration Diagram for Angurugu below.

2.5. IFD Chart

DURATION INTERPOLATION DIAGRAM — ANGURUGU (DIAGRAM 2.1)

3. STORMWATER DRAINAGE CALCULATION

3.1. Introduction and Methodology

In order to quantify the amount of water that the northern quarry catchments (shown on the map below) can supply to the Northern Quarries Water Recycle Pipeline, a catchment study was undertaken.

The Rational Model and Weeks Method have been used and the following steps outline the methodology.

1. The duration of the design storm appropriate to the catchment is determined using the Weeks Method.
2. An appropriate Average Recurrence Interval (ARI) for the design storm is selected.
3. The rainfall intensity (mm/hr) for that time and average recurrence interval is read off the relevant IFD curve.
4. An appropriate runoff coefficient is selected.
5. The peak discharge is calculated according to the Rational Model.
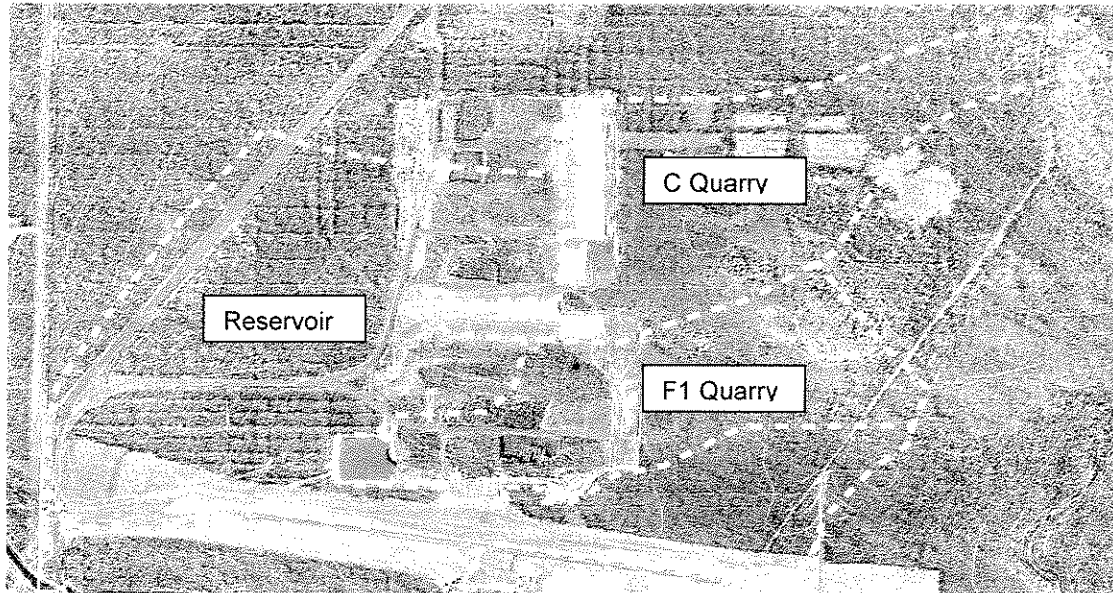
3.2. Contributing Areas

The catchment areas have been determined from a contour map and the map is shown below along with the areas.

Table 3.2
Catchment Description and Area

Catchment Description	Area (km²)
F1 Quarry	1.177
C Quarry	1.507
Reservoir	3.282

3.3. Catchment Map

Figure 3.3
Catchment Map

3.4. Time of Concentration

The storm duration for each catchment has been determined in accordance with AR&R standardised regional durations. For the region in far north Queensland, the time of concentration (t_c)can be calculated according to the following formula:

$$t_c = 0.76A^{0.38}(Weeks)$$

This equation will also be adopted for the catchments adjacent Angurugu.

