Sediment Runoff from Roadside Cuttings in Lyttelton Harbour

Report for the Lyttelton Harbour Issues Group

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1. Executive Summary

Research Questions:

- Is it possible to prioritise road cuttings in Lyttelton Harbour for remediation?
  - What variables affect road cutting erosion?
  - How can sites be prioritised for remediation?

Research Rationale:

- Sediment infilling of the Lyttelton Harbour is a major issue facing the region with environmental, ecological and economic repercussions if left unchecked.
- Surface sediment runoff from roadside cuttings has been identified by Environment Canterbury in the 'Lyttelton Harbour potential contamination source study 2007' as a source of sediment for harbour infilling.

Methods Summary:

- Identified variables from the literature that affect sediment runoff.
- Field measurements and observations taken based on the key variables.
- Devised a complementary flowchart and weighting system.
- Test the validity of the flowchart and weighting system.

Key Findings:

- Location of and descriptive data about road cuttings in Lyttelton Harbour.
- Factors related to road cutting erosion: lithology, surface area, rainfall, slope angle, onslope vegetation, upslope land use, aspect and soil moisture.
- Must recognise that each factor affects the erosion of cuttings to varying degrees.
- Prioritisation/recognition of potentially bad sites needing remediation using:
  - A discontinuous hierarchy categorisation model (flowchart) used to rank sites in the field based solely on observational data using a series of closed questions.
  - A weighting system used to rank sites within each category from the flowchart based on data collected on each variable.

Limitations:

- Main limitations were:
  - Time: this research would have benefited from a more in depth study carried out over a longer period.
  - Weather: weather hindered the ability to collect data. Clear conditions were necessary for collection of observational data. Schedules therefore revolved around

the weather. Rain was needed in order to measure sediment runoff, however once the sediment traps were set up it did not rain for weeks thus limiting the time available to adjust methods and analyse data.

Future Research:

- Further testing and modification of the flowchart and weighting system.
- Sediment derived from deeper seated failures such as slips and slumps and left in gutters.
- Sediment derived from tunnel erosion in loess deposits.
- A more quantitative study into the amount of surface sediment runoff from roadside cuttings.
- Further analysis of the relationships between variables and the degrees of their effects.

2. Introduction

Lyttelton Harbour is a muddy, relatively shallow, rock walled inlet on the northern side of Banks Peninsula on the coast of Canterbury, New Zealand (Figure 2.1). An issue of concern for the Lyttelton Harbour Issues Group/Whakaraupo is the rate of infilling to Lyttelton Harbour. There are numerous embayments around the harbour, with the shipping port on the northern side, which is a major freight hub for the Canterbury region. The harbour at present can only handle ships of 12.4 metres draught as the maximum depth of the harbour at high tide varies from 6-14 metres (Lyttelton Port Company n.d.). A major issue in the area is the rate at which sediment accumulation is occurring in the inner parts of the harbour, increasing the size of the mudflats and in hand causing the depth of the harbour to become extremely shallow (Environment Canterbury 2007). The Environment Canterbury (ECan) report 'Lyttelton Harbour potential contaminant sources study 2007' indentified that anthropogenic activities are increasing sediment contribution to the harbour. One of these activities is roading, which is causing sediment runoff as a consequence of the construction, upgrading and repair of the roads along with the erosion of exposed road cuttings (Environment Canterbury 2007). The sediment runoff that has infilled the harbour, by up to 47m horizontally since settlers came into Lyttelton, impacts many ecosystems and their habitats, in addition to pollution of waterways and loss of soil fertility (Environment Canterbury 2007).

This research report will highlight key variables that have been found to affect the rate of erosion of roadside cuttings, leading to sediment runoff into Lyttelton Harbour. The research aim of this study is to determine whether it is possible to prioritise road cuttings in Lyttelton Harbour for remediation. In order to achieve this, the key variables of: onslope vegetation, upslope land-use, slope, rainfall, lithology and soil moisture content, have been identified and will be investigated. These variables have been measured and presented in a flowchart along with a supporting weighting system using 30 sites around the harbour.

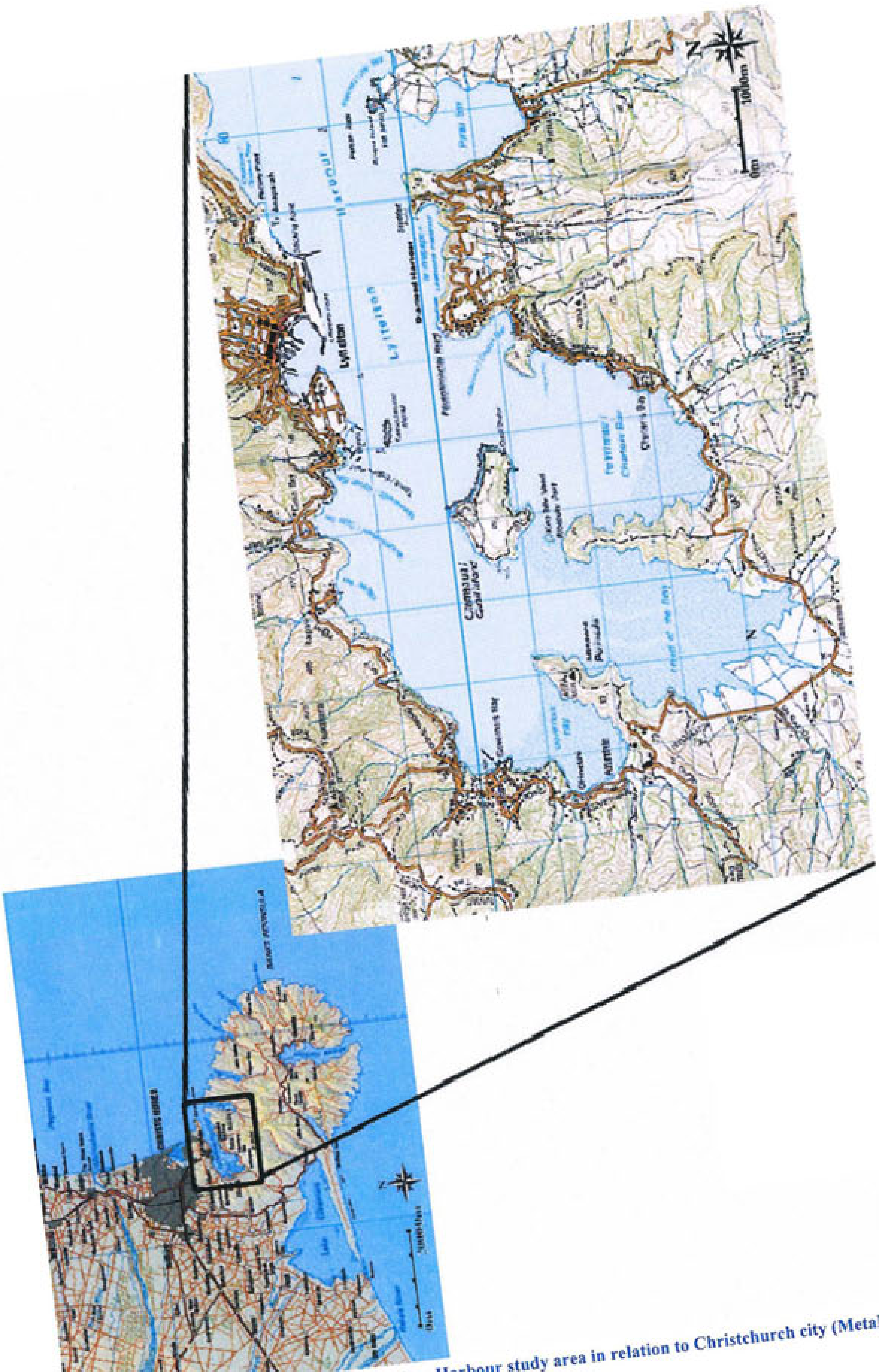

Figure 2.1: Map showing the location of the Lyttelton Harbour study area in relation to Christchurch city (MetaMedia Limited 2010).

3. Literature Review

3.1.Variables

To gain an understanding of how sediment runs off roadside cuttings it is important to address variables which impact the cuttings. Literature about erosion rates have identified a range of variables.

