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OPTIMISING THE EFFECTIVENESS OF SEDIMENTS RETENTION PONDS FOR WAIKATO SOIL MATERIALS

A thesis submitted in partial fulfilment
of the requirements for the degree

of

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by

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THE UNIVERSITY OF

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Abstract

Current Waikato sediment retention pond design is based on guidelines developed by the Auckland Regional Council. As soils in the Auckland and Waikato Regions are different, there is a need to investigate the effectiveness of sediment retention ponds in retaining sediments from Waikato soil materials. The objectives of this study were to:

- i) do a comparison between pipette, hydrometer and lasersizer methods for determining soil particle size and to characterise the sand, silt and clay in a range of Waikato soil materials,
- ii) evaluate turbidity and suspended solid concentration between the inlet and outlet of sediment retention ponds, and
- iii) investigate the use of chemical treatment (flocculants) in assisting sediment settling.

Ten samples representing a range of Waikato soil materials were collected. Particle size was determined using hydrometer, pipette and lasersizer analysis. The pipette and hydrometer gave similar results. Lasersizer analyses were similar to pipette-hydrometer analyses for six samples. The remaining four samples analysed by lasersizer did not give a close agreement to conventional methods. However, error bars showed that between-sample variability was not large. The pipette was found to be the most reliable method for determination of particle size, however the lasersizer gave fast measurements which were easily repeatable. The soil texture of the ten Waikato soil materials tested ranged from sand to clay.

A rain gauge connected to an autowater sampler was installed at the inlet of two sediment retention ponds, one at SH1 in Piarere and the other at a quarry in Ngaruawahia. Water samples were collected when rainfall reached 2mm in the previous 30 minute period. Samples were analysed for turbidity and suspended solids.

The sediment retention ponds at both sites were effective, reducing suspended solids and turbidity by at least 94%. Water samples collected at Piarere showed a 94% reduction in turbidity (from 558.68 NTU to 35.27NTU) and a 97% declination in suspended solids concentrations (from 2365.63mg/L to 78.41mg/L). Results from water samples collected at Ngaruawahia demonstrated a 97% reduction in turbidity (from 491.33 NTU to 14.46 NTU) and a 95% drop in suspended solids concentration (from 210.43 mg/L to 9.5 mg/L). Flocculants (Polyaluminium Chloride, PAC) were being used at the sediment retention pond at Ngaruawahia.

Further investigation into the effectiveness of flocculants in removing sediments from the water column found that samples 1 and 2 collected from the Ngaruawahia study site and allophanic soil materials do not require treatment with flocculants. The recommended dose of 8 ppm/litre of PAC was sufficient to treat sediment runoff without lowering pH level to a point that might induce aluminium toxicity in aquatic life of downstream rivers and streams for Ngaruawahia 3 and coarse materials of Hinuera Formation. PAC doses of 2.7ppm in the Hamilton Ash materials and 5.3 ppm in Hinuera Formation (fine materials) were sufficient to ensure flocculation. For the Piarere soil materials an 8 ppm PAC dose gave reasonable flocculation and 10.7 ppm PAC further reduced the turbidity after 24 hours.

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Chapter 1

Introduction

1.1 Background

Soil erosion is a natural process where gravity, wind and water erode the soil surface. Erosion can however, be accelerated by activities like quarrying and earthworks construction associated with subdividing land and building roads. Activities on earthwork sites such as roading, tracking, cutting, moving, ripping or contouring of land can leave the soil bare of vegetation, leading to unavoidable erosion of soils, resulting in discoloured turbid water, increased sediment or suspended solids entering water-bodies, and sediment deposition on stream and lake beds (Environment Waikato 2009a).

Elevated levels of sediment deposition diminish water clarity and the aesthetic appeal of the receiving stream or river as well as increasing the flood risk in the local area. High concentrations of suspended solids may modify or destroy in-stream qualities and habitats, disrupting the food chain and reducing the number of fish and macro-invertebrates (Bilotta & Brazier 2008).

Extensive research has illustrated that sediment generated during earthwork activities may be up to 1000 times more than that from permanent forest cover and 10 to 100 times more than sediments from pastoral land (Environment Waikato 2009a). Sediment generation accelerates with high intensity rainfall and overland flow of stormwater runoff in the catchment area of the earthwork activities (Selby 1993).

Thus it is crucial to trap sediment runoff from earthwork sites to protect waterways. Sediment retention ponds (SRP) are one of the tools used to trap sediment on-site and prevent off-site sedimentation. The main function of sediment retention ponds is to capture sediment runoff from earthwork sites during storm and rain events, and retain the sediment enriched water until the soil materials settle out of the water column (Environment Waikato 2009a). Settling may be enhanced by chemical means such as the addition of coagulants or flocculants.

The design of sediment control measures must consider both the site conditions and the types of operation to be carried out. One of the most difficult factors to predict when designing a sediment pond is the settlement characteristics of sediment-laden runoff (Winter 1998).

Limited knowledge or inaccurate assumptions of sediment pond efficiency will lead to either insufficient soil material entrapment, resulting in a high proportion of sediment discharge, or on the other hand, the developer's financial loss due to over-design of the ponds. Hence, when designing a pond three important factors to be considered are the soil characteristics (texture, structure, permeability, density and organic matter content), the sediment delivery ratio and the settling time (Morton 1996). In a well-designed SRP the suspended sediment and turbidity in the runoff will reduce from inflow to outflow, due to trapping efficiency and adequate residence time.

Under the Resource Management Act (1991), Regional Councils are required to manage the impact of land disturbance activities. Therefore guidelines for erosion and sediment control are developed by Regional Councils and require developers to plan and implement sediment control measures before undertaking land disturbance activities. The primary purpose of having guidelines is to minimize the adverse effects of sediment discharge through the appropriate use and design of control measures to prevent erosion and keep sediment on site.

The "Erosion and Sediment Control Guidelines" for Earthworks used by Environment Waikato (2009a) have been adopted from the Auckland Regional Council Technical Publication 90 (Auckland Regional Council 1999). However, the soil materials in Auckland are different from Waikato soil materials. Many Auckland soils have a high clay content, which is difficult to settle, and fine sand and silts which are the more erodible fractions of the soil (Auckland Regional Council 1999). The Waikato soils vary across the region. Soils in the south-east are formed from highly erodible pumice and raw volcanic materials. Clay soils are more common in the Coromandel area. Tephra-derived soils (Hamilton Ash Formations) with low erodibility dominate the north of the region, and soils formed in peat and volcanigenic alluvium are predominant in the Waikato basin and the lower Hauraki Plains (Singleton 1991).

There have been a number of studies undertaken in assessing the effectiveness of sediment retention ponds in the Auckland region, such as Morton (1996), Winter (1998), Bennett (2000) and Jackson (2008). There is, however, a need to better understand the sediment behaviour of the soil materials in the Waikato Region to optimise sediment retention pond design. Hence, determination of the proportion of sand, silt and clay of several major soil types in the Waikato Region will act as a reference point in providing a better understanding of the soils' settling behaviour.

1.2 Objectives

The overall aim of this study was to contribute to a more effective design for stormwater runoff sediment retention ponds for conditions specific to the Waikato region. The specific objectives of this study were to:

- 1) do a comparison between pipette, hydrometer and lasersizer methods for determining soil particle size and to characterise the sand, silt and clay in a range of Waikato soil materials,
- 2) evaluate turbidity and suspended solid concentration between the inlet and outlet of sediment retention ponds, and
- 3) investigate the use of chemical treatment (flocculants) in assisting sediment settling.

Chapter 2

Literature Review

2.1 Introduction

Erosion is a natural phenomenon which results in soil loss and water quality degradation. New Zealand is geologically young and active and, as a result, the natural level of erosion is high by international standards. In the 1980s an erosion assessment survey reported that 52% or 13.8 million hectares of land area in New Zealand was affected by erosion (Rochelle 1997, cited by Jackson 2008). Changes in land use, brought about by a growing population concentrated largely in expanding urban centres, are causing erosion and sediment pollution problems in some areas (Environment Waikato 2007).

Soil erosion susceptibility is the result of a complex set of interactions between soil type, climate, vegetative cover, terrain characteristics (slope and aspect) and land management practices (Pierzynski *et al.* 1994). Some land types are more susceptible to accelerated erosion than others. Erosion susceptible lands generally include hill country and the banks of rivers and lakes. In addition, some soils such as pumice soils are more prone to erosion than others (Singer & Munns 2006).

The expanding population in areas such as Hamilton has created a need for new houses, factories, shopping centres, schools, highways and recreational areas. To meet these needs the land topography has been changed, vegetative cover has been removed, and areas are covered by buildings or paving. The construction of new subdivisions, involving the stripping of vegetation and topsoil and recontouring of the land, results in decreased infiltration and increased runoff, erosion, sediment pollution, and flooding (Eash *et al.* 2008).

When erosion is not controlled during urban development damage can be extreme. Eroded slopes require additional stabilization. Highways, foundations, and other improvements may be undermined by erosion. Erosion damage may result in unnecessary delays in projects, expensive repairs, and an unattractive landscape (Pierzynski *et al.* 1994).

Sediment, the product of erosion, causes additional problems. When consideration is not given to reducing erosion during urban development sediment losses up to 100, 000 tons per square mile have occurred (Auckland Regional Council 1999). Sediment fills in and pollutes streams and reservoirs, reducing stream capacity, and scenic and recreational value. Storm drainage systems are filled in and flooding is increased. The removal of sediment from the downstream receiving environment is difficult and expensive (Environment Waikato 2009a).

Soil erosion is largely caused by water and wind. In the context of this study, the process of soil erosion caused by water, in particular rainfall associated with storm events, is discussed.

2.2 The Process of Soil Erosion

Soil erosion by water is a function of the erosivity (energy) of the rainfall and the erodibility of the soil. The erosiveness of flowing water depends upon its velocity, turbulence, and the amount and type of abrasive material the water transports. Velocity increases as the depth of flow and the slope of the land increase. Turbulence of flow increases as the rainfall becomes more intense and as the surface flow concentrates in depressions. The abrasive capacity of the runoff depends on the energy of the flowing water and the amount and type of suspended material in the water (Selby 1993).

Erodibility is the vulnerability of a soil to erosion for given rainfall conditions and can be divided into two parts:

- a) the physical characteristics of the soil, such as structure, texture, moisture content, density and organic matter content, and
- b) the result of human use of the soil, which is the management of the soil depending on the land use (Selby 1993).

Soil erosion is a three phase process, which involves detachment, transportation and deposition of soil particles.

2.2.1 The Detachment of Soil Particles

During water erosion soil aggregates are detached by the impact of raindrops by a combination of rolling, lifting, and abrasive action. When flowing water moves over a soil surface horizontal forces act upon the particles in the direction of flow. These forces detach particles from the soil mass by rolling or dragging them out of position. The upward movement of the water past the soil particles detaches them by a lifting action. Soil detachment by erosion occurs when particles already in transit in the flow strike or drag over particles on the soil surface and set them in motion (Singer & Munns 2006).

2.2.2 The Transportation of Dislodged Particles

Once the soil aggregates are loosened the soil aggregates are dislodged away from their original sites, usually by surface runoff. The horizontal forces of water flowing over the surface transports soil particles by rolling or sliding them along in contact with the land surface (Singer & Munns 2006).

2.2.3 The Deposition of Sediment

Deposition is the end of the erosion process. Soil materials deposited by flowing water are usually sorted by particle size. The first to be deposited are the heavier particles of lowest transportability, whereas the lighter particles of highest transportability are deposited farther downstream. The deposition of erosional debris in places where it is not wanted is one of the major damages resulting from erosion. Stream channels are clogged and reservoirs reduced in capacity by the deposition of sediment. Pollution by sediment runoff deposition is one of the major factors causing deterioration in the quality of New Zealand streams and lakes (Singer & Munns 2006).

2.3 Relationship Between Rainfall, Runoff and Erosion

Different rainfall regimes have different destructive effects on the surface and induce different rates of runoff and erosion (Wei *et al.* 2007). Numerous studies, for example Sansalone *et al.* (1998), Shaw *et al.* (2006), Brodie & Roswell

(2007), and, Wei *et al.* (2007) have shown that rainfall intensity played a vital role in runoff and sediment generation.

The characteristics of precipitation and the catchment area are the key variables that influence the rate of infiltration and the rate of storm-water runoff generated (Jackson 2008). The principal characteristics of rain that affect runoff and erosion are intensity, duration, distribution of rainfall intensity throughout the storm, frequency of occurrence, seasonal distribution and aerial distribution. Of all the factors, the frequency of occurrence and seasonal distribution of intense rains are important factors affecting runoff and erosion because rainfall seldom occurs at a uniform rate throughout the duration of a rain event. The highest rate of runoff is usually produced when the highest intensity of rain occurs at the lowest infiltration rate (Selby 1993). Hence, the relationship between rainfall intensity and the suspended particle load in stormwater runoff is dependent on:

- a) rainfall impact area ($\text{m}^2 \text{s}^{-1}$) which is the proportion of 1 m^2 of surface area impacted by raindrops per second,
- b) rainfall duration (hour),
- c) rainfall depth (mm), and
- d) average rainfall intensity (mm h^{-1}) (Brodie & Roswell 2007).

The relationship between rainfall and both infiltration rate and surface runoff has been commonly regarded as a linear function in terms of indicating the sediment yield rate from soil erodibility (Huang & Bradford 1993), as shown by the following linear equation:

$$q_s = a q_w + b \quad (2.1)$$

Where,

q_s = sediment yield rate ($\text{g m}^{-2} \text{min}^{-1}$),

q_w = runoff rate (mm min^{-1}),

a = a regression coefficient ($\text{g m}^{-2} \text{mm}^{-1}$) describing soil erodibility, and

b = also a regression coefficient ($\text{g m}^{-2} \text{min}^{-1}$).

2.3.1 Infiltration

The rate at which water can enter the soil surface is called the infiltration rate. The infiltration rate is important firstly because it affects the rate at which a soil may 'recharge' with water, and secondly because it affects the likelihood of surface runoff and hence erosion occurring during heavy rain (McLaren & Cameron 1996). The higher the rate of infiltration, the lower the rate of surface runoff and erosion. The rate of water infiltration into the soil surface is influenced by the soil's water holding capacity, pore size distribution, soil permeability and water content.

2.3.1.1 Soil Water Holding Capacity

The soil water holding capacity is the amount of water that can be retained by soil and is mainly dependent on the soil texture and structure (McLaren & Cameron 1996). The amount of rain water that infiltrates into the soil strongly depends on the soil's texture. A clay soil takes more water to wet to the same depth than sand because of the higher water-holding capacity of the clay. On the contrary, less time is necessary to wet sand to the same depth as clay because of larger pores in sand textures (Eash *et al.* 2008).

2.3.1.2 Size and Arrangement of Pore Spaces Between Soil Particles

The size and arrangement of pore spaces (porosity) determines to a large extent the infiltration rate of a soil. Soils with large pore spaces will have greater porosity and hence be able to absorb more water than soils with small pores (McLaren & Cameron 1996).

Sandy soil, because of its relatively large pore size, has a higher infiltration rate than clay soil with its smaller pore size. A sandy soil may have an infiltration rate greater than 2.5 cm h^{-1} , whereas some clay soils require more than 12 hours for water to infiltrate (Eash *et al.* 2008).

The extent of soil aggregation is another factor affecting infiltration. If fine soil particles are well aggregated the pore spaces between the aggregates are large, providing for a higher infiltration rate. Soil management practices that improve the physical condition and granulation of the soil reduce the runoff and erosion resulting from most rains (Selby 1993).

2.3.1.3 Water Content and Permeability of the Soil

The water content of the soil at the beginning of a rainfall event also affects the infiltration rate. Colloidal material in the soil tends to swell when wetted, thereby reducing both the size of pore space and rate of water movement. Soils with a high content of colloidal material tend to crack when dry, resulting in a high infiltration rate until the cracks are filled. Once the soil's moisture is high it is easier and faster for runoff to occur (Eash *et al.* 2008).

With high intensity or prolonged rainfall, water is applied to the soil faster than it infiltrates, causing the water to pond on top of the soil surface as the application rate can no longer limit the infiltration rate (McLaren & Cameron 1996).

2.3.2 Surface Runoff

Surface runoff occurs when rainfall cannot be absorbed by the soil because the rainfall intensity is greater than the infiltration capacity of the soil, which is known as infiltration excess (Hortonian) or saturation excess. Once the rate of water infiltrated into the soil is less than the rainfall rate water will accumulate on the soil surface causing ponding to occur. The water that is ponded at the surface will then flow down the slope as overland flow. As it flows it gathers momentum and picks up soil particles, which results in runoff generation transporting and depositing sediment and eventually soil erosion through time (Kirkby *et al.* 2005).

The rate of runoff is determined by the difference between the infiltration rate of water into the soil and the intensity of rainfall. The runoff rate is influenced by the size, shape and orientation of the catchment, soil characteristics, land use and land management practices, hydrologic characteristics, and the geology and topography of the watershed. The rate of runoff is higher on steeper slopes as infiltration rate is lessened (Selby 1993).

Catchment shape affects the distribution of travel times within the catchment, and channel cut and fill behaviour can strongly influence transmission losses. Thus, catchments which are closed to the outlet and with narrow incised channels have much increased runoff for their area (Kirkby *et al.* 2005).

In addition, the amount of sediment yielded in erosion processes is strongly dependent on the soil types and the size of the catchment area. No single soil

characteristic or index has been defined as providing a satisfactory means of predicting erodibility, however, the rate at which infiltration occurs is a main determinant of erosion, while the velocity of overland surface runoff will determine the amount of sediment transported (Winter 1998).

2.4 Soil Erosion in the Waikato Region

The Waikato Region is about 25,000 km², extending from Port Waikato in the north to Mount Ruapehu in the south and includes the Coromandel Peninsula (Environment Waikato 2007).

Although a large extent of the Waikato Region's 2.5 million hectares is relatively stable, the National Land Resource Inventory has identified over one million hectares affected to some degree by erosion, with almost 36,000 hectares ranked as having severe to extreme erosion (Environment Waikato 2007). A further 400,000 hectares is classified as having severe erosion potential (Environment Waikato 2007). In the Waikato Region accelerated erosion occurs in different forms depending on the locality and types of soils (Table 2.1).

2.5 Suspended Sediments

Suspended solids in runoff comprise both inorganic particles (fine sand, silt and clay) and organic particles carried and supported by water (Agudu 2001) and are often referred to as suspended sediments.

All flowing water contains suspended solids, which are particulate materials derived from the local environment by natural erosion processes. In many situations suspended solids are innocuous and their occurrence quite natural (Auckland Regional Council 1995). However, unnaturally large quantities of suspended solids can degrade the aquatic environment by decreasing water clarity and by changing the nature of sediments in receiving waters. Additionally, suspended solids are often the medium by which contaminants are transported in the water column (Auckland Regional Council 1996).

In earthwork sites suspended solids are largely soil particles washed from the construction sites. The amount of soil eroded off earthworks sites depends on the

frequency and intensity of rain that falls while the soil is exposed. In New Zealand, with its relatively high all-year round rainfall, there is a high probability that large loads of suspended solids will be generated from urban earthwork sites during the summer construction season (Auckland Regional Council 1996).

Table 2.1 Erosion susceptibility in the Waikato region

Location	Description
Central Volcanic Area (Pumice land around Taupo, Kaingaroa and Mamaku)	Lack of coherence between soil aggregates makes soils in the central volcanic area more subjected to severe gully, rill, sheet, stream bank and wind erosion
Western and Central Hill Country (Hapuakohe Range and the southern section of the Hunua Range, includes karst landscape, and caves are a feature, particularly in the Waitomo area)	Overlain with volcanic ash and is prone to sheet erosion
Eastern Ranges (Includes parts of the Kaimai, Coromandel and Hapuakohe ranges)	High rainfall in these areas intensifies erosion effects. Downstream estuaries on Coromandel Peninsula are vulnerable to accelerated infilling from sediment
Coastal Margins	More susceptible to wind erosion because of the dune systems of the East (Coromandel) and West coasts
Pukekohe, Bombay and Pukekawa Hills	Soils are prone to high rates of soil erosion due to frequency and extent of cultivation for food production. Open cultivated ground is prone to severe rill and sheet erosion during high intensity or prolonged rain events

2.6 The Effects of Sediment

Sediments are considered as pollutants because of their impact on surface receiving waters (Singer & Munns 2006). Sediments can physically block light transmission through water, which can alter the ecology of the water body. In

some areas sediment contributes to the continuing decline of aquatic habitats and impacts on microinvertebrates and benthic organisms through smothering, changes in food sources and interruptions to the life cycle, particularly due to highly turbid water (Ryan 1991).

Elevated levels of suspended solids will also reduce light penetration to the water, resulting in less light for plants to photosynthesize, while fine sediment is able to suffocate fish by clogging the gills (Ryan 1991).

Turbid water with suspended sediments will also interrupt the upstream migration of juvenile diadromous (migratory fish between freshwater and sea) native New Zealand fish species such as lamprey, smelt, eels, mullets, whitebait galaxiid and flounders (Richardson *et al.* 2001). The effects will change the in-stream communities and recovery process from the impacts of sediment will take years rather than months.

Besides ecological changes, downstream sedimentation results in poor aesthetic and amenity values, poor water quality, damage to water pumps and other structures, reduced longevity of dam structures, and increased flooding potential. Sediment can also contribute to adverse effects on the spiritual and cultural values that tangata whenua associate with a waterbody by diminishing the mauri of water (Environment Waikato 2007).

2.7 The Impact of Earthworks

Earthworks activities generally include the removal of existing vegetation and topsoil, cutting and ripping the soils for road expansion, residential developments, and a wide range of activities associated with urbanisation and developments. Erosion at construction sites could be a serious problem amounting to 100 times more erosion than when the bare A horizon of the same soil is exposed to natural elements such as wind. Erosion and sediment runoff are further accelerated during earthwork activities due to the alteration of slopes when the soil is excavated and placed in a pile with steep sided slopes (Environment Waikato 2009a).

Construction sites are vulnerable to soil erosion (Figure 2.1). Where land is left barren for extended periods of time soil losses can be severe. For example, on a

newly constructed highway in Minnesota, soil loss from a single storm on an unprotected site exceeded 2.4 ton per acre (Pierzynski *et al.* 1994). The average sediment yield from stormwater runoff was 961 T km⁻² yr⁻¹ from a catchment undergoing housing development in Auckland. In contrast a mature urban catchment generated an average of 107 T km⁻² yr⁻¹ in Auckland (Auckland Regional Council 1994).



Figure 2.1a and b. Soil disturbing activities on active earthwork sites involved cutting, blading, ripping and compaction of soils.

Compaction increases soil density and decreases the infiltration rate by decreasing the volume of pores and decreasing the number of macropores. Compaction results in decreased soil water storage (Singer & Munns 2006). Changes in soil structure during earthwork activities will reduce water penetration. In addition, heavy machinery such as diggers, trucks and bulldozers, drive across the site during the construction process resulting in further compaction of the land surface.

During earthwork activities if the soil surface is not protected by vegetation or mulches, rain and wind may consolidate the surface and also reduce the infiltration rate. Hence, during a prolonged high intensity rainfall or storm event, the raindrop impacts pack and seal the surface layer, reducing infiltration (Selby 1993).

Results of an investigation by Basher and Ross (2001) in Pukekohe, New Zealand, under natural rainfall conditions in winter, spring and summer periods demonstrated that compacted areas had low infiltration rates with a mean of $1.4 \times 10^{-7} \text{ ms}^{-1}$. Thus, any rainfall event exceeding an intensity of 0.5 mm hr^{-1} would result in runoff. However, erosion was reduced by 95% from 21 T ha^{-1} to 1 T ha^{-1} when the compacted areas were ploughed, resulting in an infiltration rate increase of two orders of magnitude, to an average of $9.7 \times 10^{-5} \text{ ms}^{-1}$ (Basher & Ross 2001).

2.8 Regulations on Sediment Discharge

2.8.1 The Resource Management Act

The government of New Zealand has enacted laws to control the discharge of sediment in order to reduce the impact of human-induced accelerated erosion. In accordance with section 30 (1) of the Resource Management Act (RMA) 1991, Regional Councils have statutory responsibilities to control the use of land for the purpose of the maintenance and enhancement of the quality of water in waterbodies, and the control of discharges of contaminants into or onto water.

Under Part 1, section 2, of the RMA (1991, amended 1995), it has been described that sediment can be considered as a contaminant through the definitions:

- i) *“Contaminant includes any substance (including gases, odorous compounds, liquids, solids, and micro-organisms) or energy (excluding noise) or heat, that either by itself or in combination with the same, similar or other substances, energy or heat;*
 - (a) *When discharged into water, changes or is likely to change the physical, chemical, or biological condition of water;*
- ii) *Discharge includes emit, deposit, and allow to escape; and*
- iii) *Soil conservation means avoiding, remedying, or mitigating soil erosion and maintaining the physical, chemical, and biological qualities of soil.”*

Although it is impossible to avoid erosion, and human activities will accelerate it, it is important to remedy and mitigate the adverse effects (Environment Waikato 2000).

2.8.2 Erosion and Sediment Control Measures in the Waikato Region

Regulation can control the potential for erosion to occur by controlling activities where there is an unacceptably high risk of erosion. Thus, to deal substantially with accelerated erosion, Environment Waikato has developed policies and rules under the Regional Policy Statement and Regional Plan.

Section 3.3.7 in the Waikato Regional Policy Statement focuses on the issue of accelerated erosion and the policy ensures that land users “*avoid where practicable, practices that cause accelerated erosion; and remedy or mitigate the adverse effects of accelerated erosion if it occurs*” (Environment Waikato 2000, page 34).

Section 5.1 of the Waikato Regional Plan (WRP) specifically addresses accelerated erosion issues and the objective is to achieve a net reduction of accelerated erosion across the Waikato Region. The WRP establishes a policies framework under Section 5.1.3 and implementation methods under Section 5.1.4 (Environment Waikato 2007).

There are currently 50 active earthwork sites in the Waikato region (Thomson, L. 2009, pers. comm., 24 July). Hence, to address the issues of increased sediment generation, escalating amounts of sediment runoff and discharges from the earthwork sites, especially in the wet period, Environment Waikato has established a series of guidelines.

2.8.2.1 Erosion and Sediment Control Guidelines

The Environment Waikato erosion and sediment control guidelines were developed based on the Auckland Regional Council's Technical Publication No 90 (TP 90) (Auckland Regional Council 1999). The guidelines focus on the principles and practices of erosion and sediment control recommended for various soil disturbing activities.

The Environment Waikato guidelines outline the principles of erosion and sediment control and the sediment transfer process, and identify the measures to be used to minimise erosion and off-site sedimentation.

It is a requirement for all projects involving soil disturbing activities in the Waikato Region to incorporate erosion and sediment controls as an integral part of development. Therefore, the developers must refer to the guidelines during planning for earthworks projects and have to produce their own erosion and sediment control plan, based on the guideline, to support their consent applications for earthwork projects or any land disturbing activities (Environment Waikato 2009a).

Once resource consent has been approved, a condition in the consent will usually clearly state that developers have to ensure that the erosion and sediment controls are in place before any form of earthworks takes place. The control measures can only be removed after the site has been fully stabilised to protect it from erosion (Environment Waikato 2009a).

2.8.2.2 Winter Work Application

Environment Waikato has clearly stated that no earthworks activities are allowed during the period of 1st May to 30th September apart from minor maintenance works, unless a written approval is acquired. As a result, any earthworks that will be still going on through the winter months must have a winter work permit (Environment Waikato 2009b).

The application for a winter earthwork permit has to include:

- i. The nature of the site and the winter soil disturbance works proposed,
- ii. the effectiveness of the existing/proposed erosion and sediment controls,
- iii. the compliance history of the site/operator,
- iv. seasonal/local soil and weather conditions, and
- v. the sensitivity of the receiving environment.

If the operators do not obtain the approval it is vital for them to stabilise the site to avoid unnecessary erosion of disturbed soil during wet winter months. Stabilisation of earthwork sites means providing adequate measures, vegetative and/or structural, that will protect exposed soil (Environment Waikato 2007).

2.8.2.3 Water Clarity Guideline

In accordance with the Environment Waikato Regional Plan (2007), and with regards to suspended solids concentration discharges, the following standards must be met:

- I. **The activity or discharge shall not increase the concentration of suspended solids in the receiving water by more than 10 percent** and either,
- II. The **suspended solids concentration of the discharge shall not exceed 100 grams per cubic metre** or,
- III. The activity or discharge shall not result in any of the following receiving water standards being breached:
 - a) in Indigenous Fisheries and Fish Habitat Class waters, 80 grams per cubic metre suspended solids concentration,
 - b) in Significant Trout Fisheries and Trout Habitat Class waters, 25 grams per cubic metre suspended solids concentration, and
 - c) in Contact Recreation Class waters, black disc horizontal visibility greater than 1.6 metres.

Although normally the assessment is made on a case by case basis when referring to relevant activities relating to discharges, the discharge must comply with the standards and terms outlined under section 5.1.4.11 of the Waikato Regional Plan and there must not be further deterioration in the receiving water suspended solids concentration as a result of activity or discharge.

2.8.2.4 On-Site Sediment and Erosion Control Measures

Minimising soil detachment and retaining eroded material prior to discharge from the site are two approaches that can be taken to control soil loss from earthwork sites (Jackson 2008; Winter 1998).

(a) Minimising Soil Detachment

Research has found that by minimising soil detachment, sediment yield is reduced by 81.2 to 94.3% compared to a bare soil plot (Pan & Shangguan 2006). The most effective form of erosion control is to minimise the area of disturbance

by retaining as much of the existing vegetation as possible, particularly on steep slopes or near watercourses (Pan & Shangguan 2006).

Retaining as much vegetation as possible on an active earthwork site is important because vegetation can help in erosion protection. Vegetation will intercept the raindrops and absorb their kinetic energy, reducing the raindrops' potential to cause soil detachment. In addition, organic matter slows the flow of runoff at the soil surface, and improves the structure and water-holding qualities of the soil. Plant roots improve infiltration by providing channels along which water can flow, and increase the soil stability by binding it together (Fangmeier *et al.* 2005).

Besides retaining existing vegetation on site, placement of topsoil over a prepared subsoil prior to the establishment of vegetation will provide limited short-term erosion control by protecting subsoils and absorbing water (Fangmeier *et al.* 2005). The application of artificial erosion and sediment control material will reduce the erosion potential of disturbed areas and reduce or eliminate erosion on critical sites during the period necessary to establish protective vegetation (Environment Waikato 2009a). Hydroseeding, mulching, turfing, seeding and geotextile matting are examples of methods applied to minimise soil detachment.

(b) Intercepting and Retaining Eroded Material prior to Discharge from Earthworks Sites

Auckland Regional Council has found that by installing proper physical control measures, the sediment yield will reduce to at least 90% of what is produced from active earthwork sites (Auckland Regional Council 1995).

It is seldom possible to avoid soil erosion while an area is being developed. For this reason silt fences, decanting earth bunds and sediment retention ponds are the common methods used to intercept and retain the eroded soil in the runoff.

2.9 Sediment Retention Pond

Sediment retention ponds on earthwork sites are constructed specifically for capturing sediment laden runoff from their catchment area. They are designed to detain and treat accumulated sediment laden runoff to reduce suspended solids concentration discharge to the downstream recipient. Retaining sediment runoff

adequately will protect the downstream environment from excessive sedimentation and water quality degradation (Environment Waikato 2009a).

A well constructed sediment retention pond provides periodic sediment removal sufficient to maintain adequate volume for the designed rainfall event.

2.9.1 Design Considerations

A sediment retention pond must capture and detain sediment laden runoff, and then have it physically treated by settling, or chemically treated using flocculants. The general design approach is to create an impoundment of sufficient volume to capture a significant proportion of the design runoff event, and to provide quiescent (stilling) conditions, which promote the settling of suspended sediment (Cheremisinoff 1995). The key problem in designing a sediment retention pond structure is determining the peak outflow rate and required storage volume.

Three most important factors in designing the pond are:

- a) Sizing the structure to meet required detention time,
- b) Sizing the structure and outlet to meet the settleability rate of sediments,
- c) Sizing the structure and outlet so that peak outflow during or after disturbance does not exceed the pre-disturbance peak (Haan *et al.* 1994).

The general steps in the design procedure include:

- a) To accommodate the 1 in 100 year storm event it is essential to make provision for a stabilised spillway,
- b) The installation of the pond(s) should occur in the initial stages of works (i.e. prior to any stripping of topsoil),
- c) Basins should be retained until the site is adequately protected against erosion,
- d) Sediment control devices should be located away from streams or below operational storm-water outlets,

- e) A hydrograph, sediment-graph and particle size distribution must be determined in order to design for outflow concentration,
- f) The emergency spillway must be sized large enough to pass the peak of the design storm without an appreciable increase in water surface elevation (Haan *et al.* 1994).

Besides the general steps above, the major factors that influence the performance of sediment retention ponds and need to be carefully considered when designing a pond are: catchment area, location, design structure, depth, residence time, trapping efficiency, hydrograph patterns, runoff flow rates, and maintenance. These are discussed in turn.

2.9.1.1 Catchment Area

The catchment area and types of land use have a strong influence on the performance of sediment retention ponds. Runoff data reported by the Minnesota Pollution Control Agency (2000) shows that the surface area and the land use effects of a catchment should be incorporated in selecting the pond size.

Sediment retention ponds are generally built as one of the control measures for exposed areas of greater than 0.3 ha with a maximum catchment area of 5 ha per pond (Environment Waikato 2009a). Both Environment Waikato and Auckland Regional Council require a sediment pond to be sized in accordance with the contributing catchment area and topography.

The two categories of pond size are the 1% and 2% ponds. A 1% pond has the equivalent capacity of 100 m³ for every hectare of contributing catchment, and the 2% pond has 200 m³ for every hectare of contributing catchment.

Auckland Regional Council requires that 2% ponds must be utilised if the catchment of a given pond has slopes in excess of 10% (approximately 6°), and/or slope lengths greater than 200 m in length. If the catchment of a pond is comparatively level and has shorter slope lengths then a 1% pond is required (Auckland Regional Council 2001).

2.9.1.2 Location

Sediment retention ponds are constructed downstream from the construction area to remove the sediment from the runoff water. The location of the sediment

retention pond needs to be considered in terms of the overall project, available room for construction and maintenance and the final location of any permanent stormwater retention facilities that may be constructed at a later stage (Environment Waikato 2009a).

2.9.1.3 Design Structure (Size and Shape)

Pond shape has a major influence on how effectively the pond volume is utilised in sedimentation. Ponds must be designed to accommodate the anticipated stormwater runoff volume that will be generated at the highest level of rainfall (Haan *et al.* 1994).

The design used by Auckland Regional Council and Environment Waikato is that a sediment retention pond consists of an inlet channel for runoff flowing from the catchment area, a forebay, main pond and the outlet discharge pipe which is a floating dewatering structure, usually a T-bar device, designed to remove water at a rate of 3 litres s⁻¹ ha⁻¹ of contributing catchment (Auckland Regional Council 1999; Environment Waikato 2009a).

A forebay is a smaller pond connected to the main pond into which all runoff is directed. It is approximately 2 m wide and 1 m deep, and is designed to trap most of the suspended sediment and bedload. The bedload is that portion of the total sediment load in runoff which is not in suspension or solution (Auckland Regional Council 1999).

The installation of a forebay is recommended because it is much easier to clean than the main pond. A level spreader is constructed between the forebay and the main pond to promote the even dissipation of flow velocities between the two segments. The level spreader spans the width of the pond (Auckland Regional Council 1999).

To ensure that the main ponds have the necessary volume for adequate detention, designs require maximising the distance between the inlet and outlet to reduce the risk of short-circuiting.

To minimise dead storage, the ratio of the average length of the flow path (L) to the effective width of the reservoir (W_e) should be greater than 2 ($L:W_e$). The

effective width is calculated from $W_e = A/L$, where A is the surface area of the reservoir (Haan *et al.* 1994). Dead storage is defined as the portion of water in the pond that does not mix with the inflow.

Ponds may take any shape, but efforts must be made to prolong detention times. Increased detention times promote quiescent settling conditions. Thus, a minimum length to width ratio of 3:1 is recommended to meet this requirement and 5:1 is recommended as a maximum operating point (Auckland Regional Council 1992, 1999).

Long, narrow, and irregular shapes could prolong the flow of sediments through ponds which are shallow. It is worth noting that while sediment retention ponds may have unique capabilities and persistent limitations, these factors must be balanced by the physical constraints imposed by the construction site and the overall management objectives (Haan *et al.* 1994).

Undersized ponds are likely to have low and occasionally negative removal efficiencies while moderate to large sized ponds have correspondingly high removal rates. Negative removal efficiencies occur when sediment concentration in the outlet exceeds that in the inflow (Haan *et al.* 1994).

2.9.1.4 Depth

Depth is one of the critical aspects in sediment retention pond design because the runoff flow velocities, turbulence and diffusion depth are strongly influenced by the pond's depth. These will increase the potential of resuspension of settled sediments. Much of the sediment removal in ponds is accomplished by gradual settling that corresponds linearly with pond's depth (Haan *et al.* 1994). In addition, the storage volume of a sediment retention pond is also associated with the pond's depth.

Sediment retention ponds are generally 1-2 m deep. Shallow ponds (< 1 m) do not have adequate retention times to achieve settlement and are prone to re-suspension. Deeper ponds (> 2.4 m) may result in short circuiting during large storm events because stratification allows relatively warm incoming water to skim along the surface of the pond, rather than plunging to the bottom and remaining in the pond (Auckland Regional Council 1999). Therefore, to determine the appropriate storage volume for sediment retention ponds the following formula is generally used:

$$V_s = Y_D / (w \times 43,560) \quad (2.1)$$

Where,

V_s = sediment storage volume and is defined as the storage occupied by the sediment deposited over the given design period (permanent or temporary sediment retention pond),

Y_D = the sediment yield over the design period and the trapping efficiency of the pond,

w = weight density of deposited sediment in pounds per cubic foot and is calculated by:

$$w = W_c P_c + W_m P_m + W_s P_s \quad (2.2)$$

Where,

W_c, W_m, W_s = unit weight of clay, silt and sand respectively,

P_c, P_m, P_s = fractions of clay, silt and sand respectively.

