Geography 309: Research Methods in Geography
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Final Group Report:

Stormwater Management in rural Lyttelton Harbour.

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Te Whare Wānanga o Waitaha
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2. Executive Summary

Research Question:

- What roadside stormwater management strategies are employed in Lyttelton Harbour and how do different parameters control the delivery of sediments to the aquatic environment?

Research Context:

- Lyttelton Harbour is an economic gateway to the world for a large portion of the South Island and it provides a large number of jobs for the local community.
- It has a large area of tidal wetlands which play a significant role in the harbour ecosystem.
- The infilling of the harbour is occurring primarily due to land derived sediments being eroded and deposited during high rainfall events.

Summary of methods:

- Various sites were selected which embody a range of management strategies used around the harbor. A number of discharge samples were taken at points along each system under three different flow regimes.
- A time-lapse camera and erosion pins were set up at one site showing advanced levels of erosion.

Key Findings:

- There are many factors that impact on the levels of erosion occurring in roadside stormwater systems. These factors include: type of system in place, drainage length serviced, discharge slope angle, precipitation, drop height from culvert, and type and amount of vegetation. Lyttelton Harbour incurs large variations in the amount of sediment entering the harbour environment due to these contributing factors.

Possible limitation in this research:

- During this research, a magnitude 7.1 earthquake occurred, and this may have affected parts of the data.

Suggestions for future research:

- The use of the methods implemented in this study applied in a much broader extent across the entire harbour.
- Further study to provide a better look at the effects of sedimentation on the benthic environment.
- Research into the limitations of applying swale to a series of differing environments.

3. Introduction

Lyttelton Harbour (Te Whakaraupo) provides important social, economic and environmental values to local and regional communities, however it is under significant threat from sediment infilling. This report covers research into roadside stormwater management strategies currently in use in Lyttelton Harbour. The aims of this research were firstly to identify what methods were in place, and secondly, to carry out an assessment of their impact on sediment delivery to the Lyttelton Harbour basin. The sites chosen to include in the investigation were spread around the harbour, and were an exemplary sample of the roadside stormwater management techniques in use in Lyttelton (Figure 1). These sites were categorised as engineered and non-engineered and showed a range of successes and failures in preventing surface erosion and subsequent sedimentation of the harbour.

Figure 1: Map of study area. The engineered sites are: Rapaki Engineered and Sumner Road. The non-engineered sites are Rapaki Swale, Teddington-west and Charteris Bay. Image retrieved and modified from Google earth on the 16/10/2010.

3.1 Background

Lyttelton Harbour is situated in Banks Peninsula and runs westward 13 km with a relatively uniform 2 km width until it spreads into three wide bays at the head of the harbour. Modern land use change in Lyttelton Harbour has seen an increase of sediment into the harbour. Not only does this create anaerobic conditions by suffocating the benthic ecosystem and adversely impacting on marine biodiversity in the area, but this sedimentation causes infilling within the shipping lanes (Thrush et al. 2004). The importance of clear shipping lanes is highly significant for Lyttelton Harbour as the South Island's most economically active harbour. Currently pressure to bring bigger more economically productive ships into the harbour. These demands for growth mean a need for dredging operations to keep these commercial lifelines open (Lyttelton Port Company (LPC) 2005). Currently, the Lyttelton Port Company (LPC) is planning what is known as capital dredging, a process that includes the removal of large amounts of virgin material from the seabed to create, or deepen, a shipping channel. This differs from maintenance dredging which is the annual clearing of deposited debris from the shipping channels (Lyttelton Port Company (LPC) 2005).

4. Literature Review

Thrush (2004) outlines that increasing the rate of sediment entering a coastal marine environment has detrimental effects on the biodiversity and ecological value of the ecosystem. Increased rates of erosion can be related to a number of factors. Although the infilling of harbour and estuarine environments with terrestrial sediments is a natural process which has occurred for millennia (Carney et al. 1999), land use change in Lyttelton Harbour has caused exaggerated levels of sediment to enter this aquatic environment. Findings of a recent study by Hewawasam (2003), demonstrated that a conversion of a forested area into agricultural land increased the rate of sediment runoff from 30 metric tons per Km^2 per year to 7000 metric tons per Km^2 per year, these results were reflected in Thrush (2004). Land use change places huge importance on the roadside stormwater management strategies employed. A significant volume of sediment is entrained by stormwater after it has left the road and discharged down slope of the culvert. This highlights the importance of a comprehensive stormwater management strategy, which not only services the road but also protects the surrounding environment from erosion processes. This idea is reinforced by Bohan (1970), where analysis of scour below the culvert was carried out to aid the designing of rip-rap protection down slope of a culvert. The concept of stormwater management integrated with land use management is reflected by Valentin, Poesen and Li (2005), their findings show that gully erosion leads to the greatest amounts of sediment transport, which are in turn a direct result of land use change. Similar investigations completed by Swift and Burns (1999), link the importance of minimising this type of erosion through restoration, reconstruction or redesign of current roadside stormwater management systems.

5. Methods

The initial step taken to address the research issue was the selection of key sample sites throughout Lyttelton Harbour, from these, templates were created in order to distinguish and compare individual sites. Following the establishment of the sites to be investigated, numerous measurement techniques were chosen in order to quantify erosion and accumulation. One principal method was applied across all sites, whilst two specialised methods were employed at the Teddington-west site as it was showing advanced levels of erosion. The methods chosen are representative of academic research methods, senior advice and resource constraints.

5.1 Site Profiling

To establish a strong understanding of the chosen sites and for ease of comparison, template profiles recorded varying characteristics in a qualitatively descriptive format (Appendix 1). These characteristics were all identified as potential factors in the level of erosion and consisted of: system type, length of road serviced by the drainage system, culvert diameter, flow drop height, gradient of discharge slope, and source environment.

5.2 Runoff Sampling

Runoff sampling was carried out on all sites, to gather data on the effect that different systems have on sediment transport. This method of collection was based on similar techniques undertaken by Frederick et al. (2007) and Zobisch et al. (1996) and was used to record the weight of sediment flowing through each system. Runoff was captured at significant junctures in the flow to clarify the effect of each stormwater system on the sediment load. Differences between these measurements were calculated and used to ascertain the volume of sediment being entrained, transported and deposited throughout the length of the flow. These flow regimes were obtained across three separate days of collection, representing low, mid and high flow days.