3.1.1. Lithology

The lithology of a road cutting greatly impacts its erodibility through differing properties of cohesion and weathering resistance. It is therefore the most important factor in surface sediment runoff. A research study done in Belgium identified that loess sediment is prone to erosional features in temperate climates (Verachtert et al. 2010). This relates to the Lyttelton Harbour because one of the major lithologies is loess derived material. Hutton (1904) found that loess in Canterbury originated from glaciers in the Southern Alps grinding and breaking down rock to fine-very fine grained (20-40gm) material. It was then deposited on Banks Peninsular by aeolian processes. Pye (1984) defined loess as a silt deposit consisting of quartz, feldspar, micas, clay minerals and carbonates. It is a yellowy-brown, non-stratified and permeable rock. The other main lithology is volcanic material ranging from basalt to trachyte. They resulted from volcanic eruptions that occurred while the region was volcanically active (Price 1980). Justin Harrison (pers comm, 2010, 22nd September) from the University of Canterbury stated *"Volcanics contribute negligible sediment to the harbour compared to loess."* With this information the research is able to be focused on determining variables that affect loess road cuttings. The two lithologies have already been identified in the ECan 2007 report, thus further investigation is not required (Figure 3.1.1).

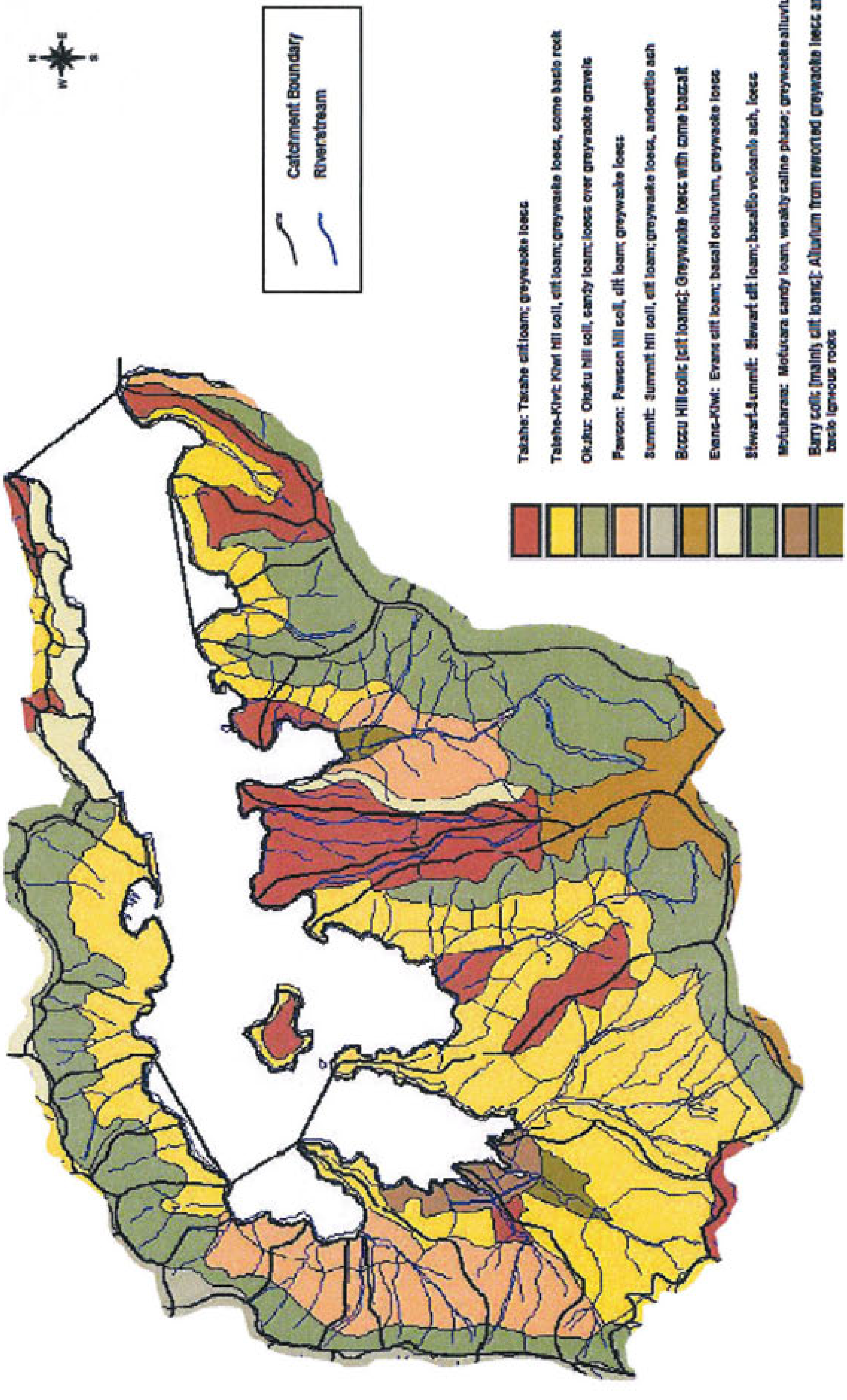

Figure 3.1.1: Lyttelton Harbour Catchment and Soil Boundaries, Rivers/Streams (Environment Canterbury 2007).

3.1.2. Slope Angle

The slope angle of a roadside cutting affects its stability because certain lithologies need a certain slope angle to remain stable. Optimum angles are chosen to match the hardness of the substrate (Bayfield, Barker and Yah 1992). Loess has the ability to stand at 90^{o} with a tendency to fracture to 90^{o} joints when dry (Pye 1984). This information gives the conclusion that the slope angle of loess must naturally erode to 90^{o} to where it is stable. Slope angles of cuttings in Lyttelton Harbour must therefore be measured.

3.1.3. Soil Moisture

Soil moisture content affects the cohesion of materials, which in turn affects stability and erodability. When saturated with water the strength of the material is reduced causing the material to erode quickly (Pye 1984). Soil moisture content is important for the understanding of erosion and runoff of loess. The ideal soil moisture for loess is 15% (Harrison 1999). In Lyttelton Harbour soil moisture percentages need to be determined.

3.1.4. Aspect

Aspect is the orientation which the roadside cutting faces, whether it is north, east, south, west or in-between. Research by Burnett et al. (2008) found that roadside cuttings facing the dominant weather direction had increased soil moisture content. They were eroded faster as a result of the increased water infiltration. The majority of precipitation in Canterbury falls during southerly weather patterns (Sturman and Tapper 2005) (Figure 3.1.4.1). Smith (1978) states that a slope facing the dominant weather direction will be 1-3^{o} lower due to rainfall impact. Aspect will need to be measured in the field.

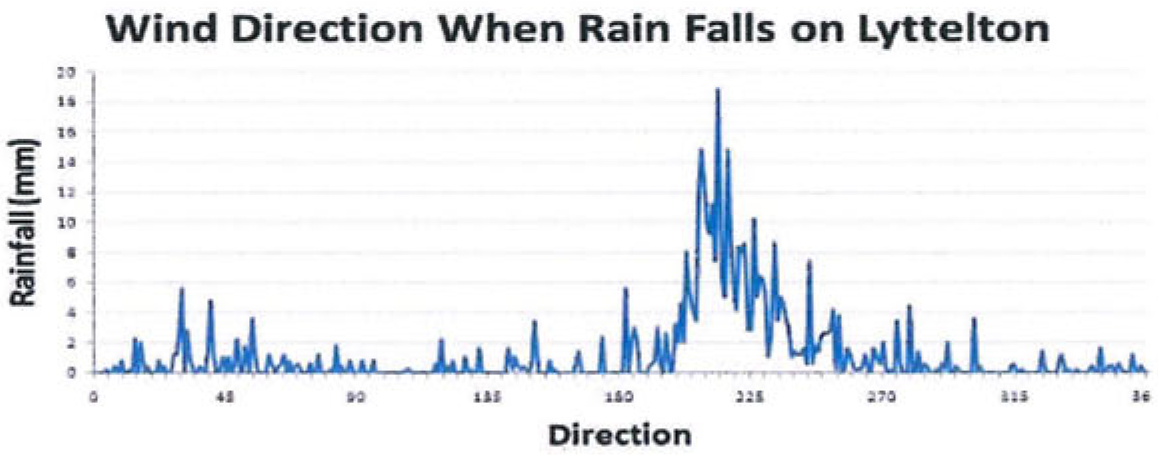

Figure 3.1.4.1: Quantity of rainfall at Lyttelton, with the direction from which it came (NIWA 2010).

