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The Use of Flocculants and Coagulants to Aid the Settlement of Suspended Sediment in Earthworks Runoff : Trials, Methodology and Design [draft]

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▪ report

The Use of Flocculants and Coagulants to Aid the Settlement of Suspended Sediment in Earthworks Runoff – Trials, Methodology and Design

Auckland Regional Council

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1 INTRODUCTION

Land contouring for urbanisation and infrastructure development has long been features of the Auckland Region. The Auckland region is also characterised by steep terrain, erosive soils, and high intensity rainfall, which ensures that erosion, and the subsequent sedimentation of freshwater and marine ecosystems is an unwanted but inextricable part of the development cycle.

Historically, erosion and sediment control measures have been used to minimise the effects of development. However, the escalating scale of development has created a growing awareness of the cumulative sediment related ecosystem impacts of many land-disturbing activities occurring within developing areas. Consequently, investigations have been undertaken to improve the existing control measures and construction methodologies, and develop new control measures.

This report presents the results of trials undertaken to determine the usefulness of chemical flocculants and coagulants in improving the settlement of suspended sediment contained in sediment laden runoff from earthworks sites, and provides the design of a system for chemical treatment of this runoff. Flocculants and coagulants act by destabilising particles that would otherwise not settle, or settle very slowly due to their size and electrical charge which cause them to repel each other.

Trials were undertaken utilising liquid and solid forms of flocculant chemicals. Initially these trials occurred during the development of the motorway north of Auckland from Albany to Puhoi (ALPURT) and on a small residential development where earthworks were being undertaken in Greenhithe, on Auckland's north shore.

1.1 ALPURT Trials

The ALPURT motorway extension development included significant earthworks in the catchments of sensitive stream systems. Due to the scale of the works and the potential effects of a number of sediment laden discharges entering these stream systems, it was determined via the resource consent process, that flocculation systems should be investigated for the purpose of increasing the effectiveness of sediment retention measures.

On this basis, a system utilising solid flocculation chemical as well as a rain activated system utilising fluid chemical were developed.

Allied Colloids (Australia Pty Ltd.), through their New Zealand agent, Chemiplas NZ Limited, supplies three flocculants in solid form as "Magnasol Floc Blocks". These "Floc Blocks" are designed to be placed in a flow of water that requires flocculant treatment, and to dissolve slowly and contribute flocculant chemical to the flow. Preliminary trials using these Floc Blocks during the ALPURT earthworks indicated that Floc Blocks may be effective in treating runoff from earthworks sites. The Floc Blocks break down in flowing water, supplying chemical to the flow that causing particles to flocculate and settle more rapidly than would have otherwise occurred. This led to the development of a dosing system for the treatment of sediment-laden runoff.

In addition, a rain-activated system that triggers liquid flocculant chemical to be added to flows entering sediment retention ponds was utilised on a number of these ponds. The results of both aspects of the field trials proved that the system were highly effective across a range of storm conditions.

1.2 Greenhithe Trials

The ALPURT trials indicated that there were potential advantages in the use of Floc Blocks in comparison to the use of the rainfall activated liquid flocculant and coagulant chemicals, particularly on sites with difficult access, small earthworks areas, or where there was a need for short term treatment only. As a result, a more comprehensive study to determine the effectiveness of the Floc Blocks was initiated.

The objective of this detailed field assessment was to establish practical means of using Floc Blocks that achieve the optimal chemical dose required to effect substantial suspended solids removal in the highly variable flow conditions to be expected from an earthworks site.

A residential subdivision development was selected at Greenhithe. The Floc Block trial system was designed and installed before earthworks commenced, and remained in place during the bulk earthworks and stabilisation period between December 1999 and June 2000. This report presents the results of the trials, which identified significant problems with the delivery of the chemical.

2 CHEMICAL FLOCCULANTS AND COAGULANTS

2.1 Introduction

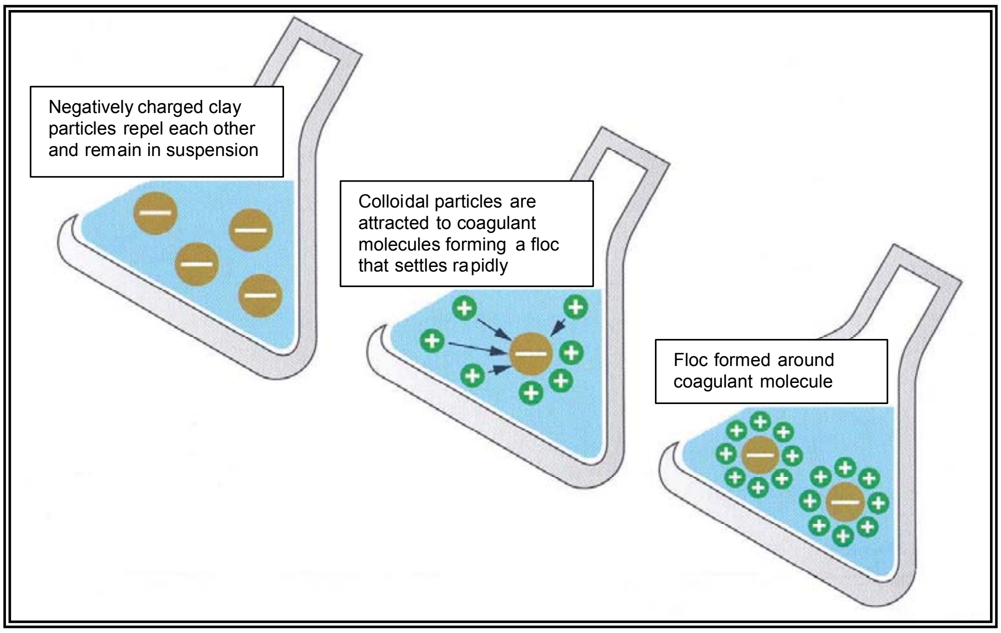
Two types of chemicals were considered for initial bench testing and field trials as follows:

- Polyelectrolyte flocculants; and
- Aluminium coagulants, consisting of Aluminium sulphate (Alum) and Polyaluminium chloride, (PAC)).

Prior to detailing these types of chemicals however, the background to coagulation and flocculation is outlined.

2.2 Coagulation

Colloidal particles are particles that fall into a general category of very fine material that has electrostatic surface charges. In general, most colloidal material has a negative charge. Particles with like charges tend to repel each other, preventing the forming of coagulated particles. These characteristics cause the colloidal particles to remain in solution. Destabilising colloidal material to allow coagulation and settlement to occur is achieved by adding reagents that develop positive charges. Positively charged ions in the solution act to destabilise the colloidal matter and allow settlement of coagulated material to occur as



depicted in Figure 1[1].

[1] Reference: Fernz Chemicals (NZ) Ltd "A Guide to Water and Wastewater Treatment", undated.

Figure 1. Chemical Settling of Colloidal Matter

2.3 Flocculation

Flocculation occurs after the addition of chemical to destabilise the charges on the colloidal particles in suspension. The particles adhere to each other via the flocculant ions on the surface of the particles. These charged ions provide an opportunity for charged particles in a system to adhere to them, thereby merging individual particles (Figure 2). This results in larger, denser flocs that settle more rapidly.

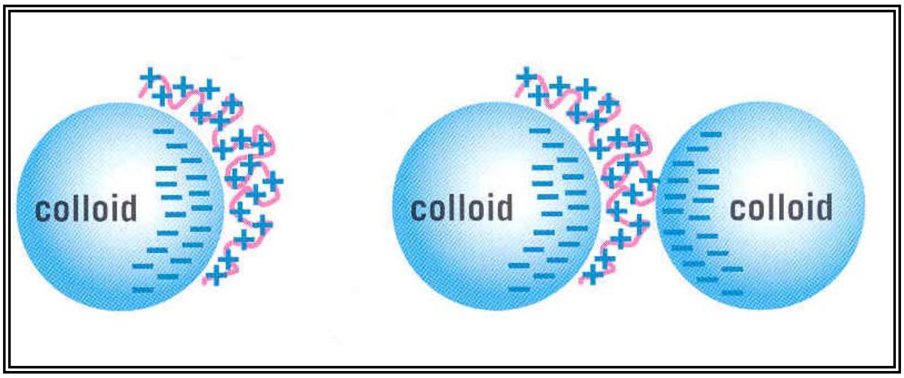


Figure 2. Colloid Linking Mechanism[2]

2.4 Polyelectrolyte (Polymer or Polyacrylamide) Flocculants

Polyelectrolytes that are potentially suitable for treatment of sediment-laden runoff are available as either concentrated liquids or solids. Three groups are available:

- Anionic;
- Cationic; and,
- Non-ionic.