The pond depth is also critical for chemically treated pond design parameters in flocculant settling because the settling velocities of flocs increase with depth. The larger the flocs, the faster the settling rate (Haan *et al.* 1994).

2.9.1.5 Residence Time

The time allowed for sediment to remain in a detention pond is a major determinant in assessing whether particles transported in runoff will be removed or not. Thus, any changes in the layout of pond design will have to consider the residence time to reduce short circuiting. The residence time is defined as the time water spends in the pond's still-water environment while flowing from the inlet to the outlet. The actual detention time and the theoretical detention time may differ because of dead storage in the pond (Haan *et al.* 1994). Dead storage is some areas or part of the pond that are totally ineffective in the settling process (Haan *et al.* 1994).

In designing a sediment retention pond, it is important to minimise dead storage so that the entire volume of the pond is effective in retarding the flow and allowing sediment to settle from suspension (Haan *et al.* 1994).

Longer detention times are more likely to enhance the chances of sediment removal while shorter detention times can adversely affect removal rates. Ferguson (1998) reports that for a particle to effectively settle out of water in a pond, its residence time must be at least as long as the settling time. The concept of theoretical detention time is based on the following calculation:

$$t_d = L/(Q/A) \quad (2.3)$$

Where t_d is the time required for a flow, L is the flow length, Q is the constant discharge, and A is the cross-sectional flow area.

For a non-steady state flow, detention storage time is the average time that a given flow resides in a pond. For a permanent pond, the total storm detention time calculation would be based on:

$$T_d [(V_p - V_s)) T_{dp} + V - V_p + V_{ds}) (T_{mo} - T_{mi})]/V \quad (2.4)$$

Where V_p is volume in the permanent pool, V_{ds} is dead storage, T_{dp} is detention time assigned to the permanent pool, V is storm runoff volume, and $T_{mo} - T_{mi}$ is the time between the centre of mass of the inflow and outflow hydrographs.

2.9.1.6 Trapping Efficiency

The trapping efficiency of a sediment retention pond is primarily a function of particle size and the retention time of the sediment-laden runoff within the pond (Haan *et al.* 1994; Auckland Regional Council 1995). The processes relating to sedimentation are characterised by the settling behaviour of the sediments in water. As a rule of thumb, smaller and lighter particles such as fine sand, silt and clay stay longer in suspension than coarser particles. However, it is possible to have large but light particles remaining in suspension while small and heavier particles settle out.

According to Haan *et al.* (1994) and the Auckland Regional Council (1995), the degree of sedimentation is influenced by:

- the nature of the flow,
- the percentage of settleable solids,
- particle size distribution,
- the distribution of the solids by their settling velocities,
- particle volume distribution of the solids,

- the density of the settleable pollutants,
- anticipated pond water temperature,
- longer detention times,
- larger surface area of settling,
- promotion of coagulation,
- promotion of laminar flow with a reduction in turbulence.

2.9.1.8 Hydrograph Patterns

The flow patterns that develop in the sediment retention pond during precipitation events are one of the key factors that influence residence time of suspended sediment in the pond. The flow characteristics of a moving water body are determined by its velocity and turbulence. High velocity, turbulent water transports more sediment and deposits less whilst lower velocity and less turbulent water will transport less and deposit more. Hence, it is important to determine the inflow hydrograph for the design event to anticipate or estimate the amount of runoff generated during rain events especially in heavy periods of rain (Haan *et al.* 1994).

2.1.9.9 Runoff Flow Rate

In the design of water management structures, it is essential that an estimate be made of the peak rate of runoff to be expected from the area draining into the structure for a given design period. The design period is selected by comparing the loss that would occur if the runoff exceeded the capacity of the structure to the cost of providing the additional capacity (Haan *et al.* 1994).

Typically sediment retention ponds are designed for 10, 25 or 100-year events. Hence the design of a sediment retention pond is such that very large runoff events will receive at least partial treatment and smaller runoff events will receive a high level of treatment. To achieve this, the energy of the inlet water needs to be low to minimise re-suspension of sediment and the decant rate of the outlet also needs to be low to minimise water currents and to allow sufficient detention time for the suspended sediment to settle out (Environment Waikato 2009a).

2.1.9.10 Maintenance

The sediment space provided should be based on the expected yield from the area during the development period. If sufficient space cannot be provided provisions should be made for periodic cleanout (Environment Waikato 2009a). Sediment ponds need to be maintained regularly and the sediment captured in the pond removed to maximise the live storage area in the basin. It is important to allow for all-weather access to the pond for maintenance needs.

The above principles show that the quality of sediment detention in ponds is governed by many factors, the absence of one or the presence of the other in an undesirable quantity can affect settling rates.

2.10 Chemically Treated Sediment Retention Ponds

Large suspended particles, such as sand, can settle readily, but finer particles like fine silts and clays will remain in the suspension for long periods of time and are unlikely under natural conditions to settle in the pond (Gregory 2006). Clay particles, classified by the International Society of Soil Scientists as < 2 microns, may not settle individually no matter the environment of deposition (Sansalone & Kim 2008).

Thus, recently there has been increased use of chemically treated sediment retention ponds at earthwork sites. Coagulants or flocculants are used to speed the settling rate of suspended solids by aggregating them together.

A field experiment conducted by Auckland Regional Council to evaluate the effect of applying flocculating agents such as polyaluminium chloride to treat sediment laden runoff from earthwork sites showed that a chemically treated sediment retention pond results in a major improvement in the sediment removal efficiency for rainstorms that exceed the hydraulic capacity of the retention pond, with 97% of sediment removal efficiency (Auckland Regional Council 2004a). The same study has also identified the benefit and advantage of using chemical treatment to improve water clarity and removal of sediment in a number of situations such as:

- (a) to treat undersized sediment retention ponds,

- (b) to improve the performance of a pond by removing very high suspended solids loading generated, especially when the discharge will go into a highly sensitive receiving environment,
- (c) to treat sediment runoff from soil materials with poor settlement, and
- (d) to treat ponds that can accommodate runoff with the required volume but that does not provide sufficient residence time.

2.10.1 The Process of Coagulation and Flocculation

There has been lots of confusion between the terms “coagulants” and “flocculants” as well as “coagulation” and “flocculation”. According to Gregory (2006) and Van Benschoten and Edward (1990), coagulants are inorganic salts such as alum, ferric sulphate and ferric chloride. Conversely, flocculants are long-chain polymers, such as Polyaluminium Chloride (PAC), polyacrylamide and chitosan.

Coagulation is the chemical process that destabilises the charges around the surface of colloidal particles to prevent them from repelling each other, in order for them to bind together to produce flocs (Figure 2.2). Flocculation is the physical process that encourages floc growth by forming a bridge between neutralised colloidal particles to aggregate them together, producing larger particles that will settle more rapidly (Figure 2.2) (Gregory 2006).

Alum or aluminium sulphate ($\text{Al}_2(\text{SO}_4)_3$) is the most common conventional coagulant used, while polyaluminium chloride is the most common alternative flocculant used in water treatment (Van Benschoten and Edzwald 1990). When aluminium coagulants or flocculants are added a hydrolysis reaction occurs. Aluminium combines with hydrogen in the water to form aluminium hydroxide ($\text{Al}(\text{OH})_3$), an insoluble molecule that attaches to the suspended solids in the water, causing the suspended solids to aggregate and rapidly sink at the bottom (Gregory 2006).

It is important to avoid overdosing upon amendment (flocculants or coagulants) application. The choice of coagulant or flocculant is determined partly by the capability of the chemical but is also influenced by other factors such as

catchment size, receiving environment sensitivity and stormwater quality (Minnesota Pollution Control Agency 2000).

A study by Auckland Regional Council (2004b) on the effects of residual flocculants on aquatic receiving environments has found through bench tests and field trials that alum had a greater effect on the pH of the receiving waterbodies than PAC. Therefore, polyaluminium chloride (PAC) is more favourable for use because of the lower dosage applied, lower cost than other inorganic coagulants, and a treatment capacity 1.3-3.0 times better.

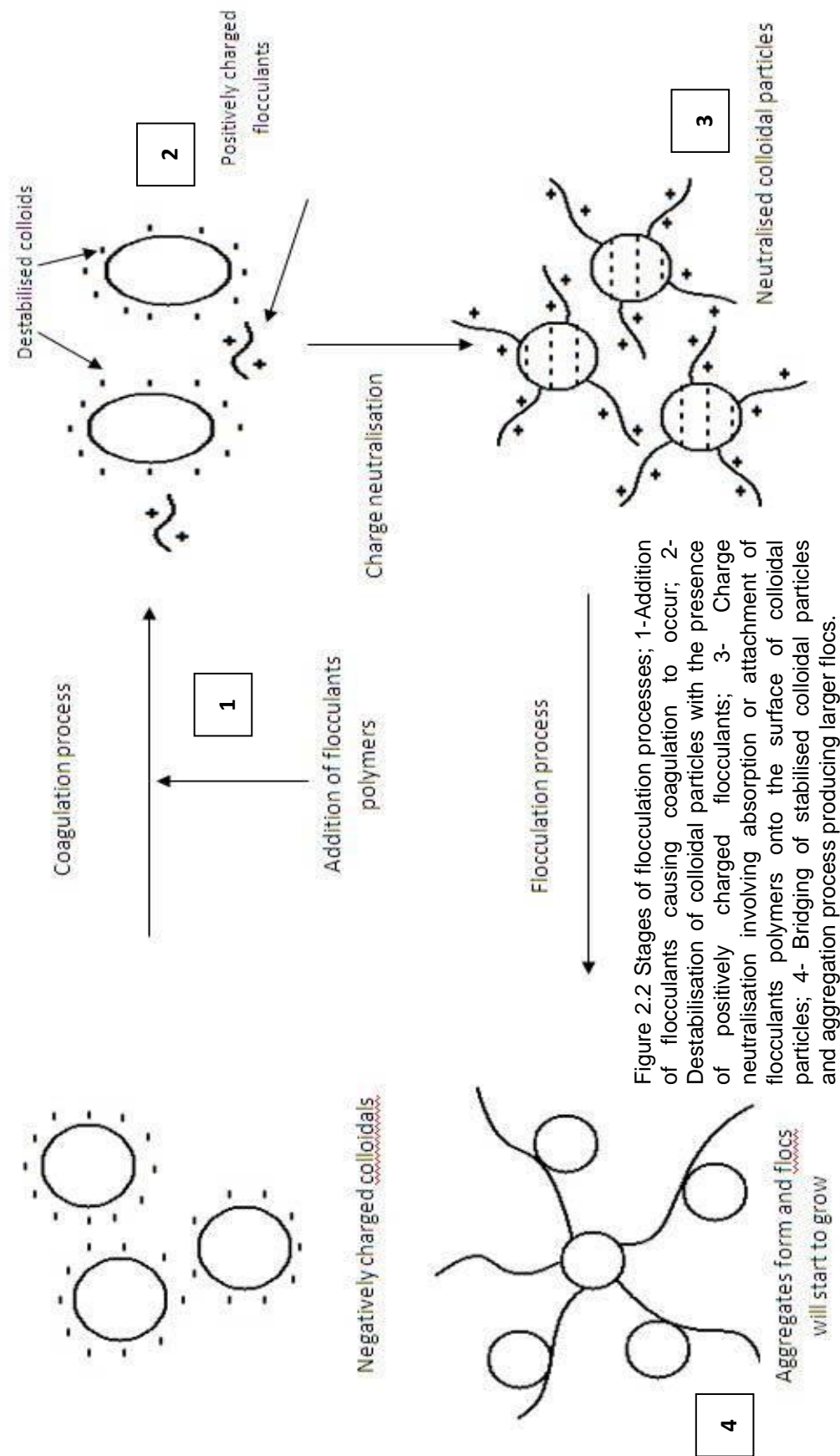


Figure 2.2 Stages of flocculation processes; 1-Addition of flocculants causing coagulation to occur; 2- Destabilisation of colloidal particles with the presence of positively charged flocculants; 3- Charge neutralisation involving absorption or attachment of flocculants polymers onto the surface of colloidal particles; 4- Bridging of stabilised colloidal particles and aggregation process producing larger flocs.

Other inherent advantages of PAC are its lower alkalinity consumption, lesser sludge production and its tendency to exist as a cluster of small spheres (< 25 mm) and/or chain-like structures, whereas alum flocs are usually fluffy, porous structures ranging from 25 to 100 mm. Due to their structure, polymeric species such as PAC cause lesser turbidity in suspension than alum (Van Benschoten and Edward 1990).

Moreover, PAC has a wide-range adaptability for different temperature source water with good solubility. It can also be used to reduce the need for pH adjustment and is often employed in the place where the pH of the receiving stream is higher than 7.5. PAC is able to perform rapid formation of large flocs at lower temperature (Gregory 2004).

2.10.2 Optimum Dosing Rate of Flocculants

The optimum dosing rate is important because overdose will lead to changes in the pH of water, reduce the effectiveness of flocculants, increase the dissolved aluminium concentration in the receiving water bodies, and eventually endanger the aquatic life of downstream recipients.

The required PAC dose is based on soil type and is determined through bench testing, whereby differing doses of coagulant are added to 1 L runoff samples collected from the site. The optimum aluminium dose (mg L^{-1}) is the one which provides the greatest clarity for the smallest change in pH, as high concentrations of PAC can increase pH levels (Auckland Regional Council 2004a); however, the clarity has to be over 100 mm depth visibility. The common dose rate is 4-8 mg of PAC per litre of stormwater to be treated.

Hence, Auckland Regional Council has developed a rainfall driven chemical dosing system after extensive field treatment, which works by providing a chemical dose proportional to rainfall. Where a high level of treatment is required because of the sensitivity of the receiving environment, the rainfall driven system is best as it does not require either a runoff flow measurement system or a dosing pump (Auckland Regional Council 2004a).

2.11 Summary

Large areas of land are stripped and laid bare because of earthwork activities without appropriate erosion and sediment control. Bare land is vulnerable to accelerated on-site erosion and greatly increased sedimentation of waterways, lakes, estuaries and harbours. Two key factors involved in soil erosion are the erosive energy of raindrop and storm-water runoff.

Sediment ponds have specific design criteria governing their performance. Pond sites may be selected based upon pond design, land use type, accessibility and prevailing conditions. Selecting the correct combination of permanent pool and temporary detention however, is a trial and error process. The general design of sedimentation ponds should create an impoundment of sufficient volume to capture a significant proportion of the design runoff and to provide quiescent conditions which promote the settling of suspended sediments. Flow control structures are used to regulate the release rate of stored water from the ponds.

At the construction area when surface runoff flow is over bare earth surfaces, some erosion is unavoidable. Thus it is important to have a sediment control device to capture and retain eroded soil particles on site. The critical design element of sediment retention and treatment structures is to capture sediment-laden runoff and detain it, or have it physically treated by filtration or chemically treated by using flocculants such as PAC (polyaluminium chloride).

Chapter 3

Characteristics of Study Sites

3.1 Introduction

Sediment retention ponds at two earthwork sites were considered in this study. This chapter provides description of the location and design of the sediment retention ponds, as well as the physical environment where field investigations were undertaken.

3.2 Location of Sediment Retention Pond

Two sediment retention ponds were selected to be used in this study (Figure 3.1):

- a) sediment retention pond 8 of Transit New Zealand's State Highway (SH) 1 road construction site at Piarere; and
- b) sediment retention pond 2 of Perry Aggregates's Greywacke quarrying site at Ngaruawahia

Both ponds are used as erosion and sediment control measures. Both locations were considered active earthwork sites with Resource Consent as a 'Discretionary Activity' from Environment Waikato.

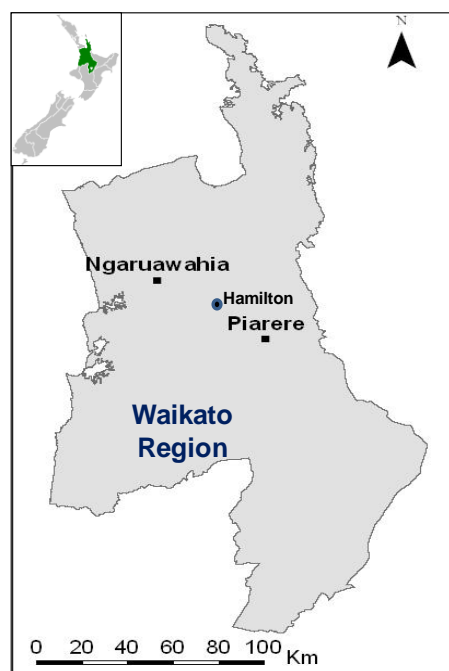


Figure 3.1 Sediment retention pond study sites; in the Waikato region; insert showing the location of Waikato region in the North Island of New Zealand.

3.2.1 Sediment Retention Pond at a State Highway 1 Road Works Sites

Sediment retention pond 8 (hereafter termed as SRP 8) was located about 20 m south of the junction of Horahora Road and State Highway 1 near Piarere (Figure 3.2). SRP 8 (Figure 3.3) was one of the seven sediment retention ponds built to control sediment, by Transfield Limited, while road realignment of a section of SH1 (4.5 kilometres) was undertaken. The purpose of realignment was to improve road safety and travel time in the area. Transfield Limited is the contractor appointed to perform the work (Environment Waikato 2008a). The main purpose of selecting SRP 8 for this study was its availability until October 2009 and its accessibility.

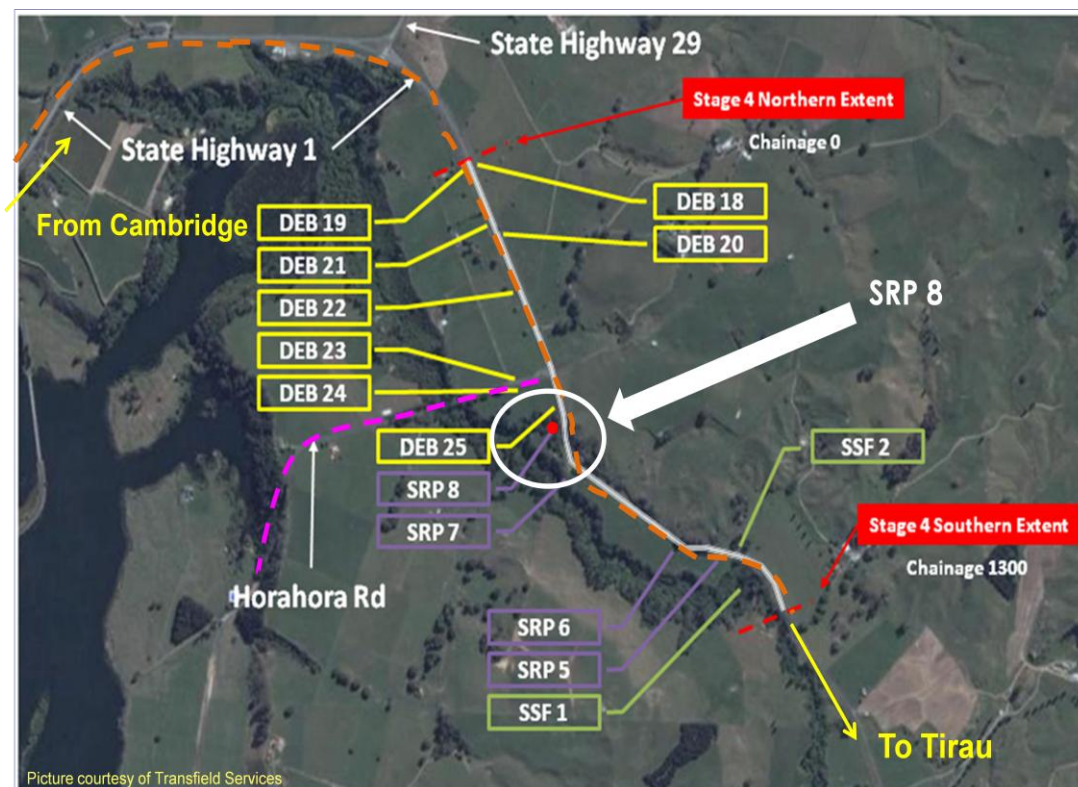


Fig 3.2: Aerial photo of realignment of SH1, showing the location of erosion and sediment control measures used (photo courtesy of Transfield 2008).



Figure 3.3 Sediment retention pond 8 in April 2009.

3.2.1.1 Earthwork Description of the Site

The general topography in Piarere area was flat to rolling with some steep areas which included ignimbrite bluffs. Land use in the area was predominantly pastoral farming and rural environment (Environment Waikato 2008a). Prior to the commencement of earthworks, the soil stratigraphy consisted of both soft and firm clays, soft silt, and loose fine sand. Physical construction works in the area include approximately 90,000 m³ of excavated cut to fill, involving 76,000 m³ of cut to waste and 14,000 m³ of topsoil (Figure 3.4). Of the cut material 81,000 m³ was estimated as rock. The surface vegetation was felled and disposed of offsite. Topsoil was stripped off and used on-site for creating earth bunds (Transfield 2008). Immediately adjacent to SRP 8 was an area where a large road cutting was made through an ignimbrite-cored hill (Figure 3.4 d). SRP 8 was built to accommodate the runoff from the road cutting and adjacent area.



Figure 3.4 Realignment of SH1 to Tirau; (a,b,c) showing the earthwork activities along the 4.5km section of SH1 involved; (d) indicates the catchment of sediment retention pond 8, arrow pointing at the location of sediment retention pond 8.

3.2.1.2 Control of On-site Runoff

The earthworks involved and the discharge of stormwater were considered as discretionary activity under Rules 5.1.4.1, 5.1.4.15 and 3.5.11.8 of the Waikato Regional Plan. As a condition of consent Transfield Limited has installed a series of erosion and sediment control measures on site.

The long section of the existing road naturally divides the work site into subcatchments. Control measures for each subcatchment depend on catchment slope and size. Sediment controls used on the construction sites include “super silt” fences, decanting earth bunds and sediment retention ponds. Silt fences were used in areas where catchment areas were small and flat, while “super silt” fences were used where more robust sediment control was required (Transfield 2008). A super silt fence allows up to four times the catchment area to

be treated by an equivalent length of standard silt fence (Environment Waikato 2009a).

Seven sediment retention ponds and 13 decanting earth bunds were installed before the work started to treat sediment laden runoff from the construction area. Dirty water was conveyed by channel/bund diversions to a Sediment Retention Pond (SRP) or a Decant Earth Bund (DEB) to be treated. The diversions were located at low points on a cross section, in order to catch all water flow from the earthworks site (Transfield 2008).

3.2.1.3 Design of Sediment Retention Pond 8, Piarere

The contributing catchment area of sediment retention pond 8 is 7000 m² (Figure 3.5), therefore a single decant system was used for the pond (Figure 3.3). The storage capacity of the main pond was 196 m³. The depth of the pond was approximately 1.43 m, and it was designed to withstand the 100 year return frequency of storm events without breaching. Polythene and geotextile were laid on the spreader batters and spillways to provide structure stabilisation (Transfield 2008).

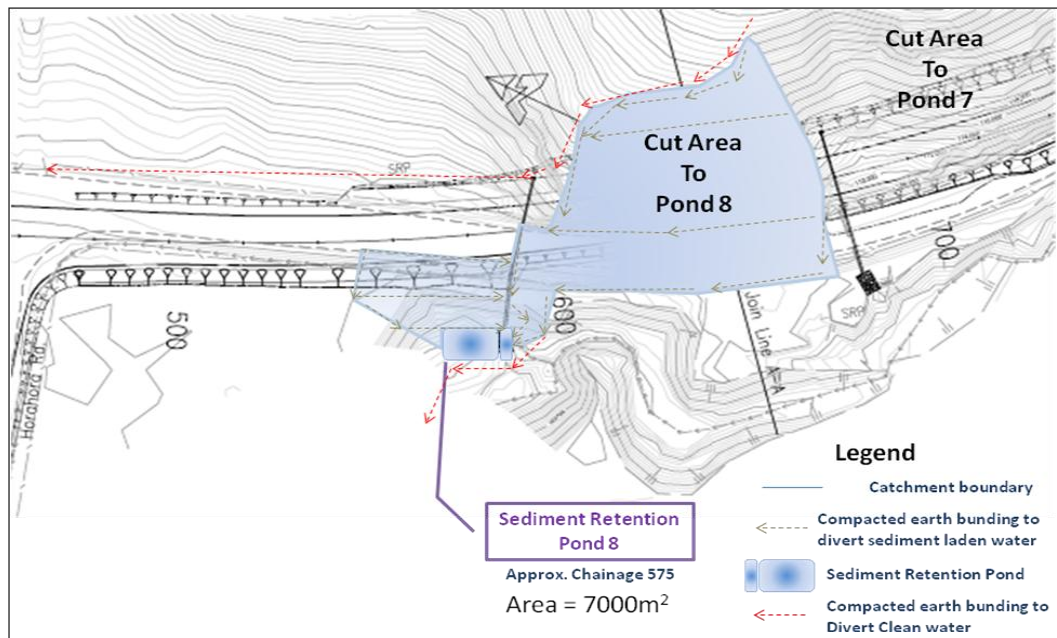


Fig 3.5 Schematic diagram showing the contributing catchment area to sediment retention pond 8 (diagram courtesy of Transfield 2008).

3.2.1.4 Inflow of the Sediment Retention Pond 8

The site was progressively built-up while field investigations were being undertaken. The inflow to the inlet of the pond came from the pipe that channelled the sediment laden water from the constructed work of the contributing catchment area. Initially, during the first site visit in April, there was no piping system to channel the runoff, just a rock and wood structure with runoff flowing through it (Figures 3.6 a and b). The flow from the catchment area of SRP 8 then was shifted to the lower end closer to the forebay area of the pond (Figures 3.7 a and b). There was water flowing to the inlet continuously from June 2009 until the site investigation was completed on the 11th of August 2009.

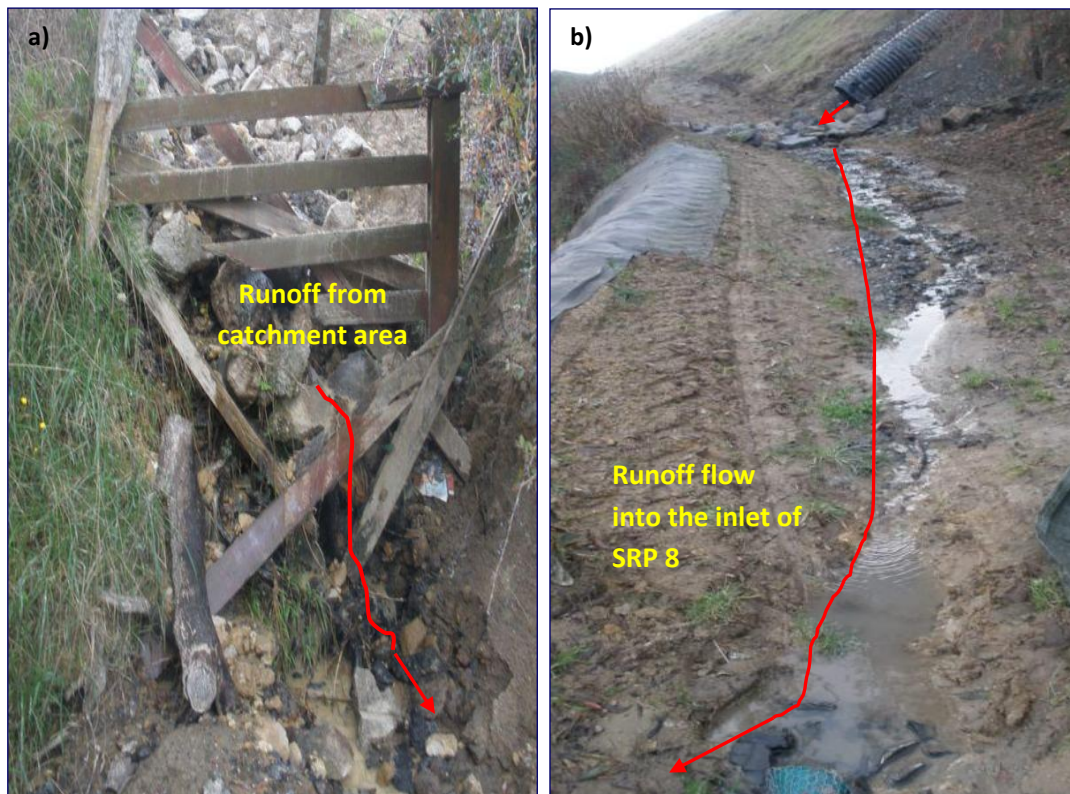


Figure 3.6 Inflow to sediment retention pond 8; a) The flow channel prior to piping system installation; b) Pipe that conducted stormwater runoff to the inlet of sediment retention pond 8.



Figure 3.7 a) and b) New inlet installed closer to the pond.

3.2.1.5 Outflow of the Sediment Retention Pond 8

Discharge from the pond occurred when the water level rose above the lower decant arm of the dewatering device. The water then entered a 2 m long, 300 mm diameter PVC pipe and discharged to the bush area below (Figures 3.8 a and b).



Figure 3.8 a) Decanting structures of sediment retention pond 8; b) Outlet pipe channelling discharge from sediment retention pond 8 to the bush area.

3.2.2 Sediment Retention Pond at Quarry Site

Sediment retention pond 2 (hereafter termed as SRP 2) was one of the two sediment retention ponds used as sediment control measures for the extension of the quarry site of Perry Aggregates at Waingaro Road, Ngaruawahia (Figure 3.9). SRP 2 was a permanently built pond with a rainfall activated dosing system to chemically treat the sediment laden stormwater runoff that flows into the pond.



Figure 3.9 Sediment retention pond 2 at Perry Aggregates, Waingaro Road quarry site.

3.2.2.1 Earthwork Description of the Site

The extension of the quarry involved removing and stripping of the vegetation and topsoils, and over-burden removal (Figure 3.10). Some overburden was used to construct a visual barrier in front of the mine area and rock extraction works (Environment Waikato 2008b).



Figure 3.10 Perry's Aggregates quarry Site at Waingaro Road in Ngaruawahia (a,b,c) showing the earthwork activities at quarry site; (d) indicates the catchment area of sediment retention pond 2, arrow pointing at the location of sediment retention pond 2.

3.2.2.2 On-Site Control Measures

A cut slope in the area was hydro-seeded to quickly establish vegetation providing the bare soil a degree of protection from raindrop impact. Hydroseeding was undertaken shortly after the haul road was constructed, when weather conditions were conducive for grass to grow (Perry Aggregates 2009). A silt fence was installed in front of the eastern wetland area to prevent any overland sheet flow entering directly into the wetland area as well as the sections adjacent to the stream (Figure 3.11) (Perry Aggregates 2009).

An open drain was built at the inner edge of each of the benches to intercept stormwater flowing off the fill slope above and to divert the stormwater runoff to lower benches and then into either of the two ponds (Perry Aggregates 2009).



Figure 3.11 Silt fence to prevent overland sheet flow entering stream.

3.2.2.3 Design of Sediment Retention Pond 2, Ngaruawahia

As part of the resource consent approval, sediment retention ponds are required to meet storage volume criteria based on the slope length and steepness of the contributing catchment. SRP 2 was required to have a minimum of 3 m³ of storage volume per 100 m² of contributing catchment (Environment Waikato 2008b).

The contributing catchment for SRP 2 was approximately 2.1 ha area (Figure 3.12). The total “as-built” storage capacity of the pond was 700 m³ and it was 45 m length x 15 m width and 1.5 m deep. The pond was designed to withstand a 1 in 100 year flood (Perry Aggregates 2009).

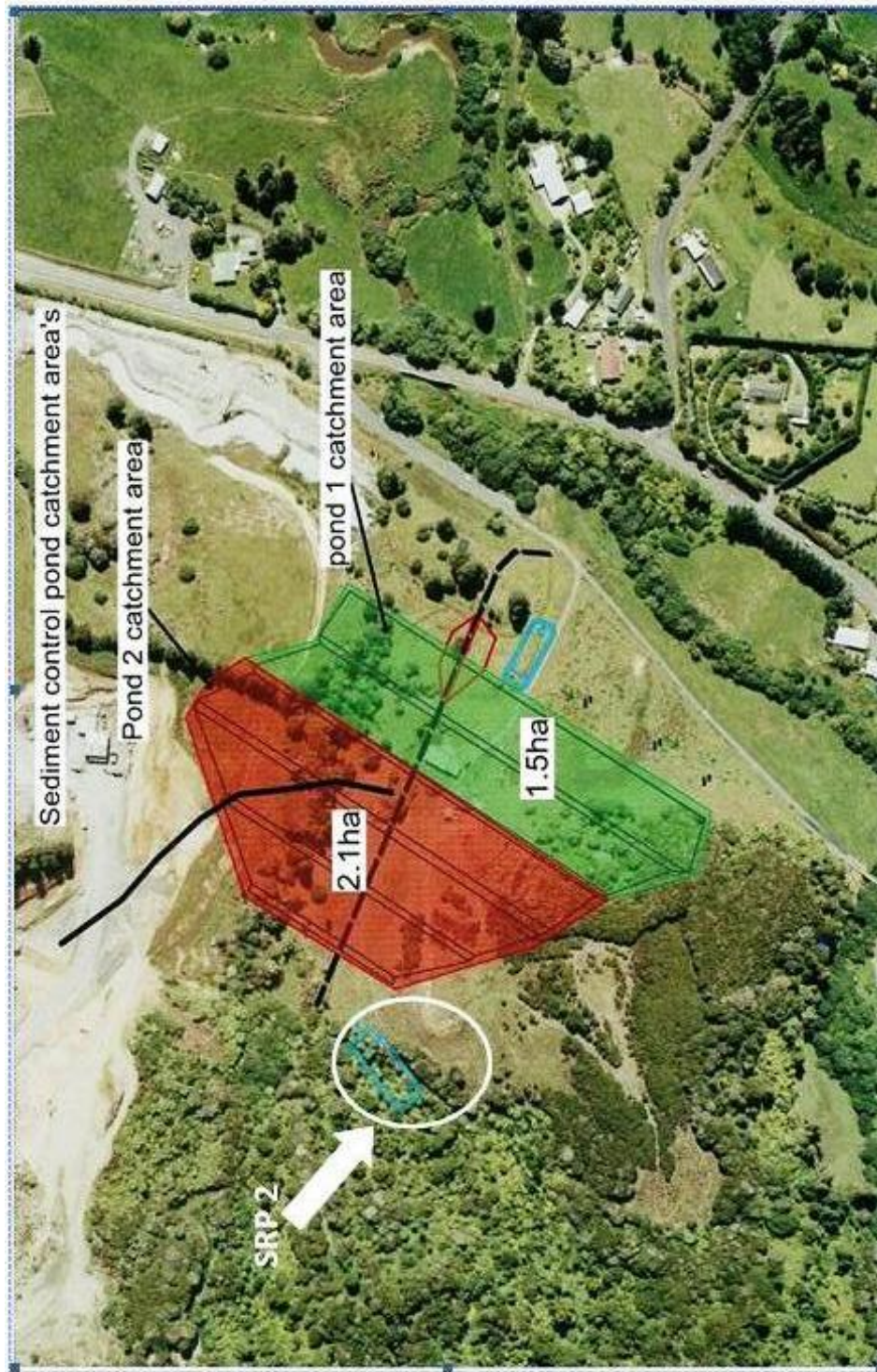


Figure 3.12 Aerial views of the location and contributing catchment area of sediment retention pond 2 (photo courtesy of Perry Aggregates 2009).

3.2.2.4 Inflow of Sediment Retention Pond 2

Water enters the pond through piping that goes underneath the land that separates the quarry area and the pond area. The inlet enters through the top corner of the forebay flowing through a channel, where the dosing pipe of PAC was located (Figure 3.13).

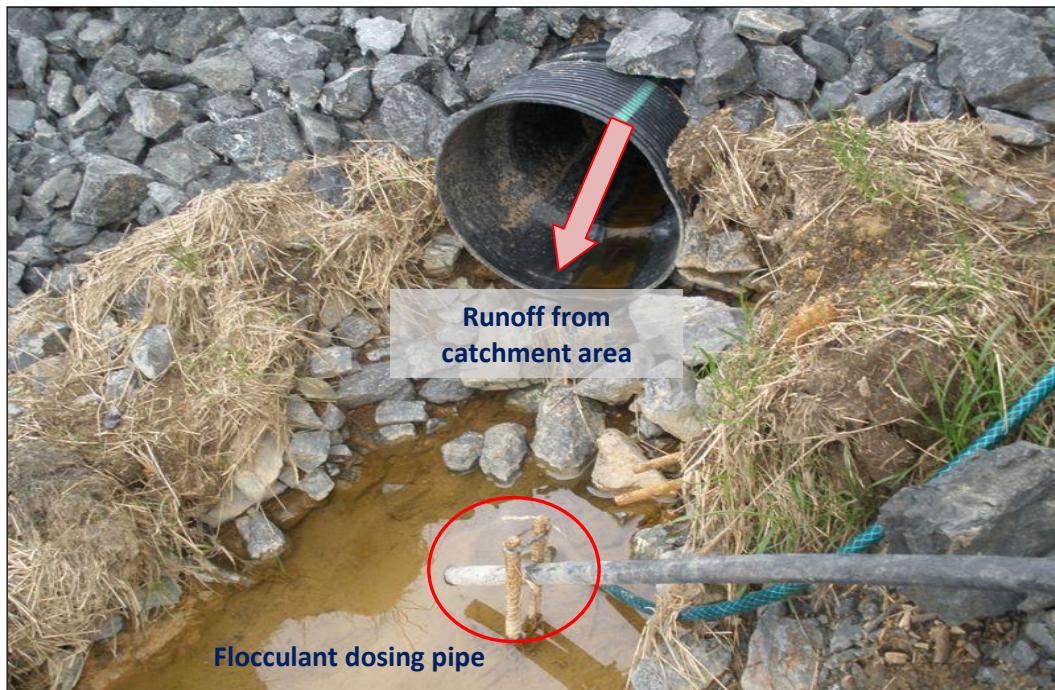


Figure 3.13 Runoff from the contributing catchment was channelled into the sediment retention pond 2 through a pipe.