A known volume of each of the suspended sediment samples were processed through pre weighed glass microfiber filters. The filters used were Whatman GF/A filters with the ability to filter any particle over 1.6 micrometers (Whatman 2009). After filtering the suspended sediment from the runoff sample, the filters were transferred to an oven preset at 60° Celsius for over 24 hours to extract moisture. Subsequently, they were placed in a desiccation cabinet for a further 24 hours to remove any remaining moisture. Following the techniques seen in Hoffman et al. (1984), the suspended sediment load within each sample was then calculated by weighing the dried filters and gaining a value of sediment mass accumulated on each filter.

5.3 Erosion Pins

In order to evaluate the erosion and deposition occurring at Teddington-west, erosion pins were set out on the sediment fan at the base of the slope. As mentioned by Haigh and Gentcheva-Kostadinova (2002), erosion pins have the advantage of being able to measure both erosion and deposition. The placement of the erosion pins helped in gaining an idea of how much sediment is going into the harbour, as the array was located only metres from the shore. Twelve erosion pins were set out in three rows of four, encompassing an area of 13.5 m^2. Primary measurements were made to set a datum level of sediment accumulation, additional measurements over the study duration were also recorded, with the start and end measurements being most significant. The change on each erosion pin was compiled using Surfer 8.0 to gain a 3D perspective on the level of accretion occurring at the base of the drainage system.

5.4 Time-lapse Camera

To help gain a visual perspective of the stormwater-induced erosion occurring at Teddington-west, a time-lapse camera was set up facing the main scour area. The time-lapse camera used was a Nokia N82 cell phone. The time-lapse camera was formatted to capture photos at half-hourly intervals throughout the entire project. The camera was strategically placed well out of the range of the flow and associated processes. As Erlingsson (1991) mentions, camera placement is exceptionally important, as it can have significant effects on flow patterns if positioned incorrectly. A link to the time-lapse images can be found in the appendices.

6. Results

Sediment sampling provided a relevant data set from a medium and a high flow regime, this was manipulated into a series of graphical outputs. Figure 2 shows that sediment concentrations through non-engineered structures encompass a range of values from 0.094-4.960 gL^{-1} in a medium flow, through to 0.274-7.226 gL^{-1} in a high flow. In comparison, engineered structures generally appear to have a greatly reduced sediment concentration passing through the system. Sediment concentrations at engineered sites did not rise above 2.383 gL^{-1} at any flow (Figure 2a). It is also evident that the sediment concentration at Sumner Road is considerably lower than at all other sites. The maximum concentration observed at this site during this research reached only 0.031 gL^{-1} (Figure 2b).

Of all sites Teddington-west showed the highest sediment concentration across all flow regimes. The increase in sediment concentration downstream of the culvert exit at Teddington-west is typically 3 to 4 times greater than any other site. Charteris Bay also shows consistent accumulation of entrained sediments downstream of the culvert exit. During the high flow, Charteris Bay almost doubled in sediment concentration (Figure 2a). Since Teddington-west can be identified from Figure 2 as a large contributor of sediment to the harbour, the suspended sediment found at all flow regimes at this site are illustrated in Figure 3.