3.1.5. Precipitation

Precipitation is a significant variable affecting rates of erosion in both quantity and intensity. The greater the rainfall, the greater the erosion will be on exposed slopes (Cerdá 2007). Its effects come from the direct impact of raindrops and surface runoff. Secondary data has been obtained from the National Institute of Water and Atmospheric Research (NIWA) to determine the variation of precipitation across the harbour. Lyttelton receives significantly less and smaller quantities of rainfall than Governors Bay (Figure 3.1.5.1). This implies that the precipitation at Governors Bay is more intense than at Lyttelton.

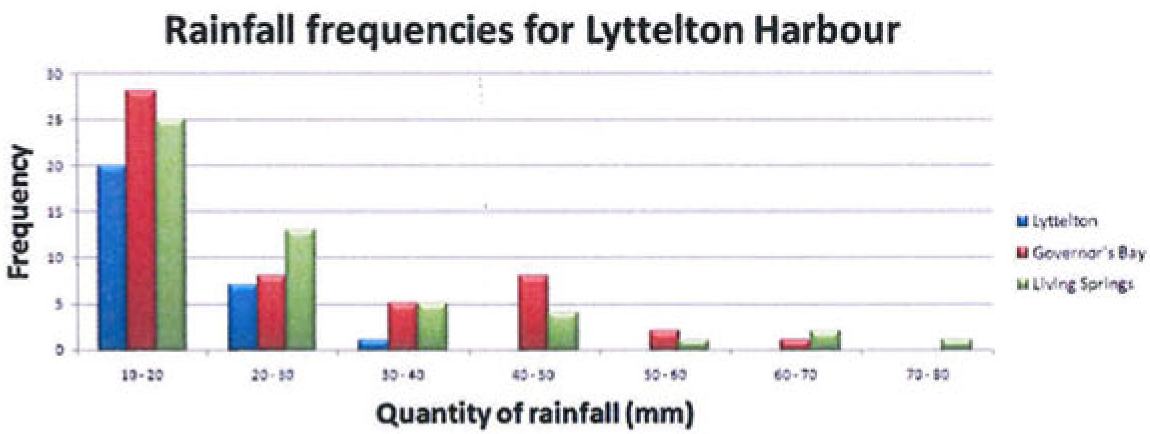

Figure 3.1.5.1: Frequency of daily precipitation quantities for Lyttelton, Governor's Bay and Living Springs, between 01/01/2009 – 01/10/2010 (NIWA 2010).

3.1.6. Onslope Vegetation

Any form of vegetation onslope is beneficial as the root systems help to bind the soil and absorb moisture (Bayfield, Barker and Yah 1992). Onslope vegetation was deemed to be the most important factor after lithology. Bayfield, Barker and Yah (1992) and Cerdá's (2007) studies found that exposed bare slopes and unengineered slopes contribute 30% more sediment to runoff. This is because water is able to drain sediment off the cutting surface. Cerdá (2007) found that slopes with natural vegetation root systems hold the slope in place reducing accidents caused by slips. The bigger the root system, the more stable the slope. Vegetation also protects from direct impact of raindrops and can trap eroded sediment. Data relating to the percentage of onslope landuse for each site is required.

3.1.7. Upslope Landuse

The influence of upslope landuse is similar to the onslope vegetation in the fact that root systems help to bind sediment and additionally absorb moisture (Nilaweera and Nutalava 1999). The only difference between the two is the presence of urban environments in upslope landuse. These environments have positive and negative impacts on sediment erosion from roadside cuttings. Adequate stormwater systems help to direct water away from cut slopes, thus reducing potential surface erosion from runoff (Field 2006). On the other hand, a lack of drainage in an urban area can concentrate higher levels of water on to road cutting slopes, which inevitably increases the rate of erosion. Qiangguo's (2002) research established that farming and building construction on loess increased erosion due to the reworking of topsoil. Data relating to the percentage of upslope landuse for each site is required.

The literature allowed research to be aimed at identifying these key variables in Lyttelton Harbour. This is significant because there is a lack of information on sediment runoff from roadside cuttings in the region.

3.2. Analytical Approaches

3.2.1. Flowchart

Flowcharts are an efficient and valuable tool when used in the context of a discontinuous hierarchy categorisation model. As Gardner (2002, p. 4F) states, "flowcharts are an improvement over written protocols that employ text alone." This statement is made in relation to the visual impact and simplicity of flowcharts which allows the user to understand how actions follow decisions. A flowchart system with simple questions would therefore be a useful way to initially investigate what roadside cuttings merit further analysis in the Lyttelton Harbour. However, due to their simplicity, they should not be used as the sole system for comparing cuttings so further enquiry into additional analytical approaches is necessary.

3.2.2. Weighting System

A dynamic weighting system is an effective way to examine issues according to Hemphill (2002). This is because the subdivision of a problem into its constituent parts allows the strength of different parameters to be evaluated. Hemphill (2002) and Field (2006) developed a hierarchy structure of their problem, which was then broken down into component parts. Scoring of impacts on a linear scale was undertaken, where a high value represented a high impact. A weighting system was developed where the weights reflected the relative importance of the impact. The combination of impacts occurred to establish an overall measure of the effect. A similar method would be functional in Lyttelton Harbour because the relative priority of key variables contributing to sediment runoff could be determined.

4. Methods

The methodology was developed in accordance with Field (2006) and Hemphill, McGreal and Berry (2002). Both studies employed techniques where issues were subdivided into constituent parts allowing the separate examination of variables. In turn, the relative priority of each factor was established leading to a hierarchical approach for weighting.

4.1. Methodological Approach

The methodology combined qualitative and comparative approaches, leaning more towards the descriptive (Ritchie, 2007). Data was obtained from both existing sources and field measurements. The descriptive approach meant data was collected from a natural state with no intervention or control, allowing natural relationships and their effects to be distinguished. Both qualitative and quantitative data was used. This allowed the accurate description of each situation, although later analysis was more challenging.

4.2. Acquired Method

The key variables to sediment runoff from roadside cuttings were identified through relevant literature. The sites needing investigation on the main road (SH 74) around Lyttelton Harbour (Figure 4.2.1) were identified and the general lithologies of these road cuttings were obtained from the 'Lyttelton Harbour potential contamination source study 2007' (Environment Canterbury 2007) (Figure 3.1.1). Secondary rainfall data was obtained from NIWA (National Institute of Water and Atmospheric Research 2010). From this, any trends across the harbour were estimated.