3.2.2.5 Outflow of Sediment Retention Pond 2

Discharge from the pond occurs when the water level rises above the lower decant arm of the dewatering device (Figure 3.14). The discharge from the pond is through a 200 mm diameter of PVC pipe directly towards the wetland area which contains wetland shrubs (Figure 3.15).



Figure 3.14 Decanting structure of sediment retention pond 2

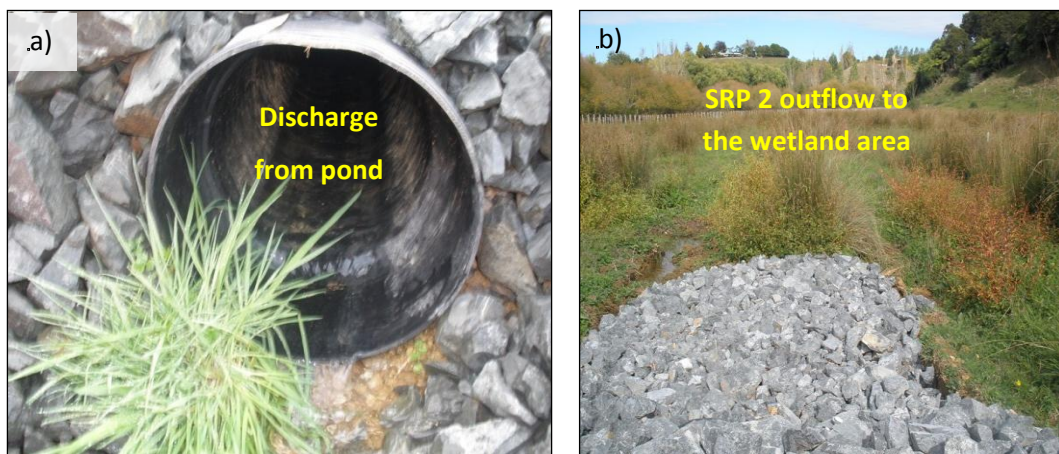


Figure 3.15 a) Outlet pipe that channelled the discharge from sediment retention pond 2; b) Discharge from the outlet was released to a wetland area.

3.2.2.6 The Use of Polyaluminium Chloride as Chemical Treatment

Southern Skies Environmental Ltd has been engaged by Perry Aggregates to prepare a Flocculation Management Plan for the construction of the sediment retention pond associated with the Waingaro Quarry extension.

The Flocculation management plan was based on the sediment retention pond flocculation system and guidelines developed on behalf of the Auckland Regional Council, utilising polyaluminium chloride (PAC) as flocculant and a rainfall initiated automatic dosing system. The system uses a rainfall catchment tray to capture rainfall with the size of the tray being determined by the required PAC dose and the land catchment size (Perry Aggregates 2009).

Rainwater caught by the catchment tray is piped into a header tank, and then into a 400 L displacement tank which floats in a larger tank containing PAC filled to the level of an outlet pipe leading to the stormwater inlet channel about 10 m upstream of the detention pond (Perry Aggregates 2009).

The greater the rate of rainwater flow into the displacement tank the greater the flow of PAC into the stormwater channel. The header tank is designed to provide for no dosing during initial rainfall of up to 12 mm of rain under dry conditions, and for attenuation of the PAC flow during the initial stages of a storm and after rain has ceased at the end of a Storm (Perry Aggregates 2009).

As the catchment area for sediment retention pond 2 is 1.5 ha, the treatment capacity of 450 m³ of water based on 3% of the contributing catchment plus an additional 45 m³ of water for the forebay are required. Thus, in compliance with ARC TP227 Guideline, Perry Aggregates had to perform bench test flocculation trials to determine the suitable dosing rate and catch-tray sizes for each pond. Samples of subsoil within the catchments that are contributing to the sediment retention pond 2 was tested. Results from the test led to the usage of dosage rate of PAC at 12 g m⁻³ (Perry Aggregates 2009).

3.3 Summary

Two sediment retention ponds have been selected as study sites. One is a temporary pond which was located at the Piarere roadwork site on State Highway 1. The other is a permanent pond treated with flocculants (polyaluminium chloride, PAC) located at the Waingaro road quarry site in Ngaruawahia.

Chapter 4

Methods

4.1 Introduction

Runoff samples were collected at both Piarere and Ngaruawahia, during the wet period between July and October 2009. Soil materials were also sampled to investigate the settling rate of different soil materials with and without chemical treatment. Four subsoil materials from the Waikato Region, the Hamilton Ash Formation, fine and coarse samples of the Hinuera Formation, and allophanic soil materials from the B horizon of a Horotiu soil were sampled. This chapter outlines the field sampling technique and laboratory analysis undertaken.

4.2 Soil Sampling

Sampling of soil was undertaken in two parts:

- (1) Soil materials typical of the earthwork sites where ponds were investigated, and
- (2) Soil materials from the Waikato Region (Hamilton Ash, fine and coarse variations of the Hinuera Formation, and allophanic soil materials).

All samples were collected using a spade, sealed in a plastic bag and transported to the University of Waikato Soil Laboratory for analysis of particle size distribution using three different methods, pipette, hydrometer and lasersizer.

4.2.1 Site and Soil Description

4.2.1.1 Ngaruawahia Soil Samples

Disturbed soil samples were collected at three sites which represent the typical soil materials from the catchment of the sediment retention pond. Samples were collected on the slope opposite the sediment retention pond (Figures 4.1 a & b).

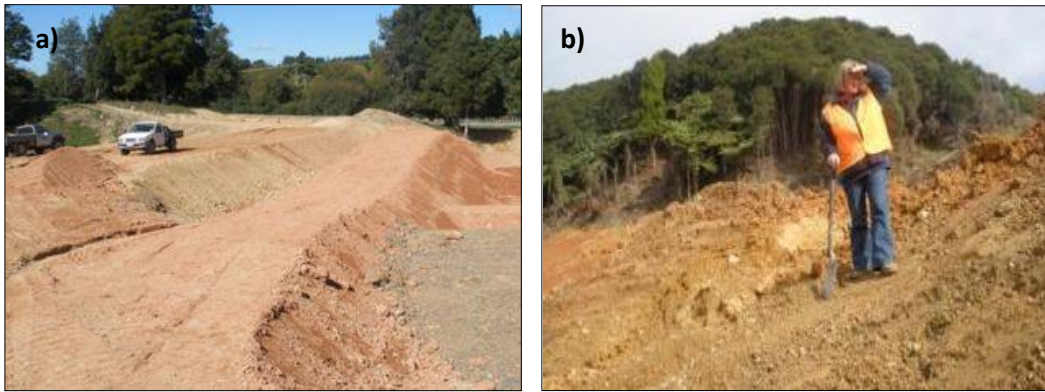


Figure 4.1 Sampling sites of Ngaruawahia soil samples. a) Sediment retention pond is located in front of the hill; b) Soil samples were collected randomly at the slope of the hilly area in front of the pond.

4.2.1.2 Piarere Soil Samples

Disturbed soil samples were collected at three sites which represent the major typical soil materials from the catchment of the sediment retention pond. Samples were collected from the base of slopes of the catchment area (Figures 4.2 a & b).

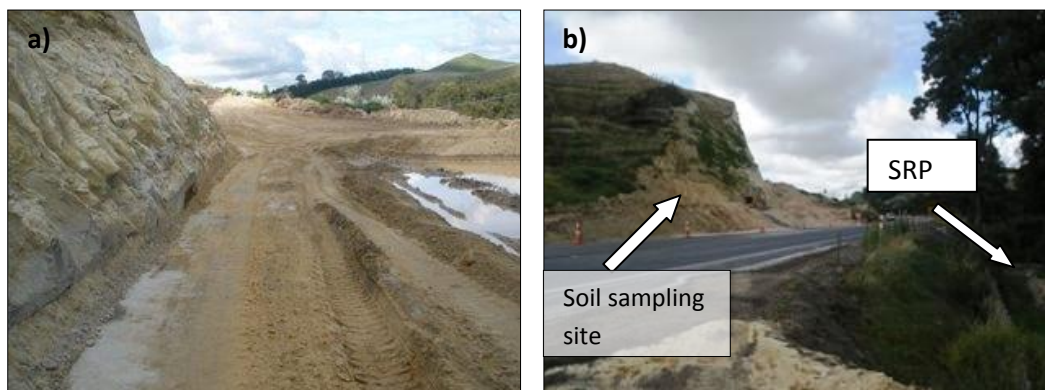


Figure 4.2 Sampling sites of Piarere soil samples. a) Soil samples were collected randomly at this base area; b) Sediment retention pond is located downhill opposite to the soil sampling site.

4.2.1.3 Waikato Soil Materials

Disturbed samples were collected from the roadside banks at Cambridge. Three types of soils were sampled – coarse and fine materials from the Hinuera Formation and an allophanic soil material from the B horizon of the Horotiu Soil (Figures 4.3 a and b).

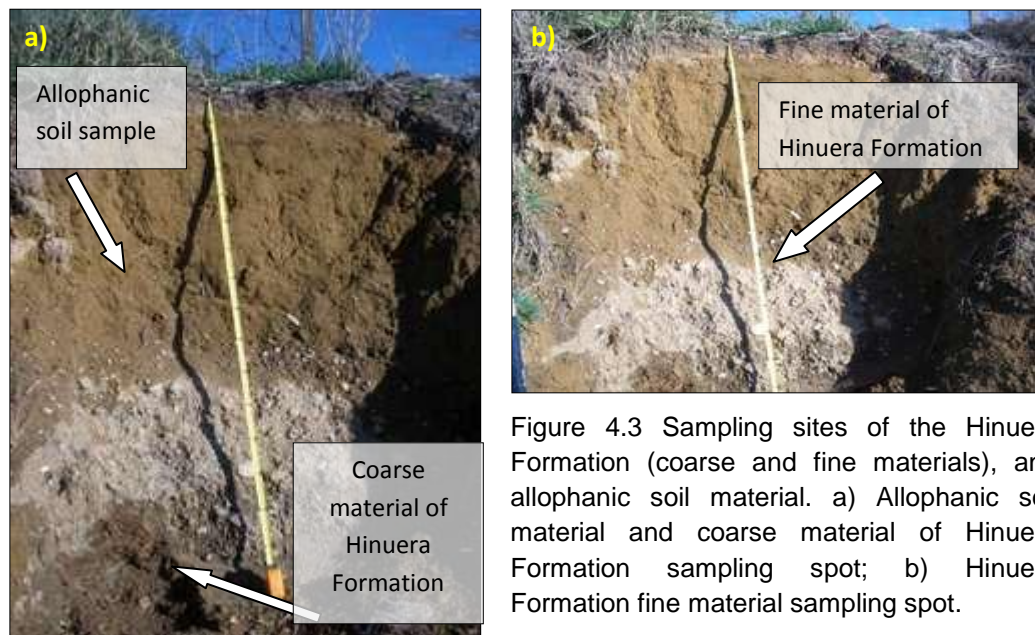


Figure 4.3 Sampling sites of the Hinuera Formation (coarse and fine materials), and allophanic soil material. a) Allophanic soil material and coarse material of Hinuera Formation sampling spot; b) Hinuera Formation fine material sampling spot.

4.2.1.4 Hamilton Ash Formation

Disturbed samples were collected from the B horizon in the base of a gully behind the campus crèche, University of Waikato (Figures 4.4 a & b).

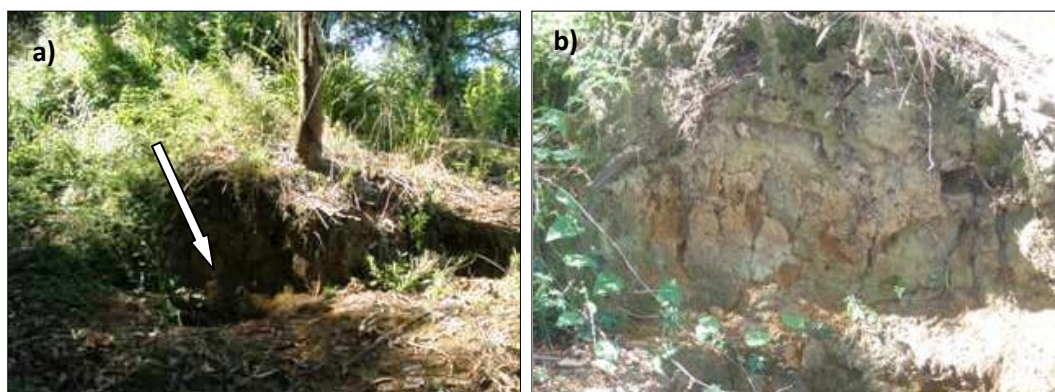


Figure 4.4 Sampling site of the Hamilton Ash Formation. a) Near slope of the gully where samples were collected (arrow pointing); b) Soil samples were collected at the base area of B horizon.

4.3 Laboratory Analysis of Soil Samples

4.3.1 Gravimetric Water Content

Water acts both as a lubricant and a binding agent in soil particulate materials, hence influencing the structural stability and strength of soil. Gravimetric water content is expressed as the ratio of the mass of water present in the sample before drying to the mass of the sample after it has been dried to a constant mass at 105°C (Rowell 1994).

The gravimetric water content of soil samples was determined based on New Zealand Standard 4402: 1986 in order to determine the water content of soil as a percentage of its dry mass. The process involved oven-drying the samples at 105°C as on air drying the soil some water may remain, the amount depending on soil texture and the humidity of the air in the drying room (Rowell 1994). The experimental procedure followed is outlined below.

- a) Samples were collected and placed in sealed plastic bags and transported to the laboratory and stored at room temperature prior to analysis.
- b) An aluminum foil tray was labelled and weighed to ± 0.01 g to determine the weight of the container (M_1)
- c) About 10-15 g of soil sample was added into the pre-weighed aluminum tray and re-weighed (M_2). 3 sets of samples were prepared.
- d) The container with sample was then placed in the oven at 105°C overnight for minimum of 16 hours.
- e) After drying, the sample was placed in the desiccators with anhydrous copper sulphate (silica gel) to allow it to cool for about 20-30 minutes.
- f) The oven-dried sample in the container was then reweighed (M_3) and the value recorded.
- g) The gravimetric water content of the soil sample was calculated by the mass of the water divided by the mass of the soil:

$$W = \frac{M_2 - M_3}{M_3 - M_1} \quad (4.1)$$

Where,

M_1 = Mass of container

M_2 = Mass of container and wet soil

M_3 = Mass of container and oven-dry soil

The result was then multiplied by 100 to give a percentage.

- h) The soil moisture factor was used to correct analytical results to a standard oven dry soil mass because in many analyses the soil that is used still contains water whether the soil had been air-dried or field moist. The calculation of soil moisture factor is calculated by:

$$\text{Moisture Factor} = \frac{\text{Mass of 'air dry' or 'field moist' soil}}{\text{Mass of oven dry soil}} \quad (4.2)$$

4.3.2 Particle Size Distribution

The proportions of both coarse (boulders, gravels and rocks) and fine earth fraction (sand, silt and clay) is referred as particle size distribution (Milne *et al.* 1995). Particle size distribution (PSD) refers to the weight percentage of sand, silt and clay in which the total composition is 100%, and is based on the soil sample that passes through a 2 mm sieve. The dominant size fraction (< 2 mm) is used to describe the soil textural class, such as sand, sandy clay, silt and clay or loam (no dominant size fraction) (Nemes & Rawls 2006). The particle size fractions for fine soil fraction, based on the Standards Association of New Zealand (1986) soil testing methods are sand (2.0-0.06 mm), silt (0.06-0.002 mm) and clay (< 0.002 mm) (Milne *et al.* 1995). Particle size fractions following the Milne *et al.* (1995) soil testing methods classification are divided into sizes group as shown in Table 4.1.

Particle size analysis (PSA) is used in soil science to evaluate soil texture which is based on different combinations of sand, silt and clay that make up the particle size distribution of a soil sample. Moreover knowledge of the particle size distribution of a soil sample is valuable in predicting hydraulic properties of soil such as settling velocity and water retention of soil materials, and understanding soil properties such as how much water, heat, and nutrients the soil will hold, how fast water will move through the soil, and what kind of structure, bulk density, and consistency the soil will have (McLaren & Cameron 1996).

Table 4.1 Particle Size Fractions (mm), adapted from Milne *et al.* (1995)

Soil Fraction	Size (mm)
Boulders	> 200
Very coarse gravel	> 200-60
Coarse gravel	60-20
Medium gravel	20-6
Fine Gravel	6-2
Coarse Sand	2.0-0.6
Medium Sand	0.6-0.2
Fine Sand	0.2-0.06
Silt	0.06-0.002
Clay	< 0.002

The process involves pre-treatment of soil to remove organic matter, dispersion of soil aggregates into discrete units by chemical, mechanical, or ultrasonic means and the separation of particles according to size range by sieving and sedimentation.

In order to do a comparison of performance, reliability and effectiveness of analysis, three methods of particle size analysis were conducted. Three replications were made for each method on each soil material.

4.3.2.1 Pipette and Hydrometer

The “Pipette” and “Hydrometer” are the classical methods of particle size analysis which are based on the principle of sedimentation. A suspension of the dispersed sample is allowed to settle, and measurements are made of the solution density at a specific depth within the sedimentation cylinder. Sedimentation rates and the setting time of the grains are based on Stokes’ Law (Beuselinck *et al.* 1998).

Stokes’ law states that large particles sink farther and more rapidly than smaller particles when suspended in a liquid. There are two critical assumptions: (1) the

particles all have the same density and (2) the particles are spherical (Gee & Bauder 1986). The settling velocity of any solid particle falling through a fluid is determined by its weight and by the hydrodynamic drag forces due to the fluid flow around it. The difference between these forces results in Stokes' law for small particles. Stokes' law relates the velocity of a spherical particle falling through a liquid to the radius of the particle, the specific gravity of the particle, and the viscosity of the liquid.

The pipette method measures the percent by weight of each particle size class in the soil sample. The hydrometer method uses the density of the soil-water mixture. The more particles that are in suspension at any one time, the denser the soil-water mixture will be. The denser the mixture, the better it will support an object placed in the mixture because the hydrometer will float higher in the denser soil-water mixture. As larger mineral particles fall from suspension, the density of the soil-water mixture decreases. As the density decreases, the hydrometer sinks farther into the mixture. The stem of the hydrometer is marked in grams of sediment remaining in suspension (Gee & Bauder 1986). Stokes' law is defined by:

$$V_s = \frac{H}{T} = \frac{2(\gamma - \beta)gr^2}{9\eta} \quad (4.3)$$

Where,

V_s = velocity of falling particle (m s^{-1})

H = distance (m) through which the particle falls in time T (s)

g = acceleration due to gravity (m s^{-2})

r = radius of the particle (m)

η = viscosity of the liquid (poise)

γ = specific gravity of the particle

β = specific gravity of the liquid (Gee & Bauder 1986).

However, a shortcoming to the application of the equation above is the fact that sediments frequently settle not as individual grains but as flocs or aggregates composed of many grains adhering to each other. The settling rates of the flocs or aggregates are greater than the settling rates of the individual constituent grains (Kranck 1980).

For particles other than spheres, a more general form of equation is used:

$$V_s = \frac{(\rho_s - \rho)gd_s^2}{18\mu\phi} \quad (4.4)$$

Where,

d_s = diameter of a sphere having the same volume as the irregular-shaped particle (m)

ϕ = coefficient of form resistance (dimensionless)

ρ_s = particle density (kg m^{-3})

ρ = density of water (kg m^{-3})

g = acceleration due to gravity (m s^{-2})

μ = settling velocity (m s^{-1}) (Gee & Bauder 1986)

4.3.2.1.1 Pipette Method

The pipette method of New Zealand Standard 4402 (1986) was adapted and the experimental procedure followed is outlined below.

(I) Sample Collection and Initial Treatment

- a) Samples were air-dried for about 3-5 days, except for Allophanic soils that were not air dried to avoid fundamental changes in their properties (Tan 2005).
- b) The air-dried samples were dry sieved through a 2 mm sieve. 2 mm aggregates were crushed to break them up whenever necessary.
- c) Soil materials that remained on the sieve (bigger than 2 mm) were weighed and recorded. Subsamples were taken for moisture content determination following the method described in section 4.3.1.
- d) Subsamples of < 2 mm fraction (samples that pass through the sieve) were also taken for moisture content determination.
- e) If the sample did not contain any coarser materials (> 2 mm), the samples were treated for organic matter removal and dispersion without prior 2 mm sieving and air-drying. Three subsamples of the field-moist soil were taken to determine moisture content.

(II) Organic Matter Removal

- a) An 800 ml beaker was weighed and about 80-150 gram of air dried or field moist (< 2 mm) soil material was put into the beaker and reweighed. Only 40-45 gram of soil was used for a very clayey soil sample.
- b) About 200 ml of 10% hydrogen peroxide (H_2O_2) was added to the air-dried soil and the mixture was gently swirled to reduce frothing and to breakdown aggregates. The mixture was then left to stand overnight and stirred occasionally.
- c) The mixture was then gently heated by placing in a container of nearly boiling water on the hot plate with gentle stirring until frothing ceased. Then the mixture was brought to the boil for at least 15 minutes. The colour of the slurry turned to pale grey or buff colour when the organic matter had been oxidised.
- d) The treated soil sample was then placed in ultrasonic bath for 15 minutes for ultrasonic dispersion to breakup soil aggregates. Afterwards 25 ml of Calgon (sodium hexametaphosphate) was added to the sample. The sample was then mixed using a mechanical shaker for at least 4 hours (overnight), to ensure that the resultant suspension was stable, the dispersion of soil particles was uniform and flocculation would not occur during sedimentation.

(III) Wet Sieving

- a) The 600 micron, 200 micron and 63 micron sieves were dried at 105°C in the oven, left to cool in a desiccator and pre-weighed. Prior to the sieving process, the mass of each sieve was recorded.
- b) The treated sample which had been mixed overnight was then diluted with sufficient distilled water to enable wet sieving through 600 micron, 200 micron and 63 micron sieves.
- c) The treated sample was sieved using 600 micron, 200 micron and 63 micron sieves stacked together and placed onto the top of a container. The samples were washed gently with distilled water using a wash bottle. Coarser soil materials left on the sieves were washed with more distilled water until all finer particles (less than 63 microns) were washed out.

- d) This procedure required great care in order not to lose any soil particles, as this will affect the total mass of material being handled.
- e) The soil materials left on the sieves were dried in the oven at 105°C to evaporate the water. After oven drying, the sieves were again shaken (while they were warm) to ensure that all material had passed through to the appropriate level. The dried soil and sieves were cooled in the desiccator and reweighed.

(IV) Settling Analysis

- a) The material that passed through the sieves was then transferred into a 1 L (1000 ml) sedimentation cylinder using deionised water (in a wash bottle) to ensure the sample was captured. The cylinder was then topped up with sufficient distilled water to fill to the 1000 ml mark. The suspension was then left to stand for 1 hour allowing time to equilibrate to room temperature.
- b) The suspension in the 1 L (1000 ml) measuring cylinder was stirred using a rod (with perforated disc on the end of the rod) in an up and down motion for 32 seconds. Thorough mixing of the suspension is important to ensure a uniform dispersion of soil particles in the suspension.
- c) Subsamples were obtained from the cylinder using the pipette draw-off method at 10 cm depth. The pipette was clipped onto the burette stand and lowered to the 10 cm depth position about 10-15 seconds prior to reading time. The samples were taken at 3 seconds, 32 seconds, 4 minutes and 48 seconds, 60 minutes and 18 seconds, and 8 hours.
- d) Once in position 20 ml was drawn-off and the pipette carefully withdrawn making sure that minimum disturbance of the suspension occurred.
- e) The suspension taken was discharged into a pre-weighed, cleaned, dried and clearly marked evaporating dish. The pipette was rinsed thoroughly with distilled water to extricate any sediment which might have settled in or on the pipette.
- f) Water was then evaporated, by drying the samples at 105-110°C in the oven. Samples were left to cool in the desiccator and weighed (to 0.001 g) to determine the mass of solid material in the samples for each respective sampling time.

- g) The calculation of the proportion of soil fraction from this method is from the following formula:

A. Dry Mass

The dry mass of the soil (M) was calculated from the formula:

$$M = \frac{100M_w}{100+w} \quad (4.5)$$

Where,

M_w = wet mass of the soil (g)

w = gravimetric water content of the soil (%)

B. Sieving

The percentage of the coarse, medium and fine sand in the pre-treated sample was determined from the formula:

i. Percentage of coarse sand (2.0-0.6 mm) = $(M_{cs}/M) \times 100$ (4.6)

ii. Percentage of medium sand (0.6-0.2 mm) = $(M_{ms}/M) \times 100$ (4.7)

iii. Percentage of fine sand (0.2-0.06 mm) = $(M_{fs}/M) \times 100$ (4.8)

Where,

M = oven dry mass of the pre-treated soil

M_{cs} = oven dry mass of coarse sand on the 600 μ m sieve

M_{ms} = oven dry mass of medium sand on the 200 μ m sieve

M_{fs} = oven dry mass of fine sand on the 63 μ m sieve

C. Sedimentation

The percentage of coarse, medium and fine silt and clay proportions in the measuring cylinder was calculated from the formula:

i. Silt (0.02 mm to 0.002 mm) = $(S (M_{32} - M_8) / M) \times 100$ (4.9)

ii. Clay (less than 0.002 mm) = $(S (M_8 - M_{calgon}) / M) \times 100$ (4.10)

Where,

S = volume proportion of the 1000 ml of suspension taken at each sampling from the formula:

$$S = 1000/V_p \quad (4.11)$$

V_p = volume of pipette which 20 ml

M_{32} = Mass of soil sample taken at 32 seconds reading

M_{8v} = Mass of soil sample taken at 8 hours reading

M_{calgon} = Mass of calgon (oven dry mass taken by 20 ml pipette from a water and calgon only control)

The pipette method depends on taking a subsample at a certain depth, h , at certain time, t . By using Stokes' Law, the settling times of the soil material can be calculated (Gee & Bauder 1986; Rowell 1994).

a) Settling velocity:

$$v = \frac{2gr^2(\rho_s - \rho_1)}{9\eta} \quad (4.12)$$

Where,

v = settling velocity (m s^{-1})

r = particle radius (m)

g = gravitational force per unit mass (9.81 m s^{-2})

ρ_s = density of particle (2600 kg m^{-3} is the average density for soil particles)

ρ_1 = density of the liquid (998 kg m^{-3} at 20°C for water)

η = viscosity of the liquid ($1.002 \times 10^{-3} \text{ Ns m}^{-2}$ at 20°C for water)

b) Settling time:

$$t = \frac{18\eta h}{g(\rho_s - \rho_1)X^2} \quad (4.13)$$

t = settling time

X^2 = particle diameter

H = viscosity of the liquid ($1.002 \times 10^3 \text{ Ns m}^{-2}$ at 20°C for water)

g = gravitational force per unit mass (9.81 m s^{-2})

h = depth

4.3.2.1.2 Hydrometer Method

The particle size distributions determined using the hydrometer method were undertaken following the New Zealand Standard Soil Testing Method 4402:1986. The hydrometer was calibrated prior to the analysis and the variable (volume of

hydrometer, distance from the initial measurement in water to the major graduation marks on the hydrometer stem and the meniscus formation) were noted for reference when calculating the particle size distribution (Tan 2005).

The hydrometer measures the density of the suspension at a given depth as a function of time. With time the density decreases as the largest particles, and then progressively smaller ones, settle out of the region of the suspension being measured (Gee & Bauder 1979). The experimental procedure followed is outlined below.

I. Calibration of Hydrometer

- a) About 800 ml of distilled water was poured into a measuring cylinder so that when the hydrometer was inserted, the water level did not rise above the 1000 ml mark. The water level was observed and the reading was recorded to the nearest 10 ml.
- b) The hydrometer was inserted in the cylinder, immersed and steadied in the water. The level of water was recorded. The difference between the initial reading and the final reading was taken as the volume of the hydrometer bulb.
- c) The hydrometer was slowly withdrawn from the water until the graduated cylinder reading at the water level indicates half the volume change on full immersion. Once in this position, the hydrometer was clamped and the reading (R) was recorded on the hydrometer stem where it was in line with the top of the cylinder (a ruler was laid across the top to provide a reference line).
- d) The distance from the water level to the top of cylinder to the nearest 0.5 mm was measured and recorded as the distance (c) from the centre of volume of the hydrometer bulb to the hydrometer reading, R.
- e) The hydrometer was removed from the cylinder and the distances (y) from each of the major graduation marks on the hydrometer stem to the reading R, were measured by counting y positive towards the top of the stem and negative towards the bulb to the nearest 0.5 mm.
- f) The measuring cylinder (1000 ml) was then filled with water up to the 1000 ml mark and the hydrometer was immersed in it. The change in level (L) was measured using a ruler and recorded in mm.

- g) The eye was placed slightly below the plane of the surface of the liquid. Then the eye was raised slowly until the surface which is seen as an ellipse becomes a straight line. Then, the point where the plane intersected the hydrometer scale was determined.
- h) Afterwards, the eye was placed slightly above the plane of the surface of the liquid and then the point where the upper limit of the meniscus intersects the hydrometer scale was determined.
- i) The difference between the two readings taken in steps (vii) and (viii) was recorded as the meniscus correction factor (C_m)
- j) The effective depth (H_R) which corresponded to each of the major graduations on the hydrometer stem (R_h) was calculated based on the following formula:

$$H_R = c + y - \left(\frac{L}{2}\right) \quad (4.14)$$

Where,

c = distance from the centre of volume of the bulb to reading R (mm).

y = distance from the reading R_h to the reading R (mm).

L = change in level of water in the cylinder when the hydrometer is immersed (mm)

- k) The value of $R'_h = R_h - C_m$ (where R'_h = hydrometer reading at the top of the meniscus for a true reading R_h and C_m = meniscus correction factor) was calculated.
- l) The relationship between H_R and R'_h was plotted as a smooth curve and this curve was used to convert values of R'_h to H_R for the solution of Stokes' Law.

II. Pre-treatment and Dispersion of Soil

The pre-treatment of soil samples to remove the organic matter and the dispersion of soil samples followed the pipette method as described in section 4.3.2.1.1.

III. Hydrometer Measurements

- 50 ml of Calgon was added to a reference cylinder (which contains only water and calgon) and distilled water was added to mark up the volume to 1 L.
- Prior to insertion of the hydrometer, the suspension was stirred using strong upward strokes of the mixing rod (a few drops of amyl alcohol was added if the suspension was covered with foam).
- As soon as mixing was completed, the hydrometer was lowered into the suspension and a reading was taken.
- The hydrometer was inserted 10 seconds before each reading. This is to allow it to float freely for a few seconds until it stabilised before taking the reading (R'_h) at the top of fully formed meniscus. Readings were taken at 1, 2, 4, 8, 15 and 30 minutes, followed with 1 hour, 2 hours and 4 hours. The hydrometer must be rinsed with distilled water and wiped dry after each reading. The 1 and 2 minute readings were repeated three times and averaged.
- In between the time readings were taken, occasionally the hydrometer was inserted in the reference cylinder to take the blank reading, r (at the top of the meniscus) and the value was recorded. The blank reading was supposed to be constant. For each reading, the hydrometer must be wiped dry before it was inserted into the suspension.

IV. Calculation

The calculation of the dry mass (M) of the pre-treated soil and the percentage of coarse, medium and fine sand applied the same formula as used in pipette method as described in section 4.3.2.1.

V. Hydrometer Readings

The observed data from the hydrometer reading was recorded and calculated following the columns in the table:

1	2	3	4	5	6	7	8
Temperature (°C)	Time, t (mins)	Blank Reading, r	R'_h	H_R (mm)	D (mm)	$R'_h +$ x	P (%)

Where,

t = elapsed time after shaking (min).

r = blank reading of the hydrometer in the reference cylinder.

R'_h = hydrometer reading at the upper rim of the meniscus. It is convenient to deal in whole numbers rather than decimals by reducing the value of the reading by 1.0 and multiplying by 1000 so that a density of 1.0255 g ml^{-1} for example becomes $R'_h = 25.5$.

H_R = effective depth corresponding to hydrometer reading R'_h , calculated by putting the value of R'_h in the formula described in equation 4.14.

x = composite correction of the meniscus, calculated by using the formula $x = 1000(1 - r)$. It is a meniscus correction for readings taken in opaque suspension at the top of meniscus.

D = equivalent particle diameter (mm)

P = percent by mass of particles smaller than size D (%)

From the observed data, the equivalent particle diameter, D (mm), was calculated using the following formula:

$$D = K \left(\frac{H_R}{t} \right) \quad (4.15)$$

Where,

K = a constant depending on the temperature of the suspension (at the time the reading was taken) and density of the soil particles ($2.65 \text{ tonnes m}^{-3}$), refer to Table 4.2.

t = time elapsed after shaking (min).

Then the percentage by mass (P) of particles smaller than the corresponding D were attained using the following formulae:

$$P = \frac{100 \rho_s}{M(\rho_s - 1)} (R'_h + x) \quad (4.16)$$

Where,

- M = total oven dry mass of soil after pre-treatment (g)
 ρ_s = solid density of soil particles (2.65 tonnes m^{-3})
 R'_h = hydrometer reading at upper rim of meniscus in the form 1000
 x = composite correction of the meniscus, calculated by using the formula $x = 1000(1 - r)$. It is a meniscus correction for readings taken in opaque suspension at the top of meniscus.

The values of P were calculated for all values of D obtained and are expressed as percentage by mass of particles smaller than the corresponding values of D .

Table 4.2 Values of K for a range of temperatures at solid densities of 2.65(t/m^3), adapted from New Zealand Soil Testing Standards (1986).

Temperature (°C)	K
16	0.00454
17	0.00448
18	0.00442
19	0.00437
20	0.00432
21	0.00426
22	0.00421
23	0.00416
24	0.00411
25	0.00407

4.3.2.2 Laser Diffraction Analysis

Laser diffraction (LD) techniques are a method for particle size measurement and can be successfully used for broad particle size distribution analysis, as LD is able to detect grain size range from 2 mm to 0.010 micron (Pieri *et al.* 2006). The technique is based on the principle that particles of a given size diffract light through a given angle, and the angle of diffraction increases with decreasing particle size (Eshel *et al.* 2004).

The forward diffraction of a laser beam, by the particles is used to determine their size distribution. The angle of diffraction is inversely proportional to particle size,

and the intensity of the diffracted beam at any angle is a measure of the number of particles with a specific cross-sectional area in the beam's path (Eshel *et al.* 2004).

4.3.2.2.1 : Malvern Mastersizer Instrument

The Mastersizer system consists of four basic components (Malvern 1996):

1. Optical measurement unit
2. Computer system
3. Malvern operating software
4. Sample presentation unit

The optical measurement unit is the main measurement facility for the system, which provides a collimated laser that passes through the sample to be measured. A large laser beam at the point of measurement illuminates thousands of particles simultaneously as they pass through it. The fraction of light scattered is the sum of all the individual particle contributions at any point (Malvern 1996).

The scattered laser light from the sample was detected by the receiver of the optical measurement unit. The laser was measured and integrated over time by the instrument while the sample was flowing through the laser. A scattering pattern accumulates within a few seconds which is statistically representative of the bulk material. Each size of particle has its own characteristic scattering pattern like a fingerprint. The pattern differentiates one particle from the other size particle (Malvern 1996). The scattering pattern is derived from the data analysed by the instrument to produce a particle size distribution.

I. Preparation of The Sample

Samples were pre-treated to remove organic materials and subjected to chemical and ultrasonic dispersion. In Mastersizer analysis, sample preparation is the most important stage of making a measurement. Poorly prepared samples cause badly dispersed and unrepresentative bulk material to be analysed which will give incorrect data. The sample needs to be representative of the bulk sample and the organic matter is destroyed because it hinders dispersion and binds the soil mineral particles together.

- a) About 1 or 2 teaspoons of air dried (< 2 mm) sample were placed in a 25 ml vial. 10 ml of 10% Hydrogen peroxide was then added to the sample. The mixture was stirred with a glass rod and left to stand overnight.
- b) Following this, the sample mixture was gently heated on a hotplate and left to cool. 10 ml of 10% Calgon was added and the sample mixture was stirred well and left to stand overnight.
- c) Before the sample was analysed using the Mastersizer, the sample was put in the ultrasonic bath for ultrasonic dispersion to disperse aggregated samples and to prevent flocculation.
- d) The prepared sample was then ready to be analysed using the Mastersizer.

II. Mastersizer Analysis

The instrument was calibrated before each reading was done. A small pipette was used to add a few drops of the sample into the optical measurement unit through a 2 mm sieve. The data from the receiver was transmitted to the computer system where the Malvern operating software calculates the size distribution. The results derived from the Mastersizer are volume based and expressed as a size distribution.

The scattering pattern is derived from the data analysed by the instrument to produce a particle size distribution. The measured data are analysed by the instrumentation to determine the volume contribution of each class by fitting theoretical scattering curves to the actual data (Malvern 1996).

