Auckland
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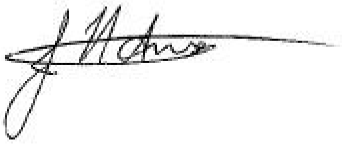
Performance of a Sediment Retention Pond Receiving Chemical Treatment

October TR 2008/021

Auckland Regional Council
Technical Report No.021 October 2008
ISSN 1179-0504 (Print)
ISSN 1179-0512 (Online)
ISBN 978-1-877483-63-9

Technical Report, first edition.

Reviewed by:



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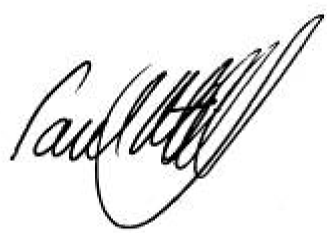

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Recommended Citation:

Moores, J.; Pattinson, P.; etc. (2008). Performance of a Sediment Retention Pond Receiving Chemical Treatment. Prepared by NIWA for Auckland Regional Council. Auckland Regional Council Technical Report 2008/021

Performance of a Sediment Retention Pond Receiving Chemical Treatment

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Prepared for
Auckland Regional Council

NIWA Client Report: AKL-2008-019, July 2008
NIWA Project: ARC06130

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Acknowledgements

Auckland Regional Council wishes to thank Northern Gateway Alliance (NGA) for hosting and providing logistical assistance with this study.

The report authors wish to thank NGA staff, in particular Karsten Stevenson, Dave Greenaway and Wayne Viall, for their assistance both on- and off-site. Thanks also to Mike Larcombe, Mike Timperley, Judy-Ann Ansen and Martin Neale for reviewing and provding valueable feedback on a draft of this report.

1 Executive Summary

1.1 Objectives

This report describes an experimental study to evaluate the effectiveness of Polyaluminium Chloride (PAC) treatment to improve the removal of sediment from earthworks run-off in a sediment retention pond at an operational earthworks site.

The objectives of the study were to evaluate:

- The reduction in sediment mass discharge to the receiving environment achieved by PAC treatment.
- The effectiveness of the treatment on specific particle size ranges.
- Variations in the effectiveness of the treatment during events of differing rainfall characteristics; and
- Concentrations of residual dissolved aluminium discharged to the receiving environment.

1.2 Methods

A field programme comprising hydrological monitoring and the collection of water samples was implemented at the ALPURT B2 motorway construction site near Orewa, north of Auckland. A rainfall gauge, weirs, water level recorders and automatic water samplers were installed at a pair of ponds that each received approximately half of the run-off from an earthworks area of 4.4 hectares in the Nukumea Stream catchment. The inflow to one pond was treated with PAC by a rainfall activated dosing system whilst the inflow to the other pond was not treated.

Water samples were obtained from seven storm events over the period March to December 2007. Samples collected at the shared pond inlet were analysed for their concentrations of total suspended solids (TSS) and particle size characteristics. Samples collected at the pond outlets were analysed for TSS, particle size and their dissolved aluminium concentration. Sediment loads and pond efficiencies were estimated from flow records and TSS concentrations at the pond inlet and outlets.

1.3 Effectiveness of PAC treatment

The results indicate that the addition of PAC is an effective method of improving the sediment removal efficiency of sediment retention ponds. The estimated total sediment load discharged from the treated pond was a third of that from the untreated pond.

The treated pond achieved an estimated sediment removal efficiency (reduction in the total sediment load in pond inflows) during the storm events studied of at least 68 per cent whilst the untreated pond performed well below this level at around 30 per cent. Efficiencies of 75 per cent or greater were achieved for five of the seven events in the treated pond and for only one event in the untreated pond.

1.4 Effectiveness in relation to particle size

There was relatively little difference between the particle size distribution of samples collected at the treated and untreated pond outlets during five of the events sampled. This suggests that the treatment is effective on the range of particle sizes which characterise the majority of sediments at the study site (0 – 31.3 μm). A limited set of results from one event provide an indication of the discharge of flocculated aggregates during periods of high pond inflow and outflow rates.

1.5 Effectiveness in relation to rainfall event characteristics

There were substantial variations in the effectiveness of PAC treatment both during and between storm events. Efficiencies of over 90 per cent were achieved during relatively small events (characterised by rainfall totals in the range 10.5 to 28 mm) during which the efficiency of the untreated pond was also relatively high. However, the sediment load removed as a result of PAC treatment during smaller events was only a minor part (1 per cent) of the total sediment load retained for all the events studied.

The improvement in pond performance as a result of PAC treatment was most marked during events, or periods of events, with relatively high rainfall depths and intensities. Whilst sediment removal efficiency in the treated pond during the larger events (characterised by rainfall totals in the range 48 to 195 mm) was lower than during the smaller events, the additional sediment load retained as a result of PAC treatment during these events was substantial. During a single large event in March 2007 the sediment load discharged to the receiving environment from the treated pond was over four tonnes less than that from the untreated pond.

These results indicate that the greatest gains from PAC treatment are achieved through dosing of ponds during relatively large storm events when the performance of sediment retention ponds without PAC treatment is relatively poor.

1.6 Residual dissolved aluminium

Median dissolved aluminium concentrations in samples from the two pond outlets were similar at 0.047 g m^{-3} and 0.044 g m^{-3} in treated and untreated pond outflow samples, respectively. Both median concentrations are less than the ANZECC (2000) trigger value for a 95 per cent level of protection of 0.055 g m^{-3}.

However, the ANZECC 95 per cent trigger value was exceeded by maximum concentrations in 13 samples collected at the treated pond outlet and in nine samples from the untreated pond outlet. The level of exceedance was greater in the treated samples than the untreated samples and generally coincided with periods of increasing flows during the early- to mid-part of each event. The maximum recorded dissolved aluminium concentration of 0.32 g m^{-3} occurred in an outflow sample from the treated pond.

2 Introduction

Sediment retention ponds are a standard erosion and sediment control measure on earthwork sites in the Auckland region. In recent years it has become increasingly common for ponds to be subject to chemical treatments to enhance the efficiency of the removal of suspended solids. Flocculants added to the flow of water entering the ponds promote the coagulation and settlement of fine sediments that would otherwise be discharged to the receiving environment.

The results of previous studies in the Auckland region indicate that chemical treatments improve the efficiency of sediment retention ponds. Based on sampling of inflows and outflows during storm events, ponds treated with Polyaluminium Chloride (PAC) have previously been reported to have treatment efficiencies as high as 99 per cent for removal of total suspended solids (ARC, 2004).

Whilst these results indicate that chemical treatment of sediment retention ponds can be a beneficial practice, previous studies have not explored variations in effectiveness during storm events nor compared how well PAC performs in events of differing rainfall characteristics. With PAC now widely used within the Auckland region, the Auckland Regional Council (ARC) determined to examine the effectiveness of PAC treatment in greater detail and to assess the extent to which its use can be further optimised.

This report describes an experimental study to evaluate the effectiveness of PAC treatment at an operational earthworks site. The objectives of the study were to evaluate:

- the reduction in sediment mass discharge to the receiving environment achieved by PAC treatment;
- the effectiveness of PAC treatment on specific particle size ranges;
- variations in treatment effectiveness during events of differing rainfall characteristics; and
- concentrations of residual dissolved aluminium discharged to the receiving environment.

The study brief sets out the following requirements:

- Monitoring of two ponds, one treated with PAC and one untreated, on an operating earthworks site within the same catchment.
- Continuous monitoring of pond outflows including emergency spillway flows.
- Automated water sample collection during six rainfall events within a six-month period, with a minimum of six samples spread across each event.
- Analysis of inflow samples for total suspended solids (TSS) and particle size, and analysis of outflow samples for TSS, particle size and dissolved aluminium.
- Estimation of suspended sediment mass loads in pond inflows and outflows.

- Estimation of pond treatment efficiencies over the period of monitoring and during each storm event.
- Investigation of the effectiveness of PAC treatment on specific particle size ranges.

This report summarises the background to the project (Chapter 3), describes the methods employed in the study (Chapter 4), presents results (Chapter 5) and provides a discussion on the study findings (Chapter 6).

3 Background

3.1 Sediment and erosion control in the Auckland region

Land disturbing (earthworking) activities in the Auckland region include residential and commercial subdivisions, quarries, cleanfills, tracking, landing sites associated with forestry and the works in the beds of rivers and streams. Based on volumes of earth moved and areal extent of land disturbance the largest earthworking activities are typically those associated with the construction of new roads and motorways (*pers. comm.*, C.Mitchell, 2007).

Earthworks in the Auckland region are regulated under Section 9(3) of the Resource Management Act (1991) and by the Auckland Regional Plan: Sediment Control (2001).

Approximately 200 resource consents relating to earthworks are granted each year by the ARC, which equates to approximately 1500 ha of earthworking activity undertaken per year (*pers. comm.*, C.Mitchell, 2007). The consents typically authorise earthwork projects planned for completion within a two- to three-year period and consequently have a short-term duration of two to five years.

The conditions of resource consents for earthworks activities specify requirements for the type and performance of erosion and sediment control measures to be installed on-site. Currently, these requirements are guided by the ARC's Technical Publication No. 90 (ARC, 1999). TP90 describes a range of structural and non-structural practices for controlling erosion and sediment discharges on earthworks sites. Structural practices include silt fences, decanting earth bunds, sediment retention ponds, and hydroseeding or mulching areas of exposed earth. Non-structural practices include restricting earthworks to a defined season (1 October to 30 April), staging restrictions to limit the area of earth exposed at any one time and industry education courses.

3.2 Use of flocculants

Sediment retention ponds have been used for a number of years in the Auckland region to reduce sediment loads discharged to receiving environments. In the late 1990s a number of trials were undertaken to investigate the effectiveness of chemical treatment of ponds to promote the flocculation of sediments and so improve sediment removal efficiency (ARC, 2004). Following the apparent success of these trials, the use of chemical treatments has become a relatively common condition of resource consents granted for land development and other major earthworking activities. As a result, the use of chemical treatment has increased extensively on earthwork sites throughout the Auckland region, ranging from large motorway projects to smaller subdivisions.

The most commonly used flocculant on earthwork sites is Polyaluminium Chloride (PAC). This is an aluminium coagulant added to sediment retention ponds in liquid form (ARC, 2004). A draft chemical treatment design guideline has been developed (BCHF, 2003), to promote a standard methodology for the dosing of sediment retention ponds with PAC. The guideline describes the design, operation and maintenance of a rainfall-activated dosing system which is widely used across the Auckland region.

3.3 Previous studies in the Auckland region

3.3.1 Sediment removal efficiency

Previous trials of the effectiveness of liquid PAC were undertaken during the construction of the Albany to Puhoi (ALPURT) section of Auckland's Northern Motorway during summer 1998/99 (ARC, 2004). The ALPURT trials also investigated the effectiveness of an alternative product, solid Magnasol Floc Blocks. This latter treatment was subsequently trialed further on a residential development site in Greenhithe in North Shore City.

The results of the 1998/99 ALPURT trials are reported as the percentage reduction in suspended sediment (SS) concentrations in pairs of inflow and outflow samples from 21 sediment treatment pond systems. In the ponds dosed with PAC, SS concentrations in pond outflow samples were 62 – 99 per cent lower than those in inflow samples. SS concentrations in two outflow samples from an untreated pond were only 4 and 12 per cent lower than SS concentrations in the respective inflow samples (ARC, 2004).

These results clearly indicate a substantial reduction in SS concentrations due to treatment of ponds with PAC. However, ponds were sampled only once (or in some cases twice) during rainfall events. Total sediment loads in and out of each pond and hence the overall efficiency of the treatment were not reported.

3.3.2 Residual dissolved aluminium

A review of the potential effects of residual flocculants on receiving environments found that they are unlikely to represent a significant risk to aquatic communities (ARC, 2006). The toxicity of aluminium corresponds with its bioavailability or occurrence in its dissolved form. This is influenced by pH, such that in more acidic conditions aluminium is mainly present in its dissolved form. The greatest risk to aquatic communities therefore corresponds with situations in which ponds outflows have a relatively high aluminium concentration and a relatively low pH.

ARC (2004) reports concentrations of dissolved aluminium in outflows from the ALPURT ponds treated with PAC. Results are in the range 0.01 to 0.07 mg l^{-1}, other than in three samples with markedly higher concentrations which are reported to be the result of either overdosing of a pond or the presence of very fine suspended sediments in the discharges. Other than these exceptions, dissolved aluminium concentrations in treated pond outflows were reported to be lower than those in samples from untreated pond outflows and USEPA water quality criteria[1] (ARC, 2006).

[1] US EPA water quality criteria for aluminium are a Criteria Maximum Concentration (CMC – an estimate of the highest concentration to which an aquatic community can be exposed briefly without resulting in an unacceptable effect) of 0.75 mg l^{-1} and a Criterion Continuous Concentration (CCC – an estimate of the highest concentration to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect) of 0.087 mg l^{-1}. Note that these criteria are for total recoverable aluminium in the water column (USEPA, 2006).

4 Methods

4.1 Study site

4.1.1 Overview of ALPURT B2 motorway construction project

The study site was located at the ALPURT B2 motorway construction site near Orewa, approximately 30 km north of downtown Auckland. ALPURT B2 is currently Transit New Zealand's largest capital project and comprises the 7.5 km extension of the Northern Motorway between Grand Drive in Orewa and Titford's Bridge just south of Puhoi, where it rejoins the existing State Highway 1 (see Figure 1). Northern Gateway Alliance (NGA), comprising Transit NZ and a number of engineering and environmental consultancies, has responsibility for delivery of the project.

Figure 1
ALPURT B2 Northern Motorway extension schematic perspective.

Courtesy of Northern Gateway Alliance

The route of the new motorway passes through a diverse landscape containing steep topography, large tracts of native bush, regionally significant streams and estuaries and areas of pastoral farmland. A large proportion of the southern end of the site contains Recommended Area for Protection (RAP) 21 including large parts of the Nukumea and Otanerua Stream catchments.

In response to the challenges presented by the steep topography of the area and the presence of ecologically significant habitats, the project involves a number of major engineering works. Viaducts have been constructed to bridge the Otanerua and

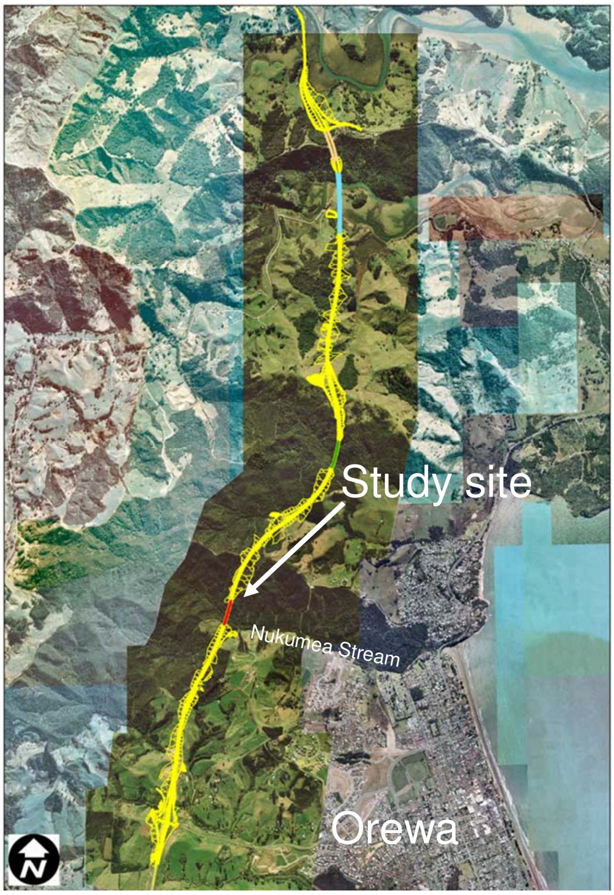
Nukumea Stream valleys whilst twin tunnels have been bored through Johnstone's Hill at the northern end of the route.

Whilst these and other measures are being implemented to avoid or mitigate adverse environmental impacts, in total over 3 million cubic metres of earthworks are required to complete the construction of the motorway. Clearly earthworks on this scale carry a significant environmental risk. As a consequence, the design and management of sediment and erosion control measures at the ALPURT B2 site is critical to the overall environmental performance of the project. Accordingly, the conditions of the project's resource consents require PAC treatment of sediment retention ponds in all areas of the site discharging to ecologically significant receiving environments.

4.1.2 Description of study site

The study sediment retention ponds were located in the Nukumea Stream catchment between the northern end of the Nukumea viaduct and Hillcrest Rd bridge (see Figure 2). The site was selected by ARC and NGA.

Figure 2
Aerial photograph showing route of ALPURT B2 Northern Motorway extension and location of the study site.



Courtesy of Northern Gateway Alliance

In this location the site geology comprises Miocene age mudstones and graded sandstones of the Pakiri Formation.

Two ponds were located adjacent to each other and were identical in design and size (see Figure 3). The ponds were designed and constructed by NGA in accordance with ARC's TP 90 guidelines. Each pond was sized to contain a minimum water volume of 660 cubic metres and to treat run-off from approximately half of the combined catchment area of 4.4 hectares (NGA, 2006).

Figure 3

View of study ponds looking south towards Nukumea Stream Valley.

The dual pond catchment extended upslope from the ponds to Hillcrest Rd ridge. The major earthworking activities within this area (during the study and in progress at the time of writing) are two cuts to remove a total of approximately 160,000 m^3 of material (NGA, 2006). A copy of the erosion and sediment control plan of the catchment is provided in Appendix 1.

Run-off was conveyed to the ponds by a diversion bund following the lower boundary of the catchment and as overland flow down a temporary haul road running through the catchment to Hillcrest Rd Bridge. Run-off was collected in a sump surrounding a 2100 mm diameter manhole riser constructed to act as a flow splitter. Water overflowed into the riser from where it was conveyed via two 450 mm diameter PVC pipes to a sediment forebay at the head of each pond (see Figure 4). Water was discharged from each forebay over a level spreader to each of the ponds.

The pond outlets comprised 1050 mm diameter manhole risers each fitted with two floating decanting intakes. Flows in excess of the capacity of the decanting intakes discharged over the lip of each riser. Trapezoidal emergency spillways of approximate base width five metres were located in the downstream bunds of each pond.

Figure 4
View of inlet sump with twin outlet pipes visible in the interior of the manhole riser.

The inflow to the treated pond was automatically dosed with PAC during rain events in accordance with ARC flocculation guidelines (BCHF, 2003). Rain falling on a tray positioned over a shed in which the flocculant was housed triggered the discharge of the PAC via a hose to the treated pond forebay. The dosing system was operated and maintained by NGA staff, with inspections occurring at approximately weekly intervals and before and after rainfall events.

Whilst this study involved comparison of the discharge from a treated and an untreated pond, resource consent requirements require that all run-off in this part of the motorway construction site is dosed with PAC before its discharge to the Nukumea Stream. A third pond was therefore located to capture the discharge from the untreated pond. A second shed and tray system dosed the inflow to this pond with PAC before discharge to the receiving environment.

4.1.3 Instrumentation

The study site was instrumented to measure and record rainfall and water levels and to collect water samples during rainfall events.

4.1.3.1 Rainfall

An automatic tipping bucket rain gauge of 0.2 mm bucket size was deployed adjacent to the pond inflow sump. Rainfall was recorded on a NIWA hydrologger at one minute intervals.

4.1.3.2 Water levels

In order to estimate flows into and out of the ponds water levels were measured at five locations: at the inlet sump, at the pond outlets and in the ponds themselves. Temporary plywood weirs were installed at the inlet, the outlets and the emergency spillways in order to allow flows to be estimated from measured water levels using the relevant rating for each type of weir (see Figure 5).