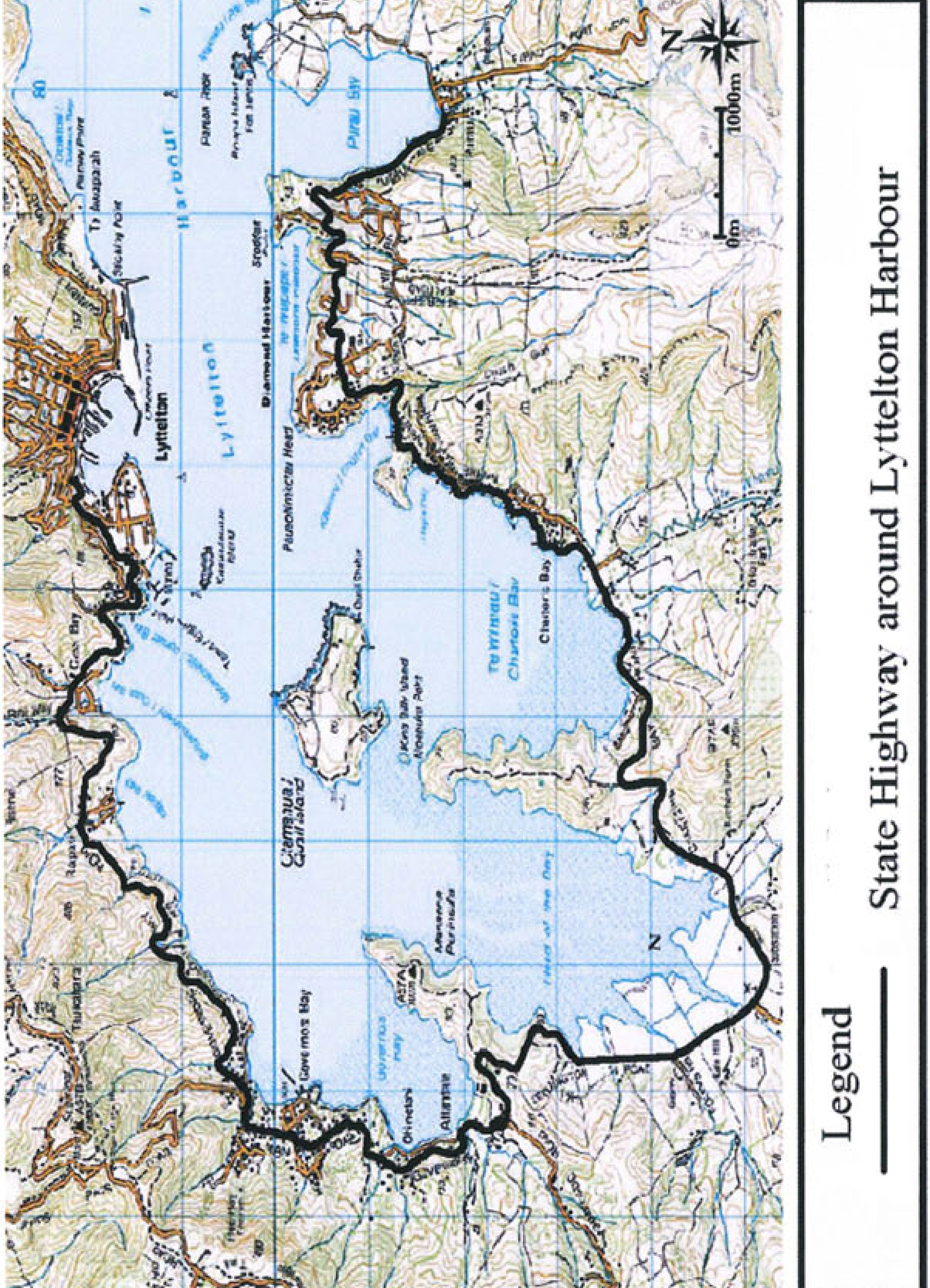

Figure 4.2.1: Map of Lyttelton Harbour showing State Highway 73 in black which is the focus area for this study (MeatMedia Limited 2010).

4.3. Field Sampling Method

Of the eight variables identified as potentially contributing sediment into Lyttelton Harbour, six required field sampling to obtain data. A raw data collection sheet was used to record this (Appendix A).

4.3.1. Slope Angle

The slope angle was measured with an inclinometer. Recordings were taken in several places on each cutting in order to provide a representative value for each slope.

4.3.2. Soil Moisture

Soil samples were taken from loess cuttings in order to analyse moisture.

i. Two samples taken from each site. One from the surface and one from 10cm depth. They were sealed in plastic bags to retain moisture.
ii. Laboratory analysis required the weighing of empty beakers and then again with the loess sample in the beaker.
iii. Samples and beakers were placed in a 30°C oven for 48 hours to remove the moisture.
iv. Dried samples were weighed again and the difference between the moist and dry weights was determined.
v. The soil moisture content was calculated into a percentage using:

$$\frac{M_w - M_d}{M_d - M_b} \times 100 \qquad (1)$$

Where, M_w = Wet weight, M_d = Dry weight, M_b = Beaker weight (New Zealand Soil Bureau 1972) (Appendix B).

4.3.3. Aspect

The direction the road cutting faced was recorded with a compass. Numerous bearings were taken at each site in order to get a representative orientation.

4.3.4. Onslope Vegetation

Onslope vegetation types were divided into four categories (trees, shrub, pasture and exposed). The approximate percentage of each category that was represented on the slope was recorded.

4.3.5. Upslope Landuse

Similarly, upslope landuse was divided into four categories (trees, bush, pasture and urban). The landuses up to 50 metres behind the road cuttings were examined. Approximate percentages were recorded.

4.3.6. Surface Area

Potential sediment runoff is proportional to the surface area of the road cutting. For simplicity each cutting was approximated to be a rectangle. This allowed measurement of the surface area, which was calculated using:

$$A = L \times H \tag{2}$$

Where, A is the area, L is the base length and H is the height.

i. Height was estimated. This value was adjusted to incorporate the sloping nature of road cuttings, using:

$$\sin(\emptyset) = \frac{h}{x} \tag{3}$$

Where, h = estimated height, x = adjusted height due to differences in slope angles and $\emptyset$ = angle in degrees.

ii. The length was determined using three methods:
    1. Smaller cuttings were measured with a tape measure.
    2. At moderately sized cuttings the same group member paced the length.
    3. Very large road cuttings were measured with the odometer on the car.

4.3.7. Site Comments

Any additional site comments, such as natural or engineered guttering, the amount of sediment in gutters and any recent slips were recorded.

4.4 Data Analysis

Raw data was entered into a spreadsheet (Appendix C). Tables were created which outline the variation of the factors across the 30 road cuttings.

4.4.1 Flowchart Analysis

A flowchart was created that assigns road cuttings to a category based on their need for remediation (Figure 4.4.1.1). It provides a simple way to evaluate road cuttings in the field. A series of questions regarding the presence of key contributors are asked.

Questions are placed in order of variable importance. Possible answers lead on to a further question or terminate in a coloured category. Categories are intended to provide a simple breakup of the cuttings into groups, ranking them on priority for further study. The flowchart method is intended to be simple enough that precise measuring instruments are unnecessary.

