Report

Waikato River Bank Erosion Survey (Taupo Gates to Ngaruawahia) - Assessment Report
Project G2011/128

Prepared for Mighty River Power (Client)

By Beca Carter Hollings & Ferner Ltd (Beca)

22 March 2013

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Framework and background of the erosion survey

Mighty River Power Ltd owns and operates eight dams and nine hydro-electric power stations along the Waikato River between Lake Taupo and Karapiro, collectively known as the Waikato Hydro System. As part of the 2006 Resource Consents issued for the Waikato Hydro System, Mighty River Power is required to undertake geomorphic surveys to measure the changes in, and causative effects of active erosion of the banks of the Waikato River and associated reservoirs, from the Taupo Gates to Ngaruawahia (Figure E-1). These surveys are repeated on a 5 yearly basis, with this being the second survey undertaken by Beca Carter Hollings and Ferner Ltd (Beca).

The initial erosion assessment was split into two segments, these being: Ngaruawahia to Lake Karapiro, and Lake Karapiro to Taupo Gates, undertaken in 2006 and 2007 respectively. The 2012 survey covers the entire Waikato Hydro System using a standardised methodology which provides greater consistency, efficiency, and enables easier comparison with future assessments.

The first surveys in 2006/2007 demonstrated that the Waikato River banks are naturally susceptible to erosion. Significant stretches of bank are comprised of unconsolidated granular materials (pumiceous sands) that have high erosion potential.

These baseline surveys identified that the most common cause of the erosion is natural bank erosion and/or natural river processes. These were primarily contributed to by the bank materials and bank morphology, with other factors including vegetation/ land use, ground/ surface water, and wind/ boat generated waves contributing a lesser amount to cause erosion. In operating the Waikato Hydro System, Mighty River Power varies the water levels in the reservoirs and rivers on a daily basis. Water levels also vary as a result of natural inflows. Water level variation from Mighty River Power operations was found to cause less than 4 % of the total erosion in the 2007 section of the survey. This factor was not addressed directly in the 2006 section of the survey.

Figure E-1: The survey length (blue line)

Findings of the 2012 erosion survey

The 2012 survey identified a total of 878 active or recently active (within the last five years) erosion sites. A further 740 sites that were identified during the 2006/2007 surveys were found to have stabilised over the last five years and are not actively eroding. These sites were classified as 'older' or 'previously recognised'.

The amount of erosion can be measured in terms of the number of individual erosion sites, or the total area of erosion. For example, there are some sections that are recorded as one large area of erosion, and other areas with small individual erosion features. The amount of erosion can also be delineated spatially by looking at the area/ number of sites per kilometre of bank. For analysis purposes, the survey area was split into 17 river or lake sections (Figure E-2).

The erosion site frequency (the number of sites per kilometre length of bank) varies between 0.1 and 3.4 sites per kilometre along each river or lake section of the survey. When the number of sites is normalised by kilometre length, there is approximately 25 % more erosion sites per kilometre length of river banks than lake banks. The greatest frequency of erosion was in sections 3 (between Karapiro and 11.8 km downstream) and 15 (between Aratiatia Dam and Lake Ohakuri). Section 8 (Waipapa River) also had a high frequency of erosion sites per kilometre; however this is partly biased because it is a short section.

The distribution of the measured area of erosion sites is highly skewed, with a few very large sites, and many small sites (see Figure E-3). Only 61 sites have an area greater than 500 m^2, and these comprise more than 50 % of the total erosion recorded. There are 19 sites (2 % of the total number of sites) which are 2,000 m^2 or more in area, comprising some 30 % of the total measured area of erosion.

Susceptibility and contributory factors

The study confirms the conclusions of the baseline surveys that there is a strong relationship between the amount of erosion, bank material type, and geological conditions. The majority (over 60 %) of the active and recent erosion sites are within the reworked loose alluvial deposits from the Taupo and Oruanui and older eruptions, whilst a quarter (27 %) have occurred within the non-welded ignimbrites (volcanic flow deposits) derived from these eruptions, see Figure E-4. The remaining sites (some 10 %) have developed in soils weathered from ignimbrites (7 %) and rock (3 %).

The slope height, slope angle, and bank material were divided into five classes (Class A to E) to assess the combined effect of bank geometry and material type, which are often inter-related. The vast majority (about 90 %) of the recent and active sites occur in either Class A or B, both of which are comprised of unconsolidated weak soils, differentiated by variable bank morphology. This indicates that there is a strong relationship with bank material as opposed to bank morphology.

In additon, there was no significant statistical correlation between the number or area of erosion sites and the morphology of the bank (i.e. height, slope, and aspect). However, it does appear that the sections that have a combination of high banks, and/or steep slopes and very weak erodible soils have proportionally more erosion than other sections (Sections 15 (river between Aratiatia Dam and Lake Ohakuri) 3 and 4 (Lake Karapiro to 11.8 km downstream)).

At each site, a primary causative factor was identified, as well as other causative factors, and a number of contributory factors. Causative factors that could be attributed to each erosion site were: river processes, wave erosion, vegetation removal or loading, boat wakes, water level variations, stock access, and land use. Contributory factors, of which more than one could be selected, were bank materials, bank slope and/or height, groundwater seepage, piping, and vegetation. This method of categorising causative and contributory factors was based on the method established in the 2007 survey.

The primary **causative** factors identified by the 2012 survey for active and recent erosion sites (see Figure E-5) are as follows:

- River processes and other natural bank erosion processes were the primary causative factor at 55 % of the erosion sites observed, and were the most common causative factor in all sections, except Section 10 (Maraetai River);
- Waves generated by natural processes (such as wind) were the primary causative factor at 23 % of erosion sites, and were a more common causative factor in the central lake sections;
- Vegetation removal or loading of vegetation (such as toppled trees) on the banks were the primary causative factors at 13 % of erosion sites observed. A greater proportion of erosion sites were attributed to vegetation load on the river banks between Aratiatia Dam and Lake Ohakuri than in other sections. Vegetation removal was a common primary causative factor for erosion on the banks of Lake Karapiro;
- Waves generated by boat wakes were the primary causative factor at 5 % of the erosion sites;
- Water level variation on the rivers and reservoirs, which could be attributed to operations by Mighty River Power, was the primary causative factor at 4 % of the erosion sites;
- Land use, including allowing stock access to the banks, was the primary causative factor at less than 2 % of the erosion sties; and
- A comparison of land-uses in 2007 and 2012 was completed using aerial photographs of the study area. It showed that there had been a land-use change at only 2 % of the bank areas over this period. There is no evidence that land-use change correlates to a change in erosion activity.

The most common **contributing** factor at the erosion sites surveyed was the bank materials, reported at 70 % of the sites (Figure E-6). Bank height contributed to erosion at about 25 % of sites observed, in particular along the lake and central river sections (from the river section Karapiro to 11.8 km downstream to the river section between Aratiatia Dam and Lake Ohakuri); and vegetation removal or loading contributed to erosion at 16 % of the recorded sites. Groundwater seepage and piping (entrainment of particles from groundwater flow) in the banks were identified as a contributing factor at less than 1 % of the sites each. However, the minor contribution to erosion reported from groundwater seepage may reflect the dry weather during the survey; it is possible that some sites identified as being contributed to by bank material may actually have also been contributed to by groundwater seepage (for example through a weaker material overlying a stronger material).

Comparison with previous studies

The number of active and recently active sites is similar to or slightly less than that recorded 5 years ago in the 2006/2007 surveys. However, the area of erosion measured during the 2012 survey is greater than that estimated during the 2007 survey of sites upstream of Lake Karapiro. Although some of the individual erosion sites have increased in area, in particular the river section between Lake Ohakuri to Lake Aratiatia (section 15), the main reason for the difference in area is the method of measurement. Previously, the erosion size was estimated by eye, primarily from a boat based survey. The 2012 survey measured erosion size using laser survey equipment (range finder), also from a boat. Measuring the actual maximum extent of the erosion and taking into account the bank slope provides a more repeatable and accurate result. Therefore the two sets of results (the 2007 and 2012 area calculations) are not directly comparable because of these different measurement methods.

To calculate the percentage of the banks that are eroding, the total area of erosion is divided by the total area of bank. The total area of the bank has not been measured directly, but is instead based on the bank length multiplied by the estimated average bank height. The proportion of bank area eroding in the river sections from Lake Karapiro and Ngaruawahia is the same (2 %) as previously calculated in the 2006 study. There has been an apparent increase in the proportion of the banks eroding for sections upstream of Lake Karapiro (sections 4 to 17), using the estimated total bank area from previous studies. However, if the bank height is assumed to be the same as sections 1 to 3 (Karapiro to Ngaruawahia), then the overall erosion rate in the upper sections is 3 % of the banks, similar to those predicted by Opus (2001) as part of the resource consent application process.

The Opus (2001) survey showed that the proportion of erosion per km length of bank is greatest in the upper reaches (river section from Lake Aratiatia to Lake Ohakuri) reducing downstream, with a slight increase between Karapiro and Hamilton. A similar trend can be observed in this survey.

Conclusions

The number of active and recently active sites is similar to or slightly less than that recorded 5 years ago in the 2006/2007 survey, with an average of 1.4 sites per kilometre length of bank.

The active and recent erosion sites covered a total area of 208,273 m^2, which equates to approximately 5 % of the banks (with some assumptions about average bank heights).

This study confirms the conclusions of the previous surveys that there is a strong relationship between the amount of erosion, bank material type and geological conditions. Just over 60 % of the erosion sites are within the weak highly erodible materials (predominately pumice sands) derived from the most recent Taupo eruption. Furthermore, 90 % of the erosion occurs within the soil-like deposits (both alluvium and non-welded ignimbrites) derived from either the last Taupo eruption or older eruption events from the Taupo Volcanic Zone.

The principal cause of erosion is river and natural processes and the bank materials are identified as the predominant contributing factor. The primary causative factors identified at each erosion site in this study were similar to the overall distribution of factors identified by the 2007 baseline survey.

Land-use or changes in land-use were not found to be a significant factor in either of the previous surveys or this survey.

Water-level variations were the principal causative factor of erosion at 4 % of the active or recent erosion sites surveyed. This is comparable with previous surveys.

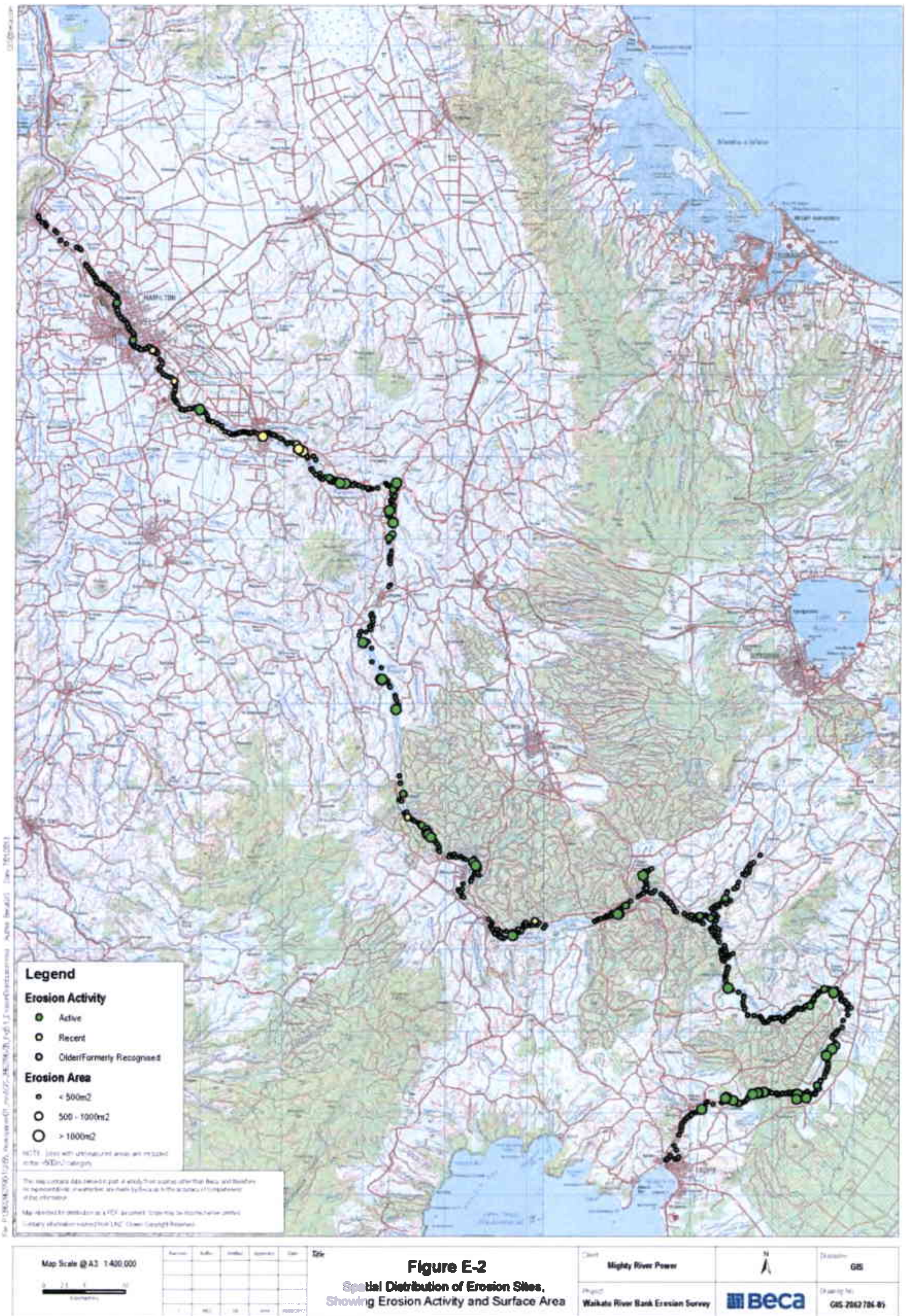

Figure E-2: The frequency distribution of active and recent erosion sites in 2012

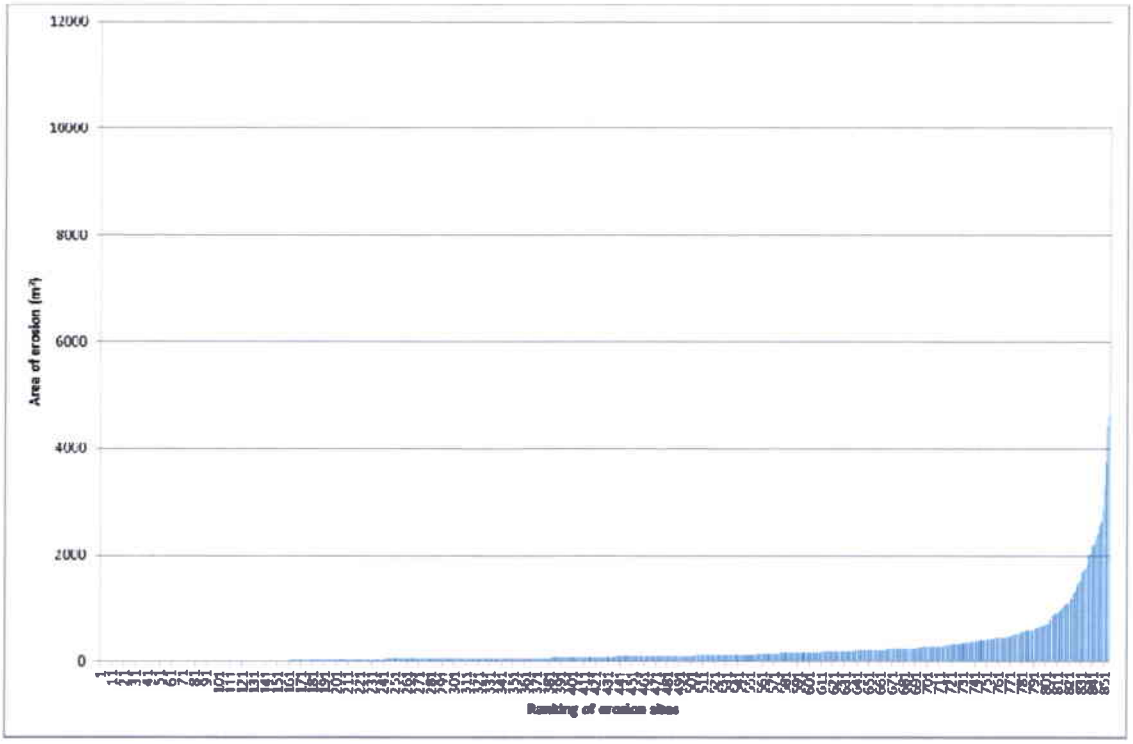

Figure E-3: Ranking distribution of sites by erosion area

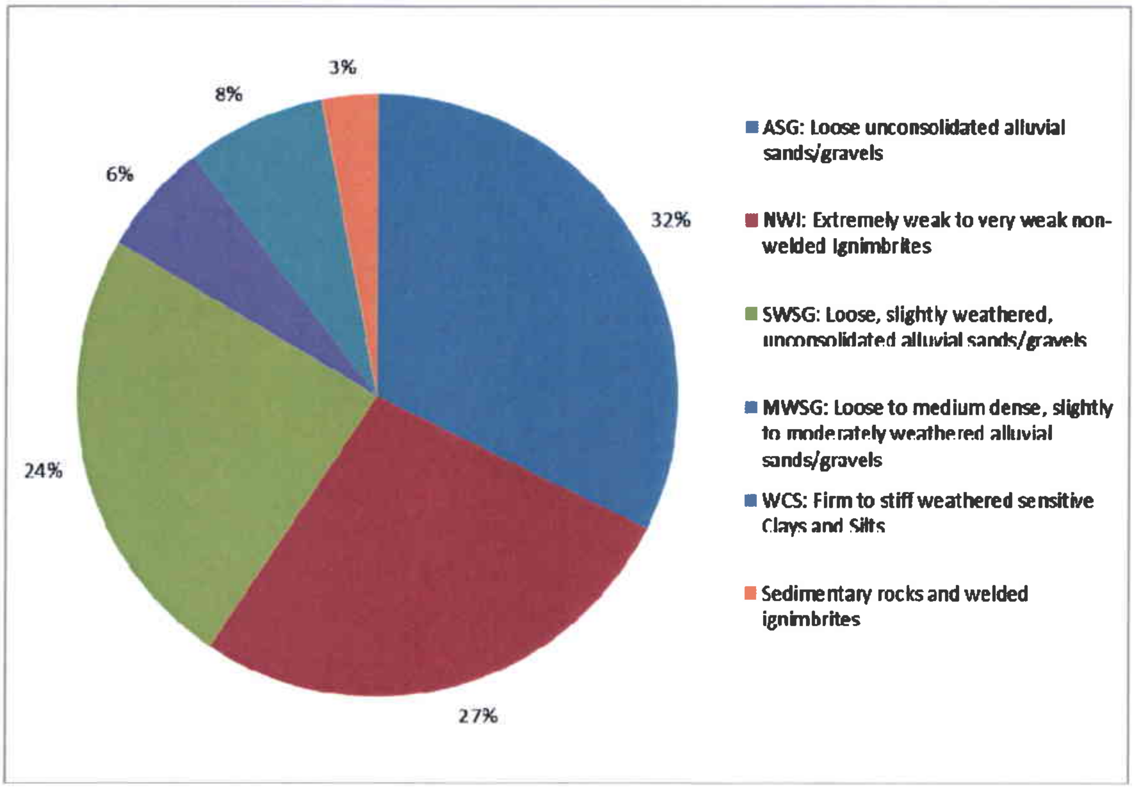

Figure E-4: Material composition of active and recent erosion sites

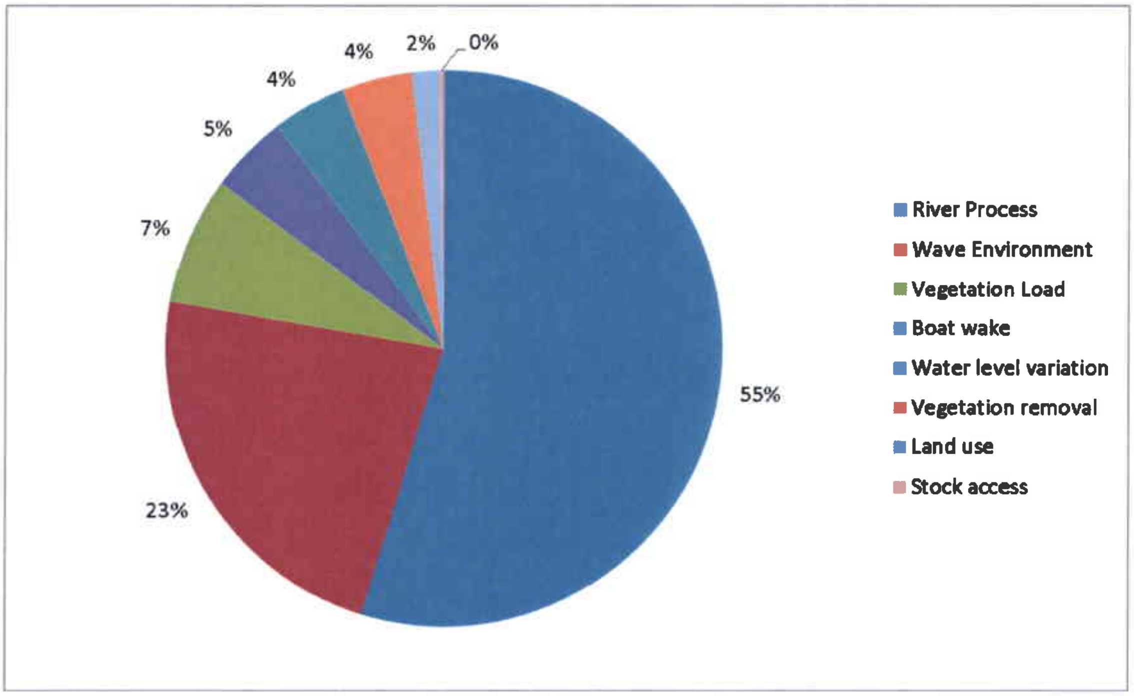

Figure E-5: Primary causative factors for the active and recent erosion sites in 2012

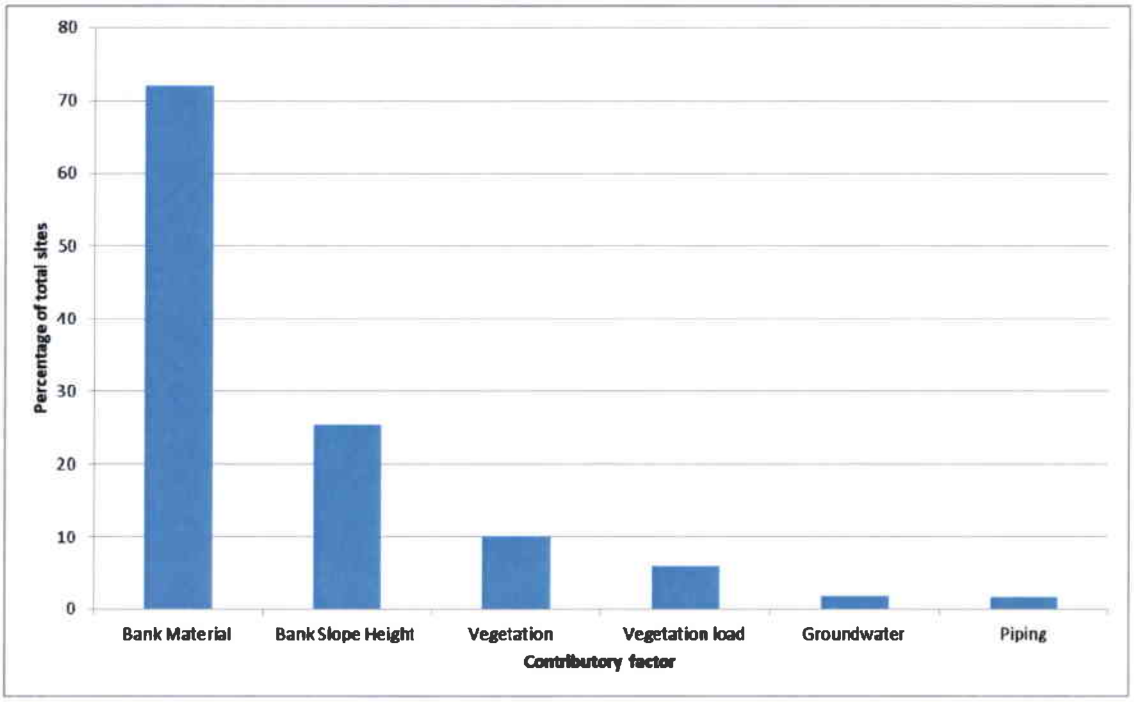

Figure E-6: Percentage of contributing factors for active and recent erosion sites in 2012

1 Introduction

Mighty River Power Ltd owns and operates eight dams and nine hydro-electric power stations along the Waikato River between Lake Taupo and Karapiro, collectively known as the Waikato Hydro System (Figure 1.1). Mighty River Power commissioned Beca Carter Hollings and Ferner Ltd (Beca) to undertake a geomorphic survey in order to measure the changes in, and causative effects of active erosion of the banks of the Waikato River and associated reservoirs. The survey is a requirement of the Resource Consents for the Waikato River Hydro System.