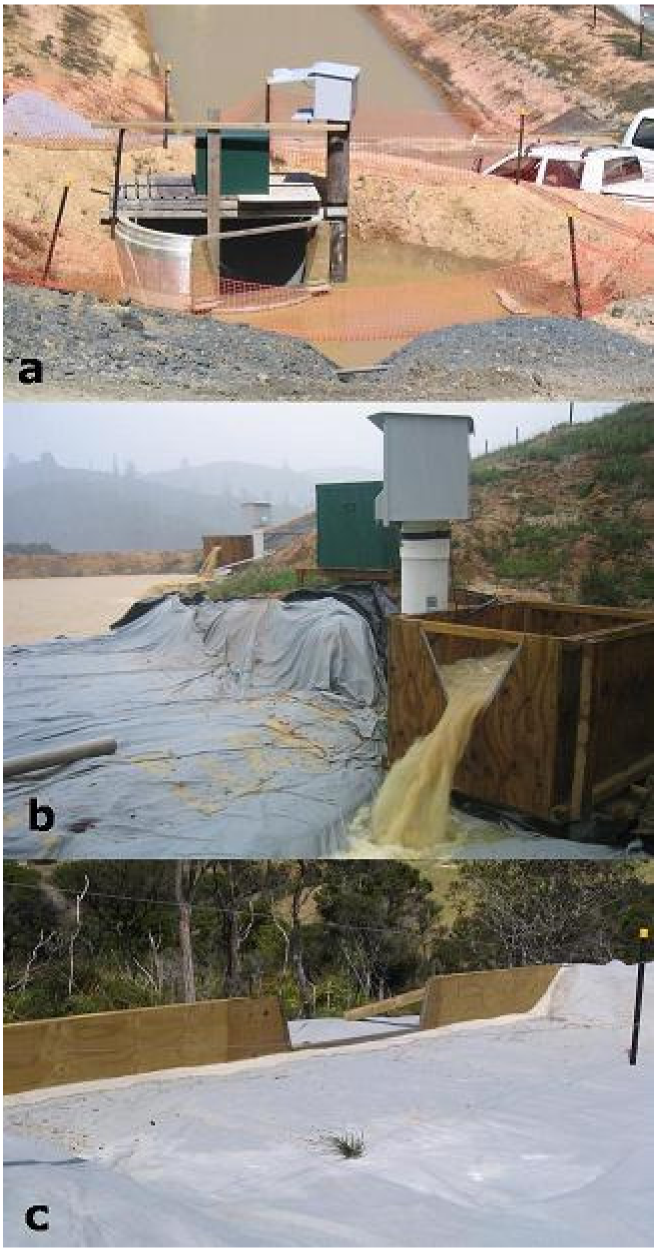
At the inlet sump, a trapezoidal Cipoletti weir of dimensions 1000 mm base width, 680 mm height and side slopes of 4:1 (vertical:horizontal) was installed in a rectangular section cut from the concrete manhole riser. Plywood box weirs were constructed at the two pond outlets, each consisting of a ½ 90 degree sharp-crested v-notch weir with a stage range of 550 mm. The boxes acted as stilling ponds, and had baffles installed to reduce the inlet velocity from the decant risers. Trapezoidal Cipoletti weirs of dimensions 1500 mm base width, 600 mm height and 4:1 side slopes were installed in the emergency spillway of each pond. All of the weirs were fitted with a 2 mm thick stainless steel strip to produce the required "sharp crest". A "zero stage" datum was built into each side of each weir, and allowed accurate stage measurements to be taken during periods when the weirs were flowing.

Float and counter-weight driven water level recorders were housed in stilling wells and recorder cabinets located adjacent to the inlet and outlet weirs and adjacent to the pond outlet manhole risers. These latter recorders were installed in order to measure water levels in the ponds and, in the event of sufficient rise, water levels through the emergency spillway weirs (in order to estimate emergency overflows, if any). Water levels were recorded on NIWA hydrologgers at one minute intervals, to a stage resolution of 1 mm.

4.1.3.3 Water sampling

Three automatic ISCO water samplers were housed in secure cabinets located at the inlet manhole riser and adjacent the pond outlet weir boxes (see Figure 5). The sampler intake hoses were installed so as to collect water samples from the intake sump and from the outlet pipe discharging from each pond. Following storm damage to equipment during the period 28 – 30 March 2007 the sampler hose at the intake was relocated so as to collect water samples from within the intake manhole riser rather than from the surrounding sump (see also Section 5.1.2).

Figure 5
Weirs, water level monitoring equipment and water sampler cabinets at (a) the inlet sump; (b) pond outlets; and (c) emergency spillways (water levels to calculate flows through the emergency spillways were measured at the pond outlet manhole risers. The water level recorder cabinets and towers at the pond outlet manhole risers are visible in Figure 3).



4.2 Data collection and water sampling

4.2.1 Site protocols

All visits to the site were made in accordance with NGA Occupational Health and Safety (OSH) requirements[2]. Field staff checked in with a site engineer (or security company personnel at weekends) and followed a route to the study site as directed. The route and location of a suitable place to park varied during the course of the study as earthwork and construction activities progressed[3]. On leaving the site staff checked out with the NGA or security contact.

4.2.2 Field methods

The automatic water samplers were set up for sampling in anticipation of forecasted rainfall. Each sampler was stocked with 24 acid-washed plastic sampling bottles. The samplers were programmed to collect up to 24 samples on a time proportional basis, with sample intervals of greater duration at the outlets than the inlet to take account of flow attenuation in the ponds. The duration of sampling intervals was determined prior to each attempted sampling event based on the forecasted duration of rainfall and experience during previous events. Although time-based sampling was employed, the loggers computed the discharge every five seconds during an event and recorded the accumulated volume between samples.

Samples were collected from the samplers and delivered to the NIWA laboratory in Auckland as soon as practicable, usually within 24 hours of the first samples being collected. In the event that the rainfall event was continuing samplers were restocked with additional bottles and the sampler re-programmed to continue sampling. A subsequent return visit was made to retrieve any further samples collected. Once returned to the laboratory, sample bottles were stored in the dark at 4°C until they could be processed (usually within 48 hours).

During each visit to set up or collect samples water level and rainfall data were collected by unloading the logged measurements onto a laptop computer. Additional regular visits were made to collect these data at times when the samplers were not activated.

During each visit to the site field staff inspected all instrumentation including comparison of observed and logged water levels, measurement of battery voltages and observation of equipment condition. Measurements, comments and any adjustments made were recorded in a log book.

In addition, field staff also inspected and recorded by photograph the condition of the ponds (for instance current water level) and other relevant aspects of erosion and sediment control such as the status of the chemical dosing system.

[2] All NIWA staff undertaking field work at the site first attended an NGA orientation covering OSH requirements.
[3] At times, and in particular following heavy rainfall, vehicular access to the study site was limited.

4.2.3 Data processing and review

On return to NIWA's Auckland offices water level and rainfall data collected from the loggers were transferred to a TIDEDA hydrological database. The database calculates weir flows from logged water levels using standard rating equations developed for each of the weir types used.

Following the collection of samples, the time series of water levels, flows and sampling time were reviewed in order to establish the way in which samples collected at the inflow and outlfows were distrubuted through the relevant event hydrograph. These data reviews provided the basis for the selection of samples for analysis (see Section 5.1.2).

4.3 Sample processing and analyses

4.3.1 Total suspended solids (TSS)

Prior to any processing to determine TSS concentrations a sub-sample of at least 30 ml was taken from each of the samples selected for analysis and tranferred to a bottle or jar for particle size determination.

The selected samples were filtered through acid-washed, dried and pre-weighed polycarbonate membranes (0.4 µm) using plastic, acid-washed, vacuum filtration equipment. Samples containing relatively large quantities of sediment were filtered as a number of sub-samples to ensure timely completion of sample processing. After filtration, the membranes were re-dried in the laboratory oven at 60°C and re-weighed to give the weight of total suspended solids in the volume filtered.

4.3.2 Particle size analysis

Particle size was determined by NIWA Hamilton using a Galai WCIS-100 particle size analyser. This is a "time-of-flight" instrument in which the size and shape of a particle is determined as it crosses a laser beam (Weiner et al., 1998). Millions of particles are measured in each sample and the frequency of occurrence of particles in a range of size bands is recorded. The frequency is reported in terms of the number, area and volume of the particles.

4.3.3 Dissolved metals

A 14 ml sub-sample was taken from the filtrate of each filtered sample for the analysis of dissolved aluminium. The sub-sample was transferred to a 15 ml acid washed or sterilised plastic vial and acidified with the addition of 1 ml of nitric acid.

These sub-samples were despatched to Hill Laboratories Ltd in Hamilton for determination of dissolved aluminium by inductively coupled plasma mass spectrometry (ICP-MS) according to method APHA 3125B.

4.4 Quality assurance procedures

4.4.1 Water level measurement and estimation of flows

The water level recorders employed in the study have a measurement accuracy of ±1 mm. They consist of a combined float and counter-weight driven digital encoder and data logger. These instruments do not drift, and are tested and calibrated by NIWA Instrument Systems before despatch. As described in Section 4.2.2 during each visit to the site field staff compared observed and logged water levels to ensure accuracy remained in the specified range.

All weirs were levelled on-site. Flows were calculated from the logged water level readings using standard ISO ratings for each weir.

4.4.2 Sample processing and analysis

The protocols NIWA follows for sample collection, storage and filtration are set out in Sections 4.2.2 and 4.3.1. An additional quality control for the estimation of total suspended solids involves frequent checking of the balance calibration with a small gold weight of about 100 mg.

The estimation of particle size distribution involved comparison and reporting of results from repeat analysis of a sample selected at random from each batch analysed. The Galai operator also re-ran analyses as necessary in order to confirm results which diverged from those obtained for preceding samples.

For the analysis of dissolved aluminium each batch of samples sent for analysis included a procedural blank and a duplicate sample. Hill Laboratories undertake a calibration standard recheck will be every 15 to 20 samples and interference check solutions and numerous blanks are analysed in each batch of samples. Once each week a riverine water reference standard (NRCC SLRS-4) is analysed to check accuracy. Samples are re-analysed if any deviation from the laboratory QC criteria is detected. Hill Laboratories are accredited by International Accreditation New Zealand for these analyses in conformance with standard NZS/ISO/IEC 17025: 2005.

4.5 Estimation of loads and efficiencies

The sediment load (L) discharged into and out of the ponds during each of the events sampled was estimated from the sampled TSS concentrations and volumes of water discharged between samples as follows:

$$L = \left(c_1 \bullet v_1\right) + \left(\sum_{i=1}^{n-1} \frac{(c_i + c_{i+1})}{2} \bullet v_{i+1}\right) + \left(c_n \bullet v_{n+1}\right) \qquad \text{(equation 1)}$$

Where:

c_i = TSS concentration in sample number i

v_i = volume discharged between sample number i-1 and sample number i

The first and third bracketed terms in equation 1 allowed for the estimation of loads prior to the first sample and following the last sample based on the TSS concentrations in the first and last samples respectively. During the rest of the event, loads were estimated from the mean TSS concentration of consecutive samples and the volume of water discharged between those pairs of samples (second bracketed term in equation 1).

The operating efficiencies of the two systems was estimated by comparing the calculated sediment loads in pond inflows and outflows. Sediment removal efficiency (SRE) was calculated as:

$$SRE(\%) = \frac{L_{in} - L_{out}}{L_{in}} \bullet 100 \qquad \text{(equation 2)}$$

Where:

L_{in} = Load into the pond[4]

L_{out} = Load out of the pond

[4] The total load into the shared pond inlet was estimated from TSS concentrations and flow volumes at the inlet sump. However, it could not be assumed that 50 per cent of this total load entered each of the ponds because flow measurements showed consistently that more water was discharged from the untreated pond than the treated pond (see Section 5.3). The proportion of this total load entering each of the two ponds was therefore estimated from the ratio of the total volume of water discharged from each of the ponds. For instance, if 55 per cent of the total volume of water discharged from the two ponds during an event was from the untreated pond, then it was assumed that 55 per cent of the split inflows, and hence sediment load, entered that same pond.

5 Results

5.1 Data description

5.1.1 Timing of sampling events

Samples from seven separate rainfall events were retained, processed and analysed[5]. Prior to the first of these, in late March 2007, samples had been collected at the pond inlet but event rainfall depths had been insufficient to fill the ponds and generate outflows. Similarly, no samples were collected during April and May 2007, despite the samplers being set up for sampling in advance of a number of forecasted rainfall events over this period.

Three events were sampled during the earthworks closed season (1 May to 30 September). The collection of further samples was postponed until the new earthworks season was well established in order to ensure that the range of events sampled included a number coinciding with the period of greatest earthworking activity.

5.1.2 Data collected during Event 1

Event 1 was by far the largest rainfall event recorded during the period of study, with 195 mm of rain falling over a 42-hour period. The quantity of sediment discharged to the inlet sump during this period was such that the water level recorder and automatic sampler both ceased to operate during the early stages of the event. Sediment deposited in the base of the inlet sump buried the water level recorder float and the automatic water sampler hose intake. The inflow record for this event constitutes a 14-hour long hydrograph finishing around five hours prior to the period of peak hourly rainfall intensities. The collection of water samples at the inlet ceased around four hours after the commencement of flows and around eight hours before the water level record indicates the start of a period of rapidly rising flows.

However, the water level recorders and automatic samplers were operational at both pond outlets throughout Event 1. Despite the absence of complete datasets for the pond inlet, it was recognised that results from the pond outlets would provide sufficient information for a comparison of the treated and untreated pond performance during a relatively extreme event, and samples were processed and analysed

[5] Not all samples collected were retained for processing. In some situations samples were discarded on-site. These included following the collection of samples at the inlet but not at the outlet (due to there being no outlflow from the ponds) or as a result of an insufficient number of samples being collected for analysis. In other circumstances samples which were returned to the laboratory were subsequently discarded prior to analysis, for instance following visual inspection of the samples and subsequent confirmation from NGA representatives that the dosing system had failed to activate (refer also to Chapter 6).

accordingly. In order to aid interpretation of results from Event 1, the following sections of this report make reference to limitations of these data where appropriate.

5.1.3 Selection of samples for analysis

Following each event, six or more samples collected from the shared inlet and each outlet were selected for processing and analysis (with the exception of inflow samples during Event 1, as described below). Samples were selected on the basis that they were well distributed through the event and coincided with the rising limb, peaks, troughs and recession of the inlet and outlet hydrographs (see Figures 6 to 12). Occassionally, rapid changes occurred in the inflow rate between successive samples such that it was not possible to select samples representative of these flow conditions (for example, the period of elevated flows between inflow samples one and two, Event 7).

The samples of treated and untreated pond outflows selected for analysis were in general correspondence in terms of their position in the sequence of samples collected from each outlet. However, each pair of samples (one treated, one untreated) were not in exact concurrence as a result of the fact that they were collected by different automatic water samplers, each of which was independently triggered by a rise in water levels at the respective pond outlet weir.

Exceptions to this general pattern were:

- Event 1 – Only three inflow samples were selected for analysis, all of which preceded the period of elevated rainfall and inflows by several hours. One more sample was selected from the treated pond outflow than from the untreated pond outflow and one pair of samples was separated by a period of two hours. These sample selections were made in recognition of differences between the outflow hydrographs of the two ponds, in particular the rapid fall and subsequent peak that occurred in outflows from the treated pond but not from the untreated pond (see Section 5.3).
- Event 2 – The automatic water sampler failed to collect samples from the treated pond outlet during the third of three successive periods of first rising and then falling flows. In contrast, samples were collected from the untreated pond outlet throughout the event. As a result, the untreated water samples selected for analysis were distributed more widely than were the samples from the treated pond.
- Event 5 – The first sample from the untreated pond outlet was collected over an hour later than the corresponding sample from the treated pond outlet as a result of differences in the pre-event pond water levels and hence, the time at which the automatic water sampler was triggered.

5.2 Description of sampling events

Table 1 summarises the characteristics of the seven rainfall events from which samples were analysed.

Table 1

Summary of rainfall characteristics during sampling events

Event number	Dates	Rainfall depth (mm)	Rainfall duration (hours)	Comments
1	28 to 30 Mar 2007	195	42	24-hour rainfall total may have exceeded that of a 1 in 10-year event[6]. Peak hourly rainfall of 27.4 mm during the middle of event[7].
2	29 to 30 Jun 2007	41	21	Relatively evenly distributed rainfall with peak hourly rainfall of 5.2 mm.
3	29 Jul 2007	48	8.5	Relatively short duration, high intensity event with peak hourly rainfall of 11 mm.
4	16 to 17 Aug 2007	68	16.5	Relatively evenly distributed rainfall until the final hour of the event during which 27 mm rain fell[8].
5	6 Nov 2007	18.5	12	Relatively evenly distributed, low intensity rainfall with peak hourly rainfall of 3 mm.
6	9 Dec 2007	10.5	21.5	Low intensity event of 9 mm over 8.5 hours followed by a further 1-hour of 1.5 mm after 12-hour dry interval.
7	18 to 19 Dec 2007	28	15	Three events separated by dry intervals of 3.5 and 5 hours. Relatively heavy rainfall during second event with peak hourly rainfall of 13.2 mm.

Figures 6 to 12 present plots of rainfall, flows and TSS concentrations during each event. Data values are plotted against common scales to allow comparison of events. Because of this, Figure 9 does not plot the upper-part of the inflow hydrograph during Event 4 whilst Figures 10 and 11 do not display much variation in flows or TSS concentrations during Events 5 and 6 (flows and TSS remained low relative to other events). Additional plots of Events 4, 5 and 6, using event-specific scales, are provided in Appendix 1.

5.3 Flows

Table 2 summarises inflow and outflow volumes and peak flows during each of the seven events. The lack of a water level record for the main-part of Event 1 means that

[6] The maximum 24-hour rainfall recorded at the ARC's nearby rain gauge at Orewa wastewater treatment ponds during Event 1 had an estimated annual recurrence interval (ARI) of 13 years (*pers. comm.*, P. White, 2007). Based on the Orewa rainfall record, all other rain events had a 24-hour ARI of less than 1-year.

[7] Based on the Orewa rainfall record, the periods of peak rainfall intensity during Events 1 and 4 had a 1-hour ARI of around two years. All other hourly rainfall intensities had an ARI < 1-year.

the full inflow hydrograph, event inflow volume and peak inflows are missing for this event.

Table 2
Summary of pond inflows and outflows.

Event number	Volumes (m^3)				Peak flows (l/sec)		
	Inflow	Treated pond outflow	Untreated pond outflow	Total outflow	Inflow	Treated pond outflow	Untreated pond outflow
1	-	982	1050	2032	-	41.6	40.6
2	703	305	413	718	25.3	8.2	9.2
3	1019	447	551	998	91.2	20.9	27.9
4	1528	732	802	1534	275.4	53.7	43.7
5	183	67	73	140	6.9	2.1	2.7
6	123	51	53	104	5.7	1.8	2.3
7	177	62	78	140	51.0	3.5	4.5

However, the water level recorded at the two pond outlets during Event 1 does allow estimation of the total outflow during Event 1 which, at over 2000 cubic metres, was the largest during any of the events. Relatively large inflows and outflows were also recorded during Events 2, 3 and 4 whilst the inflow and outflow volumes during the remaining three events were markedly lower. Inflow volumes also varied as a proportion of rainfall depth recorded during each event. During the three winter events (Events 2, 3 and 4) between 39 per cent and 51 per cent of rainfall falling on the study catchment area was discharged into the ponds. Inflow volumes during events in spring and early summer (Event 5, 6 and 7) represented lower proportions (14 – 29 per cent) of event rainfall.

Inflows and total outflows do not exactly balance. This is partly due to differences in precision between the trapezoidal inflow weir and the outflow v-notch weirs, the latter having more precise rating at lower stage readings. The differences also reflect difference in antecdent pond water levels. For instance, pond water levels were relatively low prior to Events 5 and 7 so that a relatively large proportion of the inflows contributed to recharging the pond dead storage volume (the volume below the lowest decanting intake).

The highest recorded peak inflow was 275.4 l/sec, occurring towards the latter part of Event 4. The lowest peak inflow was 5.7 l/sec during Event 6. Highest and lowest peak outflows also occurred during Events 4 and 6 respectively although these peak flows (and those during the five remaining events) were substantially lower than peak inflows as a result of attenuation by the ponds.

Figure 6

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 28 to 30 March 2007 (Event 1).