Table 3.4
Time of Concentration

Catchment Description	t_c (hours)
F1 Quarry	0.809
C Quarry	0.888
Reservoir	1.194

3.5. Average Recurrence Interval

Since the pipeline system is to collect stormwater runoff (which also forms quarry water discharge) for delivery to Dam 1, it was deemed appropriate to select an ARI of 1 year. That is, a storm of magnitude that would be expected to be seen to occur only once every year has been chosen as the design storm. The NPV calculation used to justify construction of this project is based on being able to supply water for 6 months of the year and shut off the bore field pumps for 1 month of the year.

The IFD curve is used to find $^{10}I_6$ and $^{Y}I_{tc}$.

Table 3.5
Design Intensities

Catchment Description	$^{10}I_6$	$^1I_{tc}$
F1 Quarry	25	70
C Quarry	25	76
Reservoir	25	48

3.6. Runoff Coefficient

$$C_{10} = \frac{\left(\dfrac{L}{\sqrt{S_e}}\right)^{0.156} x \left(^{10}I_6\right)^{0.929}}{100}$$

L = Mainstream Length
S_e = Equal Area Slope. Average slope in the stream channel taken so that the areas defined by the profile of the channel bed above and below S_e are equal. (m/km)
$^{10}I_6$ = Average intensity for a 6 hour storm with ARI of 10 years
Y = design value of ARI
A = area of catchment (km^2)
The runoff coefficient for the required ARI = Y (years) is calculated from the following formula.

$$C_Y = C_{10}[0.54x \log(Y) + 0.46]$$

Table 3.6
C_{10} and C_1 Values

Catchment Description	L (km)	S_e (m/km)	C_{10} Value	C_1 Value
F1 Quarry	2.8	3.2	0.508	0.233
C Quarry	1.2	3.3	0.217	0.099
Reservoir	2.2	4.1	0.202	0.093

3.7. Catchment Discharge

The peak discharge from each catchment is calculated by the following formula:

$$Q_Y = FC_Y{}^Y I_{tc} A$$

Q_Y = peak flow rate of ARI = Y (years) in m^3/s
C_Y = runoff coefficient for a storm of ARI = Y (years)
A = area of catchment (km^2)
F = 0.278 (conversion factor)

From calculating the ARI 1 storm event, a 3 month event is half of the discharge produced by the 1 year event.

Table 3.7
Q Values

Catchment Description	Q_1 (m^3/s)	$Q_{3\ month}$ (m^3/s)
F1 Quarry	5.337	2.668
C Quarry	3.152	1.576
Reservoir	4.072	2.036

3.8. Estimated Volume of Water Produced for Dam 1

In order to justify the project and to estimate the volume of water that the catchments will supply to Dam 1, the following calculations are now made.