After the Resource Consents for the Waikato Hydro System were granted in 2006, a baseline survey of erosion sites was completed in two separate phases: from Karapiro to Ngaruawahia in 2006 (by URS) and from the Taupo Gates to Karapiro in 2007 (by Beca). The 2012 survey is the first repeat survey since the Resource Consent was granted in 2006. The main objectives of this survey, as outlined in the Technical Brief provided by Mighty River Power dated March 2012, are:

- To understand spatial patterns of erosion and the factors causing and contributing to erosion, as well as any changes to the spatial distribution and causative/ contributing factors over time;
- To record the geomorphic properties of the river banks and reservoir edges in 2012 between Taupo Gates and Ngaruawahia;
- To evaluate changes to the geomorphic properties of the river banks and reservoir edges over time;
- To create a database of erosion sites from the 2006/2007 and the current surveys;
- To document the erosion site inventory process in a manual with the objective of achieving consistency in future surveys; and
- To comply with the resource consent requirements: determination of the amount and investigation of the causes of active river and reservoir edge erosion, as well as identification of any emerging trends and comparison with effects anticipated when the consent was granted, to the satisfaction of the Waikato Hydro System Resource Consents Peer Review Panel.

This document reports the results of the 2012 Waikato River erosion survey and is structured as follows:

- The scope of work related to this survey;
- Brief background to the Waikato Hydro System and previous relevant work;
- A summary of the development of the database and an overview of the approach to the 2012 survey;
- The results of the 2012 survey and comparison with the previous survey; and
- Conclusions.

The erosion site inventory manual and database are provided as separate documents.

Figure 1.1: Overview of the Waikato Hydro System

2 Scope of Work

The scope of work as outlined by the Technical Brief provided by Mighty River Power dated March 2012 is:

- Review the previous erosion site inventory categories developed and data collected by the URS (2006) and Beca (2007) surveys and:
  - Develop a database to include all erosion sites and data collected to date as well as data from the 2012 survey
  - Recommend which parameters should be collected in 2012, based on the 2007 method for the upper river/ reservoir section plus any amendments to the parameters to assist with comparison and consistency with the previous survey of the lower river section
- Complete a detailed erosion site inventory of the banks of the river between the outlet of Lake Taupo and Ngaruawahia;
- Obtain an overview of surrounding land-use and vegetation types;
- Analyse and report on the amount of erosion, the spatial variability of erosion sites, and how these have changed over time;
- Analyse and report on the factors causing and contributing to erosion, including natural factors and those related to land-use and hydro activity such as ramping or other hydro related effects and how these have changed over time.

3 Background

3.1 Waikato Hydro System

The Waikato Hydro System consists of eight dams and nine hydro-electric power stations which are owned and operated by Mighty River Power. The Waikato River has been used to generate power since the commissioning of the Horahora Power Station in 1913. This power station was flooded in 1947 with the creation of Karapiro Dam. The oldest power station still in operation on the Waikato River is Arapuni Dam and power station, first commissioned in 1929.

3.2 Geological setting

The Waikato River originates from Lake Taupo, a volcanic caldera in the central North Island. The geology of the upper Waikato is dominated by volcanism from the Taupo Volcanic Zone (TVZ) and back arc rifting, caused by the subduction of the Pacific plate under the Australian plate, to the east of the North Island.

The TVZ is an active volcanic and rifting system, some 1.8 million years old, which has produced very large eruptive events. The deposits from these large events dominate the upper Waikato catchment in the form of welded (stronger) and non-welded (weaker) ignimbrites (massive volcanic flow deposits), interlayered with reworked sediments and thin lenses of volcanic ash of the Walton Subgroup. These older Quaternary deposits have eroded to form low lying hills and valleys. More recent primary and reworked volcanic sediments have formed terraces overlying the older deposits. The most voluminous deposits are products from the Oruanui eruption (~27,000 years ago), that have been reworked forming the younger beds of the Hinuera Formation. The most recent deposits are derived from the Taupo eruption (~1,800 years ago) comprising primary deposits of the Taupo Pumice Formation and reworked Taupo Pumice Alluvium.

In the upper reaches of the Waikato River, from Taupo to Lake Ohakuri, the banks primarily comprise recently deposited Taupo Pumice Formation and reworked Taupo Pumice Alluvium. Near Orakei-Korako indurated lake sediments previously known as the Huka Group, occur. Banks in the upper reaches are subject to active seismicity, geothermal activity and in places, potential subsidence from extraction of steam.

In the central section of the survey from Lake Ohakuri to Lake Arapuni the Waikato River banks are predominantly comprised of variably welded ignimbrites interspersed with narrow near vertical sections comprised of strong to moderately strong rhyolitic domes and basement greywacke rocks. Late Quaternary reworked volcanic sediments of the Hinuera Formation overlie the ignimbrites in the broader valleys and these sediments generally form steep terraces.

In the lower Waikato section (Hamilton Basin) the banks are predominately comprised of river-deposited late Quaternary sediments, primarily Hinuera Formation which has in-filled and buried paleo (pre-existing) valleys and hills. Taupo Pumice Alluvium forms low lying banks along sections of the river.

3.3 Resource Consent monitoring requirements

The primary resource consents for the Waikato Hydro System are Waikato Regional Council resource consents 105226 (structures on the bed of the river), 105227 (divert and take water), and 105228 (discharge water). Each resource consent has the same conditions relating to the monitoring of on-going effects and comparison of these effects with those anticipated when the consents were granted. The consents require 5 yearly geomorphological surveys which determine the amount, and investigate the causes of, active erosion of river banks and reservoir edges.

The consents also include a requirement for Mighty River Power to engage a Peer Review Panel. The purpose of the Peer Review Panel is to provide an independent technical review of the design, implementation, and results of the monitoring programmes undertaken. Peer Review Panel member Professor Michael Crozier reviewed the proposed data collection methodology early in the project and then undertook a technical review at the conclusion of the survey.

3.4 Previous surveys

Following the granting of the resource consents in 2006, the first full survey of bank erosion was commissioned by Mighty River Power for the river section between Ngaruawahia and Lake Karapiro. This was carried out by URS during 2006 and reported in 2007. Following this survey, Beca was commissioned in 2007 to survey the reservoir and river sections from Lake Karapiro to the Taupo Gates, the results of which were reported in 2008. These two surveys form the baseline inventory of erosion sites. This 2012 survey was commissioned by Mighty River Power to cover the entire river length and reservoirs between Ngaruawahia and the Taupo Gates. In 2012, the two previous survey sections have been completed as a single study.

Prior to these baseline surveys, a range of work was carried out, either as part of other projects or to support the Resource Consent process for the Waikato Hydro System. Studies specific to bank erosion and geomorphic processes include:

- Works Consultancy in 1996 investigated erosion at the following sites: Reporoa - 2 km upstream of Mihi Bridge, Tahorakuri, Tahorakuri 11B and Tahorakuri 7B3B in their Mid-Waikato Flooding and Erosion Study;
- Opus surveys in 1999, 2000 and 2001 investigated geomorphic processes active in the Waikato River and in 2002 conducted a formal analysis of bank stability relationships at sites in Hamilton City;
- Land and Water Studies Ltd in 2000 investigated wave generated erosion and effects of shoreline structures;
- Dr J.A. McConchie (Victoria University) published studies on geomorphic processes and provided evidence in respect of the Mighty River Power resource consent in 2001. He co-authored with Toleman and Toleman & Hawke in 2005 on boat wake as a cause of erosion on the Waikato River and effects of flow regulations on sediment transport, respectively;
- URS investigated landslides in reservoirs on the Waikato River in 2001; and
- A. Wood of the University of Waikato completed an MSc thesis in 2006 on the morpho-dynamic channel and stability of the Waikato River. The study extended from Karapiro to Ngaruawahia and included an erosion survey. The thesis has not been cited in this study.

3.5 Factors influencing erosion

Riverbank and reservoir erosion are dynamic geomorphic processes. There are many factors which influence bank erosion and these include the river flow properties, bank material composition, climate, subsurface conditions, channel geometry and vegetation. Human activities such as land use practices, stormwater management, boating and bank protection structures also have an effect on these processes.

The baseline surveys demonstrated that the Waikato River and reservoir banks are naturally susceptible to erosion. Significant stretches of banks are comprised of unconsolidated granular materials that have high erosion potential. The method used to assess the factors influencing erosion in the 2012 survey is described in section 4.5.

3.6 River history

3.6.1 Aggradation and degradation

The ancestral Waikato River channel has evolved over the last 220,000 years, changing its course at least four times between Thames Valley (Hauraki Plains) and the Waikato valley (Hamilton Basin), in response to deposition of material from active volcanism, climatic conditions and faulting effects in the TVZ. The latest significant diversion of the river into the Waikato valley occurred some 21,000 years ago. The change in course is believed to be due to sediment aggregation (river choking) from a series of break-out floods near Huka Falls, following the voluminous deposition of material from the Oruanui eruption of the Taupo volcano some 27,000 years ago.

About 18,000 years ago, after a period of high sediment loading, river meandering and deposition of the Hinuera Formation (sourced from the Oruanui eruption) began to decrease in response to drier climatic conditions. The river began to down-cut (degrade) and to follow its present course (McCraw, 2011). The down-cutting continued resulting in a stepped series of steep river banks cut into the weak, erodible Hinuera Formation.

The Taupo eruption around 200 AD provided further volcanic deposits, initially primary ash and pumice in the upper 200 km section of the river and subsequently break-out sedimentary flood deposits. The Taupo Formation deposits occur in terraces 20 m above the current river level at Karapiro and at 5 m above current river level at Ngaruawahia. Subsequent down-cutting and sediment re-deposition resulted in 1 m to 2 m high banks of loosely consolidated pumiceous gravelly sands present today along sections of the river.

The Waikato River is believed to have eroded some 6 m to 9 m below its present level after the Taupo eruption. It is postulated that river aggradation began again after the arrival of people, some 800 years ago (Schofield, 1967, Smart, 2003). The overall river aggradation is thought to be some 9 m to 10 m since the Taupo eruption (Selby and Lowe, 1992). It is likely that human activity associated with deforestation and river use in the last 800 years has contributed to some river bed aggradation, for example, in 1928 over 5 million cubic metres of sediment migrated downstream from the river diversion at the Arapuni spillway. Other natural events such as earthquakes or landslides that could have dammed the river, as postulated at Taupiri (Selby & Soons, 1992) may have contributed. Sand mining of the bed load in the lower reaches during the 20th century is also likely to have had an effect, resulting in (perhaps localised) degradation or a lessening of the rate of aggradation.

River bed surveys that commenced after the completion of the Karapiro Dam in 1947 indicate some bed degradation has occurred in the surveyed sections since this time (Smart, 2003). Carbon dating (^{14}C) of organic material encountered 4.5 m to 7.5 m below the current river bed in Hamilton City has a reported age of 2050 years before present (Smart, 2005), therefore the organic matter is likely to be material overwhelmed by the Taupo eruption. This indicates that bed levels are currently higher than before the Taupo eruption.

3.6.2 Intensity of boat activity on the hydro reservoirs

There are a number of diverse boating activities carried out on the Waikato River. This section presents an overview of the expected boating activities on the Waikato River, drawn from publicly available information. No survey of boating activities has taken place to support this overview. The areas of major activity are considered to be the Hamilton area, Lake Karapiro and from Lake Aratiatia to Lake Taupo.

- The section of river that flows through Hamilton appears to have the most diverse river traffic with many schools and clubs using rowing skiffs as well as rowing races taking place. Power boats regularly use the river including boat demonstrations by manufacturers and boating shops. Jet-skiing is restricted in most areas of the Waikato apart from the section near towns;

- Lake Karapiro plays host to a number of boating events each year, including waka ama, rowing, dragon boats, water skiing and yachting. Additionally there is a significant number of fishing boats in Lake Karapiro and to a lesser extent Lake Arapuni;
- The section from Lake Aratiatia to Lake Taupo is popular for jet boating. There are four main jet companies operating throughout the year conducting as many as 20 trips per day in summer, although there is considerably less activity during the winter.

Information about the number and type of boats in each section of the Waikato River is not readily available. An accurate assessment of boating activities is difficult to determine due to the diverse range of activities. A large proportion of the boats are used for recreational purposes for which there are few records. For example, there are over 44,000 registered jet skis in the Waikato Region according to the Waikato Regional Council. The proportion of those that are used on the Waikato River cannot be easily determined.

The key commercial operators are indicated in Table 3.1.

Table 3.1: Information about commercial boat operators on the Waikato River

Survey section	Key commercial boat operators
Between 11.8 km and 32.3 km from Karapiro	Cruise Waikato - daily boat cruises
Between Karapiro and 11.8 km downstream	Cruise Waikato - daily boat cruises
Lake Karapiro	1) Karapiro Cruiser 2 times a week, 2) Camjet jet boat 3 times a week
Lake Maraetai	The Paddleboat Company - once a day in summer, none in winter
Lake Ohakuri	New Zealand Riverjet - Jet boating summer two trips / day, winter 1 trip / day
Lake Aratiatia	1) Rapid Jets - Jet boating summer 20 trips/ day, winter 1 trip/ day 2) Huka Falls Jet - 5 trips/ day in summer, 1 trip/ day in winter 3) River cruise 3 trips/ day
Lake Aratiatia to Taupo Gates	1) Rapid Jets - Jet boating summer 20 trips/ day, winter 1 trip/ day 2) Huka Falls Jet - 5 trips/ day in summer, 1 trip/ day in winter

3.6.3 Wind direction and wave heights on the hydro reservoirs

Turbulent fluctuations in a flow, whether generated by wind or vessels is known to entrain particles when bank shear stresses are exceeded. The amount of entrainment (erosion) is primarily a factor of the energy of the wave (a function of wave height, period, angle of approach, wind direction and velocity) and shear strength of the bank materials. Other factors that affect wave-generated bank erosion include: bed and bank geometry and bank vegetation.

Trials have found that there are threshold values of wave height and period above which sediment concentrations are greatly increased (Nanson et. al., 1994). Once the threshold is exceeded and the bank erodes, lower energy waves may be able to transport the material (McConchie & Toleman, 2003). "*The threshold is proportional to wave height; therefore increasing the wave height monotonically increases the ability of surface waves to exceed the erosion threshold*" (Gourlay, 2011). Studies on the Waikato River show that "*wind-generated waves ranged in amplitude from*

1 mm to 24 mm" and "*boat-generated waves were found to be 2 to 80 times greater than wind generated waves*" (McConchie & Toleman, 2003). Therefore boat-generated waves are likely to have a far greater effect on bank erosion than wind-generated waves, if the erosion threshold is exceeded.

There is little wind information for much of the Waikato River and associated hydro lakes due to the relatively sparse surrounding population. A study has been undertaken for Mighty River Power using wind data from the Wairakei Power Station (1964 – 1966) which was considered to be the most representative of the wind regimes at the eight hydro lakes (McConchie, 2001). "*The hydro reservoirs (lakes) are long narrow water bodies. Fetches are generally short even though winds are topographically channelled along the lakes and this limited the size of the waves are produced....wave energies are higher in confined waters than in wide fetches. The region in general has less wind than most other parts of the country with the strongest and most frequent winds coming from the west and southwest*". The study describes a computer programme called "lakewave" that was used to analyse the expected wave regime on the hydro lakes. "*The results of this analysis show a high degree of correlation between the areas of lakeshore erosion and the wave climate. The correlation between the wave regime and lakeshore erosion is reinforced by the fact that the lakes with the longest fetch i.e. greatest wave energy, appear to have the most problems with lakeshore erosion. Lake Ohakuri with longer fetches and "weaker" bank material has significantly more lakeshore erosion than Arapuni for example*" (McConchie, 2001).

The same study also notes that "*the amount of erosion on the shores of the various lakes is highly variable, reflecting largely on the geology but also the fetch, which controls wind generated wave height and energy*".

Roper (2001) in his assessment of environmental effects surmises that "*Wind generated waves and waves from boating activity can have a significant effect on bank stability and erosion*" as "*fetch lengths on some of the lakes are large enough for wind to generate substantial wave action. The winds that do occur tend to be funnelled by the local topography along the straighter reaches of the river and lakes. An analysis of the distribution of wave energy around the shores of the lakes shows a strong link between wave action and shoreline instability*".

Wind generated waves may therefore contribute to the erosion observed, particularly on the hydro lakes. Separating the effects of wind generated wave erosion from other factors such as boating activity is difficult without detailed investigation. In this study both boat wake and wind generated waves are causative factors of erosion.

3.6.4 River flow and reservoir level history

This section provides a summary of water levels at the eight hydro reservoirs and at two Waikato River monitoring locations, since the last surveys in 2006/2007. Fluctuations in water level are the result of hydro operations, floods, droughts, and operations to accommodate other river users. Hydro lakes are also lowered to meet the demands of other lake uses (e.g., construction or repair of boat ramps, sport events, cultural events).

The Waikato Hydro System has been operated in accordance with its Resource Consents. In the years since the last surveys, there have been the following extreme events:

- Floods - July 2008, October 2008, September 2010, January 2011
- Droughts - April 2008 and May 2010.

Figure 3.1 to Figure 3.8 in this section present the water levels of Waikato Hydro System reservoirs (showing half-hour average levels), and Figure 3.9 and Figure 3.10 show flow from Karapiro and on the Lower Waikato River (also half-hour averages). Data is presented from 2000 to 2012, to allow a visual comparison between pre-consent and post-consent (April 2006) operation, and also between the survey dates. Each reservoir level on the Waikato Hydro System has a specified normal operating range, maximum control level, and minimum control level; these are indicated on the graphs. A comparison of the levels and flows between 2000 and 2006 (the period preceding the baseline erosion survey) and 2006 and 2012 (the period between the baseline survey and this survey) are presented in Table 3.2.

Table 3.2: Assessment of changes in levels/ flows between survey periods

Lake level / river flow monitoring station	Assessment of changes in range of levels/ flows between survey periods
Aratiatia	A wider range of levels was recorded in the period 2000 to 2006, including levels below the normal range lower level of 336.4 m more often than in the period 2007 to 2012.
Ohakuri	The operating range and levels in Lake Ohakuri in the period 2007 to 2012 is similar to that in the 2000 to 2007 period, but the frequency of lake levels below the normal range lower level was more common in 2007 to 2012.
Atiamuri	Since 2009, Atiamuri has operated over a wider and slightly lower range than for the period 2000 to 2009.
Whakamaru	For the period 2007 to 2012, Whakamaru has operated over a similar range to 2000 to 2007, except that since mid-way through 2009, there have been more high and low lake levels recorded that are outside the normal operating ranges, but within the control levels.
Maraetai	For the period 2006 to 2012, Maraetai has operated over a slightly broader range then the preceding years, with lower lake levels being more frequent.
Waipapa	The lake ranges in 2000 were a relatively narrow band between 127.4 and 128.1 m. In 2001 this changed to a 4 m range (125 to 129 m). Since 2002, lake level has operated over a 3 m range (125.2 and 128.2 m), but this range has been extended since 2009.
Arapuni	Arapuni has operated over a reasonably similar range for the period 2000 to 2012.
Karapiro	The range of lake levels in the period 2007 to 2012 is similar to the 2000 to 2007 period.
Karapiro outflow	The outflow from the Karapiro Dam to the Lower Waikato River has remained constant throughout the period from 2000 to 2012.
Ngaruawahia river flow	The river flow at Ngaruawahia is the combined flow from both the Lower Waikato and Waipa Rivers. The flow at Ngaruawahia has been relatively constant throughout the period from 2000 to 2012.