Anionic polyacrylamide is negatively charged flocculant commonly used for industrial applications including raw potable water clarification, and for clarification, thickening and dewatering of wastewater and sludge. Because these polymers have a high affinity for solids, the remaining concentration in treated waters is very low in all but serious overdose situations.

Cationic polyacrylamides are positively charged and are commonly used in a number of municipal wastewater treatment plants to improve solids removal during pre-settlement. They are recognised as flocculants with greater toxicity implications for fish and other aquatic organisms than anionic or non-ionic polyelectrolytes. This is because the gills of fish are negatively charged, and the cationic polymer binds to them resulting in mechanical suffocation.

[2] Reference: Fernz Chemicals (NZ) Ltd "A Guide to Water and Wastewater Treatment", undated

Long polymer chains of polyacrylamide polyelectrolyte can degrade readily in aquatic systems. The oil fraction in liquid polyelectrolyte is readily degradable. Acrylamide, which is a raw material from which polyacrylamide polyelectrolytes are made, is highly toxic, and is reported by suppliers to be present in polyacrylamide polyelectrolytes at a maximum concentration of 0.1%. However, Acrylamide is completely degraded by bacteria in surface waters.

Bench testing indicated that a number of polyacrylamide formulations achieved accelerated settlement of suspended solids from runoff from the ALPURT construction works. However, in practise, major difficulties were identified with the use of liquid polyacrylamides for dosing of stormwater on remote sites. These difficulties included:

1. Liquid polyacrylamide concentrations as supplied, are highly viscous and would require onsite pre-dilution with water to achieve a suitable consistency for dosing and mixing with sediment-laden runoff.
2. Pre-dilution would require special mixing equipment and storage tanks, which would be difficult to provide for on remote sites with difficult or limited access.
3. Pre-dilution would require electric power that would present a difficulty on remote sites with difficult access.
4. After pre-dilution, the polyacrylamide has a limited storage life.
5. Complete mixing with stormwater would still be difficult because of the high viscosity of the prediluted polyacrylamide.

Three solid polyacrylamide products marketed by Allied Colloids as 'Floc Blocks', which act to settle solids in stormwater, were evaluated in bench tests utilising sediment laden runoff from the ALPURT construction works. The products were:

- Percol AN1 - an anionic polyacrylamide blend;
- Percol AN2 - an anionic polyacrylamide blend; and
- Percol CN1 - a cationic polyacrylamide blend.

Bench tests were undertaken to determine the performance of the three Floc Block formulations, using sediment laden runoff from both a clay soil site, and a limestone soil site. The results showed that AN2 performed best for both runoff types.

The Floc Blocks used in the trials were 300 x 100 x 85 mm in size and weighed approximately 3 kg.

Because AN2 was the most effective in terms of the dose required to achieve satisfactory reduction of suspended solids, and also because anionic polyacrylamides have lower toxicity to aquatic organisms than cationic polyacrylamides, AN2 was selected for ongoing trails.

Effective dose rates were between 1 and 4mg/L of dry AN2 (not the partially hydrated Floc Block formulation). Subsequent testing showed that the addition of AN2 above the optimum dose range led to a reduction in flocculation and suspended sediment removal. Analysis of pH in bench tests showed that AN2 did not affect pH even at excessive dose rates of 6 and 8 mg/L.

2.5 Aluminium Coagulants

2.5.1 Common Uses

Aluminium coagulants are commonly used for potable water treatment and removal of sediment from stormwater. In the United States there is considerable experience with the direct dosing of eutrophic lakes with Alum, which has achieved major reductions in suspended solids, phosphorus, nitrogen, biochemical oxygen demanding substances, chlorophyll 'a' and turbidity for long periods following dosing.

Bench testing showed that both Alum and Polyaluminium Chloride (PAC) achieved encouraging results for the settlement of suspended solids in sediment-laden runoff from ALPURT.

2.5.2 Toxicity and Chemistry in Water

The aluminium coagulants contain high concentrations of the toxic ionic form of aluminium. The USEPA freshwater ambient water quality criteria for dissolved aluminium at a pH between 6.5 and 9.0 are as follows:

Chronic: 0.087mg/L (4 day average not to be exceeded)

Acute: 0.750mg/L (1 hour average not to be exceeded)

It is generally accepted that dissolved aluminium at a concentration between 0.050 and 0.100mg/L and a pH between 6.5 –and 8.0 presents little threat of toxicity. However, at lower pH, the toxicity increases with an effect of possible major concern being the coagulation of mucus on the gills of fish.

After the addition of aluminium coagulants to water containing dissolved and/or suspended matter, dissolved aluminium ions are rapidly incorporated into microscopic aluminium hydroxide and aluminium phosphate precipitates. As they form these precipitates, they combine with phosphorus, suspended solids, metals, and other dissolved and suspended matter. The insoluble precipitates that are formed from this process are stable. As the particle size increases, the density also increases, and they tend to sink towards the bottom (as shown in Figure 2).

The toxic aluminium derived from the coagulant dose is very rapidly reduced by the precipitation and coagulation reactions. Even if coagulant is added at a dose rate in excess of that required for effective removal of solids and nutrients, the dissolved aluminium is still reduced very rapidly to a low concentration with no serious toxicity implications.

2.5.3 Toxicity of Floc

Alum floc is not toxic to benthic organisms. Small planktonic crustaceans present in water samples collected from sediment retention ponds used for coagulation testing during the ALPURT trial program, showed no toxicity during the coagulation and settlement periods.

2.5.4 Chemistry of Deposited Sludge or Sediment

Insoluble precipitates formed by the addition of Alum to water containing dissolved and/or suspended matter are stable. International research conducted on the toxicity and leaching characteristics of Alum sludge has indicated that most pollutants are tightly bound to the aluminium matrix with little or no affinity for release from either dried or wet sludges. The aluminium appears to be tightly bound in Alum treated sediment under both reduced and oxidised conditions, and at pH ranges between 5 and 7. The release of aluminium from Alum treated sediment appears to be relatively unaffected by changes in the redox potential within the sediment.

3 DESIGN OF A LIQUID CHEMICAL DOSING SYSTEM

3.1 Introduction

After bench testing had demonstrated that the liquid Alum and PAC flocculant achieved satisfactory suspended solids settlement from construction stormwater samples, a field trial was designed.

Initial consideration was given to the installation of a runoff proportional dosing system of which the major components would be a flow measurement weir or flume; an ultrasonic sensor and signal generating unit, and a battery driven dosing pump. Together with the cost of preparatory site work, chemical storage tanks and secure housings, the cost per treatment system was estimated to be approximately $12,000.

Although the use of a pressure transducer for flow measurement would have reduced the cost to approximately $9,000, difficulties were envisaged with maintenance of the flow measurement weir or flume, because of the high quantity of bedload that can be generated in runoff from earthworks sites.

An alternative system, which provides a chemical dose proportional to rainfall, was developed. The rainfall driven system had the major advantage that it did not require either a runoff flow measurement system or a dosing pump. This system had a total cost of approximately $2,400 per installation.

3.2 Design of Rainfall Driven Dosing System

3.2.1 Principles of Operation

The main components of the rainfall driven dosing system are shown diagrammatically in the Figures 3 to 7.

The rainfall volume collected from a rainfall catchment tray is used to displace the liquid treatment chemical from a storage or reservoir tank into the stormwater diversion channel prior to entering the sediment retention pond.

The size of the constructed catchment tray is determined by the size of the catchment draining to the sediment retention pond. The practise developed through the ALPURT trials has assumed that 100% of the rain falling onto saturated earthworks areas, and 60% of the rainfall onto the stabilised contributing catchment area will require treatment at the design dose rate.