C Quarry currently has an excavation holding approximately 150, 000 m^3 of turbid water. Based on the assumption that during the wet season (assumed to be four months in duration), there is a rainfall event every day of a magnitude of half of the 1 in 3 month discharge of duration of 30 minutes, the following volumes of water could be expected to be supplied to Dam 1 from the construction of a Northern Quarries recycle pipeline.
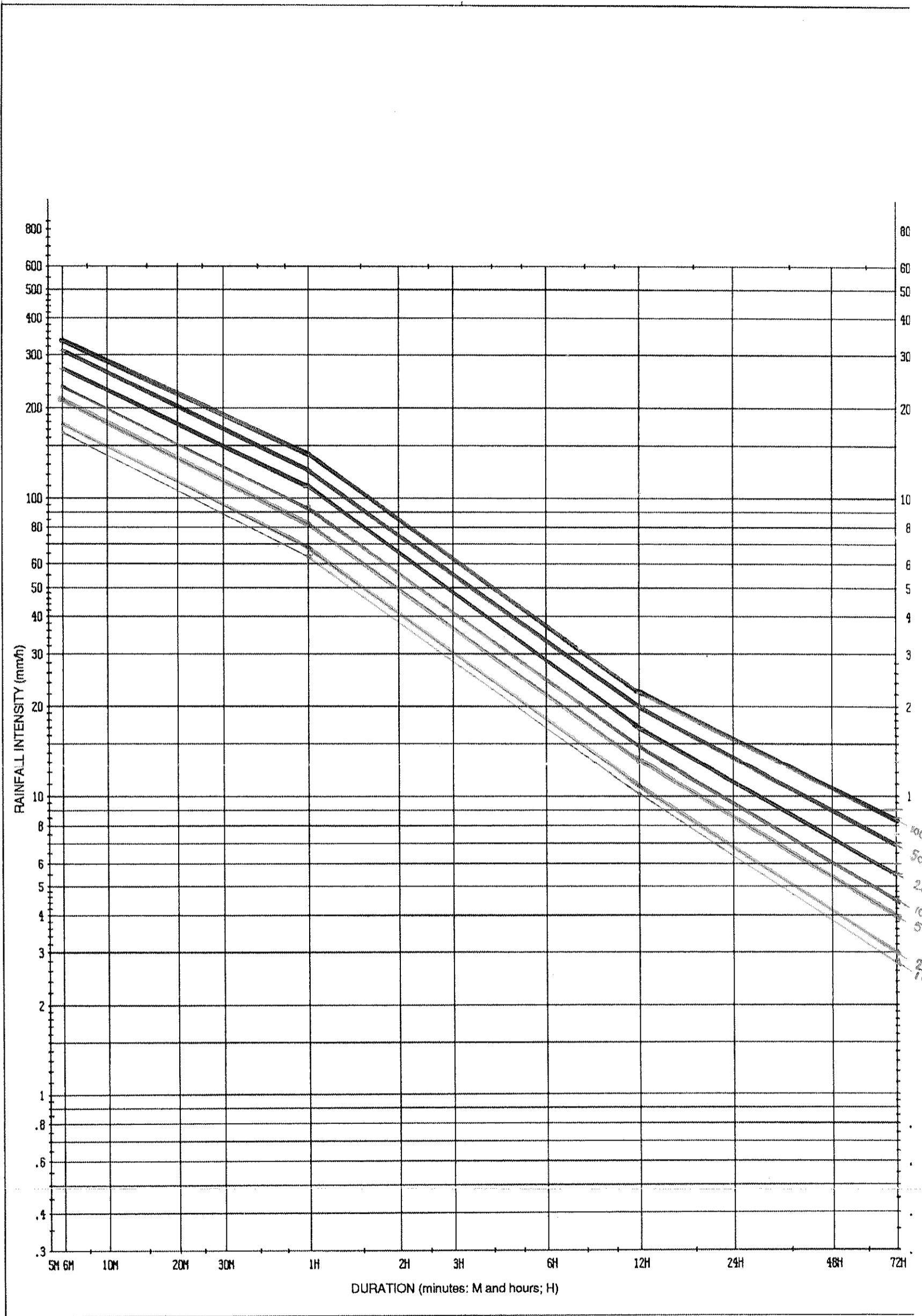
Table 3.8
Estimate Water Volumes

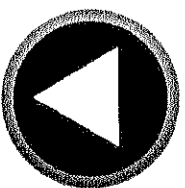| Catchment Description	$Q_{1\ month}$ (m^3/s)	Volume of Water (m^3)
F1 Quarry	1.334	144,000
C Quarry	0.788	85,100
Reservoir	1.018	110,000

4. CONCLUSION

The results show that the bore field pumps (which are assumed to pump at 280 l/s) could be stopped for two weeks every wet season which is not adequate justification in itself for construction of the Northern Quarries recycle line.

This study however makes some pretty broad assumptions about the amount of rainfall that could be harvested from these catchments and a more detailed study should be undertaken. Also, ground water infiltration should be factored in to give a more realistic quantity of water that could be sourced from the Northern Quarries.

It is concluded that further investigation is warranted, particularly due to the current zero discharge policy into Angurugu River.