The calculation of particle sizes by the Mastersizer was developed based on the Mie Theory and Fraunhofer Model which pointed out that by knowing the size of the particle and other details about its structure, accurate prediction of the way the particle will scatter light can be made (Malvern 1996).

The lens used can measure the range of particle size from 3.0×10^{-5} mm to 2 mm. The results were divided to volume proportion of coarse, medium and fine sand, and silts and clay based from the particle size fraction following the New Zealand Standard.

4.4 Sediment Retention Pond Sampling

4.4.1 Inflow Water Sampling

An autowater sampler was installed at the inlet of each sediment retention pond at each sites to collect the runoff flowing into the inlets of the pond during periods of moderate to heavy rain. 24 polypropylene bottles were used to collect 500 ml of samples for each bottle. The autowater sampler, which operated on 12-volt wet cell battery, was connected to a Campbell Scientific CR10x data logger that connects up to the rain gauge. The rain gauge was set at 2 mm of rainfall, and the sampler will turn on when 2 mm of rain fall occurs in a period of 30 minutes (Figure 4.5). The collected inflow samples were analysed for turbidity and suspended solid (SS).



Figure 4.5 Inflow sample collection at sediment retention ponds using autowater sampler; a) Rain gauge connected to Campbell Scientific CR10x data logger; b) Campbell Scientific CR10x data logger which is connected to autowater sampler; c) The autowater sampler which operated on 12-volt wet cell battery; d) Twenty four polypropylene sampling bottles.

4.4.1.1 Piarere

The autowater sampler was installed at the Piarere site from 7th to 20th July 2009 at the inlet of sediment retention pond 8 (Figure 4.6).

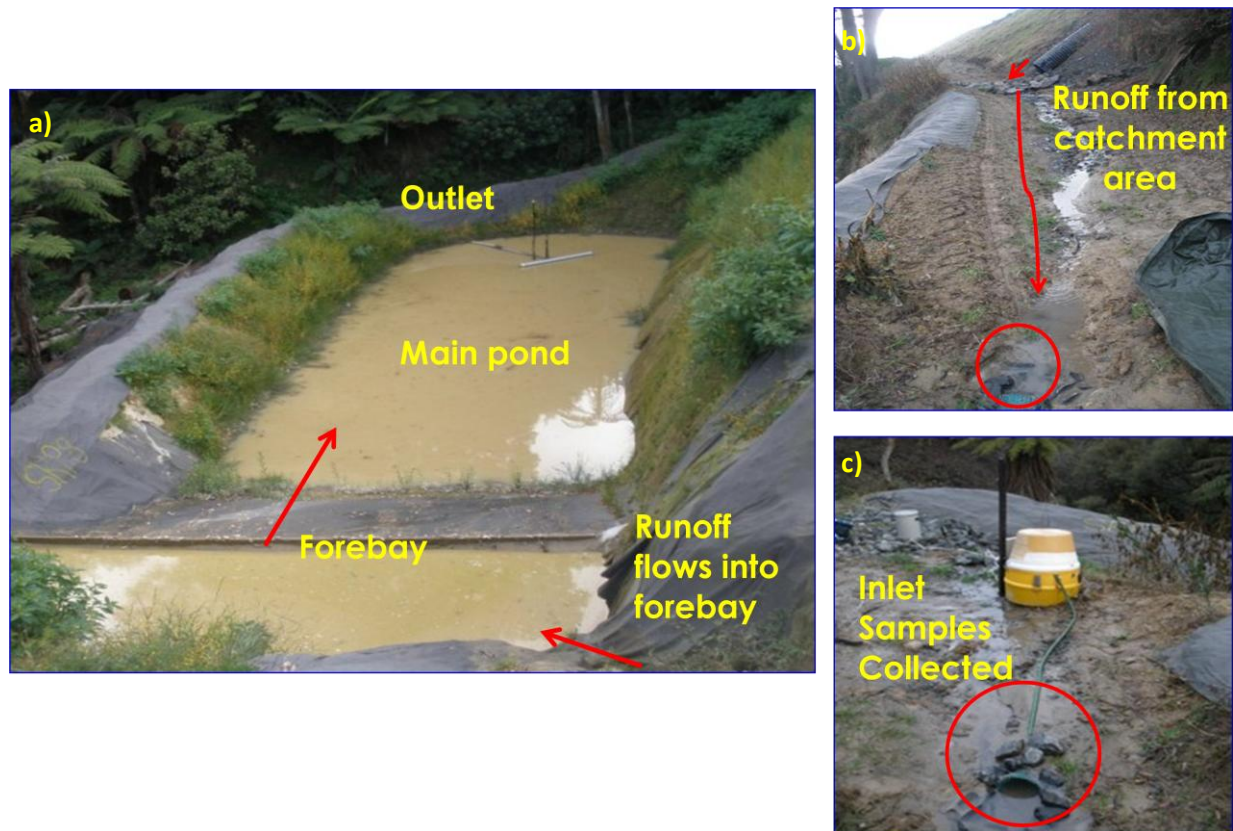


Figure 4.6 Inflow water samples were collected at the inlet of sediment retention pond in Piarere; a) Sediment retention ponds; b) Flow path of runoff from the catchment area; c) Inflow samples collected through autowater sampler suction funnel and hose pipe.

4.4.1.2 Ngaruawahia

The autowater sampler was installed at the Ngaruawahia site from 20th July to 2nd October 2009 at the inlet of the Ngaruawahia pond (Figure 4.7).

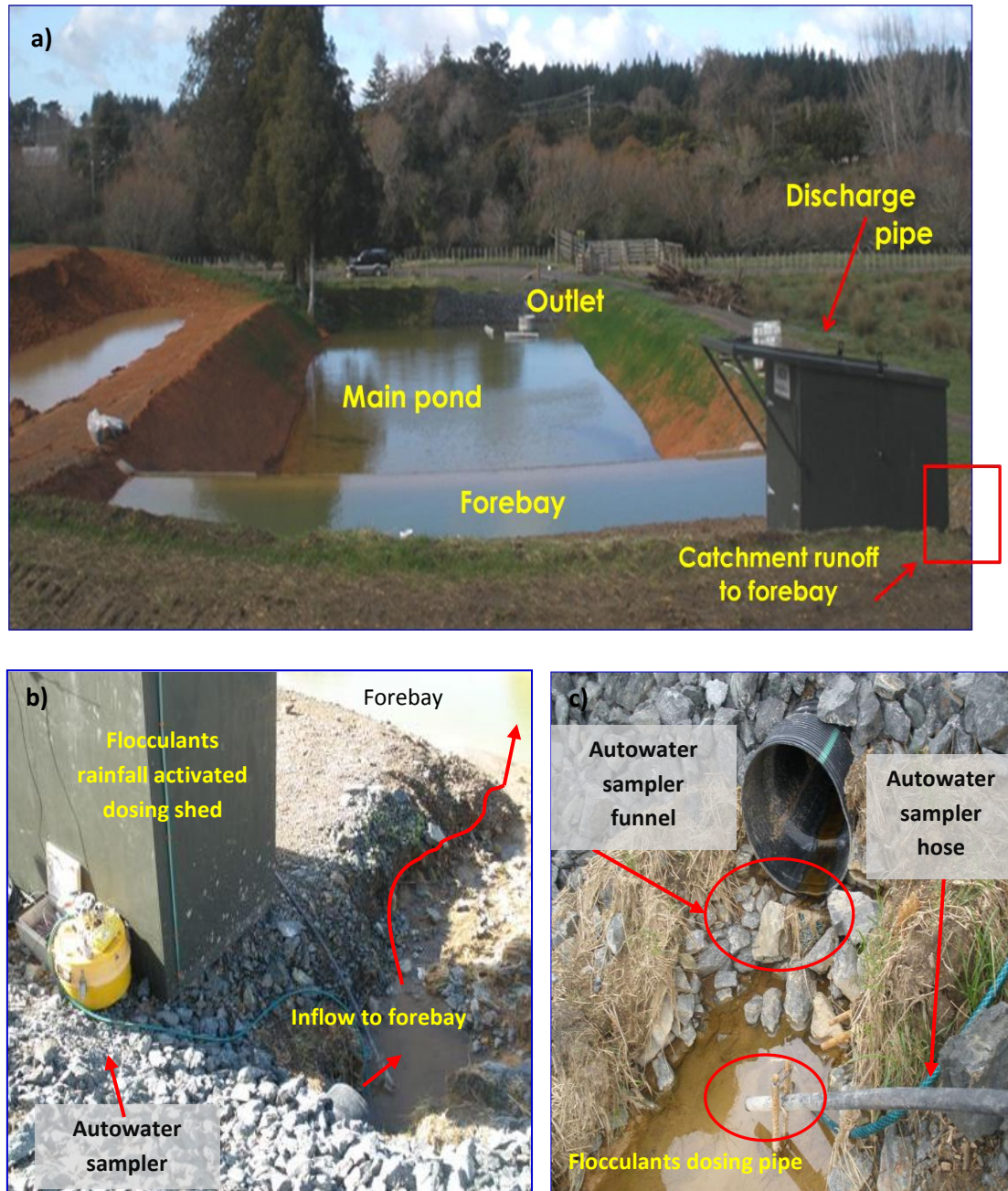


Figure 4.7 Runoff from catchment area was collected at the inlet pipe of sediment retention pond at Ngaruawahia (sampling funnel is partially obscured by vegetation in this photo).

4.4.2 Discharge Water Sampling

The discharge water sampling for the sediment retention ponds at Piarere and Ngaruwahia was achieved by putting a ten litre bucket right underneath the discharge pipe. Outlet samples were collected after a series of rain events.

4.4.2.1 Piarere

Outlet samples at the sediment retention pond in Piarere were collected on three dates, 10th, 14th and 20th July 2009, after periods of rain (Figure 4.8).



Figure 4.8 a, b and c Discharges from ponds were collected directly from the sediment retention pond's outlet pipe at Piarere.

4.4.2.2 Ngaruawahia

Outlet sample collections at the sediment retention pond in Ngaruawahia were taken on three dates, 13th of August, 2nd September and 2nd October 2009 (Figure 4.9).

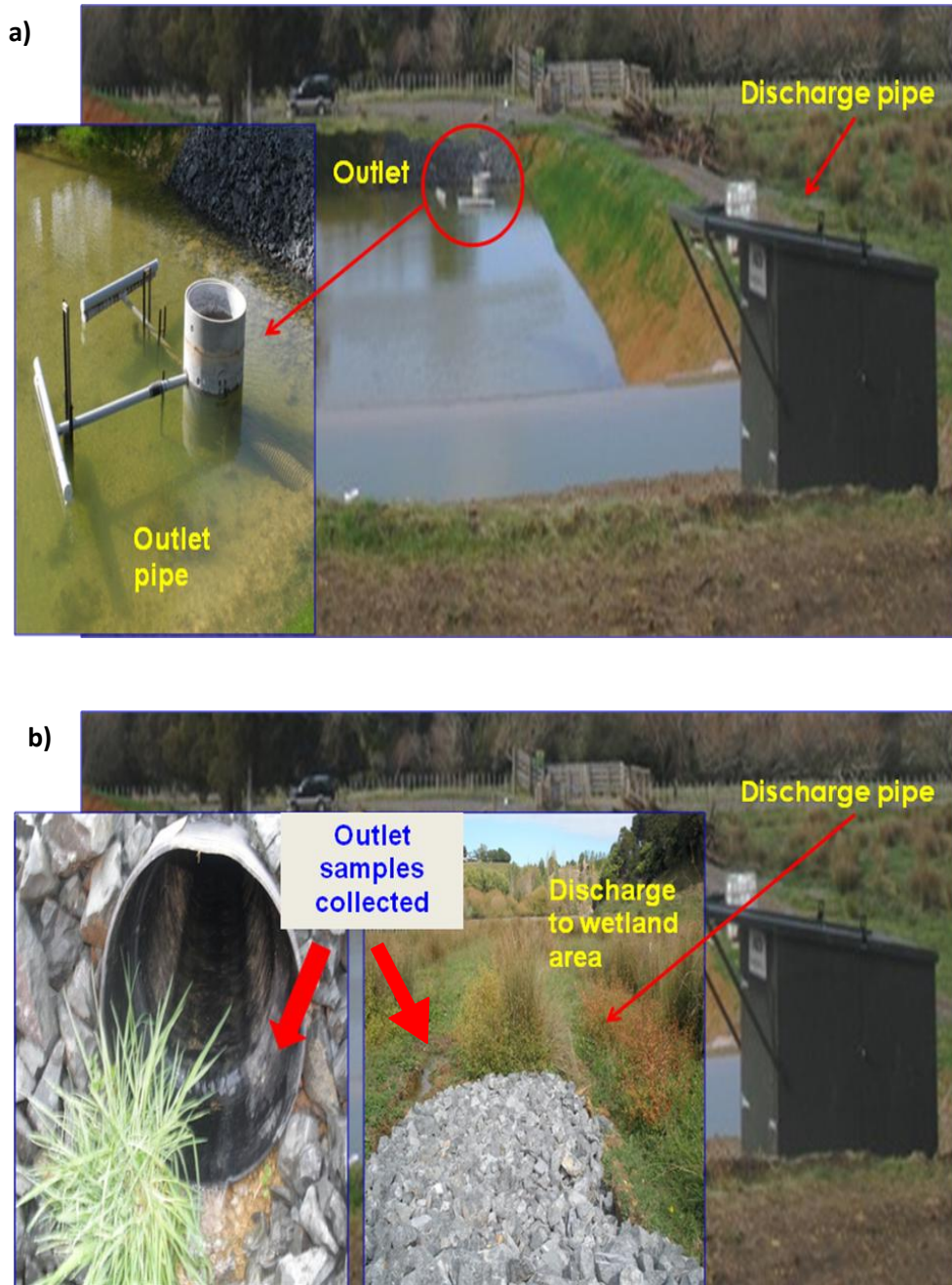


Figure 4.9 a and b Discharges from ponds were collected directly from the sediment retention pond's outlet pipe at Ngaruawahia.

4.5 Laboratory Analysis of Sediment Laden Water

4.5.1 Total Suspended Solid (TSS)

Total suspended solids is defined as those solids which are retained by a glass fibre filter and dried to constant weight at 103-105°C. Total suspended solid analysis was carried out following the standard method of American Public Health Association (2005). The sediment/water samples were stored in a cold room at 4°C prior to testing. The testing was carried out at room temperature in the laboratory.

(I) Preparation of Filter Paper

- a) The 70 mm GC-50 fibreglass filter paper was placed on a Buchner funnel. The Buchner funnel was placed onto the top of a filtration flask and connected to a vacuum pump.
- b) Then the funnel and flask was rinsed with distilled water to remove loose glass fibres from the filter paper.
- c) Following this, the filter paper was left to dry in the oven by putting the filter paper into an aluminium tray for 1 to 2 hours.
- d) Then the oven dried filter paper was left to cool in the desiccator and weighed (Wb). The filter paper was kept in the desiccator until needed to be used.

(II) Suspended Solid Measurement

- a) A Buchner funnel was placed onto the top of a filtration flask and connected to a vacuum pump and vacuum was applied.
- b) The pre-weighed filter paper was placed on top of the Buchner funnel. The filter paper was wettened with distilled water to ensure a tight seal under-suction effects. The filter paper was smoothed gently with fingers to ensure there were no air bubbles trapped beneath it.
- c) A sample was shaken thoroughly to mix, and a pipette was used to extract 25 ml of samples which was filtered through the Buchner funnel. Three replicates were made for each sample.
- d) The sample was rinsed with distilled water around the edge of the Buchner funnel to ensure all suspended solids were rinsed down onto the filter paper.

- e) The filter paper was left for about 1-2 minutes with suction still applied to ensure all water had been drained.
- f) The filter was carefully removed, placed in the oven-dried and pre-weighed evaporating dish and left in the oven to dry at 105°C overnight.
- g) The oven dried suspended solid was cooled in the desiccators and reweighed.
- h) Total suspended solid is calculate as:

$$\text{mg suspended solid per litre} = \frac{(a - b) \times 1000}{v} \quad (4.17)$$

Where,

- a = weight of filter and dried residue (mg)
- b = weight of filter (mg)
- v = volume of sample filtered (ml)
- 1000 = conversion factor; ml to L

4.5.2 Turbidity

Turbidity was measured using a HACH 2100P portable turbidimeter. Turbidity measurement is based on a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension under the same conditions. The higher the intensity of scattered light, the higher the turbidity of the samples (Ministry for the Environment 1994). The turbidity result was measured in nephelometric turbidity units (NTU).

Standard reagents of 20 NTU, 50 NTU, 100 NTU and 800 NTU were made and used for calibration. Then the sample reading was taken. Samples were put into a sample cell before being inserted in the turbidimeter. The cells must be wiped clean with tissue to ensure the surface is free from dust and fingerprints. The cell must be held at the top to avoid fingerprints on the cell wall. Dirty sample cells and entrapment of air bubbles will cause false results (HACH 2001).

A matched pair of cells or the same cell was used for both standardisation and sample measurement because the small difference between sample cells will cause a significant impact on the measurement and result (American Public Health Association 2005).

4.6 Summary

Soil and water samples were collected during the wet period in between April to August 2009. Ten samples representing a range of Waikato soil materials were collected. Samples included soil materials on active earthwork sites as well as four typical soil materials from the Waikato Region, weathered tephra, fine and coarse textured alluvium, and allophanic soil materials. Particle size was determined using hydrometer, pipette and lasersizer analyses. Three replicates of each sample were used for each method of analysis.

Soil analysis was in particular looking at the particle size distribution in order to characterise the soil texture which has significant influence of the erodibility and erosivity of soil. Proneness of soils to erosion depends on the proportion of sand, silt and clay in the soil materials.

Sediment samples were collected over two months from the inlets and outlets of sediment retention ponds at two active earthwork sites. The Piarere site comprised sand dominated material from unwelded ignimbrite. The Ngaruawahia site comprised strongly weathered silty clay derived from greywacke and older tephra. A flocculant (PAC) was in use at Ngaruawahia.

An auto-water-sampler installed at the inlet of each pond was set to collect a sample when 2 mm of rainfall occurred in the previous 30 minute period. Twenty four polypropylene bottles were used to collect samples. The auto-water-sampler operated on a 12-volt wet cell battery and was connected to a Campbell Scientific CR10x data logger and a rain gauge.

The sediment-water samples were stored in a cold room at 4°C prior to testing. The testing was carried out at room temperature in the laboratory. Suspended solid analysis of the inlet and outlet samples of the pond was carried out following American Public Health Association (2005). Turbidity was measured using a HACH 2100P portable turbidimeter.

Chapter 5

Particle Size Analysis: Results & Discussion

5.1 Introduction

The objective of this chapter was to compare three different methods of particle size analysis, pipette, hydrometer and lasersizer, and to characterise the particle size distribution of common soil materials from the Waikato region. Soil samples were collected at two sediment retention pond sites (described in section 3.2) and representative samples were collected from the Hamilton Ash Formation, the Hinuera Formation (coarse and fine materials) and from an allophanic soil material.

5.2 Particle Size Analysis

Particle size distribution is commonly used for soil classification (Gee & Bauder 1986). The size distribution is also referred to as the soil texture. Soils can be classified into 12 textural classes as represented in the textural triangle (Figure 5.1).

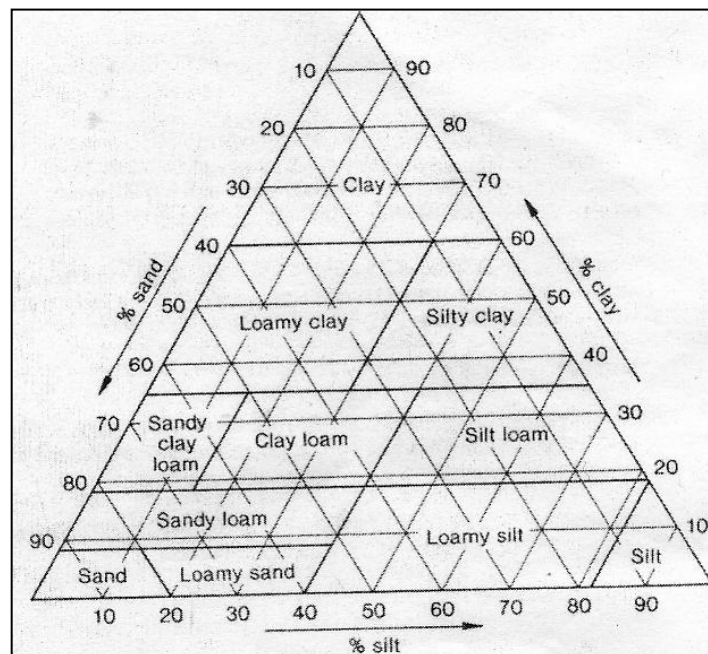


Figure 5.1 A textural triangle shows the percentages of sand, silt and clay content of the various textural classes (Milne *et al.* 1995).

5.3 Experimental Design

Three replicates of each of the ten soil or subsoil samples (Figure 5.2) were analysed for particle size using the pipette, hydrometer and lasersizer. The fraction of sand, silt and clay was measured as a percentage for each sample. The mean and standard deviation were calculated for each method and soil samples.

T-tests values were then calculated to do a comparison between the pipette-hydrometer analysis, the pipette-lasersizer analysis and the hydrometer-lasersizer analysis sand, silt and clay fractions of each sample, and significant differences (P) values were calculated. If P calculated is higher than 0.05 ($P > 0.05$), there is no significant difference between fractions produced by the three methods. However, if P calculated is equal or lower than 0.05 ($P \leq 0.05$) there is a significant difference between the fractions produced by the three methods.

5.4 Comparison between Pipette, Hydrometer and Lasersizer Methods of Particle Size Analysis

Particle size analyses of the ten samples using the three different methods produced heterogenous results. Six samples which were Hamilton Ash Formation, Hinuera Formation fine materials, allophanic soil materials and three samples from Piarere study site, showed a good agreement between the sand, silt and clay fractions yielded from the three particle size analysis methods (Figure 5.3). Full data sets for particle size analysis are provided in Appendix A.

The Hamilton Ash samples comprised an average of 63% clay, 12% sand and 25% silt as determined by pipette and hydrometer (Figure 5.3 a). Lasersizer analysis of the Hamilton Ash samples indicated the same proportion of clay (an average of 64%), but very little sand (an average of 4%) and a mean of 32% silt. Although there was no significant difference in the proportion of silt and clay yielded by the three methods, there was a significant difference in the proportion of sand yielded by hydrometer and pipette compared with the lasersizer ($P < 0.05$).



Figure 5.2 Ten soil samples collected in the Waikato Region.

Samples from the Piarere site were dominated by sand. All three Piarere samples comprised an average of 75% sand, 23% silt and 2% clay according to the pipette and hydrometer analysis (Figures 5.3 b, c and d). Although the lasersizer analysis exhibited the same trend as the pipette and hydrometer, the fraction of silt given by the lasersizer was higher from the pipette-hydrometer analysis with a mean of 33%, resulting in smaller fractions of clay (an average of 1%) and sand yielded (an average of 66%). Results from the Piarere soil material showed no significant difference between the three methods.

The allophanic soil material had a fairly consistent proportion of sand, silt and clay for all three methods (Figure 5.3 f). The allophanic material was strongly dominated by sand, with a moderate amount of silt and a minimal fraction of clay. Both the pipette and hydrometer analyses yielded a similar fraction of sand at an average of 62%, while the lasersizer analysis gave an average of 68% sand. At 29% the silt fraction yielded by the lasersizer was less than that from the hydrometer (an average of 42%) or the pipette (an average of 38%). The clay fraction yielded by the pipette and lasersizer analyses was similar at an average of 2%. The hydrometer yielded a higher amount of clay (an average of 6%) compared to the other methods.

Samples of fine materials of Hinuera Formation also had no significant difference between the three methods (Figure 5.3 f). Both the pipette and hydrometer analyses yielded similar fractions of sand, silt and clay with an average of 46.3% sand, 45.5% silt and 8% clay. Analysis with the lasersizer yielded a higher fraction of sand with a mean of 53%, a similar fraction of silt with a mean of 44% and lesser amount of clay with a mean of 3%.

The other four samples, Ngaruawahia 1, Ngaruawahia 2, Ngaruawahia 3 and coarse materials from Hinuera Formation, showed some variation in the fractions of sand, silt and clay yielded by pipette, hydrometer and lasersizer analyses (Figures 5.4 a,b,c and d).

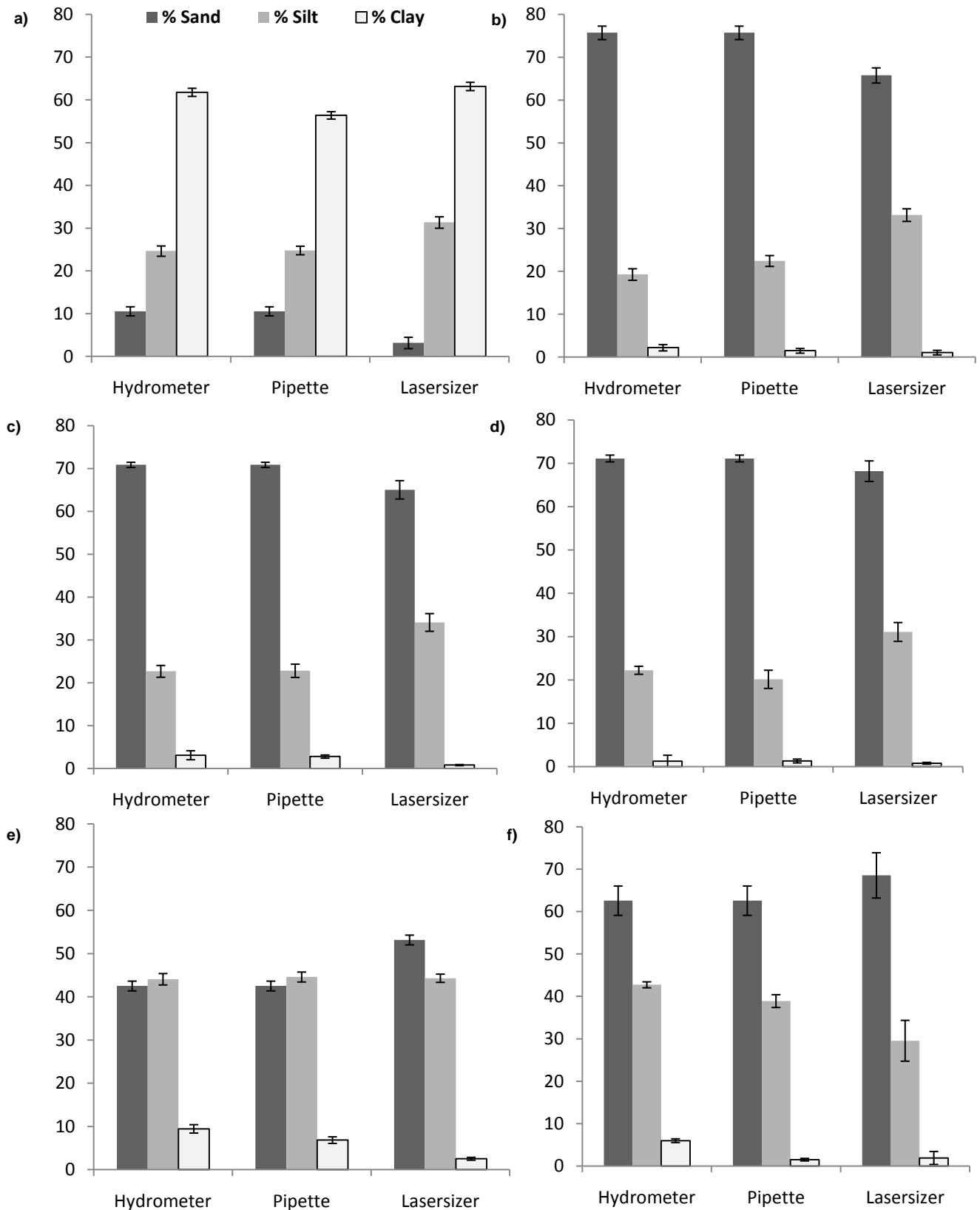


Figure 5.3 Particle size determined using the pipette, hydrometer and lasersizer; (a) Hamilton Ash Formation; (b) Piarere 1; (c) Piarere 2; (d) Piarere 3; (e) Hinuera Formation (fine materials); (f) Allophanic soil materials. Error bars are one standard deviation of the mean. The y-axis on each graph represents the percentage of sand, silt and clay.

The trend varied for all three samples collected at Ngaruawahia (Figures 5.4 a, b, c). The hydrometer and pipette methods showed good agreement for the proportion of sand, silt and clay in all three samples. The lasersizer, however yielded different results for the fractions of sand, silt and clay.

Samples from the Ngaruawahia 1 site comprised an average of 53% clay, 31% silt and 16% sand (as determined by both pipette and hydrometer), with clay as a dominant fraction. However, the lasersizer analysis showed silt as the dominant fraction with a mean of 52% yielded, which indicates a significant difference ($P < 0.05$) from both the pipette and hydrometer. Both the sand (an average of 30%) and clay (an average of 18%) fractions determined by the lasersizer were significantly different ($P < 0.05$) from both the pipette and hydrometer results (Figure 5.4 a).

Samples 2 and 3 from Ngaruawahia study site had silt as the dominant fraction for all three analysis methods (Figures 5.4 b and c). Samples from Ngaruawahia 2 consisted of an average of 28.5% sand, 42.5% silt and 29% clay for both pipette and hydrometer analyses. In contrast, the lasersizer analysis shows a significant difference ($P = 0.001$) by yielding a higher proportion of silt at a mean of 60% and a very small fraction of clay at a mean of 10% ($P = 0.005$) compared to the hydrometer and pipette. The sand fraction, however, showed good agreement with the pipette and hydrometer analyses at an average of 30%.

The pipette and hydrometer analyses of sample 3 from Ngaruawahia study site showed similar fractions of sand and silt, although the hydrometer analysis yielded a higher proportion of clay than the pipette analysis. The lasersizer analysis yielded a higher fraction of sand (a mean of 42%) and silt (a mean of 51%) compared with the pipette and hydrometer analyses, with a significant difference in the percentage of silt yielded ($P < 0.05$). The amount of clay (a mean of 7%) indicated a significant difference compared with the pipette and hydrometer analyses ($P < 0.05$) (Figure 5.4 c).

In the case of the Hinuera Formation (coarse materials), analysis by the pipette and hydrometer showed that the soil was dominated by sand at 95% (mean), with only 3% (mean) of silt and 2% (mean) of clay (Figure 5.4 d). However, the lasersizer analysis yielded a different proportion of sand and silt at 55% (mean) and 43% (mean) respectively; a significant difference ($P < 0.001$) compared with

the pipette and hydrometer analyses. The clay fraction however, was relatively consistent for all three methods.

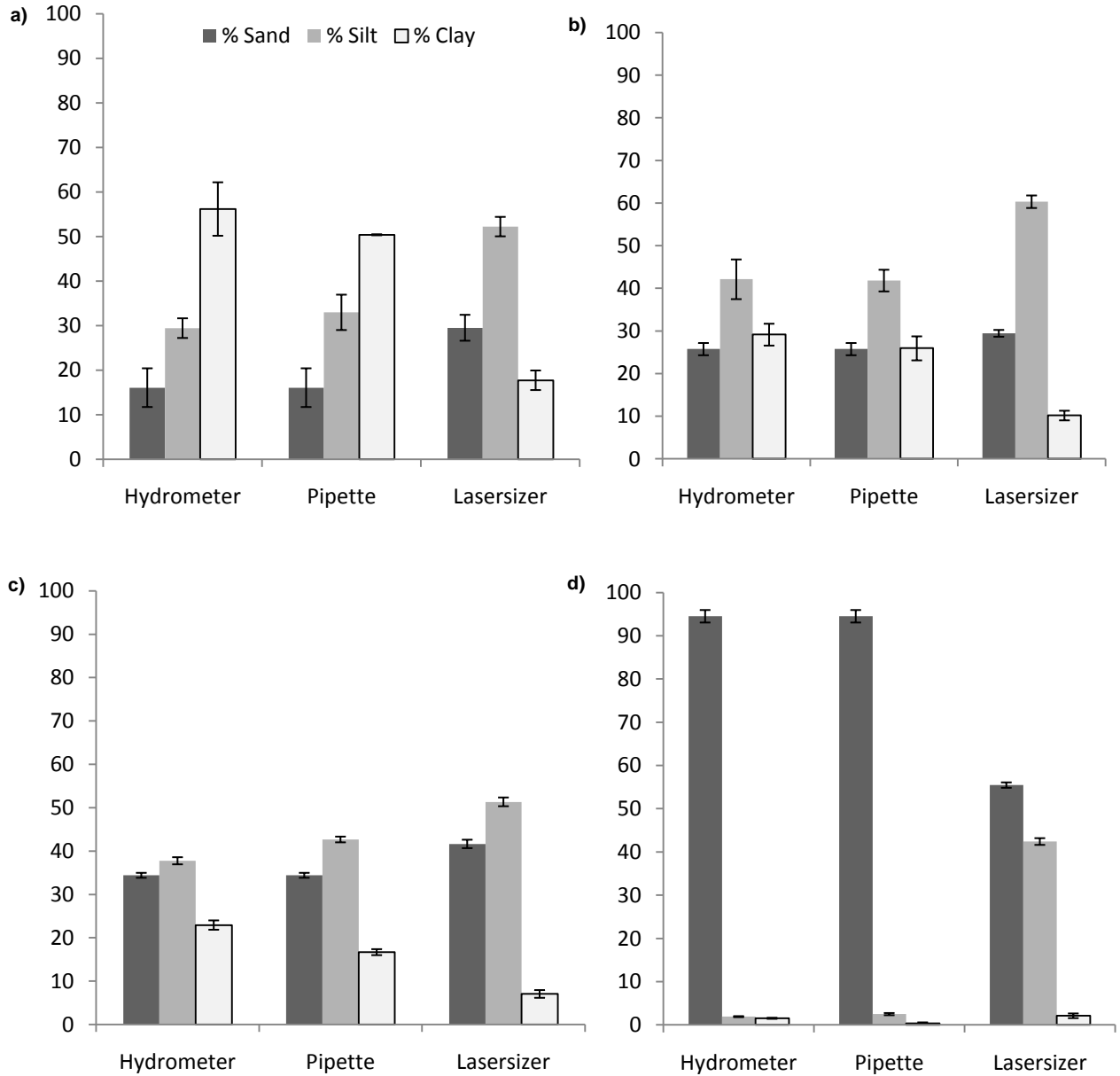


Figure 5.4 Particle size determined by the pipette, hydrometer, and lasersizer analysis; (a) Ngaruawahia 1; (b) Ngaruawahia 2; (c) Ngaruawahia 3; (d) Hinuera Formation (coarse materials). Error bars are one standard deviation of the mean. The y-axis on each graph represents the percentage of sand, silt and clay.

5.5 Soil Texture Analysis

Based on the proportion of sand, silt and clay that was obtained from the particle size analyses using the pipette, hydrometer and lasersizer methods, the textures of 10 soil samples were determined by referring to the New Zealand Standard Association's (1986) soil diagram (Figure 5.5). The Waikato soil materials range from clay to sand. Due to some variation in the proportions of sand, silt and clay obtained from the three different analyses, the results obtained from the pipette analysis were used as a basis to characterise the soil materials.

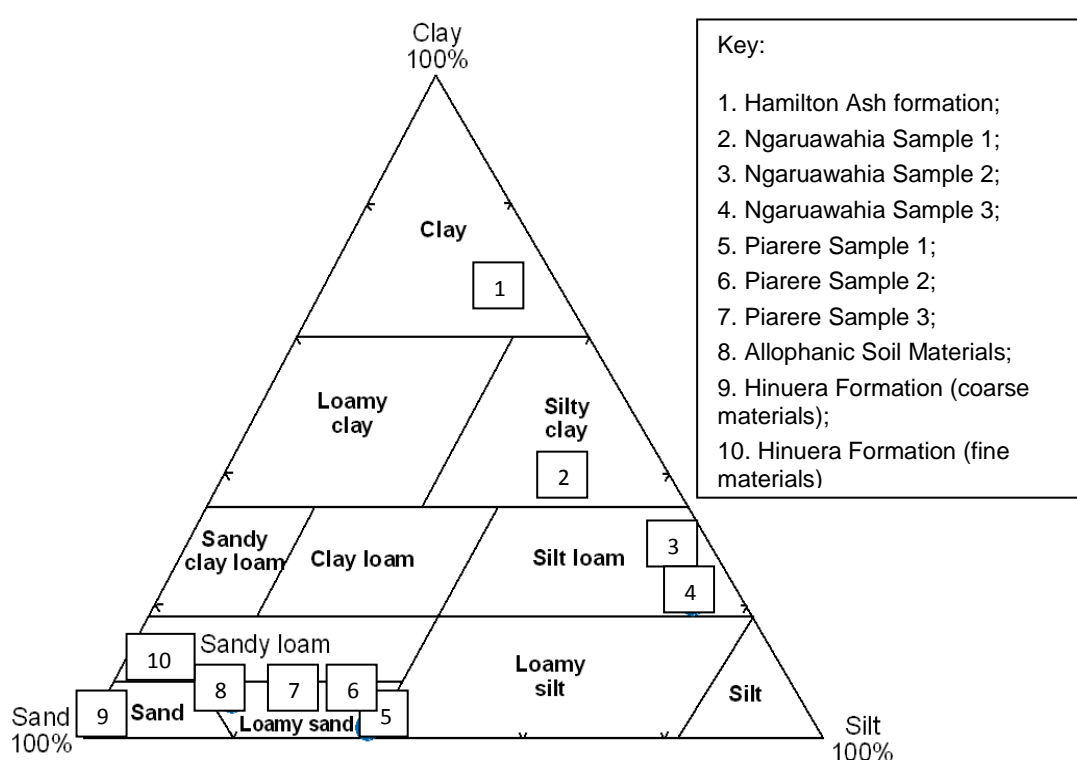


Figure 5.9 Soil texture of Waikato soil materials. Diagram adapted from Milne *et al.* (1995)

5.6 Discussion

Traditional sedimentation techniques involving the pipette and hydrometer clearly demonstrated a good agreement in the fraction of sand, silt and clay for all samples. The sand fraction for the pipette and hydrometer methods was equal because the same preparation method was used by sieving one large sample. Differences between fractions yielded by the lasersizer analysis and the pipette-

hydrometer techniques could be attributed to differences in the techniques used, in particular particle density and particle shape.