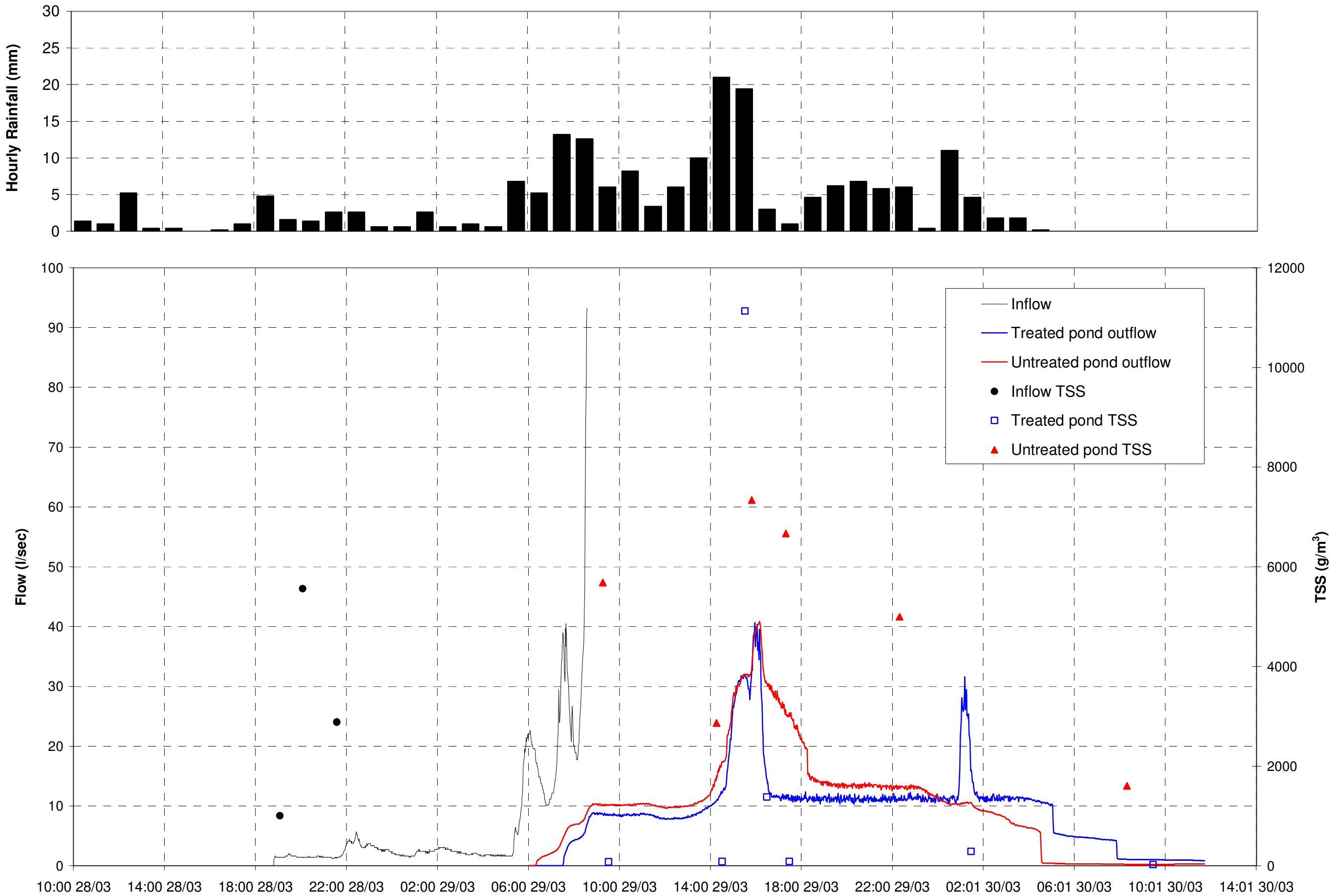


Figure 7

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 29 to 30 June 2007 (Event 2).

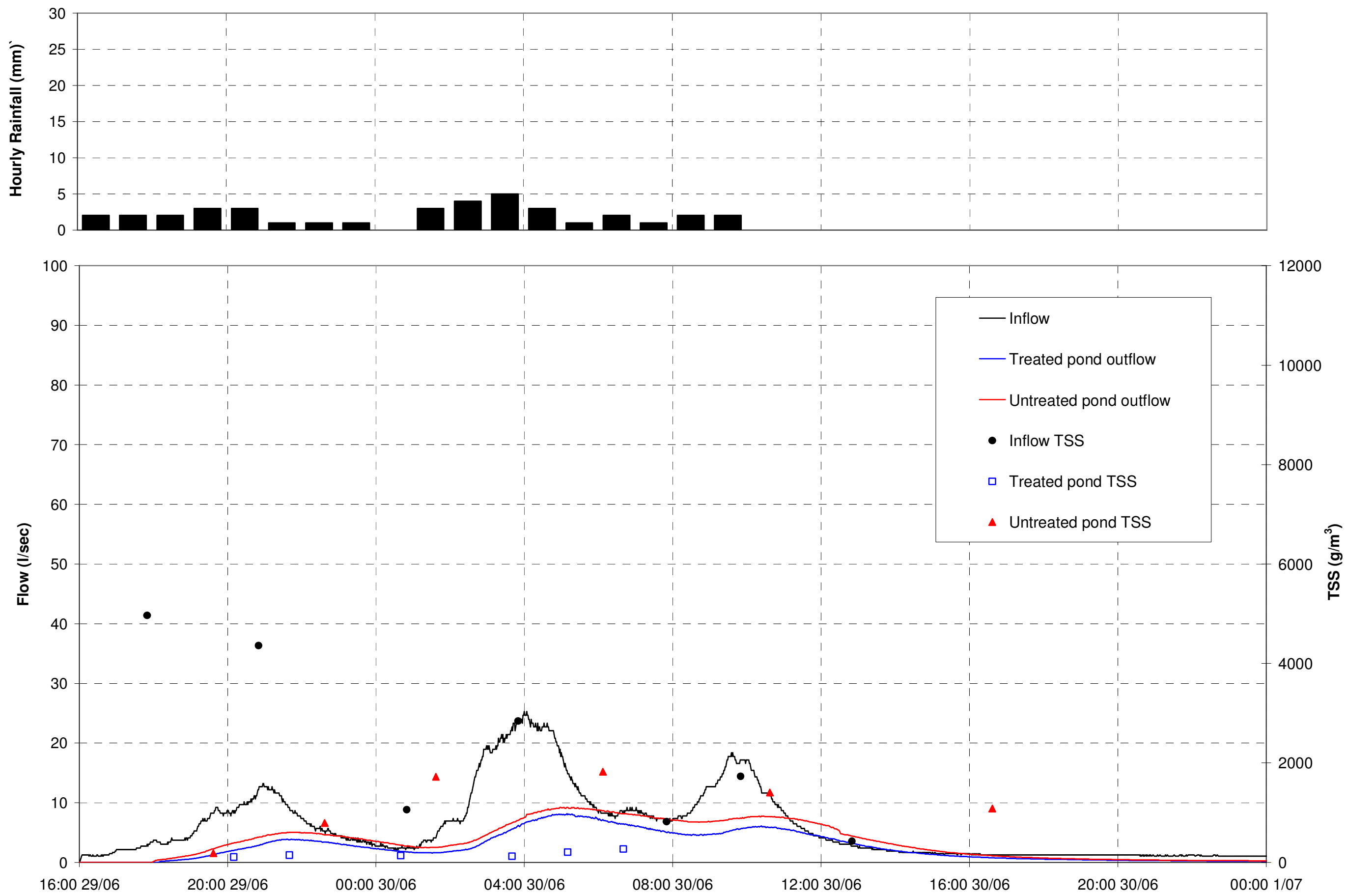


Figure 8

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 29 July 2007 (Event 3).

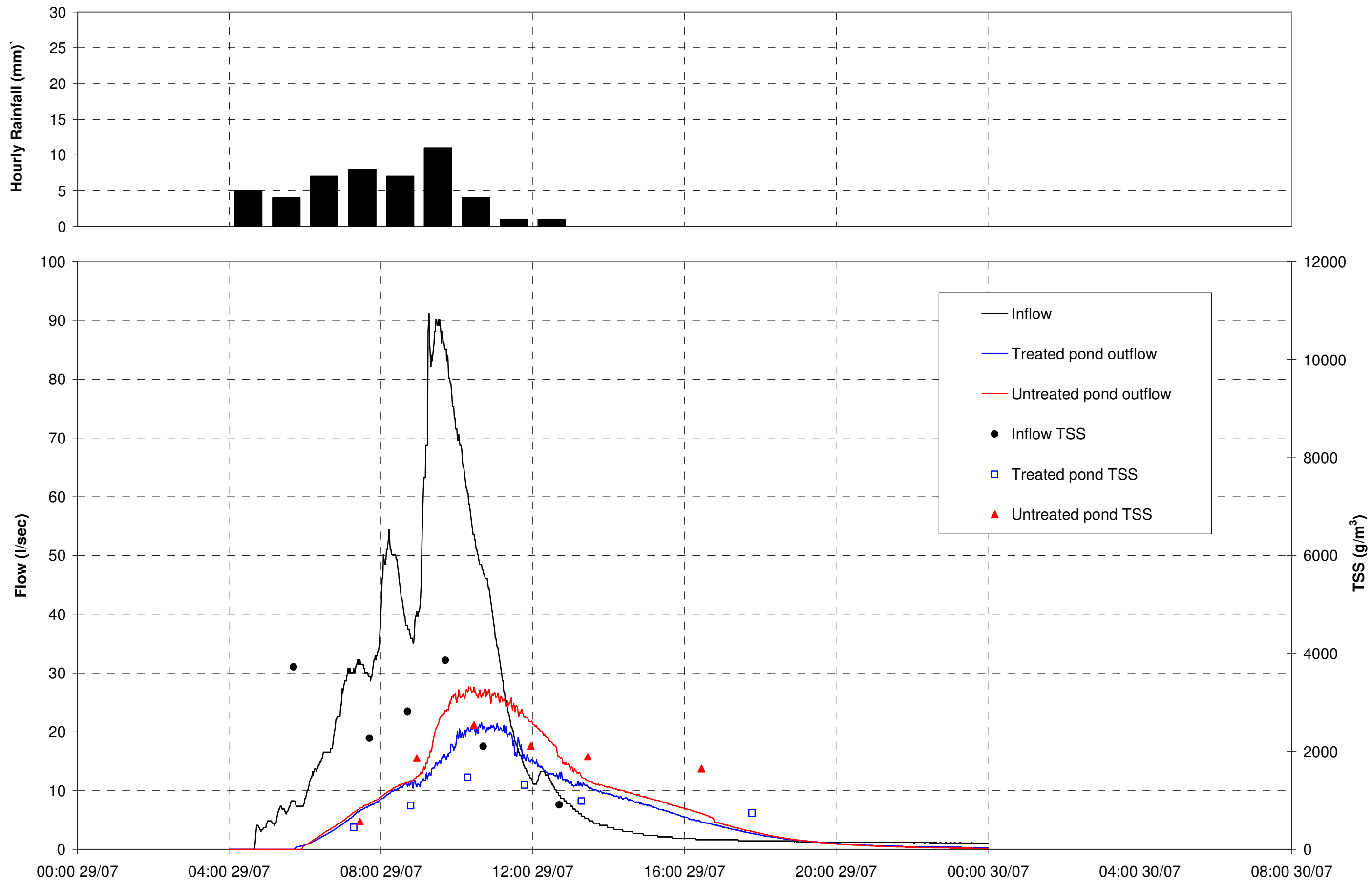


Figure 9

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 16 to 17 August 2007 (Event 4).

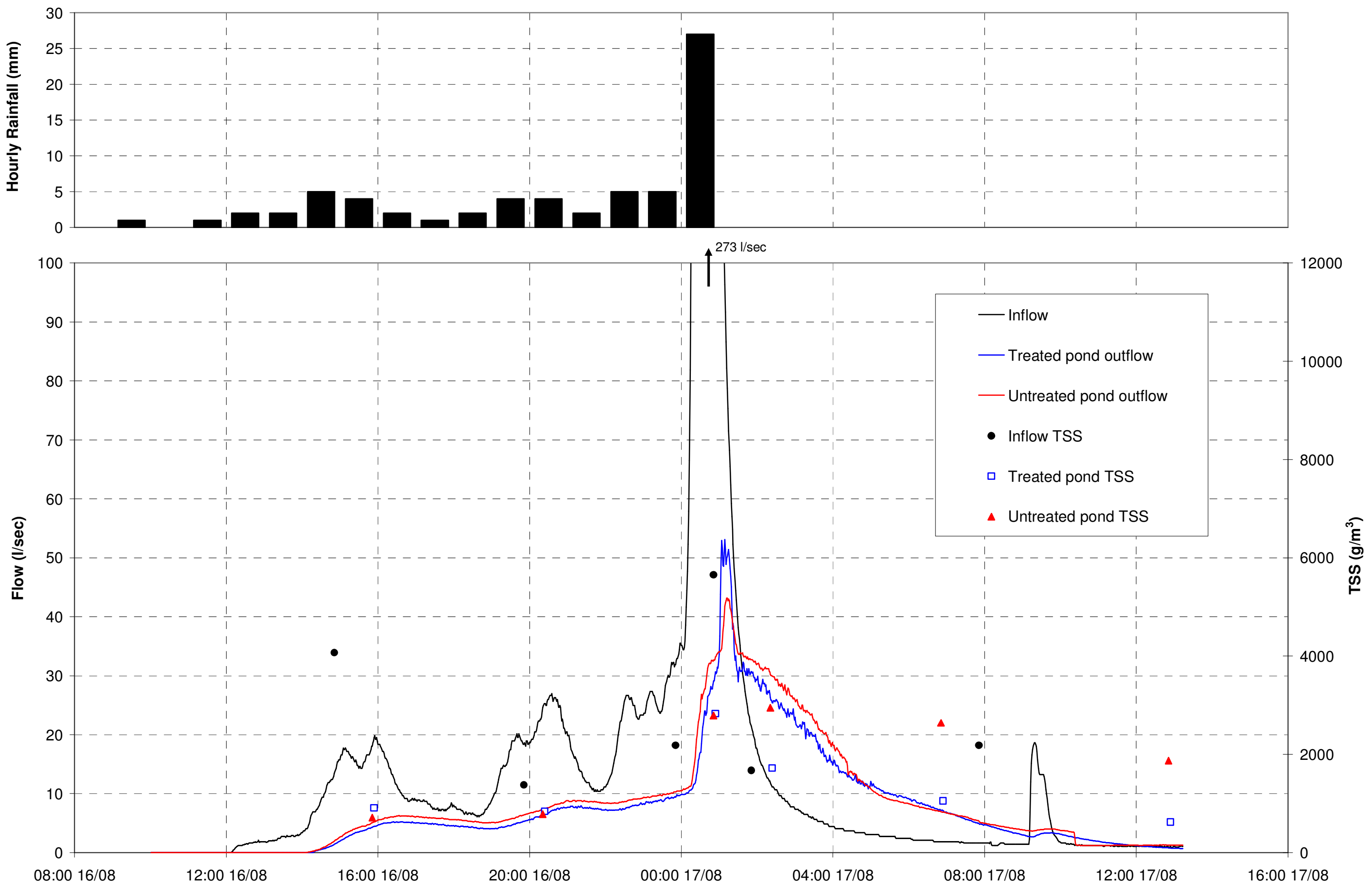


Figure 10

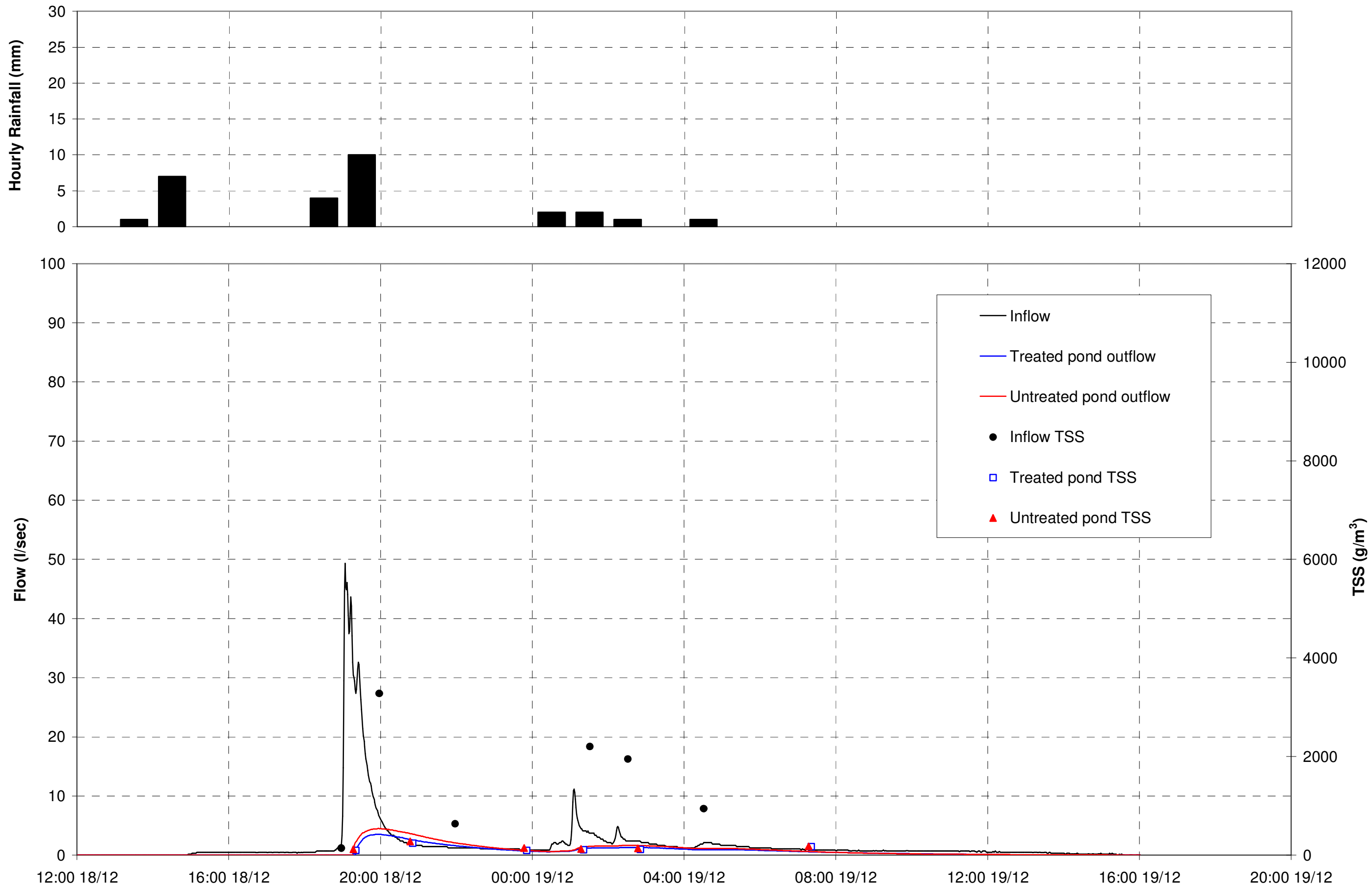
Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 6 November 2007 (Event 5).

Figure 11

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 9 December 2007 (Event 6).

Figure 12

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 18 – 19 December 2007 (Event 7).



As well as showing the attenuating effect of the ponds, the outflow hydrographs presented in Figures 6 to 12 provide an indication of differences in the quantity of water discharged from each pond. Event flow volumes and peak-flow rates were up to 35 per cent and 31 per cent higher, respectively, at the untreated pond outlet than at the treated pond outlet, although in general the pattern of the two hydrographs during each event correspond well. These differences are attributable in part to the configuration of the inlet pipes discharging water to each pond. The entrance to the untreated pond inlet pipe was constructed approximately 50 mm lower than that to the treated pond. NGA staff subsequently added a concrete lip to the untreated pond inlet pipe in order to equalise the invert heights of the two pipes. While this ensured that water would begin to flow into each pipe at the same time, it also resulted in differences between the cross sectional area of the pipe entrances once the the water level rose above their respective inverts. At any given water level, the cross sectional area of the pipe entrance to the untreated pond inlet pipe was greater than that of the entrance to the treated pond inlet pipe. As a result, flow into (and out of) the untreated pond was greater than that into the treated pond.

Other differences between the inlet pipes that may have contributed to variations in hydraulic performance and resulted in greater flows to the untreated pond included: differences in the angle of entry to each pipe from the inlet sump; differences in pipe length; and differences at the point of discharge to the sediment pond forebays. Discharge from the untreated pond inlet pipe fell freely into the pond forebay while the exit from the pipe to the treated pond was wholly or partly submerged.