RAINFALL INTENSITY (mm/h)

DURATION (minutes: M and hours; H)

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DURATION INTERPOLATION

DIAGRAM

ANGURUGU

DIAGRAM 2.1

LOG - PEARSON TYPE III INTERPOLATION DIAGRAM
FOR STANDARD AVERAGE RECURRENCE INTERVALS (ARI)

ANGURUGU

DIAGRAM 2.2
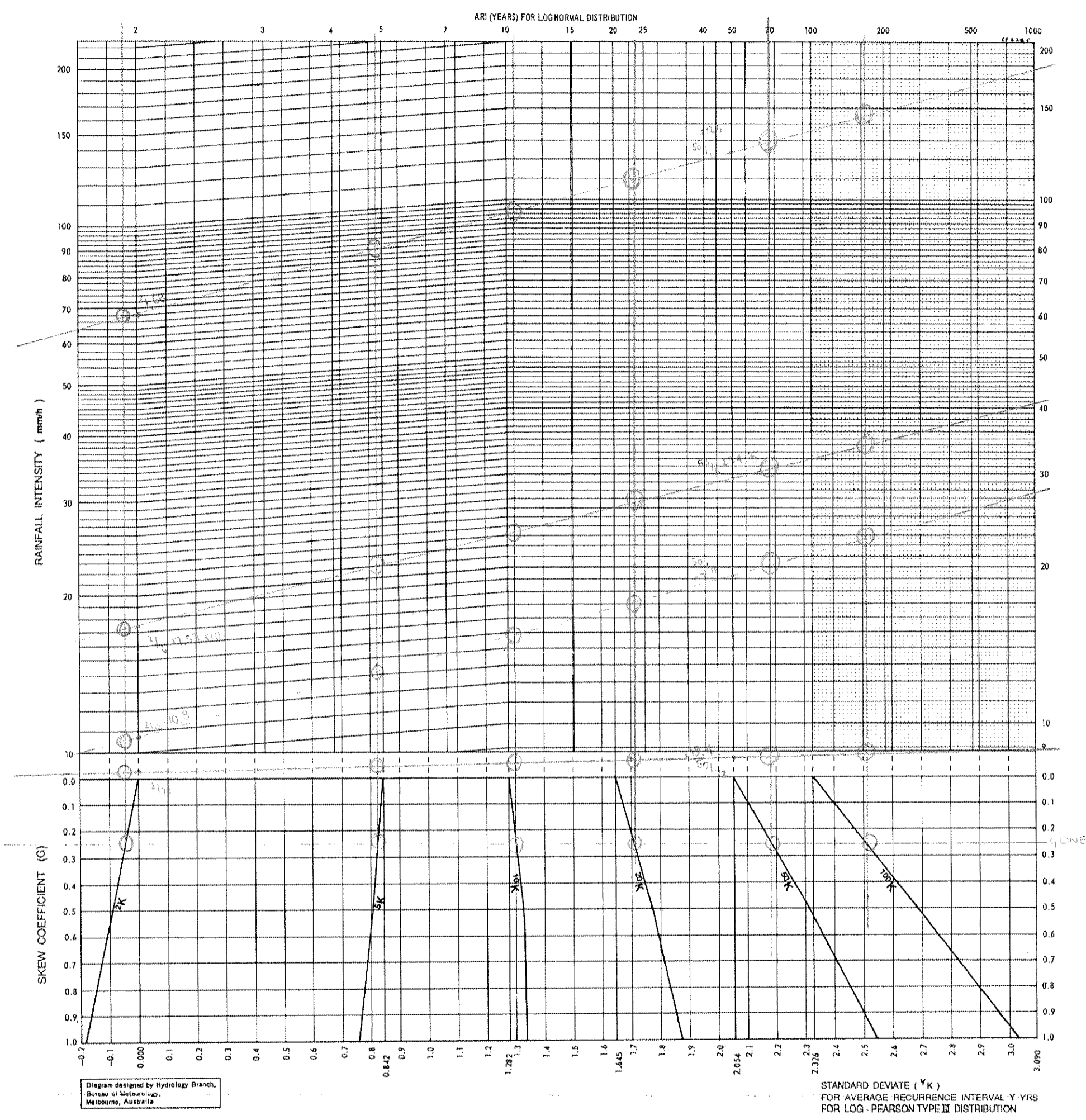
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