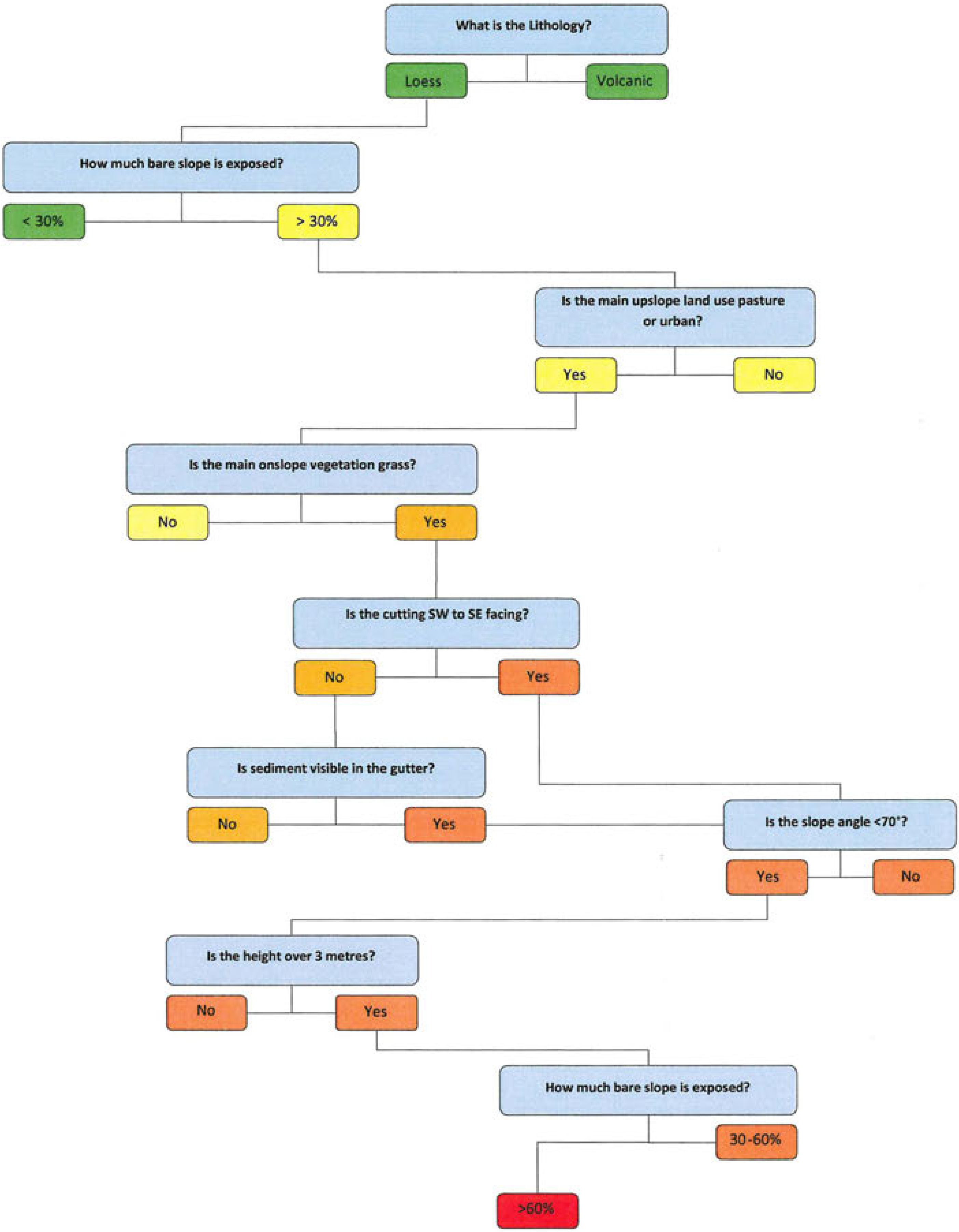

Figure 4.4.1.1: The flowchart that was developed for assigning road cuttings to a category based on their need for remediation. A series of closed ended questions regarding the presence of key contributors at the site are asked. The questions are placed in order of variable importance with respect to surface runoff from slopes. For this reason lithology is the first question, followed by onslope vegetation. Possible answers either lead on to a further question or terminate in a coloured category. The categories are high priority (red), moderate priority (orange – yellow) and low priority (green). They are intended to provide a simple breakup of the cuttings into groups, ranking them on priority for further study. The moderate category it is divided into three further groups in order to show a gradational change of priority.

4.4.2 Weighting System

A weighting system was developed in order to rank loess sites within the three categories from the flowchart (Figure 4.4.1.1).

Table 4.4.2: Table summarizing the values assigned to the weighting system variables.

Variable	Onslope Vegetation				Upslope Land-use				Aspect							
Category	Trees	Bush	Grass	Bare	Trees	Bush	Pasture	Urban	N	NE	E	SE	S	SW	W	NW
Weighting	1	1.2	2	4	1	1.2	2	2	1	1	1.5	1.5	2	2	1.5	1.5

Variable	Soil Moisture			Slope Angle				Rainfall		
Category	<13%	13-17%	>17%	80°+	79° - 70°	69° - 60°	<60°	Lyttelton to Rapaki	Rapaki to Charteris Bay	Charteris Bay - Purau
Weighting	2	1	2	1	1.3	1.6	1.9	1.3	1.5	1.3

The weighting system works by measuring a cutting in terms of each variable, then categorising each measurement to give it a weighting. The weighting reflects the importance of the variable in causing sediment runoff against the other categories in the group. Each category is then multiplied together using the weighting to get an answer. Multiple cuttings need to be evaluated because the weighting system output is only a relative value to be compared. A higher number represents a higher need for prioritisation. Two equations were used to determine the weighting:

$$= Onslope\ Vegatation \times Upslope\ landuse \times Aspect \times Soil\ moisture \times Slope \times Rainfall \tag{4}$$

$$= Onslope\ Vegatation \times Upslope\ landuse \times Aspect \times Soil\ moisture \times Slope \times Rainfall \times \frac{Surface\ Area}{1000} \tag{5}$$

4.5 Testing

Testing of the weighting system is necessary in order to determine its validity for ranking road cuttings based on their need for prioritisation.

i. Three sediment traps, consisting of a PVC half-pipe and a sediment bag were built and placed in the field (Appendix D). These would measure the sediment runoff from the three sites in comparison to each other. Sediment traps were placed at: a high priority site, a moderate priority site and a low priority site.

ii. The amount of sediment deposited into each trap is observed.

5 Results

The research undertaken has covered approximately 90% of the roadside cuttings in Lyttelton Harbour around the main highway. All variables identified in the literature review were found to be important in Lyttelton Harbour, but to varying degrees.

5.1 Variables

The lithology of the area can be split into loess and volcanics. Table 5.1.1 shows the percent of each lithology found at the 30 sites. It shows that loess is the main lithology.

Table 5.1.1: The two major lithologies and their corresponding percentages out of the 30 sampled sites. This shows that loess is the main slope material of the road cuttings observed with a 67% majority.

Lithology	
Loess	**Volcanics**
67%	33%

The slope angle varies considerably both on slope and between sites. Table 5.1.2 shows a relatively even spread of slope angles across the top three measured ranges. Slopes of 60° or less were found to be relatively rare with only 7% of the 30 sites in this range.

Table 5.1.2: The variety of slope angles and the frequency with which they are found. The percentage values are the number of average slope angles out of the 30 sampled that fall into each category.

Slope Angle			
<60°	**60°-69°**	**70°-79°**	**>80°**
7%	27%	33%	33%

The soil moisture content results show that 50% of the road cuttings sampled have a moisture content of 17% or more which is above the ideal range of 13-17% (Table 5.1.3). Only 17% of the sampled cuttings were found to be below the ideal range. Approximately one third of the cuttings are within the desired range.

Table 5.1.3: The percentage soil moisture content in the 19 loess sites and how often they occur. The desired range is between 13% and 17% soil moisture content for loess. Below this the loess can absorb moisture while above this it will start to lose strength.

Soil Moisture		
<13	**13-17**	**>17**
17%	33%	50%

Table 5.1.4 illustrates that NE-E aspects and SW-W aspects make up one third of the slope directions respectively. This shows a relatively even split between northerly aspects and the southerly aspects.

Table 5.1.4: Summarises the aspect of road cuttings around Lyttelton Harbour. Percentages are based out of the 30 sampled sites.

Aspect							
N	NE	E	SE	S	SW	W	NW
17%	13%	20%	3%	7%	23%	10%	7%

Table 5.1.5 illustrates that, in general, the cuttings had less than 33% coverage of vegetation. This shows that the slopes often had more exposed slope than vegetated slope. This is further supported by the fact that 80% of the slopes had greater than 33% bareslope.

Table 5.1.5: Cuttings were given a percentage of each vegetation type present on the slope. This table summarises the percent coverage range for all slopes.

Onslope Vegetation			
Bareslope	<33%	33%-66%	>66%
	20%	40%	40%
Pasture	<33%	33%-66%	>66%
	60%	30%	10%
Bush	<33%	33%-66%	>66%
	93%	3%	3%
Trees	<33%	33%-66%	>66%
	97%	0%	3%

Table 5.1.6 demonstrates that the main upslope vegetation type is pasture. This is shown by the fact that 70% of the cuttings had greater than 33% pasture coverage up slope while the other vegetation types have the majority less than 33% coverage.

Table 5.1.6: Cuttings were given a percentage of each vegetation type present upslope from the site. This table summarises the percent coverage range for all upslope land coverage.

Upslope Vegetation			
Urban	<33%	33%-66%	>66%
	87%	7%	7%
Pasture	<33%	33%-66%	>66%
	30%	27%	43%
Bush	<33%	33%-66%	>66%
	77%	13%	10%
Trees	<33%	33%-66%	>66%
	80%	13%	7%

Table 5.1.7 shows that half the sites are smaller than 500 m^2. The remaining 50% of the sites are spread between 500-1000m^2 and greater than 1000m^2. One third of the sites are between 500-1000m^2 and only 17% are greater than 1000 m^2. It was observed that the largest cuttings were generally a volcanic lithology and loess was generally less than 500 m^2.

Table 5.1.7: shows the ranges of surface areas for road cuttings around Lyttelton Harbour.

Surface Area (m^2)		
<500 m^2	500-1000 m^2	>1000 m^2
50%	33%	17%

5.2 Flowchart

The flowchart analysis ranked 13% of the roadside cuttings as a high priority for remediation (Table 5.2.1). The sites were 7, 8, 11 and 24A. 11 out of 30 of the sites resulted in a moderate prioritisation, varying from a low moderate to high moderate need for remediation. 50% of the roadside cuttings have a low priority for remediation. This figure is relatively high due to 11 of the sites being volcanic.

Table 5.2.1: The percentage of road cuttings in Lyttelton Harbour established as high, moderate or low priority for remediation. These are based on data from all 30 sites.

Flowchart			
Priority	High	Moderate	Low
	13%	37%	50%

5.3 Weighting System

The ranking of sites for prioritisation using the flowchart approach has been critiqued with the weighting system method. The results are displayed in Table 5.3.1. Site 11, positioned at the entrance to Governors Bay is the road cutting most in need of remediation, as determined by the flowchart and supported by the weighting system.