Differences in pond water levels preceding storm events also contributed to differences in the flow volumes discharged at each of the pond outlets. Antecedent pond water levels in the untreated pond were generally higher than those in the treated pond, most likely as a result of differences in leakage rates through the beds of the ponds.

Figures 6 to 12 also show the timing of the operation of the pond outlet decants and the limited occurrence of flows over the manhole risers. Outflows below a flow rate of around 31 l/sec (treated pond) and 33 l/sec (untreated pond) represent flows discharged solely through the floating decants. Periods of higher flows (ie in excess of the maximum flow rates through the decants) during Events 1 and 4 coincide with the highest pond water levels recorded and indicate the occurrence of discharge over the top of the outlet manhole risers during these parts of the events.

During Event 1 there were marked differences in the outflow hydrographs of the two ponds. Following the period of peak outflows at around 1600 hrs on 29 March, the outflow from the treated pond receded more rapidly than the outflow from the untreated pond. In addition, there was a second peak in the treated pond outflows later in the event that did not occur in the untreated pond. These differences point to variations in the performance of the pond decants. The flow and pond water level records suggest that in the untreated pond, both decants were in operation following the event peak until around 1800 hrs, dropping to 1 decant until around 0430 on 30 March. In contrast, the records suggest that only one of the decants in the treated pond were working following the event peak (explaining the sudden drop in outflow rate)[8]. The subsequent second peak at around 0100 hrs (30 March) appears to indicate a brief second period of flows overtopping the manhole riser. This again suggest that one of the decants in the treated pond was not fully operational. The lack of a corresponding second peak in the outflow hydrograph of the untreated pond indicates that the decanting devices provided sufficient capacity to prevent the pond water level rising over the lip of the manhole riser in that pond.

There was no flow through the emergency spillways of either pond during any of the seven events.

5.4 TSS concentrations

Table 3 provides summary statistics of sample TSS concentrations whilst Figure 13 presents the median and range in water samples collected during each of the seven events. A full table of the results for each sample is given in Appendix 3.

Table 3

Summary statistics of TSS concentrations in water samples collected at Nukumea flocculation study ponds, Events 1 to 7.

	TSS concentration (g m^{-3})		
	Inflow	**Treated pond outflow**	**Untreated pond outflow**
Minimum	141.6	23.3	114.8
25th percentile	601.4	56.7	184.2
Median	1057.0	117.6	747.2
75th percentile	2816.5	767.5	1876.6
Maximum	5653.4	11130.0	7338.8

Minimum, 25th percentile, median and 75th percentile TSS concentrations were highest in inflow samples and lowest in samples of the treated pond outflows. The median, minimum and maximum concentrations in samples collected during each event were also highest in inflow samples and lowest in samples of the treated pond outflows, other than in samples collected during Event 1 (see Figure 13).

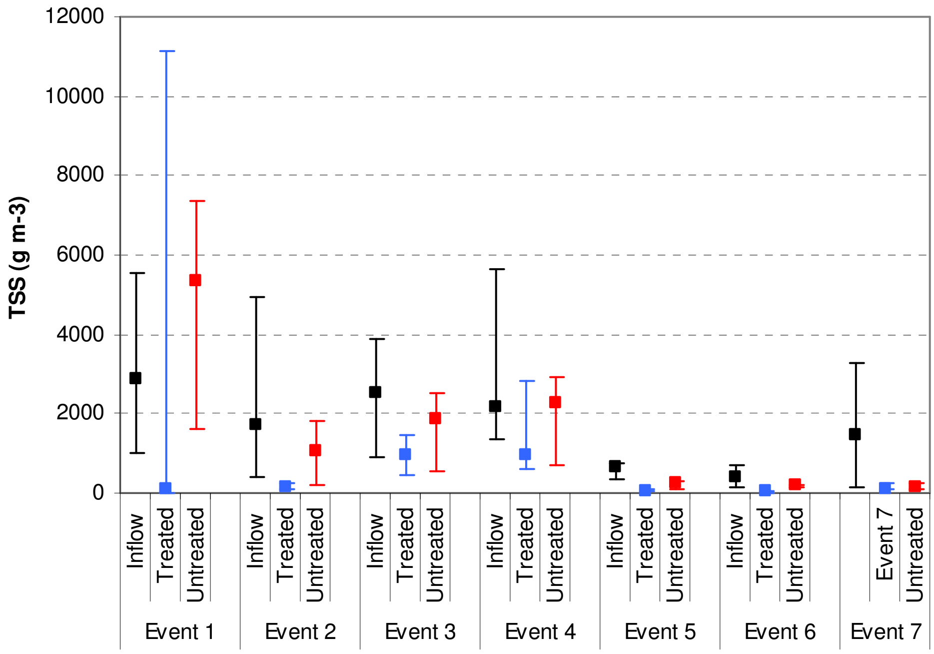
Note that caution is required when comparing the concentrations of TSS in inflow and outflow samples collected during Event 1. As described in Section 5.1.3, only three samples were analysed from Event 1 inflows, all of which were collected during a 4-hour period of relatively low inflows at the onset of the event. In contrast, the samples collected and analysed from the two pond outlets during Event 1 were distributed over the full duration of the event, including the periods of heaviest rainfall and peak flows.

[8] At the time, NGA staff gave anecdotal evidence that one of the decanting outlets from the treated pond was blocked.

Reflecting these differences in the timing of sample collection, TSS concentrations in infow samples taken during Event 1 were lower than those in samples of the untreated pond outflow and one of the samples from the treated pond outflow. This latter sample had the highest TSS concentration (11130 g m^{-3}) of any sample analysed. The sample coincided with the occurrence of peak outflows from the pond, at 1532 hrs on 29 March (see Figure 6).

Figure 13

Median and Range of TSS Concentrations in water samples of pond inflows and outflows collected during Events 1 to 7, Nukumea flocculation study ponds.



Concentrations of TSS in inflow samples collected during Events 1, 2, 3, 4 and 7 were relatively high (median TSS concentrations ≥ 1446 g m^{-3}). Concentrations in untreated pond outflow samples were also relatively high during Events 1, 2, 3 and 4 (median TSS concentrations ≥ 1081 g m^{-3}). The TSS concentrations in samples collected from the untreated pond outflows during Event 1 were markedly higher than those during any other event (median TSS concentration of 5339 g m^{-3}).

TSS concentrations in samples collected from the treated pond outflows were also relatively high during Events 3 and 4 (median TSS concentrations ≥ 982 g m^{-3}) and in one sample collected from Event 1 (referred to above, also see Figure 6). TSS concentrations in the remaining treated pond outflow samples collected during Event 1 and in all samples of treated outflows collected during Events 2, 5, 6 and 7 were relatively low (median TSS concentrations ≤ 139 g m^{-3}).

In summary, the TSS concentrations in samples of outflow from the two ponds were:

- markedly lower from the treated pond than the untreated pond during Events 1 (other than those corresponding with the timing of peak outflows) and Event 2;
- relatively high from both ponds during Events 3 and 4; and
- relatively low from both ponds during Events 5, 6 and 7.

But in all cases, TSS concentrations (as indicated by the median value) were lower in samples taken from the treated pond than in those taken from the untreated pond.

Inflow TSS concentrations varied within each event, most noticeably in association with flows. Relatively high TSS concentrations frequently corresponded with periods of rising and peak flows.

There was also variation in the degree of correpondence between TSS concentrations in samples of outflows from the two ponds. During Event 1 TSS concentrations varied considerably over the duration of the event whilst during Events 6 and 7 TSS concentrations in outflows from both ponds remained relatively low throughout (see Figure 6, 11 and 12).

During Events 2, 3, 4 and 5 TSS concentrations in the outflows from the two ponds were relatively similar during the initial stages of each event before diverging, with the higher concentrations occurring in the outflows from the untreated pond. In each event, the point of divergence corresponded with, or followed, a period of elevated flows (see Figure 7, 8, 9 and 10).

The variations in TSS concentrations described here are of consequence for the estimation of sediment loads and treatment efficiency during each event.

5.5 Sediment loads and treatment efficiency

Table 4 presents estimated sediment loads conveyed in pond inflows and outflows and the estimated sediment removal efficiency of the two ponds.

The estimated total load into the shared inlet (prior to flow splitting) ranged by three orders of magnitude, from 44.6 kg (Event 6) to a value in excess of 10,000 kg (Event 1). While the total load into the ponds during Event 1 can not be accurately estimated, a minimum estimate has been made from the calculated load discharged at the untreated pond outlet (see Table 4).

Sediment loads discharged from the treated pond were lower than from the untreated pond during all events, ranging from 35 to 89 per cent of the loads discharged from the untreated pond. The total load out of the treated pond ranged from 2.1 kg (Event 6) to 1235 kg (Event 1). The lowest and highest loads out of the untreated pond occurred in these same two events, being 9.2 kg and 5286 kg, respectively.

Table 4

Sediment loads in pond inflows and outflows and sediment removal efficiency of the treated and untreated ponds.

	Treated pond			Untreated pond		
Event number	Sediment load in[1] (kg)	Sediment load out (kg)	Efficiency (%)	Sediment load in[1] (kg)	Sediment load out (kg)	Efficiency (%)
1	≥ 4942[2]	1235	≥ 75.0[2]	≥ 5286[3]	5286	-[3]
2	599	64.8	89.2	808	564	30.2
3	1182	469	60.3	1457	1058	27.4
4	2223	1167	47.5	2422	1797	25.8
5	51.6	3.07	94.1	55.7	18.4	67.0
6	21.9	2.05	90.6	22.7	9.15	59.7
7	122	9.34	92.3	153	13.8	91.0

Notes: Sediment loads in inflows to each of the two ponds were estimated from the total sediment load at the shared pond inlet and the ratio of outflow volumes from the two ponds during each event (refer to Section 4.5).

Despite incomplete inflow records and lack of representative inflow sampling results during Event 1 an estimate of the minimum load into the treated pond and hence, of a minimum treatment efficiency can be made. The minimum load into the untreated pond is assumed to be equal to the load out of that pond (5286 kg). The minimum load into the treated pond is then estimated to be 93.5 per cent of this figure, based on the ratio of outflows from the two ponds.

Other than assuming that the sediment load into the untreated pond was greater or equal to the load out during Event 1, it is not possible to estimate the sediment load into the untreated pond nor its treatment efficiency during Event 1 due to incomplete inflow records and lack of representative sampling results.

Sediment removal efficiencies were higher in the treated pond during all events. Efficiencies of 75 per cent or greater were achieved during five of the seven events in the treated pond and during only one event in the untreated pond. The efficiency of both ponds was lowest during Events 3 and 4, both of which had relatively high incoming sediment loads.

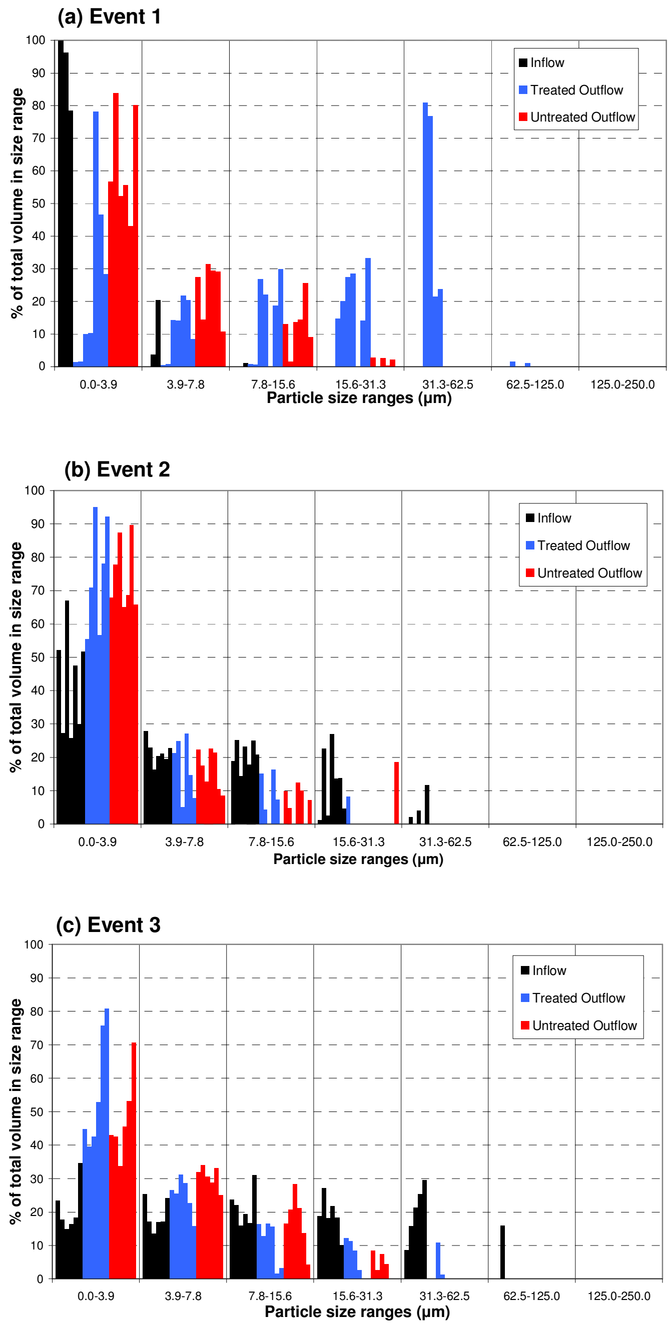
The sediment removal efficiency of the treated pond on the total loads discharged to the ponds during Events 2 to 7 (from which complete inflow data is available) was 59.2 per cent, twice that of the untreated pond. This increases to a value of ≥ 67.7 per cent if the estimated minimum load into the pond during Event 1 is included in the total inflow load.

5.6 Particle size distribution

Figures 14 a – f present the particle size distribution in water samples collected during six of the seven events. The results are expressed as the proportion of the total sediment volume in each of the following seven size classes (based on the Wentworth scale): clay (0 – 3.9 µm), four silt classes (3.9 – 7.8 µm , 7.8 – 15.6 µm, 15.6 – 31.3 µm and 31.3 – 62.5 µm), very fine sand (62.5 – 125 µm) and fine sand (125 – 250 µm). A full table of the results for each sample is given in Appendix 3.

Figure 14 (a – c)

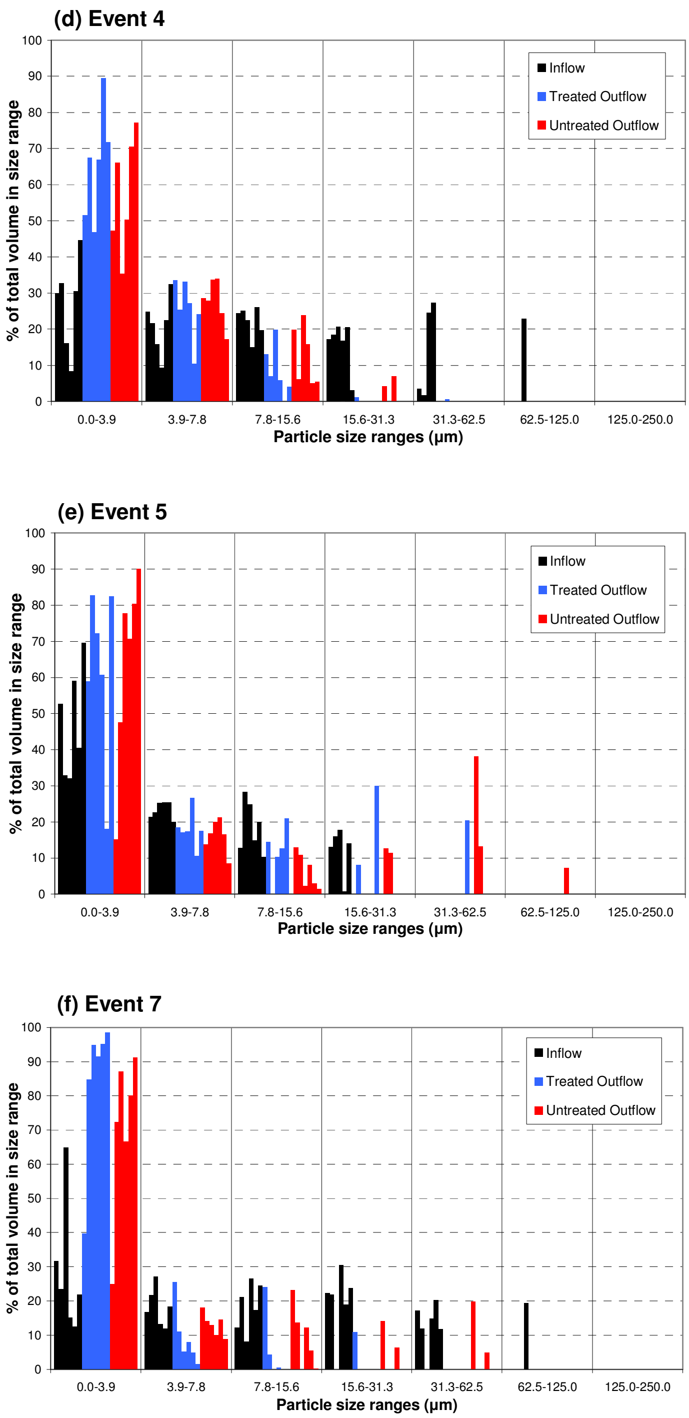
Proportion of total volume of suspended sediment particles in size range classes between 0 and 250 µm diameter in water samples of pond inflows and outflows collected during Events 1 to 3, Nukumea flocculation study ponds[9].



[9] Bars represent the proportion of the total volume of sediments in a sample in the particle size class and are arranged from left to right to represent samples collected sequentially through the event. For example, the first black bar in each particle size class represents he proportion of sediments in the first sample of pond inflows falling within that particular size class.

Figure 14 (d – f)

Proportion of suspended sediment particles in size ranges classes between 0 and 250 µm diameter (volume equivalent) in water samples of pond inflows outflows collected during Events 4, 5 and 7, Nukumea flocculation study ponds.



The results from analysis of samples collected during Event 1 are markedly different to those collected during Events 2 to 7. During Event 1, samples collected at the pond inlet contained only relatively fine sediments, mostly in the 0 – 3.9 µm size range[10]. Samples collected at the pond outlets contained higher proportions of coarser sediments. Those collected at the treated pond outlet contained, on average, a substantially higher proportion of sediments > 15.6 µm than those collected at the untreated pond outlet. Median particle sizes varied in the ranges 0.65 – 1.87 µm in inflow samples (mean 1.08 µm), 2.08 – 43.58 µm in treated pond outflow samples (mean 19.56 µm) and 1.35 – 3.78 µm in untreated pond outflow samples (mean 3.02 µm).

The proportion of sediments in each size range class varied during the course of Event 1. Initially, sediments discharged from the treated pond were predominantly > 31.3 µm (more than 76 per cent of the total volume). Subsequent samples coinciding with the period of peak outflows contained relatively evenly distributed sediments in size classes ranging from 0 to 62.5 µm. The next sample (taken during recession of peak flows) had a relatively high proportion of very fine sediments (78 per cent < 3.9 µm). Samples taken at the treated pond outlet towards the end of the event had more evenly distributed particle size characteristics, but did not contain any particles > 31.3 µm in size. Sediments in samples collected at the untreated pond outlet during Event 1 were restricted to particle size of < 31.3 µm throughout the event, with five out of six samples containing more than 50 per cent of sediments in the finest size class, 0 – 3.9 µm.

The results for Events 2 to 7 also indicate a marked difference between the particle size characteristics of inflow and outflow samples but, in contrast to Event 1, samples collected at the inlet during these events contained a higher proportion of relatively coarse sediments than those collected at the pond outlets. A second point of difference is the similarity between the results for samples collected from the treated and untreated pond. Median particle sizes in samples collected during Events 2 to 7 varied in the ranges 2.38 – 31.9 µm in inflow samples (mean 8.97 µm), 0.82 – 15.72 µm in treated pond outflow samples (mean 2.93 µm) and 1.17 – 23.04 µm in untreated pond outflow samples (mean 3.56 µm).