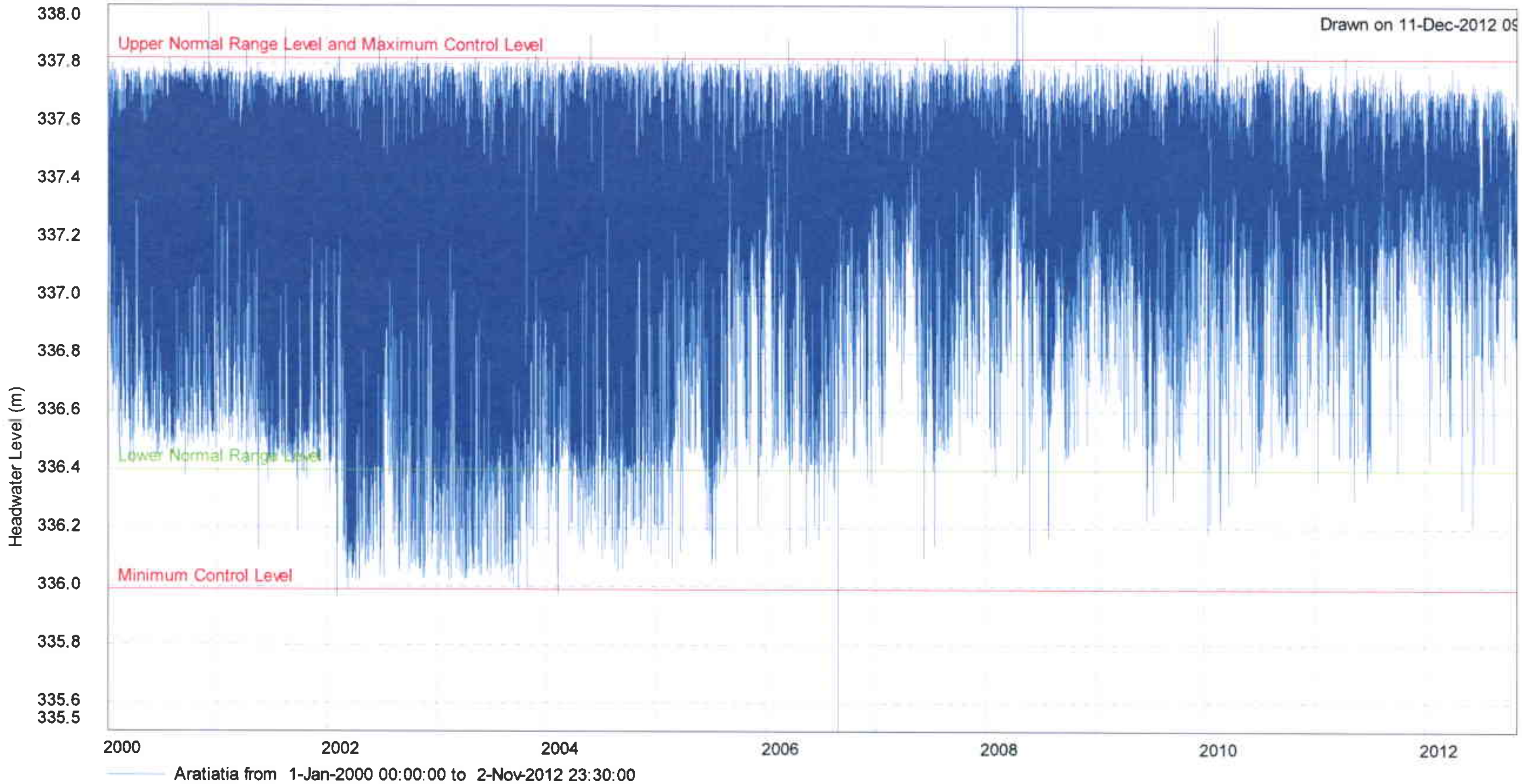

Figure 3.1: Lake Aratiatia headwater levels

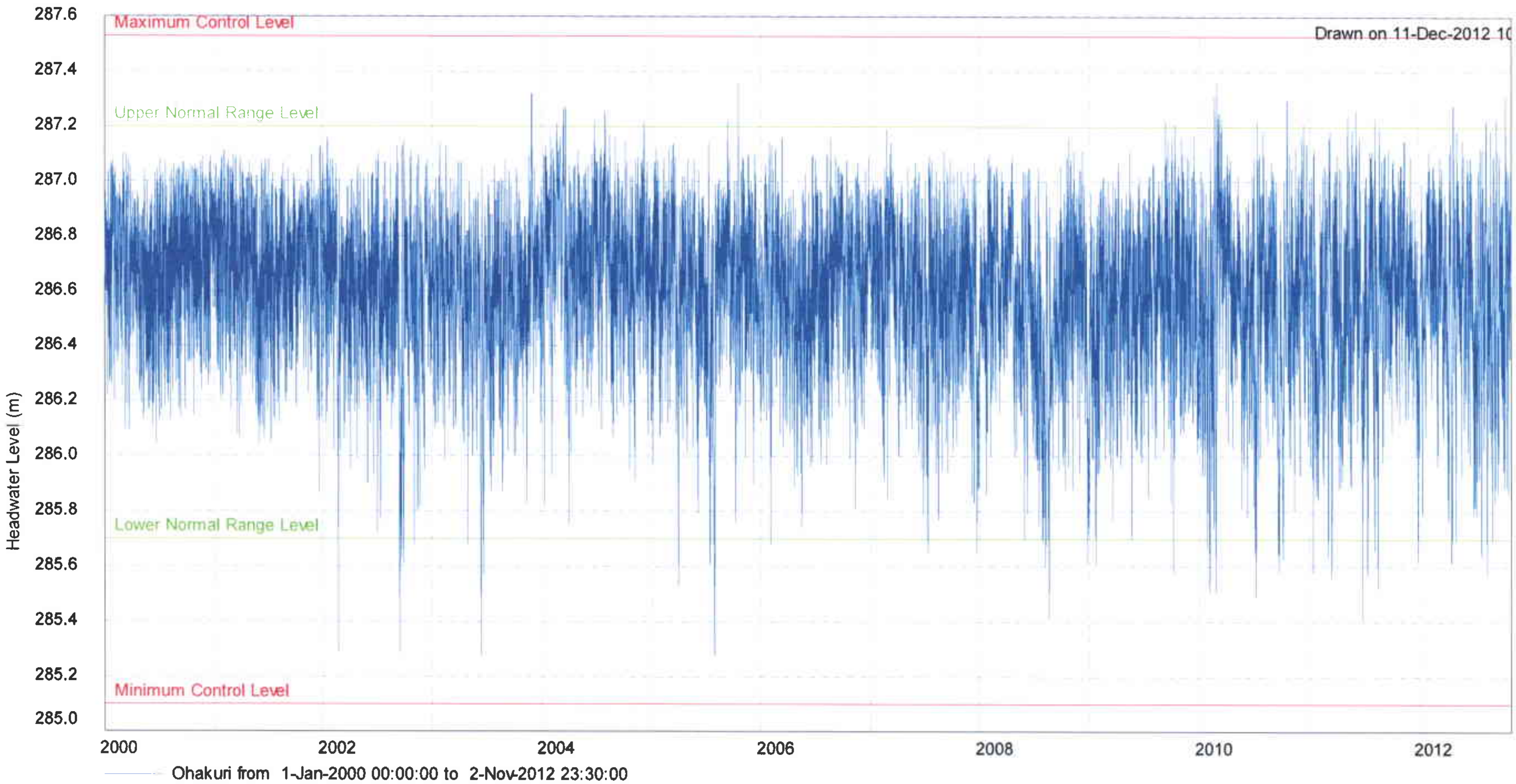

Figure 3.2: Lake Ohakuri headwater levels

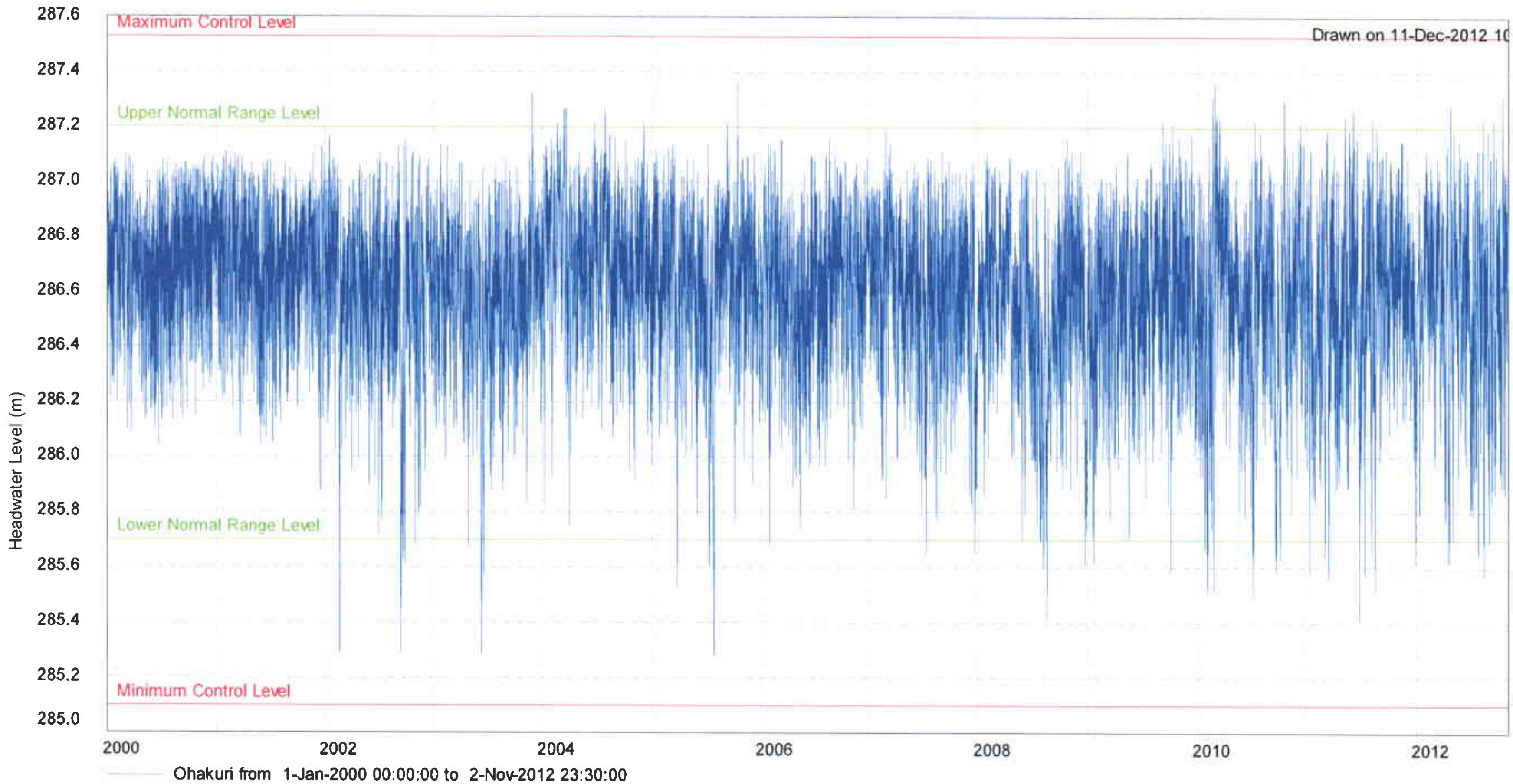

Figure 3.3: Lake Atiamuri headwater levels

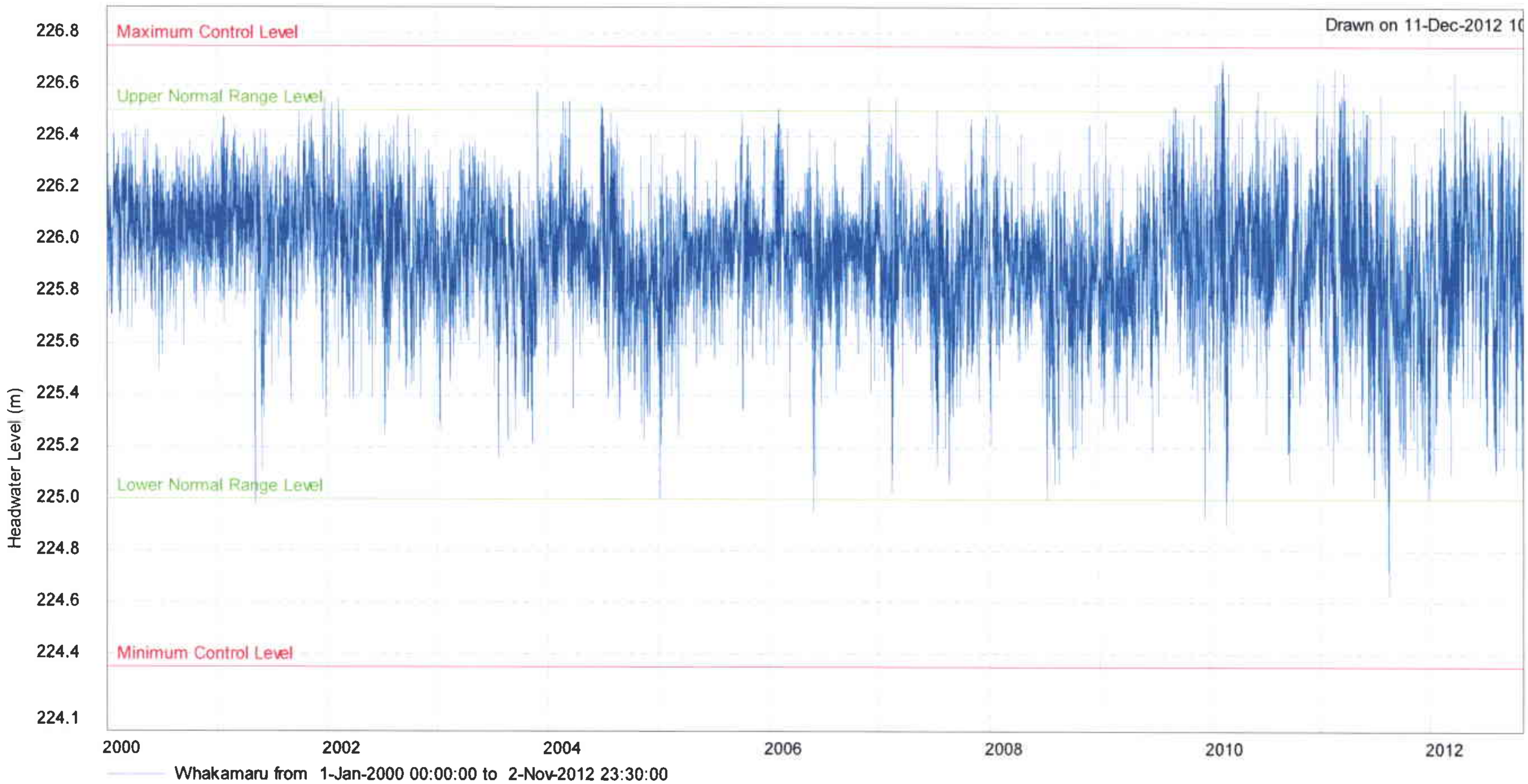

Figure 3.4: Lake Whakamaru headwater levels

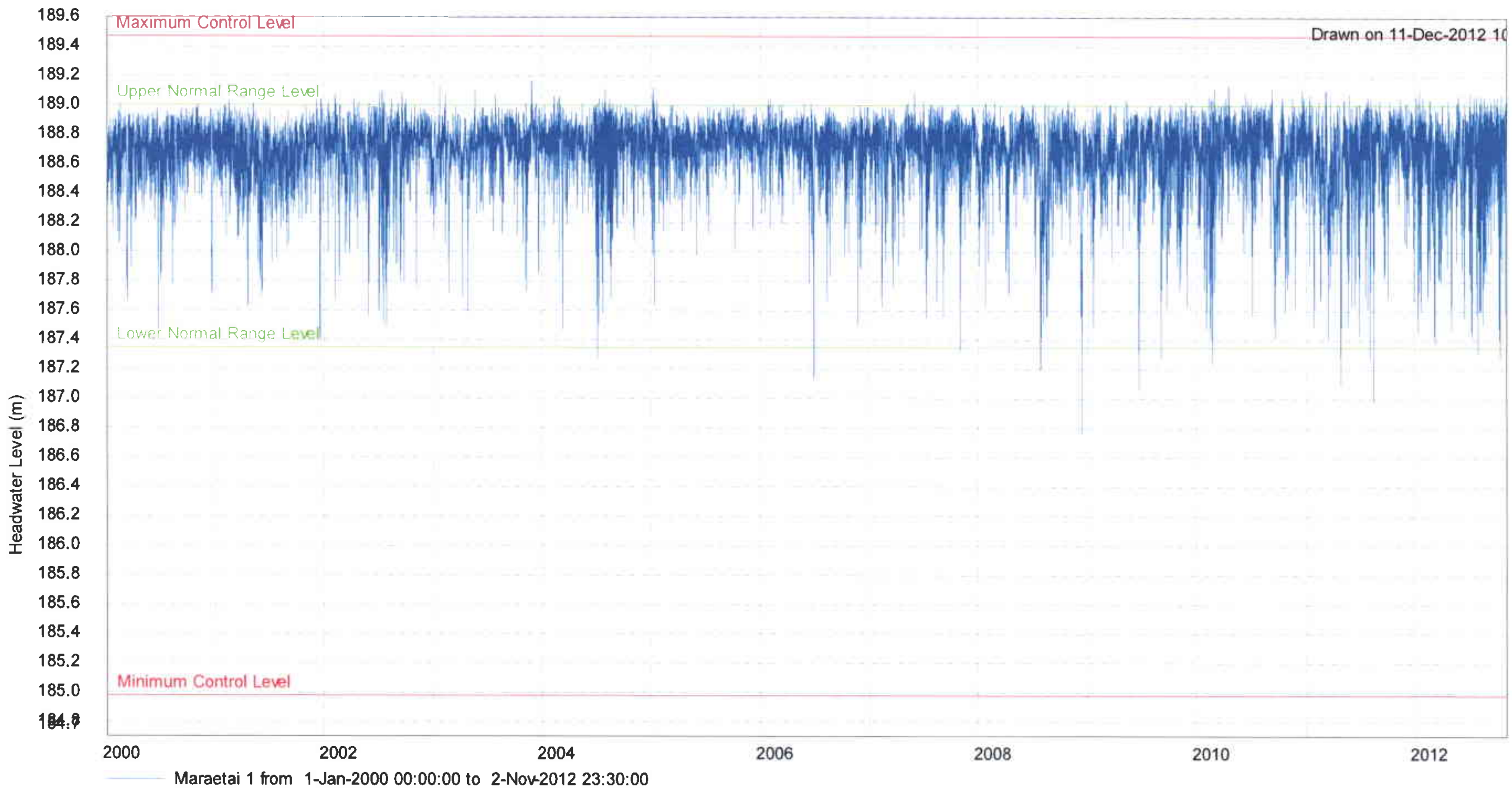

Figure 3.5: Lake Maraetai headwater levels

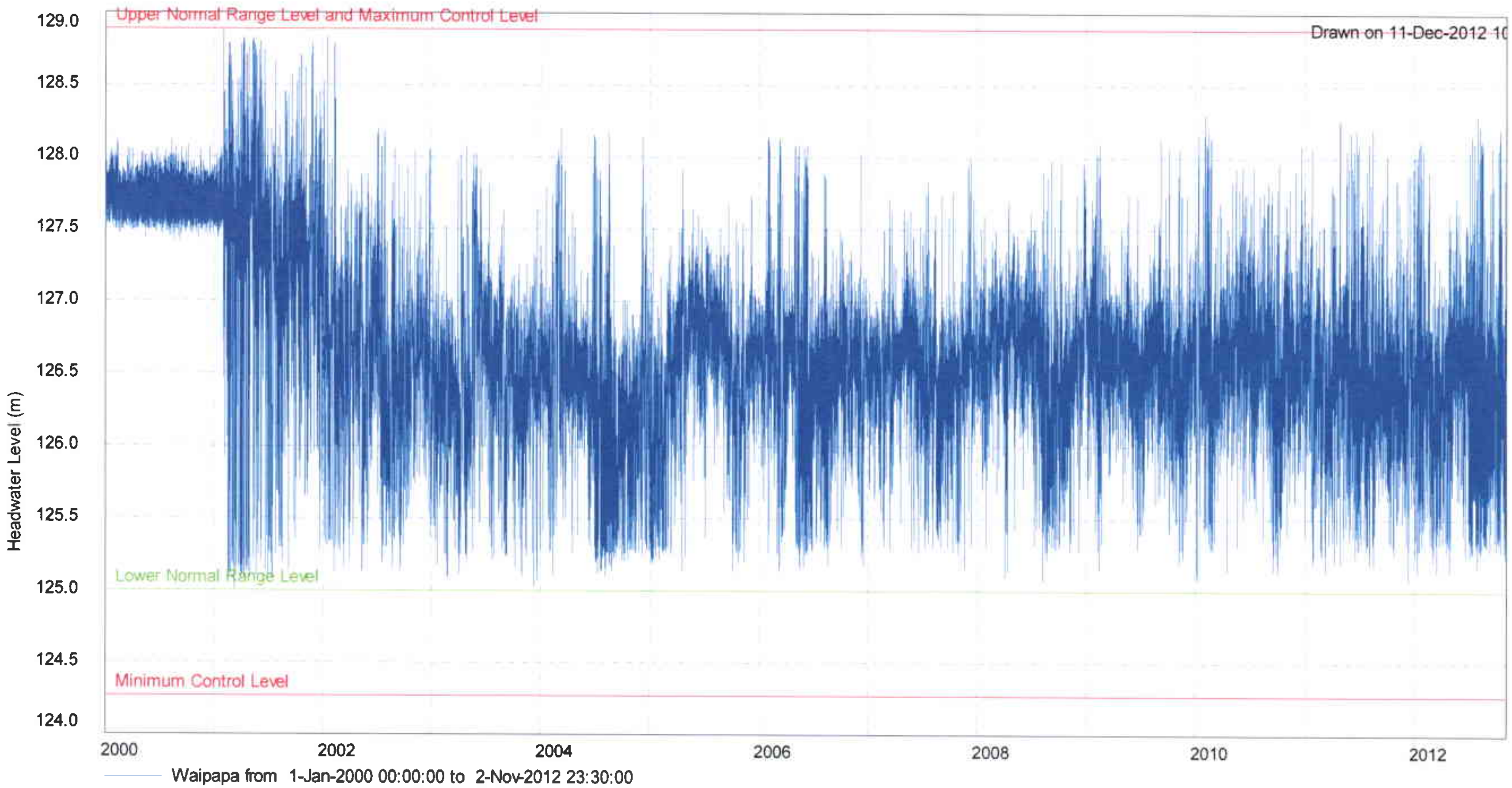

Figure 3.6: Lake Waipapa headwater levels

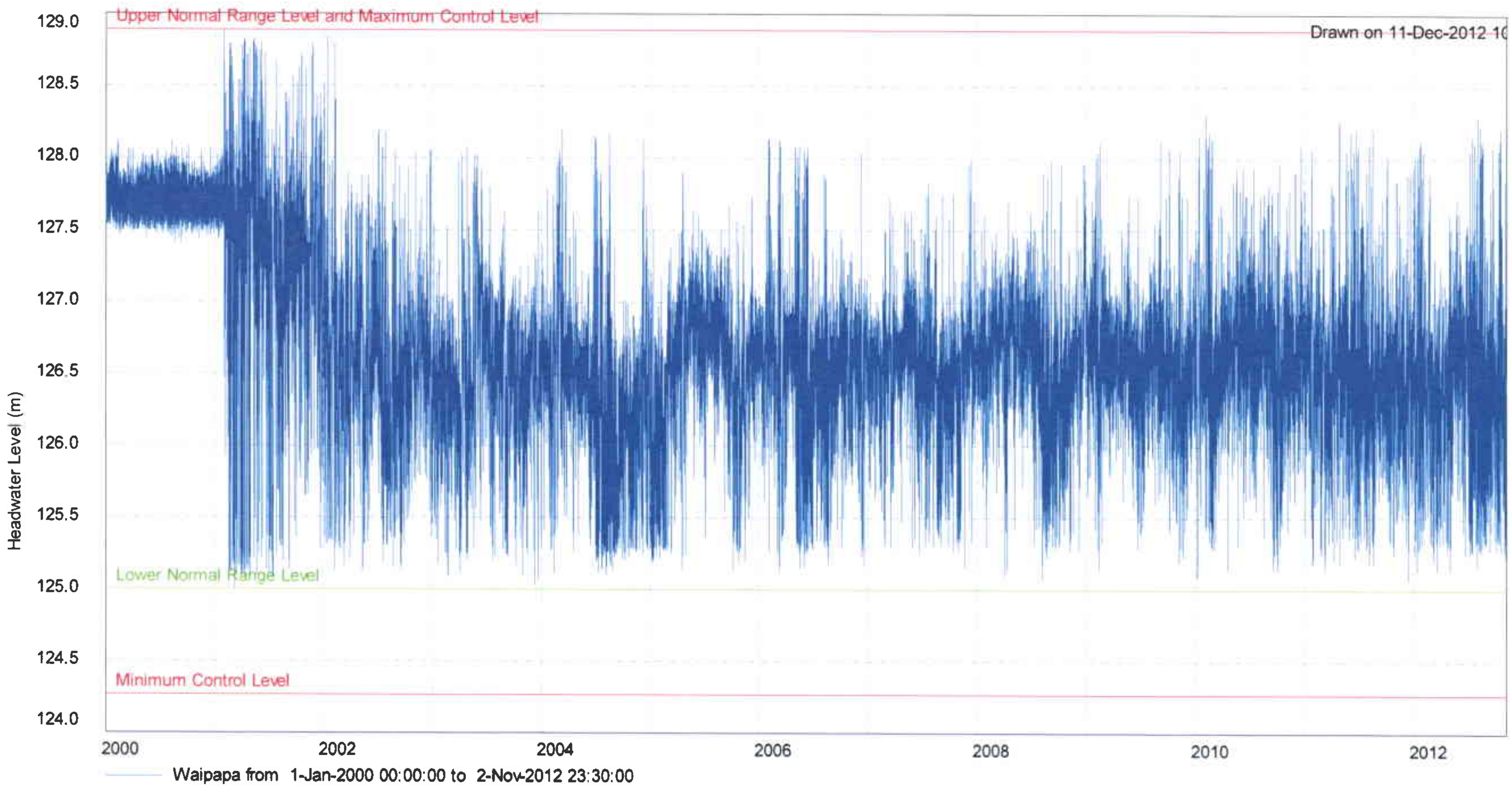

Figure 3.7: Lake Arapuni headwater levels

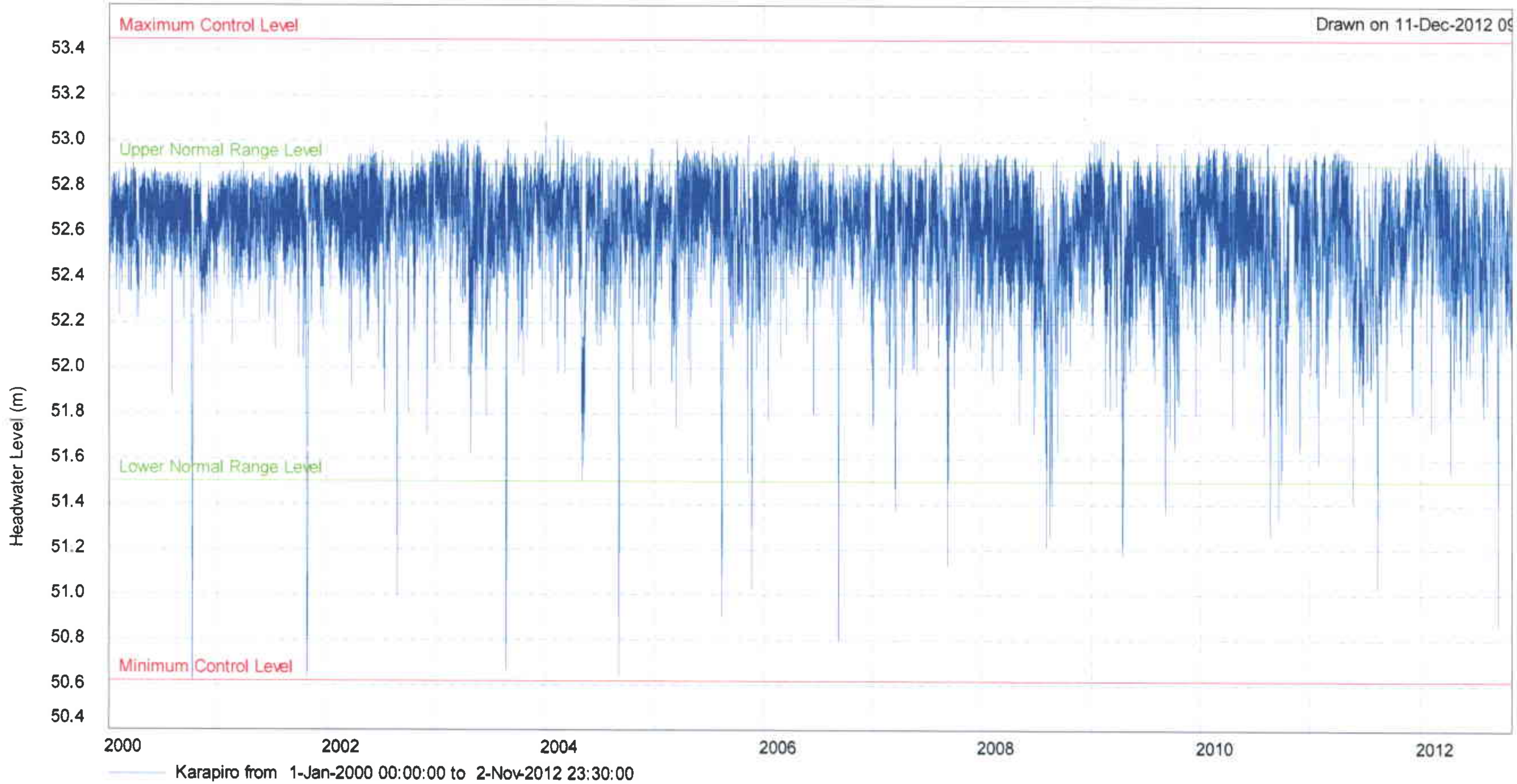

Figure 3.8: Lake Karapiro headwater levels

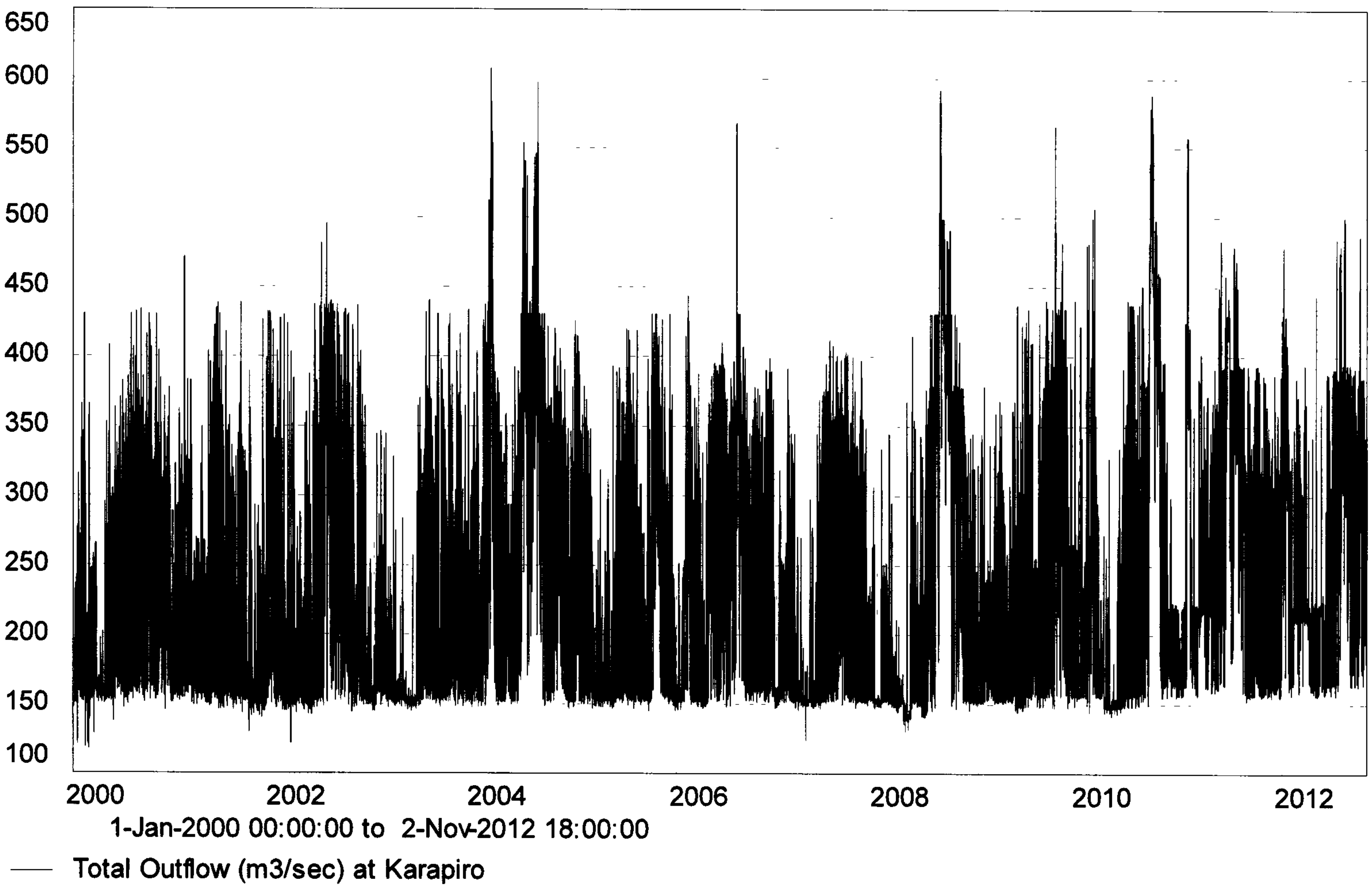

Figure 3.9: Outflow from Lake Karapiro

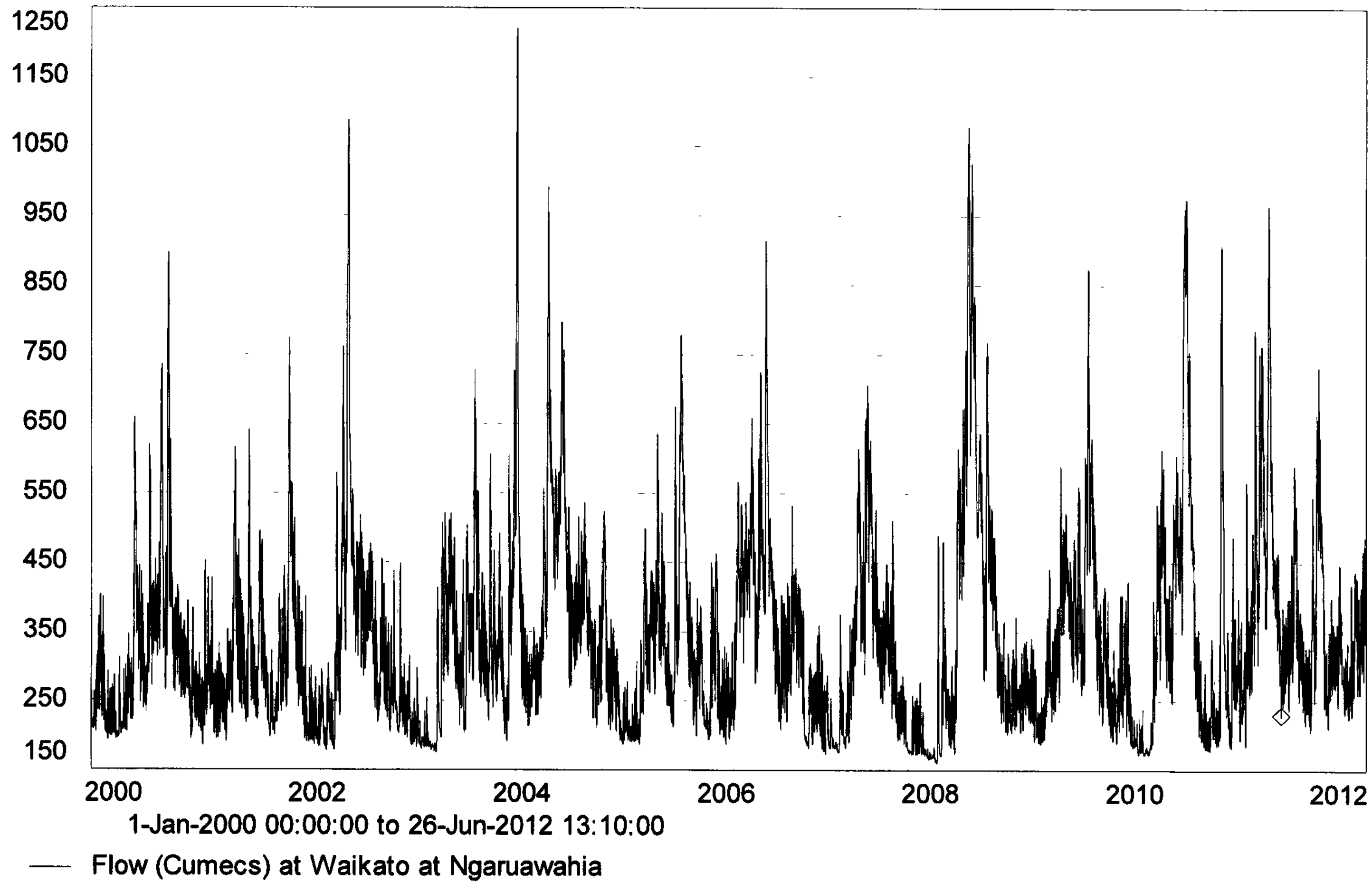

Figure 3.10: Waikato River flow at Ngaruawahia

4 Erosion Survey Methodology

4.1 Overall project methodology

The general methodology for the 2012 Waikato River bank erosion survey data collection, inventory field selection and review process is set out in a flow diagram in Figure 4.1. The 2012 study included:

- Definition of erosion inventory parameters for the 2012 study;
- Compilation of the current and previous erosion inventories into one database;
- Development of an Erosion Inventory Manual, which outlines the methods used for recording erosion at each site;
- Sourcing and analysis of aerial photographs from 2007 and 2012, to categorise land use at the top of bank throughout the study area; and
- Analysis of the 2012 and previous survey data to produce this report.

It is envisaged that future surveys will continue to add to the erosion inventory database, and will follow the procedures outlined in the Erosion Inventory Manual, to enable consistency and comparison between surveys.

4.2 Definition of erosion inventory parameters

The inventory parameters logged in the two previous surveys were reviewed to design the erosion inventory parameters for 2012. The inventory parameters include a number of fields (e.g. position on bank) and some fields include pre-defined sub-categories that the field staff must select from (e.g. inner bend, outer bend, straight section). The 2012 inventory fields and sub-categories are substantially the same as the previous study from the Taupo Gates to Karapiro (2007). There are some differences in the definition of sub-categories from the previous study from Karapiro to Ngaruawahia (2006), however the fields recorded at each site were generally similar.

The 2012 inventory parameters were developed with consideration of how they would be used in the analysis to allow comparison of general trends with previous surveys. The parameters were agreed with Mighty River Power prior to the 2012 survey. A full list of inventory parameters logged at each erosion site can be found in the manual, along with a description of the methodology, classification descriptions, calculations and examples. Key fields include:

- Site ID
- Bank bearing, flow bearing
- Bank geomorphology
- Erosion (failure) type
- Land use at top of bank
- Groundwater seepage
- Primary causative factor
- Engineering geologic unit (material type)
- Study section
- River position
- Geomorphic bank class
- Activity (age of movement)
- Principal geological unit
- Other causative factors
- Rate of erosion
- Tectonic and seismic activity
- Site and Grid reference
- River bed morphology
- Erosion site geometry
- Vegetation cover
- Man-made features
- Contributing factors
- Area of erosion

4.3 Database description

A database was developed to collate the GIS datasets of erosion sites from both the 2006/2007 and 2012 studies in a standard structure. The data fields recorded at each erosion site in 2006 and 2007 were matched to those defined for 2012, to enable comparisons between data sets over time. A step-by-step description of the processes to migrate the 2007 datasets into the 2012 database schema is outlined in the Erosion Inventory Manual. The database also includes the two land-use datasets (2007 and 2012) which have been categorised from the two aerial photography sets.

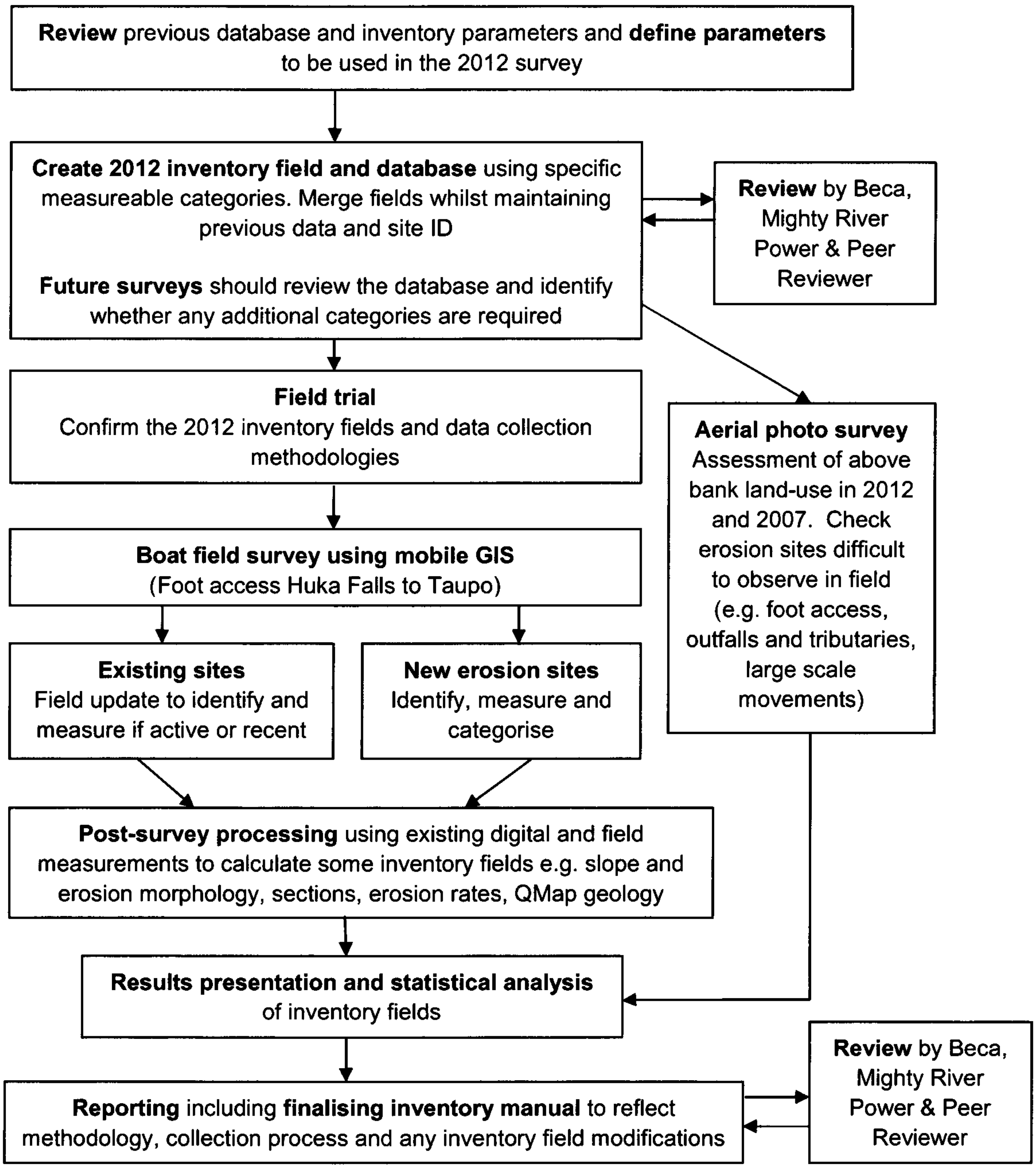

Figure 4.1: Flow diagram showing the overall project methodology

4.4 Approach to the 2012 field survey

Most of the erosion survey was undertaken by boat, measuring the physical fields of previously identified and new erosion sites. The 5 km section from Taupo gates to the Huka Falls was surveyed by foot. The field survey data was input directly into a mobile GIS database. Figure 4.2 shows a screenshot of the mobile GIS database with erosion sites and data fields. Data was collected in accordance with the Erosion Inventory Manual.

For each new erosion site, the size category defines the amount of data entered. This was modified from the baseline surveys on the lower portion of the study area, from Karapiro to Ngaruawahia. Table 4.1 describes the extent of data recorded, based on the size of each erosion site, for the current and previous studies.

Table 4.1: Extent of data recorded for each size of erosion site

Data recorded	2006 study Karapiro to Ngaruawahia	2007 study Taupo Gates to Karapiro	2012 Study All areas
Full inventory parameters recorded	Sites greater than 2 m^2	Sites greater than 10 m^2	
Only selected inventory parameters recorded	n/a	Sites greater than 3 m^2	
Location noted, but no parameters recorded	n/a	Sites less than 3 m^2	New sites not recorded

In addition, the activity of the erosion defines the data capture. Sites are considered as:

- Active if erosion has occurred in the last year; or
- Recent if erosion has occurred in the last five years; or
- Formerly recognised where the erosion is now considered stable, i.e. there has been no further erosion since the last survey 5 years ago.

To assess the activity of previously recorded erosion sites, the photo from the last survey and the existing erosion were compared for signs of stabilisation, such as re-vegetation, discolouration and rounding of features. Any changes in activity since the last survey were recorded and updated in the 2012 database. For the sites still considered active (<1 year old) or with recent erosion (1 to 5 year old movements), full data capture was undertaken as per Table 4.1. However; at formerly recognised sites where no erosion had occurred in the last five years, only the inventory fields and/ or categories that were not previously surveyed were captured.

Some parameters were measured in the field during the survey and others were calculated after the survey from data processing. These post-survey calculations include: slope angle, erosion area and bank class.