Table 5.3.1: Comparison of the three different outcomes of ranking road cuttings. The colourings applied to the cutting numbers indicate how they were ranked by the flowchart. The weighting system output is shown alongside using equations four and five. The rankings are sorted in terms of equation four because the flowchart does not take surface area as an input. The top cuttings as ranked by the flowchart are comparatively grouped with the top cuttings as ranked by the weighting system.

Road Cutting Number	Equation 4 Results	Equation 5 Results
11	78.84	77.2
6	40.56	28.48
7	39.94	29.75
12	39.17	31.1
19	31.59	53.12
24A	30.04	58.33
24B	29.64	12.6
13A	28.21	40.89
8	22.75	27.72
14	22.18	27.62
3	20.57	25.65
1	16.97	10.68
4	16.3	8.97
26	15.57	31.08
10	14.86	30.55
29	14.64	25.32
5	14.04	6.54
13B	13.27	7.24
23	5.09	12.92

5.4 Testing of Flowchart and Weighting System

During collection of the sediment trap observations were made.

- The low priority site had collected no sediment.
- The sediment bag at the moderate site was a quarter full.
- The sediment trap at the high priority site had become detached from the cutting due to heavy erosion behind the trap. Therefore no sediment was collected in the bag.

5.5 Map

The map in Figure 5.5.1 was constructed using the priorities determined from the flowchart method.

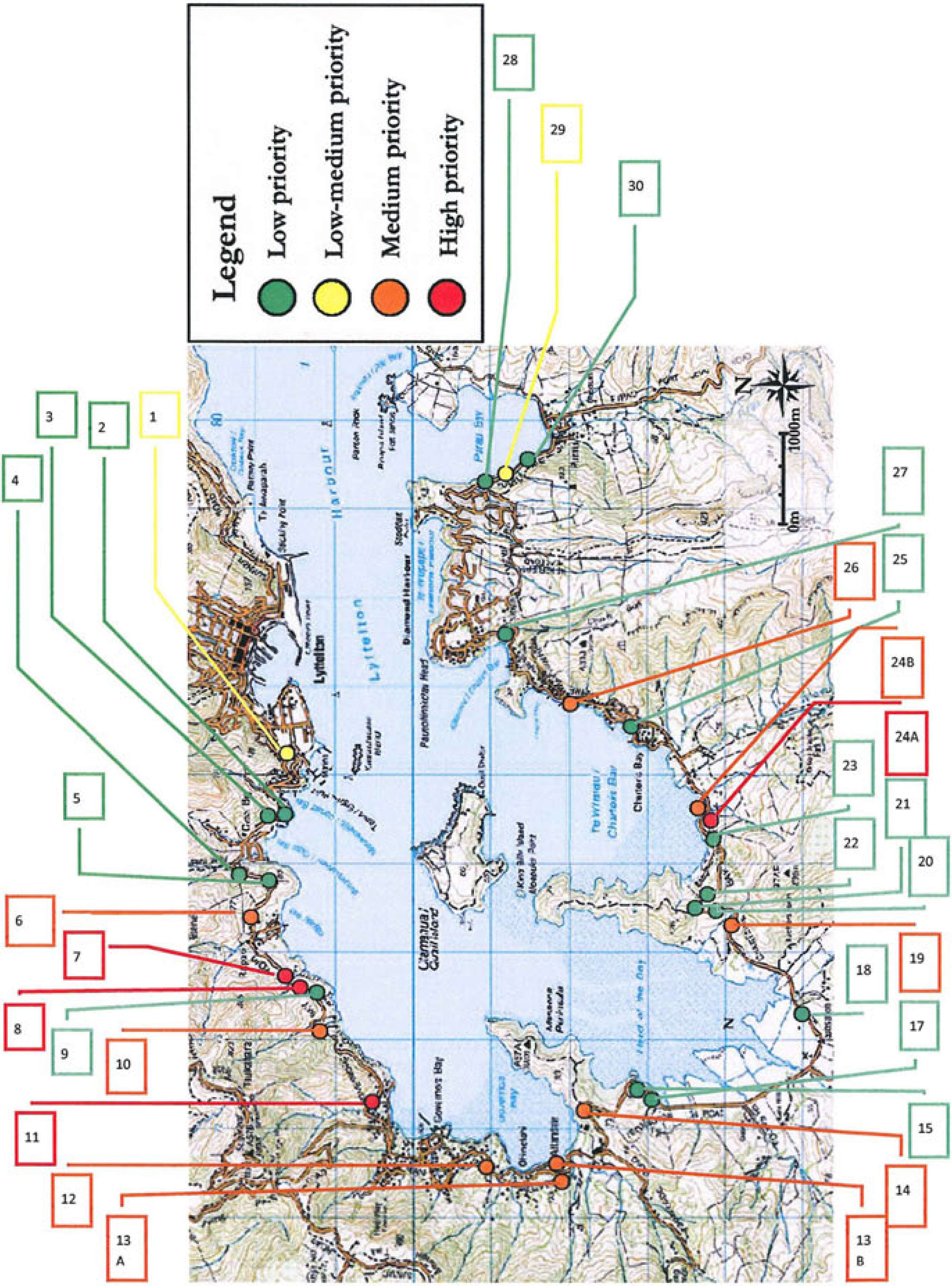

Figure 5.5.1: Prioritisation of road cuttings for remediation in Lyttelton Harbour. Site numbers are displayed in the relevant boxes and th box colour reflects the prioritisation level. The ranking is based on the flowchart method. Each site number refers to a site image i Appendix E (MetaMedia Limited 2010).

6 Discussion

Remediation of roadside cuttings in Lyttelton Harbour is a priority to the community. The sediment accretion into the harbour needs reducing in order to control the impacts to the waterways, ecosystem and economics (Environment Canterbury 2007). The research undertaken has established that it is possible to prioritise roadside cuttings for remediation (Figure 5.5.1).

The spatial distribution of roadside cuttings in Lyttelton Harbour can be seen in figure 5.5.1. It is evident that the highest priority sites are located between Rapaki and Allandale. There are several reasons for this. There is a concentration of south - south-west facing cuttings in this area causing them to bear the direct impact of southerly precipitation. In turn, they become saturated and unable to dry out as they are on the shady side of the harbour. This is apparent in the soil moisture contents for these sites because they are greater than 18% (Appendix B). Due to the high saturation, these sites have the potential for greater levels of sediment to be removed because there is less cohesion and no ability to absorb excess water. There is a clear grouping of low priority sites from Teddington to Charteris Bay. This is due to the presence of six volcanic cuttings which have negligible sediment runoff due to their chemical composition and induration. In turn, the growth of the mudflats at the head of the harbour is not entirely attributed to road cuttings because there is a lack of loess in this area. Another low priority trend is visible in the Cass Bay area. Low surface exposures of less than 20% are the reason for this, as well as the protection offered to these sites through easterly and westerly aspects.

Results obtained from the testing of the flowchart and weighting system proved that the variables identified in Lyttelton Harbour are significant contributors to sediment runoff. The most important variables are exposure and lithology. Onslope vegetation is directly tied to exposure as a lack of vegetation leaves the surface immediately exposed to the elements. Many of the remaining variables can be related to exposure to varying degrees. Aspect affects the exposure to sunlight and southerly storms. Slope angle affects the area exposed to weather with a 60^0 slope having three times as much area exposed to direct impact of rain as an 80^0 slope. Surface area is directly related to the area exposed. Soil moisture content, which affects cohesion and erodability of the surface material, is controlled by slope exposure. The more shaded or exposed to rain a slope is, the wetter it will be while the more sun it receives, the drier it will be. Upslope vegetation is independent of exposure but is still an important variable as it can remove or reduce surface flows reaching the cutting. Lithology is also important as the area is composed of one of the most erodible materials (loess) and one of the most resistant materials (volcanics). Due to loess being a relatively uncompacted sediment it is easily eroded by rainfall and surface flows.

From this research, it has been observed that a great contributor to sediment infilling of the harbour is from roadside slips which are not cleared from the gutters. This sediment is broken down by the flow of stormwater discharge and is then able to be transported into the harbour. Further research into this issue is recommended.