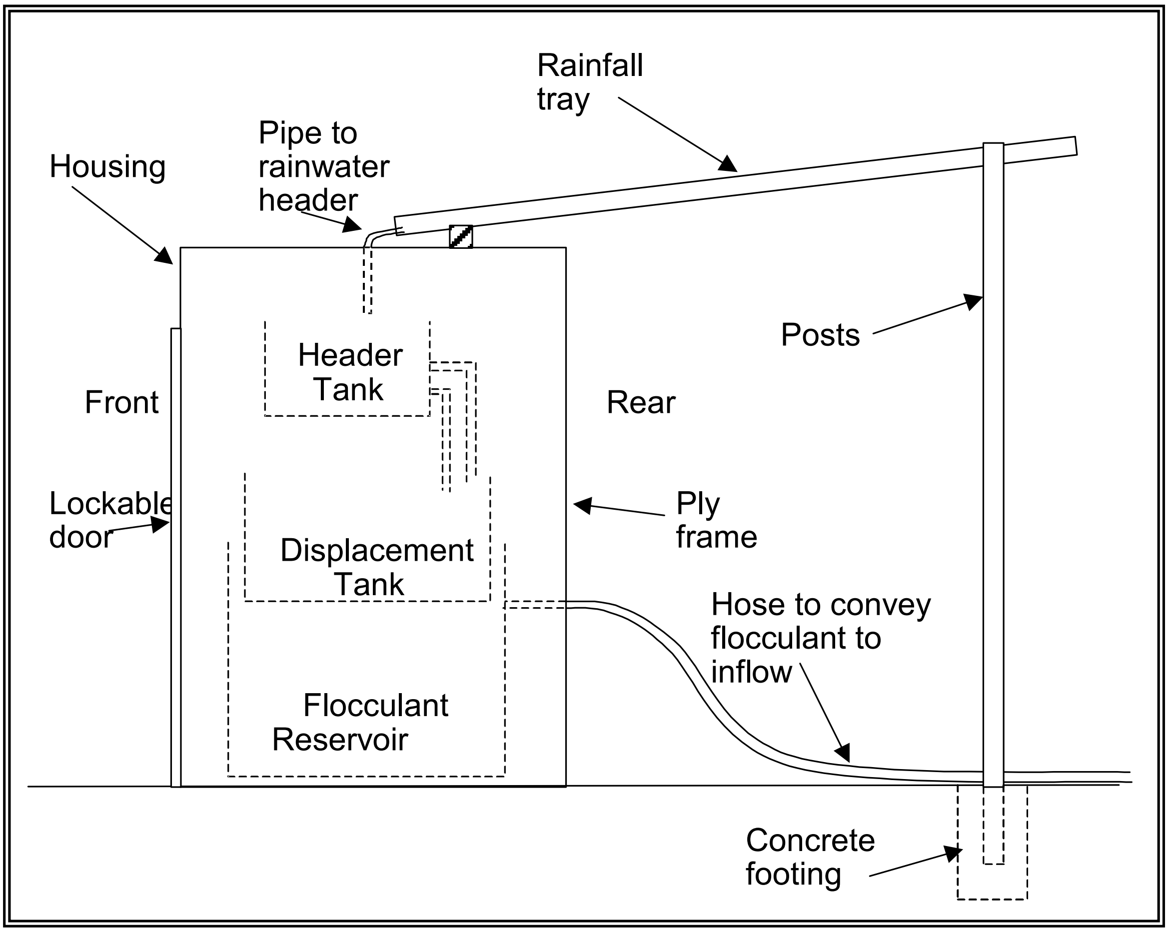
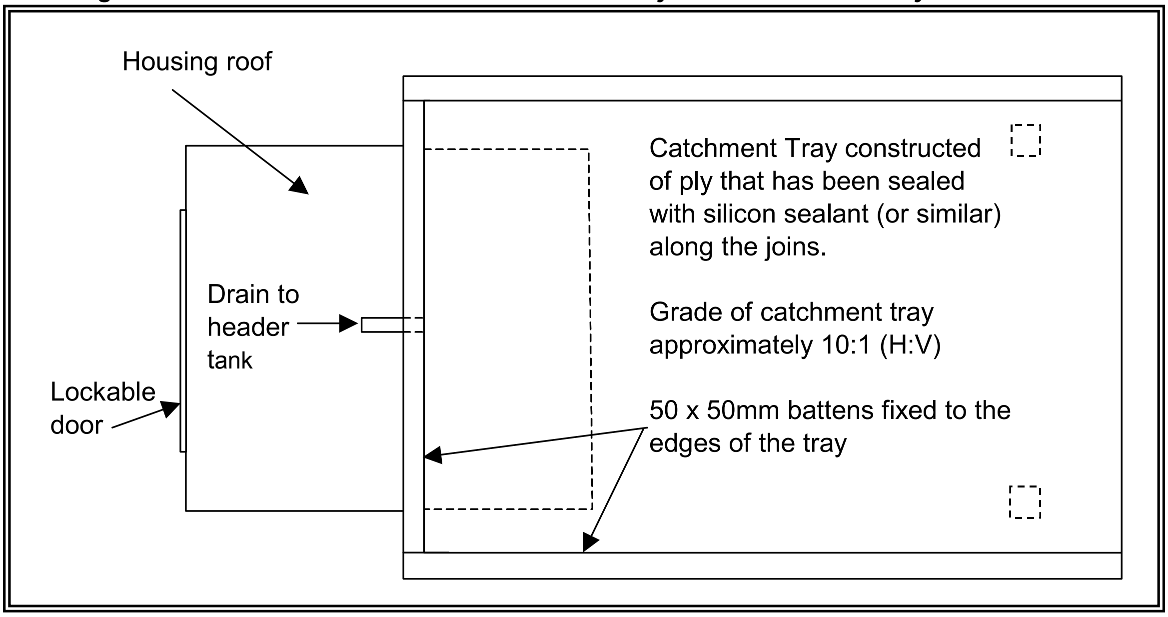


Figure 3. Rainfall Activated Flocculation System Housing Detail – Side View

Figure 4. Rainfall Activated Flocculation Housing

Figure 5. Rainfall Activated Flocculation System Catchment Tray – Plan View



Rainfall from the catchment tray (Figures 5 and 6) is drained into a header tank (Figure 7). This provides a storage capacity that avoids dosing during initial rainfall following a dry period and to attenuate dosing at the beginning and end of a rainstorm (to simulate the runoff hydrograph).

Figure 6. Rainfall Catchment Tray

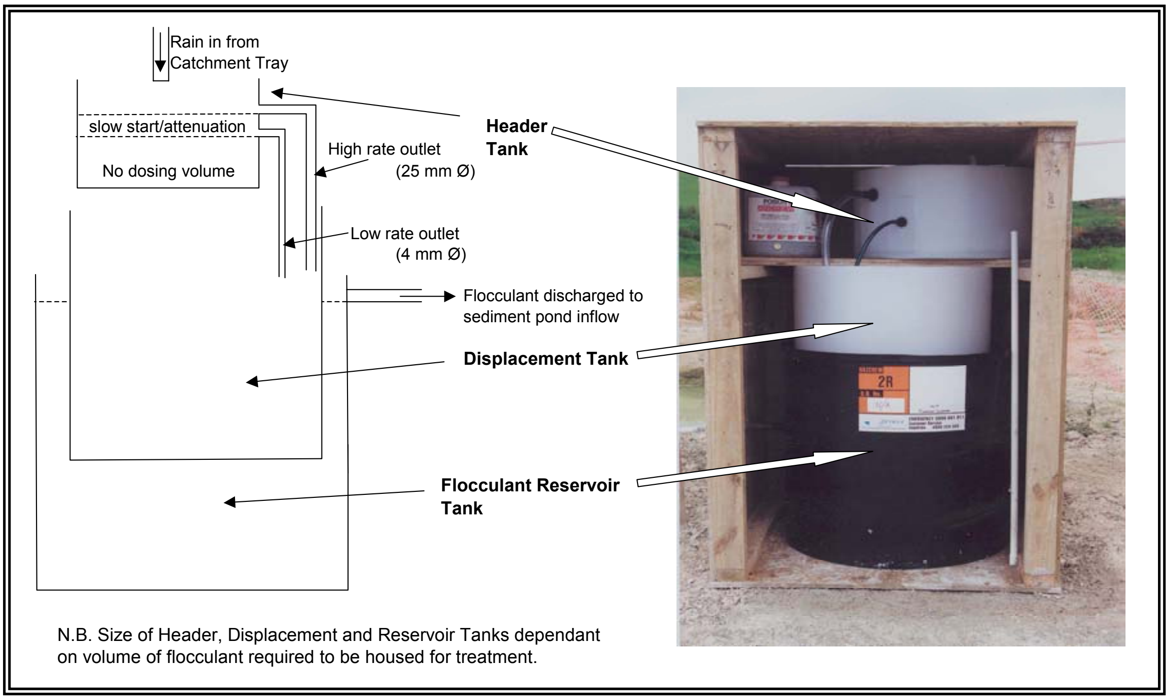


Figure 7. Rainfall Activated Flocculation Dosing Detail

From the header tank, the rainwater discharges by gravity into a displacement tank which floats in the chemical reservoir (Figure 7). As the displacement tank fills with rainwater, chemical is displaced through the outlet in the reservoir tank and then flows by gravity to the dosing point.

Mixing of the flocculant with flows into the pond needs to occur. This can be achieved by discharging the outlet pipe into an area of turbulent flow prior to entering the pond. The outlet pipe is shown in Figure 4. In this instance, the pipe discharges into the sediment laden flow immediately prior to the pond. However, depending on site characteristics, it may be more appropriate to discharge into flows further up the catchment.