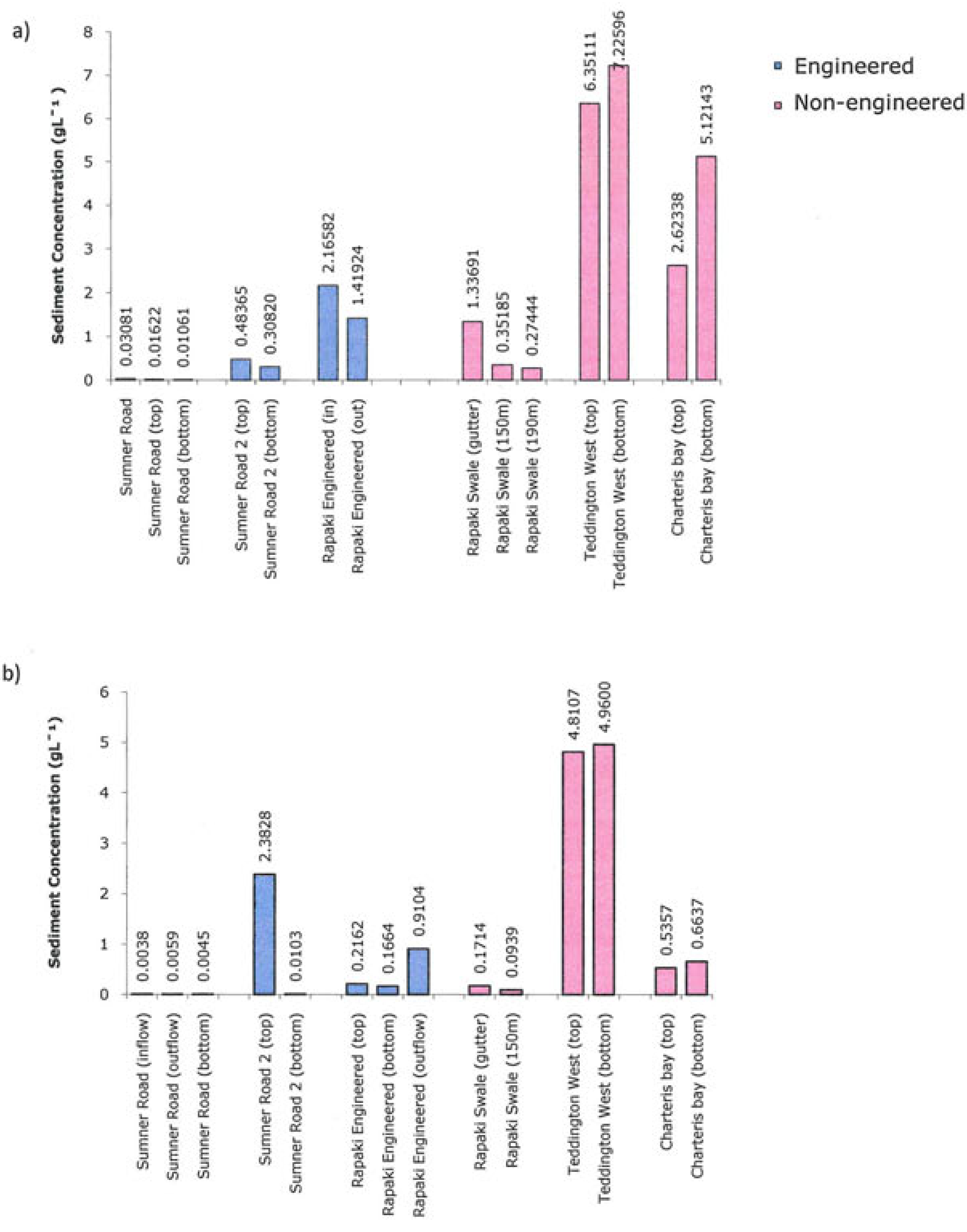

Figure 2: Bar graphs showing suspended sediment concentrations at different sites in. a) High flow regime b) medium flow regime.

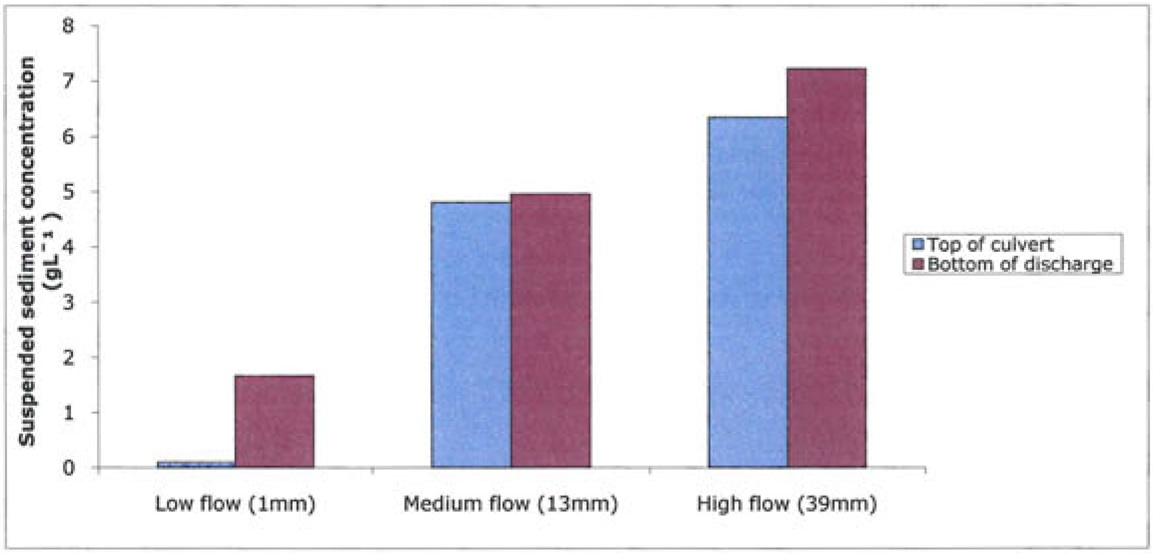

Figure 3: Bar graph showing sediment concentrations across all flow regimes at Teddington-west.

Rapaki Swale was the only non-engineered site shown to remove sediment from the flow over the sampling range (Figure 2). Figure 4 shows that Rapaki swale retains approximately 1.0 gL^{-1} along its' 200 m length in high rainfall conditions. The graph also shows the difference between the Rapaki swale, Teddington-west and Charteris Bay, and their relative performances under medium and high flow regimes. Teddington-west and Charteris Bay experience much greater levels of erosion at higher flow, whereas Rapaki swale shows greater levels of deposition.

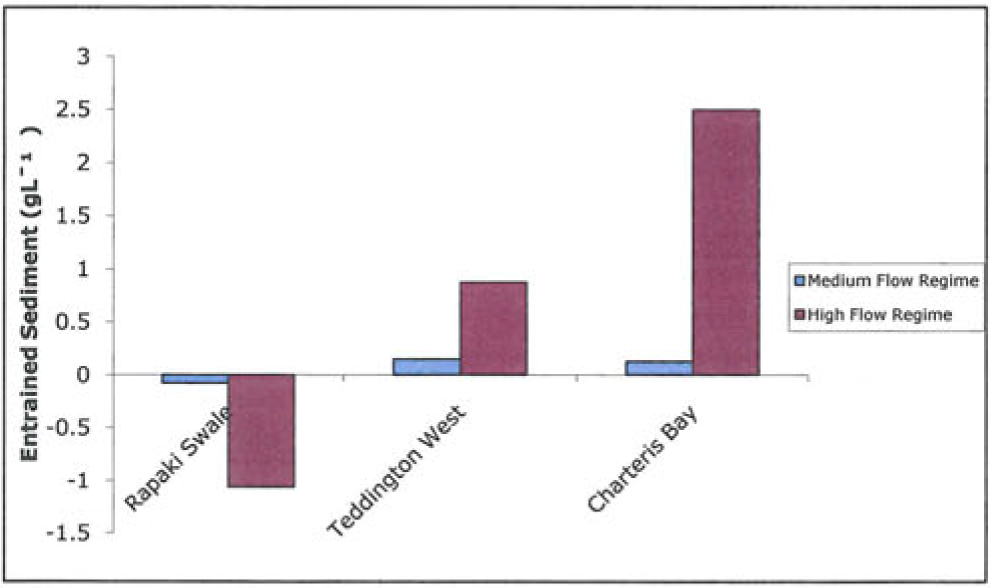

Figure 4: Bar graph showing absolute erosion rates from three sites where overland flow occurs between the roadside and the harbour. Negative values indicate deposition.

Three of the non-engineered sites presented results enabling a comparison about the function of slope angle on surface soil erosion. All three sites had sections of overland flow between a culvert outlet and the harbour. The amount of erosion that occurred over the length of the three watercourses has been divided by the length of the watercourse to give a value of sediment concentration (gL^{-1}) eroded or deposited for every metre of the channel. This standardises erosion rates over variable slope angles into units of ($gL^{-1}m^{-1}$). As can be seen in Figure 5 rates of erosion, as a result of overland flow, increase significantly with increased slope angle. Deposition can be seen to occur for every metre at 10°. Around 0.05 $gL^{-1}m^{-1}$ erosion occurs at 35° and over 0.2 $gL^{-1}m^{-1}$ erodes under this flow regime on the 45° slope. Though Figure 5 represents high flow results on variable slope angle, a similar relationship is evident across all flow regimes.