4.5 Evaluation of factors influencing erosion

The 2012 survey evaluated the factors influencing erosion by identifying causative and contributory erosion factors at each erosion site, based on the definitions used in the 2007 study from Karapiro to the Taupo Gates, and recommendations of the Peer Review Panel at that time. These factors are described and examples provided in the Erosion Inventory Manual. In the survey, the factors influencing erosion have been recorded at each erosion site in three groups:

a) Primary causative factors,

b) Other causative factors – where there is evidence of more than one hydraulic and/ or land-use contributing to the erosion. The categories used in the survey are the same as the primary causative factors, and

c) Contributing factors.

4.5.1 Causative factors

Causative factors are hydraulic processes and land-use activities that might cause erosion. They have been categorised as:

- Boat wake
- River and natural processes
- Water level variations
- Wave environment (i.e. wind generated waves)
- Removal of vegetation
- Vegetation load (new to 2012 survey),
- Stock access
- Other land-use (specified from the list of land-use activities).

River and natural processes are defined as erosion where river flow was visible or where no other external factor was apparent, i.e. considered to be a natural erosion process. This factor includes processes such as weathering and stress release jointing that leads to slabbing and spalling erosion, entrainment of particles from overland flow or seepage, sliding of weak materials on steep river banks, where no other triggering factors have been observed. This factor is strongly related to bank geology and bank geometry, i.e. erosion commonly occurred where steep banks consisted of loose unconsolidated granular materials. Other contributing factors are used to differentiate river processes and provide further information.

Water level variation is a natural process, but it is the only causative factor that is influenced by the Mighty River Power operations on the Waikato River. To generate electricity, water in each reservoir is passed through a turbine and flows downstream to the next reservoir or river section. The greatest rate of electricity generation typically occurs in response to peak times of electricity demand, on a twice-daily basis. At other times, the flow of water from each reservoir may be reduced to allow the reservoir to fill again. Therefore, the reservoir and river levels also vary in response to the electricity generation requirements, but remain within a range that is specified by the resource consents for the Waikato Hydro System. This rise and lowering of water levels in response to generation demand is known as 'ramping'. This survey has been commissioned to monitor the effect that operational ramping may have on the amount of erosion in the Waikato River, as part of the consent requirements.

It should be noted that natural water level variation also occurs, some of which is mitigated by the reservoirs, e.g. the reservoirs provide some storage capacity for flood events, resulting in less water level variation downstream than would occur naturally.

4.5.2 Contributory factors

Contributing factors are factors or natural processes which make the banks more susceptible to erosion but generally do not on their own cause active erosion. They have been identified as:

- Bank materials

- Bank slope and/ or height,
- Groundwater where wet bank sections are observed (seepage),
- Piping,
- Vegetation.

We note that there are some circumstances where natural processes such as groundwater seepage and piping can cause erosion; however for the purposes of this study they have not been grouped this way, in order to more clearly differentiate between natural and external causes. A distinction has been made between loss or loading of vegetation considered to have triggered movement and that considered to have contributed to movement.

4.6 Aerial photos and land-use categorisation

Analysis of the land-use at the top of the bank was carried out from aerial photographs. One set of aerial photographs was provided by Mighty River Power which records land-use in 2007. A second set of aerial photographs was obtained specifically for this project and records land-use in May 2012.

Land-use at the top of the bank was assessed along the whole of the river corridor between Taupo and Ngaruawahia. This exercise solely considered the use of the land above the river bank, not the vegetation growing on the river bank itself. Land-use was mapped using the following categories:

- Forestry
- Grazing
- Industrial
- Lifestyle
- Natural
- Orchard
- Recreational (domain)
- Seasonal cropping
- Urban.

4.7 Analysis methodology

To analyse the data spatially, the survey results were typically grouped by survey section. These sections are the same as those used in the 2006/2007 studies, and are shown in Table 4.2 and Figure 4.3. It should be noted that reach sections are of variable length, therefore data has been normalised to sites per kilometre or percentages, as appropriate. Survey section 8 (the Waipapa River) is a short length (5.6 km) and a statistic bias appears with the data in this reach.

In addition, results were analysed across the whole survey area for trends in selected parameters. Erosion parameters by site were also compared with land-uses and causative and contributory factors.

Statistics and spatial display of the data in GIS were used to establish trends.

Table 4.2: Summary of the 17 survey sections

Section number	Section name	Type	Total bank length (km) (sum of true left + right)
1	32.3 km from Karapiro to Ngaruawahia	River	44.4
2	11.8 km to 32.3 km from Karapiro	River	41.3
3	Karapiro to 11.8 km downstream	River	23.6
4	Lake Karapiro	Lake	71.8
5	Lake Arapuni	Lake	43.4
6	Arapuni River Section	River	15.5
7	Lake Waipapa	Lake	14.2
8	Waipapa River Section	River	5.6
9	Lake Maraetai	Lake	29.4
10	Maraetai River Section	River	8.5
11	Lake Whakamaru	Lake	33.9
12	Whakamaru River Section	River	16.5
13	Lake Atiamuri	Lake	25.9
14	Lake Ohakuri	Lake	115.0
15	River section between Aratiatia Dam and Lake Ohakuri	River	71.2
16	Lake Aratiatia	Lake	12.0
17	River section between Taupo Gates and Lake Aratiatia	River	12.6

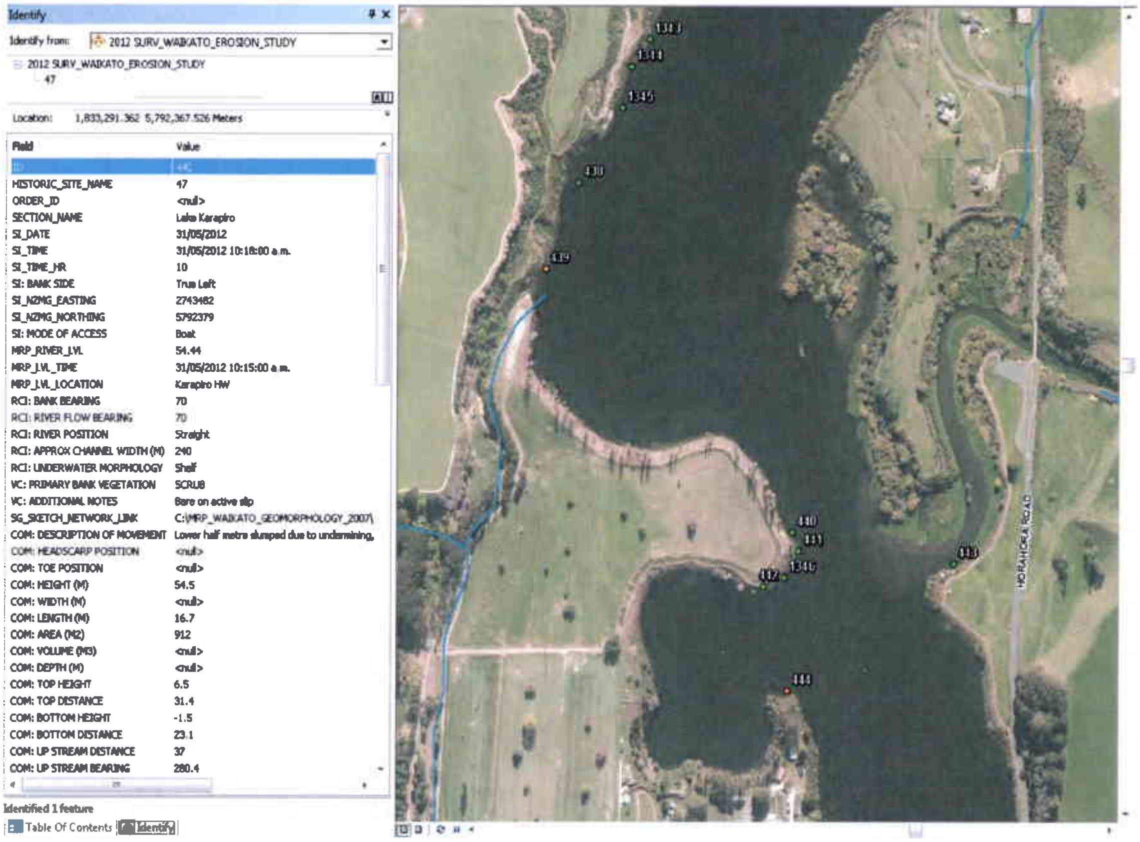

Figure 4.2: Screen shot of the GIS database

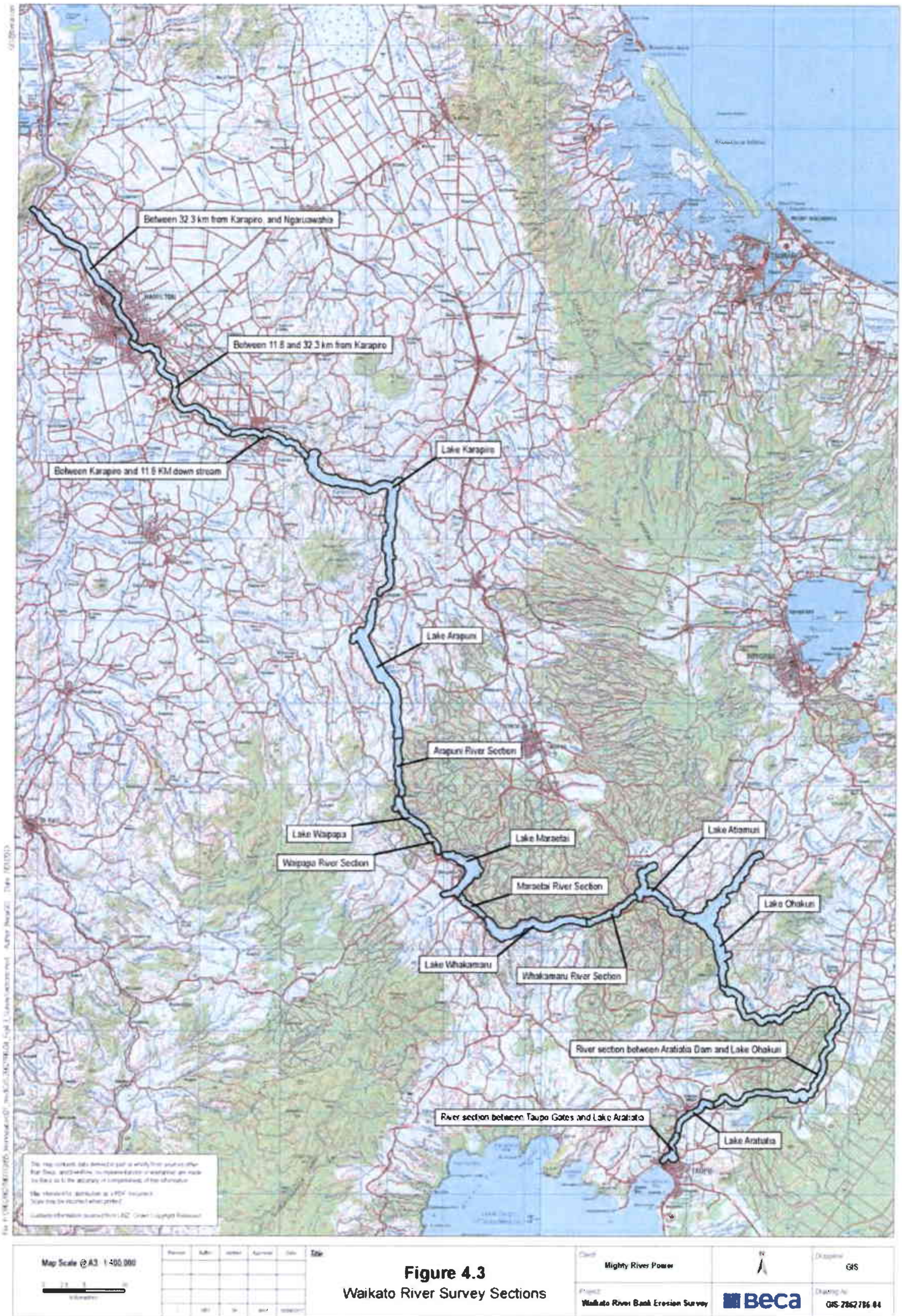

Figure4.3: Waikato River survey sections

5 2012 Erosion Survey Results

The 2012 survey results are discussed below, with emphasis on the active (<1 year old) and recent (1 – 5 year old) erosion. Section 6 of the report discusses how the patterns of erosion have changed over time.