3.2.2 Example of Volumetric Design

The example given here is for an earthworks catchment of 1 hectare and chemical treatment using PAC. The required dose is determined by bench tests using sediment-laden runoff from the site, or from a site that has similar soil characteristics.

Calculation of Rainwater Catchment Tray Area

The following process is used to calculate the rain catchment tray area:

- Determine the dose of aluminium to achieve the optimal coagulation and settlement for the given soil characteristics on site, determine by bench testing
- For this example, use 8mg/L

- Liquid PAC obtained from Fernz Chemicals (NZ) Ltd contains 10.1% of Al_2O_3 by weight. This is equivalent to 53,470 mg/kg aluminium or 64,164 mg/L aluminium, as the density of PAC is 1.20.
- At 8 mg of aluminium per litre, 1 L of PAC would treat 8,020 L of stormwater.
- Assume a catchment area of 1 ha and then assume runoff to be treated is the equivalent of 50mm of runoff
- For a 1 ha catchment, this is 500 m^3 of stormwater runoff
- The volume of PAC required to treat 500 m^3 of runoff at 8 mg Aluminium /L is 62.3 L.
- The density of PAC is 1.2. Therefore, to displace 62.3 L of PAC, it would require a volume of 74.8 L of rainwater to be collected.
- To collect 74.8 L of rainwater from a 50mm rainfall event, it would require an area of 1.5 m^2.

Table 1 presents the rainfall catchment required for different PAC dose rates. The optimal does rate should be determined by bench testing for each site, or as per that applied to a site with similar soil characteristics.

Table 1. Rainfall Catchment Tray Area Required for Different PAC* Dose Rates.

Aluminium Dose Required (mg/L)	***Catchment Tray Area/Hectare (m^2)✦***
2	0.375
4	0.75
6	1.125
8	1.5
10	1.875
12	2.25

Note: * PAC with 10.1% of Al_2O_3 by weight

✦ Stabilised catchment calculated at 60% of area given.

Header Tank

The header tank provides:

- Zero chemical discharge until a pre-selected quantity of rain has fallen, to allow for initial infiltration and saturation of dry ground before runoff commences;
- A slow start to the dosing rate to allow for the response time of runoff flowing off the site at the beginning of a storm; and
- An extension of the dosing period beyond the rainfall period to provide treatment of runoff that occurs following cessation of rainfall.

The zero discharge rainfall can be adjusted for site characteristics, and the slow start/attenuation characteristics can also be regulated for site-specific conditions by changing the discharge rate from the low rate header tank outlet, and by providing low rate outlets at different levels from the header tank. The standard header tank design adopted for ALPURT provides for up to 10mm of rainfall before dosing commences. This would require provision of a delayed start volume below the low rate outlet of the header tank of 10 L/m² of rainfall catchment tray.

The ALPURT header tank design for small earthworks catchments has a low rate outlet consisting of a 4mm internal diameter hose, and a high rate outlet that has sufficient capacity to carry the maximum predicted flow from short-term rainfall of about 40mm/hour.

For catchments with long flow paths, or other site conditions that attenuate the flow to the treatment site and retention pond, the capacity of the low rate outlet from the header tank can be further reduced. Additional low capacity outlets installed at different levels within the header tank live storage volume, enable the dose rates to more accurately follow the runoff hydrographs.

Displacement Tank Size

The displacement tank (Figure 7) is to be a neat fit inside the reservoir tank. A larger displacement tank and reservoir tank system will reduce the degree of servicing required.

The minimum displacement tank capacity should be the 24-hour rainfall for a 2-year return period. In the ALPURT area this is approximately 86 mm of rain, giving a volume of 129 L from a constructed catchment of 1.5 m^2.

A standard design was adopted for the ALPURT project. This consisted of a 400 L displacement tank within a 550 L reservoir tank, which provides for the dosing of up to 320 L of PAC.

Chemical Reservoir Tank

The chemical reservoir tank (Figure 7) should have sufficient capacity to provide for the dosing of runoff from a major storm, based on analysis of local rainfall statistics (refer to displacement tank sizing above).

The outlet of the ALPURT standard design system was located at a level that is reached by filling with 2 x 200 L drums of PAC.

3.3 Set Up and Servicing of the Rainfall Driven Dosing System

3.3.1 Header Tank

The water level of the header tank is set to allow for a certain rainfall before chemical dosing starts. In summer, after a week or more without rain, this was found to be approximately 10 mm in the ALPURT area.

It was noted on one occasion during the summer, when approximately 10mm of rain fell in 15 minutes on dry ground, substantial runoff occurred, delaying the start of dosing. This lead to insufficient dosing of the first flush into the pond. It is noted however, that there was some buffering effect of these flows due to the pond containing only clean water prior to the storm.

In wet weather, the header tank is set with no delay in dosing. When a dry period occurs following rain, the header tank volume below the low capacity outlet is reduced to provide no dosing of the first part of the next storm event. This is to prevent overdosing of a pond, with possible implications in terms of reduced pH, an increased free aluminium concentration, and also conserved PAC. Water may be removed from the header tank using a siphon.

3.3.2 Refilling with Chemical

When dosing has occurred and the capacity of the dosing system is reduced to the degree that there is insufficient to dose a major storm, the displacement tank has to be emptied and the chemical reservoir refilled.

The displacement tank may either be emptied using a siphon, or baled out by hand. The chemical reservoir can be filled using a drum pump, to pump from a 200 L drum.

3.3.3 Monitoring and Adjustment for Changing Site Conditions

Each new chemical treatment system is monitored carefully during the first few rainfall events to check that the system is effective, and to ensure that overdosing is not occurring.

If overdosing is suspected because the pond dead storage water is exceptionally clear, samples are taken for pH and dissolved aluminium analysis.

If overdosing occurs or it is clear that the quality of stormwater runoff is improving because of stabilisation of the site, the chemical dose may be reduced by reducing the size of the catchment tray. This may be done by placing a diagonal batten across the tray with a hole through the tray rim at the lower corner, so that water from the tray area above the batten discharges to waste.

4 THE ALPURT TRIALS

4.1 Introduction

A trial pond was established at Bawden Rd (north of Albany) where significant cut and fill earthworks were taking place in the catchment. The works took place in limestone (Onerahi chaos) soils. Two trial ponds were constructed in series with a valved gravity connection between the ponds and valved outlets.

The chemical treatment trials using Alum were carried out at an aluminium dose rate of 5.5 mg/L. The treatment system was monitored carefully to determine effects of the Alum dosing on suspended solids removal, pH and the dissolved aluminium concentration in the discharge of the retention pond.

The Alum system performed satisfactorily in terms of reduction of suspended solids under a range of rainfall conditions varying from very light rain to a very high intensity, short duration storm, where 24mm of rain fell over a period of 25 minutes.

The pH of the stormwater runoff at the Bawden Road trial pond site was between 7.9 and 8.2. Dosing with Alum at 5.5 mg/L reduced the pH by approximately 0.5 pH units. Dissolved aluminium concentration in the discharge from the retention pond averaged approximately 0.10 mg/L, and was often lower than the dissolved aluminium concentration in the inflow to the pond from the site.

Bench tests were undertaken to evaluate whether an excessive dose of Alum would result in increased levels of dissolved aluminium concentrations. The results (Table 2) showed that the addition of aluminium at up to 12.6 mg/L did not result in any increase in the dissolved aluminium concentration in the reacted sample, after a one-hour settlement period. Because of the high natural pH of limestone soil runoff, the addition of Alum up to 12.6mg/L aluminium did not result in a significant reduction in pH.

The treatment benefit of Alum addition was most evident for the intense storm conditions for which the runoff flow exceeded the hydraulic capacity of the retention pond (i.e. the [pond discharged via the spillway). With Alum treatment, the suspended solids removal was 92% compared with removal without Alum treatment of about 10% for a similar storm on the same catchment with the same retention pond.

Table 2. Results of Alum Addition to Limestone Soil Runoff to Evaluate Effects of Alum Overdose

Sample	Al (mg/L)	Settlement time (hr)	pH	SS (mg/L)	Diss. Al (mg/L)
A	0	1	7.92	2760	1.1
A	1	1	8.12	2560	0.11
A	2.1	1	7.95	1770	0.68(1)
A	4.2	1	7.86	445	0.15
A	6.3	1	7.78	267	0.43(1)
B	0	0	8.04	8080	0.075
B	0	1	8.06	3690	0.071
B	4.2	1	7.73	728	0.50(1)
B	8.4	1	7.69	189	0.19
B	12.6	1	7.5	90	0.13

Note (1) fine sediment/flocs noted in filtered samples

4.2 Polyaluminium Chloride (PAC) Trial

4.2.1 Advantages of PAC

It became clear that there was a need during the ALPURT project for the chemical treatment of runoff from clay soil in catchments that naturally produce more acidic runoff. It was determined to investigate the use of PAC as a coagulant in this instance, as PAC is less acidic than Alum. Table 3 presents comparative data for Alum and PAC treatment of representative runoff samples from clay soil catchments.