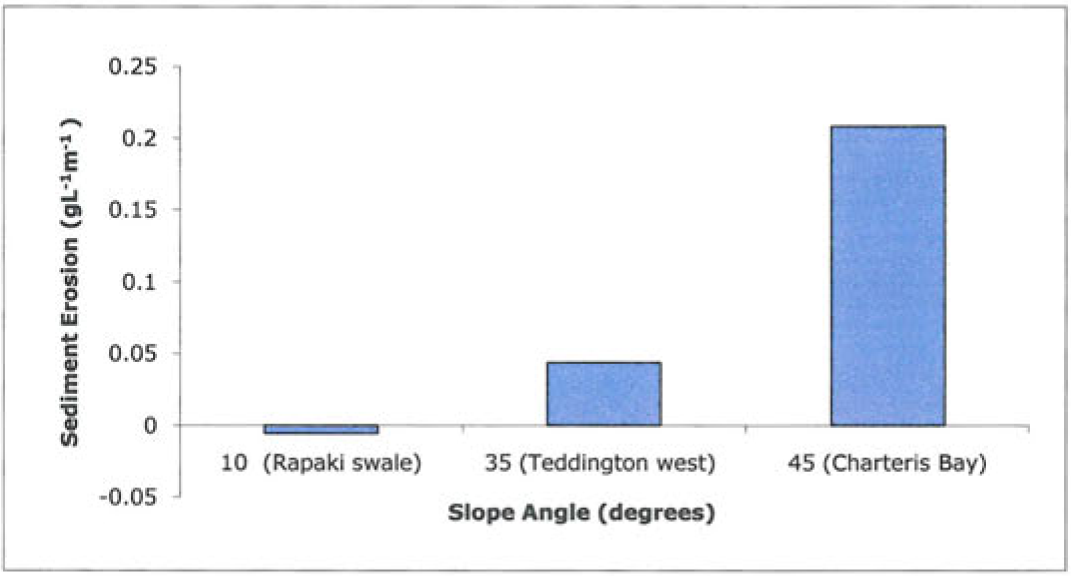

Figure 5: Bar graph showing increased rates of surface erosion on steeper slope angles during high flow. Note that negative erosion (deposition) occurs on slope angle of 10°.

The performance of Rapaki swale over the measured distance of its watercourse is shown in Figure 6. This result shows clearly that the proportion of sediment present in the sample declines considerably along the length of the swale.

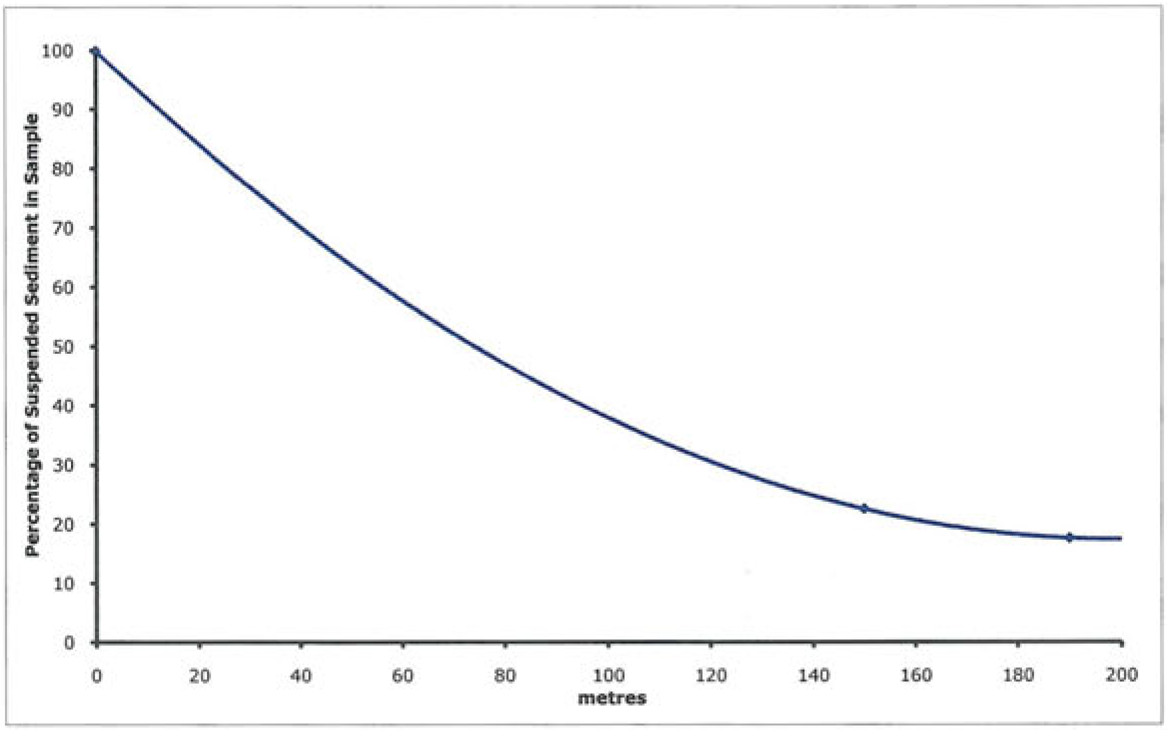

Figure 6: Line graph showing the deduction of entrained sediment over the distance of Rapaki swale.

Measurements at Teddington-west, Rapaki engineered and Charteris Bay indicate that larger drops from culvert to slope correspond with increases in downslope sediment concentration (Figure 7).