5.6.1 Dependency on Particle Density

The lasersizer analysis is independent of the particle density and produces results in volume percentage, while the pipette-hydrometer methods are based on mass percentage and are dependent on the density of soil particles as well as gravitational force (Stokes' Law principle). The volume percentage of the clay-size fraction obtained by lasersizer was generally lower than the mass percentage derived by pipette and hydrometer, while the opposite trend was observed for the silt-size fraction, as shown in the analysis of the three samples from Piarere (Figures 5.3 b,c,d), and the three samples from Ngaruawahia (Figures 5.4 a,b,c). Analysis of samples of fine materials from the Hinuera Formation (Figure 5.3 e) showed that while the clay fraction was lower, the sand fraction was higher and the silt fraction was similar to the pipette and hydrometer.

5.6.2 Heterogeneity of Particle Density

An obvious source of error in the pipette and hydrometer methods is the assumption of a single value for particle density for the various soil minerals present. Particle density of soil components may vary between soils and among the different size fractions in a given soil type. It is commonly taken that the particle density of soil materials is 2.65 mg m^{-3} . Yet, Clifton *et al.* (1999) found that the density of sediment particles can vary between 1.66 and 2.99 mg m^{-3} . The uncertainty regarding the actual density of the particles may distort the size distribution in the sedimentation analysis, resulting in errors in the estimation of size fractions.

5.6.3 Different Shapes and Angles of Soil Particles

The error in accuracy, bias in the size distribution, and possibilities of errors in the estimation of the fractions of sand, silt and clay in the ten samples using all three methods, may also be attributed to the assumption that particles in soils have equivalent spherical shapes for simplicity and ease of analysis. Consequently the

particle size distribution is dependant on the method used for analysis (Eshel *et al.* 2004).

Soil particles have varying shapes and angles and may require a three-dimensional description. In sedimentation techniques (pipette and hydrometer), the effect of particle shape may lead to overestimation of the fine fraction because there is a likelihood of a non-spherical particle passing through or being retained on a sieve of a given mesh size in the sieving process, depending on the shape of the soil particle and the probability of the soil particle assuming an orientation that allows it to pass through the sieve (Eshel *et al.* 2004).

According to Pieri *et al.* (2006), laser diffraction analysis identifies the shape of soil grains as spheres, leading to an underestimation of the clay fraction because particles are assigned to a larger size fraction. This means, a shift of the particle size distribution toward its coarser fractions on the basis of its apparent radius. The impact of the non-spherical clay particles may be the reason for the lower fraction of clay and higher fraction of silt or sand measured by the lasersizer for three samples from Piarere (Figures 5.3 b, c, d), three samples from Ngaruawahia (Figures 5.4 a, b, c), and samples of fine materials from the Hinuera Formation (Figure 5.3 e) compared to the pipette-hydrometer methods.

Conversely, particle shape also has an effect on sedimentation-based techniques. The most stable position of a settling non-spherical particle is the one in which the maximum cross-sectional area is perpendicular to the direction of motion (Eshel *et al.* 2004). This stable position increases the expected particle drag, which, in turn, results in a decrease in the settling velocity (Mathews 1991). Thus, the fine size fraction tends to be overestimated in the pipette and hydrometer methods.

According to Mathews (1991), the rule of thumb of the net outcome of non-spherical soil particles is that a coarser particle will be retained in the sieve than the actual diameter particles that correspond to the sieve mesh size. However, this rule does not apply to a soil sample that contains a significant quantity of very flat disk-shaped particles, although their particle diameter exceeds the size of sieve aperture (Eshel *et al.* 2004).

In this study, in order to minimise the over or under estimation of soil fractions while doing the experiment, the $> 63\ \mu\text{m}$ fraction that was left in the sieve after wet sieving the soil samples was dried in the oven overnight. Afterwards the whole fraction of soils which was $> 63\ \mu\text{m}$ was re-sieved while the sieve was still warm to make sure all the fractions were well separated. Applying this technique improved the particle size distributions obtained using the three methods (Figure 5.3).

5.6.4 Reliability of the Particle Size Analysis Methods

All of the three methods are reliable and it cannot be concluded that the traditional sedimentation techniques (pipette and hydrometer) are better than the laser diffraction analysis (mastersizer or lasersizer).

Several authors (Pieri *et al.* 2006; Konert & Vandenberghe 1997) reported that the lasersizer method is a valid method for particle size distribution analysis, even though it provides data that are not fully comparable with the classical sedimentation methods. Martin & Montero (2002) found that analysing particle sizes using laser diffraction offers the possibility of studying the volume distribution of soils in scales that are not often explored, while applying gravitational sedimentation techniques. Pieri *et al.* (2006) reported that using the laser diffraction technique would provide more details of the particle size especially in the clay range where particle size distribution can be measured down to 0.05 microns, with as many as 25 size classes below $2\ \mu\text{m}$.

Providing a wide range of size classes is of particular importance because the availability of a continuous particle size distribution, rather than an arbitrary division of the particles among a limited number of size fractions (as is obtained by the pipette and hydrometer methods), enables a more detailed data analysis and a simultaneous use of the same data sets for classification of the analyzed samples under different classification systems.

Moreover, the lasersizer analysis only required a short time of analysis (5-10 minutes per sample), high repeatability and a small size of sample needed ($\leq 1\ \text{g}$). In addition, using the lasersizer for prediction of soil hydraulic properties such as porosity and pore-size distribution will eliminate the need to adopt the

rough approximation of a single value for soil particle density in the prediction process (Eshel *et al.* 2004).

Two main disadvantages of using the lasersizer are the high cost of the instrument and the lack of a database that correlates laser diffraction derived particle size distribution with soil properties (Eshel *et al.* 2004).

Both pipette and hydrometer on the other hand, have extensive databases supporting it, with equations to calculate settling time. The main disadvantages however, of these two methods would be on the long measuring time, and the validity of Stokes' law only for sphere-shaped particles, causing the non-spherical particles to settle more slowly because of increased drag, than occurs for the particles with equivalent spherical diameters. For the pipette method, sieving the samples requires careful handling in order to ensure there is not a loss of soils fraction during the process.

For hydrometer in particular, one potential source of error lies in having to calibrate the hydrometer before any measurement takes place. Incorrect calibration will lead to inaccurate results when particle size distribution is calculated.

The error bars in Figure 5.3 and 5.4 did portray a consistency in the proportion of sand, silt and clay of the three methods. Results of particle size analysis give excellent agreement for both the pipette and hydrometer for all ten samples of soil. Lasersizer analysis does give a wider variability as showed by the error bars compared to pipette and hydrometer such as in the analysis of allophanic soil materials, Piarere 1 and 2, though exhibit the same trend and portraying a good agreement between the methods.

5.7 Conclusions

Assessment of the ten samples collected showed that one sample was characterised as clay, one was silty clay, two were silt loam, one was sandy loam, one was sand and four were loamy sand. Six samples measured showed no significant differences between the fractions of sand, silt and clay yielded from the pipette, hydrometer and lasersizer (Hamilton Ash, Piarere, Hinuera Fine, Allophane). Four samples measured showed agreement in some fractions but

significant differences in others (Ngaruawahia, Hinuera coarse). All three methods were reliable and each has their own advantages compared with the others. The pipette method is independent of sample mass and has high reliability. The hydrometer method provides easy reading and the lasersizer method is quick to use, easily repeatable, and only needs a small amount (<5g) of sample. In this study, the pipette method has been chosen to be used as a basis for soil characterisations. The hydrometer is too tedious requiring a difficult calibration technique and the lasersizer was good for a fast assessment of sample without having so much emphasis on reliability.

5.8 Summary

The lasersizer gave good agreement with the pipette and hydrometer methods for six of the ten samples tested. However for four of the samples, there was a marked difference between the particle size distribution determined by the lasersizer and that determined using the pipette and hydrometer methods.

There is no method that serves as a universal yardstick in the determination of particle size distribution of soil materials, because both the classic methods (pipette and hydrometer) and the newer method (laser diffraction analysis) have inherent limitations and assumptions. The choice of which method to use depends on the purpose of laboratory analysis, either wanting to perform a fast analysis with a small amount of sample (lasersizer), investigating the gravitational force in soil particles settling rate, or determining the required time for soil particles to settle (pipette and hydrometer).

Characterisation of the ten samples based on the soil texture diagram indicates a wide range of soils in the Waikato region consisting of clay, silt-loam, sand, loamy sand, sandy loam and silty clay. Determining the soil texture and understanding the soil settling behaviour will assist in estimating sediment retention pond design, especially the residence time. Residence time is vital in order to ensure sediment runoff is retained for an adequate time to allow suspended solids to settle.

Chapter 6

Sediment Retention Pond: Comparison of Inlet & Outlet Samples

6.1 Introduction

Trapping efficiency and residence time are two key features in designing a sediment retention pond. In order to obtain information about the amount of sediment flowing into the sediment retention ponds and the effectiveness of the ponds in capturing and retaining sediment runoff, two sediment retention ponds were sampled, one at Piarere and one at Ngaruawahia (Section 3.2).

Samples were collected during wet periods in the winter months with the aim to capture sediment produced during high intensity rain events considering that the sediment discharge from the earthwork sites was dependent on overland surface runoff following high intensity of rainfall.

Seventy samples were collected over the course of investigation, 28 were from the Piarere sediment retention pond, and 42 from the Ngaruawahia sediment retention pond. The samples collected from the inflow and discharge of the sediment retention ponds were analysed for turbidity and suspended solids (SS) concentration. Full data sets are contained within Appendices B1 and B2.

Turbidity and suspended solids between the inflow and outflow were compared to develop an understanding of the movement of stormwater and sediment within the pond and to estimate the effectiveness of the pond at retaining sediment. The detailed methods of analysis for turbidity and suspended solids were described in section 4.5.1 and 4.5.2.

6.2 Results and Initial Discussion

6.2.1 Piarere

Samples were successfully collected during periods of rainfall between the 7th and the 20th of July 2009. The concentration of suspended solids and turbidity were determined for inflow and outflow samples collected from the sediment retention pond.

6.2.1.1 Relationship between Rainfall, Suspended Solids and Turbidity

Analysis of inlet samples collected from 7th to 20th July 2009 showed some variation between the correlation of rainfall with suspended solids and turbidity. The first four periods of rainfall (Figure 6.1) portrayed that suspended solids concentration and turbidity level were strongly correlated with level of rainfall, increasing with higher rain and decreasing with minimal intensity of rain.

Afterwards, the trend has changed starting from 4:15am on 8th of July. A contradictory outcome was obtained where the intensity of rainfall was very low but the concentration of suspended solids was high, with turbidity level increasing and decreasing with the level of suspended solids although the value of turbidity was not too high compared to suspended solids.

Initially the autowater sampler was set to collect samples following 1.0 mm in every 15 minutes, hence the reason of mean rainfall during samples collection from 7th to 10th July 2009 was 1.16 mm per 30 minutes. High suspended solids levels were observed during 7th to 10th July (at 3:30 and 3:45 on 8th July). Although rainfall during this period was minimal, the high suspended solids readings could be due to previous accumulated rainfall from 3rd to 6th July, which was 29.5 mm (Environment Waikato 2009c). Lots of rain may have caused more sediment from the catchment area to be detached and transported to the pond, which may perhaps explain the of high suspended solids level at 4023.60 mg L⁻¹ and high turbidity at 2411.67 NTU.

Samples collections were then changed to 2 mm of rainfall in 30 minutes period starting from 11th July 2009. High suspended solids and low turbidity values were also observed in samples collected from 11th to 14th July 2009 (Figure 6.1). The measured suspended solid value was 4156 mg L⁻¹ and turbidity levels during this period of sampling were quite low at 435 NTU. The reason would be possibly due

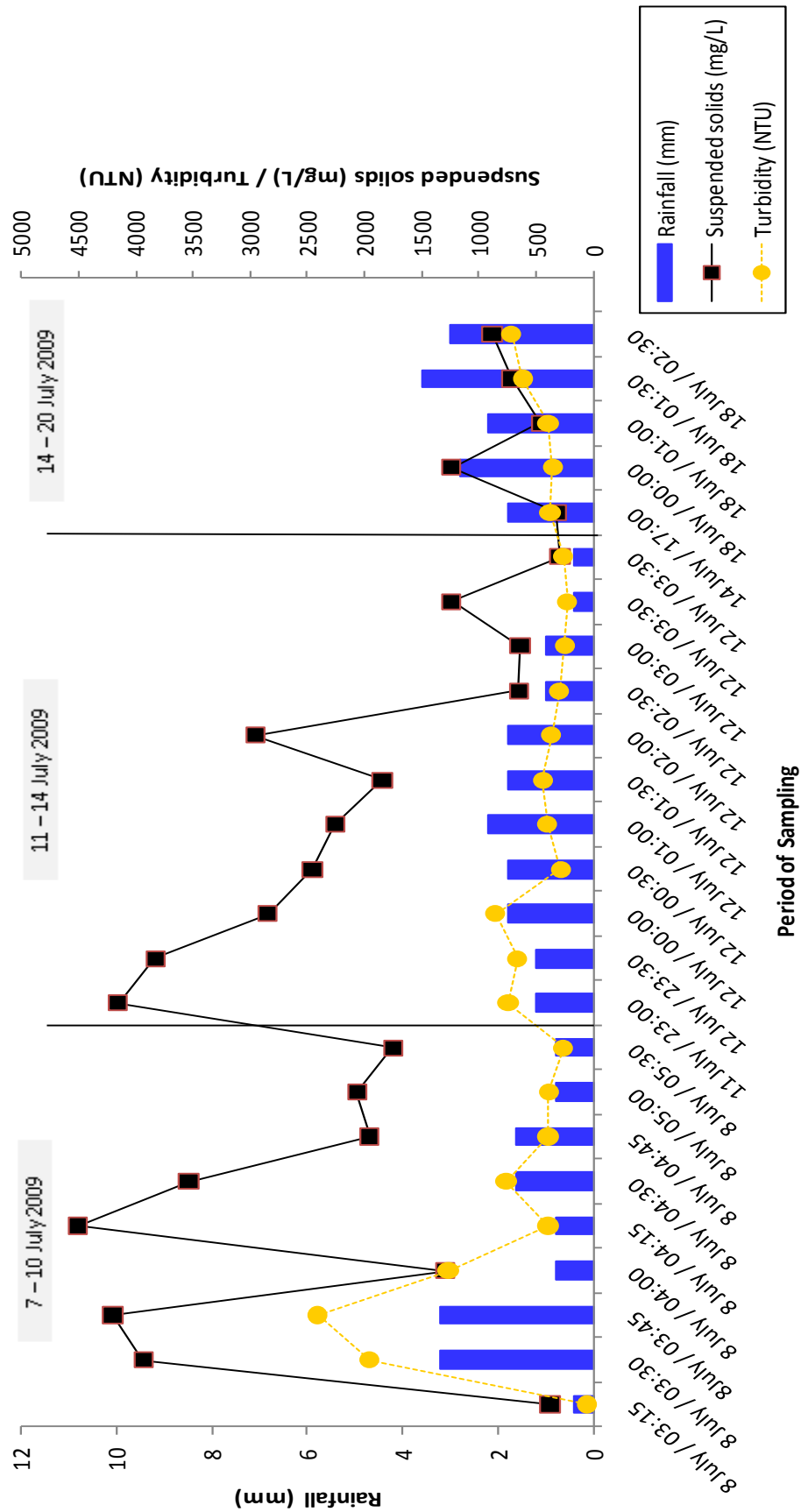


Figure 6.1 Relationship between rainfall, suspended solids and turbidity of the inlet samples collected at the Piare sediment retention pond.

to the soil types at Piarere which are dominated by sand, which settles rapidly and does not have a strong influence on the colour of the runoff, thus leading to relatively low turbidity readings.

Both suspended solids and turbidity levels during the last period of sampling (14th to 20th July 2009) showed a similar pattern except for one spike that indicates a sudden increase in suspended solids concentration, which may be caused by the presence of organic matter such as roots or debris during the analysis. The highest suspended solids level is 1242.27 mg L⁻¹, with an average of 723.07 mg L⁻¹ for all samples. Turbidity gave a highest reading at 718 NTU with an average of 492 NTU for all samples.

6.2.1.2 Relationship Between Suspended Solids and Turbidity

Results showed that the relationship between suspended solids and turbidity for inlet samples collected at Piarere had a weak correlation ($R^2 = 0.279$) (Figure 6.2). Observation of the trend in Figure 6.1 demonstrate that while there is some correlation between turbidity and suspended solids, the relationship is inconsistent. For some analyses the turbidity values correlate with suspended solid value. However for some analyses a contradictory outcome was observed where the turbidity value is low with high suspended solids.

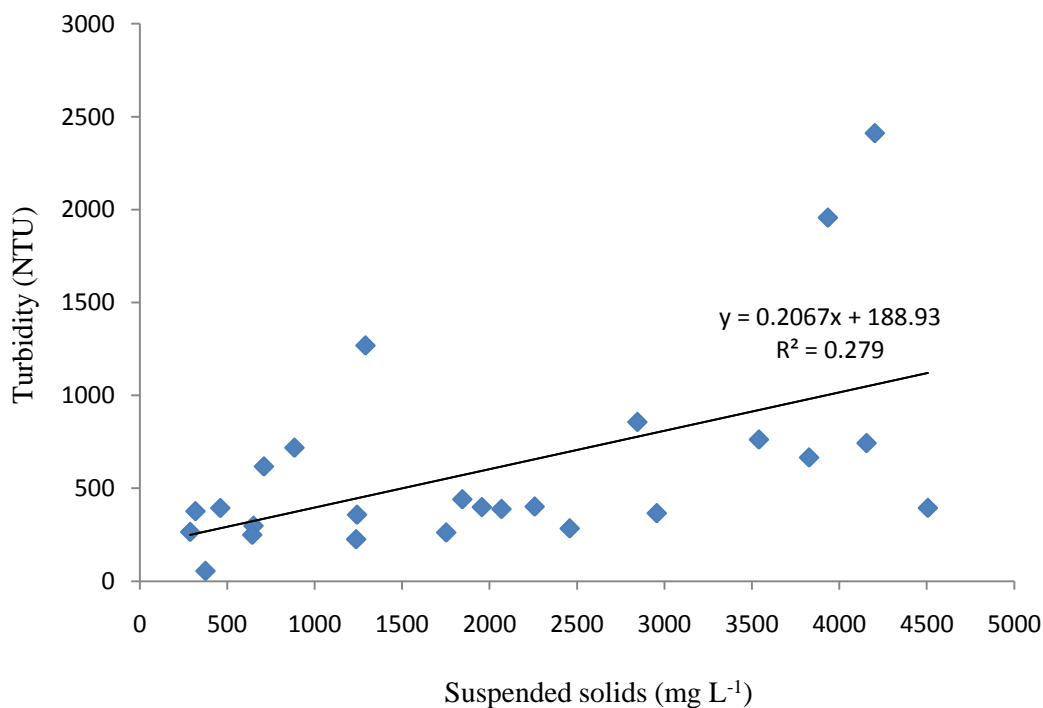


Figure 6.2 Relationship between suspended solids and turbidity of inlet samples collected at Piarere sediment retention pond.

6.1.2.3 Comparison Between the Inlet and Outlet of the Sediment Retention Pond (Suspended Solids and Turbidity)

There was a large reduction in suspended solids and turbidity between the pond inflow and outflow at the sandy Piarere site (Figures 6.3 a and b). Observation while transferring samples collected by autowater sampler to sampling bottles showed that most of the samples were clear with sediments sitting at the bottom of the bottles. When these samples were analysed for suspended solids and turbidity analysis, the bottles were shaken vigorously causing the clear samples to turn dark turbid.

Three periods of sampling from 7th - 20th of July 2009 showed an average of 97% reduction in suspended solid levels and an average of 94% reduction in turbidity levels between the inlet samples and the outlet samples, indicating the pond has been effective in retaining sediment runoff from the catchment area.

As the Piarere site was dominated by sandy soil materials, dislodging of soils particles with high erosivity of rainfall was presumeably easier, thus leading to the high suspended solids concentration in the collection period of 7-10th July. A lower concentration of suspended solids and lower turbidity were observed in spite of the relatively high rainfall in the preceeding 30 minutes on 8 July 2009.

6.2.2 Ngaruawahia Site

Samples were successfully collected during periods of rainfall between 31st August and 30th September 2009 at the Ngaruawahia site. The concentration of suspended solids and turbidity was determined for inflow and outflow samples collected from the sediment retention pond.

6.2.2.1 Relationship Between Rainfall, Suspended Solids and Turbidity

Figure 6.4 shows that both suspended solids and turbidity correlate with rainfall level. The mean rainfall, 30 minute rainfall event of > 2 mm during the first period of sample collection, from 31st August to 30th September 2009, was 2.63 mm, while the accumulated rainfall before the sampling period from 20th of August to 31st August was 26.5 mm (Environment Waikato 2009c), which may accounted for the high amount of suspended solids during the first three rain events.

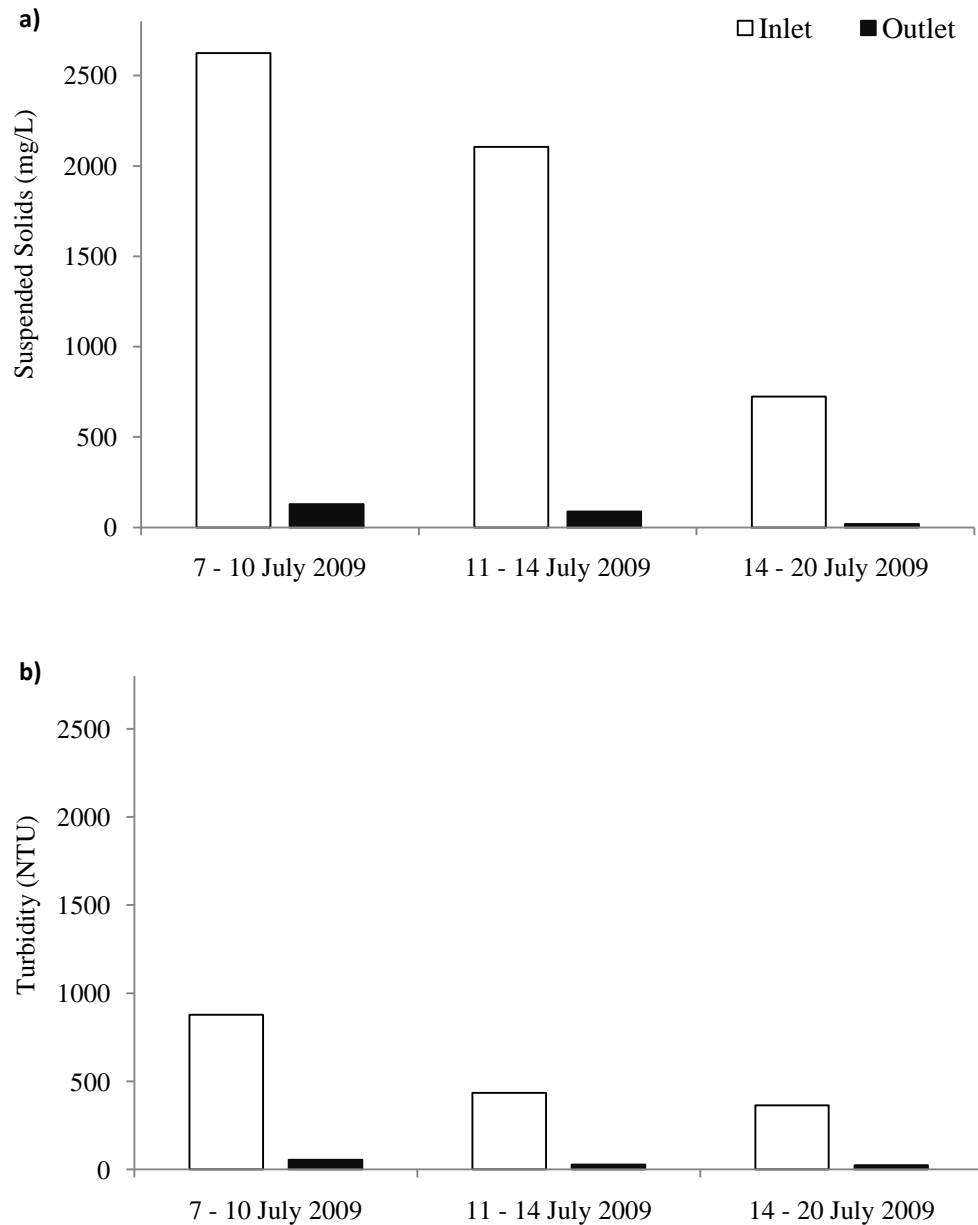


Figure 6.3 Comparison between inlet and outlet of Piarere sediment retention ponds. (a) Suspended solids and (b) Turbidity. The x-axis represents the sampling period.

As the soils have been saturated with water, surface runoff occurs and carries the easily eroded soils materials with it. Although the level of rainfall was quite high at 3.6-3.8 mm, the value of suspended solids and turbidity have declined, suggesting that erosive energy of rainfall is not sufficient to erode the soil particles.

High turbidity of samples in contrast to 'medium' readings of suspended solids could be due to the influence of colour of the water samples during collection, which was observed as orangey brown.

There was also evidence of quite an intense rain event from 23rd to 30th September 2009 as illustrated in the same graph (Figure 6.4), with a maximum of 10.6 mm but the average turbidity of samples collected is below 100 NTU. However, changes in suspended solids correspond to changes in the hydrological pattern as observed from the graph. Six sharp spikes (Figure 6.4) demonstrate a high concentration of suspended solids present with a sudden drop of suspended solids as the rainfall decrease. The water samples were clear when collection was made, suggesting the presence of fine organic materials attached to soil materials. The highest suspended solids measured was 590 mg L⁻¹ with the average reading at 242.46 mg L⁻¹. Turbidity gave the highest reading at 172 NTU with the average reading at 73.44 NTU during this period of sampling (2nd to 30th September 2009).

6.2.2.2 Relationship Between Suspended Solids and Turbidity

Results showed that there was no relationship between suspended solids and turbidity for inlet samples collected at Ngaruwahia sediment retention pond ($R^2 = 0.1797$) (Figure 6.5). Analysis of the samples collected failed to produce a consistent pattern where suspended solids and turbidity correlate with each other. This may be due to samples appearing visibly clear but generally contained lots of fine particles, with the exception of a few samples which displayed orangey-brown colours with very little particles present.

6.2.2.3 Comparison Between Inlet and Outlet (Suspended Solids and Turbidity)

There was a large reduction in suspended solids (95%) and turbidity levels (97%) between the pond inflow and outflow at the Ngaruwahia sediment retention pond, except for a sampling period between 2nd and 11th August 2009 (Figure 6.6), when the inflow had low suspended solids and low turbidity. The inlet water samples were clear indicating that the rainfall, while sufficient to set the sampler off, was not sufficient to cause overland flow and sediment entrainment.

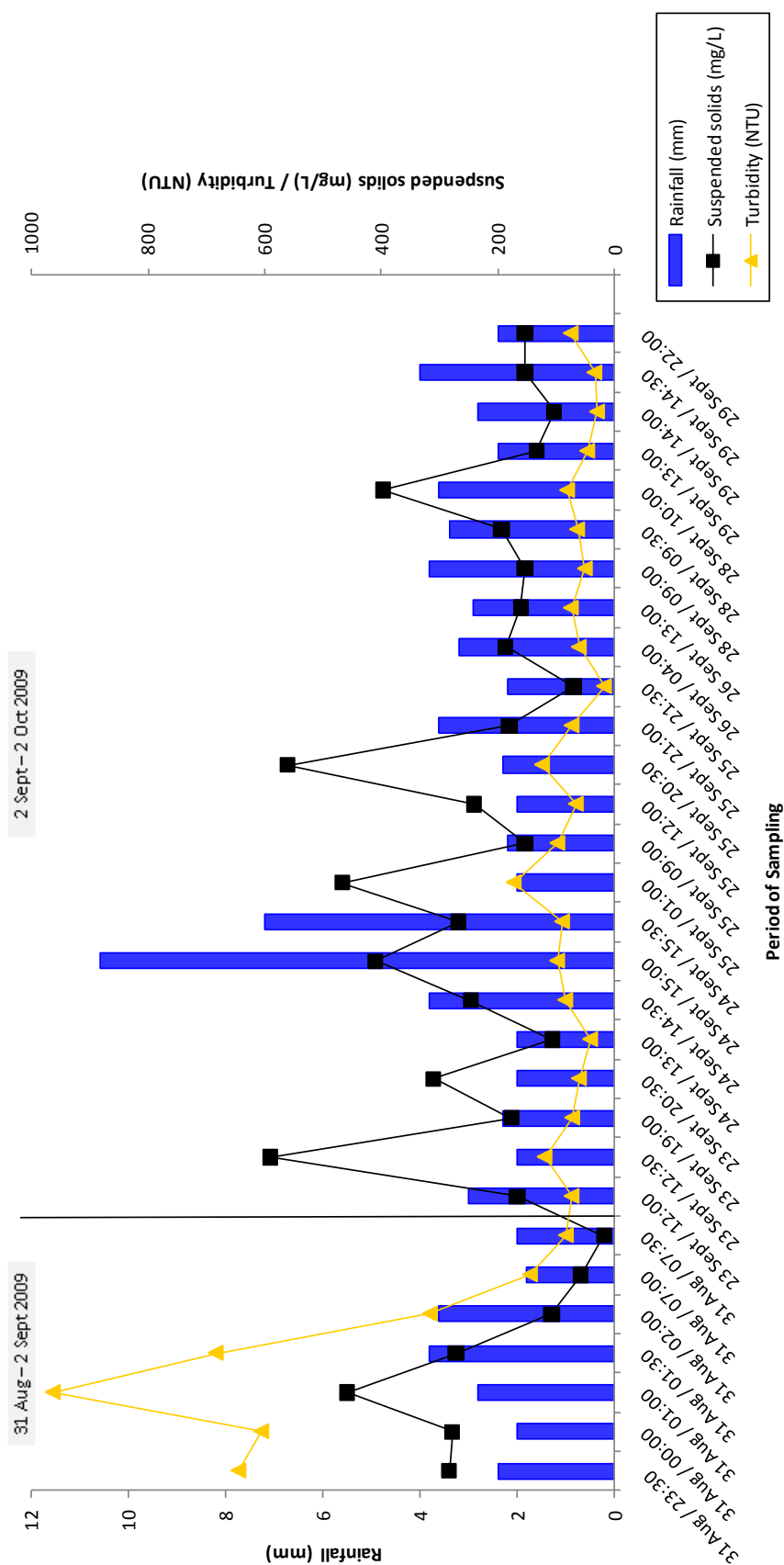


Figure 6.4 Relationship between rainfall, suspended solids and turbidity of inlet sample collected at the Ngaruawahia sediment retention pond.

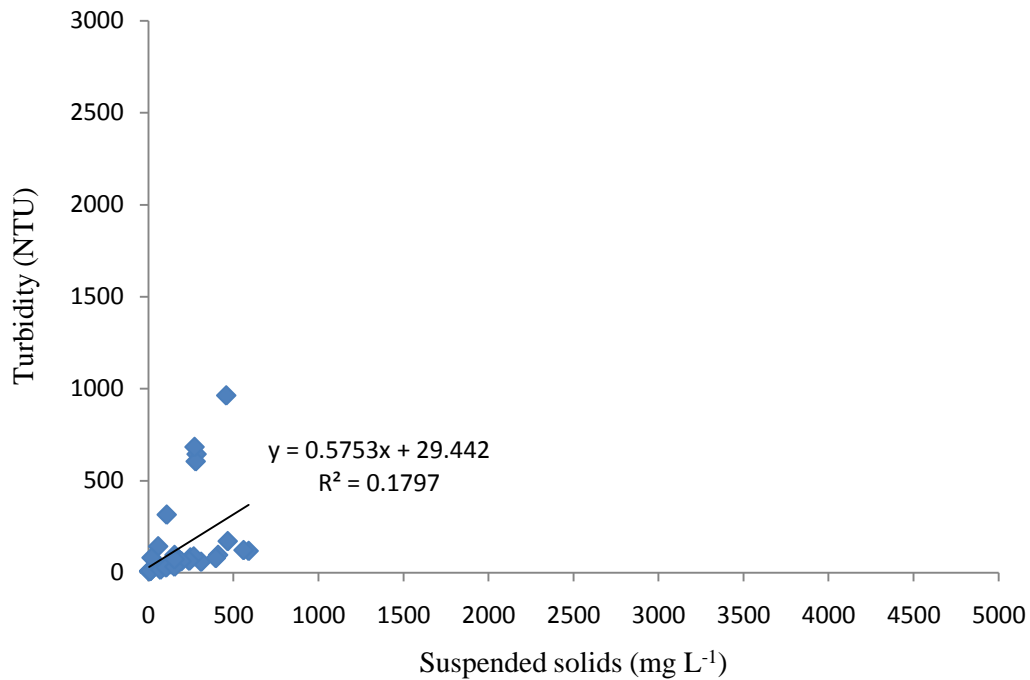


Figure 6.5 Relationship between suspended solids and turbidity of inlet samples collection at Ngaruawahia sediment retention pond.

6.3 Discussion

6.3.1 Effectiveness of Sediment Retention Ponds in Retaining Sediments

Soil types in the Piarere study site catchment area were strongly dominated by sand, while the Ngaruawahia study site was dominated by silt loam (section 5.5.2). In addition, both ponds are different, as the sediment retention pond at Piarere was a temporary pond and not chemically treated, while Ngaruawahia's sediment retention pond is a permanent pond and chemically treated with flocculants (polyaluminium chloride, PAC).

However, results of both ponds clearly indicated that there was a large reduction of suspended solids and turbidity between inflow and outflow, with almost similar percentages in terms of suspended solids and turbidity. Both ponds showed a 96% reduction in suspended solids and 94% reduction in turbidity (Figures 6.3 and 6.6). The possible reasons for this could be the following:

- a) the sandy soil types at Piarere resulted in more rapid settling of sediment following the sedimentation principles of Stokes' Law; and

- b) flocculants used at the sediment retention pond in Ngaruwahia to treat sediment-laden runoff from the quarrying sites ensured effective settling of silty soil material.

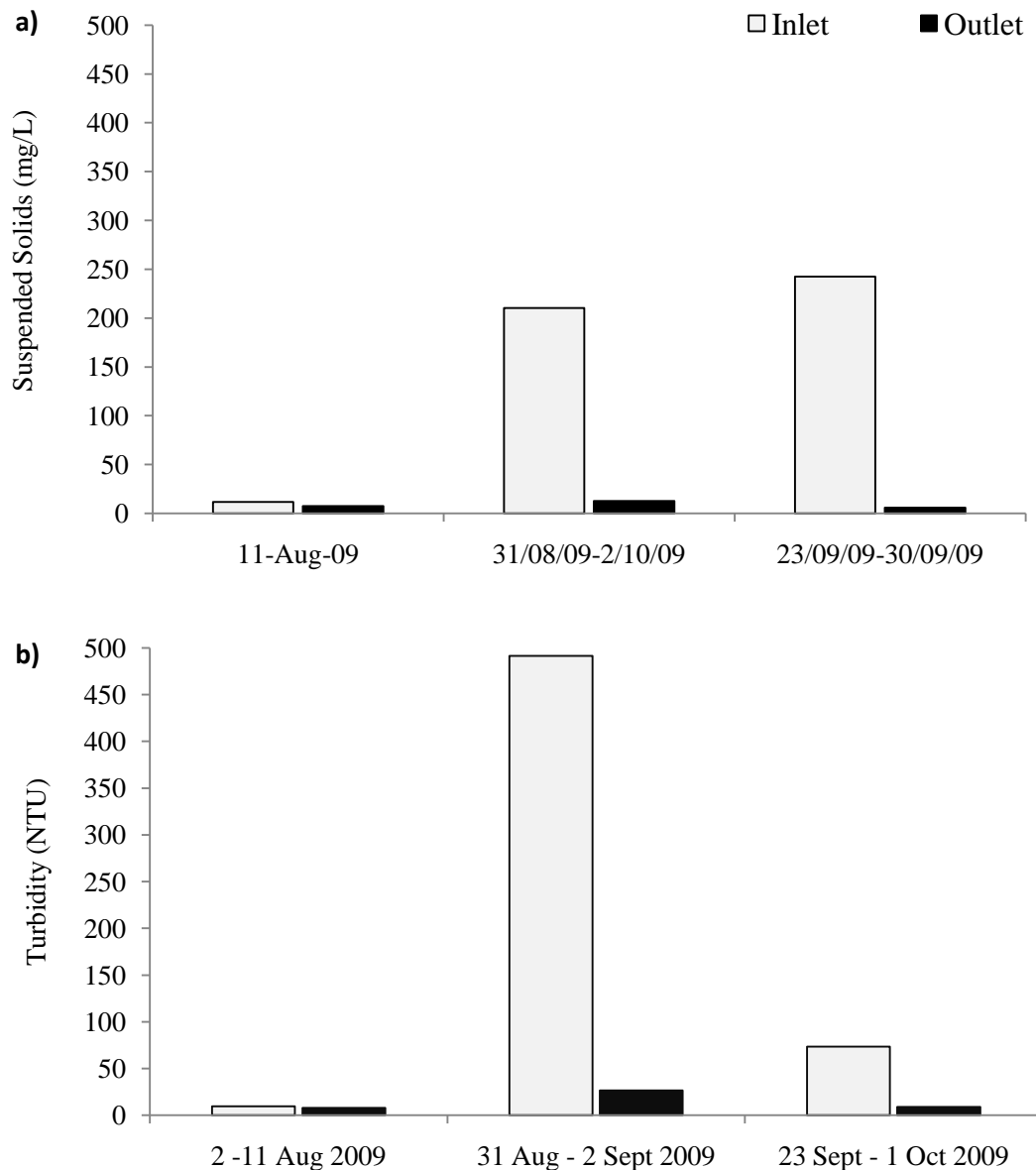


Figure 6.6 Comparison between inlet and outlet of Ngaruwahia sediment retention ponds (a) Suspended solids and (b) Turbidity. The x-axis represents the sampling period.