Sediments in inflow samples collected during Events 2 to 7 were relatively evenly distributed amongst four size range classes, with 34 per cent in the range 0 – 3.9 µm, 21 per cent in the range 3.9 – 7.8 µm, 20 per cent in the range 7.8 – 15.6 µm and 15 per cent in the range 15.6 – 31.3 µm. In contrast, samples collected at both pond outlets had a much higher proportion of the finest sediments, with 68 per cent and 63 per cent of sediments in the range 0 – 3.9 µm in treated and untreated pond samples respectively.

The contrast between particle size characteristics of inflow and outflow samples was evident during each of Events 2 to 7. Sediments in inflow samples were distributed across the range 0 – 31.3 µm whilst sedmients in outflow samples were most frequently < 3.9 µm (event means of 48 – 84 per cent < 3.9 µm). The majority of

[10] The three inlet samples analysed were collected during the early stages of Event 1, prior to the onset of peak flows. Caution is required when comparing results for these inflow samples with those for Event 1 outflow samples for the reasons described in Section 5.4.

samples collected at the pond outlets during Events 2 to 7 did not contain sediments > 31.3 µm in size. The most notable exceptions were two samples of untreated pond outflows collected during Events 5 and 7 and a single sample of treated pond outflows collected during Event 5. These samples contain 34 – 58 per cent sediments of size > 15.6 µm.

Particle size characteristics varied during the course of each of Events 2 to 7. To some extent these variations followed a similar pattern coinciding with time since the onset of each event. Outflow samples from both ponds tended to have relatively high proportions of their coarsest sediments in samples collected during periods of rising or peak flows, early- to mid-event. The particle size characteristics of inflow samples collected during the early part of each event followed a less consistent pattern. However, samples of both inflows and outflows collected during the latter part of Events 2 to 7, coinciding with periods of receding or stable flows, had relatively high proportions of the finest sediments (up to 98 per cent of sediments < 3.9 µm).

5.7 Dissolved aluminium

Table 5 provides summary statistics of sample dissolved aluminium concentrations whilst Figure 15 presents the median and range in water samples collected during each of the six events from which samples were analysed[11]. A full table of the results for each sample is given in Appendix 3.

Median dissolved aluminium concentrations in samples from the two pond outlets were similar whilst 25th percentile concentrations were identical. Minimum, 75th percentile and maximum concentrations were higher in samples from the treated pond than from the untreated pond. The maximum dissolved aluminium concentration of 0.32 g m^{-3} occurred in a sample of treated water collected during Event 1[12]. This was over three times the maximum concentration in samples taken from the untreated pond outlet.

Table 5

Summary statistics of dissolved aluminium concentrations in water samples collected at Nukumea flocculation study ponds.

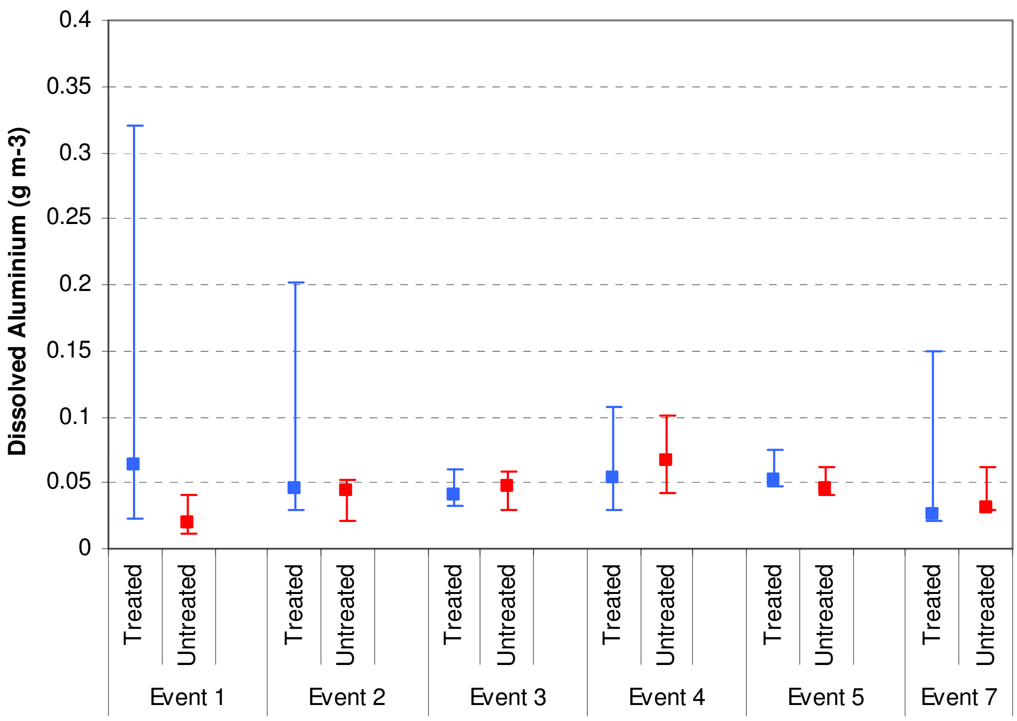
	Dissolved aluminium concentration (g m^{-3})	
	Treated pond outflow	**Untreated pond outflow**
Minimum	0.021	0.011
25th percentile	0.032	0.032
Median	0.047	0.044

[11] In accordance with the project brief samples from six of the seven events were analysed for dissolved aluminium. Samples from Event 6 were only analysed for TSS.

[12] A subsequent analysis of a sub-sample retained from this sample was undertaken to check the original result. The repeat analysis gave a higher concentration of 0.378 g m^{-3}. The variation between these results is within the normal range of analytical variability.

	Dissolved aluminium concentration ($g\ m^{-3}$)	
	Treated pond outflow	Untreated pond outflow
75th percentile	0.070	0.052
Maximum	0.320	0.101

Figure 15
Median and range of dissolved aluminium concentrations in water samples of pond outflows collected during Events 1 to 5 and 7, Nukumea flocculation study ponds. Samples collected during Event 6 were not analysed for dissolved aluminium.



Relatively high median and/or maximum dissolved aluminium concentrations occurred in samples taken from the treated pond outlet during Events 1, 2, 4 and 7. Median and maximum concentrations in samples collected from the untreated pond were relatively low during all events other than Event 4.

Maximum concentrations of dissolved aluminium were higher in samples of treated water than of untreated water during each event. However, median and/or minimum concentrations were higher in samples from the untreated pond than the treated pond during Events 3, 4 and 7.

Figure 17 presents the time series of dissolved aluminium concentrations during each of the six events from which samples were analysed. Other than during Event 1, the highest aluminium concentrations in outflows from the treated pond occurred in the early- to mid-part of each event (with the highest value occurring in the first or second sample analysed from each event). In each case, these samples coincided with rising flows during the early stages of the event. Dissolved aluminium concentrations tended to be lower and relatively stable during the latter stages of each event when flows were in recession. In contrast, during Event 1 the highest concentration (the maximum concentration in any of the samples analysed) occurred in a sample taken at the very end of the event.

Figure 17(a)

Flow and dissolved aluminium concentrations in water samples of pond outflows collected during Events 1, 2 and 3, Nukumea flocculation study ponds (note scales vary).

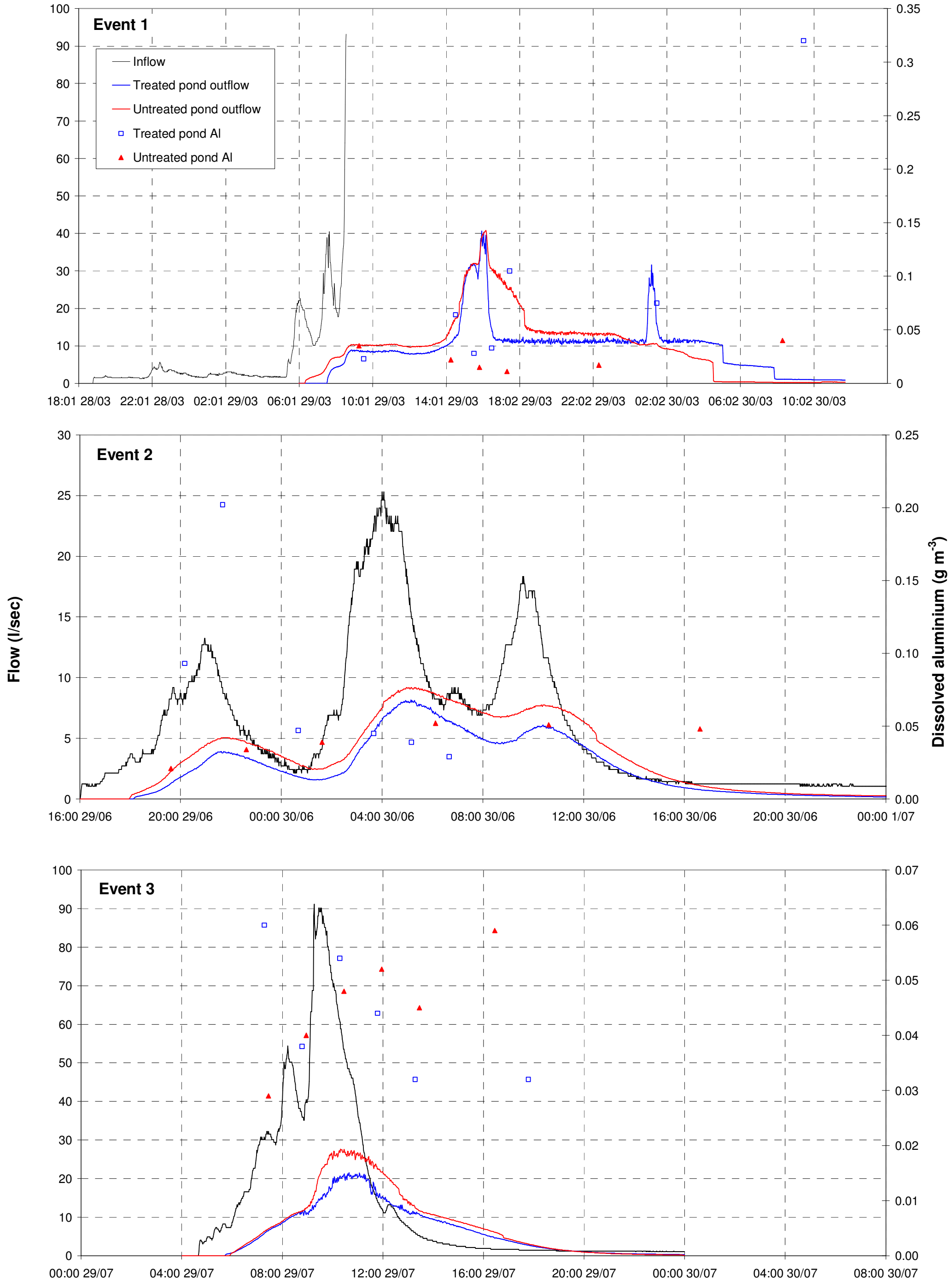
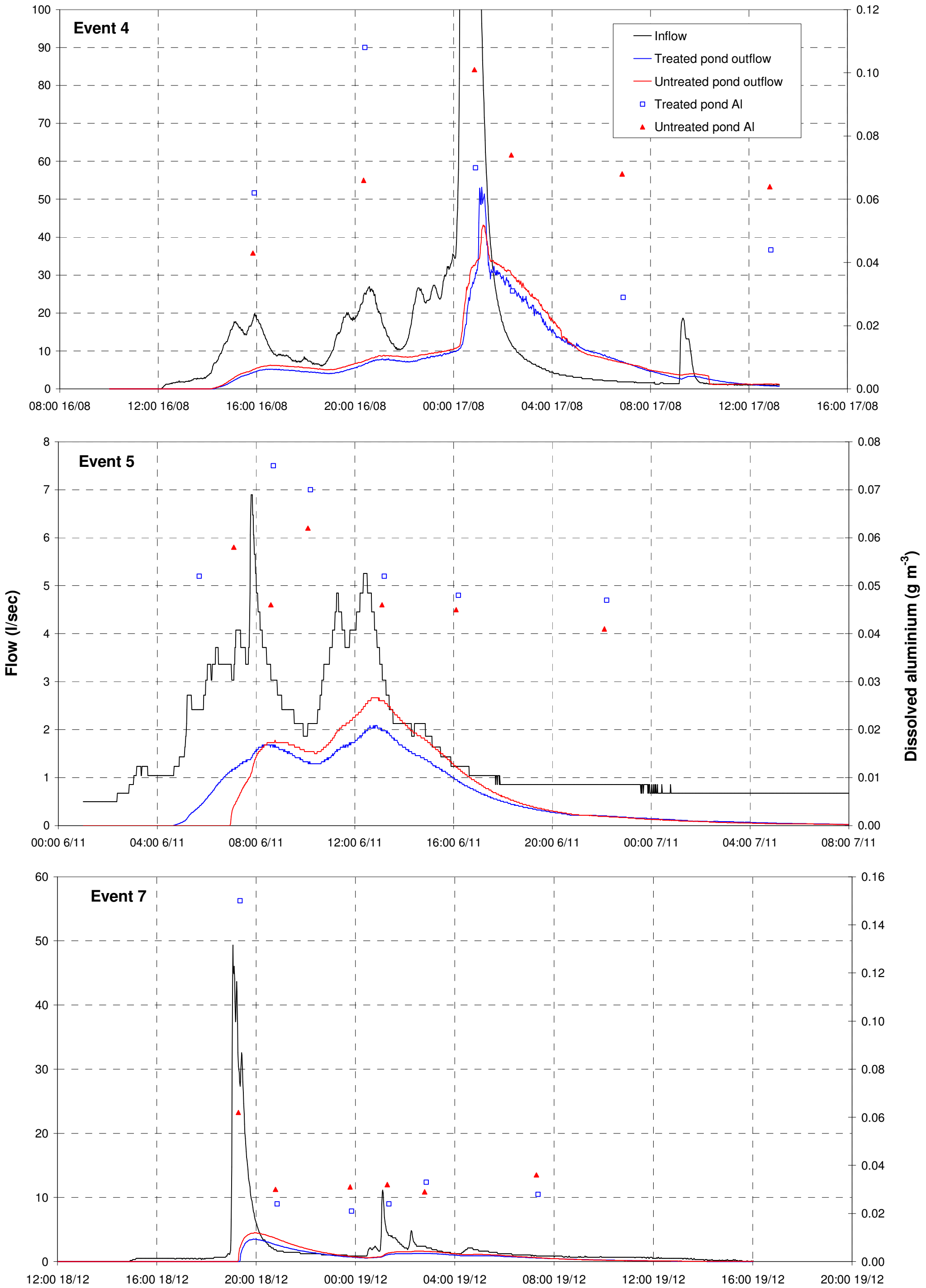


Figure 17 (b)

Flow and dissolved aluminium concentrations in water samples of pond outflows collected during Events 4, 5 and 7, Nukumea flocculation study ponds (note scales vary).



Dissolved aluminium concentrations in samples taken from the untreated pond were less variable, with a semi-interquartile range of 0.02 g m^{-3} compared to 0.038 g m^{-3} in treated pond samples. Relatively high dissolved alumium concentrations in samples taken from the untreated pond coincided with early flow peaks, but only during Events 4 and 7. In other events concentrations remained relatively constant or peaked at times that outflows were in recession.

5.8 Quality assurance results

5.8.1 Particle size analysis

Table 6 presents the results of repeated particle size analyses conducted for quality assurance purposes. The results indicate satisfactory consistency between repeated analyses.

Table 6
Results of repeat particle size analyses,

Batch	Sampling date	Sampling time	Sampling site	Particle size (µm)			
				Mean		Standard deviation	
				Run 1	Run 2	Run 1	Run 2
1	29/03/07	0917	Untreated pond	4.49	4.50	3.76	3.73
2	16/08/07	0051	Inflow	38.60	35.31	30.22	25.37

5.8.2 Dissolved aluminium

Table 7 presents the results of dissolved aluminium analyses conducted for quality assurance purposes.

The analytical results for duplicate samples from Events 1 to 4 are in close agreement. There is a 33 per cent percent difference between duplicate sample results from Event 5 and a six-fold difference in the results from Event 7.

The results from Event 7 were queried, resulting in a repeat analysis of the samples by the analytical laboratory. The results of the repeat analysis were reported to be within 20 per cent of the originals (*pers.comm.*, J. Connick, Feb 2008). It was not possible to reprocess the original sample for a further repeat analysis as none had been retained. Consequently, the reason for the difference between results for these duplicate samples is uncertain.

Table 7
Dissolved aluminium concentrations in QA samples.

Event	Dissolved aluminium concentration (g m-)			
	Duplicate samples			Blanks
	Sample 1	Sample 2	Source of duplicates	
1	0.075	0.069	Treated pond	0.006
2	0.045	0.046	Treated pond	<0.003
3	0.052	0.050	Untreated pond	0.006
4	0.064	0.069	Untreated pond	<0.003
5	0.048	0.032	Treated pond	0.011
7	0.028	0.170	Treated pond	0.011

However, of the two results, the lower value is consistent with dissolved aluminium concentrations in preceding samples during Event 7 (range 0.024 to 0.033 g m^{-3}). The lower value of 0.028 g m^{-3} was therefore used in preparing the summary statistics and plots presented in Table 5 and Figure 15 respectively.

6 Discussion

6.1 Effectiveness of PAC treatment

6.1.1 Overall performance

The results described in Chapter 5 indicate that addition of PAC is an effective method for improving the sediment removal efficiency of sediment retention ponds. Over the seven events monitored the total sediment load discharged from the untreated pond was three times that from the treated pond, at an estimated 8.75 and 2.95 tonnes respectively. Combining the results of Events 1 to 7, the treated pond achieved an estimated sediment removal efficiency of at least 68 per cent The untreated pond performed well below this level (around 30 percent)[13].

However, the results also indicate substantial variations in the effectiveness of PAC treatment both during and between storm events. The following section describes and provides an interpretation of the key aspects of pond performance during each of the seven events monitored. Section 6.1.3 then describes an evaluation of the factors that may have contributed to this variability in effectiveness.

6.1.2 Variations in performance

Event 1 was by far the largest event (in terms of total rainfall, flows and sediment loads) and PAC treatment proved to be effective, with the treated pond discharging less than a quarter of the total sediment load of the untreated pond (estimated to be 1.2 and 5.3 tonnes respectively). Photographs taken during the event clearly show differences in the colour and clarity of water in the ponds and in samples collected from the outlets (see Figure 18).

The particle size distribution of samples collected during this event provide evidence that these differences were the result of flocculation of sediments due to PAC treatment. The discharge from the treated pond contained apparently coarser sediments than either the pond inlet or the untreated pond outlet. The most likely explanation is that these larger particles were flocculated aggregates that were unable to settle prior to discharge[14].