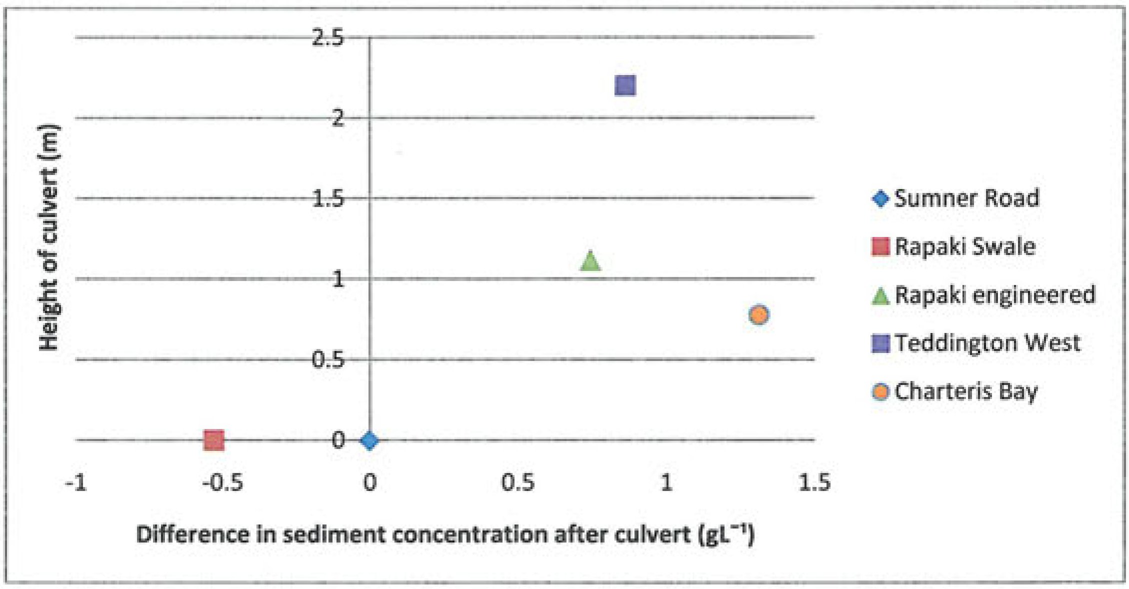

Figure 7: Scatter plot showing culvert exit drop at each site in comparison with differences in sediment concentration downslope (averaged across all flow regimes).

The array of erosion pins at the outfall of Teddington-west showed significant accumulation of sediment on the low angle outwash fan over this research period. A maximum accumulation of 30 mm and a minimum of 1 mm (Figure 8) can be seen across the array. From modelling and analysing techniques within Surfer 8.0, the final sediment accumulation across this area was calculated as 0.23 m^3. This is nevertheless only a snapshot of the accumulation fan and represents a rough approximation of 10% of the total fan accumulation.

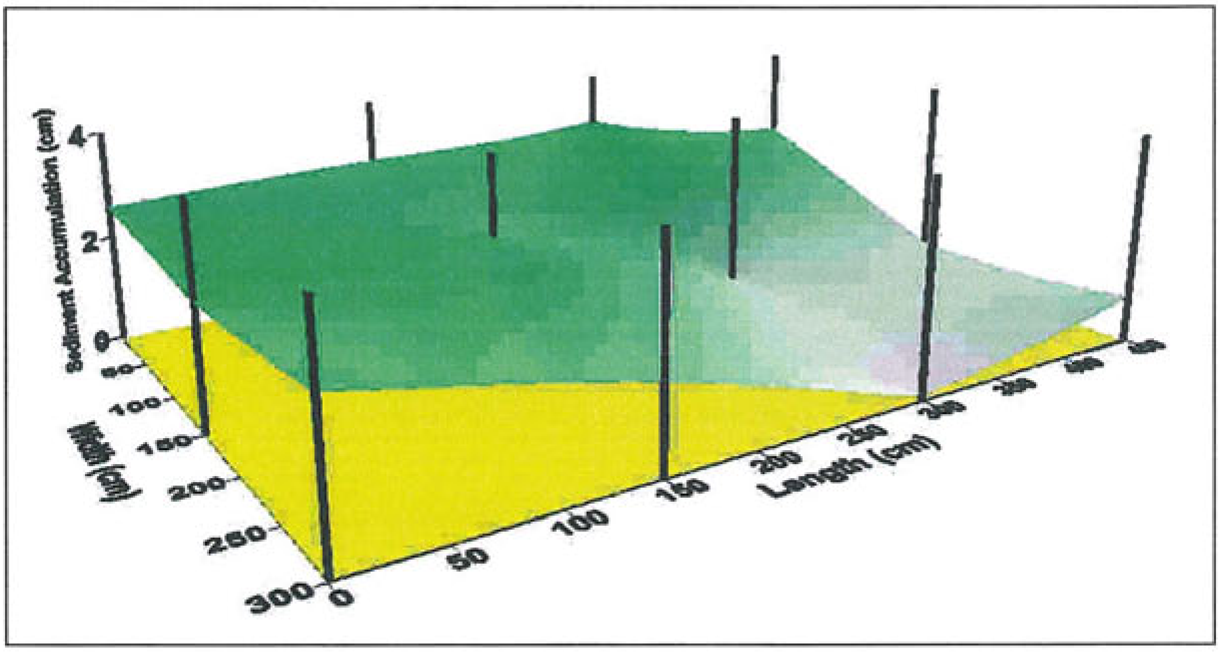

Figure 8: Image showing sediment accumulation across erosion pins creating an elevated surface with the yellow original surface having no accumulation/erosion.

7. Discussion

7.1 Engineered Sites

Figure *2* clearly depicts the effectiveness of engineered sites at removing sediment from the flow compared to the non-engineered sites. Rapaki engineered is the most effective as it shows a decrease of 0.747 gL^{-1} of sediment. This is potentially due to the gravel tailings and geotextile surface before the culvert entrance, dissipating the water's energy and filtering some sediment. The flow exits the culvert onto a gabion basket, which dissipates the energy and reduces the initial scour. The outflow measurement (Figure 2b) shows the concentration increasing; this sample was taken 5 m below the gabion basket as the flow resumed on its natural watercourse. This is evidence that the gabion basket stops initial scour but does not prevent the water channelling and eroding below the basket (Merrill 2004). Even though both Sumner Road sites decrease the sediment concentration in the water, the suspended sediment is a low concentration to start with. This could be due to the soil type in the area being predominantly hard volcanic rock, compared to that of the harbour headwaters (Appendix 1), where the soil is dominated by loess and consequently more susceptible to erosion from all forms of weathering.