5.1 Spatial distribution of erosion

The amount of erosion along the banks of the Waikato Hydro System can be described by the number of sites observed, the density of sites observed, or by the total area of erosion recorded. Over 1600 active, recent, or formerly recognised erosion sites were identified during the 2012 survey, of which 878 were active or recent erosion sites. A site plan showing the location, size, and age of all erosion sites is presented in Figure 5.1.

The active and recent erosion sites covered a total area of 208,273 m^2, which equates to approximately 5 % of the banks (with some assumptions about average bank heights as discussed in 6.2.7).

5.1.1 Age of erosion

The total number of erosion sites identified in each survey section is shown on Figure 5.2. Most erosion sites were either identified as active or older/ formerly recognised; 46 % of formerly recognised sites are considered active. Only 8 % of sites are considered to be 'recent', with activity that is more than 1 year old, but less than 5 years old.

The largest number of total erosion sites is in the river section between the Aratiatia Dam and Lake Ohakuri (section 15) with 424 sites (of which 215 are considered active). Other survey sections had significantly less erosion sites, each with less than half the total number of sites as section 15.

The sections with larger numbers of active and recent erosion sites are:

- Section 15 (river section between Aratiatia Dam and Lake Ohakuri) with 240 sites;
- Section 4 (Lake Karapiro) with 145 sites; and
- Section 14 (Lake Ohakuri) with 97 sites.

The sections with a significant number of old/ formerly recognised sites are:

- Section 15 (river section between Aratiatia Dam and Lake Ohakuri) with 184 sites; and
- Sections 1 to 3 (between Ngaruawahia and Karapiro Dam) with 116, 108 and 88 sites respectively.

5.1.2 Density of sites

The survey sections are not all the same length (refer to discussion in 4.7 above); therefore to compare the density of erosion across the Waikato Hydro System, the number of erosion sites per survey section were divided by the total length of the section.

The river section downstream of Lake Karapiro (section 3) has the highest density of erosion sites, with just over 6 sites per kilometre of river bank, although over half of these are formerly recognised and are no longer active.

Figure 5.3 and Figure 5.4 shows the density of active and recent erosion. All reaches have an erosion density (active or recently active sites) of less than 3.5 erosion sites per kilometre, with an average density of 1.4 sites per kilometre of bank length. The sections with greater erosion density of active and recent sites are:

- Section 15 (river section between Aratiatia Dam and Lake Ohakuri) with 3.4 sites per kilometre;
- Section 8 (Lake Waipapa) with 2.8 sites per kilometre; and
- Section 3 (Karapiro to 11.8 km downstream) with 2.5 sites per kilometre.

The frequency of active sites is considered to be moderate to high in terms of the Australian Geotechnical Society slope stability rating guidelines (AGS, 2007) and is similar to the 2007 baseline survey. Comparison of the 2012 and baseline survey is discussed further in section 6.

There is a significant erosion density correlation for active erosion sites between reservoirs compared to river sections. There are significantly more active and recent sites (20 % more) in the river sections compared to the lake sections, when considering total area of erosion and 27 % more erosion sites per kilometre length of river banks (63 %) compared to lake banks (36 %) when normalised by kilometre length.

5.1.3 Size of erosion sites

The size of erosion sites was assessed by calculating the surface area of each erosion feature from measurements made during the field survey. Figure 5.5, Figure 5.6 and Table 5.1 compare the total area of bank erosion (in m^2), by study area. Note that the erosion area was not able to be measured at 23 sites. The figures indicate that the majority of the measured erosion area is located in a small number of sections, particularly:

- Section 15, river section from Aratiatia Dam to Lake Ohakuri (by far the largest amount of erosion);
- Section 4, Lake Karapiro;
- Section 2 and 3, between Lake Karapiro and 32.3 km downstream; and
- Section 14, Lake Ohakuri.

These are some of the larger survey sections. The data has been normalised by dividing the measured erosion area by the length of the river bank within each section as presented in Figure 5.7 and detailed in Table 5.1. This shows that the greater area of erosions is found in three river sections of:

- Section 15 (river section from Aratiatia Dam to Lake Ohakuri);
- Section 8 (Waipapa River); and
- Section 3 (between Karapiro and 11.8 km downstream) has the greatest amount of erosion per km of river bank.

Section 8, the Waipapa River, is highlighted by this metric due to the short reach length of just over 5 km with one large erosion site. Both the normalised erosion density (sites per kilometre) and erosion area density (area per kilometre) have a similar ranking of survey sections.

Table 5.1 summarises the average and median area of erosion sites in each surveyed section and other key characteristics. It shows that the larger average areas of erosion occur in sections 5 to 8, from the Waipapa River to Lake Arapuni, as well as section 15 (river section between Aratiatia Dam and Lake Ohakuri) and section 3 (between Karapiro and 11.8 km downstream), with average areas in the range of approximately 300 m^2 to 500 m^2 per site. Normalised erosion area with bank length has a different distribution as discussed above.

Table 5.1: Measured area of active and recent erosion by survey section

Survey section	Total area of erosion (m^2)	Number of sites	Average area per site (m^2)	Median area per site (m^2)	Area by bank length (m^2/km)
1. 32.3 km from Karapiro to Ngaruawahia	4749	31	153	90	107
2. 11.8 km to 32.3 km from Karapiro	12761	62	206	66	309
3.Karapiro to 11.8 km downstream	17731	58	306	143	753
4.Lake Karapiro	29850	146	204	70	416
5.Lake Arapuni	9653	22	439	127	223
6.Arapuni River section	652	2	326	326	42
7.Lake Waipapa	5568	11	506	266	393
8.Waipapa River section	4778	16	299	113	846
9.Lake Maraetai	8103	32	253	72	276
10.Maraetai River section	395	4	99	62	46
11.Lake Whakamaru	8082	44	184	96	238
12.Whakamaru River section	8683	35	248	61	527
13.Lake Atiamuri	5293	40	132	77	204
14.Lake Ohakuri	14966	98	153	108	130
15.River section between Aratiatia Dam and Lake Ohakuri	74002	234	316	80	1039
16.Lake Aratiatia	2960	19	156	64	247
17.River section between Taupo gates and Lake Aratiatia	48	1	48	48	4
Sites where area was not recorded or could not be determined	N/A	23	N/A	N/A	N/A
Total	**208273**	**878**			

The ranking of the erosion sites and distribution by different size classes are shown in Figure 5.8 and Figure 5.9. There is a highly skewed distribution of erosion sites identified. The majority of active erosion sites surveyed are comparatively small and cumulatively make only a small contribution to the total erosion area. Conversely, the majority of the total recorded area of erosion is at a relatively small number of sites. Of the 855 active or recent sites, 774 were recorded as being less than 500 m^2 in area, with only 81 sites greater than 500 m^2. Only 19 (2 %) of sites were larger than 2,000 m^2 in area; these comprise nearly 30 % of the total recorded erosion by area. The largest recorded site is approximately 10,000 m^2 in area and is located in survey section 15; it is more than twice the size of the next largest erosion feature. More information on this site and other large sites is provided in Appendix A.

5.2 Erosion failure types

During the field survey, the mode of failure was described at each erosion site as: slide, scour, slab and spall, rockfall, flow and (tunnel) gully erosion. Definitions and examples of these failure modes can be found in the Erosion Inventory Manual. Slides have been separated into rotational and planar failures in this survey. The latter two categories (flow and gully erosion) occurred at a small percentage of sites, and have been grouped together as 'other' in the analysis.

Table 5.2 below, shows the number of sites and the average area of sites, by failure type. Slides are the most dominant erosion type (just less than 50 %). This includes both rotational and planar movements. About one third of the erosion sites have slab and spall erosion mechanisms, which is a function of stress release of the bank surface. Scour comprised about 10% of the erosion types identified. The table emphasises the relatively small site areas associated with scour erosion.

Table 5.2: Summary of erosion sites by failure type

Erosion failure type	Number of sites	Mean area per site (m^2)	Standard Error
Scour	53	91	14
Slab and Spall	340	199	22
Slide	441	295	34
Other	19	281	134
Not identified	2	114	26
Area not measured	23	-	-
Total	878		

Figure 5.10 shows a comparison of the erosion failure types per kilometre of study area. Key conclusions are:

- Slides are the most common failure type in all sections, except section 10 (Maraetai river);
- Slides are the dominant failure mechanism in the northern and central sections (sections 1 to 9),
- Slides are more common (approximately 25 %) in the lake banks than the river sections;
- Planar slides are significantly more (20 % more) prevalent than rotational slides;
- Slabbing and spalling failures are a common failure type in the sections downstream of Lake Karapiro (sections 1 to 3) and the dominant failure mechanism in the southern section upstream of Whakamaru (sections 12 to 16);
- Scour is more common in the central and southern sections (sections 7 to 17); and
- Rock fall is a minor (1 % of total sites) failure type, except in section 10 where 3 out of 4 failures are rock falls. Rock fall is more common from river banks than lake banks.

Figure 5.11 shows the distribution of failure types recorded with respect to site erosion size. A chi-squared test of the distribution provides strong statistical evidence of significant differences between the area categories (p-value 0.02). The figure shows fewer scour and slab and spall failure types with increasing area size and more slide type movements with increasing area size.

5.3 Erosion occurrence by geology

5.3.1 Geological units

Geological and Nuclear Sciences Ltd (GNS) publishes a 1:250,000 map series showing the surface geology across New Zealand, known as QMap. This map series has been updated and republished since the previous surveys. The database records the geological units along the banks of the Waikato River and reservoirs. This has been updated in 2012 to reflect the latest QMap geology. Conversion from older units to the new unit names is provided in the Erosion Inventory Manual. The 14 mapped geological units are briefly described in Table 5.3.

Table 5.3: Summary of geological and engineering geological units in the survey

Unit name	Unit Code (QMap)	Type of Deposit	Engineering Geological Description
Tauranga Group (undifferentiated)	Q1a	Unconsolidated silts, sands and gravels	Loose unconsolidated alluvial sands/gravels
Taupo Pumice Alluvium	Q1a - TPA	Unconsolidated pumiceous sands and gravels	Loose unconsolidated alluvial sands/gravels
Taupo Pumice Formation	Q1v	Non-welded Ignimbrite	Extremely weak-very weak non-welded Ignimbrites
Hinuera Formation	Q3a	Unconsolidated volcanic sands and gravels deposited by ancestral Waikato River	Loose unconsolidated alluvial sands/gravels
Oruanui Formation	Q3v	Non-welded Ignimbrite	Extremely weak-very weak non-welded Ignimbrites
Walton Subgroup	eQa	Pumiceous alluvium and colluvium primarily from rhyolitic sources	Loose unconsolidated alluvial sands/gravels, loose - medium dense unconsolidated airfall deposits, and firm to stiff weathered ash
Tauranga Group (Indurated lake sediments)	mQk	Lacustrine sandstone, siltstone and breccia	Extremely weak-very weak thinly bedded sandstone/siltstone
Maroa Group	Q3m-Q9m	Rhyolite	Moderately strong to strong slightly weathered massive Rhyolite
Ongaroto Group	mQn	Undifferentiated Rhyolite lava and pyroclastic deposits	Moderately strong to strong slightly weathered massive Rhyolite
Mokai Formation	Q7m	Poorly welded ignimbrite	Weak to strong welded Ignimbrites
Kaingaroa Formation	Q7k	Welded Ignimbrites	Weak to strong welded Ignimbrites
Ohakuri Formation	Q7o	Massive to flow banded ignimbrite	Extremely weak -very weak non-welded Ignimbrites
Whakamaru Group	Q9w	Non-welded to welded Ignimbrite	Weak to strong welded Ignimbrites
Mangaokewa Formation (Part of	eQo	Non-welded Ignimbrite	Extremely weak -very weak non-

Pakamanu Group)			welded Ignimbrites
Pakaumanu Group (not including eQo)	eQp	Welded Ignimbrites	Weak to strong welded Ignimbrites
Manaia Hill Group	Jm	Greywacke	Extremely weak-very weak weathered highly fractured Greywacke & moderately strong to strong unweathered fractured Greywacke

Figure 5.12 shows the surface geology of the Waikato Hydro System, extracted from the QMap geological map.

Appendix B identifies the spatial distribution of the erosion sites with the mapped geology and engineering geological material identified. Figure 5.13 summarises the percentage of erosion sites within each mapped geological unit overall and Figure 5.14 summarises by survey section. The majority (just over 60 %) of the active and recent erosion is within the reworked alluvial deposits from the Taupo and Oruanui eruptions, whilst a further 20 % has occurred within the non-welded ignimbrites (pyroclastic deposits) derived from these eruptions. About 10 % of the erosion has occurred in older soil-like deposits comprised of non-welded ignimbrites and sediments. Some 10 % of erosion has occurred in rock units, mostly in the indurated lake sediments (previously known as the Huka Group).

5.3.2 Engineering geological units

Engineering geological units are a classification of bank materials into behavioural types, as opposed to geological units that classify materials based on their age and source of deposition. Engineering geological units have been identified in this survey in order to:

a) Group materials that have a similar behaviour in a slope; and

b) Identify the specific material type that is eroding.

The geological maps broadly identify the soil or rock at the surface, however geology may vary with depth and therefore vertically down the river bank. Geological units may be difficult to distinguish from a boat, but the engineering geological units are more easily identified. Geological units are stratigraphically identified, and can include a range of different engineering geological units. This means that the engineering geological units are a useful grouping of geological units.

Figure 5.15 provides the distribution of engineering geological units at erosion sites, by survey section. Almost all (97 %) of the erosion sites are within soils (including non-welded ignimbrites), with only 3 % of the sites in rock masses. By contrast, 10 % of the sites are mapped as a rock geological unit. Therefore, 7 % of erosion occurs in clays and silts derived from weathering of the mapped geological rock units (i.e. the bank is mapped as rock but the material in which the erosion has occurred is the soils weathered from the rock).

There is a close correlation of erosion with the mapped reworked alluvial deposits (geological unit) and observed loose granular soils (engineering geology unit), with 62 % of the sites in these materials.

5.4 Erosion occurrence by bank slope, class, and position

5.4.1 Bank slopes and aspect

The slope of the bank was recorded at each erosion site, during the field survey. Figure 5.16 shows that erosion occurs on banks of all angles, with slightly more erosion on banks of 45° to 75°. In general the survey results showed *no significant* statistical relationship between bank slope and erosion area size. However the frequency of sites on steeper (> 60°) banks is more than 1 per kilometre in section 15 (river section between Lake Ohakuri to Lake Aratiatia) and section 3 (river section from Karapiro to 1.8 km downstream).

No statistical relationship was found between river bank aspect and erosion frequency.

5.4.2 Bank classes

Previous studies identified five generalised bank conditions based on bank slope, bank materials and types of erosion (Beca 2008). These bank morphology classes A to E are defined in the Erosion Inventory Manual. They range from:

- Class A: wide alluvial platforms with gently inclined slopes and surficial erosion;
- Class B: moderately steep banks of consolidated alluvium or weak (soil-like) rock, typically with shallow erosion varying from slabbing to slides;
- Class C: very steep slopes comprised of rock with rock falls and slabbing erosion; and
- Class D to E: comprised of bedded heterogeneous materials of varying erosion resistance and failure mechanisms.

Table 5.4 shows the number of sites and mean area of sites that occur within each bank class type. The majority (90 %) of the recent and active sites (777) are either Class A or B, which characterises erosion as primarily occurring in the unconsolidated weak soils of varying bank morphology, from gentle to steeply inclined. Almost 50 % of the sites are identified as within low banks (typically < 1 m high) with slopes generally of less than 60°. This indicates that the bank height and slope is not generally a primary factor in the frequency of erosion. Instead, the unconsolidated weak nature of the soils is a significant factor.

Figure 5.17 shows the distribution of bank classes at each erosion site, by survey section. It shows generally similar ratios of Class A and B sites across the whole survey area, but most of the class D sites clustered in Section 15 (the river section between Aratiatia Dam and Lake Ohakuri).

Figure 5.18 shows a comparison of the bank classes and erosion site size. The chi-squared test indicates there is strong statistical evidence for the difference in site surface area between the bank classes (p-value 0.031). The figure shows a similar proportion of erosion sites that are Bank Class A for the three area size classifications. However, sites with a large erosion area (> 400 m^2) have a lower proportion of Class B sites and a higher proportion that are Class C. A summary of the mean site erosion area with respect to bank class is presented in Table 5.4.

Table 5.4: Summary of erosion sites by bank class

Bank Class	Number of Sites	Mean area per site (m^2)	Standard Error
Bank Class A	411	286	37
Bank Class B	353	177	15
Bank Class C-E	87	315	54
Not identified	4	219	91
Area not measured	23	-	-
Total	878		

5.4.3 Failure types by bank class

There is a strong correlation between the type of erosion, and bank class. A comparison of the cross-tabulated frequencies using a chi-squared test provides strong evidence of significant differences between the distributions (p value < 0.001). Figure 5.19 compares the bank class and the failure types, and shows that Bank Class A has predominately slide failures, while Bank Class B has predominately slab and spall type failures.

5.4.4 Position in relation to adjacent river channel form

On river sections of the field survey, the position of each erosion site was logged with respect to the river channel, i.e. either on the inside bend, outside bend, or on a straight section of river.

Figure 5.20 shows the morphology of all active, recent and formerly recognised erosion sites within the river sections. This indicates that only a very few river erosion sites (7 %) are located on inside bends, 20 % on outside bends and over 70 % on straight sections of the river. The percentage of erosion on outside bends was highest in the Lower Waikato river (section 1 to 3, Karapiro Dam to Ngaruawahia), the Whakamaru River (section 12), and the river section between the Aratiatia Dam and Lake Ohakuri (section 15).

The survey results showed no evidence of a significant relationship for river sections between the site's river morphology (i.e. the site location on a straight section, inside bend or outside bend) and erosion *area size*.

The position on the river was compared with the failure types at each erosion site, as is shown in Figure 5.21. A comparison of the cross tabulated frequencies using a chi-squared test provide evidence of a significant difference between distributions (p value = 0.001). The main variance between site river morphology and erosion type is the proportionally higher number of sites on the inside bend for which scouring is identified as the erosion type. There is no strong indication of a significant difference between the distribution of outside bend and straight section erosion failure types (p value = 0.13).

5.4.5 Erosion site position in relation to water level

During the field survey, the height of each erosion site in relation to the water level was recorded. Almost all erosion sites were recorded within 1 m of the water level during survey. The water level during the survey has not been adjusted for daily variations, as water levels during the survey period were within the 'normal' range, which is generally ± 1 m.

Figure 5.22 shows the percentage of total erosion sites where the lowest point of the surveyed erosion feature is within 1 m of the water level.

Figure 5.23 shows the number of erosion sites within each survey section that are within 1 m, 1 to 3 m, and more than 3 m above the water level. Most sections were almost entirely made up of erosion sites that extend to within 1 m of the water level. A minor number of sites with erosion occurring more than 3 m above water level occurred in the following sections:

- section 15 (river section between Aratiatia Dam and Lake Ohakuri); and
- sections 3 and 4 (Karapiro Lake to 11.8m downstream of Karapiro).

5.4.6 Bank height relationship

The survey has grouped banks into three size categories, being:

- Less than 5 m high;

- 5 to 20 m high; and
- Greater than 20 m.

The height of the bank at the erosion sites as a percentage is shown in Figure 5.24. Sections with a greater proportion of high banks are:

- Section 10 (Maraetai River Section): 100 % (four) of active/ recent sites in this area are on banks greater than 20 m in height;
- Section 6 (Arapuni River Section), two active/ recent sites, one > 20 m high, the other 5 to 20 m high; and
- Section 3 (Karapiro to 11.8 km downstream), there are 59 active/ recent sites with 85 % being on banks that are more than 5 m high.

Sections 6 and 10 have the lowest number (6 in total) of erosion sites in the survey. The low erosion rate and high banks in these sections occur because the banks are comprised primarily of rock. Of interest is the greater bank height at erosion sites in section 3. Section 3 erosion sites are more commonly occurring in older and stronger alluvial and volcanic soils than at river sites further downstream and there is a slightly greater presence of erosion at the top of the bank than in other sections.

Bank heights vary across the surveyed sections, with erosion occurring in higher banks in the northern and central river sections (sections 1 to 6, 8 and 10) and on lower banks of the southern lake sections (11-17). A survey of all the bank heights (irrespective of if erosion was present) was not completed, so the erosion occurrence data cannot be normalised by the percentage of high, medium of low banks in each section.

5.5 Causative and contributory factors to erosion

As discussed in Section 4.5, the primary causative factor, other causative factors, and contributory factors were recorded for each erosion site.

5.5.1 Causative factors

Figure 5.25 shows the overall distribution of primary causative factors, and Figure 5.26 shows the total distribution of primary causative factors for active and recent sites in 2012, as well as those active or recent in both 2012 and 2007. River (and natural) processes are by far the greatest primary causative factor that has triggered movement. River processes were the primary causative factor in 65 % of erosion sites (including those formerly recognised) and in over 50 % of the active and recent movements observed in 2012. Wave environment followed by vegetation (both removal and loading) are the next most common causative factors (20 % and 16 % respectively) of active erosion in 2012. Land-use and boat wakes comprise just over 5 % of the erosion in 2012, and water level variation just under 5 %.

Figure 5.27 compares the primary causative factor and erosion type. Boat wake and land-uses are the primary causative factors triggering scour. Vegetation removal and vegetation loads appear to result in slide type movements. Water level variation, river processes, wave environment and land-use are also common causes of slide movements. Slab and spall movements are commonly triggered by river (and natural) processes, wave environment, and boat wake.

Figure 5.26 shows the primary causative factors by survey section, of erosion sites normalised by kilometre. The following observations are made:

- River and natural processes are considered to be the most significant causative factor in the river sections downstream of Lake Karapiro (sections 1 to 3);
- River and natural processes are also the most significant causative factor in the river sections 15 (between Aratiatia Dam and Lake Ohakuri) and section 12 (Whakamaru river section); and is a prominent factor at section 8 (Waipapa river section);
- Natural processes comprise some 5 % to 15 % of erosion sites in the lake sections;
- Wave environment is shown to be a significant causative factor in the central reservoirs of sections 4 (Lake Karapiro), section 9 (Lake Maraetai), section 11 (Lake Whakamaru) and section 14 (Lake Ohakuri);
- Boat wake is a significant causative factor in section 16 (Lake Aratiatia) and is a minor causative factor in section 4 (Lake Karapiro), reflecting the high frequency of boating activity in these sections;
- Vegetation load is a more significant causative factor in section 15 (river section between Aratiatia Dam and Lake Ohakuri) than in other sections;
- Vegetation removal is a more significant causative factor in section 4 (Lake Karapiro) compared to any other surveyed sections;
- Land-use including stock access, whilst not a significant factor (< 2 %), is a greater component of both primary and other causative factors in the upper reaches (sections 16 and 17, between Taupo Gates and Aratiatia Dam), compared to other sections of the survey;
- Water level variation is a minor causative factor being attributed to less than 5 % (68 erosion sites) of the total sites and 4 % (36 sites) of the active and recent erosion in the 2012 survey; and
- Water level variation is the most common causative factor in the central river and lake reaches, in particular sections 7 and 8 (Waipapa river and lake). However, there is very little erosion in these two sections, with only 24 sites caused by water level variation (out of a total of 37 sites).

5.5.2 Other causative factors

More than one causative factor (a principal and other factor) can be selected at each site. Table 5.5 compares the percentage of sites attributed to "other causative factors" with the principal causative factor. The ranking of these factors generally mirrors the primary causative factors, although it can be seen that water level variation influences a greater percentage of sites than vegetation removal or loading.