The depth to which this study could investigate was hindered by limitations and bias, both of which related to time and weather. The research was carried out over 12 weeks. This predisposed the study to be biased in the selection of roadside cuttings to study as there was a lack of time to investigate all cuttings present. The erosion map in the 'Lyttelton Harbour potential contamination source study 2007' helped choose the sites for further study in addition to observations made in relation to cutting size. The size of the cuttings limited the type of equipment that could be used. The use of a total station was a method investigated, however the time required to collect data using this method was unrealistic due to the time assigned. Obtaining a representative slope angle proved to be a limitation as formation of a talus slope caused the angles to differ across the cutting. The use of a total station would have removed this limitation. Climatic bias was attempted to be removed by related data being gathered on the same day to ensure consistency in weather conditions. However, during the day of soil sample gathering light drizzle occurred half way through collection. This would not have affected soil moisture at depth, although surface samples could have been influenced. Removal of data collection bias was done through the allocation of variable measurements. The same individual was assigned pacing of road cutting length, measurement of slope angle and determination of landuse and vegetation type percentages. This ensured consistency between data from all road cuttings. Use of a total station to measure onslope vegetation percentages would have improved accuracy compared to the estimated values used. When setting up sediment traps for testing of the flowchart and weighting system, it was difficult to establish a site that was representative of the total road cutting. The results are therefore only applicable to the area immediately above the sediment traps. Time and weather were additional limitations present during the testing of the flowchart and weighting system. Lack of time to test more than three sites was unavailable due to the high pressure weather systems that dominated after the initial testing.

7 Further Studies

Quantitative analysis of actual sediment runoff by the use of surveying equipment and more in depth data collection methods is recommended to improve the weighting system. Further studies should be done to research the amount of sediment contributed to the harbour from slumps in the gutter, as they lay on the drain being eroded and transported by stormwater systems. In depth collection of precipitation data at the face of road cuttings would be valuable in order to quantify the amount of rainfall available to erode the site. Additional modification and more in depth testing of the weighting system would assist in improving the accuracy and transferrable nature of the technique.

8 Conclusion

The rationale behind this study was able to inform the Lyttelton Harbour Issues group/Whakaraupo on the sediment contribution from roadside cuttings to the infilling of Lyttelton Harbour. The research undertaken has established that it is possible to prioritise road cuttings in Lyttelton Harbour for remediation. This was done by the identification of factors that affect road cutting erosion, the two most important in Lyttelton Harbour being lithology and exposure. All the other variables recognised such as: rainfall, slope, aspect, upslope landuse and soil moisture content are less significant contributors to the sediment runoff in Lyttelton Harbour. In order to prioritise the 30 sites that were identified for remediation, a flowchart and weighting system was developed. The differing strengths of the contributing variables were reflected in these. Field testing and observations of the methods used support the flowchart and weighting system. This indicates they are viable ways to distinguish the sites and rank them for remediation so could be applied to alternate roadside cuttings in Lyttelton Harbour. Limitations and bias have been a source of error throughout this study. Further investigation of sediment runoff from roadside cuttings is needed in order to modify and improve the flowchart and weighting system.

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Appendices

Appendix A

Raw Data Collection Sheet

Site Number	

GPS Number	

Bay Name	

Photo Numbers	

Date	

Time	

Weather	

Upslope Landuse (%)	Pasture	Bush	Trees	Urban

Onslope Landuse (%)	Grass	Bush	Trees	Bareslope

Lithology (circle)	Loess	Volcanic

Bearing (°)	

Aspect (circle)	N	NE	E	SE	S	SW	W	NW

Surface Area	Height (m)	Length (m)	Slope Angle (°)	

Site Comments:

Site Sketch:

Appendix B

Samples 1	In oven @ 12.30pm 16/8/10		Out of oven @ 11.30pm 18/8/10	
Site Number	First weight (g)	Second weight (g)	Beaker weight (g)	Soil Moisture Content (%)
1	91.568	87.265	44.048	9.957
3	105.173	95.444	47.651	20.357
4	97.328	89.73	41.235	15.668
5	79.505	77.823	39.53	4.392
6	77.466	71.445	41.993	20.443
7	97.081	86.235	32.788	20.293
8	80.542	74.413	38.535	17.083
10	110.369	101.026	44.721	16.594
11	153.34	133.717	39.602	20.850
12	142.081	124.788	43.007	21.145
13	106.814	96.279	41.707	19.305
14	132.508	117.073	42.817	20.786
15	83.057	78.014	44.881	15.220
19	84.404	80.495	40.332	9.733
23	66.505	61.925	29.384	14.075
24	84.437	73.971	24.543	21.174
26	80.634	75.342	37.555	14.005
29	82.592	76.274	41.106	17.965
Samples 2				
Site Number	First weight (g)	Second weight (g)	Beaker weight (g)	Soil Moisture Content (%)
1	79.512	75.535	38.004	10.597
3	79.066	72.458	38.873	19.675
4	93.274	85.445	42.264	18.131
5	93.156	90.227	38.381	5.649
6	62.064	56.833	31.52	20.665
7	89.281	81.363	39.83	19.064
8	84.426	78.197	39.58	16.130
10	92.134	84.739	39.499	16.346
11	93.499	82.926	33.78	21.513
12	92.465	69.94	31.852	59.139
13	76.73	69.94	34.379	19.094
14	90.174	82.567	40.106	17.915
15	81.348	75.344	32.029	13.861
19	69.884	65.47	30.7	12.695
23	65.468	60.991	30.033	14.462
24	96.143	87.928	42.143	17.943
26	82.432	75.94	35.591	16.090
29	65.611	60.234	31.056	18.428

Appendix C

Site Number	Bay Name	Aspect	Height (m)	surface area (m2)	Length (m)	Soil/Rock Type	Upslope Landuse (%)				Onslope Vegetation (%)			Exposed Cutting (%)
							Bush	Pasture	Trees	Urban	Bush	Pasture	Trees	
1	Britain Tce/Park Tce Intersection	E	9	252	28.5	Loess	25	0	25	50	30	20	20	30
2	Corsair Bay	S	11	706	64	Basalt	50	0	0	50	5	0	0	95
3	Cass Bay	W	7	499	72	Loess	50	50	0	0	5	90	0	5
4	Cass Bay	E	4	220	55	Loess	0	100	0	0	0	90	0	10
5	Cass Bay	E	3	186	60	Loess	0	50	50	0	0	80	0	20
6	Rapaki Bay	SW	2	281	115	Loess	0	100	0	0	0	50	0	50
7	Rapaki Bay	E	7	298	43	Loess	0	100	0	0	0	40	0	60
8	Btwn Rapaki and Governors	E	4	487	120	Loess	0	100	0	0	5	35	0	60
9	Btwn Rapaki and Governors	SE	13	805	63	Basalt	0	100	0	0	15	15	0	70
10	Btwn Rapaki and Governors	E	7	822	117	Loess	20	70	10	0	10	40	0	50
11	Governors Bay	SW	4	392	92	Loess	10	80	10	0	0	10	0	90
12	End of Governors Bay	S	6	318	55	Loess	0	100	0	0	10	50	0	40
13A	By Jack's Cottage	NE	2	580	280	Loess	40	50	10	0	0	10	0	90
13B	By Jack's Cottage	SW	2	218	108	Loess	40	50	10	0	0	60	0	40
14	Allansdale	NW	7	498	68	Loess	20	50	30	0	0	50	0	50
15	Btwn Allansdale and Teddington	NE	5	3046	600	Loess	0	50	50	0	0	20	0	80
18	After Teddington	NW	5	372	70	Rhyolite	0	60	40	0	0	40	0	60
19	After Teddington	N	4	673	158	Loess	0	80	20	0	0	50	0	50
20	Before Charteris Bay	SW	5	647	140	Rhyolite	10	90	0	0	10	20	0	70
21	Before Charteris Bay	N	4	289	68	Rhyolite	10	90	0	0	15	30	0	55
22	Before Charteris Bay	N	7	530	80	Rhyolite	10	90	0	0	0	20	0	80
23		W	4	1015	250	Loess	80	0	20	0	0	20	70	10
24A	Charteris Bay	N	5	777	153	Loess	0	90	10	0	0	10	0	90
24B	Charteris Bay	SW	4	168	41	Loess	0	50	50	0	0	10	0	90
25	Charteris Bay	W	6	4216	700	Rhyolite	90	0	10	0	70	0	0	30
26	Charteris Bay	SW	5	798	150	Loess	10	0	0	90	10	30	0	60
27	Church Bay	SW	14	3554	250	Rhyolite	90	0	10	0	40	0	10	50
28	Diamond Harbour	NE	12	843	70	Rhyolite	10	0	0	90	10	20	0	70
29	Purau	NE	5	692	130	Loess	0	0	100	0	10	10	0	80
30	Purau	N	8		220	Rhyolite	0	0	100	0	10	10	0	80