7.2 Non-engineered Sites

Initial sediment concentrations at the culvert exit on non-engineered sites were greater than corresponding sampling points at engineered sites, indicating either soil type or upslope stormwater management is contributing to high sediment loads at non-engineered sites. The high flow regime shown in Figure 2b illustrates a distinct trend for non-engineered sites to increase in sediment concentration as the stormwater discharge travels downslope, the exception in this study being Rapaki swale. This can partially be attributed to the volume of discharge from the culvert, vegetation of the downslope, and slope angle; Teddington-west had the highest discharge volume of 10 Ls^{-1}, higher than any other site by 6.5 Ls^{-1}. This is because it drains a 420 m length of road, which is double the drainage length of most other sites because of a blocked drain at approximately 200 m above the culvert. This relative increased discharge is significant because it is delivering more sediment to the harbour environment and at a faster rate than any other sites (Van Dijk & Kwaad 1996). Assuming a 24 hour period with a continuous flow of 10 Ls^{-1}, which was measured during the high flow event, an approximation of 4-6 tonnes of sediment can be estimated to be passing through the downstream sampling location at Teddington-west. Unlike other sites, across all three flow regimes Teddington-west entrains sediment downslope of the culvert exit, increasing with higher flow (Figure 3).

7.3 Vegetation

Vegetation is widely recognised as a significant contributing factor to hillside stability (Goldberg 2009). The dominant vegetation at Teddington-west is a Macrocarpa plantation forest with an exposed soil surface. The Charteris Bay site is predominately covered in bush scrub type vegetation. There are very few grasses providing groundcover at either of these sites. This is identified as the ideal vegetation type for binding sediment and limiting scour and erosion of bare soils (Deletic & Fletcher 2006; Fiener & Auerswald 2003).

7.4 Slope Angle

Both Teddington-west and Charteris Bay discharge onto high slope angles (Figure 5), consequently increasing the rate of erosion. Shallow slopes in comparison to steeper slopes appear to show deposition of sediment rather than erosion, this is because the flow velocity decreases on the lower angles and allows entrained sediments to settle out the solution (Montgomery 1994). Evidence of this can be seen at the Rapaki swale site; with a low angle of 10°, it shows deposition of sediment not erosion over the length of the swale. Figure 5 implies that there is a critical angle between 10° and 35°, where slopes shift from behaving as sediment sinks and become sources. Naturally the critical angle will be site specific and depend on local variables such as; vegetation type, lithology, soil saturation and flow regime (Deletic & Fletcher 2006).

7.5 Rapaki Swale

Rapaki swale is an exception to sediment increase at non-engineered sites, as it decreases the sediment concentration effectively over the 200 m watercourse that samples were taken. The presence of natural, densely vegetated grassland and low angle slope disrupts the flow and traps entrained sediments. This is assisted by a ground level culvert exit, therefore producing no initial scour. It is a notable observation that the performance of the Rapaki swale improves under the higher flow regime (Figure 4). This may be due to higher flows dispersing the stormwater, thus increasing the area of grassy vegetation acting to filter and retain suspended sediments. To perform effectively and have the ability to spread the flow and retain sediment, swale structures need maximum area both, in width across the slope and length downslope (Figure 6) (Charlesworth et al. 2003; Deletic & Fletcher 2006).

7.6 Erosion Pins

The erosion pins were set-up in an area assumed to be reflective of the entire accretion fan for Teddington-west. The array was constructed in order to ascertain how much sediment was accumulating as a result of upslope erosion. Figure 8 shows the 3 m by 4 m array that represents approximately 10% of the fan, total accretion of sediment within this area during the study period was approximately 0.23 m^3. This zone bears similar characteristics to Rapaki swale in that energy is dissipated due to the low slope angle (≤5°), and interaction with vegetation filters sediment. However, a large volume of suspended sediment can still be seen flowing from this outwash fan into the harbour.

7.7 Culvert Drop Height

The variation in distance between the culvert and the surface it discharges onto leads to large disparities in the amount of energy being concentrated on the slope. Figure 7 indicates there is a relationship between drop heights and the difference in suspended sediment downslope of the culvert. Physical observations of the sites suggested that drop height greatly increased the scale of the scour. At Rapaki engineered where stormwater is discharged onto a gabion basket initial scour was reduced, however there was still undercutting and erosion downslope of the basket. The discharge from Rapaki swale and Sumner Road is level with the downslope. This causes no increase in sediment concentration as no extra energy is gained from drop height.

7.8 Limitations

The most significant limitation of this study was the time available to conduct the research. The short time period available meant that only a snapshot sample of the issues surrounding stormwater management in Lyttelton Harbour could be gained. The small time period also created a limited window of opportunity to obtain data during multiple high flow regimes.

The September 4th 2010 earthquake left an uncertainty in any post-earthquake data and consequently could not be confidently relied upon. Although the majority of the data was collected prior to the earthquake, some erosion pin data was gathered after the event. Despite showing no observable variation in the rate of accumulation, the data set had to acknowledge the occurrence of the event and therefore some reliability may be lost.

When carrying out research and field work in a group situation inconsistencies naturally occur. Therefore, a small margin of error can be applied to the data.

8. Conclusion

Stormwater management within the Lyttelton Harbour area plays a significant role in the sedimentation of the harbour, particularly in regards to roadside runoff. Erosion through poor stormwater management techniques increases the infilling of the harbour, which has social, economic and environmental impacts. There are many factors that could impact on the level of erosion occurring throughout Lyttelton Harbour including; quality of stormwater management, slope angle, drainage length, vegetation and culvert drop height. Of the sites identified in this study, those at Teddington-west and Charteris Bay are contributing the greatest relative concentrations of sediment and require the most urgent level of attention. Effective stormwater management techniques are however reducing the amount of sediment reaching the aquatic environment. It was concluded that Rapaki swale is highly effective at removing sediment from stormwater discharge, and this method could potentially be applied to other sites in an aim to reduce surface erosion. There are many avenues for future research that will benefit the body of understanding of stormwater management issues in Lyttelton Harbour. Notably, these should include: further investigation of the constraints affecting the performance of swale systems; swale site suitability analyses; and development of more effective loess filters for engineered systems.