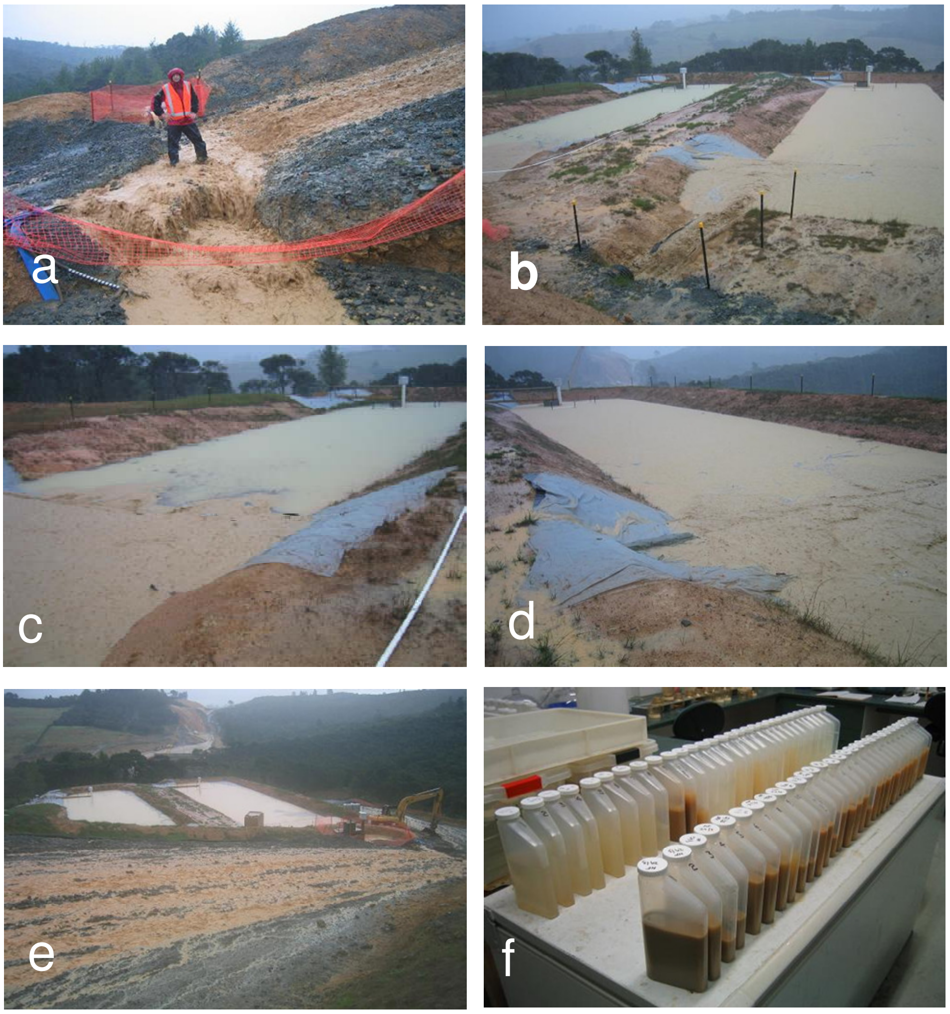
However, during the period of peak-flow out of the ponds the performance of the PAC treated pond was poor, with elevated TSS concentrations (up to 11130 g m^{-3})

[13] These estimates of efficiency do not account for any pre-treatment of sediment laden water entering the ponds, for instance interception or deposition of bed load at any sediment control measures employed upstream of the ponds.

[14] Another possibility is that the presence of coarser material reflects the flushing of plankton from the pond, the antecedent long dry spell giving rise to conditions under which a plankton bloom could have become established (*pers.comm.*, M. Larcombe (April 2008).

measured in samples collected at this time. These samples were also characterised by an increase in the proportion of fine sediments and relatively low dissolved aluminium concentrations.

Figure 18
Photographs of the study site and samples, 29 March 2007 (Event 1): (a) sediment laden inflows prior to discharge to the inlet sump; (b) treated pond (left) and untreated pond (right) prior to period of peak discharges; (c) difference in colour and clarity of water at head of treated pond indicating the action of PAC prior to period of peak discharges; (d) homogeneity in colour and clarity of water in the untreated pond; (e) ponds immediately following the period of peak flows; and (f) samples collected at the treated pond outlet (left) and untreated pond outlet (right) showing change in colour and clarity of treated pond samples number 9, 10 and 11 (coinciding with event peak flows).



NIWA staff were on-site to collect samples and restock the autosampler during this part of the event and observed a change in the colour and turbidity of the treated pond consistent with a cessation in the flocculation of sediments. The analytical results and observations on-site indicate failure of the PAC system at this point in the event. Possible reasons for this include:

- that the dose rate at this time was insufficient to be effective given the mass and rate of delivery of suspended sediments during this part of the event; or
- that dosing of the pond ceased as a result of the PAC dosing tank running dry or failure of the system elsewhere, for instance as a result of a hose disconnection.

Following the recession of the event peak the PAC again became effective with TSS concentrations one to two orders of magnitude lower than those in water discharged from the untreated pond.

The PAC treatment was effective throughout Event 2. Rainfall was relatively evenly distributed and the three periods of peak flows that occurred were characterised by relatively gradual rates of rise and recession. It appears that the system worked well during this event, achieving an estimated treatment efficiency of nearly 90 per cent in contrast to the 30 per cent efficiency of the untreated pond.

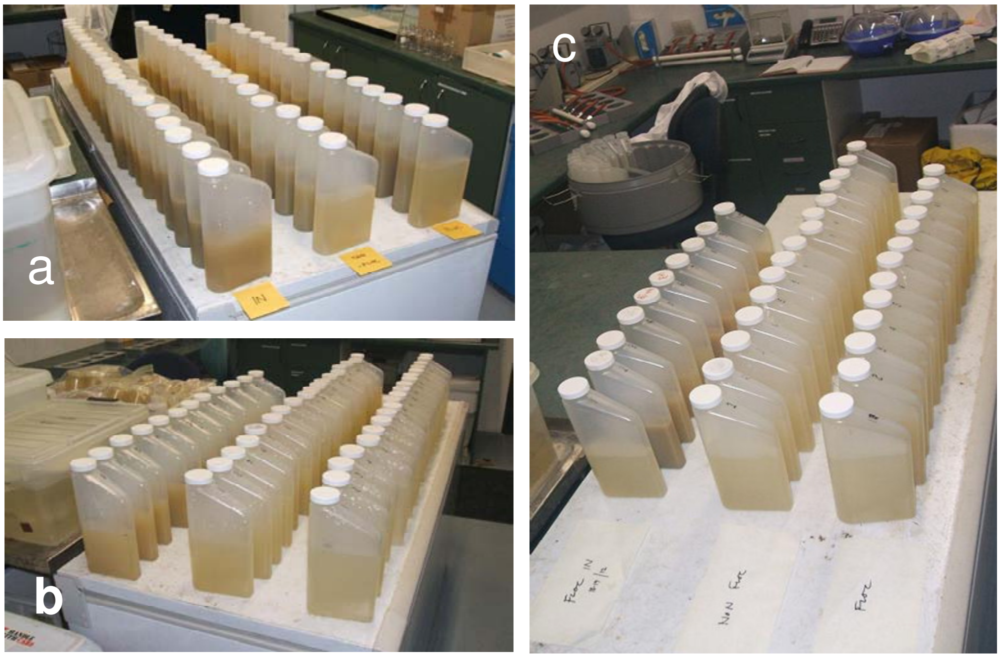
Event 3 was of relatively short duration and featured an almost undisturbed rise to peak flows followed by rapid recession. Compared to the untreated pond, the PAC treatment was again effective, although the estimated sediment removal efficiency was lower than preceding events at 60 per cent. The divergence in pond performance occurred as flows rose towards the event peak. TSS concentrations in the first sample analysed from each pond were similar (and both relatively low) with a more marked difference between subsequent pairs of samples through and following the period of peak flows. In contrast to Event 1, PAC treatment did make a substantial difference to pond performance during the period of peak flows in this event.

In terms of rainfall depths and duration Event 4 was similar to Event 2 until the final hour during which 27 mm of rain fell. This resulted in the highest peak inflow and outflows recorded during any of the events. In a similar fashion to Event 3, the performance of the ponds was comparable during the early stages of the event but diverged following the period of peak flows. Figure 19 (a) shows the apparent similarity in outflow samples from the two ponds other than those collected during the latter stages of the event. As a result of the apparent initial underperformance of the PAC treatment, the estimated sediment removal efficiency of the treated pond was relatively low at 47.5 per cent.

One possible explanation for the early underperformance of the treated pond during both Events 3 and 4 is a delay in the delivery of PAC following the onset of rainfall. This could have occurred as a result of the dosing system header tank being empty at the start of these events or the attenuating influence of a choke in the delivery system *(pers.comm*. M.Larcombe, April 2008).

Events 5 and 6 were the smallest events, both characterised by relatively low total rainfall, rainfall intensity, flows and sediment loads. Both ponds achieved relatively high sediment removal efficiencies compared to previous events, with estimated efficiencies of 90 – 94 per cent (treated) and 60 – 67 per cent (untreated). Figure 19 (b) shows the relatively light colour and good clarity of samples collected from not only the treated pond but also the untreated pond during Event 5.

Figure 19
Water samples collected at the pond inlet and outlets during (a) Event 4, (b) Event 5 and (c) Event 7. In each photo samples are from the inlet (left), untreated pond (centre) and treated pond (right).



In similar fashion to Events 3 and 4, the performance of the two ponds diverged during the event, with TSS concentrations increasing slightly in samples taken from the untreated pond but remaining low in samples taken from the treated pond. Dissolved aluminium concentrations in samples from each pond during Event 5 were similar suggesting the dosing of the treated pond with PAC was at an appropriate rate (not too high).

Whilst pond performance was good during these events in terms of sediment removal efficiencies, the mass of sediment removed during Events 5 and 6 was only a minor part of the total sediment load removed during all seven events. During the seven events monitored an estimated total load of at least 6.2 tonnes of sediments was deposited in the the treated pond. Only 1 per cent of this was the result of treatment during Events 5 and 6.

Event 7 was characterised by a relatively large early peak inflow followed by recession and subsequent smaller peaks of similar magnitude to Events 5 and 6. The performance of the ponds was virtually identical, with estimated efficiencies of 92 per cent and 91 per cent for the treated and untreated ponds respectively. In contrast to previous events TSS concentrations in samples taken from the two pond outlets during this event did not diverge. Figure 19 (c) shows the similarity of samples collected at the two outlets throughout the event.

In the case of this event the similarity between pond performance appears to reflect the untreated pond performing well rather than the treated pond performing poorly. NGA staff have confirmed that the PAC dosing system had been inspected and was believed to be functioning correctly during this event. The results of sampling of treated pond outflows support this. The performance of the untreated pond during Event 7 may indicate that conditions prior to and during this event were conducive to its optimum performance. Alternatively, there is a possibility that pond was also receiving PAC. A potential mechanism by which this could have happened is by leakage from the pipe conveying PAC to the third pond located downstream of the untreated pond (refer Section 6.1.3.4).

6.1.3 Factors influencing effectiveness of PAC treatment

6.1.3.1 Event hydrology

Based on the seven events monitored, PAC is effective during storm events of considerably different rainfall depth, intensity and duration. Whilst highest efficiencies (> 90 per cent) were achieved during relatively small events, in terms of mass of sediment removed the improvement in pond performance as a result of PAC treatment was most marked during events (or periods of events) with relatively high rainfall depths and intensity (Events 1 to 4 of the seven monitored here). It was during these types of event that the performance of the untreated pond monitored as part of this study was particularly poor (≤ 30 per cent).

Extrapolating from the events monitored during this study, it is evident that over the life of an earthworks project a large proportion of the total sediment load discharged to receiving environments will occur during a small number of relatively large storms. Dosing of ponds during these events makes the greatest contribution to the overall reduction in sediment outputs to be gained from PAC treatment. Dosing during relatively small events makes only a minor contribution to the long-term improvement in pond performance.

Sediment retention ponds are relatively effective without chemical treatment during smaller events because the delivery of suspended sediments occurs at a relatively low rate. There is sufficient time for a large proportion of suspended solids to settle prior to discharge of water from the pond outlet.

The results of this study suggest that this is not the case during larger events when large quantities of suspended sediments are delivered to the pond in relatively high water flows. Residence time, and hence time available for settlement to occur, is shorter, and the mass of sediments discharged from the pond is correspondingly higher. Dosing a pond with PAC during these events promotes settlement of suspended sediments that would otherwise be likely to be conveyed to the outlet.

6.1.3.2 Seasonal factors

Consistent with the discussion in Section 6.1.3.1, untreated sediment retention ponds can be expected to achieve highest efficiencies during periods when soil moisture content and pond water levels are relatively low, typically during mid to late summer. Rain falling during these conditions does not generate run-off until the available soil moisture storage has been exceeded or unless rainfall intensity is sufficient to exceed the infiltration capacity of the soil. Once run-off does occur, low pond water levels can provide a substantial buffer against the occurrence of pond outflows. Based on experience gained during this study, the number of events that result in discharges from ponds during the mid- to late-part of the earthworks season can be limited. Under such circumstances sediment ponds are effective irrespective of PAC treatment.

During winter, soil moisture levels are typically closer to capacity leading to a more rapid and proportionately greater run-off response to rainfall, as demonstrated by the analysis of rainfall and flow records collected for this study. Events occuring in winter (Events 2, 3 and 4) had a higher proportion of rainfall contributing to pond inflows (39 – 51 per cent) than those occuring in the earthworks season (14 – 29 per cent). With more frequent rainfall, pond water levels are maintained at a higher level and pond residence times are relatively short. Consequently pond performance is relatively poor, with the potential for relatively frequent discharges of elevated sediment loads. Because treatment with PAC appears to make the greatest improvement during events when pond residence time is limited, its use in winter has the potential to make a substantial difference to the annual sediment load discharged from a site. The total sediment load retained in the treated pond during three winter events (Events 2, 3 and 4) was over a tonne (82 per cent) greater than that in the untreated pond despite this being the closed season for earthworks.

This finding is of importance given the seasonal nature of earthwork activities. During the “closed” season (1 May to 30 September) earthwork activities are restricted (subject to the specific provisions of individual consents) and areas of bare earth mulched or grassed over. NGA staff report that approximately 1.4 ha of the study catchment was open (exposed) during winter 2007, rising to 3.5 ha in October 2007 (pers. comm., W.Viall (NGA), April 2008). Despite the closure or reduction in scale of earthwork sites over winter, the results of this study support continuation of PAC treatment through this period.

6.1.3.3 Sediment characteristics

This study did not investigate site to site variations in the performance of PAC treatment. However, there were temporal changes in the characteristics of the study catchment (corresponding with the location and extent of earthworks activities) which had the potential to result in variations in the characteristics of sediments discharged to the study ponds.

The results of the particle size analysis suggest this was not the case. The particle size characteristics of inflow samples were similarly distributed amongst four size ranges during five of the six events from which samples were analysed. This suggests that earthworks activities in the catchment did not result in substantial variations in the characteristics of sediments discharged to the study ponds.

The effectiveness of treatment did not appear to correspond with the preferential removal of particles of a particular size. Samples collected at the outlets of the treated and untreated ponds during Events 2 to 7 generally had similar particle size characteristics. These results suggest that PAC treatment is effective on the range of particle sizes generally found in these sediments.

6.1.3.4 Design, operation and maintenance of dosing system

ARC's guideline design for PAC dosing systems includes a low- and high-rate outlet from the rainfall header tank, the low rate operating during the initial and final (post-rainfall) stages of an event (BCHF, 2003). The system operating at the study site had three outlets, each of which would come into operation sequentially as the water level in the header tank rose in response to rainfall inflows.

It is possible that some of the variations in the effectiveness of the PAC treatment during and between the events monitored resulted from differences in the delivery of PAC to the treated pond. Performance during Event 1, for instance, suggests dosing occurred at a continuously high rate throughout the event other than around the time of the peak, when dosing may have ceased. At other times, for instance during the initial stages of Events 3 and 4, TSS concentrations in the treated pond outflows were relatively high, which could indicate underdosing or delay in the delivery of PAC due to the attenuating influence of the system choke or an initially empty header tank.

However, the fact that dissolved alumiunium concentrations in some of these same samples were relatively high would appear to contradict this possibility. High dissolved alumiunium concentrations would be expected to result from overdosing rather than underdosing.

Given this evidence, and the fact that measurement of the dosing rate was outside the scope of this study, it is not possible to establish the extent to which a relationship exists between dosing rate and pond performance. None the less, based on the results of this study it is clear that for much of the time the rainfall activated system does deliver PAC at an effective rate.

However, the study has also demonstrated that the delivery of PAC can fail. This appears to be as a result of the operation of the system rather than its design. In addition to the possible failure of the system during Event 1, the authors are aware of one confirmed event during which the system failed to dose the pond. Samples collected during an event on 10 June 2007 were discarded after NGA staff confirmed failure of the system due to a break in the delivery line. This failure occurred despite regular (weekly) inspections of the system by NGA staff.

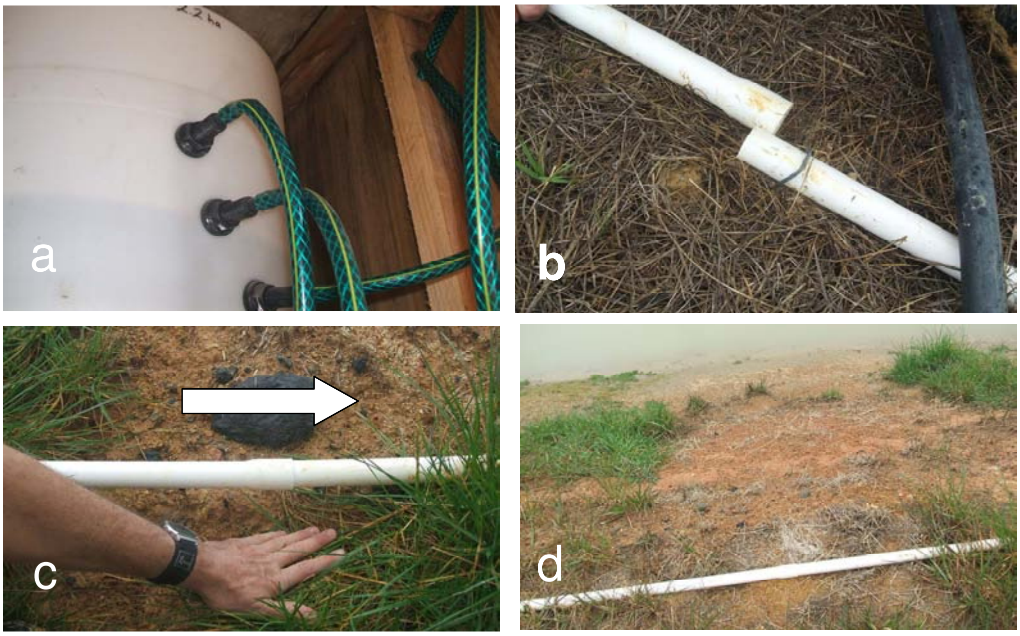
Subsequently, NIWA field staff made checks of the system before and after sampling events to avoid further redundancy of samples. Observations which could be linked to actual or potential underperfomance of the system were:

- kinks in the hoses from the header tank which could inhibit the funcitioning of the dosing system;
- loose pipe joints and reversed pipe joints allowing leakage of PAC; and
- areas of dead vegetation adjacent to pipe joins suggesting that leakage had indeed occurred.

Figure 20 presents photographs of each of these observations.

Again, monitoring of the dosing system during its operation lay outside the scope of the project but it is apparent that (other than the known instance of failure) regular inspection of the system generally ensured its effective operation. The observations set out above may therefore be only marginal factors when considering ways to improve the operation of the PAC dosing system.

Figure 20
Aspects of the PAC dosing system: (a) kinks in header tank hose; (b) loose pipe joint, taken apart for purpose of photo; (c) reversed pipe joint with arrow indicating direction of flow; and (d) area of dead vegetation indicating possible leakage of PAC from pipe joint.



6.1.3.5 Design, operation and maintenance of sediment ponds

The design, operation and maintenance of sediments ponds could also influence the effectiveness of PAC treatment. PAC treatment might be expected to make a more marked improvement in the performance of poorly designed ponds which otherwise provide only a short residence time.

Sediment and erosion control monitoring contractors for ARC have confirmed that the study ponds were constructed to TP90 specifications. The results of this study should be transferable to any similarly designed pond, subject to consistency in the operating and maintenance regime.

6.2 Residual dissolved aluminium

The median concentration of dissolved aluminium in samples of treated and untreated water were similar at 0.047 and 0.044 g m^{-3} respectively. Both are less than the

ANZECC (2000) trigger value for a 95 per cent level of protection[15] of 0.055 g m^{-3} and the USEPA water quality criteria for chronic exposure (CCC) of 0.087 g m^{-3}.

However, the ANZECC 95 per cent trigger value was exceeded by dissolved aluminium concentrations in 13 samples collected at the treated pond outlet (at least one from each of six events) and in nine samples from the untreated pond outlet (four events). The level of exceedance was greater in the treated samples than the untreated samples and occurred (with the exception of Event 1) during periods of increasing flows during the early- to mid-part of each event.

The concentration of dissolved aluminium in water samples taken from the untreated pond is indicative of the background concentration, unless contamination (for instance from pipe leakage) occurred. Higher concentrations in samples taken from the treated pond are likely to reflect the presence, of "unused" aluminium ions originating from the PAC. Dissolved aluminium ions originating in PAC rapidly form aluminium hydroxide and aluminium phosphate precipates which bind with suspended solids (ARC, 2004). Relatively high concentrations of dissolved aluminium are indicative of the presence of free alumiunium ions as yet unincoporated in these precipitates.