Appendix D

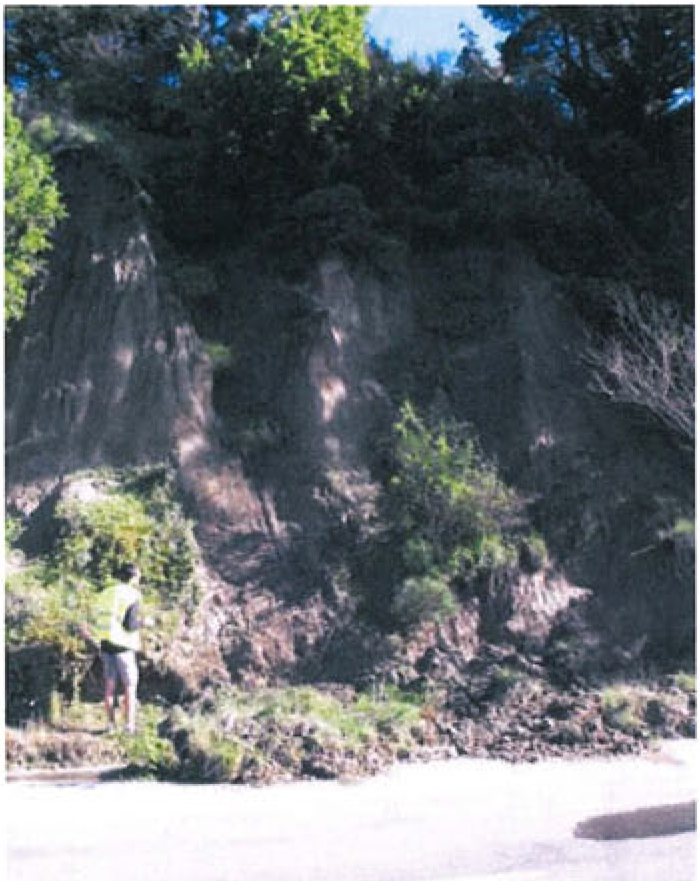
Low Priority Site – 13B

Moderate Priority Site - 14

High Priority Site - 12

Appendix E

Site One

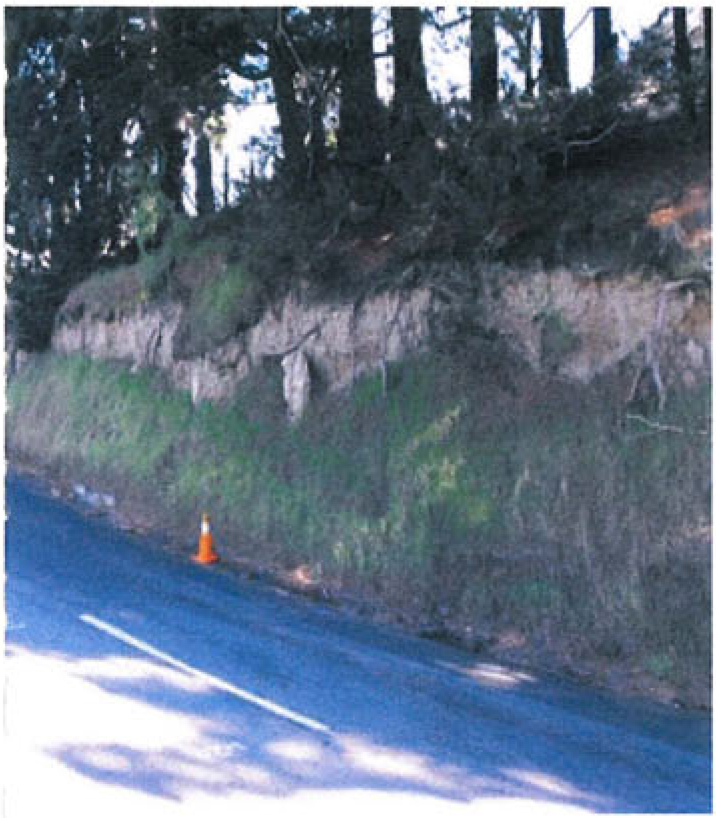


Site Three

Site Two

Site Four

Site Five



Site Seven

Site Six

Site Eight

Site Nine

Site Eleven

Site Ten

Site Twelve

Site Thirteen A

Site Fourteen

Site Thirteen B

Site Fifteen

Site Seventeen

Site Eighteen

Site Nineteen

Site Twenty

Site Twenty-One

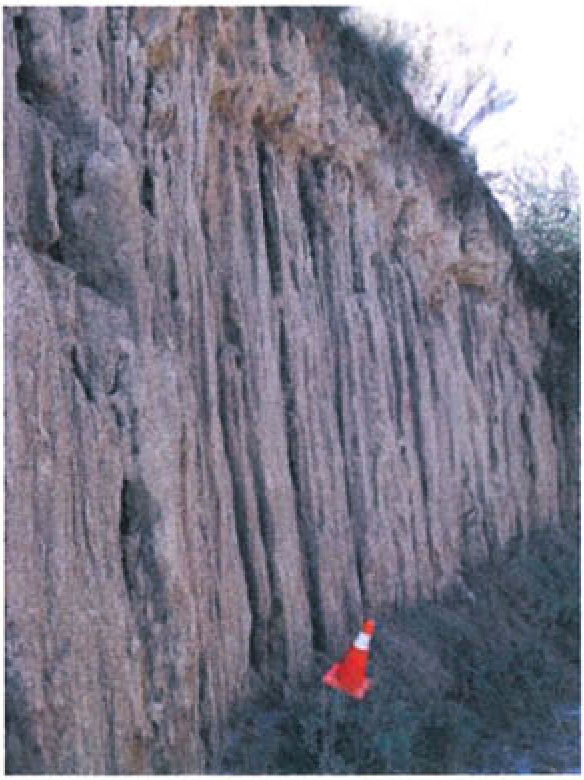
Site Twenty-Four A

Site Twenty-Two

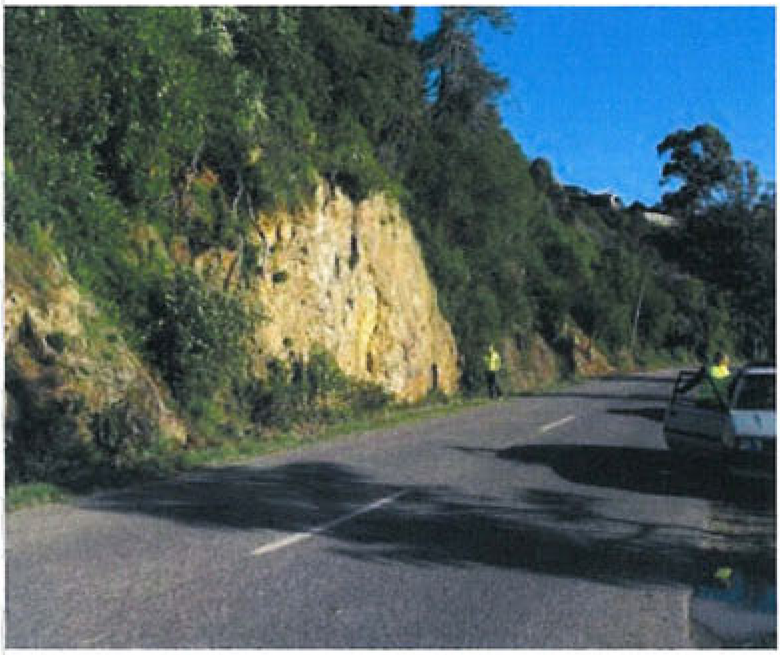
No Picture

Site Twenty-Three

Site Twenty-Four B



Site Twenty-Five



Site Twenty-Seven

Site Twenty-Six

Site Twenty-Eight

Site Twenty-Nine

Site Thirty

No Picture