Table 3. pH Data for Alum and PAC Treated Stormwater Samples

Source	Coagulant	Al conc. (mg/L)	pH	Alkalinity)	SS (mg/)L
Oteha Valley Rd	Nil (raw)	-	5.64	1	1504
SE Pond	Alum	8	4.42	<1	71
	Alum	12	4.34	<1	71
	PAC	8	4.64	<1	107
	PAC	12	4.63	<1	85
Lonely Track Rd	Nil (raw)	-	6.68	16	680
Gully1	Alum	8	4.64	<1	117
	Alum	12	4.54	<1	113
	PAC	8	6.03	7	81
	PAC	12	5.54	3	112
Awanohi Rd	Nil (raw)	-	7.15	60	1130
Adj. Okura Rd	Alum	8	5.88	13	84
	Alum	12	4.85	<1	84
	PAC	8	6.71	43	229
	PAC	12	6.45	35	78

Samples were taken after 1 hour of settlement. The alkalinity was measured given the quantity of $CaCO_3$ (g/m^3) in solution. Longer settlement would result in further reduction in suspended solids. The data in Table 3 shows that PAC has a consistently lower effect in terms of pH reduction on receiving waters into which the retention ponds discharged.

4.2.2 Results of PAC Trials

The use of PAC for treatment of sediment laden runoff was investigated extensively along the ALPURT project during the 1998/99 summer, and during the winter of 1999. A total of 21 systems were used, with contributing catchments ranging between 0.5 and 15 hectares.

The overall treatment efficiency of PAC treated ponds in terms of suspended sediment retention was between 90 - 99% for ponds with a good physical design. Lower treatment efficiency occurred where the ponds did not operate properly due to mechanical problems with decanting devices, or physical problems such as multiple inflow points, high inflow energy, or poor separation of inlets and outlets.

Table 4 presents representative data for PAC dosed stormwater from clay soils earthworks catchments, and shows that a high degree of suspended solids reduction is achieved in PAC dosed ponds.

Table 4. Suspended Solids Removal from PAC Treated Stormwater

Pond	(a) Date	Inflow Flow SS		Outflow Flow SS		Reduction of SS (%)
Mason's Rd	28.11.1998	3	26 300	3	144	99.4
Mason's Rd	04.12.1998	2	5 100	2	40	99.2
OVR E	13.06.1999	15	1 639	8	51	96
OVR E	04.07.1999	2	749	2	56	92
23800E	28.11.1998	8	14 800	6	966	93
23800E	22.01.1999	1	18 700	2	67	99
B1 Gully	08.04.1999	0.3	4 300	0.4	3	99.9
B1 Gully	01.05.1999	0.5	16 900	3.0	59	99.6

The data in Table 5 indicates considerable variation of inflow suspended solids concentration between the ponds sampled. These significant variations reflect the condition of the catchments and the nature of current works occurring. All the treated ponds achieved good suspended solids removal (77 - 98%) compared to that of untreated ponds (4 - 12%). PAC dosing caused an obvious reduction in pH in all ponds except Lonely Culvert.

Tables 5. Inflows and Discharges of PAC Treated Ponds

Pond	Time	Inflow				Outflow				Reduction of SS (%)
		Flow L/s	SS mg/L	pH	Al mg/L	Flow L/s	SS mg/L	pH	Al mg/L	
1.3.8 Over	0850	12	238	8.97	0.084	9	53	6.66	0.026	77
	1135	20	253	9.97	0.077	12	55	6.79	0.068	78
Lonely	0938	40	25830	6.83	0.052	3	266	7.62	0.072	98
	1045	15	13310	6.62	0.093	20	214	7.02	0.018	98
21340	0918	8	399	8.78	0.25	3	40	6.56	0.016	89
	1110	7	2564	7.03	0.11	15	57	6.55	0.01	88
D5	0910	6	2132	6.81	0.16	4	65	5.96	0.025	96
	1110	7	2564	7.03	0.11	4	56	5.47	0.01	97
Untreated Pond	1930	12	1571	7.88	0.22	4	1378	7.74	0.31	12
	1100	9	1522	8.02	0.17	4	1459	7.83	0.29	4

The dissolved aluminium concentrations in the outflows from chemically treated ponds varied between 0.010 - 0.072 mg/L, and were lower in most of the outflows compared with the inflows. The dissolved aluminium concentration in the outflow from the untreated pond was much higher (0.29 - 0.31 mg/L) than in the outflows from the treated ponds.

It has been noted that the dissolved aluminium concentration is related to the characteristics of the suspended solids, with high concentrations of dissolved aluminium occurring in samples that also had high concentrations of very fine suspended solids. This trend has been discussed with a chemical analyst, and is attributed in part to small quantities of very fine solids passing through the filter that is used to filter samples before analysis. Dissolved aluminium by definition, is the fractions passing through the 0.45-micron filter. If very small sediment particles pass through the filter, they also contribute to the dissolved aluminium concentration.

The dissolved aluminium concentrations in the outflows from the treated pond samples recorded in Table 6 were below the USEPA chronic criterion of 0.087 mg/L (4 day average not to be exceeded), and well below the acute criterion of 0.750 mg/L (1 hour average not to be exceeded).

The data in Table 6 indicates significant removal of suspended solids, particularly in the ponds with high-suspended solids in the inflows. In contrast, the untreated pond had the highest concentration of suspended solids concentration in the outflow.

The data for the Mason's Rd pond provides an example of a PAC overdose situation, in which the pH after dosing had been reduced to 4.44, and the dissolved aluminium concentration was at a high level of 1.lmg/L. The outflow data for pond 2444OW also indicates a possible PAC overdose, with a low pH of 4.70, although the dissolved aluminium was not markedly elevated.

Table 6 PAC Dosed Sediment Retention Pond Monitoring Data, 21.10.99

Pond	Inlet/ Outlet	Time	Flow (L/S)	pH	SS (mg/L)	Al (mg/L)	Hard (mg/L)	Reduction of SS (%)
Masons	In	1700	3	6.44	4704	0.02	72	
	Out	1705	3	4.44	41	1.10	49	99
OVRE	In	1720	12	8.80	23240	0.29	65	
	Out	1725	10	9.04	272	0.07	95	98
OVRW	In	1740	8	6.86	28845	0.02	194	
	Out	1745	10	6.89	338	0.02	85	98
2444OW	In	1750	3	-	164	0.20	58	
	Out	1745	2	4.70	15	0.34	47	90
D5	In	1815	6	7.65	770	0.03	206	
	Out	1820	5	6.15	36	0.01	159	95
2134OW	In	1825	3	10.73	128	0.31	64	
	Out	1827	4	6.84	14	0.03	81	89
Debs	In	1845	4	11.47	752	0.21	135	
	Out	1850	6	9.82	279	0.31	98	62
Lonely	In	1855	4	11.12	254	0.07	113	
	Out	1900	8	8.31	72	0.16	113	71
Untreated	Out	1835	3	8.63	712	0.06	89	

The Table 6 data clearly shows the effects of lime stabilisation on the road foundation, on the pH of the inflows to ponds 2134OW, Debs, and Lonely. The relatively high dissolved aluminium concentrations in the discharges from Deb's and Lonely appeared to be related to the very fine suspended solids in the discharges. Hardness data was obtained as part of ongoing investigations of the chemistry of PAC dosing of runoff from clay soils, with relatively low pH.

Table 7 provides additional data on pH, suspended solids, and dissolved aluminium in discharges of PAC treated ponds.

Table 7. Discharge Data from PAC Dosed Sediment Retention Ponds

Pond	pH	SS (mg/L)	Diss. Al (mg/L)
Masons Rd	4.68	10	1.50
OVRE	6.20	22	0.07
Lucas E	5.25	67	0.07
24100E	7.19	54	0.03
Kewa Rd	5.26	16	0.06
D5	6.19	46	0.12
21340W	6.90	10	0.05
21900E	7.46	258	0.10
Deb's culvert	8.01	94	0.24
Lonely culvert	7.21	63	0.08
Untreated Pond	7.45	438	0.12

The data in Table 7 for Mason's Rd illustrates a PAC overdose situation with low pH and high dissolved aluminium. The concentrations of dissolved aluminium were generally low, even for the discharges from Lucas East and Kewa Rd ponds that had relatively low pH.

The Deb's culvert pond data in Table 7 shows the influence of lime stabilisation in the catchment. The pond discharge also had a relatively high dissolved aluminium concentration.