The change in dissolved aluminium concentrations over the duration of each event (other than Event 1) is therefore likely to reflect the interaction between the PAC dosing rate and the supply of suspended sediments. Following the onset of each event, inflows into the pond initially contributed to pond storage. By the time that the pond water level had risen sufficiently to result in a discharge at the pond outlet, event rainfall was well established and, during certain events, relatively heavy. As a result, by this stage of each of these events it is probable that the flocculant dosing system would have been operating at its highest rate. Subsequently, following the cessation of rainfall, the dosing rate of PAC would have reduced and then ceased.

At the same time, the supply of suspended sediments would have continued with the addition of sediments conveyed in pond inflows during the recession of each event. As the remaining available aluminium ions in the pond precipitated, residual dissolved aluminium concentrations fell, to levels similar to or even less than background concentrations. As a result, discharges of relatively high concentrations of dissolved aluminium were restricted to the early- to mid-parts of five of the six events.

In contrast, concentrations of dissolved aluminium during Event 1 peaked at the tail end of the event recession. The reason for this is unclear. It appears that there may have been a discharge of PAC to the pond unrelated to the normal operation of the dosing system, as there was no rainfall at that time.

[15] Following ANZECC (2000) guidance, the Nukumea Stream can be considered a slightly to moderately disturbed system for which a 95 per cent level of protection is appropriate. The trigger value applies only to waters having a pH>6.5. A single measurement of pH in the Nukumea stream at the point of discharge from the ponds of 6.71 was recorded on 19/02/08. ARC measurements of pH in the upper Nukumea Stream are in the range 6.9 to 8.1 (*pers.comm*, G.Barnes, Feb 2008). .

7 Conclusions

7.1 Effectiveness of PAC treatment

This study has investigated the effectiveness of PAC treatment of sediment retention ponds by implementing a programme of hydrological monitoring and the collection and analysis of water samples at an active earthworks site. The results of the study contrast the performance of two ponds receiving sediment laden inflows from a shared catchment: one treated (dosed with PAC), and one untreated.

The study has demonstrated that the addition of PAC is an effective method of improving the sediment removal efficiency of sediment retention ponds. The estimated sediment load discharged from the treated pond was a third of that from the untreated pond. Combining the results of Events 1 to 7, the treated pond achieved an estimated sediment removal efficiency of at least 68 per cent while the untreated pond performed well below this level at around 30 per cent.

The treatment appears to be effective on the range of particle sizes which characterise the majority of sediments at the study site (0 – 31.3 μm). Results from one event provide an indication of the discharge of flocculated aggregates at times when pond residence time is limited.

There are substantial variations in the effectiveness of PAC treatment both during and between storm events. The estimated sediment removal efficiency of the treated pond varied between 47 per cent and 94 per cent during the seven storm events monitored. The highest efficiencies were achieved during relatively small events (characterised by low rainfall totals and intensities) during which the efficiency of the untreated pond was also relatively high. However, the sediment load removed as a result of PAC treatment during these types of events was only a minor part (one per cent) of the total sediment load retained in the treated pond.

The improvement in pond performance as a result of PAC treatment is most marked during events (or periods of events) with relatively high rainfall depths and intensities (Events 1 to 4 of the seven events monitored). Whilst sediment removal efficiency in the treated pond during these types of event was as low as 48 per cent, the additional sediment load retained as a result of PAC treatment was substantial. During a single large event in March 2007 (Event 1) the sediment load discharged to the receiving environment from the treated pond was estimated to be over four tonnes less than that from the untreated pond.

These results indicate that the greatest gains from PAC treatment are achieved through dosing of ponds during larger storm events when the performance of sediment retention ponds is otherwise relatively poor.

Events of this type occur throughout the year and, based on the evidence of this study, can result in the discharge of substantial quantities of sediment during the earthworks closed season. Wet ground conditions and high pond water levels limit pond residence time and promote the relatively rapid discharge of water from ponds at this time of year. Despite the lack of active earthworking operations and implementation of other erosion and sediment control measures, continuation of PAC treatment through winter is clearly beneficial.

Variations in the effectiveness of the PAC treatment may also reflect the design and operation of the rainfall activated dosing system. Aspects of the design which delay PAC delivery or trigger variations in the dosing rate of the system could concievably result in variations in TSS concentrations but, as this rate was not measured, it was not possible to establish the extent to which a relationship exists between PAC delivery and pond performance.

However, it is known that the system failed to activate during at least one event and may have run dry around the peak of the large event of March 2007 (Event 1). Pond water samples collected at these times were indistinguishable from those collected from the untreated pond. These failures occurred despite regular (weekly) inspections of the system by NGA staff.

Whilst these instances demonstrate that the system is fallible, the result of this study suggest that the rainfall activated dosing system did operate effectively during the majority of storms.

7.2 Residual dissolved aluminium

The results of analyses of water samples suggest that, on average, dissolved aluminium concentrations in water discharged from ponds treated with PAC are similar to those in water from untreated ponds. The median concentration of dissolved aluminium in samples of treated and untreated water were similar at 0.047 and 0.044 g m^{-3} respectively. Both are less than the ANZECC (2000) trigger value for a 95 per cent level of protection of 0.055 g m^{-3}.

However, there appears to be a greater chance that ponds treated with PAC will occassionally exceed the trigger value for dissolved aluminium.The ANZECC 95 per cent trigger value was exceeded by dissolved aluminium concentrations in 13 samples collected at the treated pond outlet (at least one from each of six events) and in nine samples from the untreated pond outlet (four events). The level of exceedance was also greater in the treated samples than the untreated samples.

7.3 Recommendations

The discussion contained in Chapter 6 of this report offers a number of explanations for variations in the performance of the PAC treatment based on the experimental results and observations made in the field. Additional insight could be brought by monitoring of the operation of a rainfall activated dosing system during a number of storm events to allow evaluation of the influence of the timing of PAC delivery and variations in dosing rate on pond performance.

A second finding warranting further examination is the occurrence of elevated dissolved aluminium in some samples. The extent to which these elevated concentrations may result in actual or potential adverse effects on receiving waters and biota is likely to depend on dilution and duration above effects threshold concentrations. Greater certainty on the potential for adverse effects from PAC use could be gained through an evaluation of these factors.

8 References

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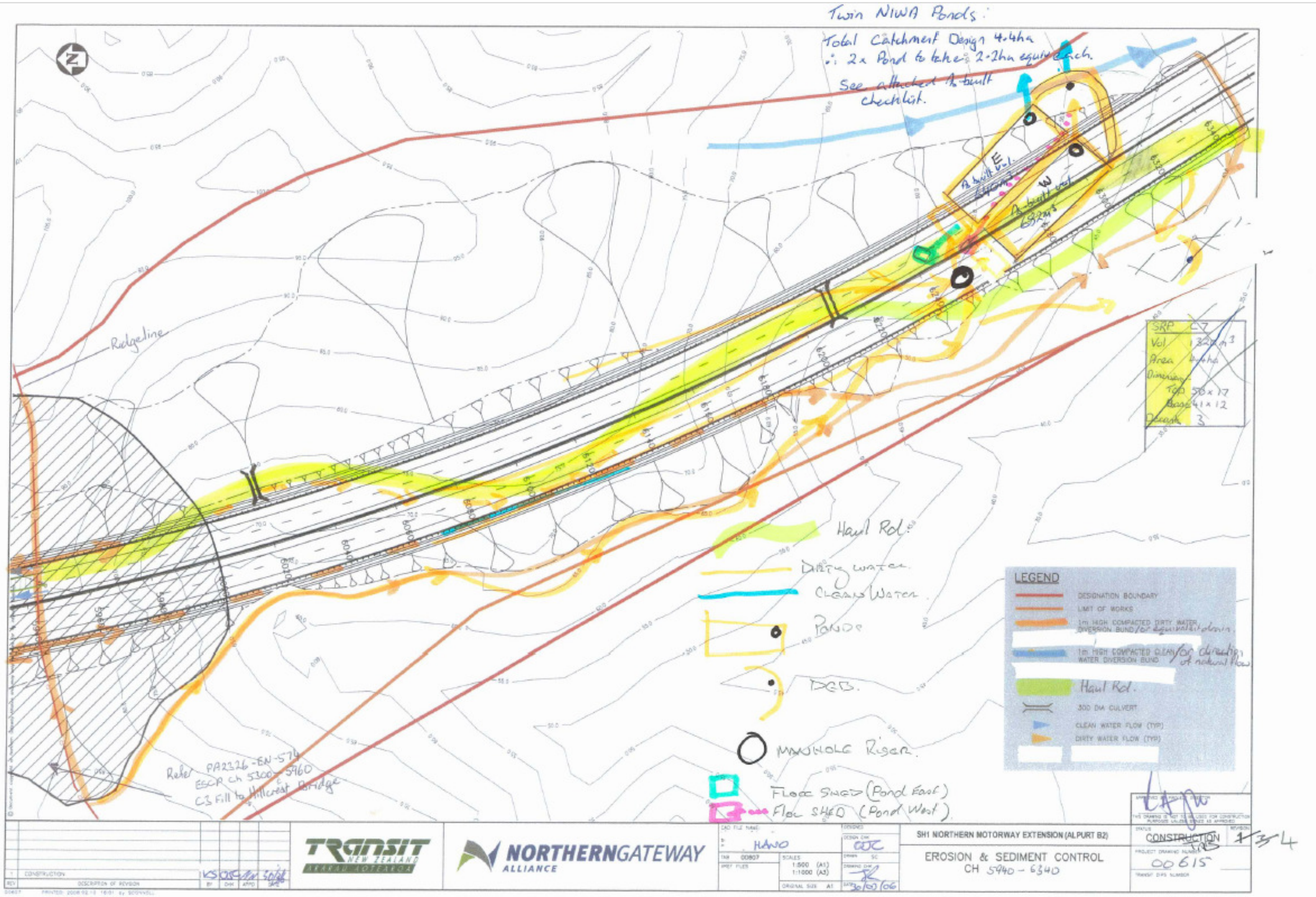
9 Appendix 1 – Erosion and Sediment Control Plan, Nukumea Study Ponds Catchment

Figure A1.1

Sediment and erosion control plan, Nukumea study ponds catchment (courtesy of Northern Gateway Alliance).



10 Appendix 2 - Additional Figures of Events 4, 5 and 6

Figure A2.1

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 16 to 17 August 2007 (Event 4).

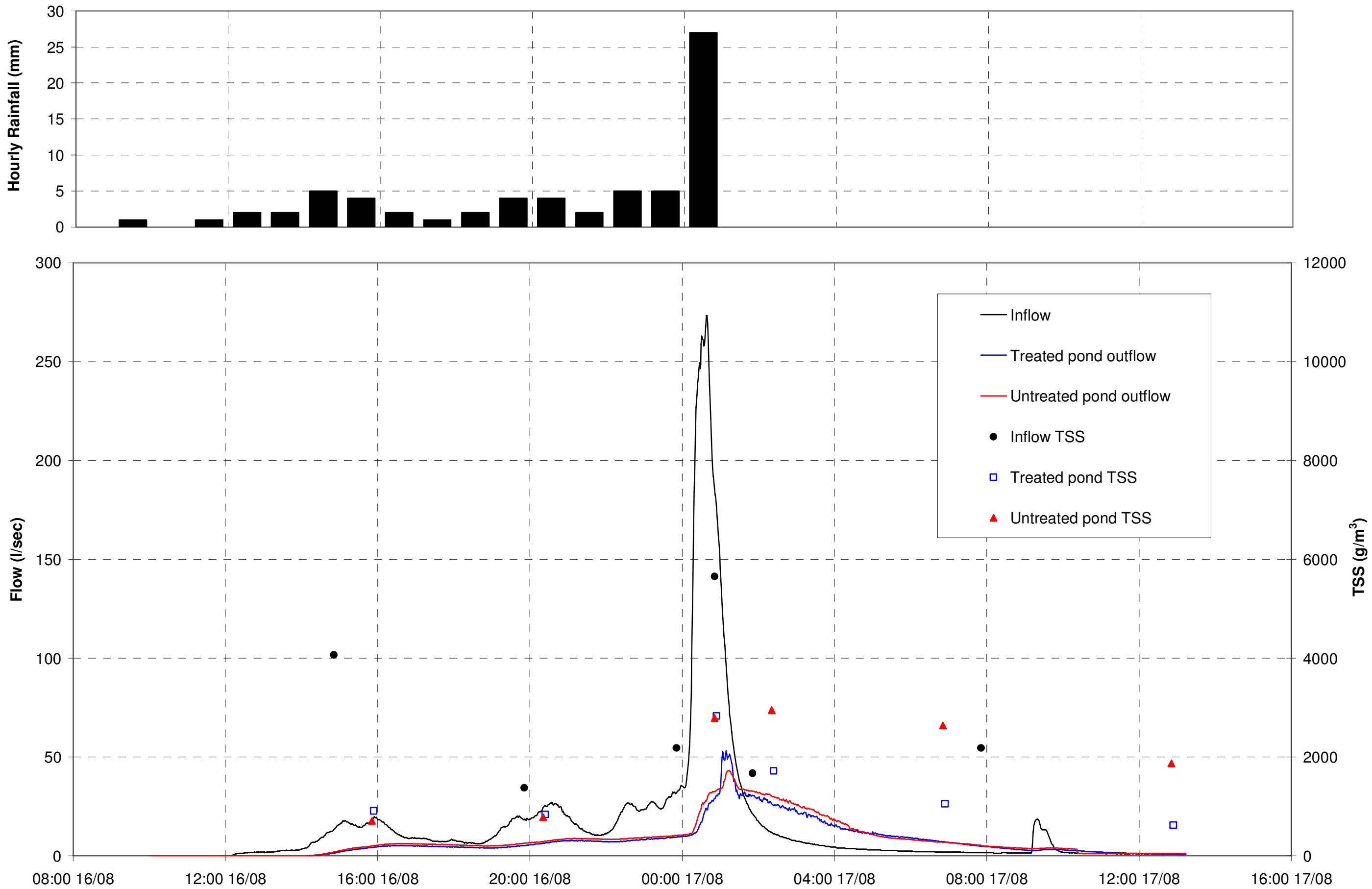


Figure A2.2

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 6 November 2007 (Event 5).

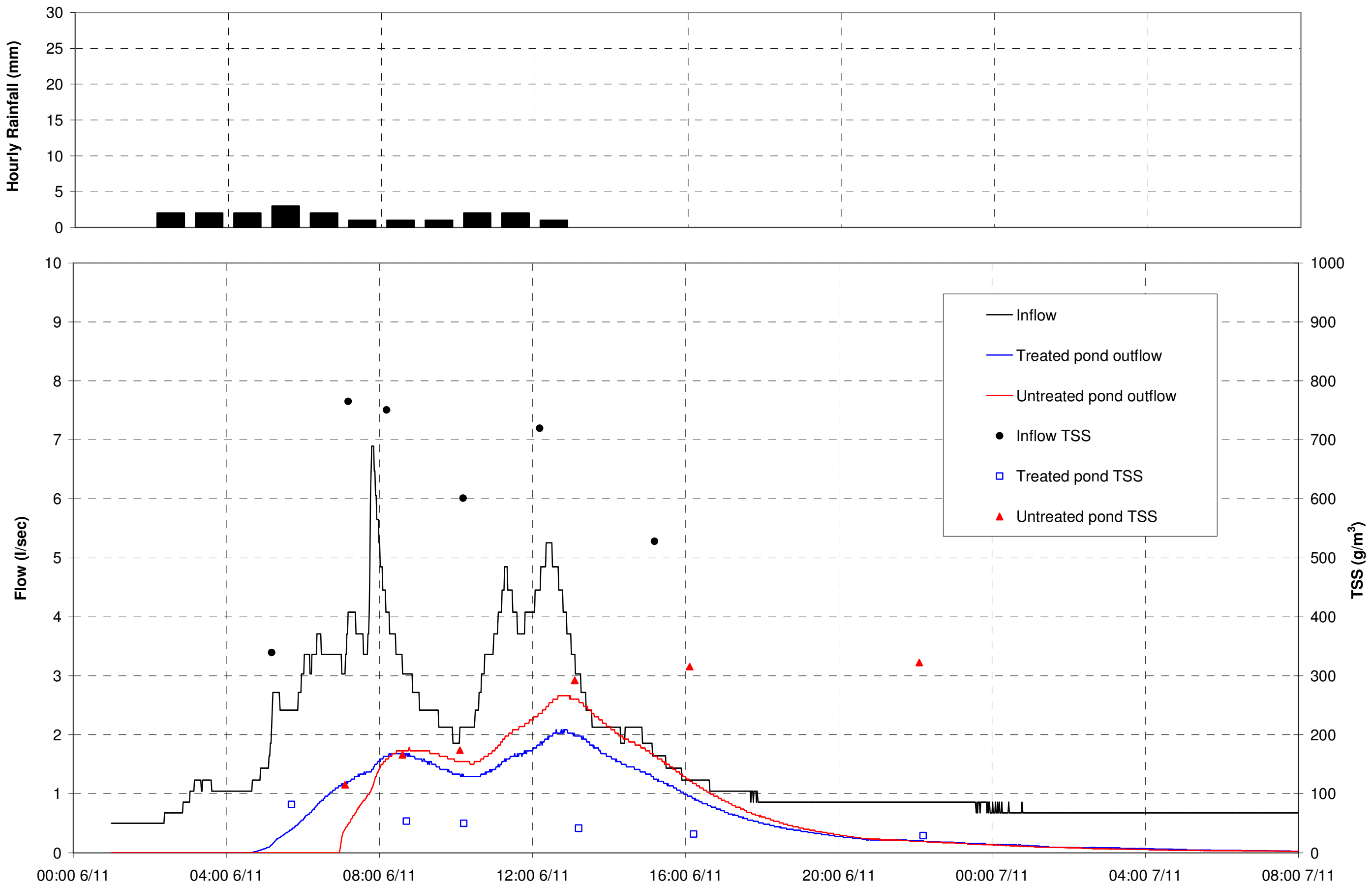


Figure A2.3

Rainfall, flows and TSS concentrations, Nukumea flocculation study ponds, 9 December 2007 (Event 6).

11 Appendix 3 – Results of Sample Analyses

Table A3.1

TSS and dissolved aluminium concentrations in water samples collected at pond inlet and outlets, Nukumea flocculation study ponds. Bracketed results are those of duplicate samples.

Event	Site	Date	Time	TSS ($g\ m^{-3}$)	Dissolved aluminium ($g\ m^{-3}$)
1	Inflow	29/03/07	1905	1005.7	-
		29/03/07	1435	5561.2	-
		29/03/07	2135	2881.6	-
	Treated pond outflow	29/03/07	0932	77.9	0.023
		29/03/07	1432	82.4	0.064
		29/03/07	1532	11130.0	0.028
		29/03/07	1630	1381.1	0.033
		29/03/07	1729	86.5	0.105
		30/03/07	0129	288.2	0.075 (0.069)
		30/03/07	0929	24.5	0.32
	Untreated pond outflow	29/03/07	0917	5682.6	0.035
		29/03/07	1417	2865.3	0.022
		29/03/07	1550	7338.8	0.015
		29/03/07	1720	7228.0	0.011
		29/03/07	2220	4996.3	0.017
		30/03/07	0820	1603.6	0.04
	Blank	-	-	-	0.006
2	Inflow	29/06/07	1750	4964.8	-
		29/06/07	2050	4358.9	-
		30/06/07	0050	1057.0	-
		30/06/07	0350	2840.9	-
		30/06/07	0750	819.8	-
		30/06/07	0950	1730.7	-
		30/06/07	1250	424.7	-
	Treated pond outflow	29/06/07	2010	105.5	0.093
		29/06/07	2140	143.2	0.202
		30/06/07	0040	135.7	0.047
		30/06/07	0340	123.3	0.045 (0.046)
		30/06/07	0510	203.1	0.039
		30/06/07	0640	268.2	0.029
	Untreated pond outflow	29/06/07	1937	186.9	0.021
		29/06/07	2237	790.1	0.034
		30/06/07	0137	1721.9	0.039
		30/06/07	0607	1821.3	0.052
		30/06/07	1037	1406.4	0.051
		30/06/07	1637	1081.2	0.048
		1/07/07	0007	1006.6	0.044
	Blank	-	-	-	< 0.003

Table A3.1 (cont.)