9. Acknowledgements

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11. Appendix 1: Site Templates

Appendix 1 holds site specific information presented in a common template format. It is intended for use as a quick reference guide to familiarise the reader with the particulars of individual sites. It details all sites with arbitrary names and gives both descriptive and latitude/longitude coordinates for all site locations. Specific technical details for the sites are listed and include: drainage length, culvert diameter, height of outlet above the discharge slope and, gradient of the outflow or discharge slope. Sediment concentrations for all flows have been included where the data has been collected and the templates give descriptions of upper and lower catchment environments for each site. For more information, photos and time-lapse camera results, please visit the Lyttelton stormwater management website; www.lytteltonstormwater.yolasite.com.

Site Templates in geographical order as follows:

- Sumner Road
- Old Quarry
- Cass Bay
- Rapaki swale
- Rapaki engineered
- Ohinetahi
- Allandale
- Teddington-west
- Teddington-east
- Charteris Bay

Site	**Sumner Road**	Lat;43°36'01.51"S Long;172°44'08.48"E		
Location	Sumner Road above port coal store			
System	Sediment trap + Conduit		Sediment Concentration (gm/L)	
Drainage Length (m)	120	Flow Regime	Top	Bottom
Culvert Diameter (mm)	TBA	Low Flow	0.0025	0.0028
Height of outlet (mm)	TBA	Mid Flow	0.0059	0.0045
Gradient of outflow	TBA	High Flow	0.031	0.016

Source Environment

Long section of ashphalt roading. Hillside upslope of road is near vertical, exposed mixed quality igneous. Unlikely to yeild great volumes of entrainable sediments. Sediment trap is likely to effectively remove bedload sediments and larger clasts.

Outflow Environment

An overland conduit follows a steep valley gradient. A flow exists under the conduit (leakage or baseflow)

Lower Catchment

Little or no erosion is present where flow exists beneath the conduit despite steepness and apparent constraint of channel banks. Lush, long grass, lines this flow path.

Site	**Old Quarry** Lat;43°36'01.51"S Long;172°44'08.48"E			
Location	On Sumner Road, opposite road to Timeball			
System	Uncontrolled		Sediment Concentration (gm/L)	
Drainage Length (m)	80	Flow regime	Top	Bottom
Culvert Diameter (mm)	No culvert	Low Flow	No Data	
Height of outlet (mm)		Mid Flow	No Data	
Gradient of outflow	>45°	High Flow	0.19	

Source Environment

Source environment is a small drainage trough between a section of anticamber on Sumner Road and an unpaved layby on the port side of the road. Low gradient and small area, however stormwater over this catchment is clearly incising a channel and flow is eroding where it leaves the roadside.

Outflow Environment

Stormwater here discharges to LPC reclaimed land, this is a large flat area where inflitration is possible.

Lower Catchment

Rivulet descends through bramble and surface mat vegetation. The area is overarched by a canopy of large wilding pines. This discharge slope appears to be in static equilibrium for the time being but it is steep and may remobilise under extreme conditions.

Site	**Cass bay** Lat;43°36'01.51"S Long;172°44'08.48"E			
Location	West side of Cass bay above gabion reinforcing			
System	Uncontrolled		Sediment Concentration (gm/L)	
Drainage Length (m)	60	Flow regime	Top	Bottom
Culvert Diameter (mm)	No Culvert	Low Flow	No Data	
Height of outlet (mm)	N/A	Mid Flow	No Data	
Gradient of outflow	30°	High Flow	No Data	

Source Environment

Very similar to Old Quarry. Run-off occurs over a small section of sealed road where the camber leads flow away from the inside gutter. This flow though usually very small has found passage over the road edge where it is eroding the bank. There is little or no source environment for sediments to become entrained in stormwater.

Outflow Environment

Gum tree plantation. Little to no ground cover vegetation, exposed loess slope

Lower Catchment

Rill erosion is taking place directly down slope. There appears to be ample space for suspended sediments to settle out and accumulate before reaching the harbour waters.

Site	Rapaki swale	Lat;43°36'01.51"S Long;172°44'08.48"E		
Location	SW side of Rapaki Bay			
System	Culvert to meadow swale		Sediment Concentration (gm/L)	
Drainage Length (m)	257	Flow Regime	Top	Bottom
Culvert Diameter (mm)	440	Low Flow	0.052	No Data
Height of outlet (mm)	0	Mid Flow	0.17	0.094
Gradient of outflow	11°	High Flow	1.37	0.27

Source Environment

Hillside run-off and roadside ditch guttering. There is ample opportunity for sediment entrainment in the source environment

Outflow Environment

Low angle meadow (200 m approx), sown in pasture grass.

Lower Catchment

Lush green grass lines agricultural land. This swale passes over a sheep paddock before entering a more established creek. Water passing over this area is not constrained by channelisation and is free to fan and avulse.

Site	**Rapaki engineered** Lat;43°36'01.51"S Long;172°44'08.48"E			
Location	West of Rapaki on Lyttelton, Governers Bay Road			
System	Series filters, discharge to gabion		Sediment Concentration (gm/L)	
Drainage Length (m)	252	Flow Regime	Top	Bottom
Culvert Diameter (mm)	465	Low Flow		0.076
Height of outlet (mm)	1115	Mid Flow	0.22	0.17
Gradient of outflow	22°	High Flow	2.17	1.42

Source Environment

Long section of roadside ditch guttering. Several large bank cuttings.