The data presented in Tables 4 to 7 show that PAC treatment of clay soils runoff can achieve a very high degree of suspended solids removal without significant adverse effects on the chemistry of the treated runoff. However it is necessary, to avoid overdosing, which can reduce the pH and can then increase the dissolved aluminium concentration in the discharge. The runoff from clay soils that are naturally acidic requires particular care to ensure that overdosing does not occur.

The data obtained for clay soils runoff indicates that the dissolved aluminium concentration in the treated runoff does not increase rapidly until the pH is reduced below 5. At this stage it is desirable to avoid discharges having a pH below 5.5.

5 PRELIMINARY FLOC BLOCK TRIALS

5.1 ALPURT Floc Block Trial

5.1.1 Background

Preliminary field trials were undertaken as part of the ALPURT motorway project using the AN2 Floc Blocks to treat sediment-laden runoff from limestone-derived soils (Onerahi Chaos).

The first trials were undertaken by placing the Floc Blocks in plastic mesh bags ("*netlon*") in plywood flumes through which the runoff from the site was directed (refer to Figure 8).

Figure 8: Floc Blocks and Flume Detail

Those trials encountered problems with the high bedload of granular material in the runoff flow. The material accumulated against, partially buried, and stuck onto the Floc Blocks inhibiting solubility of the chemical.

The trial was then moved to a channel that was formed to divert flows following some primary treatment within in a forebay to the sediment retention pond (Figure 9). The reconfigured array of Floc Blocks achieved good treatment for low flows of estimated at 2 L/s new Floc Block when the concentration of suspended solids contained within the storm runoff was between 10,000 to 20,000 mg/L, and significant bedload from the inflows had occurred. The quantity of solids in the runoff, following an intense rainfall event continued to be a problem, as both the forebay and Floc Block channels were filled with sediment (Figure 10).

Figure 9: Floc Blocks within Channel between Forebay and Pond

Figure 10: Pond Inlet Channel Full of Sediment

As the earthworks area was gradually stabilised, the quality of runoff to the preliminary trial site was improved. Additional tests in a new flume also showed that effective treatment was achieved at flows up to 2 L/s per new Floc Block for runoff with suspended solids concentrations up to 5,000 mg/L.

5.1.2 Results

Preliminary findings were as follows:

- A constant stormwater flow through a Floc Block treatment flume is best in terms of providing the optimum chemical dose for suspended solids removal. It is difficult to provide an array of Floc Blocks that provide optimal dosing for a highly variable stormwater flow.

- The performance of a Floc Block treatment system is dependent on both flow and suspended solids concentrations.
- It is desirable to restrict the maximum flow through the treatment flume for any Floc Block system. A practical flow limit is approximately 20 L/s. For this reason, either multiple flumes should be used, or the catchment discharging flows minimised to the extent that flows in excess of 20 L/s are not likely. Alternatively, larger flows could be bypassed via a diversion mechanism (e.g. throttling the flows prior to discharging through the flume).
- The treatment capacity of Floc Block AN2 on limestone derived soil (Onerahi chaos) runoff proved to be approximately 2 L/s per block at 10,000 mg/L suspended solids, and approximately 1 L/s per block at 20,000 mg/L suspended solids.
- Floc Block treated stormwater requires less time for settlement of suspended solids than aluminium coagulant treated stormwater because the flocs that form are large, dense, and fast settling. Therefore, it is considered that retention ponds utilising a Floc Block system do not need to be as large as those for an aluminium coagulant treatment system.
- Floc Block treatment has a high potential for removal of suspended solids from stormwater with consistent quality, particularly for small catchments; when flow balancing can be achieved prior to treatment.

5.2 Greenhithe Floc Block Trial

5.2.1 Background

Despite the limited research undertaken, the preliminary results of the trial using Floc Block during the ALPURT development were considered to be encouraging enough to conduct a specific trial. The trial aimed to:

(1) Determine the effectiveness of the Floc Block form of polyacrylamide; and

(2) Design of a robust dosing system for delivery of the chemical such that the system could be rapidly and easily transferred to other sites.

The trial site selected consisted of a four-hectare area of pastoral farmland with an easy contour falling from south to north towards a tidal creek, which is a tributary of the Lucas Creek Estuary.

The earthworks design for the site required the stripping of topsoil from the entire site, and bulk earthworks for cut and fill balance within the site.

During the earthworks stage, the site was divided into three stormwater catchments, each of which drained to a sediment pond with dead storage, live storage, and a floating decant, operating within the live storage range.

The trial site was the sediment pond for the largest earthworks catchment that varied between 2 - 3 ha at different stages of the earthworks. The sediment-laden runoff was collected by cut-off bunds, which combined to form a single channel about 15m before entering the sediment retention pond.

The trial was undertaken in a purposely-built flume, located in the sediment-laden runoff flow path immediately before the sediment pond (Figures 8 and 9).

5.2.2 Flume Design

The preliminary trials had shown the importance of achieving a moderate degree of turbulence in the Floc Block area to assist the chemical in dissolving into the flow, and had indicated that there were potential difficulties with achieving the optimum dose for a highly variable stormwater flow regime.

The design of the trial flume provided cages, which housed the Floc Blocks vertically. They could be slid in and out of the flume to enable the number of cages in a flume to be varied. The flume was roofed both to inhibit interference, and to shade the Floc Blocks to minimise the tendency to break down when exposed to sun and air (Figure 10).

The cages were designed to provide vertical slot flow paths around the Block (Figure 9), with the velocity of the water, and the interference from the mesh and the Floc Block providing turbulence. The cross section of the flow path could be reduced by placing pieces of plywood against the side of the cage. This system provided for increasing exposure of the Floc Block surface to the stormwater as the flow and depth of stormwater increased.

The flume contained four 200mm wide by 400mm deep channels, installed on a slope of about 1 in 10. The flume was sealed into a bund, with provision for very high flows to go over the top of the flume (Figure 8). Two 100mm deep weirs were initially placed across the upstream ends of two of the flumes to better direct low flows (Figure 9).

A forebay of approximately $10m^3$ was required up slope of the flume to trap bedload and heavy material that could interfere with Floc Block operation. Because of site constraints, the contractor provided a forebay of some $5m^3$.

5.2.3 Trial Results

Initial Period Without Rain

The Floc Blocks were installed on 17 December 1999. On 24 December 1999, when no stormwater had passed through the flumes, it was noted that there was some cracking of the Floc Blocks as a result of drying. On 4 January 2000, there had been no stormwater through the flumes, and the breakdown of Floc Blocks was quite serious (as shown in Figure 10).

The breakdown of the Floc Blocks is a potential problem. It may result in the transport of pieces of unreacted Floc Block into the sediment pond by stormwater flow after a dry period. The larger pieces that fell off the Blocks swelled when exposed to stormwater and formed a sticky mass that blocked the bottom of the cage, and thereby interfered with the flow path around the Blocks.

Spraying water to the Blocks during dry periods could prevent this problem. It has also been noted that Blocks that have been in water for a long period become partially hydrated and when dried are much more resistant to cracking than new Blocks. It is considered that soaking new Blocks before installation may prevent major breakdowns.

First Stormwater Flow through Flume

The first stormwater flow through the flume was from a very intensive rainstorm on 19 January 2000, when 25-30mm of rain fell over a 30 - 40 minutes. The topsoil had been stripped from the entire site, but bulk of earthworks had not been started. There were two Floc Blocks were in each of the four flumes.

Stormwater runoff on 19 January 2000 transported a large bedload off the site to the treatment pond. The forebay and the up-channel of the flume were completely filled with soil, and the treatment flume was completely clogged (as shown in Figures 11 and 12). About 60m^3 of soil and sediment was retained on the bottom of the pond (measured when pond dried out in February). Pieces of clay of up to 50mm diameter had been transported into the flume.

Before the storm on 19 January 2000, the large pieces of Floc Blocks had broken down further than shown in Figure 10. There was a sticky mass of soil and Floc Block in each Floc Block cage after the rain.

During the recovery of the Floc Blocks from the sediment, it was noted that the Blocks that had been buried in the sediment, and had been substantially weakened by the penetration of water into the Blocks. The fragments did not have the viscous outer layer that forms when the Blocks are submerged in water. The large pieces of Blocks crumbled very easily, and required careful handing until they were later exposed to water and became viscous on the outside.

Data for water samples taken from the discharges of the trial pond and the two other site ponds on 20 January 2000, about 24 hours after the rainfall were as follows:

Table 8 Floc Block Trial Discharge Data, 20/01/00

Pond	Flow (L/s)	PH	SS (mg/L)
Trial Pond	2.0	4.96	2423
East Pond	0.05	4.47	7252
Upper Pond	0.01	4.68	7310

Low pH values, and the high suspended solids concentrations show very poor settlement. Although the Floc Block treatment system was overwhelmed by bedload, the trial pond had a lower SS than the other two ponds.