Event	Site	Date	Time	TSS ($g\ m^{-3}$)	Dissolved aluminium ($g\ m^{-3}$)
3	Inflow	29/07/07	0542	3729.7	-
		29/07/07	0742	2272.9	-
		29/07/07	0842	2816.5	-
		29/07/07	0942	3861.6	-
		29/07/07	1042	2102.3	-
		29/07/07	1242	913.0	-
	Treated pond outflow	29/07/07	0717	448.6	0.06
		29/07/07	0847	897.2	0.038
		29/07/07	1017	1473.5	0.054
		29/07/07	1147	1316.2	0.044
		29/07/07	1317	987.4	0.032
		29/07/07	1747	743.2	0.032
	Untreated pond outflow	29/07/07	0727	567.8	0.029
		29/07/07	0857	1866.3	0.04
		29/07/07	1027	2538.9	0.048
		29/07/07	1157	2110.6	0.052 (0.05)
		29/07/07	1327	1890.4	0.045
		29/07/07	1627	1651.1	0.059
	Blank	-	-	-	0.006
4	Inflow	16/08/07	1451	4067.7	-
		16/08/07	1951	1378.6	-
		16/08/07	2351	2187.1	-
		17/08/07	0051	5653.4	-
		17/08/07	0151	1672.8	-
		17/08/07	0751	2185.5	-
	Treated pond outflow	16/08/07	1554	911.9	0.062
		16/08/07	2024	840.2	0.108
		17/08/07	0054	2829.1	0.07
		17/08/07	0224	1721.6	0.031
		17/08/07	0654	1052.5	0.029
		17/08/07	1254	622.5	0.044
	Untreated pond outflow	16/08/07	1551	711.9	0.043
		16/08/07	2021	782.6	0.066
		17/08/07	0051	2790.2	0.101
		17/08/07	0221	2949.1	0.074
		17/08/07	0651	2640.5	0.068
		17/08/07	1251	1872.0	0.064 (0.069)
	Blank	-	-	-	< 0.003

Table A3.1 (cont.)

Event	Site	Date	Time	TSS (g m^{-3})	Dissolved aluminium (g m^{-3})
5	Inflow	6/11/07	0511	339.5	-
		6/11/07	0711	765.2	-
		6/11/07	0811	750.9	-
		6/11/07	1011	601.4	-
		6/11/07	1211	719.5	-
		6/11/07	1511	528.0	-
	Treated pond outflow	6/11/07	0542	82.0	0.052
		6/11/07	0842	53.7	0.075
		6/11/07	1012	49.8	0.07
		6/11/07	1312	41.6	0.052
		6/11/07	1612	31.7	0.048 (0.032)
		6/11/07	2212	29.1	0.047
	Untreated pond outflow	6/11/07	0706	115.4	0.058
		6/11/07	0836	166.2	0.046
		6/11/07	1006	173.9	0.062
		6/11/07	1306	292.1	0.046
		6/11/07	1606	315.6	0.045
		6/11/07	2206	322.5	0.041
	Blank	-	-	-	0.011
6	Inflow	9/12/07	1256	474.2	-
		9/12/07	1356	403.8	-
		9/12/07	1456	709.1	-
		9/12/07	1626	416.2	-
		9/12/07	1726	340.0	-
		9/12/07	0848	150.1	-
		9/12/07	0948	264.6	-
	Treated pond outflow	9/12/07	1354	57.7	-
		9/12/07	1415	60.7	-
		9/12/07	1654	45.8	-
		9/12/07	2054	29.6	-
		10/12/07	0554	23.3	-
		10/12/07	0954	33.7	-
		10/12/07	1154	36.7	-
	Untreated pond outflow	9/12/07	1358	132.3	-
		9/12/07	1458	142.8	-
		9/12/07	1658	180.6	-
		9/12/07	2058	199.8	-
		10/12/07	0558	191.3	-
		10/12/07	0958	186.2	-
		10/12/07	1158	185.4	-

Table A3.1 (cont.)

Event	Site	Date	Time	TSS ($g\ m^{-3}$)	Dissolved aluminium ($g\ m^{-3}$)
7	Inflow	18/12/07	1858	141.6	-
		18/12/07	1958	3279.1	-
		18/12/07	2158	633.7	-
		19/12/07	0131	2200.4	-
		19/12/07	0231	1949.5	-
		19/12/07	0431	944.3	-
	Treated pond outflow	18/12/07	1921	98.4	0.15
		18/12/07	2051	241.7	0.024
		18/12/07	2351	95.6	0.021
		19/12/07	0121	107.3	0.024
		19/12/07	0251	111.8	0.033
		19/12/07	0721	173.5	0.028 (0.17)
	Untreated pond outflow	18/12/07	1917	114.8	0.062
		18/12/07	2047	276.6	0.03
		18/12/07	2347	144.9	0.031
		19/12/07	0117	124.5	0.032
		19/12/07	0247	134.0	0.029
		19/12/07	0717	179.8	0.036
	Blank	-	-	-	0.011

Table A3.2

Particle size characteristics in water samples collected at pond inlet and outlets, Nukumea flocculation study ponds.

Event	Site	Date	Time	Particle size (µm)			% of total sediment volume in size ranges (µm)						
				Median	Mean	SD	0.0-3.9	3.9-7.8	7.8 -15.6	15.6-31.3	31.3-62.5	62.5-125.0	125.0-250.0
1	Inflow	29/03/07	1905	0.65	0.85	0.21	100	0	0	0	0	0	0
		29/03/07	1435	0.71	1.1	0.86	96.34	3.66	0	0	0	0	0
		29/03/07	2135	1.87	2.58	1.84	78.53	20.47	1	0	0	0	0
		Mean		1.08	1.51	0.97	91.62	8.04	0.33	0	0	0	0
	Treated pond outflow	29/03/07	0932	43.58	42.6	12.6	1.42	0.57	0.8	14.72	80.92	1.57	0
		29/03/07	1432	42.92	40.76	12.6	1.6	0.73	0.64	20.13	76.89	0	0
		29/03/07	1532	15.19	19.7	15.02	9.94	14.3	26.82	27.44	21.5	0	0
		29/03/07	1630	16.84	21.08	15.87	10.36	14.2	22.13	28.5	23.81	1	0
		29/03/07	1729	2.08	2.44	1.52	78.19	21.81	0	0	0	0	0
		30/03/07	0129	4.48	6.82	6.32	46.68	20.34	18.74	14.24	0	0	0
		30/03/07	0929	11.82	11.83	8.58	28.3	8.48	29.91	33.31	0	0	0
		Mean		19.56	20.75	10.36	25.21	11.49	14.15	19.76	29.02	0.37	0
	Untreated pond outflow	29/03/07	0917	3.47	4.49	3.76	56.8	27.41	13.04	2.75	0	0	0
		29/03/07	1417	1.42	2.24	1.76	83.98	14.42	1.6	0	0	0	0
		29/03/07	1550	3.78	4.81	3.69	52.38	31.42	13.57	2.63	0	0	0
		29/03/07	1720	3.58	4.35	3.31	55.72	29.48	14.47	0.34	0	0	0
		29/03/07	2220	4.51	5.76	4.06	42.99	29.2	25.6	2.2	0	0	0
		30/03/07	0820	1.35	2.62	2.77	80.21	10.74	9.05	0	0	0	0
		Mean		3.02	4.05	3.23	62.01	23.78	12.89	1.32	0	0	0

Table A3.2 (cont.)

Event	Site	Date	Time	Particle size (µm)			% of total sediment volume in size ranges (µm)						
				Median	Mean	SD	0.0-3.9	3.9-7.8	7.8-15.6	15.6-31.3	31.3-62.5	62.5-125.0	125.0-250.0
2	Inflow	29/06/07	1750	3.75	4.99	4.06	52.14	27.84	18.87	1.15	0	0	0
		29/06/07	2050	7.75	10.24	8.12	27.27	22.96	25.17	22.59	2.02	0	0
		30/06/07	0050	2.41	3.95	3.97	66.96	16.18	14.37	2.5	0	0	0
		30/06/07	0350	8.89	11.32	9.07	25.76	20.31	23.1	26.86	3.98	0	0
		30/06/07	0750	4.17	6.79	6.69	47.47	20.99	17.86	13.69	0	0	0
		30/06/07	0950	7.98	12.41	12.47	29.99	19.45	25.06	13.75	11.76	0	0
		30/06/07	1250	3.78	5.36	4.44	51.77	22.78	20.8	4.66	0	0	0
		Mean		5.53	7.87	6.97	43.05	21.50	20.75	12.17	2.54	0	0
	Treated pond outflow	29/06/07	2010	3.41	5.49	5.84	55.35	21.24	15.16	8.25	0	0	0
		29/06/07	2140	1.67	2.85	2.37	70.86	24.88	4.26	0	0	0	0
		30/06/07	0040	0.96	1.33	1.05	94.98	5.02	0	0	0	0	0
		30/06/07	0340	3.48	4.31	3.41	56.65	27.1	16.25	0	0	0	0
		30/06/07	0510	1.66	2.65	2.42	78.11	14.62	7.27	0	0	0	0
		30/06/07	0640	1.06	1.55	1.24	92.2	7.8	0	0	0	0	0
		Mean		2.04	3.03	2.72	74.69	16.78	7.16	1.38	0	0	0
	Untreated pond outflow	29/06/07	1937	1.67	3.1	2.8	67.79	22.31	9.9	0	0	0	0
		29/06/07	2237	1.52	2.63	2.31	77.68	17.49	4.82	0	0	0	0
		30/06/07	0137	1.26	1.9	1.47	87.26	12.74	0	0	0	0	0
		30/06/07	0607	2.64	3.51	3.01	64.99	22.66	12.36	0	0	0	0
		30/06/07	1037	2.51	3.45	3.11	68.58	21.41	10.02	0	0	0	0
		30/06/07	1637	1.17	1.79	1.47	89.54	10.47	0	0	0	0	0
		1/07/07	0007	2.35	6.4	8.06	65.84	8.48	7.13	18.55	0	0	0
		Mean		1.87	3.25	3.18	74.53	16.51	6.32	2.65	0	0	0

Table A3.2 (cont.)

Event	Site	Date	Time	Particle size (µm)			% of total sediment volume in size ranges (µm)						
				Median	Mean	SD	0.0-3.9	3.9-7.8	7.8-15.6	15.6-31.3	31.3-62.5	62.5-125.0	125.0-250.0
3	Inflow	29/07/07	0542	8.02	11.98	10.79	23.52	25.36	23.72	18.73	8.67	0	0
		29/07/07	0742	12.66	16.06	12.59	17.75	17.2	22.08	27.16	15.81	0	0
		29/07/07	0842	19.97	31.44	30.06	14.86	13.55	16.07	18.2	21.3	16.02	0
		29/07/07	0942	14.46	20.98	18.44	16.39	17.11	19.3	21.77	25.43	0	0
		29/07/07	1042	13.83	20.95	17.98	18.44	17.17	16.66	18.28	29.46	0	0
		29/07/07	1242	5.98	7.41	5.29	34.68	24.16	31.08	10.08	0	0	0
		Mean		12.49	18.14	15.86	20.94	19.09	21.49	19.04	16.78	2.67	0
	Treated pond outflow	29/07/07	0717	4.36	6.82	6.14	44.81	26.58	16.4	12.2	0	0	0
		29/07/07	0847	4.89	9.63	10.21	39.55	25.44	12.79	11.27	10.94	0	0
		29/07/07	1017	4.5	6.68	6.41	42.57	31.16	16.52	8.44	1.31	0	0
		29/07/07	1147	3.74	4.91	3.88	53.02	28.66	15.67	2.66	0	0	0
		29/07/07	1317	2.33	2.79	1.93	75.72	22.58	1.7	0	0	0	0
		29/07/07	1747	1.48	2.44	1.98	80.88	15.8	3.32	0	0	0	0
		Mean		3.55	5.55	5.09	56.09	25.04	11.07	5.76	2.04	0	0
	Untreated pond outflow	29/07/07	0727	4.39	6.38	5.58	42.98	31.97	16.6	8.46	0	0	0
		29/07/07	0857	4.41	5.62	4	42.51	34.02	20.77	2.69	0	0	0
		29/07/07	1027	5.63	7.07	5.05	33.69	30.55	28.4	7.35	0	0	0
		29/07/07	1157	4.29	5.87	4.78	45.49	28.83	21.22	4.46	0	0	0
		29/07/07	1327	3.74	4.29	2.76	53.18	33.14	13.68	0	0	0	0
		29/07/07	1627	2.73	3.09	2.2	70.66	24.99	4.35	0	0	0	0
		Mean		4.2	5.39	4.06	48.09	30.58	17.50	3.83	0	0	0

Table A3.2 (cont.)

Event	Site	Date	Time	Particle size (µm)			% of total sediment volume in size ranges (µm)						
				Median	Mean	SD	0.0-3.9	3.9-7.8	7.8-15.6	15.6-31.3	31.3-62.5	62.5-125.0	125.0-250.0
4	Inflow	16/08/07	1451	6.78	9.86	8.67	29.99	24.8	24.45	17.21	3.54	0	0
		16/08/07	1951	6.77	9.3	7.77	32.78	21.73	25.22	18.49	1.78	0	0
		16/08/07	2351	13.61	19.37	16.38	16.17	15.89	22.53	20.8	24.62	0	0
		17/08/07	0051	31.91	38.6	30.22	8.36	9.37	15.1	16.77	27.38	23.04	0
		17/08/07	0151	6.99	9.15	7.42	30.66	22.55	26.11	20.63	0.05	0	0
		17/08/07	0751	4.35	5.07	3.5	44.58	32.48	19.84	3.1	0	0	0
		Mean		11.74	15.23	12.33	27.09	21.14	22.21	16.17	9.56	3.84	0
	Treated pond outflow	16/08/07	1554	3.82	4.88	4.19	51.49	33.51	13.14	1.19	0.67	0	0
		16/08/07	2024	2.77	3.36	2.47	67.48	25.44	7.08	0	0	0	0
		17/08/07	0054	4.12	4.95	3.29	46.92	33.17	19.91	0	0	0	0
		17/08/07	0224	2.93	3.32	2.14	66.88	27.18	5.94	0	0	0	0
		17/08/07	0654	1.38	1.95	1.43	89.56	10.44	0	0	0	0	0
		17/08/07	1254	1.92	2.94	2.31	71.76	24.16	4.09	0	0	0	0
		Mean		2.82	3.57	2.64	65.68	25.65	8.36	0.20	0.11	0	0
	Untreated pond outflow	16/08/07	1551	4.13	5.73	5.01	47.23	28.66	19.92	4.19	0	0	0
		16/08/07	2021	3	3.43	2.41	66.04	27.81	6.15	0	0	0	0
		17/08/07	0051	5.27	6.69	4.78	35.4	33.71	23.92	6.98	0	0	0
		17/08/07	0221	3.88	4.58	3.11	50.28	33.96	15.76	0	0	0	0
		17/08/07	0651	2.73	3.14	2.37	70.44	24.47	5.09	0	0	0	0
		17/08/07	1251	1.74	2.71	2.36	77.26	17.29	5.45	0	0	0	0
		Mean		3.46	4.38	3.34	57.78	27.65	12.72	1.86	0	0	0

Table A3.2 (cont.)

Event	Site	Date	Time	Particle size (µm)			% of total sediment volume in size ranges (µm)						
				Median	Mean	SD	0.0-3.9	3.9-7.8	7.8-15.6	15.6-31.3	31.3-62.5	62.5-125.0	125.0-250.0
5	Inflow	6/11/07	0511	3.67	6	5.95	52.63	21.37	12.91	13.09	0	0	0
		6/11/07	0711	6.6	8.36	6.41	32.87	22.62	28.42	16.09	0	0	0
		6/11/07	0811	6.29	8.7	7.06	32.04	25.32	24.89	17.75	0	0	0
		6/11/07	1011	3.23	4.3	3.75	59.09	25.35	14.85	0.71	0	0	0
		6/11/07	1211	5.01	7.58	6.8	40.54	25.47	19.85	14.14	0	0	0
		6/11/07	1511	2.38	3.5	3.29	69.56	20.09	10.35	0	0	0	0
		Mean		4.53	6.41	5.54	47.79	23.37	18.55	10.30	0	0	0
	Treated pond outflow	6/11/07	0542	3.19	4.96	4.77	58.92	18.55	14.45	8.09	0	0	0
		6/11/07	0842	1.72	2.32	1.51	82.84	17.16	0	0	0	0	0
		6/11/07	1012	2.06	3.12	2.69	72.25	17.41	10.33	0	0	0	0
		6/11/07	1312	3.02	3.71	2.69	60.73	26.68	12.59	0	0	0	0
		6/11/07	1612	15.72	16.98	11.6	18.06	10.55	20.94	29.98	20.48	0	0
		6/11/07	2212	1.32	2.1	1.64	82.53	17.47	0	0	0	0	0
		Mean		4.51	5.53	4.15	62.56	17.97	9.72	6.35	3.41	0	0
	Untreated pond outflow	6/11/07	0706	23.04	30.03	24.44	15.15	13.72	12.98	12.71	38.2	7.24	0
		6/11/07	0836	4.16	10.79	12.49	47.58	16.79	10.97	11.45	13.22	0	0
		6/11/07	1006	1.66	2.52	1.91	77.76	19.95	2.29	0	0	0	0
		6/11/07	1306	2.19	3.19	2.8	70.7	21.2	8.1	0	0	0	0
		6/11/07	1606	1.48	2.45	1.93	80.39	16.54	3.07	0	0	0	0
		6/11/07	2206	1.3	1.89	1.52	90.06	8.51	1.43	0	0	0	0
		Mean		5.64	8.48	7.52	63.61	16.12	6.47	4.03	8.57	1.21	0

Table A3.2 (cont.)

Event	Site	Date	Time	Particle size (µm)			% of total sediment volume in size ranges (µm)						
				Median	Mean	SD	0.0-3.9	3.9-7.8	7.8-15.6	15.6-31.3	31.3-62.5	62.5-125.0	125.0-250.0
7	Inflow	18/12/07	1858	8.37	13.66	12.1	31.55	16.66	12.26	22.36	17.17	0	0
		18/12/07	1958	9.36	13.36	11.97	23.48	21.66	21.16	21.9	11.8	0	0
		18/12/07	2158	2.64	3.4	2.61	64.88	27.08	8.04	0	0	0	0
		19/12/07	0131	14.23	16.32	11.71	15.11	13.2	26.49	30.4	14.81	0	0
		19/12/07	0231	21.87	30.33	25.68	12.41	11.85	17.29	18.98	20.14	19.32	0
		19/12/07	0431	10.46	15.16	14	21.83	18.25	24.52	23.74	11.66	0	0
		Mean		11.16	15.37	13.01	28.21	18.12	18.29	19.56	12.60	3.22	0
	Treated pond outflow	18/12/07	1921	5.02	7.11	6.01	39.64	25.4	24.05	10.91	0	0	0
		18/12/07	2051	1.36	2.25	2.07	84.77	11	4.23	0	0	0	0
		18/12/07	2351	1.18	1.45	0.98	94.8	5.2	0	0	0	0	0
		19/12/07	0121	1.2	1.66	1.38	91.51	7.96	0.53	0	0	0	0
		19/12/07	0251	0.9	1.31	1.07	95.08	4.92	0	0	0	0	0
		19/12/07	0721	0.82	1.09	0.67	98.54	1.46	0	0	0	0	0
		Mean		1.75	2.48	2.03	84.06	9.32	4.80	1.82	0	0	0
	Untreated pond outflow	18/12/07	1917	10.27	15.28	14.23	24.94	18.06	23.08	14.09	19.83	0	0
		18/12/07	2047	1.73	3.36	3.3	72.27	14.08	13.65	0	0	0	0
		18/12/07	2347	1.26	1.89	1.56	87.12	12.89	0	0	0	0	0
		19/12/07	0117	1.47	6.12	9.29	66.57	9.99	12.21	6.33	4.9	0	0
		19/12/07	0247	1.37	2.55	2.48	80.03	14.49	5.48	0	0	0	0
		19/12/07	0717	1.22	1.68	1.39	91.14	8.71	0.15	0	0	0	0
		Mean		2.89	5.15	5.38	70.35	13.04	9.10	3.40	4.12	0	0