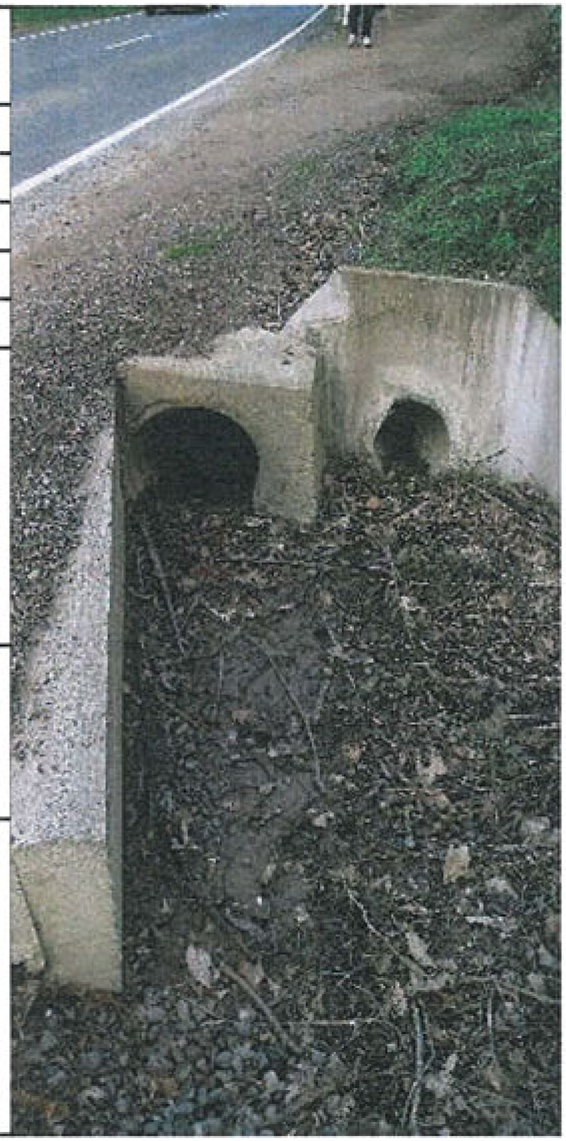
Outflow Environment

Culvert flows out of roadside retaining wall and falls onto a gabion basket 1.2m below. Moderate slope.

Lower Catchment

Dense vegetation lines a natural drainage gully, there is little to suggest that major erosion is happening in this tributary however, splash and rill erosion is evident above and around the gabion basket.

Site	**Ohinetahi**	Lat;43°36'01.51"S Long;172°44'08.48"E		
Location	Ohinetahi, above broad unpaved carpark/ layby			
System	Debris grill, sump, twin culvert		Sediment Concentration (gm/L)	
Drainage Length (m)	220	Flow regime	Top	Bottom
Culvert Diameter (mm)	255 and 157	Low Flow	N/A	N/A
Height of outlet (mm)	0	Mid Flow	N/A	N/A
Gradient of outflow	5°	High Flow	N/A	N/A



Source Environment

This system appears to capture stormflow from two distinct catchment environments. A collapsing roadside cutting exists above a well vegetated gutter ditch which flows through tailings and a debris grill into a sump.

Outflow Environment

Tailings, low gradient unpaved carpark

Lower Catchment

The carpark here appears to be a suitable area for settling out of sediment and infiltration of stormwater. There is both room for run-off to fan and good apparent drainage material in the layby.

Site	**Allandale**	Lat;43°36'01.51"S Long;172°44'08.48"E		
Location	Allandale (old dump site) tidal fringe			
System	Settling pond		Sediment Concentration (gm/L)	
Drainage Length (m)	260	Flow regime	Top	Bottom
Culvert Diameter (mm)	465	Low Flow	No Data	
Height of outlet (mm)	0	Mid Flow	0.012	0.0058
Gradient of outflow	0°	High Flow	0.14	

Source Environment

This settling pond recieves waters from steep farmland and vegetated slopes. A long section of roadside guttering comes down into the bay area from the Ohinetahi watershed and some of this drainage is likely to be captured by the system.

Outflow Environment

Tidal flats. This system outflows directly into the harbour when water levels cause the pond to overflow.

Lower Catchment

Settling pond is the lower most feature of this catchment.

Site	**Teddington-west** Lat;43°36'01.51"S Long;172°44'08.48"E			
Location	West side of Teddington			
System	Culvert to slope		Sediment Concentration (gm/L)	
Drainage Length (m)	420*	Flow regime	Top	Bottom
Culvert Diameter (mm)	315	Low Flow	0.103	1.663
Height of outlet (mm)	1800-2600**	Mid Flow	4.81	4.96
Gradient of outflow	35°	High Flow	6.35	7.23

Source Environment

A long section of roadside guttering. Collapsed bank cuttings periodically obstruct the watercourse. *Another drainage culvert 217 metres up the road is blocked and so this site services drainage for 420 metres of roading. ** High flows have trajectories that carry further downhill

Outflow Environment

Extensive rilling erosion is undercutting and toppling trees in a small Macrocarpa plantation. This process appears to have displaced high volumes of the lower catchment.

Lower Catchment

Sediment is accumulating over low gradients at the coastal fringe. The deposition fan is becoming colonised by scrubby vegetation and grass.

Site	**Teddington-east** Lat;43°36'01.51"S Long;172°44'08.48"E			
Location	East side of the "Head of the bay"			
System	Culvert to slope		Sediment Concentration (gm/L)	
Drainage Length (m)	174	Flow regime	Top	Bottom
Culvert Diameter (mm)	615	Low Flow	0.031	N/A
Height of outlet (mm)	0	Mid Flow	0.094	N/A
Gradient of outflow	2°	High Flow	No Data	N/A

Source Environment

Natural gully drainage over sporadically vegetated farmland. A long straight section of gutter ditch lies beneath some roadside cuttings (bank facing NW) joins this system at the culvert entrance.

Outflow Environment

Agricultural, steep sided valley pasture. Healthy grass and tussocks line a temporal stream bed.

Lower Catchment

Significant evidence of historical downslope erosion. Channel has incised several metres into the valley profile. With consent to access property, this would make a suitable site for in depth investigation into swale performance.

Site	Charteris Bay	Lat;43°36'01.51"S Long;172°44'08.48"E		
Location	South end of Charteris Bay			
System	Culvert to slope		Sediment Concentration (gm/L)	
Drainage Length (m)	210	Flow Regime	Top	Bottom
Culvert Diameter (mm)	327	Low Flow	No Data	No Data
Height of outlet (mm)	780	Mid Flow	0.54	0.66
Gradient of outflow	46°	High Flow	2.62	5.12

Source Environment

High and steep roadside cutting feeds loess sediments to ditch on inside bend of road. Hard surfaces also drain to inside bend. The outside of the bend is wide, vegetated and permeable, saturation levels in this area probably fluctuate daily and seasonally.

Outflow Environment

Steep, uncontrolled and eroding. Scrubby vegetation, coarse unsorted amalgam of sediments.

Lower Catchment

Water is culverted under road to steep vegetated bank directly to the tidal zone. Flow is scouring a deepening channel through coarse aggregate stones and mud.