Table 5.5: Comparison of % of principal factor and other causative factors

Causative Factor	Principal (%)	Other (%)
River processes	55	52
Wave environment	23	27
Vegetation (removal and load)	8	5
Water Level variation	5	14
Landuse	2	1
Stock Access	<1	1

5.5.3 Contributory factors

Figure 5.29 shows the contributory factors recorded for each erosion site summarised by the whole survey area, and Figure 5.30 summarises by survey section. The figures indicate that:

- Bank materials are a dominant contributing factor in every section, excluding Maraetai River (Section 10), contributing in 72 % of the erosion sites;
- Bank height contributes to a quarter (25 %) of the erosion sites and these sites are more common in section 15 (between Aratiatia Dam and Lake Ohakuri), section 3 (between Karapiro and 11.8 km downstream) and section 14 (Lake Ohakuri);
- Vegetation including loading contributes to 16 % of the active and recent sites, mostly in section 15 (between Aratiatia Dam and Lake Ohakuri); and
- Groundwater (seepage) and piping was noted to be a contributing factor at a small number of sites (as for previous surveys). On average less than 2 % of the 2012 sites were attributed to these factors. Groundwater seepage is more prevalent in the banks of Lake Karapiro and the river banks up to 11.8 km downstream (sections 3 and 4). It is possible that the effects of groundwater and surface water erosion at the top of the bank have been underestimated due to the dry conditions at the time of the survey;

5.6 Erosion occurrence by land-use

As discussed in Section 4.6, the 'top-of-bank' land-use was categorised throughout the Waikato Hydro System by reviewing aerial photos from 2007 and 2012. Graphs showing the length of bank within each land-use category are presented in Figure 5.31 for 2007 and Figure 5.32 for 2012.

5.6.1 Changes in land use since 2007

Figure 5.33 shows the changes in land-use between 2007 and 2012. The length of bank in each survey section where the type of land-use has reduced is shown below the x-axis, and where it has increased is shown above the x-axis. For example, in survey Section 5 (Lake Arapuni), there was an increase in seasonal cropping of approximately 3 km of river bank, made up mostly from a reduction in forestry and grazing. A total of 10 km of bank length was identified to have undergone a change in the land-use over the 5 year period, representing less than 2 % of the total bank length surveyed.

However; it should be noted that there are potential sources of error in these calculations; the resolution of the 2012 images is higher than those from 2007 and there is an element of subjectivity when assessing the difference in categories, for example the difference between seasonal cropping and grazing. It should also be noted that the analysis is based on a snapshot of land-use at 5 year intervals and the land may have been used for other activities in the intervening periods.

5.6.2 Correlation between changes in land use and erosion

Table 5.6 summarises the number of erosion sites with respect to whether a change of land-use occurred, and in relation to the age and activity status of the erosion. In the table, the age/status of erosion sites has been categorised as being either:

1) Sites which were logged as active or recent in the 2012 survey, but were not identified in the previous 2007 survey (i.e. newly identified sites);

2) Sites which were logged as active or recent in the 2012 survey, and were also identified in the previous 2007 survey (i.e. sites with on-going erosion); and

3) Sites which were identified as being active during the 2007 survey but were not in the 2012 survey (i.e. sites where erosion has stopped since 2007 and the area is re-vegetating).

Sites which could not be clearly classified into the above three categories were excluded from the table.

Table 5.6 shows that the proportion of the sites where land-use change has occurred is similar for the three site age categories, being consistently 7%. The results indicate at sites where erosion has occurred land-use change between 2007 and 2012 is not in itself a strong indicator of activity status of the erosion site (i.e. whether it is a new erosion site in 2012; the prolonging of an erosion activity at an existing site between 2007 and 2012, or the cessation of an erosion activity recorded in 2007). The results also suggest that even when river and lake sections are considered separately, land-use change is not correlated to the activity period of erosion site.

Table 5.6: Number of erosion sites with respect to erosion age and activity, and land-use change status

Erosion age and activity	Change in site land-use		Total	Proportion of land use change during activity period (%)
	No	Yes		
2012 only - Newly identified sites	413	33	446	7.4%
2012 and 2007 – Sites with on-going erosion	410	29	439	6.6%
2007 only – Erosion has stopped	566	41	607	6.8%
Total	**1,389**	**103**	**1,492**	

5.6.3 Comparison between changes in land use to grazing and erosion

Changing land use to grazing can sometimes be associated with an increase in erosion, if vegetation has been removed in the process. The relationship between the change in land-use to grazing and the number of erosion sites is shown in Table 5.7. The results also show no strong statistical evidence (p-value 0.477) to indicate that the distribution of erosion sites where a land-use change specifically to 'grazing' different in the last 5 years from earlier surveys.

Table 5.7: Number of erosion sites with respect to erosion age and activity and land-use change to 'grazing' status

Erosion age and activity	Change in site land-use to 'grazing'		Total
	No	Yes	
2012 only - Newly identified sites	433	13	446
2012 and 2007 – Sites with on-going erosion	431	8	439
2007 only – Erosion has stopped	595	12	607
Total	**1,459**	**33**	**1,492**

5.6.4 Comparison between changes in land use and erosion area size

The number and surface area of active erosion sites in 2007 with respect to land-use change is given in Table 5.8. Statistical comparisons of the mean areas (using a t-test assuming an unequal variance between means) provide only very weak statistical evidence (p-value 0.0718) that the mean area of erosion sites is greater at those sites where there has been a land-use change. The level of statistical significance is higher than the commonly used threshold of 0.05.

Table 5.8: Amount and size of erosion active sites with respect to land-use change status

Land-use change status	Number of sites	Mean area per site (m^2)	Standard Error
No land-use change	788	218	16
Land-use change	59	562	187

The table excludes 8 sites which were not classified in all three activity periods. The inclusion of these sites would change the mean area of 'no land-use change' sites to 220 m^2. The table also excludes the 23 sites for which an erosion area was not calculated.

5.6.5 Comparison between changes in land use and primary causative factor

The survey results suggest that the distribution of primary causative factors at sites that were active (or recent) in the 2012 survey vary according to whether there has been a change in the land-use of the site between 2007 and 2012 (Pearson chi-squared p-value <0.001). The results indicate that for sites where a land-use change has occurred, there is a proportionally higher number of sites which identify 'vegetation removal' as a principal causative factor.

5.6.6 Comparison of erosion frequency in relation to land use types

Figure 5.34 displays the frequency distribution of active and recent erosion sites identified in 2012 with respect to land-use classifications and compares the observed frequency with an 'expected' distribution (based on the proportion that the land-use type occupies along each side of surveyed bank). The figure shows there is evidence of significant difference between observed and expected erosion site land-use distributions (Pearson chi squared p-value 0.027). Differences are largely associated with the greater than expected number of erosion sites at grazing and seasonal cropping land-uses, and a lower than expected number of erosion sites and natural land-uses.

Differences between observed and expected land-use distribution are more statistically significant on the river sections (p-value <0.001) than the lake sections (p-value 0.56). Figure 5.35 shows the same data, for river sections only.

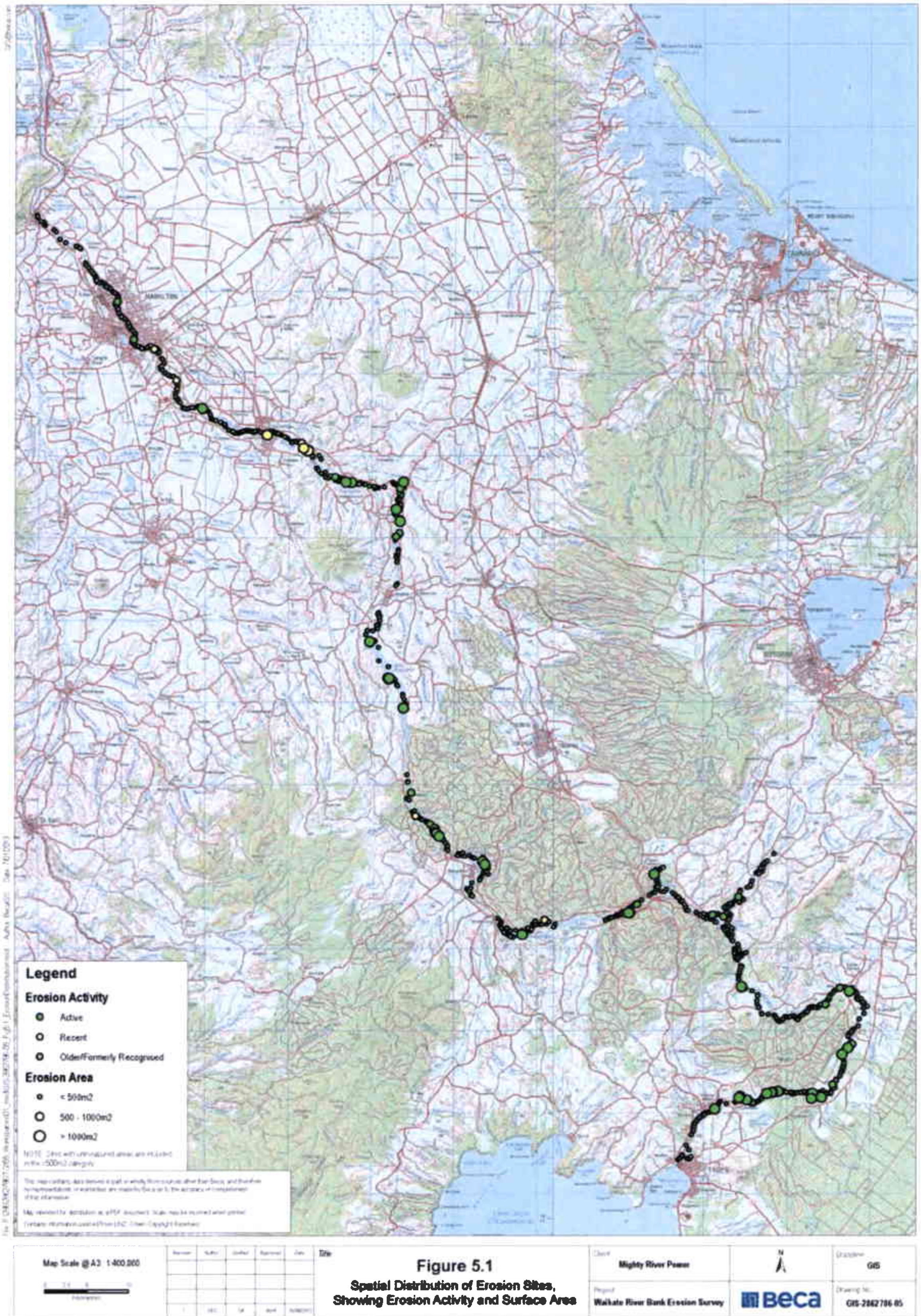

Figure 5.1: Spatial distribution of erosion sites, showing erosion activity and surface area