Very low pH of stormwater runoff from exposed clay soils below the topsoil layer, has been noted in the North Shore area.

5.2.4 Results of Additional Trials

January 2000

A trial was carried out during light rain on 25 January 2000 when the flow through the low flow flumes was about 1*l*/s. Good flocculation was achieved with 2 vertical Floc Blocks in a flow of about 0.5*l*/s, and there was no indication of overdosing. The pond water levels reached about 150mm below the minimum decant level.

The data contained in Table 9 was collected from samples taken on 27 January 2000 from the outlet areas of the three ponds, when the pond water levels were below the minimum decant levels. There had been no further discharge from the ponds since 20 January 2000.

Table 9 Floc Block Trial Discharge Data, 27/01/00

Pond	Flow (L/s)	pH	SS (mg/L)
Trail Pond	0	5.54	510
East Pond	0	4.99	1673
Upper Pond	0	5.05	2948

The data shows the low pH of the stormwater runoff and the high remaining suspended solids after a settlement period of about 7 days. The suspended solids in the trial pond were; however, substantially lower than in the other two ponds.

February and March 2000.

At the beginning of February, Floc Blocks in mesh bags were placed in two flumes (one in a low flow and one in a high flow flume), with cages in the other two.

The forebay above the trial flume, was removed during the course of construction of a sewer line, and was not replaced.

On 15 March 2000, the lower 20% of the catchment of the trial pond had been topsoiled, and road formation had started. Runoff of high sediment loadings was still considered likely, if intense rain occurred.

There was no significant stormwater flow through the trial flume during February and March.

April 2000.

At the beginning of April, 20% of the trial pond catchment that had been topsoiled, had a good grass strike. No additional topsoiling had occurred. The remainder was vulnerable to erosion by heavy rain. Completion of some of the permanent stormwater drainage diverted some of the surface runoff from the site into the culvert discharging to the trial pond (Figure 13).

Heavy rain fell on 21 April 2000 (total of about 50mm) and stopped on 22 April 2000. Major erosion of the surface stormwater channels above the trial flume occurred, and a topsoil and clay bedload again entered the flume, which clogged and partially buried cages and the baskets holding the Floc Blocks. The mesh on the Floc Block cages was clogged by fibrous plant material and new grass (Figure 14).

Data for the discharge flow from the trial pond on 22 April 2000 when the water level had fallen to close to the minimum decant level is contained Table 10.

Table 10 Floc Block Trial Discharge Data, 22/04/00

Time	Flow (L/s)	pH	SS (mg/L)
1055	0.3	6.98	492

This data shows a major increase in pH compared with the first stormwater runoff from the site, and a reduced suspended solids concentration.

During the 21/22 April 2000 rainstorm, it was clear that a substantial quantity of sediment had been discharged into the trial pond via the stormwater system. That part of the inflow to the pond was not chemically treated.

About 16mm of rain fell overnight on 24/25 April 2000 and again resulted in erosion of the stormwater channel leading to the flume, and deposition of soil both in front of and through the flume. The flumes with the baskets remained relatively clean (Figure 5) but the mesh on the cages was again clogged with fibrous material as shown in Figure 15. The stormwater system had again discharged a large quantity of sediment into the trial pond. The data for the discharge flows on 25 April 2000 are contained in Table 11.

Table 11 Floc Block Trial Discharge Data, 25/04/00

Pond	Time	Flow (1/s)	pH	SS (mg/1)
Trial Pond	0900	0.4	6.78	519
Upper Pond	0930	0.2	5.55	1179

This data shows a marked difference in quality between the trial pond and the upper pond samples. The trial pond pH was much higher and suspended solids much lower. The pH difference is attributed to the partial topsoiling and grassing of the trial pond catchment, while the difference in suspended solids could be partly due to the treatment of some of the inflow to the trial pond.

May 2000

By 08 May 2000 most of the trial pond catchment had been topsoiled and new grass was emerging.

Rain of about 20mm on 07 – 08 May 2000 produced a stormwater flow which passed successfully through the two low flow flumes with mesh baskets.

There was moderate rain overnight on 11 – 12 May 2000, easing to stop at 09.00. The live storage volume of the trial pond was full at 08.00 – 08.30, with an overflow of about 5l/s and overflow was reduced completely by 09.35.

The flow through the treatment flume was only a minor proportion of the total flow into the trial pond. Most of the inflow was entering via the permanent stormwater reticulation. The culvert outlet of the permanent stormwater reticulation was submerged when the pond live storage was full, shown in Figure 13.

Two Floc Blocks were placed in a cesspit that was collecting stormwater from a clay soil area in the upper part of the trial pond catchment at 0830, and three Floc Blocks were placed in the mouth of the submerged culvert inlet to the trial pond (Figure 13).

With two Floc Blocks in mesh baskets, suspended material contained in flume flow was coagulated of about 2.5 L/sec per flume. The degree of coagulation was further improved with the addition of two more Floc Block baskets. Build up of soil around the Floc Block cages and some around the Floc Block baskets had occurred.

Data contained in Table 12 was obtained for water quality samples at the trial pond, at the end of the conclusion of the storm event on 12 May 2000.

Table 12 Floc Block Trial Discharge Data, 12/05//00

Time	Sample Type	Flow (1/s)	PH	SS (mg/1)
0840	Inflow to flume	5	6.04	1150
0850	Pond Discharge	20	6.61	1870
0900	Inflow via culvert	10	6.97	1980
0935	Pond discharge	10	6.07	1810
1035	Pond discharge	6	6.78	1720

These data show that high concentrations of suspended solids were present in the pond discharge before and after the storm. The Floc Block did not appear to have had any significant treatment effect during the period of peak runoff flow.

On 15 May 2000, the Floc Blocks that had been placed in the cesspit on 12 May 2000 were removed as they had become soft and viscous as a result of remaining submerged for a prolonged period. The three Floc Blocks in the culvert exit were left in place, as they were out of the water when the live storage volume of the trial pond had been discharged. They were not as soft as those in the cesspit.

On 30 May 2000 (Table 13), samples were taken during a wet period that had been preceded by local, very heavy showers. At the time of sampling, the water level of the trial pond was about 300mm below the overflow level indicating a heavy shower in the area shortly before samples were gathered.

Table 13 Floc Block Trial Pond Discharge Data, 30/05/00

Sample Type	Flow (L/s)	PH	SS (mg/L)
Inflow via culvert	25	7.09	765
Inflow to flume	5	6.56	331
Pond discharge	8	7.05	494

The data shows that the inflow via the culvert was the major inflow, and had a poorer quality than the inflow through the flume, which consisted of stormwater from a largely stabilised catchment area. The pH of the inflows was higher than that previously recorded, indicating the changing nature of the surface soils (more topsoil and grass). Suspended solids concentrations were also lower than previously recorded indicating increased stabilisation of the catchment.

***June 2000*.**

On 06 June 2000, more bedload had been discharged through the flume. The pond water was still highly turbid, and two more Floc Blocks were added to the culvert outlet.

On 27 June 2000 during a period of light rain, when the flow through each of the trial flumes was about 1 L/s, significant coagulation occurred with four Floc Blocks in mesh baskets per flume. The pond water level was close to the minimum decant level, and slight floc formation was slightly occurring at the mouth of the culvert where the flow was estimated to be about 2 L/s.

On 29 June 2000, it was evident that approximately 80mm of rain had fallen overnight. The pond surface had overtopped the live storage level, and at 08.30 was estimated to be 250mm below the top of the live storage. Significant erosion had occurred within the channel above the flume. Bedload material was deposited in front of the flume, and in one of the flume channels that still had Floc Block cages. However, shortly after this, good coagulation of the discharge of about 0.3 L/s through each trial flume was observed to be occurring (4 Floc Blocks in mesh baskets per flume), and very slight coagulation was evident in the culvert area (5 Floc Blocks in mesh baskets submerged in flooded culvert outlet). The relatively poor coagulation at the mouth of the culvert was attributed to the low flow velocity of water passing the Floc Blocks. The results of the samples from the trial pond and upper pond discharges on 29.06.00 are contained in Table 14.

Table 14 Floc Block Trial Discharge Data, 29/06/00

Pond	Sample type	Flow (L/s)	pH	SS (mg/L)
Trial pond	Discharge	4	6.96	620
Upper pond	Discharge	1.5	5.87	2100

These results are again indicative of the different degree of stabilisation of the catchments of the two ponds. The trial pond catchment was largely stabilised, and had a relatively high pH and low suspended solids, whereas the catchment of the upper pond included an area of bare clay, which resulted in lower pH and higher suspended solids.

Although the Floc Block was achieving some treatment during the low flows at the end of the stormwater inflow period, it is unlikely that there was significant treatment of the total storm flow.