Overall results of suspended solids and turbidity analyses of outflow from both ponds are in agreement with the guidelines established by Environment Waikato. The Waikato Regional Plan (Environment Waikato 2007) has clearly stated that

for permitted activity, discharge shall not increase the concentration of suspended solids in the receiving water by more than 10 percent for natural class water or shall not exceed 100 grams per cubic metre for Waikato region surface class water. There is no specific guideline set for turbidity measurement, but it is stated that the black disc measurement for water clarity shall not increase by more than 20%. As a close relationship is usually found between turbidity and visual clarity (black disc visibility) (Davies-Colley & Smith 2001), the guideline can be applied to turbidity measurement.

The methods of collecting samples at the inlet and outlet were different. Inflow samples were collected depending on the intensity of rainfall as described in section 2.4.1. The outflow samples were collected directly from the discharge pipe of sediment retention pond using a twenty litre bucket as there was only one autowater sampler available.

Although the ponds were effective in retaining sediment, there was no strong supporting evidence because sampling of inflow was only carried out during 25 different rain events at Piarere and 39 rain events at Ngaruawahia. Only three outflow collections for each site were carried out and the collections were not strongly correlated with rainfalls because collection was done after periods of rain. Making comparisons between inlet and outlet was not as precise and accurate as it should ideally be.

6.3.2 Influence of Precipitation

One of the essential factors for sediment transport is sediment availability, which is strongly linked to the patterns of precipitation events and surface overland flow. Sediment discharge rate was expected to change in response to changes in rainfall including total precipitation as well as intensity (Zabaleta *et al.* 2007). Results from both ponds demonstrate that although in theory the hydrological pattern would be expected to be strongly correlated with sediment discharge and there is an established relationship between storm hydrographs and suspended solids concentration, the relationship is not homogeneous at all times and may not be consistent (Figures 6.1 and 6.4).

In the case of the Piarere site, which is strongly dominated by sand and more easily eroded compared with silt and clay, the continuous rain (29.5 mm) before

the start of collection in the 4 preceeding days has resulted in high levels of suspended solids, although the average rainfall during the first and second periods was only 1.13 mm and 1.42 mm respectively (Figure 6.1).

At Ngaruawahia, the suspended solids level was not as high as observed at Piarere (458 mg L⁻¹ compared to 3336.32 mg L⁻¹) with an average of 210.43 mg L⁻¹ during the first collection after 26.5 mm of rainfall in the preceeding 4 days. This may indicate that the rainfall, while sufficient to cause overland flow and sediment entrainment, was not enough to erode and detach silty soil types with strong aggregate bonds.

Failure and limitations of the autowater sampler resulted in the collection of fewer samples during rainfall events than anticipated. The equipment installed is able to collect 23 samples meaning that 23 different rain events could be collected over each sampling period. However, the average collection made was about nine samples at one period of collection except during the last period of sampling at Ngaruawahia (23rd to 30th September 2009) where 23 different samples were collected. Flat batteries also resulted in failure to collect samples during some high intensity rain events.

6.3.3 Relationship Between Suspended Solids and Turbidity

Turbidity in water is caused by the presence of suspended matter, which results in the scattering and absorption of light rays. The greater the amount of suspended solids in the water, the murkier it appears and the higher the measured turbidity. It has to be kept in mind that water of low turbidity is not necessarily without dissolved solids. Dissolved solids do not cause light to be scattered or absorbed, thus the water looks clear.

Overall turbidity measurements observed from assessment of the samples collected do not posses a strong correlation with suspended solids. Results demonstrated that only a weak correlation exists between turbidity and suspended solids at the Piarere site ($R^2 = 0.279$) and no correlation exists at the Ngaruawahia site with $R^2 = 0.1797$, possibly because of different approaches used while doing the analyses.

The turbidity and water clarity relationship with suspended solids concentration (SSC) in water are poorly understood (Davies-Colley & Smith 2001). Turbidity is a parameter that is related to suspended solids. It is used to measure relative water clarity and can also be employed to estimate the concentration of suspended solids. Unfortunately turbidity is difficult to measure in absolute units and different analytical instruments would give different results (Ministry for the Environment 1997).

Correlation of turbidity measurements to suspended sediment concentrations has been criticized as inaccurate, with a large variability in the signal caused by constituents other than suspended sediments such as organic materials, air bubbles, floating debris, and water colour, causing a bias in readings. It has also been extensively proved that colour, shape and particle size, along with wavelength, affect the scatterance of the samples (Pavanelli & Bigi 2005).

According to Campbell *et al.* (2005) correlations between turbidity and suspended solids concentration often fail at high concentrations, where the calibration relationship between turbidity and light scattering becomes non-linear. Furthermore, small particles scatter light more uniformly and are more sensitive to shorter wavelengths, whereas large particles tend to forward scatter the incident light. This leads to a greater sensitivity of the instrumentation for finer particles than larger ones. For this reason, solutions of equal suspended solid concentration but different composition may not scatter the same amount of light. Thus the lack of correlation between suspended solids and turbidity measurements could not be regarded as unusual.

6.4 Conclusions

It can be concluded that both of the sediment retention ponds at Ngaruawahia and Piarere have been effective in retaining sediment runoff from the catchment area of earthwork sites during wet seasons as determined by suspended solids and turbidity values, which indicate a large reduction between inflow and outflow of the pond.

At the sandy Piarere site, there was a large reduction in suspended solids (97%) and turbidity (94%) between pond inflow and outflow. The same results also

occurred at the silty loam Ngaruawahia sites with a large reduction in suspended solids (95%) and turbidity (97%).

The suspended solids levels at both ponds showed a strong association with rainfall intensity, where high rainfall led to large amounts of suspended solids collected at both sites. Turbidity value on the contrary showed heterogeneous results. Initial collection during the first period of sampling at both Piarere (7th to 10th July 2009) and Ngaruawahia (31st August to 2nd September 2009) showed a strong association with rainfall events and also suspended solids levels. However, towards the end of the sampling period, the average values at both ponds do not indicate high levels of turbidity with average values at Piarere 492 NTU and at Ngaruawahia 73.44 NTU.

6.5 Summary

Monitoring of two sediment retention ponds was undertaken during wet winter periods. Although winter months are considered non-earthwork operation months, earthwork activities were still active on both sites. The sediment runoff flowing through the pond was collected according to precipitation events, with minimum collection at 2 mm of rain.

Overall 25 periods of rainfall were sampled at Piarere from 7th to 20th of July 2009. At Ngaruawahia 39 periods of rainfall were sampled during sample collection from 31st August to 30th September 2009.

Both sites were effective, reducing suspended sediments and turbidity by at least 94%. The suspended solid values and turbidity values have been following the guidelines established by Environment Waikato for a permitted activity. The guidelines state that discharge from earthwork sites shall not increase the concentration of suspended solids in the receiving water by more than 10 percent for natural class water and shall not exceed 100 grams per cubic metre for Waikato region surface class water.

However, it is recognised that there is some limitation in the collection of samples because of malfunctions of the water collection instruments and inaccuracy in the measurement of a few initial samples at Piarere because of the dilution factor.

Chapter 7

Assessment of the Use of Flocculants (PAC) for Settling of Waikato Soil Materials

7.1 Introduction

Coagulants and flocculants are added to water to neutralise surface-charge and induce aggregation so that gravitational forces overcome the effect of Brownian motion and suspended particles settle downwards in the water column (Bratby 2006). However, an excess dose of the coagulant or flocculant may cause charge reversal and restabilisation of suspended particles and changes in pH which will affect aquatic life in the receiving environment (Qasim *et al.* 2000).

The predicted trend was that when the sediment runoff water mixture was treated with flocculants there would be a continuous reduction in turbidity with time and that the highest addition of coagulant or flocculant will settle sediments most rapidly. Therefore, a jar-test experiment was conducted to determine the optimum dose of coagulant or flocculant to be used for coagulation and sedimentation of a range of Waikato soil materials.

Dosage amounts are very important for the optimal performance of coagulants and flocculants (Bratby 2006). The lowest dose at which suspended solids were significantly reduced should be considered as the effective dose.

Polyaluminium Chloride (PAC) is a polymerised form of flocculants and is increasingly being used rather than traditional coagulants such as alum because PAC is a less acidic product, hence has less effect in pH reduction. PAC is also preferred for use in naturally acidic locations because it has less influence on the pH in sensitive receiving waters (Gregory 2006).

According to the Auckland Regional Council, one litre of PAC will treat 8,020 L of stormwater at 8 mg of Aluminium per litre. Hence, for one litre of stormwater, a 1.25×10^4 litres of PAC or 0.125 cm^3 was needed. An experiment was carried out to ascertain whether the recommended dose worked effectively.

Soil material from the same ten samples used to analyse particle size distribution (chapters 4 and 5), was used to assess the effectiveness of PAC on soils from the Waikato region. This chapter explains the experimental procedures used and the results obtained. The full data set is enclosed in Appendix C.

7.2 Experimental Procedure

The method used for the jar-test experiment was adapted from Qasim *et al.* (2000):

- i. Six samples of about 50 grams of field moist soil were weighed for each soil. The samples were then mixed with distilled water and six lots of 1000 ml of soil-water mixture were produced.
- ii. Six tester jars of 1000 ml were filled with the prepared soil-water mixture. The suspension was mixed at 300 rpm for 15 minutes.
- iii. Once the mixing stopped, a dosage of 2.7, 5.3, 8, 10.7 and 13.3 ppm of PAC respectively was added immediately to five tester jars, with the sixth jar acting as a control (with no addition of flocculants).
- iv. A turbidimeter was used to measure turbidity after 30 minutes and 1, 4, 8 and 24 hours. The turbidity of the sample was taken at a depth of 10 cm in each jar, using a 10 ml pipette.
- v. The pH of the sediment-water mixture in each jar was measured with a pH meter after a 24 hour holding period.

7.3 Results and Initial Discussion

7.3.1 pH

Addition of PAC can lead to a decrease in pH especially at the higher concentration of PAC added. Results demonstrated that most of the pH falls between 4.6-6.5 (Table 7.1). All samples were slightly acidic and the acidity increased when higher concentrations of flocculant were added.

7.3.2 Samples Collected at Piarere

All three samples collected from the Piarere site showed similar results. The soil materials of the three samples which had a loamy sand texture (Section 5.5), settled over time as shown in Figures 7.1, 7.2 and 7.3. Addition of 13.3 ppm PAC made the soils aggregate and settle quickly compared with lesser amounts (Figures 7.4, 7.5 and 7.6).

Table 7.1 The pH values of ten samples of soils after treatment with PAC.

PAC Concentration (ppm)	Piarere 1	Piarere 2	Piarere 3	Ngaruawahia 1	Ngaruawahia 2	Ngaruawahia 3	Hamilton Ash Formation	Hinuera Formation Fine Material	Hinuera Formation Coarse Material	Allophanic Soil Material
0	6.77	6.58	6.45	5.12	4.73	6.25	5.96	5.92	7.2	7.29
2.7	6.46	6.11	6.16	4.93	5.44	5.41	5.46	5.67	5.7	5.82
5.3	6.01	5.83	5.72	4.84	4.43	5.83	5.32	5.4	5.67	5.31
8	5.81	5.69	5.45	5.02	4.83	5.42	5.17	5.3	4.83	4.84
10.7	5.6	5.47	5.32	5.11	4.35	5.15	5.04	5.24	4.71	4.63
13.3	5.3	5.38	5.4	5.10	4.5	5.32	4.87	5.27	4.7	4.42

The turbidity gradually decreased with time, and the water clarity increased as illustrated in Figures 7.4, 7.5 and 7.6. The control sample had an average 75% reduction in turbidity at 630 NTU after a 24 hour holding period, while samples treated with 2.7 and 5.3 ppm PAC had an average 80% reduction (590 NTU and 400 NTU, respectively).

After 24 hours, a 99.8% turbidity reduction was achieved for 13.3 ppm of PAC at 4 NTU (Figures 7.1, 7.2 and 7.3). The recommended dose of 8 ppm PAC gave an average of 89% turbidity reduction for all three samples at 154 NTU, while 10.7 ppm PAC resulted in an average reduction of 96% at 65 NTU. Following this, using 10.7 ppm of PAC to treat loamy sand types of soil was recommended because of the optimum results produced. The pH values read after a 24 hours holding period were 5.6 (sample 1), 5.47 (sample 2) and 5.32 (sample 3).

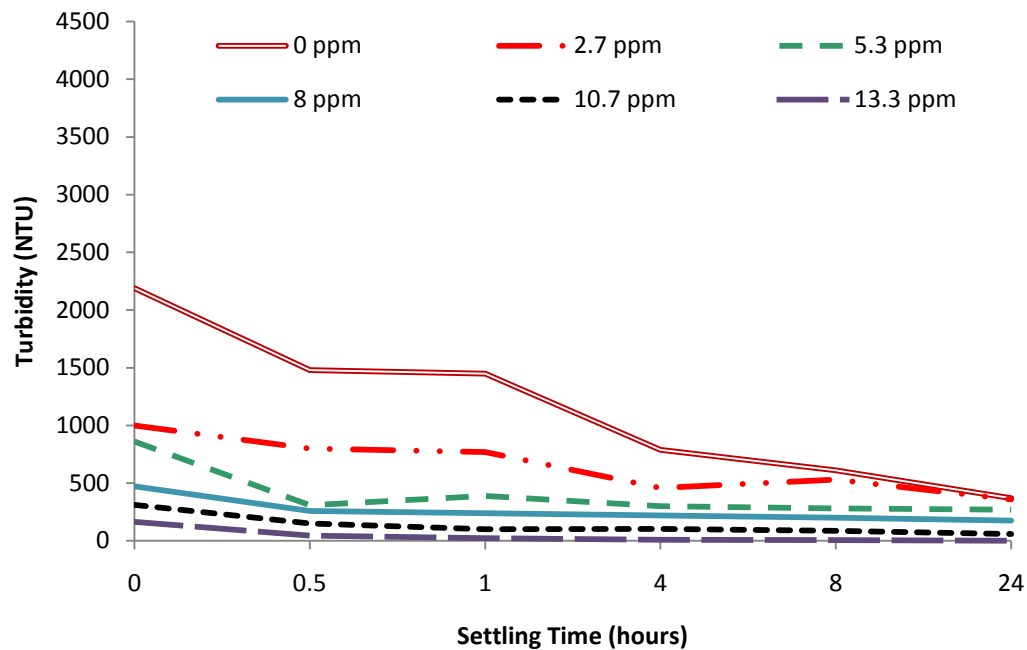


Figure 7.1 Turbidity reductions over a 24-hour period with addition of PAC for Piarere Sample 1.

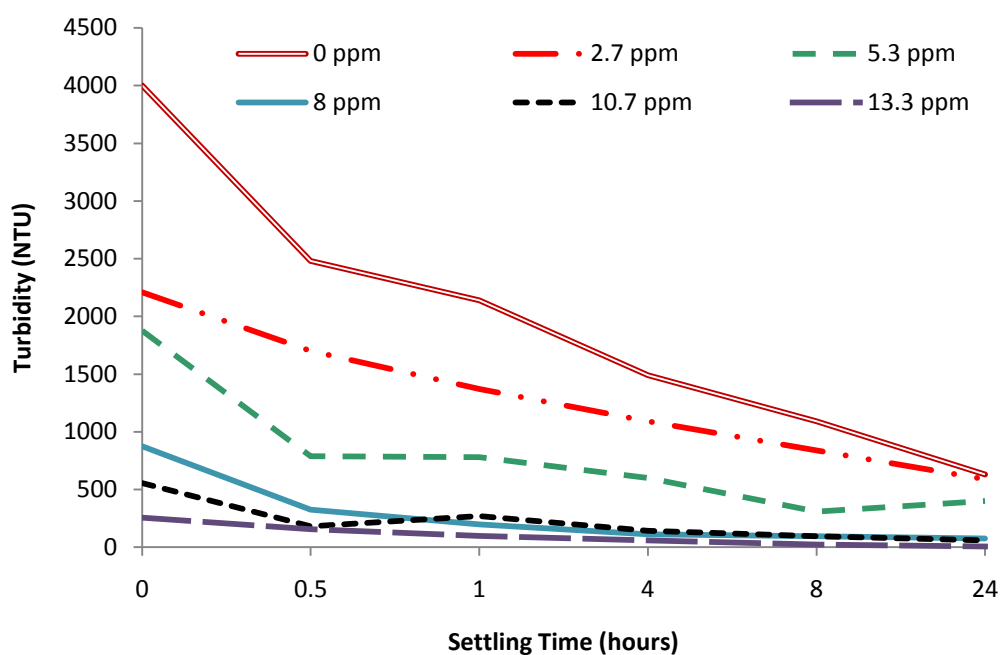


Figure 7.2 Turbidity reductions over a 24-hour period with addition of PAC for Piarere Sample 2.

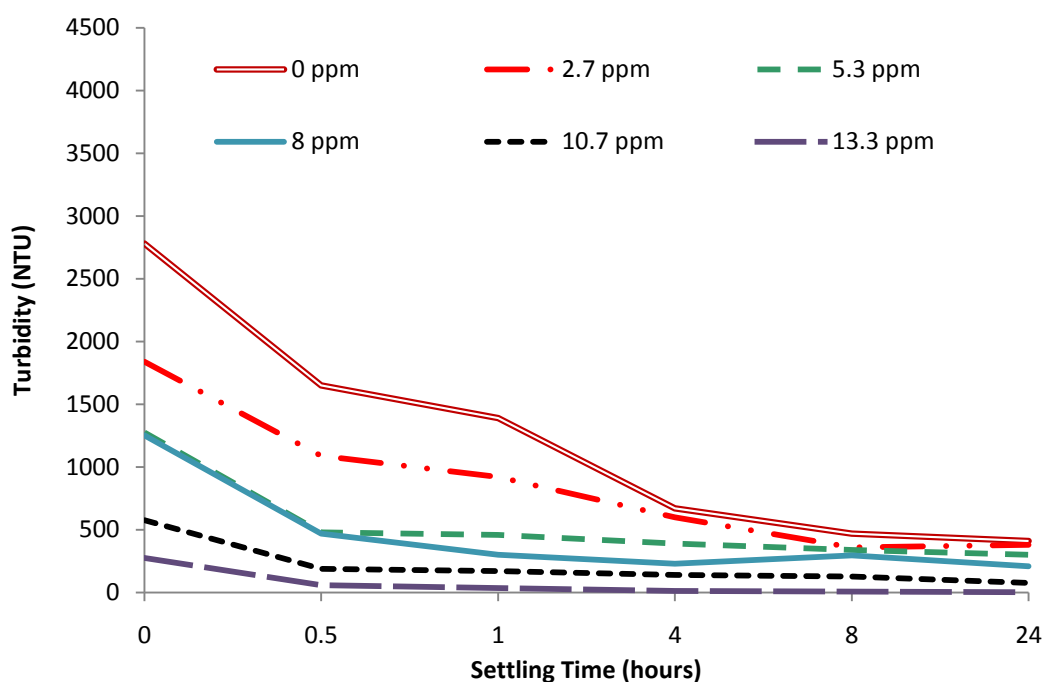


Figure 7.3 Turbidity reductions over a 24-hour period with addition of PAC for Piarere Sample 3.



Before addition of PAC



30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.4 Jar-test of Piarere 1 soil samples.



Before addition of PAC



30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.5 Jar-test of Piarere 2 soil samples.



Before addition of PAC



30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.6 Jar-test of Piarere 3 soil samples.

7.3.3 Samples Collected at Ngaruawahia

i) Ngaruawahia 1 and 2

Both samples 1 and 2 collected at the Ngaruawahia study site showed similar trends and results. Observation using the jar test experiment for loamy silt (sample 1) and silty clay (sample 2) soil textures (Section 5.5) showed abrupt settling within the first two minutes after the mixing stopped and there was no difference with or without addition of flocculants to the soil-water mixture. Most of the soil particles had settled before the first measurement time at 30 minutes (Figures 7.7, 7.8, 7.9 and 7.10).

The initial turbidity level for the control sample was 22,115 NTU and reduced to 17 NTU after 30 minutes. After a 24-hour holding period, the turbidity reading of the control sample had declined to 3 NTU, which indicated a 99% turbidity reduction compared with the initial measurement. As a result, it was considered unnecessary to treat runoff from either Ngaruawahia 1 or Ngaruawahia 2 with flocculants. Addition of PAC at 2.7, 5.3, 8, 10.7 and 13.3 ppm did not indicate any significant differences in turbidity reduction compared with the control samples with the turbidity measurement at 2, 4, 5, and 6 NTU respectively.

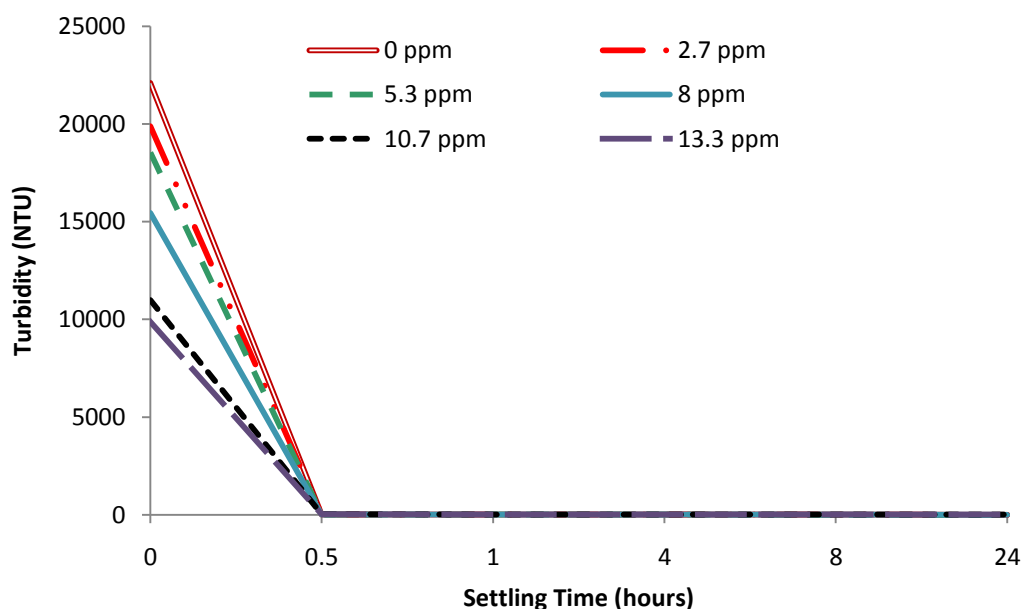


Figure 7.7 Turbidity reductions over a 24-hour period with addition of PAC for Ngaruawahia Sample 1. (Note: Initial turbidity was high for all samples. However, even the control sample settled very rapidly to give the lowest turbidity readings after 30 minutes than any of the other samples).

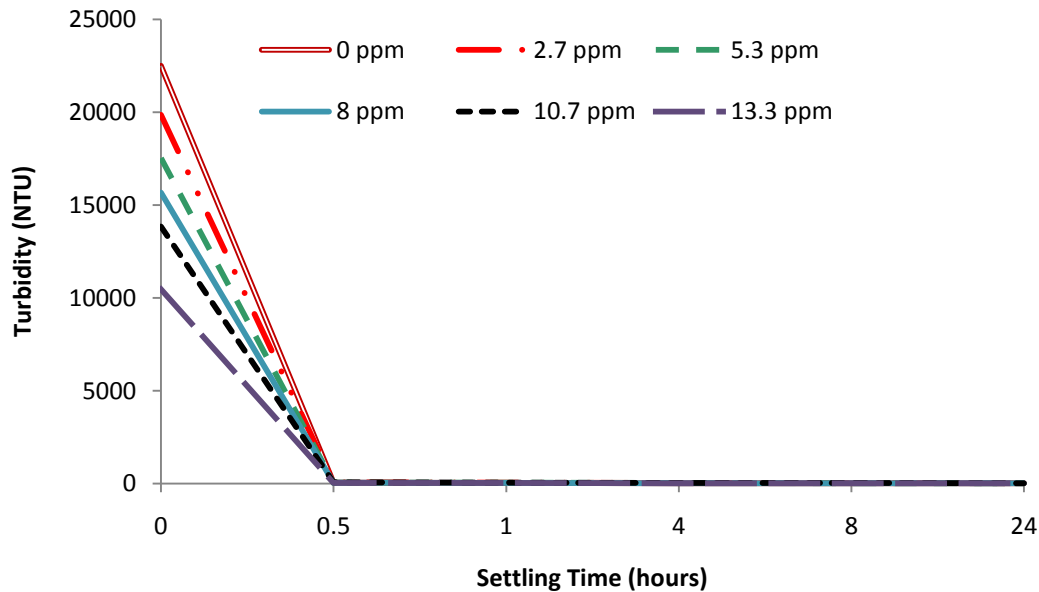


Figure 7.8 Turbidity reductions over a 24-hour period with addition of PAC for Ngaruawahia Sample 2. (Note: Initial turbidity was high for all samples. However, even the control sample settled very rapidly to give the lowest turbidity readings after 30 minutes than any of the other samples).

ii) Ngaruawahia 3

Sample 3 from the Ngaruawahia site behaved differently to samples 1 and 2 by taking much longer to settle. The turbidity gradually decreased with time and treatment with the highest amount PAC at 13.3 ppm made the soil particles settle very quickly compared with lesser concentrations of 2.7, 5.3, 8 and 10.7 ppm (Figures 7.11 and 7.12). It took longer for soil particles in the control sample and samples treated with small amounts of PAC (2.7 and 5.3 ppm) to settle. Visibly, the clarity of control samples showed little difference from the start of the measurement until the end of the 24-hour holding period. The same was observed with the addition of lower concentrations of PAC (2.7 and 5.3 ppm), where the turbidity reduction achieved was 70% and 85% after a 24-hour holding period at 280 NTU and 60 NTU respectively (Figure 7.12).



Before addition PAC



30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.9 Jar-test of Ngaruawahia 1 soil samples.



Before addition of PAC



30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.10 Jar-test of Ngaruawahia 2 soil samples.

A sudden increase in turbidity (Figure 7.11) between the 30 minutes to 1 hour reading for the 0 ppm PAC could be due to resuspension of the samples while collecting the sample with a pipette. Treatment with both 10.7 and 13.3 ppm PAC gave the lowest turbidity value of 3 NTU (99% turbidity reduction) after a 24-hour holding period compared with the initial measurement. The recommended dosage of 8 ppm of PAC gave a similar result at 5 NTU (99.9% reduction) and was sufficient to treat the sediment runoff from Ngaruawahia Sample 3, with a pH value after a 24-hour holding period of 5.42.

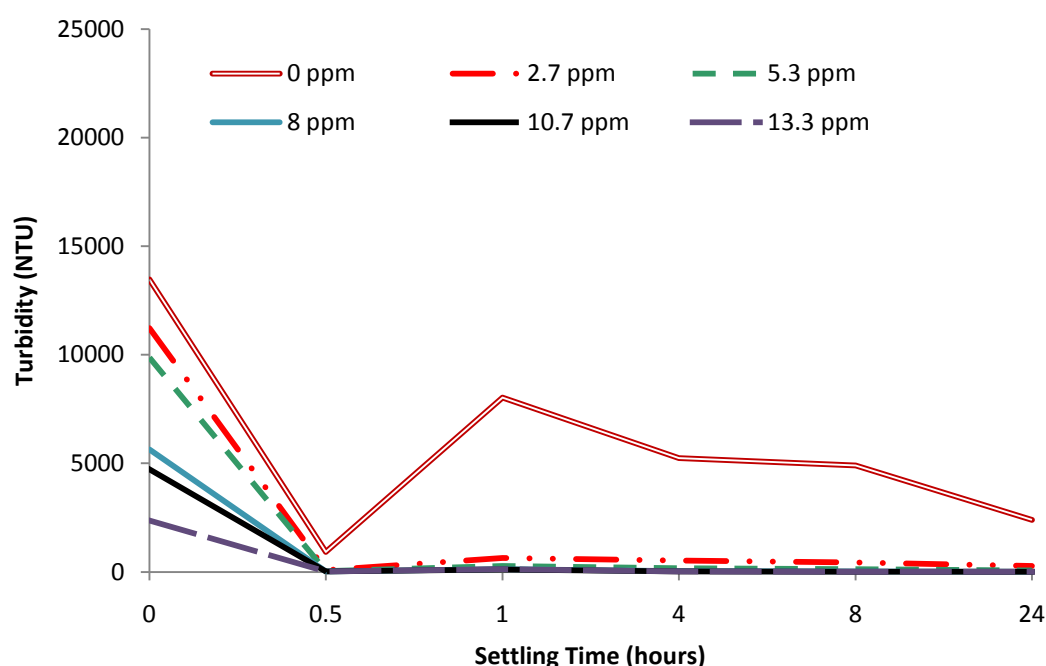


Figure 7.11 Turbidity reductions over a 24-hour period with addition of PAC for Ngaruawahia Sample 3.

7.3.4 Hamilton Ash Samples

The settling behaviour of samples collected from the Hamilton Ash formation with a clayey texture (Section 5.5) was a bit different than predicted. Overall, the water clarity gradually increased with time especially after 4, 8 and 24-hour holding periods (Figures 7.13 and 7.14). The soil particles started to aggregate and flocs were formed and settled immediately for 2.7, 5.3, 8 and 10.7 ppm PAC (Figure 7.14). However, addition of 13.3 ppm PAC took much longer to settle. There was not much difference in turbidity for the first 30 minutes and also after 1 hour of 13.3 ppm PAC being added. However, turbidity reduction was observed after 4 hours, and the water clarity increased after a 24-hour holding period of 13.3 ppm PAC treatment between 30 minutes and 24 hours (Figure 7.14).



Before addition of PAC



30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.12 Jar-test of Ngaruawahia 3 soil samples.

The initial turbidity reading was quite high at 2420 NTU for the control sample, which gradually decreased with time to 660 NTU after 24 hours, giving a 73% turbidity reduction (Figure 7.14). The five samples treated with flocculants at 2.7, 5.3, 8, 10.7 and 13.3 ppm had a 99 % turbidity reduction after a 24-hour holding period. Both 8 and 10.7 ppm gave the best measurement at 2 NTU, while 5.3 and 13.3 ppm indicated a turbidity measurement of 4 NTU, and 2.7 ppm gave a measurement of 21 NTU. Therefore, it is suggested that treating runoff from Hamilton Ash formation with 2.7 ppm of PAC is sufficient with optimum residence time to produce clear water before discharging into the downstream recipient waters, with a pH value of 5.46 after a 24-hour holding period.

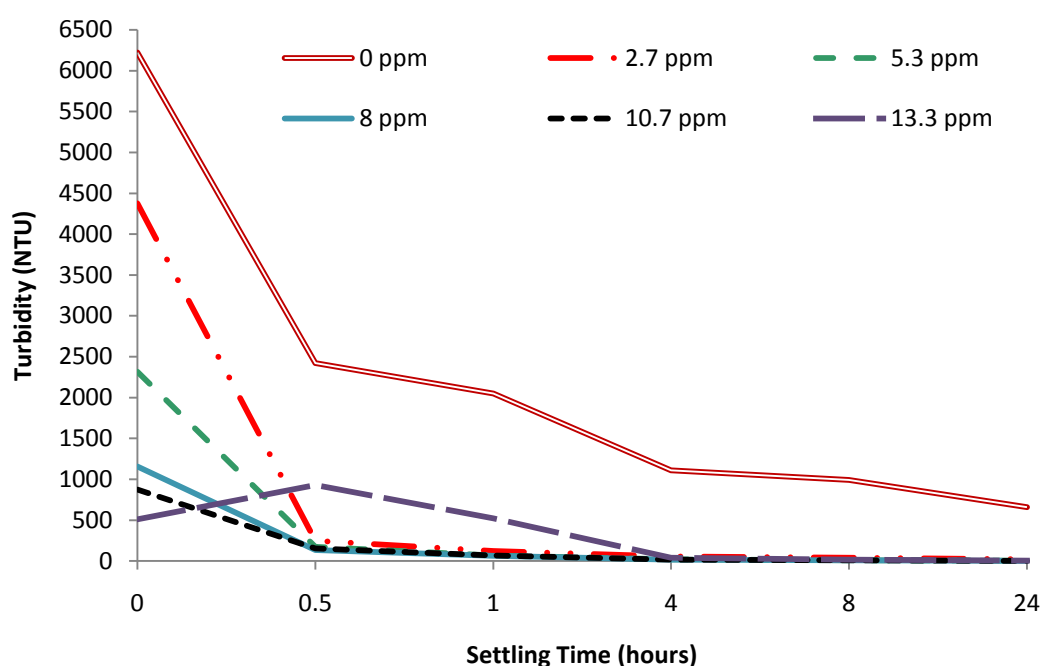


Figure 7.13 Turbidity reductions over a 24-hour period with addition of PAC for Hamilton Ash samples.

7.3.5 Hinuera Formation (Fine Material) Samples

The settling rate of soil samples from the Hinuera Formation (fine materials), with a sandy loam texture (section 5.5), was as predicted (Figures 7.15 and 7.16). The sample treated with the highest amount of PAC (13.3 ppm) visibly settled within the first 30 minutes to reach a turbidity of 144 NTU. The same occurred with samples treated with 10.7 and 8 ppm of PAC.



Before addition of PAC



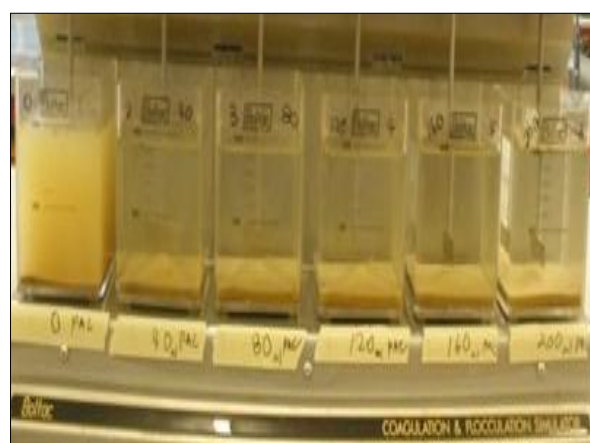
30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.14 Jar-test of Hamilton Ash soil samples.

It took longer for the sample treated with 5.3 ppm PAC to settle, with nearly eight hours passing before turbidity was reduced to 497 NTU. The control sample (no addition of PAC) and the sample treated with 2.7 ppm PAC, showed little turbidity reduction, with measurements of 920 NTU (2.7 ppm) and 1080 NTU (control sample) after a 24-hour of settling period (Figures 7.15 and 7.16)

All three dosages of PAC at 13.3 ppm, 10.7 ppm, and 8 ppm had a 99% turbidity reduction after 24 hours. Samples treated with 13.3 ppm PAC had the highest water clarity after a 24-hour holding period (3 NTU). Treatment with 10.7 ppm PAC gave a reading of 6 NTU, while treatment with 8 ppm PAC gave a reading of 57 NTU after 24 hours. Although the recommended dose of 8 ppm was the optimum dosage of PAC, 5.3 ppm would be sufficient to treat runoff from the Hinuera Formation fine materials, with a 96% turbidity reduction (171 NTU) after a 24-hour holding period and a pH value of 5.67.

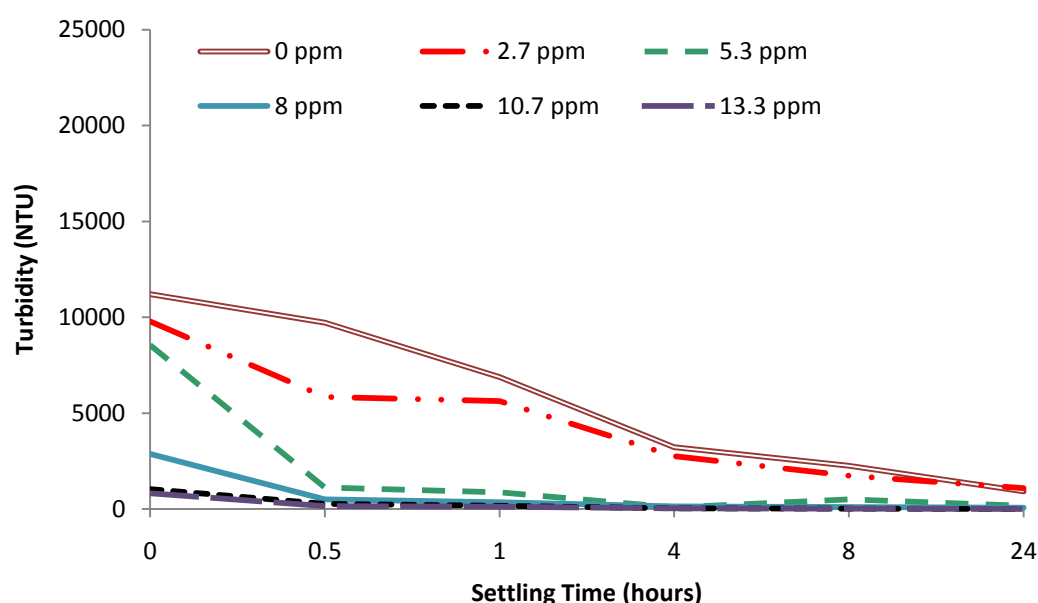


Figure 7.15 Turbidity reductions over a 24-hour period with addition of PAC for Hinuera Formation (fine material) samples.