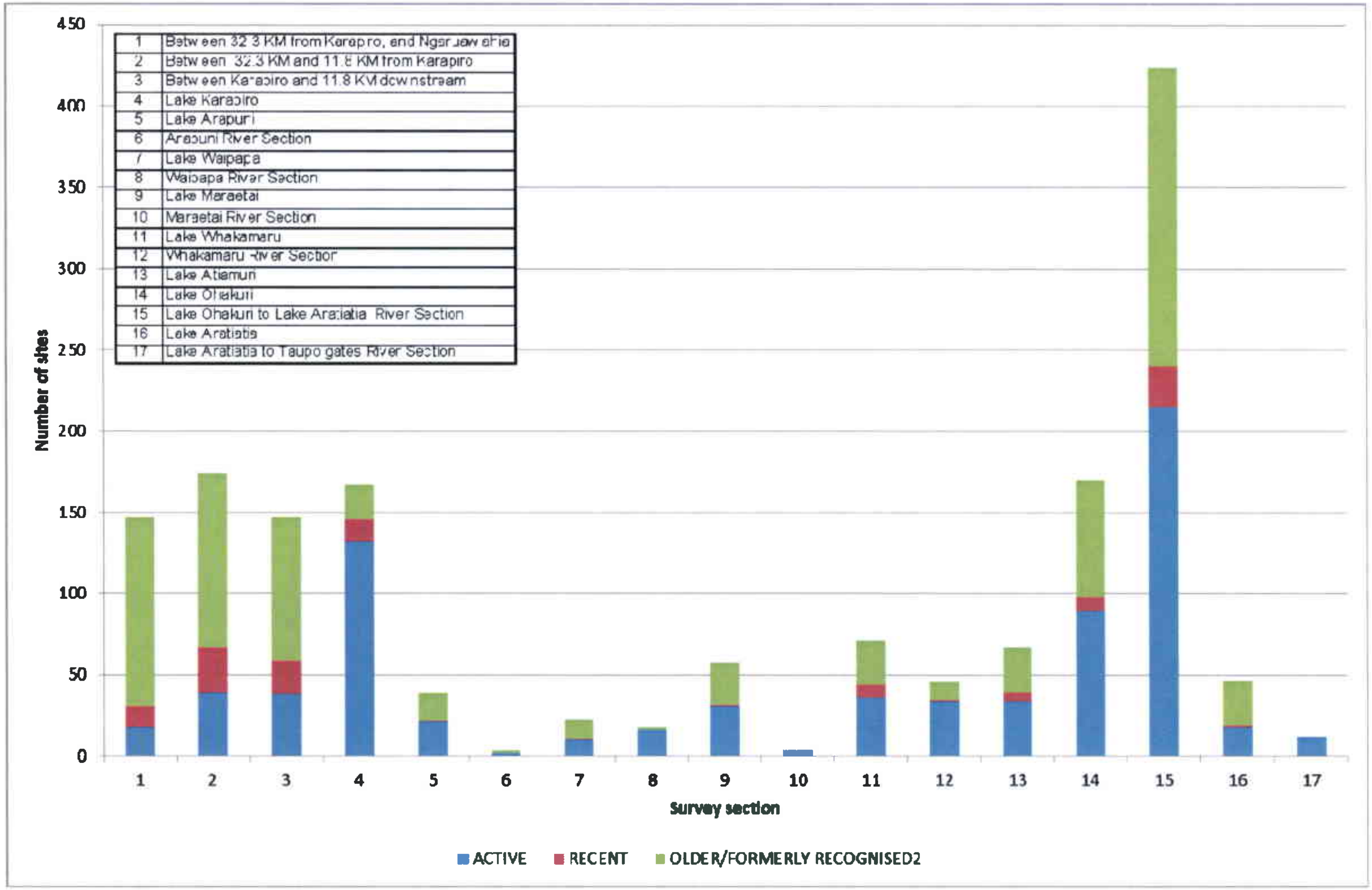

Figure 5.2: Graph of the number of erosion sites, by survey section

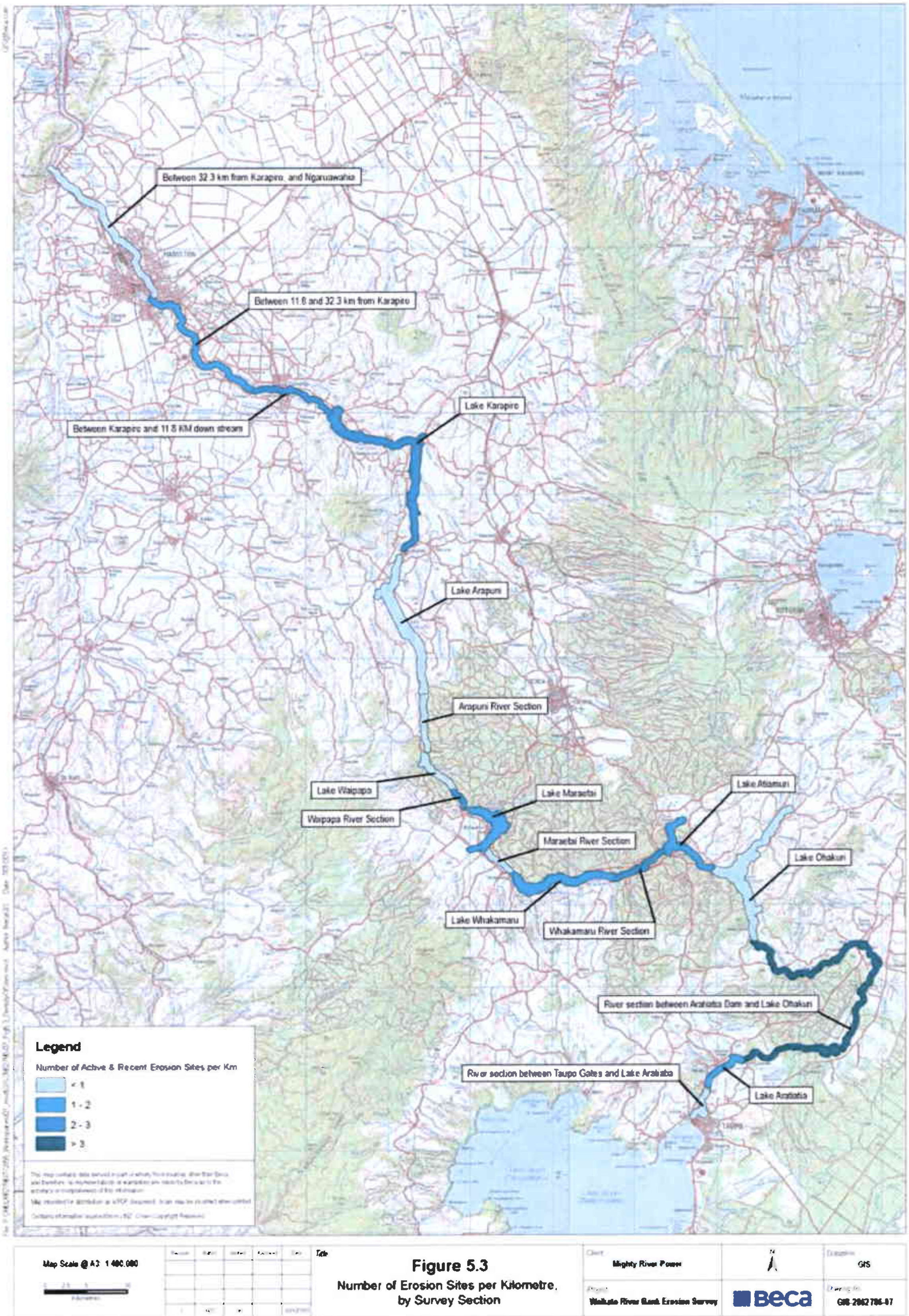

Figure 5.3: Number of erosion sites per kilometre, by survey section

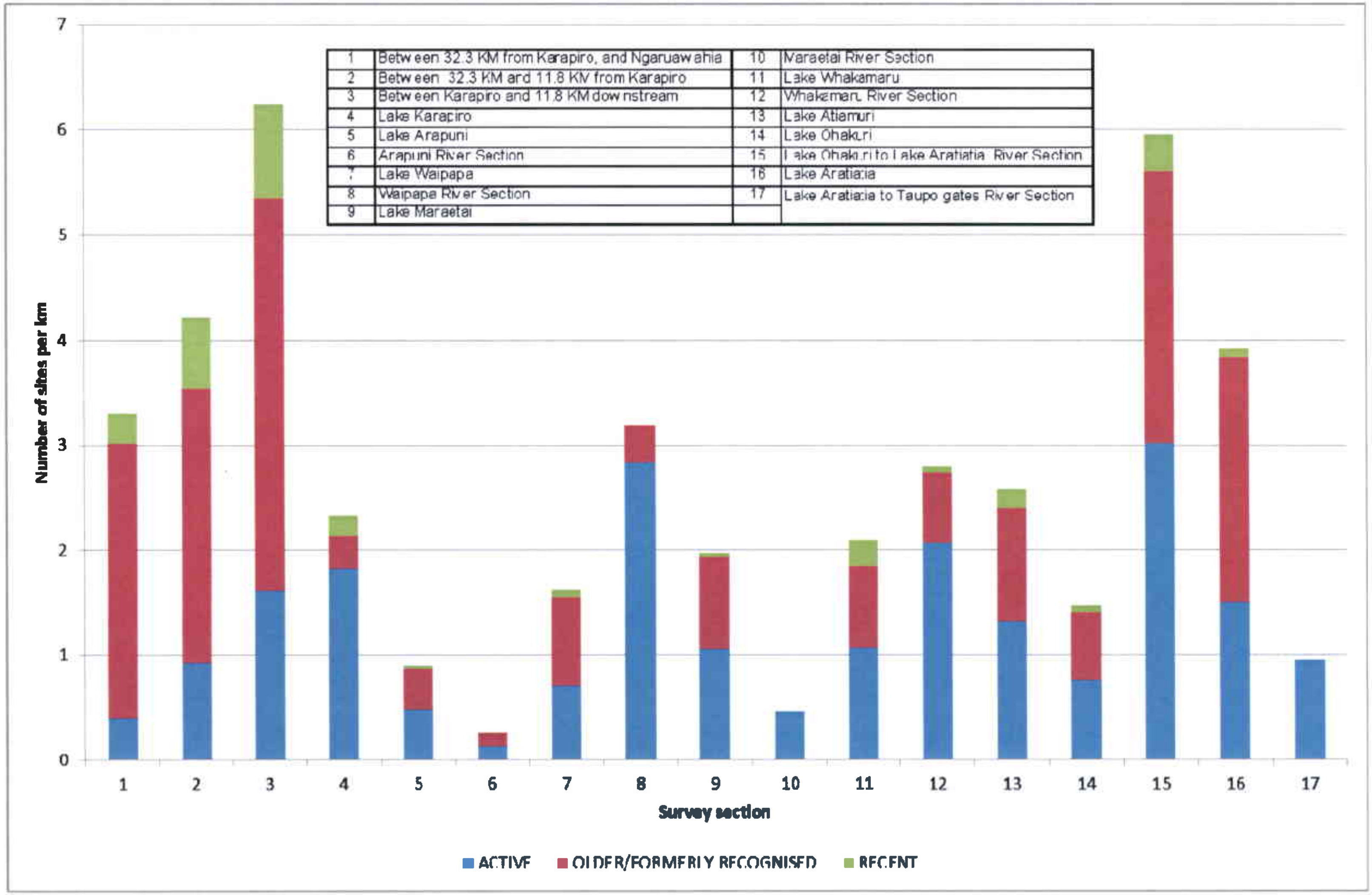

Figure 5.4: Graph of the density of sites per kilometre, by survey section

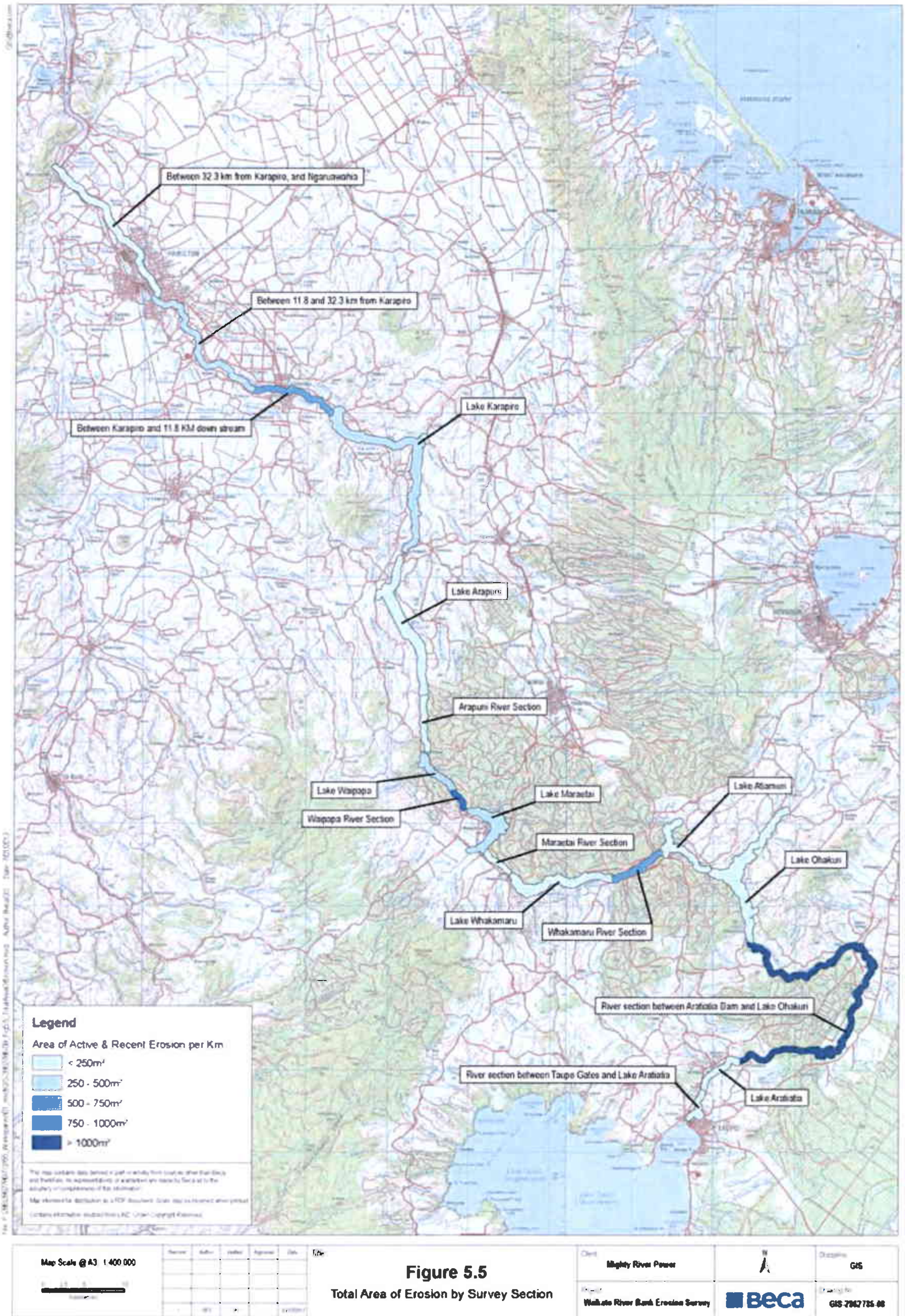

Figure 5.5: Total area of erosion, by survey section

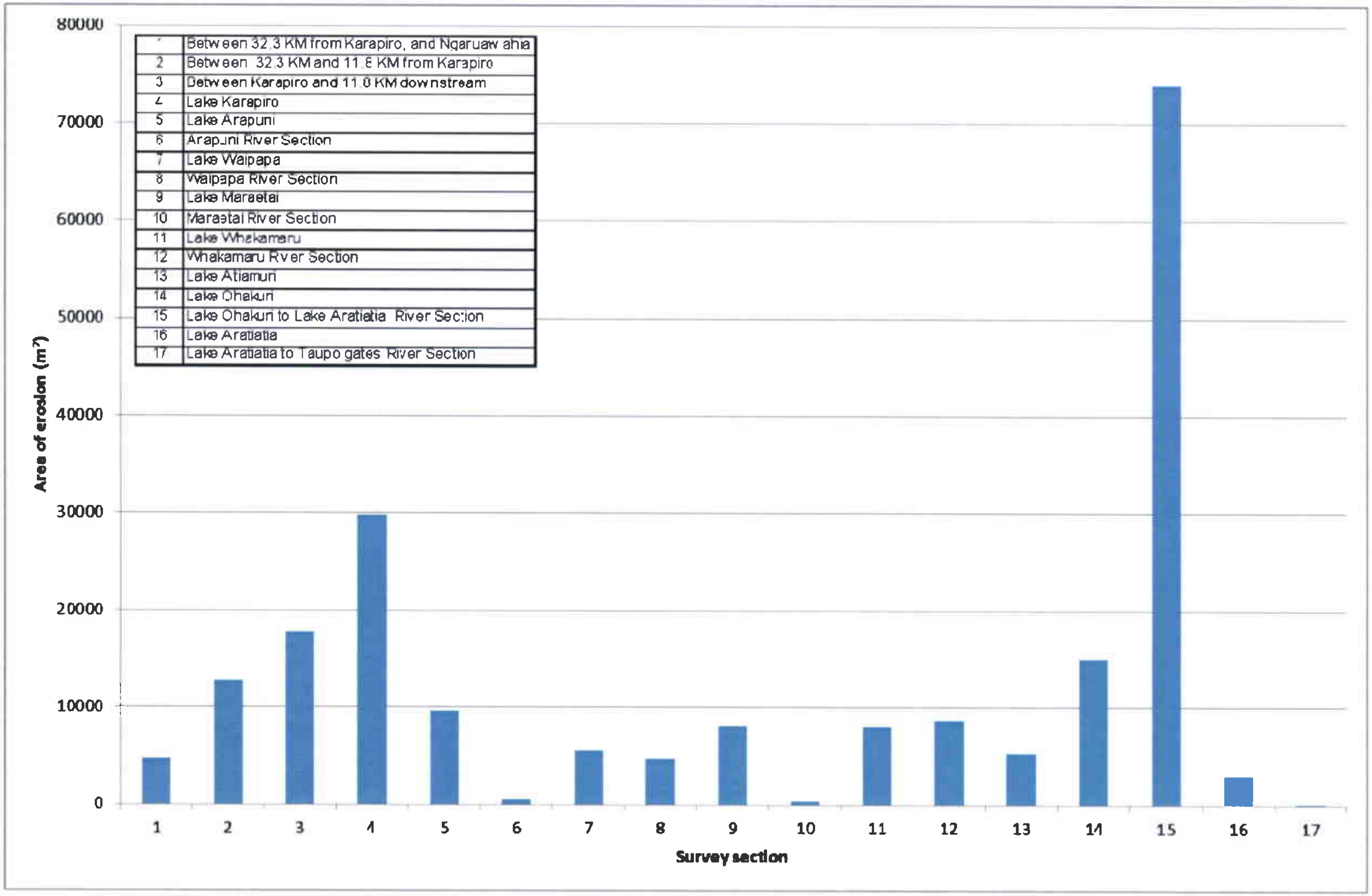

Figure 5.6: Graph of the total area of erosion, by survey section

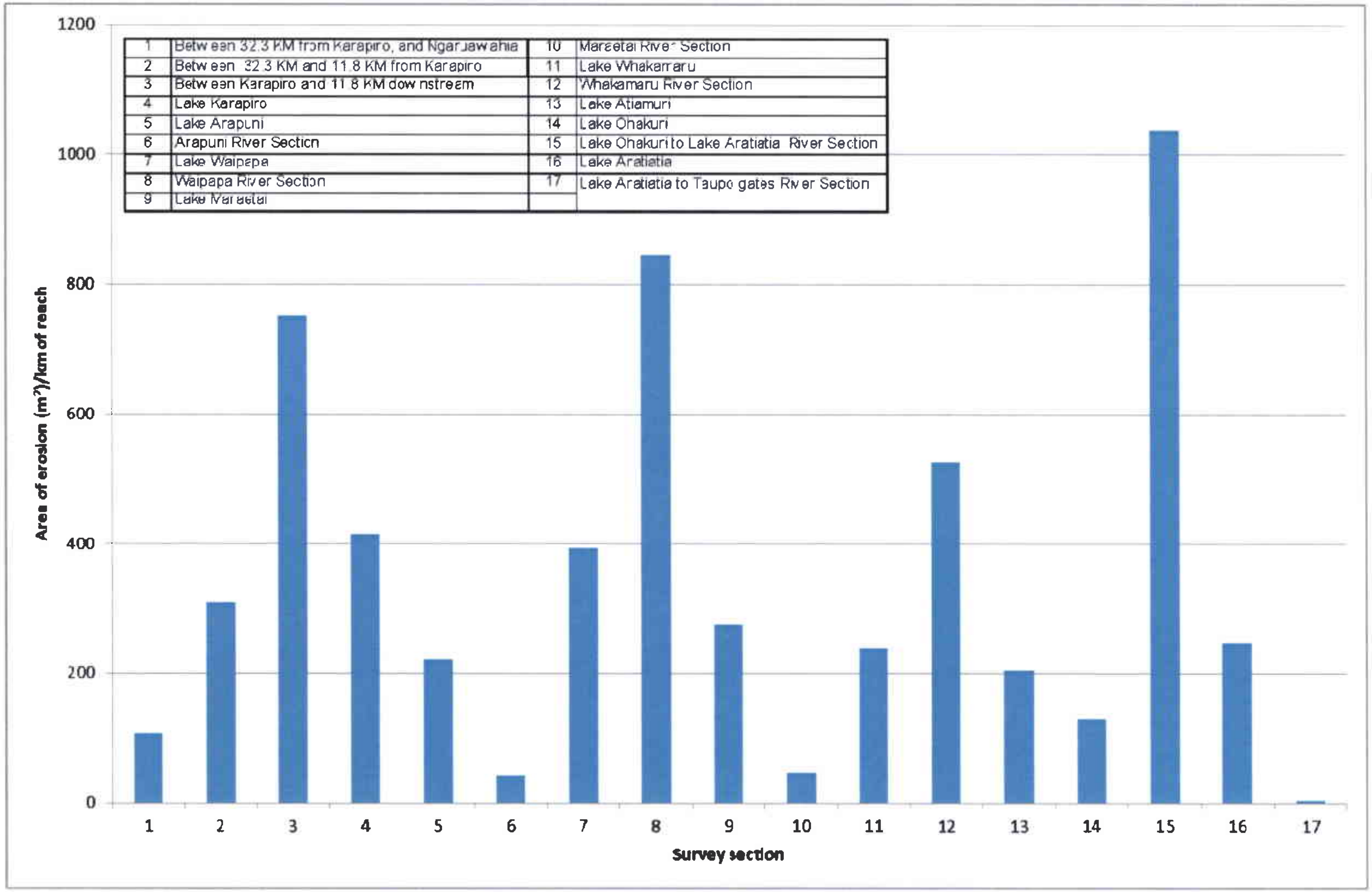

Figure 5.7: Graph of the area of erosion per kilometre, by survey section

Figure 5.8: Graph of the ranked distribution of erosion sites, by erosion site size