5.3 Discussion

The field study was constrained by the lack of an effective sediment forebay, and the high bedload of soil transported by stormwater, which clogged the flumes and interfered with the flow of stormwater passing the Floc Blocks.

The bed load problems necessitated cleaning and reinstallation of the flume system during and/or after each rainstorm and prevented any effective experimentation to develop methods of treating peak storm flows with Floc Blocks.

The following sections summarise the information obtained from the field trials.

5.4 Characteristics of Floc Block in Stormwater Treatment Conditions

Floc Blocks are convenient for transportation, handling, and installation on difficult sites, however, physical cracking and breakdown of the Floc Blocks under shaded dry conditions is a matter of concern. It potentially results in the loss of pieces of unreacted Floc Block into the environment, and also forms in a non-standard shape of the Floc Block when it is later exposed to stormwater, which may increase the rate at which the Floc Blocks degrade if the surface area is enlarged. The Floc Block became very weak when buried in wet sediment. Water appeared to penetrate and weaken it considerably, making cleaning difficult.

Observations made during the Floc Block trial indicated that cracking and breakdown of new Floc Block may be able to be prevented by soaking new Floc Blocks in water for a period to enable hydration of the outer layer to a degree that does not rapidly dry out and crack.

Softening of Floc Blocks during periods of continued submergence in water can lead to problems because of the highly viscous nature of the softened block which adheres strongly to anything it comes into contact with, and the tendency of the softened material to flow through mesh. Soft Floc Block, flowing under the influence of gravity was a problem when suspended in the mouth of a large culvert where the Blocks were periodically submerged (Refer Figure 16).

It is highly desirable to avoid exposure of Floc Blocks to bedload. Bedload materials adhere to the highly viscous Floc Blocks and inhibit the solubilisation of the Block by the stormwater. In circumstances with high bedload, the obstruction caused by the Floc Blocks may initiate deposition of bedload and clogging of stormwater flow paths.

Floc Blocks will perform best in the absence of bedload. On sites prone to bedload transport along stormwater channels, a forebay is adequate to retain bedload from intense rainstorms. It would be necessary to achieve optimal Floc Block treatment.

5.5 Potential Performance

It is important to achieve a solubilisation of Floc Block that produces a concentration within the optimum dose range. If under dosing occurs, there appears to be no effective treatment; i.e. 50% of the optimum dose does not result in removal of 50% of the suspended solids load.

Although overdosing was resulted in poor treatment performance in bench tests, there has been no indication of overdosing in any field trials.

Solubilisation of Floc Blocks into stormwater requiring treatment is optimised when there is a shallow turbulent flow around and over the Floc Blocks.

In submerged conditions with a low current flow passing the Floc Blocks, insufficient polyacrylamide is released from the Block to provide treatment of the stormwater.

In prolonged submerged conditions such as in the cesspit trial, the Floc Block softened to a degree that resulted in flow of the Floc Block and adhesion to any surface it came into contact with.

When placed in plastic mesh baskets flat across the bottom of a flume with a fall of about 1 in 10, the treatment potential for AN2 is about 2*l*/s per new Floc Block for earthworks stormwater with a suspended solids concentration of more than 5,000mg/*L*.

The use of battens on the bottom of the flume is a simple way to create turbulence in the Floc Block area, and to promote mixing of water that has been in contact with the Floc Blocks.

The use of vertical Blocks in cages offers some potential for treatment over a greater flow range than horizontally placed Blocks. But, the Greenhithe field trial was confounded by problems with continual bedload blocking of the small spaces around the Blocks, and with the softened Block material flowing vertically downwards to fill the bottom of the cage altering the flow dynamics around the Block.

There may be potential for improving the treatment capacity of Floc Block by a combination of more sophisticated cages and careful control of the energy of stormwater flows during contact with the Blocks. However, the deformation of the Blocks as they soften and breakdown mitigates against sophisticated design.

5.6 Optimal Flow for Floc Block Treatment

A saturated earthworks site will produce stormwater flows of more than 60 L/s/ha under intense rainfall conditions. Stormwater flows from earthworks sites are extremely variable and it is difficult to provide an array of Floc Blocks that will provide optimal dosing for such variable flows. With large numbers of Blocks in a single channel system there could be some potential for overdosing in low flow conditions.

The ideal operating condition for Floc Block treatment of earthworks stormwater appears to consist of exposure of the Block to water only during the storm flow period, with the Block being out of the water when there is no storm flow.

It is desirable to design a Floc Block treatment system to treat a specified maximum flow, and to use a flow balancing system ahead of the Floc Block treatment system to ensure that the maximum design flow is not exceeded. The flow balancing system could also perform the bedload removal function for catchments that produced bedload.

A practical upper limit for Floc Blocks in a single flume or flow path for the treatment of earthworks stormwater should be set at 10 Blocks because of the risk of overdosing low flows. This would require restriction of the maximum stormwater flow to 15 – 20*l*/s per flume or flow path. A number of flumes could be used to treat stormwater from catchments producing higher maximum flows.

6 SITUATIONS WHERE CHEMICAL TREATMENT MAY NEED TO BE CONSIDERED

Note – need to include reference to flocculation criteria – to be developed further and incorporated into TP

The requirements for sediment retention ponds for earthworks areas are provided in TP90 'Erosion and Sediment Control' (ARC 1999). The performance of ponds constructed according to the TP90 specifications is generally good, but a number of situations have been identified where chemical treatment can provide a marked improvement in sediment removal. These are:

- **Undersized Sediment Retention Pond**

  Chemical treatment is an advantage when a pond of a required size cannot be constructed. This may occur because of topographical constraints, difficult foundation conditions, or the presence of natural habitat s of high ecological value.

- **Physical Characteristics of Sediment Retention Pond**

  In some situations a pond of a required volume can be accommodated but the design of the pond cannot be optimised in terms of shape, depth, location of inlet and outlet, or energy attenuation of the inflow. Chemical treatment can improve performance in such conditions.

- **Soils Type**

  Some soil types produce suspended sediment in earthworks stormwater that has very poor settlement in a normal sediment reduction pond. For example, the ALPURT project had suspended solids concentrations between 1500 - 4200 mg/L in waters of sediment ponds after several days with no inflow to the ponds. Chemical treatment has been found to be effective with such soil types.

- **Sediment Generation Potential of Earthworks Area**

  In earthworks areas with highly erodible soils or very steep or long steep slopes, there is a high risk of increased erosion and sediment runoff in rainstorms. Chemical treatment can be effective in removing the very high suspended solids loadings generated in such conditions.

- **Use of the Earthworks Site**

  Some common uses of earthworks sites, particularly repeated machinery movements (for example on haul roads) can result in high sediment loadings in stormwater. Chemical treatment would improve sediment removal from stormwater in such conditions.

- **Performance of the Sediment Retention Pond**

  If a sediment retention pond does not perform adequately, addition of chemical flocculants will improve performance.

- **Receiving Environment Sensitivity**

  Chemical treatment provides a means of reducing the sediment discharge to highly sensitive receiving environments.

- **Cumulative Discharges**

  The number of sediment retention pond discharges should be considered, as well as the assimilative capacity of the receiving environment.

7 SUMMARY

7.1 Advantages Of Aluminium Coagulant Treatment

Analysis of long term rainfall and stormwater suspended solids data obtained from the ALPURT trials shows that more than 60% of the sediment runoff from an earthworks site occurs during the two or three rainstorms per earthworks season which exceed 30mm in 24 hours. Rainstorms of sufficient size and intensity to overflow the retention pond, discharge disproportionately large sediment load to the receiving environment.

For a normal earthworks site, with a well designed sediment retention pond, and without any influence of the factors listed above, treatment with PAC would achieve the benefits summarised in Table 15.

Table 15. Advantages of PAC Treatment of Earthworks Runoff for Standard Catchments on an Earthworks Season Basis

Treatment	Retention Pond Size	
	3%	2%
Without PAC treatment		
Total sediment discharged to receiving water, tonnes (dry weight)/ha	5.8	9.2
Efficiency of sediment removal in pond (%)	81	69
With PAC treatment	1.0	2.1
Total sediment discharged to receiving water, tonnes (dry weight)/ha		
Efficiency of sediment removal in pond (%)	97	93

Chemical treatment results in a major improvement in the sediment removal efficiency for rainstorms that exceed the hydraulic capacity of the retention pond. This is shown in Table 15 by the increased quantity of sediment removed by chemical treatment for the smaller pond sizes.

If any of the factors listed in Section 6 occur to either increase sediment erosion, or decrease pond performance; chemical treatment will have an advantage over gravity settlement alone.

7.2 Advantages of the Use of Floc Blocks

To be completed