Before addition of PAC



30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.16 Jar-test of Hinuera Formation (fine material) soil samples.

7.3.6 Hinuera Formation (Coarse Material) Samples

The settling rate of soil samples from the Hinuera Formation (coarse materials) with a sandy texture (section 5.5) behaved as predicted, conforming to Stokes' Law that coarser particles will settle more rapidly than finer soil materials (Figures 7.17 and 7.18).

Observation throughout 24 hour retaining periods showed that although the soil materials had settled, the colour of the suspension remained and influenced the turbidity and clarity of the samples. Visibly, small differences existed between the control sample and five other samples treated with different concentrations of PAC because of the colour of the samples (Figure 7.18), possibly caused by the concentration of iron in the soil materials or dissolved tannin extracted from decaying plant materials. The colours of all six samples start to fade only after 8 hours and after 24 hours the water clarity increased (Figure 7.18).

The control sample had a 72% turbidity reduction over 24 hours to 83 NTU. Samples treated with 2.7 and 5.3 ppm PAC had a 65% (70 NTU) and 76% (71 NTU) turbidity reduction respectively. Both 8 and 10.7 ppm PAC gave a relatively close result with the turbidity measurements of 63 and 61 NTU respectively (a 79% reduction). Treatment with 13.3 ppm PAC produced an 80% reduction at 60 NTU. Based on these results, applying 8 ppm of PAC to treat sediment-laden runoff of coarser materials from the Hinuera Formation is sufficient with a pH value after 24 hours of 4.83.

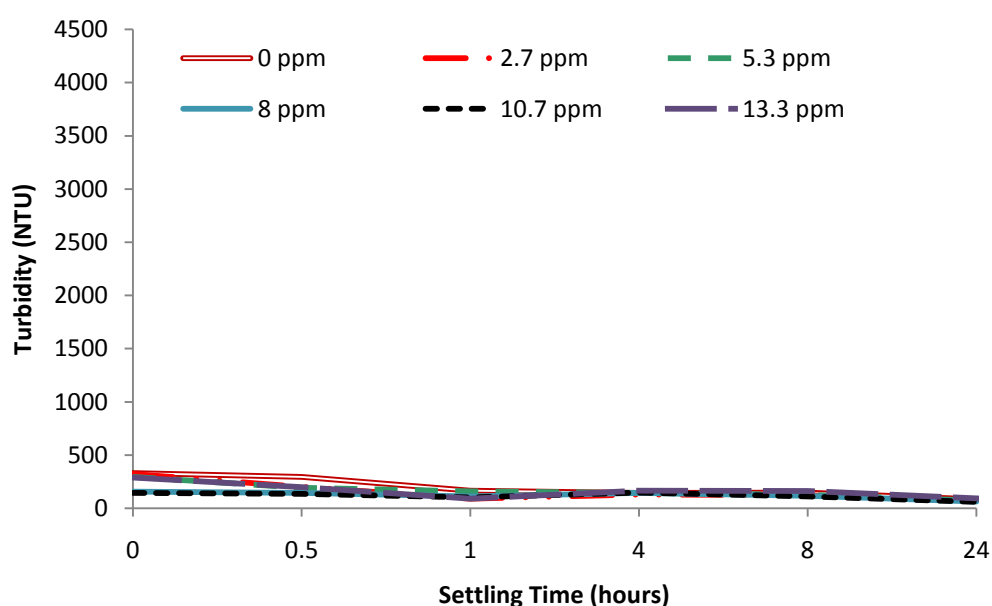


Figure 7.17 Turbidity reductions over a 24-hour Period with addition of PAC for Hinuera Formation (coarse material) samples.



Before addition of PAC



30 minutes



1 hour



4 hours



8 hours



24 hours

Figure 7.18 Jar-test of Hinuera Formation (coarse material) soil samples.

7.3.7 Allophanic Soil Materials

The settling behaviour of allophanic soil samples with a loamy sand texture (section 5.5) showed peculiar characteristics. Observation during the experiment showed that soil samples with 0 ppm PAC settled more rapidly than those treated with PAC (Figures 7.19 and 7.20). Visibly, samples treated with 2.7, 5.3, 8 and 10.7 ppm PAC produced higher clarity compared with samples treated with 13.3 ppm PAC after 4 hours (Figure 7.20).

Only after 8 hours did the clarity of samples in the five jar tests treated with flocculants start to improve. However, treatment with 13.3 ppm PAC showed very slow progress and it was only after 24 hours that water clarity in the jar-test increased.

The soil particles settled without the assistance of flocculants, with a turbidity value of 1.35 NTU after a 24-hour holding period for the control sample (a 97% reduction). On average a 97% turbidity reduction was achieved after 24 hours for the five other samples treated with PAC.

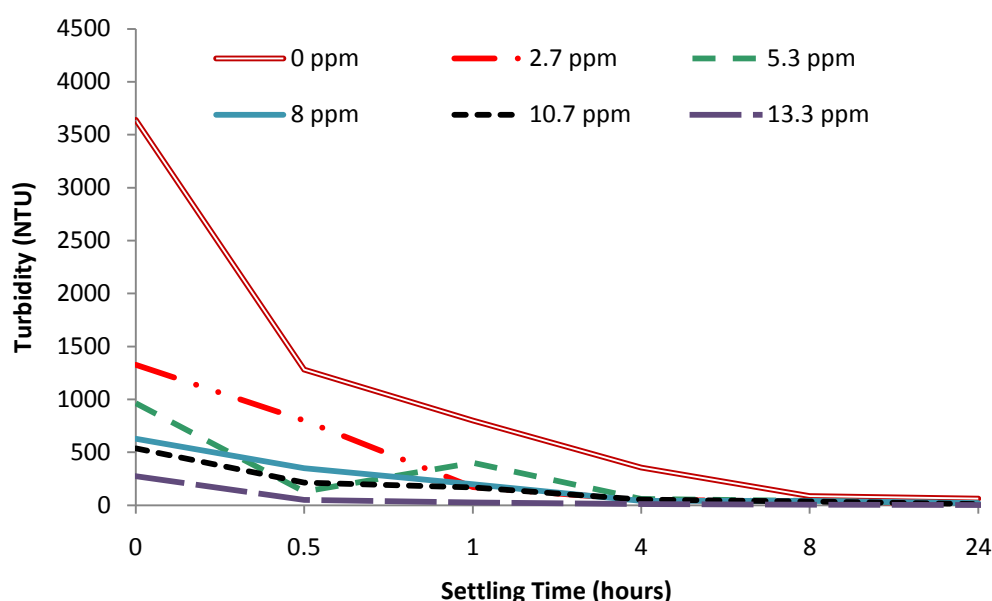


Figure 7.19 Turbidity reductions over a 24-hour period with addition of PAC for allophanic soil materials. Note: Experiment was repeated twice to confirm the result.

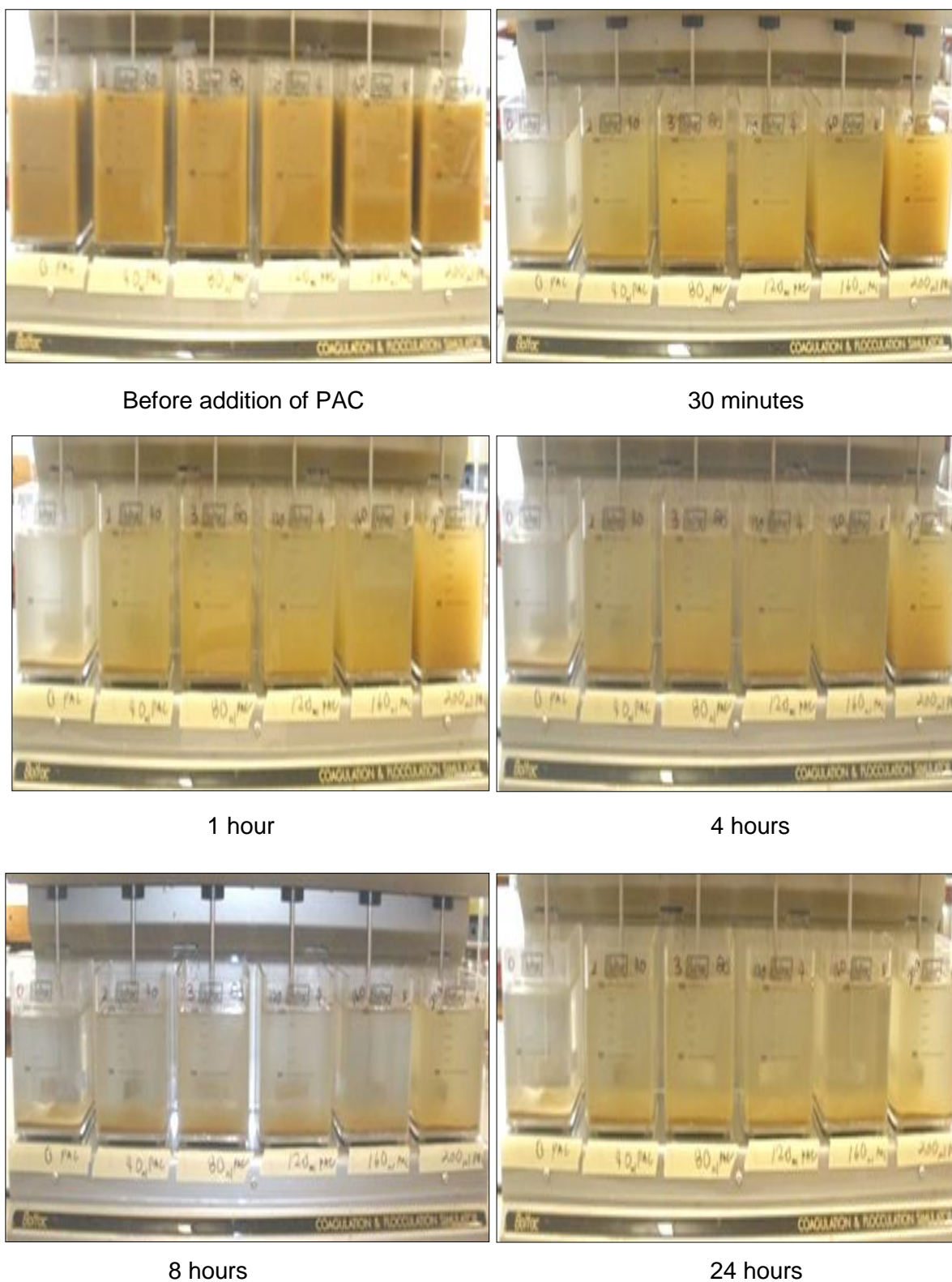


Figure 7.20 Jar-test of allophanic soil materials.

7.4 Discussion

7.4.1 pH

The optimum aluminium dose (mg L^{-1}) provides the greatest clarity for the smallest change in pH, as high concentrations of PAC can decrease pH levels (Auckland Regional Council 2004a). Water clarity however, has to be over 100 mm depth visibility (Auckland Regional Council 1999) or must not exceed 280 NTU of turbidity measurement for discharge from a construction site (USEPA 2009).

Addition of 13.3 ppm PAC gave the highest turbidity reduction (mean 99%) for seven samples (Piarere 1, Piarere 2, Piarere 3, Ngaruawahia 3, Hamilton Ash Formation, and fine and coarse materials of Hinuera Formation) compared with lesser amounts of PAC. However, the concentration level of aluminium (Al) based coagulants or flocculants used is of concern as they may induce a threat of toxicity.

One of the primary concerns with the concentration of PAC used is the high correlation of aluminium toxicity to pH. According to USEPA (2008) freshwater ambient water quality criteria for dissolved aluminium are as follows:

Chronic: 0.087 mg L^{-1} (4 day average not to be exceeded)	} at a pH between 6.5 and 9.0
Acute: 0.750 mg L^{-1} (1 hour average not to be exceeded)	

It is generally accepted that dissolved aluminium at concentrations between 0.050 and 0.100 mg L^{-1} and a pH range of 6.5-8.0 presents little threat of toxicity. However, at lower pH, the toxicity increases with an effect of possible major concern being the coagulation of mucus on the gills of fish. Cationic polymeric material is known to exhibit higher toxicity for gill blockage in fish, which causes ion regulatory dysfunctions and suffocation (Poleo 1995). This is mitigated by the presence of solids and organic matter, to which cationic amendments such as PAC readily adsorb (Bolto 1995; Droppo *et al.* 2008)

The pH values, as tabulated in Table 7.1, show that the mean pH for samples treated with PAC was 5.3, while the recommended dosage of 8 ppm gives an average pH of 5.4. All control samples gave an average pH value of 6.2. Addition of 10.7 and 13.3 ppm PAC gave a mean pH value of 5.2.

It is important not to overdose with added flocculants because overdosing will lower the pH, posing a threat of toxicity to aquatic species (Sansalone & Kim

2008). The addition of aluminium (Al (III)) based chemicals to water is similar to an acidimetric titration of the water (Droppo *et al.* 2008). As a result, the pH of the system after the addition of flocculants will depend upon the flocculants dosage and the alkalinity of water.

As the mortality of fish is predominantly higher in environments with a pH below 5, especially in some life stages (egg, larvae, fry and juvenile) of certain fish species (Bolto 1995), the pH values obtained from the jar test experiment were still within acceptable limits. This is probably most important when pH is less than 4.5, when acidic aluminium-rich water is acutely toxic to fish. The aluminium polymerization process seems to be the most important factor contributing to acute hypoxic death in fish (Poleo 1995).

7.4.2 Settling Characteristics with Different Amounts of PAC

Comparison of the settling characteristics of the replicate suspensions with different amounts of flocculants (0, 2.7, 5.3, 8, 10.7, 13.3 ppm) showed variations which could relate to the effects of flocculants on soil particle settling behaviour. There was a lack of rapid onset of settling in the suspensions, evidenced by high turbidity measurements in the initial stages. A possible reason for this observation relates to the rate of floc formation

Under gravity settling, heavier particles fall rapidly out of suspension, leaving the lighter ones in suspension, while in flocculated settling, flocs are made up of all the particle sizes present in suspension (Bratby 2006). Unflocculated grains settled one size at a time, heavier ones settling first, leaving lighter particles in suspension. In the flocculated suspensions, particles of all sizes settle at the same rate leaving a clear liquid column above because floc settling is not affected by particle size (Bratby 2006).

In this study measurements were only done up to 24 hours because findings from a study by Amudda and Aladeb (2006) showed that above a 24-hour holding period, the turbidity and suspended solids removal efficiency is almost constant.

From observations made in the jar-test experiment, all the heavier particles had settled out after the first 30 minutes and most of the finer particles such as clay and fine silt from the suspension settled after the 24-hour holding period. This agreed with the theory of Stokes' Law that after a certain period of time, the

amount of finer particles decreases (more rapid with treatments), even without any addition of flocculants.

With the exception of three soil samples (samples 1 and 2 of Ngaruawahia and allophanic soil materials), which behave differently than expected, addition of PAC as a flocculant resulted in significant reductions in turbidity and improved clarity of the water, with reductions of more than 95% on average for all soil samples investigated.

7.4.3 Different Soil Behaviour

Samples 1 and 2 from the Ngaruawahia study site and the allophanic soil materials of the B horizon from Horotiu soil behave differently when treated with PAC (Figures 7.9, 7.10 and 7.20). Findings from the jar-test experiment showed that Ngaruawahia samples 1 and 2, and the allophanic soil material do not require treatment with flocculants.

Abrupt and rapid settlement of Ngaruawahia samples 1 and 2 for each jar treated with different concentrations of PAC, including the control sample (no addition of PAC), was observed within 2-3 minutes when mixing stopped. This strange behaviour from the silty clay types of soils (Section 5.5) may be attributed to the mineralogy of clay particles.

Although soil materials of samples 1 and 2 from Ngaruawahia do not require treatment with flocculants, soil materials of sample 3 from Ngaruawahia do need treatment with flocculants to speed up settling and reduce turbidity. Hence, installing a rainfall driven PAC dosing system at the sediment retention pond at Ngaruawahia improves the rate of sediment settling.

In the case of allophanic soil materials, there would be a possibility of charge reversal causing them to disperse instead of flocculating and settling. According to Haan et al. (1996) charge reversal can sometimes occur as a result of overdosing when using a trivalent ion (three positive charges) such as aluminium based flocculants and in the case of this study, with PAC.

In contrast to general clay materials, allophanic soil materials have a cation exchange capacity (CEC), which makes them possess comparable amounts of positive and negative charges in the pH range 3-9 and these charges are pH-dependent (Iimura 1961). This may explain the peculiar observation made during

the jar-test experiment for allophanic soil materials (Figure 7.20). Allophanic soil materials may be dispersible into extremely small particles or may be essentially nondispersible in water because of its variable charges (Rao 1995).

7.5 Conclusion

It can be concluded from the jar-test experiments that addition of flocculants such as PAC are effective for treating water in high suspended sediment environments.

Apart from the three samples that behaved differently (Ngaruawahia 1, Ngaruawahia 2, and allophanic soil materials) by settling rapidly without the assistance of flocculants, seven samples (Piarere 1, Piarere 2, Piarere 3, Hamilton Ash Formation, Hinuera fine and coarse materials) showed a mean of 95% reduction in turbidity measurements over the 24-hour holding period.

While adding amendments such as those studied here may be an effective way to reduce suspended sediment concentrations, care must be taken to ensure that the amendments do not produce toxicological effects or community structural changes within the aquatic environment. Nonetheless, if an amendment can form flocs that effectively increase the rate of settling, with no toxicological effects, it may be an effective agent for the management of high turbidity environments.

7.6 Summary

Findings from the assessment of the use of PAC to treat a range of Waikato soil materials showed that:

- ❑ A PAC dose of 10.7 ppm L⁻¹ was optimum for Piarere 1, Piarere 2 and Piarere 3 samples which were characterised as loamy sand.
- ❑ A PAC dose of 8 ppm L⁻¹ was sufficient to treat sandy types of soil material such as Hinuera Formation coarse material and sandy loam types of soil such as Ngaruawahia 3.
- ❑ A PAC dose of 5.3 ppm L⁻¹ was optimum to treat sample of fine materials from the Hinuera Formation.
- ❑ 2.7 ppm of PAC per litre was sufficient to treat clayey types of soil such as Hamilton Ash Formation.

- ❑ Flocculants should not be used on allophanic soil materials as variable changes in the surface charges in low pH will cause them to disperse instead of flocculating.
- ❑ Samples 1 and 2 from Ngaruawahia study site, which were characterised as silty clay, also do not have to be treated with flocculants because they are able to settle rapidly at 0 ppm of PAC.
- ❑ Jar-testing results reveal that there was variability between the optimum dose of PAC and soil materials. Thus, performing the jar-test experiment before setting up a PAC dosing site is vital to avoid spending money unnecessarily on treating soil materials with flocculants. Jar-testing would also prevent overdosing with flocculants and large decreases in pH which are the primary concern for potential toxicity to aquatic species.

Chapter 8

Conclusions

8.1 Introduction

Activities on earthwork sites cause erosion of soils and it is imperative to trap the resulting sediment to protect waterways. Current Waikato sediment retention pond design is based on guidelines developed by the Auckland Regional Council. As soils in the Auckland and Waikato Regions are different, there is a need to better understand the sedimentation behaviour of the soil materials in the Waikato Region to investigate the effectiveness of sediment retention ponds in retaining sediments from different soil materials.

The primary aim of this research was to investigate the effectiveness of sediment retention ponds designed for the different types of soils and conditions specific to the Waikato Region. Sampling of typical soil materials in the Waikato region was undertaken in order to characterise the fractions of sand, silt and clay as well as to investigate the use of chemical treatment for different soil materials. Two active earthwork sites were chosen as reference points to achieve the aim of this research. Each area consisted of a catchment with sediment runoff to a sediment retention pond.

This chapter summarises the major findings in answering the specific objectives of this study which were to:

- i) do a comparison between pipette, hydrometer and lasersizer methods for determining soil particle size and to characterise the sand, silt and clay in a range of Waikato soil materials,
- ii) evaluate turbidity and suspended solid concentrations between the inlet and outlet of sediment retention ponds, and
- iii) investigate the use of chemical treatment (flocculants) in assisting sediment settling.

8.2 Major Findings

8.2.1 Comparison of Particle Size Analysis Methods

Ten samples representing a range of Waikato soil materials were collected. Samples included soil materials from active earthwork sites (weathered rock materials) as well as from four typical soil materials in the Waikato Region, weathered tephra, fine and coarse textured alluvium and allophanic soil materials. The aim was to compare the effectiveness of three methods of particle size determination. Particle size distribution was determined using hydrometer, pipette and lasersizer analysis. Three replications of each sample were used for each method of analysis.

There was an excellent agreement between the pipette and hydrometer methods for all ten samples. Comparison between pipette-hydrometer and lasersizer showed relatively good agreement for six samples. However, some significant differences between the lasersizer and the pipette and hydrometer methods were identified for four samples. Each method gave good replication as shown by the error bars in Figures 5.3 and 5.4.

Pipette, hydrometer, and lasersizer analysis each had advantages and disadvantages. There was no definite proof that one method is better than the other because each method is based on different principles and theory. Both pipette and hydrometer analysis involved sieving and sedimentation techniques following Stokes' Law, while the basis for lasersizer analysis is light diffraction through a given angle by soil particles. Based on the experiments done the pipette method would be the recommended technique to perform particle size analysis of soil materials because of its reliability and the direct measurement involved. However, in many situations the lasersizer may provide a quicker method with adequate results.

8.2.2 Characterisation of Waikato Soil Materials

The soil materials tested ranged from sand to clay, demonstrating the wide range of soil materials in the Waikato region. Characterisation of soil materials from the earthwork sites is important to help in understanding the behaviour of soils especially the settling behaviour, infiltration rate and erodibility.

8.2.3 Effectiveness of Sediment Retention Ponds

Sediment samples were collected over two months from the inlets and outlets of sediment retention ponds at two active earthwork sites. The Piarere site comprised sand dominated material from unwelded ignimbrite. The Ngaruawahia site comprised strongly weathered silty clay derived from greywacke and older tephra. A flocculant (PAC) was in use at Ngaruawahia.

Samples collected at the inlet and outlet of sediment retention ponds were analysed for suspended solids and turbidity. Collection times were associated with rainfall events with a minimum of 2 mm rain.

At the sandy Piarere site, there was a large reduction in suspended solids (97%) and turbidity (94%) between pond inflow and outflow. At the silty Ngaruawahia site, there was also a large reduction in suspended solids (97%) and turbidity (95%) between the inlet and outlet except for a sampling period between 2nd and 11th August 2009. During this period, the inflow had very low suspended solids and turbidity and the inlet water samples were clear, indicating that the rainfall, while sufficient to set the sampler off, was not sufficient to cause overland flow and sediment entrainment.

Both ponds were effective in trapping and retaining sediment runoff from earthwork catchment areas as determined by suspended solids concentrations and turbidity measurement.

8.2.4 Chemical Treatment

The recommended dose for aluminium based flocculants (PAC) used to treat one litre of stormwater is 8 ppm based on the research done by Auckland Regional Council (2004b).

Jar-test experiments were performed on the same soil samples that were used for particle size analysis. Six tester jars were used in the experiment. The first jar was a control with no flocculants added, while the other five jars contained different concentrations of PAC at 2.7, 5.3, 8, 10.7 and 13.3 ppm. The aim was to observe the turbidity reduction achieved after 24 hours with different strengths of PAC and to investigate the need for chemical treatment, and the most effective dose of flocculants to use in sediment retention ponds installed at active earthwork sites.

The experiment showed that runoff from Ngaruawahia 1, Ngaruawahia 2 and allophanic soil materials do not need to be treated with flocculants because in the case of Ngaruawahia 1 and 2, the control sample with 0 ppm PAC was just as effective as higher doses, while the addition of PAC to allophanic soil materials had a dispersing effect due to the soil's variable charges and a net positive charge when the pH drops. Runoff from other soil materials such as the Hinuera Formation (fine materials), sample 3 from Ngaruawahia and all three samples collected from the Piarere study sites would benefit from chemical treatment.

Treatment with PAC certainly increased the water clarity and produced a large reduction in turbidity with an overall mean reduction of 95% for 8 ppm and 99% for both 10.7 ppm and 13.3 ppm for the three samples from Piarere, Ngaruawahia 3, fine and coarse materials of Hinuera Formation and Hamilton Ash Formation. The recommended dose of 8 ppm L⁻¹ was sufficient to treat soil samples from coarse materials of Hinuera Formation and Ngaruawahia 3. However, some soil materials only need to be treated with less than 8 ppm of PAC such as in the case of Hamilton Ash at 2.7 ppm and Hinuera Formation (coarse material) at 5.3 ppm. For three samples collected at the Piarere study sites, although 8 ppm gave reasonable flocculation, 10.7 ppm was considered an optimum dose of PAC.

Care has to be taken with the concentration of PAC used because of the aluminium toxicity which could impose a threat to the aquatic life of downstream rivers or streams especially at the lower pH. Thus, measuring the pH of runoff after treatment with PAC is vital.

8.3 Conclusions

It can be concluded from the findings that determining the particle size distribution of soil materials is important in order to understand the soils' settling behaviour. Soil materials at earthwork sites in the Waikato Region may be highly variable, ranging from sand to clay.

Sediment retention ponds are effective in trapping and retaining sediment runoff. However, sediment retention ponds designed according to the specific types of soil at the particular earthwork sites (sandy, silty, loamy or clayey), could be more cost effective and beneficial to both earthwork operators and regional council than using the same design for all sediment retention ponds, regardless of soil types.

The addition of flocculants such as PAC may improve the water clarity and accelerate the settling rate of soil materials. The effectiveness of flocculants depends on soil mineralogy and not all soil materials will respond to treatments with flocculants. Due to the wide range of soil materials in the Waikato region, performing a jar-test experiment is necessary to identify the most effective dosing rate for flocculants at any specific site.

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Soil Sample	Piarere Sample 2												Soil Texture		
Method	Hydrometer					Pipette			Lasersizer						
Reading	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation
% of Sand	70.20	71.27	71.22	70.90	0.60	70.20	71.27	71.22	70.90	0.60	65.93	66.65	62.63	65.07	2.14
% of Silt	22.03	24.28	21.78	22.70	1.38	21.93	24.62	21.95	22.83	1.55	33.39	32.50	36.45	34.11	2.07
% of Clay	3.11	4.16	2.07	3.11	1.05	3.23	2.59	2.58	2.80	0.37	0.67	0.85	0.92	0.81	0.13
Total	95.34	99.71	95.07			95.36	98.48	95.75			99.99	100.00	100.00		

Std Deviation	Hydrometer	Pipette	Lasersizer
% Sand	0.60	0.60	2.14
% Silt	1.38	1.55	2.07
% Clay	1.05	0.37	0.13

% Silt			
Hydrometer	Lasersizer	Pipette	t-test
22.03	33.39		
24.28	32.5		
21.78	36.45		0.00238

% Silt			
Hydrometer	Pipette	t-test	
22.03	21.93		
24.28	24.62		
21.78	21.95		0.914589

% Silt		
Pipette	Lasersizer	t-test
21.93	33.39	
24.62	32.5	
21.95	36.45	0.002229

% Clay			
Hydrometer	Lasersizer	t-test	
3.11	0.67		
4.16	0.85		
2.07	0.92		0.06039

% Clay			
Hydrometer	Pipette	t-test	
3.11	3.23		
4.16	2.59		
2.07	2.58		0.664336

% Clay		
Pipette	Lasersizer	t-test
3.23	0.67	
2.59	0.85	
2.58	0.92	0.00643

% Sand			
Hydrometer	Lasersizer	t-test	
70.2	65.93		
71.27	66.65		
71.22	62.63		0.03429

% Sand			
Hydrometer	Pipette	t-test	
70.2	70.2		
71.27	71.27		
71.22	71.22		1

% Sand		
Pipette	Lasersizer	t-test
70.2	65.93	
71.27	66.65	
71.22	62.63	0.034287

A1-III

Soil Sample	Ngaruawahia Sample 1														Soil Texture
Method	Hydrometer					Pipette					Lasersizer				
Reading	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation
% of Sand	11.34	19.86	17.06	16.09	4.34	11.34	19.86	17.06	16.09	4.34	29.06	26.89	32.65	29.53	2.91
% of Silt	27.65	31.91	28.78	29.45	2.21	37.43	29.80	31.74	32.99	3.97	54.42	52.23	50.06	52.24	2.18
% of Clay	63.11	52.66	52.78	56.18	6.00	50.52	50.29	50.40	50.40	0.12	16.16	20.25	16.83	17.75	2.19
Total	102.1	104.43	98.62			99.29	99.95	99.2			99.64	99.37	99.54		

Std Deviation	Hydrometer	Pipette	Lasersizer
% Sand	4.34	4.34	2.91
% Silt	2.21	3.97	2.18
% Clay	6.00	0.12	2.19

% Silt	Hydrometer	Lasersizer	t-test
27.65	54.42		
31.91	52.23		
28.78	50.06	0.00022	

% Silt	Hydrometer	Pipette	t-test
27.65	37.43		
31.91	29.8		
28.78	31.74	0.265678	

% Silt	Pipette	Lasersizer	t-test
37.43	54.42		
29.8	52.23		
31.74	50.06	0.004582	

% Clay	Hydrometer	Lasersizer	t-test
63.11	16.16		
52.66	20.25		
52.78	16.83	0.003856	

% Clay	Hydrometer	Pipette	t-test
63.11	50.52		
52.66	50.29		
52.78	50.4	0.237061	

% Clay	Pipette	Lasersizer	t-test
50.52	16.16		
50.29	20.25		
50.4	16.83	0.0014625	

% Sand	Hydrometer	Lasersizer	t-test
11.34	29.06		
19.86	26.89		
17.06	32.65	0.015149	

% Sand	Hydrometer	Pipette	t-test
11.34	11.34		
19.86	19.86		
17.06	17.06	1	

%Sand	Pipette	Lasersizer	t-test
11.34	29.06		
19.86	26.89		
17.06	32.65	0.0151492	

Soil Sample	Ngaruawahia Sample 2															Soil Texture
Method	Hydrometer					Pipette					Lasersizer					
Reading	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation	Silt Loam
% of Sand	26.00	27.07	24.23	25.77	1.43	26.00	27.07	24.23	25.77	1.43	28.55	29.91	29.95	29.47	0.80	
% of Silt	42.13	46.81	37.50	42.15	4.66	39.17	42.14	44.22	41.84	2.54	61.48	58.68	60.87	60.34	1.47	
% of Clay	29.17	26.69	31.81	29.22	2.56	26.71	22.83	28.30	25.95	2.81	9.97	11.41	9.18	10.19	1.13	
Total	97.30	100.57	93.54			91.88	92.04	96.75			100.00	100.00	100.00			

Std Deviation	Hydrometer	Pipette	Lasersizer
% Sand	1.43	1.43	0.80
% Silt	4.66	2.54	1.47
% Clay	2.56	2.81	1.13

% Silt			
Hydrometer	Lasersizer	t-test	
42.13	61.48		
46.81	58.68		
37.5	60.87	0.014435	

% Clay			
Hydrometer	Lasersizer	t-test	
29.17	9.97		
26.69	11.41		
31.81	9.18	0.001957	

% Sand			
Hydrometer	Lasersizer	t-test	
26	28.55		
27.07	29.91		
24.23	29.95	0.027572	

% Silt			
Hydrometer	Pipette	t-test	
42.13	39.17		
46.81	42.14		
37.5	44.22	0.92714	

% Clay			
Hydrometer	Pipette	t-test	
29.17	26.71		
26.69	22.83		
31.81	28.3	0.21064	

% Sand			
Hydrometer	Pipette	t-test	
26	26		
27.07	27.07		
24.23	24.23	1	

% Silt			
Pipette	Lasersizer	t-test	
39.17	61.48		
42.14	58.68		
44.22	60.87	0.00120514	

% Clay			
Pipette	Lasersizer	t-test	
26.71	9.97		
22.83	11.41		
28.3	9.18	0.0047853	

% Sand			
Pipette	Lasersizer	t-test	
26	28.55		
27.07	29.91		
24.23	29.95	0.02757175	

Soil Sample	Ngaruawahia Sample 3																Soil Texture
Method	Hydrometer						Pipette				Lasersizer						
Reading	1	2	3	Average	Std Deviation		1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation	
% of Sand	34.68	34.76	33.73	34.39	0.57		34.68	34.76	33.73	34.39	0.57	46.31	40.60	37.98	41.63	4.26	
% of Silt	38.39	36.82	38.03	37.75	0.82		41.90	42.98	43.09	42.66	0.66	47.39	53.64	52.96	51.33	3.43	
% of Clay	21.68	23.51	23.57	22.92	1.07		16.29	16.26	17.47	16.67	0.69	6.29	5.76	8.06	6.70	1.20	
Total	94.75	95.09	95.33				92.87	94.00	94.29			99.99	100.00	99.00			

Std Deviation	Hydrometer	Pipette	Lasersizer
% Sand	0.57	0.57	4.26
% Silt	0.82	0.66	3.43
% Clay	1.07	0.69	1.77

% Silt	Hydrometer	Lasersizer	t-test
	38.39	47.39	
	36.82	53.64	
	38.03	52.96	0.01633

% Silt	Hydrometer	Pipette	t-test
	38.39	41.9	
	36.82	42.98	
	38.03	43.09	0.001556

% Silt	Pipette	Lasersizer	t-test
	41.9	47.39	
	42.98	53.64	
	43.09	52.96	0.040162

% Clay	Hydrometer	Lasersizer	t-test
	21.68	6.29	
	23.51	5.76	
	23.57	9.06	0.000566

% Clay	Hydrometer	Pipette	t-test
	21.68	16.29	
	23.51	16.26	
	23.57	17.47	0.002087

% Clay	Pipette	Lasersizer	t-test
	16.29	6.29	
	16.26	5.76	
	17.47	9.06	0.0053701

% Sand	Hydrometer	Lasersizer	t-test
	34.68	46.31	
	34.76	40.6	
	33.73	37.98	0.096056

% Sand	Hydrometer	Pipette	t-test
	34.68	34.68	
	34.76	34.76	
	33.73	33.73	1

% Sand	Pipette	Lasersizer	t-test
	34.68	46.31	
	34.76	40.6	
	33.73	37.98	0.0960558

Soil Sample Method	Hamilton Ash Formation											Soil Texture		
	Hydrometer				Pipette			Lasersizer						
Reading	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation				
% of Sand	8.29	11.17	12.27	10.58	2.06	8.29	11.17	12.27	10.58	2.06	4.20	3.17	1.61	
% of Silt	19.27	29.51	25.20	24.66	5.14	19.01	28.68	26.72	24.80	5.11	34.05	29.87	31.35	2.34
% of Clay	67.58	56.47	61.32	61.79	5.57	63.38	51.12	54.72	56.41	6.30	59.57	63.82	63.17	3.32
Total	95.14	97.15	98.79			90.68	90.97	93.71			97.82	97.56	97.69	

Std Deviation	Hydrometer	Pipette	Lasersizer
% Sand	1.06	1.06	1.33
% Silt	1.20	1.00	1.33
% Clay	0.95	0.87	0.97

% Silt

Hydrometer	Lasersizer	t-test
19.27	34.05	
29.51	30.13	
25.2	29.87	0.139266

% Silt

Hydrometer	Pipette	t-test
19.27	19.01	
29.51	28.68	
25.2	26.72	0.974325

% Silt

Pipette	Lasersizer	t-test
19.01	34.05	
28.68	30.13	
26.72	29.87	0.0003212

% Clay

Hydrometer	Lasersizer	t-test
67.58	59.57	
56.47	66.12	
61.32	63.82	0.735102

% Clay

Hydrometer	Pipette	t-test
67.58	63.38	
56.47	51.12	
61.32	54.72	0.330614

% Clay

Pipette	Lasersizer	t-test
63.38	59.57	
51.12	66.12	
54.72	63.82	0.1976829

% Sand

Hydrometer	Lasersizer	t-test
8.29	4.20	
11.17	1.31	
12.27	4	0.007991

% Sand

Hydrometer	Pipette	t-test
8.29	8.29	
11.17	11.17	
12.27	12.27	1

% Sand

Pipette	Lasersizer	t-test
8.29	4.2	
11.17	1.31	
12.27	4	0.0091827

Soil Sample	Hinuera Formation (fine material)														Soil Texture	
Method	Hydrometer					Pipette					Lasersizer					
Reading	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation	
% of Sand	41.54	42.22	43.75	42.50	1.13	41.54	42.22	43.75	42.50	1.13	56.65	50.05	52.76	53.15	3.32	Sandy Loam
% of Silt	43.22	42.25	46.73	44.07	2.36	46.46	42.66	44.65	44.59	1.90	40.43	47.53	44.95	44.30	3.59	
% of Clay	10.76	8.32	9.30	9.46	1.23	7.62	6.09	6.86	6.86	0.77	2.92	2.42	2.29	2.54	0.33	
Total	95.52	92.79	99.78			95.62	90.97	95.26			100.00	100.00	100.00			

Std Deviation	Hydrometer	Pipette	Lasersizer
% Sand	1.13	1.13	3.32
% Silt	2.36	1.90	3.59
% Clay	1.23	0.77	0.33

% Silt	Hydrometer	Lasersizer	t-test
	43.22	40.43	
	42.25	47.53	
	46.73	44.95	0.929288

% Silt	Hydrometer	Pipette	t-test
	43.22	46.46	
	42.25	42.66	
	46.73	44.65	0.780205

% Silt	Pipette	Lasersizer	t-test
	46.46	40.43	
	42.66	47.53	
	44.65	44.95	0.91042993

% Clay	Hydrometer	Lasersizer	t-test
	10.76	2.92	
	8.32	2.42	
	9.3	2.29	0.007023

% Clay	Hydrometer	Pipette	t-test
	10.76	7.62	
	8.32	6.09	
	9.3	6.86	0.045338

% Clay	Pipette	Lasersizer	t-test
	7.62	2.92	
	6.09	2.42	
	6.86	2.29	0.00421952

% Sand	Hydrometer	Lasersizer	t-test
	41.54	56.65	
	42.22	50.05	
	43.75	52.76	0.021626

% Sand	Hydrometer	Pipette	t-test
	41.54	41.54	
	42.22	42.22	
	43.75	43.75	1

% Sand	Pipette	Lasersizer	t-test
	41.54	56.65	
	42.22	50.05	
	43.75	52.76	0.0216265

Soil Sample	Hinuera Formation (coarse material)												Soil Texture		
Method	Hydrometer					Pipette			Lasersizer						
Reading	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation
% of Sand	93.68	96.18	93.68	94.51	1.44	93.68	96.18	93.68	94.51	1.44	56.19	55.09	55.13	55.47	0.62
% of Silt	2.04	1.90	1.81	1.92	0.12	2.75	2.25	2.50	2.50	0.25	41.75	42.23	43.27	42.42	0.78
% of Clay	1.40	1.56	1.64	1.53	0.12	0.25	0.26	0.62	0.38	0.21	2.06	2.68	1.60	2.11	0.54
Total	97.12	99.64	97.13			96.68	98.69	96.80			100.00	100.00	100.00		

Std Deviation	Hydrometer	Pipette	Lasersizer
% Sand	1.44	1.44	0.62
% Silt	0.12	0.25	0.78
% Clay	0.12	0.21	0.54

% Silt			
Hydrometer	Lasersizer	t-test	
2.04	41.75		
1.9	42.23		
1.81	43.27	8.92E-05	

% Clay			
Hydrometer	Lasersizer	t-test	
1.4	2.06		
1.56	2.68		
1.64	1.6	0.200545	

% Sand			
Hydrometer	Lasersizer	t-test	
93.68	56.19		
96.18	55.09		
93.68	55.13	6.17E-05	

% Silt			
Hydrometer	Pipette	t-test	
2.04	2.75		
1.9	2.25		
1.81	2.5	0.03884	

% Clay			
Hydrometer	Pipette	t-test	
1.4	0.25		
1.56	0.26		
1.64	0.62	0.00292	

% Sand			
Hydrometer	Pipette	t-test	
93.68	93.68		
96.18	96.18		
93.68	93.68	1	

% Silt			
Pipette	Lasersizer	t-test	
2.75	41.75		
2.25	42.23		
2.5	43.27	3.03E-05	

% Clay			
Pipette	Lasersizer	t-test	
0.25	2.06		
0.26	2.68		
0.62	1.6	0.0199348	

% Sand			
Pipette	Lasersizer	t-test	
93.68	56.19		
96.18	55.09		
93.68	55.13	6.166E-05	

Soil Sample	Allophanic Soil Material											Soil Texture
Method	Hydrometer			Pipette			Lasersizer					
Reading	1	2	3	Average	Std Deviation	1	2	3	Average	Std Deviation		
% of Sand	60.57	60.58	66.57	62.57	3.46	60.57	60.58	66.57	62.57	3.46		
% of Silt	43.55	42.31	42.35	42.74	0.70	40.50	37.50	38.72	38.91	1.51		
% of Clay	5.74	6.50	5.74	5.99	0.44	1.79	1.59	1.19	1.52	0.31		
Total	109.86	109.39	114.66			102.86	99.67	106.48				
						100.00	100.01	100.00				

Std Deviation	Hydrometer	Pipette	Lasersizer
% Sand	3.46	3.46	5.34
% Silt	0.70	1.51	4.81
% Clay	0.44	0.31	1.53

% Silt		
Hydrometer	Lasersizer	t-test
43.55	29.9	
42.31	24.57	
42.35	34.18	0.0391898

% Silt		
Hydrometer	Pipette	t-test
43.55	40.5	
42.31	37.5	
42.35	38.72	0.031449

% Silt		
Pipette	Lasersizer	t-test
40.5	29.9	
37.5	24.57	
38.72	34.18	0.0669157

% Clay		
Hydrometer	Lasersizer	t-test
5.74	3.67	
6.5	0.83	
5.74	1.25	0.0357112

% Clay		
Hydrometer	Pipette	t-test
5.74	1.79	
6.5	1.59	
5.74	1.19	0.000267

% Clay		
Pipette	Lasersizer	t-test
1.79	3.67	
1.59	0.83	
1.19	1.25	0.7026827

% Sand		
Hydrometer	Lasersizer	t-test
60.57	66.43	
60.58	74.61	
66.57	64.57	0.1916646

% Sand		
Hydrometer	Pipette	t-test
60.57	60.57	
60.58	60.58	
66.57	66.57	1

% Sand		
Pipette	Lasersizer	t-test
60.57	66.43	
60.58	74.61	
66.57	64.57	0.1916646

Suspended Solids Measurement (mg/L)

Piarere SRP Inlet : 7 - 10th July 2009

A	B	C	D	E	F	G	H	I	J	K	L	M
Container No (autowater sampler)	Rainfall (mm)	Sample volume (ml)	Bottle No	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of Solid (g)	Mass of Solid (mg)	TSS (undiluted) (mg/ml)	TSS (undiluted) (mg/l)	volume of sample diluted (ml)	Corrected TSS (mg/l)	Average
1	0.4	100	1	2.1543	2.1847	0.0304 0.0000 0.0000	30.4000 0.0000 0.0000	0.30400	304.00	618.00	375.74 0.00 0.00	375.74
3	3.2	10	2	2.1588 2.4277 2.1604	2.1858 2.4524 2.1955	0.0270 0.0247 0.0351	27.0000 24.7000 35.1000	2.70000 2.47000 3.51000	2700.00 2470.00 3510.00	680.00 680.00 680.00	3672.00 3359.20 4773.60	3934.93
4	0.8	10	3	2.2777 2.1929 2.1734	2.3054 2.2225 2.2013	0.0277 0.0296 0.0279	27.7000 29.6000 27.9000	2.77000 2.96000 2.79000	2770.00 2960.00 2790.00	740.00 740.00 740.00	4099.60 4380.80 4129.20	4203.20
5	0.8	50	4	2.4010 2.2568	2.4486 2.3041	0.0476 0.0473 0.0000	47.6000 47.3000 0.0000	0.95200 0.94600 0.0000	952.00 946.00	680.00 680.00 680.00	1294.72 1286.56 0.00	1290.64
6	1.6	10	5	2.1663 2.1668 2.1648	2.1903 2.1982 2.1939	0.0240 0.0314 0.0291	24.0000 31.4000 29.1000	2.40000 3.14000 2.91000	2400.00 3140.00 2910.00	800.00 800.00 800.00	3840.00 5024.00 4656.00	4506.67
7	1.6	10	6	2.1586 2.1701 2.1601	2.1824 2.1930 2.1882	0.0238 0.0229 0.0281	23.8000 22.9000 28.1000	2.38000 2.29000 2.81000	2380.00 2290.00 2810.00	710.00 710.00 710.00	3379.60 3251.80 3990.20	3540.53
8	0.8	10	7	2.2613 2.4331 2.1699	2.2805 2.4497 2.1822	0.0192 0.0166 0.0123	19.2000 16.6000 12.3000	1.92000 1.66000 1.23000	1920.00 1660.00 1230.00	610.00 610.00 610.00	2342.40 2025.20 1500.60	1956.07
9	0.8	10	8	2.1497 2.1633 2.1719	2.1647 2.1791 2.1848	0.0150 0.0158 0.0129	15.0000 15.8000 12.9000	1.50000 1.58000 1.29000	1500.00 1580.00 1290.00	710.00 710.00 710.00	2130.00 2243.60 1831.80	2088.47
10	0.2	10	9	2.1554 2.1515 2.1605	2.1698 2.1699 2.1724	0.0144 0.0184 0.0119	14.4000 18.4000 11.9000	1.44000 1.84000 1.19000	1440.00 1840.00 1190.00	588.00 588.00 588.00	1693.44 2163.84 1399.44	1752.24

Piarere SRP Outlet : 11/7/2009

A	B	C	D	E	F	G	H
Replication No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of Solids (g)	Mass of Solids (mg)	TSS (mg/ml)	TSS (mg/l)
1	200	2.2541	2.2580	0.0000	0.00000	0.0000	0.00
2	200	2.2650	2.2686	0.0039	3.90000	0.0195	19.50
3	200	2.4250	2.4288	0.0036	3.60000	0.0180	18.00
4	200	2.2511	2.2551	0.0038	3.80000	0.0190	19.00
5	200	2.1815	2.1852	0.0040	4.00000	0.0200	20.00
6	200	2.1815	2.1852	0.0037	3.7000	0.0185	18.50

Suspended Solids Measurement (mg/L)

Piarere SRP Inlet : 11 - 14/7/09

A	B	C	D	E	F	G	H	I	J	K	L	M
Container No (autowater sampler)	Rainfall (mm)	Bottle No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of solids (g)	Mass of solids (mg)	Mass TSS (undiluted) (mg/ml)	Mass TSS (undiluted) (mg/l)	volume of sample diluted (ml)	Corrected TSS (mg/l)	Average
1	1.2	1	10	2.1719	2.2079	0.0360	36.00	3.60	3600.00	600.00	4320.00	4156.00
			10	2.2737	2.3111	0.0374	37.40	3.74	3740.00	600.00	4488.00	
			10	2.2661	2.2966	0.0305	30.50	3.05	3050.00	600.00	3660.00	
2	1.8	2	10	2.2454	2.2687	0.0233	23.30	2.33	2330.00	640.00	2982.40	3827.20
			10	2.1675	2.2001	0.0326	32.60	3.26	3260.00	640.00	4172.80	
			10	2.1892	2.2230	0.0338	33.80	3.38	3380.00	640.00	4326.40	
3	1.8	3	10	2.1601	2.1828	0.0227	22.70	2.27	2270.00	608.00	2760.32	2845.44
			10	2.2459	2.2707	0.0248	24.80	2.48	2480.00	608.00	3015.68	
			10	2.1502	2.1729	0.0227	22.70	2.27	2270.00	608.00	2760.32	
4	2.2	4	10	2.2007	2.2245	0.0238	23.80	2.38	2380.00	570.00	2713.20	2458.60
			10	2.4245	2.4430	0.0185	18.50	1.85	1850.00	570.00	2109.00	
			10	2.2726	2.2950	0.0224	22.40	2.24	2240.00	570.00	2553.60	
5	2.2	5	10	2.2612	2.2818	0.0206	20.60	2.06	2060.00	580.00	2389.60	2258.13
			10	2.2017	2.2189	0.0172	17.20	1.72	1720.00	580.00	1995.20	
			10	2.1634	2.1840	0.0206	20.60	2.06	2060.00	580.00	2389.60	
6	1.8	6	10	2.2694	2.2874	0.0180	18.00	1.80	1800.00	530.00	1908.00	1844.40
			10	2.2638	2.2792	0.0154	15.40	1.54	1540.00	530.00	1632.40	
			10	2.1746	2.1934	0.0188	18.80	1.88	1880.00	530.00	1992.80	
7	1.8	7	10	2.2765	2.3017	0.0252	25.20	2.52	2520.00	555.00	2797.20	2956.30
			10	2.2603	2.2876	0.0273	27.30	2.73	2730.00	555.00	3030.30	
			10	2.2576	2.2850	0.0274	27.40	2.74	2740.00	555.00	3041.40	
8	1	8	50	2.2786	2.2979	0.0193	19.30	0.39	386.00	590.00	506.09	650.31
			50	2.2781	2.2976	0.0195	19.50	0.39	390.00	590.00	511.33	
			50	2.2614	2.2970	0.0356	35.60	0.71	712.00	590.00	933.51	
9	1	9	50	2.1878	2.2235	0.0357	35.70	0.71	714.00	555.00	792.54	643.06
			50	2.2702	2.2871	0.0169	16.90	0.34	338.00	555.00	375.18	
			50	2.1473	2.1816	0.0343	34.30	0.69	686.00	555.00	761.46	
10	0.4	10	10	2.1765	2.1853	0.0088	8.80	0.88	880.00	565.00	1130.00	1237.01
			10	2.1738	2.1839	0.0101	10.10	1.01	1010.00	565.00	1296.93	
			10	2.2688	2.2788	0.0100	10.00	1.00	1000.00	565.00	1284.09	
11	0.4	11	50	2.1665	2.1813	0.0148	14.80	0.30	296.00	450.00	309.77	288.14
			50	2.1639	2.1774	0.0135	13.50	0.27	270.00	450.00	282.56	
			50	2.1697	2.1827	0.0130	13.00	0.26	260.00	450.00	272.09	

Piarere SRP Outlet : 14/7/2009

A	B	C	D	E	F	G	H
Replication No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of Solids (g)	Mass of Solids (mg)	TSS (mg/ml)	TSS (mg/l)
1	200	2.2787	2.3073	0.0286	28.60	0.14300	143.00
2	200	2.2364	2.2591	0.0227	22.70	0.11350	113.50
3	200	2.2653	2.2830	0.0277	27.70	0.13850	138.50
4	200	2.1500	2.1736	0.0236	23.60	0.11800	118.00
5	200	2.1981	2.2221	0.0240	24.00	0.12000	120.00
6	200	2.1513	2.1787	0.0274	27.40	0.13700	137.00

Suspended Solids Measurement (mg/L)

Piarere SRP Inlet : 14-20/7/09

A	B	C	D	E	F	G	H	I	J	K	L	M
Container No (autowater sampler)	Rainfall (mm)	Bottle No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of Solids (g)	Mass of Solids (mg)	Mass TSS (undiluted) (mg/ml)	Mass TSS (undiluted) (mg/l)	volume of sample diluted (ml)	Corrected TSS (mg/l)	Average
24	3.6	1	25	2.1559	2.1694	0.0135	13.5000	0.54000	540.00	550.00	594.00	
			25	2.2594	2.2766	0.0172	17.2000	0.68800	688.00	550.00	756.80	709.87
			25	2.2429	2.2606	0.0177	17.7000	0.70800	708.00	550.00	778.80	
23		2	25	2.2588	2.2770	0.0182	18.2000	0.72800	728.00	550.00	800.80	
	3		25	2.1571	2.2656	0.1085	108.5000	4.34000	4340.00	550.00	4774.00	884.40
			25	2.1519	2.1739	0.0220	22.0000	0.88000	880.00	550.00	968.00	
22		3	25	2.1486	2.1557	0.0071	7.1000	0.28400	284.00	550.00	312.40	
	2.2		25	2.2732	2.2874	0.0142	14.2000	0.56800	568.00	550.00	624.80	460.53
			25	2.2766	2.2867	0.0101	10.1000	0.40400	404.00	550.00	444.40	
1		4	25	2.2498	2.2788	0.0290	29.0000	1.16000	1160.00	550.00	1276.00	
	1.2		25	2.1712	2.2044	0.0332	33.2000	1.32800	1328.00	550.00	1460.80	1242.27
			25	2.1856	2.2081	0.0225	22.5000	0.90000	900.00	550.00	990.00	
2		5	25	2.1693	2.1737	0.0044	4.4000	0.17600	176.00	550.00	193.60	
	1.8		25	2.2639	2.2759	0.0120	12.0000	0.48000	480.00	550.00	528.00	318.27
			25	2.2590	2.2643	0.0053	5.3000	0.21200	212.00	550.00	233.20	

Piarere SRP Outlet : 20/7/2009

A	B	C	D	E	F	G	H
Replication No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of Solids (g)	Mass of Solids (mg)	TSS (mg/ml)	TSS (mg/l)
1	200	2.2610	2.2677	0.0067	6.70000	0.0335	33.50
2	200	2.2544	2.2717	0.0173	17.30000	0.0865	86.50
3	200	2.2782	2.2957	0.0175	17.50000	0.0875	87.50
4	200	2.1502	2.1678	0.0176	17.60000	0.0880	88.00
5	200	2.2591	2.2779	0.0188	18.80000	0.0940	94.00

Turbidity Measurement (NTU)

Piarere SRP Inlet : 7 - 10th July 2009

Container No (autowater sampler)	Rainfall (mm)	Bottle No	Turbidity (NTU)	Dilution Factor	Corrected Turbidity (NTU)	Average
1	0.4	1	52	0	0	54.00
			56	0	0	
			54	0	0	
3	3.2	2	379	5	1895	1956.67
			381	5	1905	
			414	5	2070	
4	0.8	3	479	5	2395	2411.67
			481	5	2405	
			487	5	2435	
5	0.8	4	252	5	1260	1268.33
			252	5	1260	
			257	5	1285	
6	1.6	5	372	0	0	393.67
			395	0	0	
			414	0	0	
7	1.6	6	739	0	0	762.00
			758	0	0	
			789	0	0	
8	0.8	7	386	0	0	398.00
			399	0	0	
			409	0	0	
9	0.8	8	383	0	0	387.67
			385	0	0	
			395	0	0	
10	0.2	9	258	0	0	261.33
			261	0	0	
			265	0	0	

Piarere SRP Outlet : 11/7/2009

Replication No	Turbidity (NTU)
1	26.3
2	27.4
3	28.0
4	27.5
5	28.0
6	27.0

Turbidity measurement (NTU)

Piarere SRP Inlet : 11 - 14/7/09

Container No (autowater sampler)	Rainfall (mm)	Bottle No	Turbidity (NTU)	Average
1	1.2	1	771 749 708	742.67
2	1.8	2	694 662 640	665.33
3	1.8	3	876 862 831	856.33
4	2.2	4	332 273 245	283.33
5	2.2	5	391 409 403	401.00
6	1.8	6	414 447 459	440.00
7	1.8	7	360 325 411	365.33
8	1	8	281 294 317	297.33
9	1	9	242 247 257	248.67
10	0.4	10	212 234 229	225.00
11	0.4	11	252 267 274	264.33

Piarere SRP Outlet : 14/7/2009

Replication No	Turbidity (NTU)
1	27.0
2	58.3
3	63.7
4	48.3
5	52.8
6	44.7

Turbidity Measurement (NTU)

Piarere SRP Inlet : 14-20/7/09

Container No (autowater sampler)	Rainfall (mm)	Bottle No	Turbidity (NTU)	Dilution Factor	Corrected Turbidity (NTU)	Average
24	3.60	1	553	0	0	617
			620	0	0	
			677	0	0	
23	3.00	2	143	5	715	718
			144	5	720	
			144	5	720	
22	2.20	3	358	0	0	393
			405	0	0	
			416	0	0	
1	1.20	4	70	5	351	357
			75	5	375	
			69	5	345	
2	1.80	5	342	0	0	376
			393	0	0	
			394	0	0	

Piarere SRP Outlet : 20/7/2009

Replication No	Turbidity (NTU)
1	21.5
2	27.0
3	20.1
4	22.5
5	28.1
6	23.3

Suspended solids measurement (mg/L)

Ngaruawahia SRP Inlet : 2nd - 11 th August 2009

A	B	C	D	E	F	G	H	I	J
Container No (autowater sampler)	Rainfall (mm)	Bottle No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of solids (g)	Mass of solids (mg)	Mass TSS (undiluted) (mg/ml)	Mass TSS (undiluted) (mg/l)
1	0	1	100	2.1616	2.1628	0.0012	1.2000	0.01200	12.00
2	0	2	100	2.1508	2.1512	0.0004	0.4000	0.00400	4.00
3	0	3	100	2.1638	2.1646	0.0008	0.8000	0.00800	8.00
4	0	4	100	2.1660	2.1666	0.0006	0.6000	0.00600	6.00
5	0	5	100	2.1906	2.1910	0.0004	0.4000	0.00400	4.00
6	0	6	100	2.4181	2.4186	0.0005	0.5000	0.00500	5.00
7	0	7	100	2.1555	2.1566	0.0011	1.1000	0.01100	11.00
8	0	8	100	2.1550	2.1559	0.0009	0.9000	0.00900	9.00

Ngaruawahia SRP Outlet - 13/8/09

A	B	C	D	E	F	G	H
Replication No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of Solids (g)	Mass of Solids (mg)	TSS (mg/ml)	TSS (mg/l)
1	200	2.2301	2.2323	0.0022	2.20	0.0110	11.00
2	200	2.1577	2.1597	0.0020	2.00	0.0100	10.00
3	200	2.2143	2.2157	0.0014	1.40	0.0070	7.00
4	200	2.2121	2.2141	0.0020	2.00	0.0100	10.00
5	200	2.2592	2.2625	0.0033	3.30	0.0165	16.50
6	200	2.1535	2.1566	0.0031	3.10	0.0155	15.50

Suspended Solids Measurement (mg/L)

Ngaruawahia SRP Inlet: 31/8 - 2/9/2009

A	B	C	D	E	F	G	H	I	J
Container No (autowater sampler)	Rainfall (mm)	Bottle No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of solids (g)	Mass of solids (mg)	TSS (undiluted) (mg/ml)	TSS (undiluted) (mg/l)
1	2.4	1	50	2.1612	2.1755	0.0143	14.3000	0.28600	286.00
			50	2.1692	2.1832	0.0140	14.0000	0.28000	280.00
			50	2.4195	2.4337	0.0142	14.2000	0.28400	284.00
2	2	2	50	2.1873	2.2014	0.0141	14.1000	0.28200	282.00
			50	2.1627	2.1768	0.0141	14.1000	0.28200	282.00
			50	2.3927	2.4062	0.0135	13.5000	0.27000	270.00
3	2.8	3	50	2.1631	2.1858	0.0227	22.7000	0.45400	454.00
			50	2.2662	2.2884	0.0222	22.2000	0.44400	444.00
			50	2.1662	2.1900	0.0238	23.8000	0.47600	476.00
4	3.8	4	50	2.2638	2.2772	0.0134	13.4000	0.26800	268.00
			50	2.2533	2.2673	0.0140	14.0000	0.28000	280.00
			50	2.1574	2.1707	0.0133	13.3000	0.26600	266.00
5	3.6	5	50	2.2270	2.2321	0.0051	5.1000	0.10200	102.00
			50	2.2241	2.2294	0.0053	5.3000	0.10600	106.00
			50	2.2150	2.2207	0.0057	5.7000	0.11400	114.00
7	1.8	7	50	2.1610	2.1635	0.0025	2.5000	0.05000	50.00
			50	2.1375	2.1407	0.0032	3.2000	0.06400	64.00
			50	2.2098	2.2118	0.0020	2.0000	0.04000	40.00
9	2	9	50	2.2513	2.2521	0.0008	0.8000	0.01600	16.00
			50	2.2488	2.2492	0.0004	0.4000	0.00800	8.00
			50	2.2468	2.2478	0.0010	1.0000	0.02000	20.00

Ngaruawahia SRP Outlet - 2/9/09

A	B	C	D	E	F	G	H
Replication No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of Solids (g)	Mass of Solids (mg)	TSS (mg/ml)	TSS (mg/l)
1	200	2.1546	2.1582	0.0036	3.60	0.0180	18.00
2	200	2.2201	2.2227	0.0026	2.60	0.0130	13.00
3	200	2.1422	2.1455	0.0033	3.30	0.0165	16.50
4	200	2.2974	2.2995	0.0021	2.10	0.0105	10.50
5	200	2.2226	2.2241	0.0015	1.50	0.0075	7.50
6	200	2.2257	2.2279	0.0022	2.20	0.0110	11.00

Suspended solids measurement (mg/L)

Ngaruawahia SRP Inlet : 23 - 30 /9/09

A	B	C	D	E	F	G	H	I	J
Container No (autowater sampler)	Rainfall (mm)	Bottle No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of solids (g)	Mass of solids (mg)	TSS (undiluted) (mg/ml)	TSS (undiluted) (mg/l)
1	3	1	10	2.1864	2.1883	0.0019	1.90	0.1900	190.00
			10	2.1863	2.1879	0.0016	1.60	0.1600	160.00
			10	2.2493	2.2508	0.0015	1.50	0.1500	150.00
2	2	2	10	2.1848	2.1920	0.0072	7.20	0.7200	720.00
			10	2.1809	2.1871	0.0062	6.20	0.6200	620.00
			10	2.1832	2.1875	0.0043	4.30	0.4300	430.00
3	2.3	3	10	2.1846	2.1869	0.0023	2.30	0.2300	230.00
			10	2.2807	2.2822	0.0015	1.50	0.1500	150.00
			10	2.2832	2.2847	0.0015	1.50	0.1500	150.00
4	2	4	10	2.2918	2.2967	0.0049	4.90	0.4900	490.00
			10	2.2932	2.2953	0.0021	2.10	0.2100	210.00
			10	2.2066	2.2089	0.0023	2.30	0.2300	230.00
5	2	5	10	2.2361	2.2374	0.0013	1.30	0.1300	130.00
			10	2.2238	2.2251	0.0013	1.30	0.1300	130.00
			10	2.2190	2.2196	0.0006	0.60	0.0600	60.00
6	3.8	6	10	2.2659	2.2689	0.0030	3.00	0.3000	300.00
			10	2.2306	2.2327	0.0021	2.10	0.2100	210.00
			10	2.2885	2.2908	0.0023	2.30	0.2300	230.00
7	10.6	7	10	2.1468	2.1505	0.0037	3.70	0.3700	370.00
			10	2.1623	2.1668	0.0045	4.50	0.4500	450.00
			10	2.1497	2.1538	0.0041	4.10	0.4100	410.00
8	7.2	8	10	2.2183	2.2230	0.0047	4.70	0.4700	470.00
			10	2.2100	2.2121	0.0021	2.10	0.2100	210.00
			10	2.2283	2.2295	0.0012	1.20	0.1200	120.00
9	2	9	10	2.2232	2.2275	0.0043	4.30	0.4300	430.00
			10	2.1670	2.1723	0.0053	5.30	0.5300	530.00
			10	2.2124	2.2168	0.0044	4.40	0.4400	440.00
10	2.2	10	10	2.2072	2.2084	0.0012	1.20	0.1200	120.00
			10	2.2449	2.2471	0.0022	2.20	0.2200	220.00
			10	2.2262	2.2274	0.0012	1.20	0.1200	120.00
11	2	11	10	2.2154	2.2179	0.0025	2.50	0.2500	250.00
			10	2.2252	2.2272	0.0020	2.00	0.2000	200.00
			10	2.1432	2.1459	0.0027	2.70	0.2700	270.00
12	2.3	12	10	2.2681	2.2715	0.0034	3.40	0.3400	340.00
			10	2.1432	2.1494	0.0062	6.20	0.6200	620.00
			10	2.1961	2.2033	0.0072	7.20	0.7200	720.00
13	3.6	13	10	2.2617	2.2638	0.0021	2.10	0.2100	210.00
			10	2.1823	2.1841	0.0018	1.80	0.1800	180.00
			10	2.2076	2.2091	0.0015	1.50	0.1500	150.00
									Average TSS (mg/L)
									166.67
									590.00
									176.67
									310.00
									106.67
									246.67
									410.00
									266.67
									466.67
									153.33
									240.00
									560.00
									180.00

Suspended solids measurement (mg/L)

Ngaruawahia SRP Inlet : 23 - 30 /9/09

A	B	C	D	E	F	G	H	I	J
Container No (autowater sampler)	Rainfall (mm)	Bottle No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of solids (g)	Mass of solids (mg)	TSS (undiluted) (mg/ml)	TSS (undiluted) (mg/l)
14		14	10	2.1800	2.1809	0.0009	0.90	0.0900	90.00
	2.2		10	2.2629	2.2637	0.0008	0.80	0.0800	80.00
	2.2728		10	2.2732	2.2732	0.0004	0.40	0.0400	40.00
15	3.2	15	10	2.1877	2.1916	0.0039	3.90	0.3900	390.00
			10	2.2699	2.2708	0.0009	0.90	0.0900	90.00
			10	2.1873	2.1881	0.0008	0.80	0.0800	80.00
16	2.9	16	10	2.1970	2.1985	0.0015	1.50	0.1500	150.00
			10	2.1891	2.1913	0.0022	2.20	0.2200	220.00
			10	2.2092	2.2103	0.0011	1.10	0.1100	110.00
17	3.8	17	10	2.1528	2.1554	0.0026	2.60	0.2600	260
			10	2.2002	2.2011	0.0009	0.90	0.0900	90
			10	2.2631	2.2642	0.0011	1.10	0.1100	110
18	3.4	18	10	2.2006	2.2031	0.0025	2.50	0.2500	250
			10	2.1923	2.1939	0.0016	1.60	0.1600	160
			10	2.1989	2.2006	0.0017	1.70	0.1700	170
19	3.6	19	10	2.1814	2.1870	0.0056	5.60	0.5600	560
			10	2.1968	2.2000	0.0032	3.20	0.3200	320
			10	2.1559	2.1590	0.0031	3.10	0.3100	310
20	2.4	20	10	2.1669	2.1697	0.0028	2.80	0.2800	280
			10	2.1744	2.1749	0.0005	0.50	0.0500	50
			10	2.1780	2.1787	0.0007	0.70	0.0700	70
21	2.8	21	10	2.4229	2.4231	0.0002	0.20	0.0200	20
			10	2.1723	2.1737	0.0014	1.40	0.1400	140
			10	2.1999	2.2014	0.0015	1.50	0.1500	150
22	4	22	10	2.1724	2.1753	0.0029	2.90	0.2900	290
			10	2.2796	2.2805	0.0009	0.90	0.0900	90
			10	2.2743	2.2751	0.0008	0.80	0.0800	80
23	2.4	23	10	2.4020	2.4033	0.0013	1.30	0.1300	130
			10	2.2696	2.2713	0.0017	1.70	0.1700	170
			10	2.2514	2.2530	0.0016	1.60	0.1600	160

Ngaruawahia SRP Outlet - 1/10/09

A	B	C	D	E	F	G	H
Replication No	Sample Volume (ml)	Mass Tray + Filter (g)	Mass Tray + Filter + TSS (g)	Mass of Solids (g)	Mass of Solids (mg)	TSS (mg/ml)	TSS (mg/l)
1	200	2.1973	2.1980	0.0007	0.70	0.0035	3.50
2	200	2.1516	2.1535	0.0019	1.90	0.0095	9.50
3	200	2.2365	2.2375	0.0010	1.00	0.0050	5.00
4	200	2.2346	2.2358	0.0012	1.20	0.0060	6.00
5	200	2.2251	2.2260	0.0009	0.90	0.0045	4.50
6	200	2.2971	2.2983	0.0012	1.20	0.0060	6.00
							5.75

Turbidity Measurement (NTU)

Ngaruawahia SRP Inlet : 2nd - 11 th August 2009

Container No (autowater sampler)	Rainfall (mm)	Bottle No	Turbidity (NTU)
1	0	1	12.00
2	0	2	8.00
3	0	3	9.00
4	0	4	12.00
5	0	5	8.56
6	0	6	10.30
7	0	7	9.88
8	0	8	10.30

Ngaruawahia SRP Outlet - 13 August 2009

Replication No	Turbidity NTU
1	7.84
2	7.93
3	7.63
4	7.50
5	8.15
6	7.73

Turbidity Measurement (NTU)

Ngaruawahia SRP Inlet: 31/8 - 2/9/2009

Container No (autowater sampler)	Rainfall (mm)	Bottle No	Turbidity (NTU)	Dilution Factor	Corrected Turbidity (NTU)	Average
1	2.4	1	662.00 632.00 640.00	0 0 0	0 0 0	644.67
2	2.0	2	607.00 604.00 605.00	0 0 0	0 0 0	605.33
3	2.8	3	97.00 96.00 96.00	10 10 10	970 960 960	963.33
4	3.8	4	665.00 697.00 689.00	0 0 0	0 0 0	683.67
5	3.6	5	315.00 314.00 319.00	0 0 0	0 0 0	316.00
7	1.8	7	141.00 146.00 145.00	0 0 0	0 0 0	144.00
9	2.0	9	78.00 84.00 85.00	0 0 0	0 0 0	82.33

Ngaruawahia SRP Outlet - 2/9/09

Replication No	Turbidity NTU
1	25.00
2	26.00
3	26.00
4	28.00
5	27.00
6	28.00

Inlet and Outlet SRP Analysis (Ngaruawahia)

Turbidity Measurement (NTU)

Ngaruawahia SRP Inlet : 23 - 30 /9/09

A Container No (autowater sampler)	B Rainfall (mm)	C Bottle No	D Turbidity (NTU)	E Average
1	3	1	66.4 74.2 77.3	72.63
2	2	2	98.0 130.0 129.0	119.00
3	2.3	3	69.6 68.5 76.1	71.40
4	2	4	56.7 59.2 63.8	59.90
5	2	5	36.9 42.9 42.2	40.67
6	3.8	6	78.7 91.5 79.9	83.37
7	10.6	7	92.0 101.0 99.1	97.37
8	7.2	8	91.2 86.7 88.7	88.87
9	2	9	176.0 162.0 178.0	172.00
10	2.2	10	88.7 99.3 103.0	97.00
11	2	11	64.5 61.1 70.3	65.30
12	2.3	12	132.0 116.0 122.0	123.33
13	3.6	13	81.1 61.6 75.0	72.57
14	2.2	14	15.5 16.7 18.5	16.90
15	3.2	15	59.6 60.2 60.7	60.17
16	2.9	16	79.6 67.4 74.4	73.80
17	3.8	17	52.0 49.1 48.2	49.77
18	3.4	18	66.5 64.1 58.4	63.00
19	3.6	19	83.0 83.9 73.7	80.20
20	2.4	20	45.5 45.7 45.9	45.70
21	2.8	21	30.7 26.7 29.2	28.87
22	4	22	35.7 32.6 31.9	33.40
23	2.4	23	72.0 73.1 76.8	73.97

Ngaruawahia SRP Outlet - 1/10/09

Replication No	Turbidity NTU
1	9.10
2	9.20
3	8.80
4	9.40
5	8.90
6	8.60

Sample 1 of Piarere

ml of PAC added	Time of reading				
	0 min	30 mins	1 hr	4 hrs	8 hrs
0	2190	1480	1450	790	610
40	1000	800	770	460	530
80	860	310	390	300	280
120	473	260	240	220	200
160	311	150	100	105	88
200	164	45	23	10	6

Sample 2 of Piarere

ml of PAC added	Time of reading				
	0 min	30 mins	1 hr	4 hrs	8 hrs
0	4000	2480	2140	1490	1090
40	2210	1700	1370	1090	840
80	1875	790	780	600	310
120	875	325	197	112	95
160	557	182	271	142	95
200	256	156	97	60	22

Sample 3 of Piarere

ml of PAC added	Time of reading				
	0 min	30 mins	1 hr	4 hrs	8 hrs
0	2780	1650	1390	670	470
40	1840	1090	920	600	360
80	1275	480	460	390	340
120	1254	470	300	230	296
160	578	190	170	140	127
200	277	58	36	12	9

Sample 1 of Ngaruawahia

ml of PAC added	Time of reading				
	0 min	30 mins	1 hr	4 hrs	8 hrs
0	22100	17	15	11	7
40	19875	11	9	7	6
80	18543	10	8	6	5
120	15448	21	21	12	10
160	10987	22	20	13	10
200	9875	23	21	14	11

Sample 2 of Ngaruawahia

ml of PAC added	Time of reading				
	0 min	30 mins	1 hr	4 hrs	8 hrs
0	22513	45.8	34.1	21.9	19.4
40	19873	68.8	49.3	34.6	31.1
80	17543	60	59.7	33.1	26.9
120	15684	45.2	38.6	22.4	18.1
160	13845	65.7	57.8	39	27.9
200	10463	42.4	35.7	22.7	17.9

Sample 3 of Ngaruawahia

ml of PAC added	Time of reading				
	0 min	30 mins	1 hr	4 hrs	8 hrs
0	13470	927	8030	5240	4900
40	11223	77	640	530	440
80	9875	40	280	170	130
120	5639	18	127	33	17
160	4732	21	108	26	11
200	2365	27	132	28	14

Hamilton Ash Formation

ml of PAC added	Time of reading					
	0 min	30 mins	1 hr	4 hrs	8 hrs	24 hrs
0	6220	2420	2050	1110	990	660
40	4375	246	122	57	39	21
80	2317	174	69	20	10	4
120	1157	132	64	17	8	2
160	874	152	68	17	8	2
200	511	930	520	40	16	4

Hinuera Formation (coarse material)

ml of PAC added	Time of reading					
	0 min	30 mins	1 hr	4 hrs	8 hrs	24 hrs
0	330	296	164	144	148	83
40	321	202	91	128	123	70
80	294	192	160	144	126	71
120	157	144	110	144	117	63
160	143	136	103	147	111	61
200	288	197	90	164	163	93

Hinuera Formation (fine material)

ml of PAC added	Time of reading					
	0 min	30 mins	1 hr	4 hrs	8 hrs	24 hrs
0	11200	9720	6880	3230	2250	920
40	9784	5850	5630	2750	1740	1080
80	8551	1120	860	77	497	171
120	2874	500	352	137	96	57
160	1033	264	158	31	15	6
200	811	144	110	25	11	3

Allophanic soil materials

ml of PAC added	Time of reading					
	0 min	30 mins	1 hr	4 hrs	8 hrs	24 hrs
0	3640	1280	800	355	87	62.6
40	1327	800	170	51	38	15
80	963	130	400	61	40	15.8
120	627	350	200	42	42	19.1
160	536	214	169	52	34	10.9
200	275	51	27	12	5	3.5