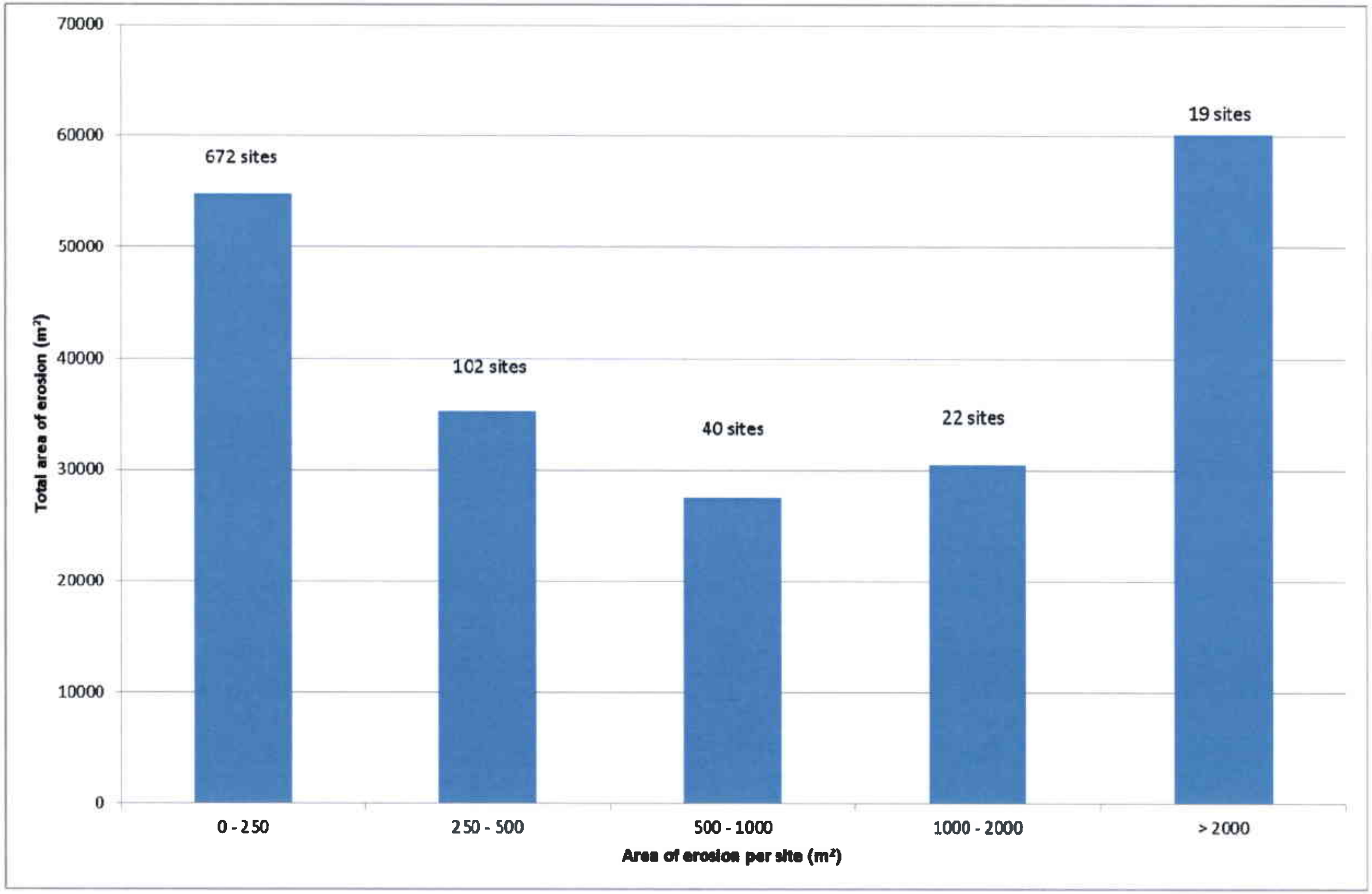

Figure 5.9: Graph of the total area of erosion, by erosion site size

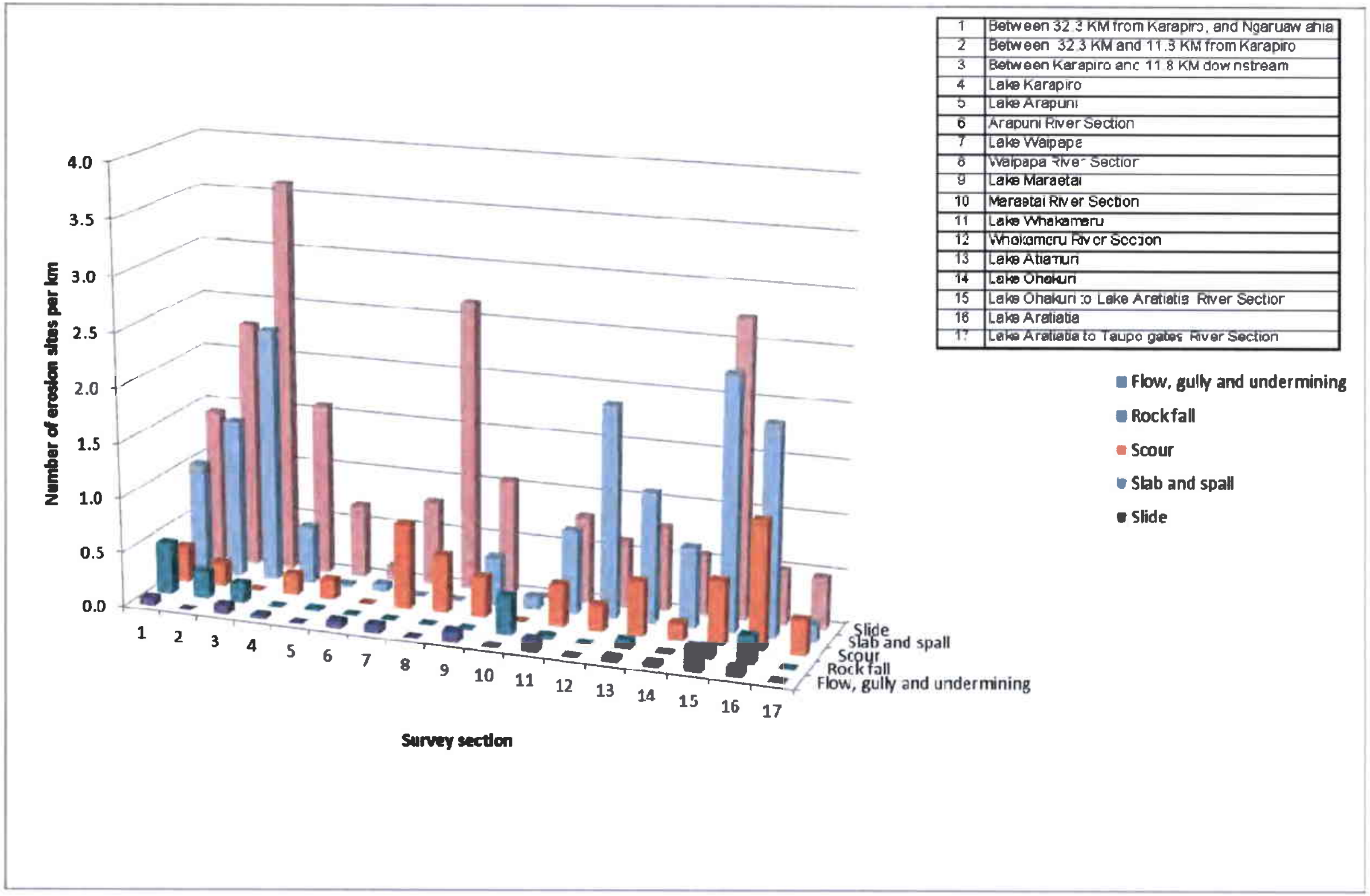

Figure 5.10: Graph of the erosion failure type by kilometre, by survey section

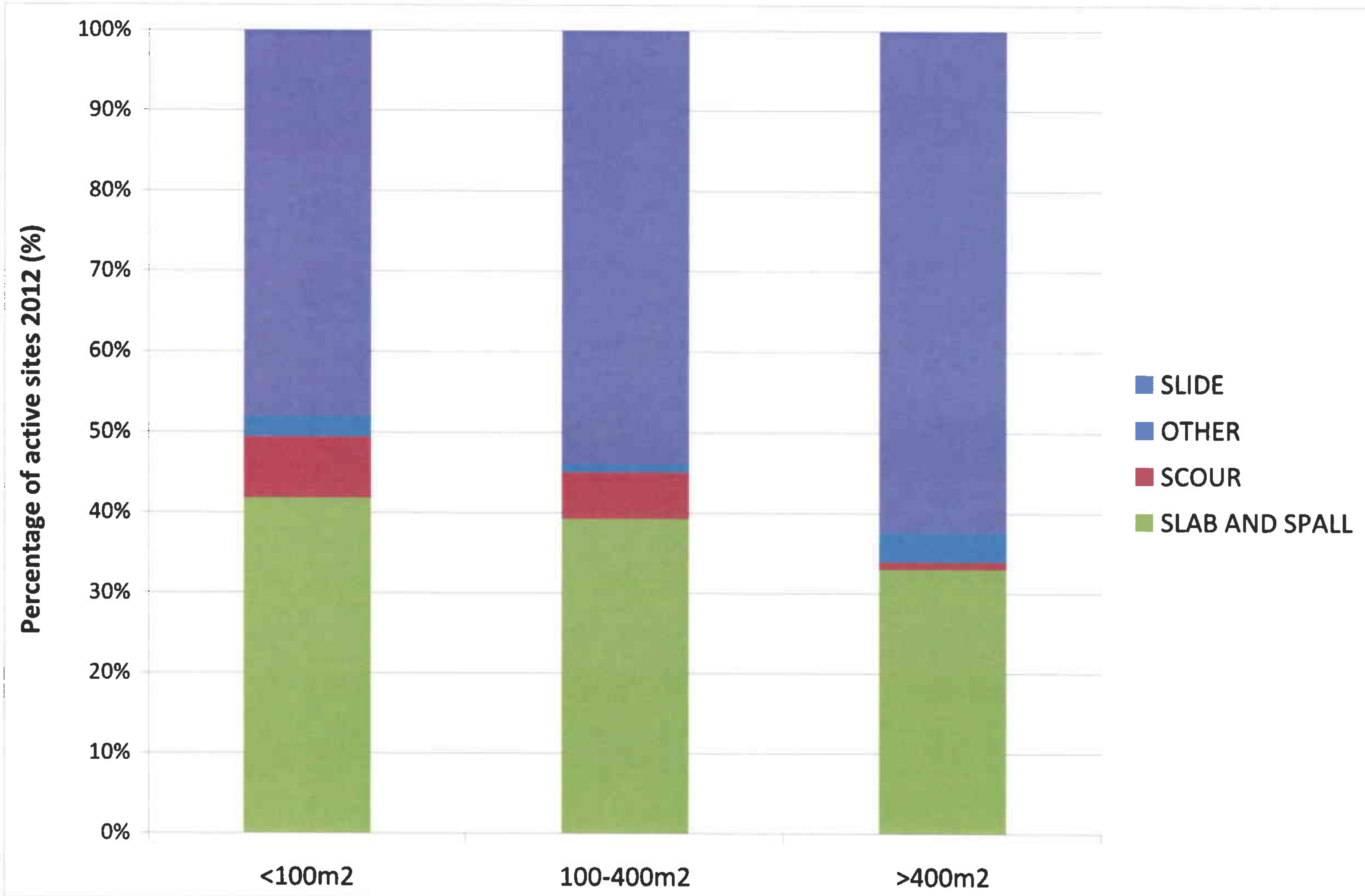

Figure 5.11: Graph of erosion failure types, by erosion site size

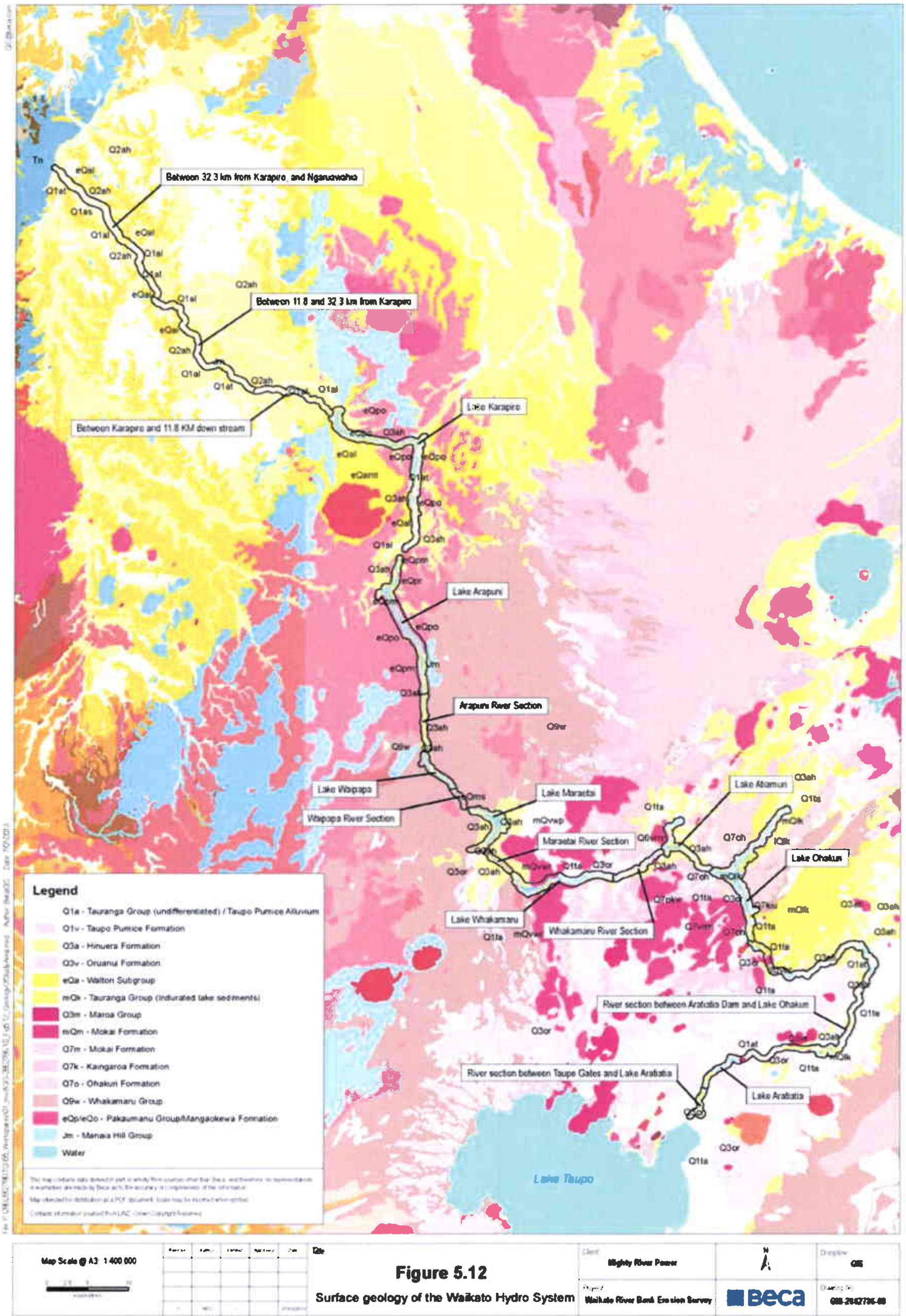

Figure 5.12: Surface geology of the Waikato Hydro System

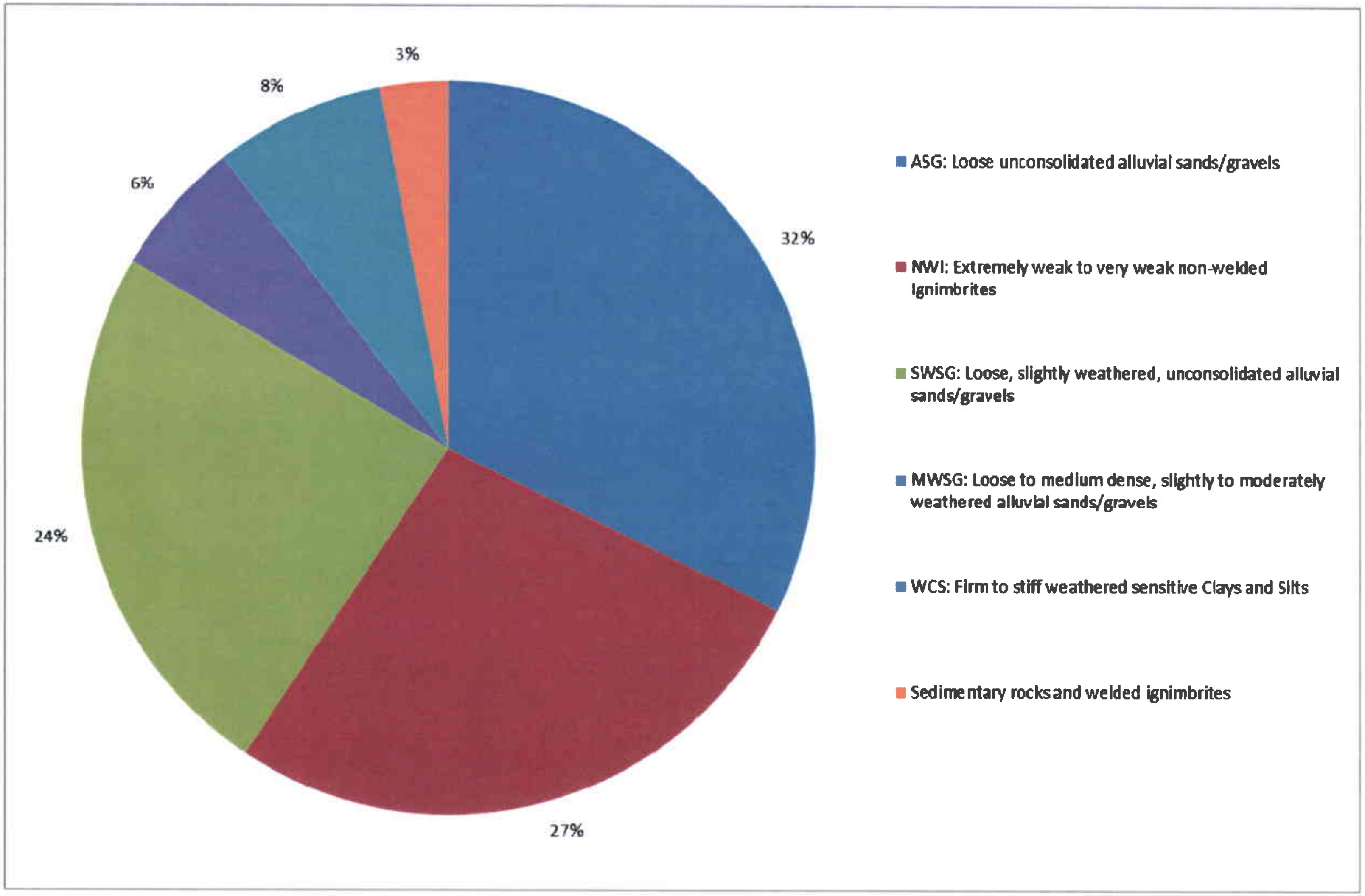

Figure 5.13: Graph of the distribution of geological units overall

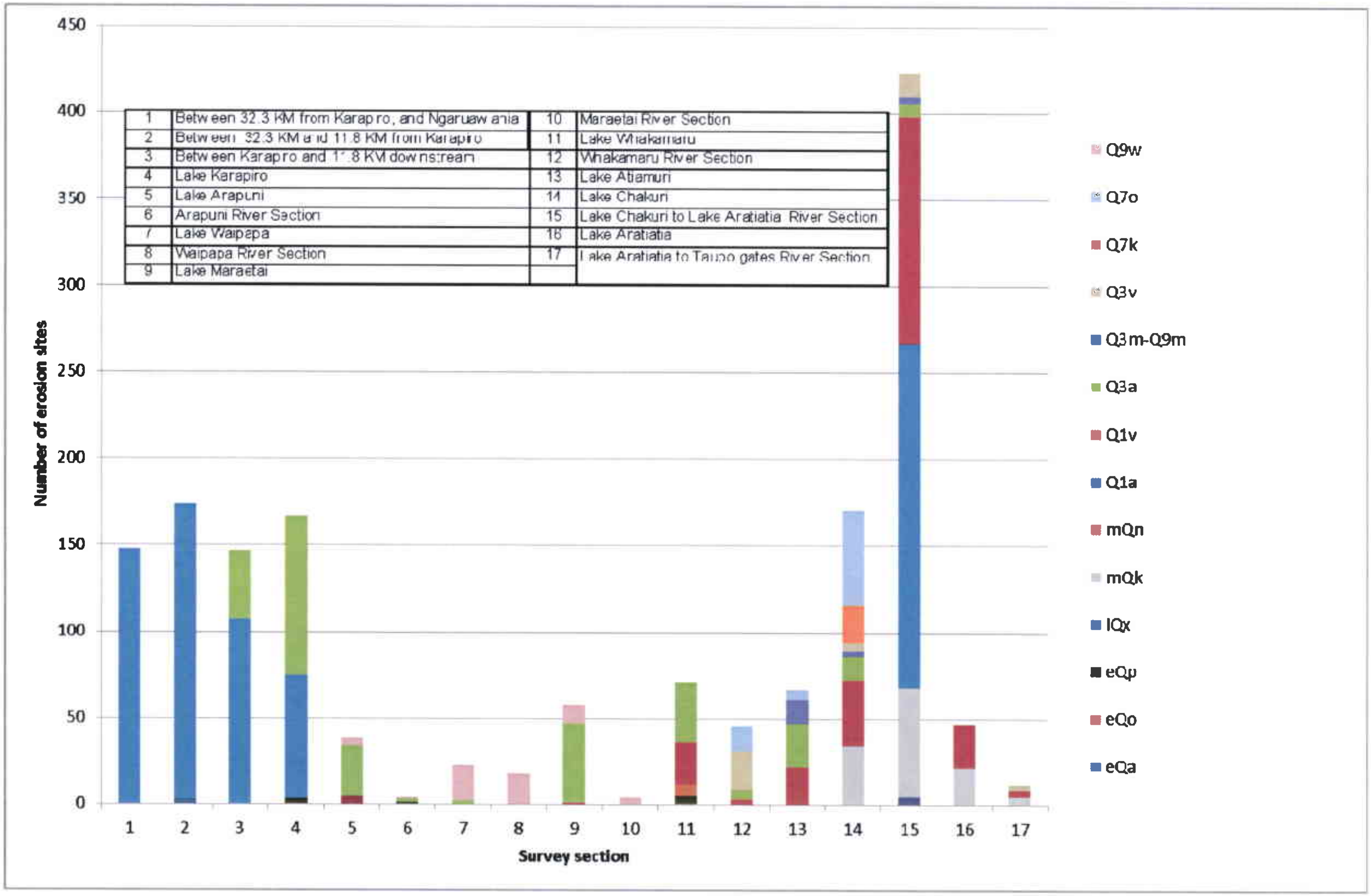

Figure 5.14: Graph of the distribution of geology units, by survey section

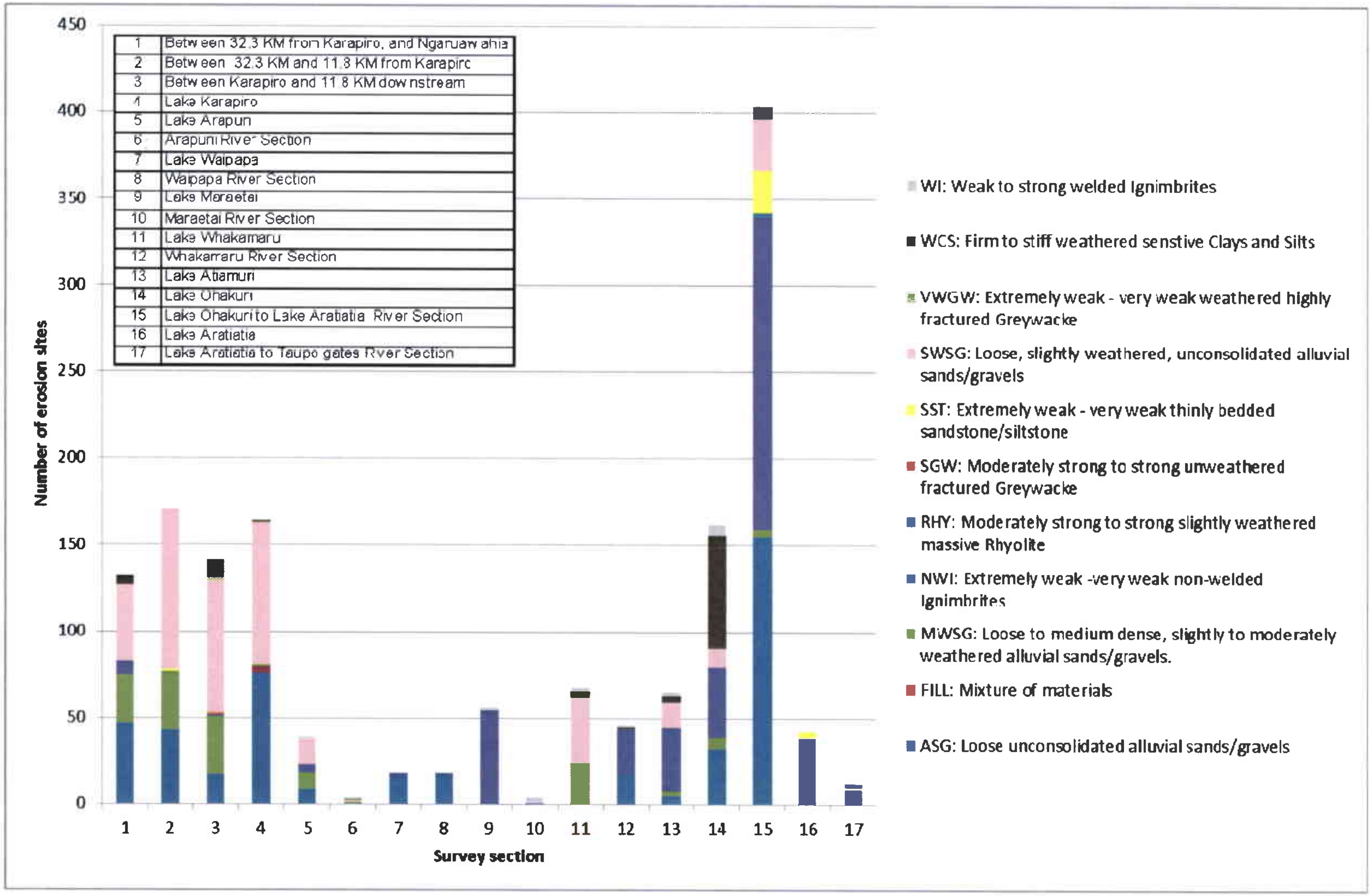

Figure 5.15: Graph of the distribution of engineering geology units, by survey section

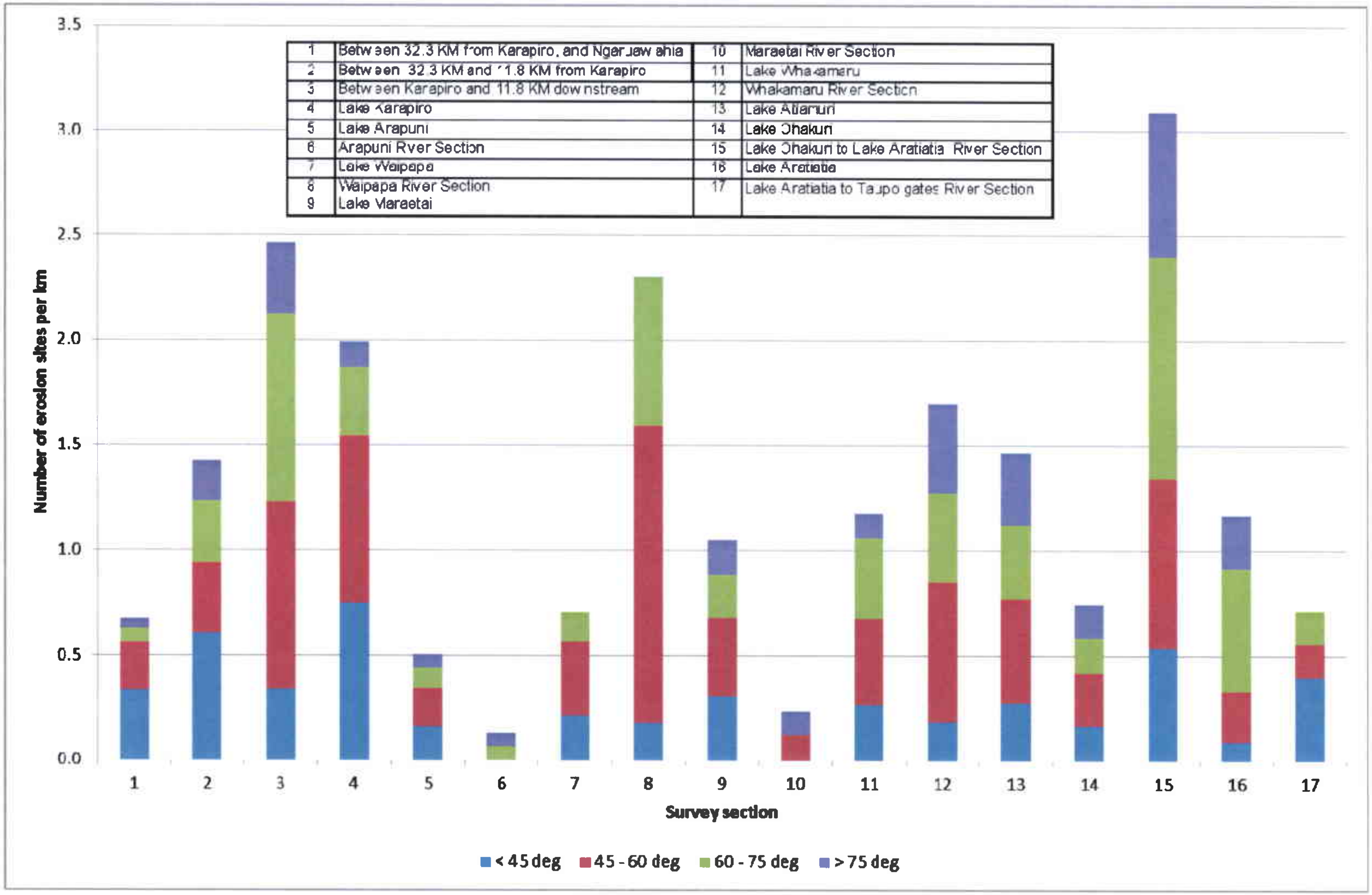

Figure 5.16: Graph of the distribution of bank slopes, by survey section

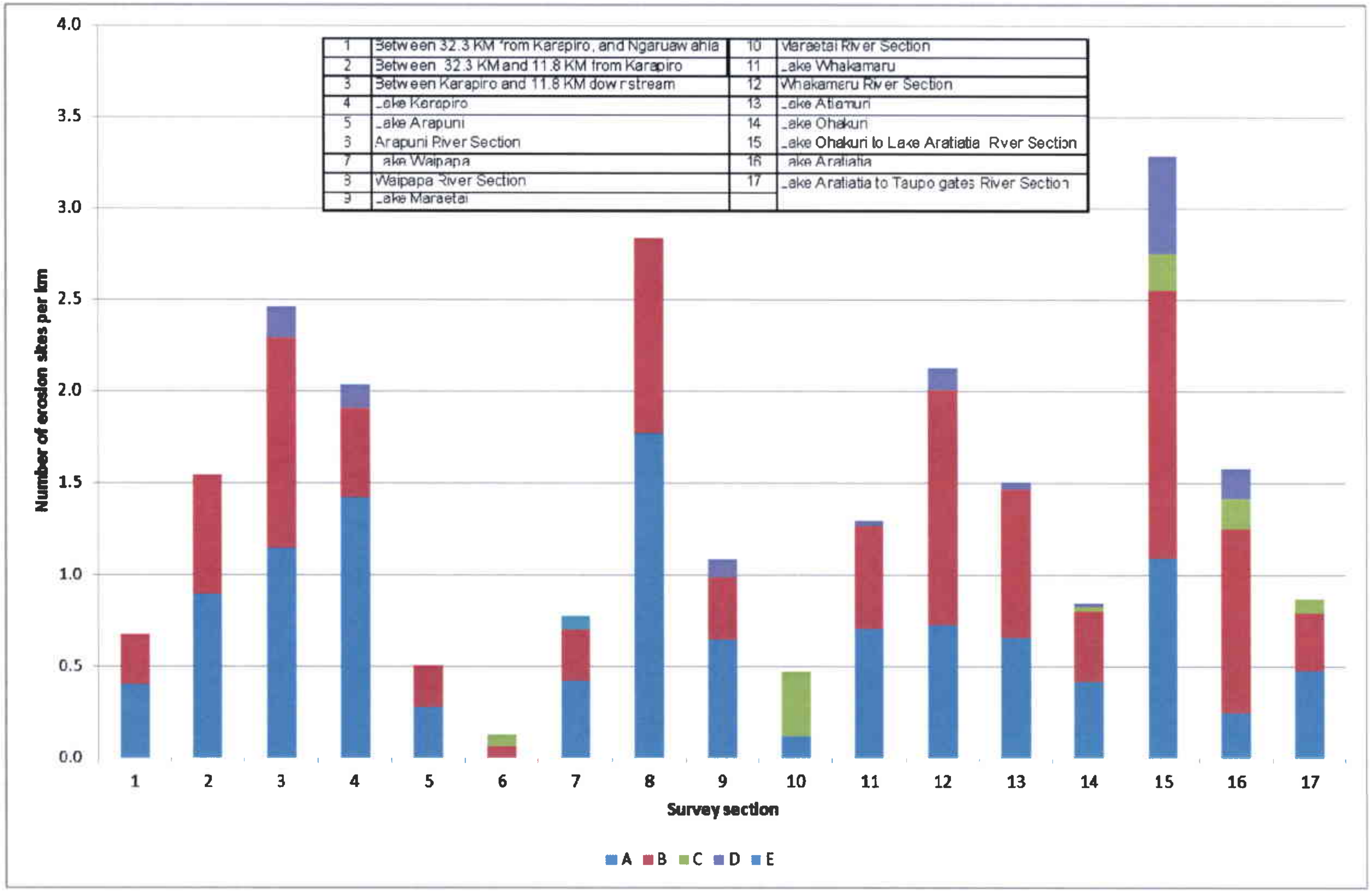

Figure 5.17: Graph of the distribution of bank classes, by survey section

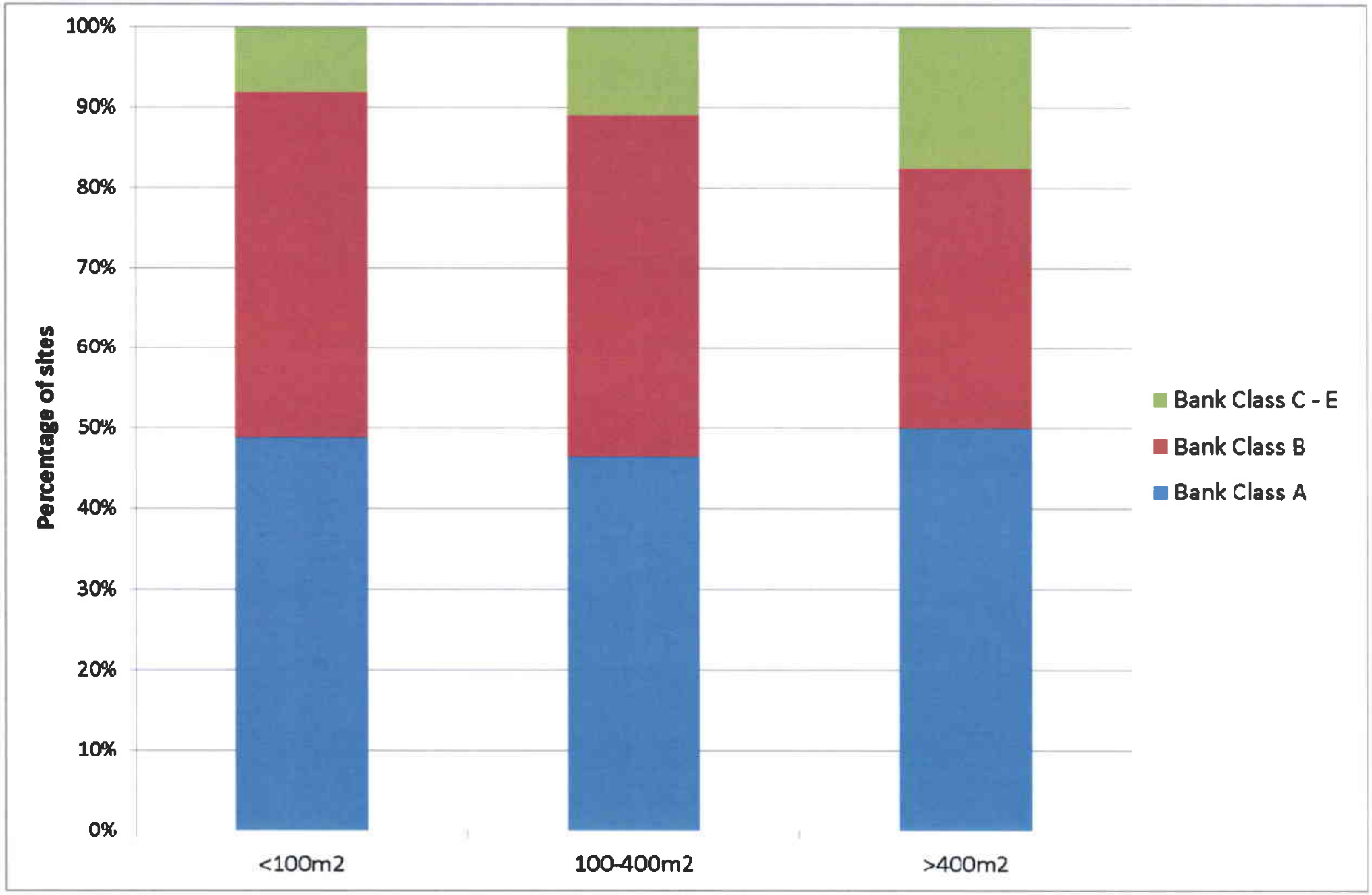

Figure 5.18: Graph of bank classes, by erosion site size

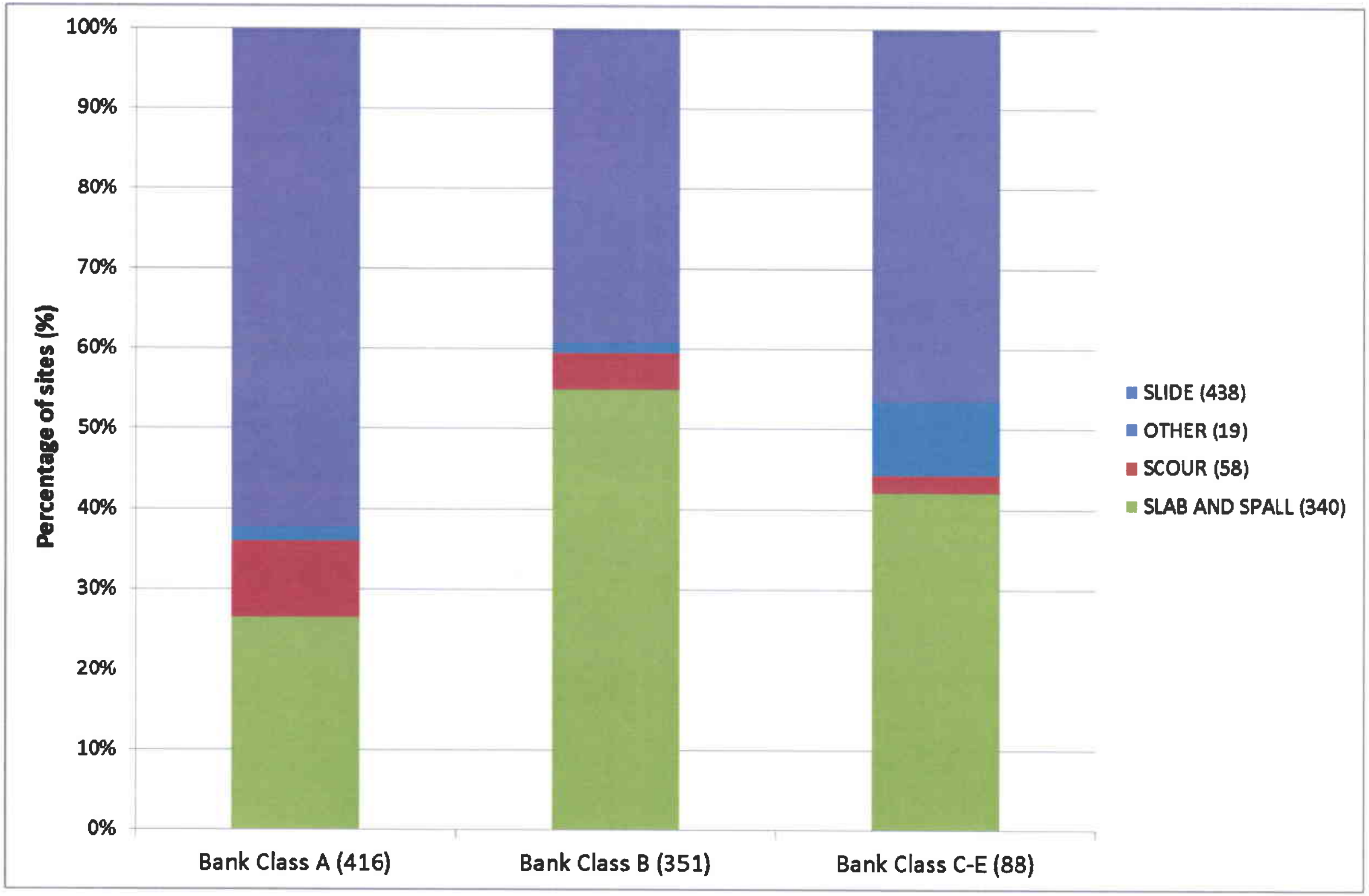

Figure 5.19: Graph of erosion failure types, by bank class

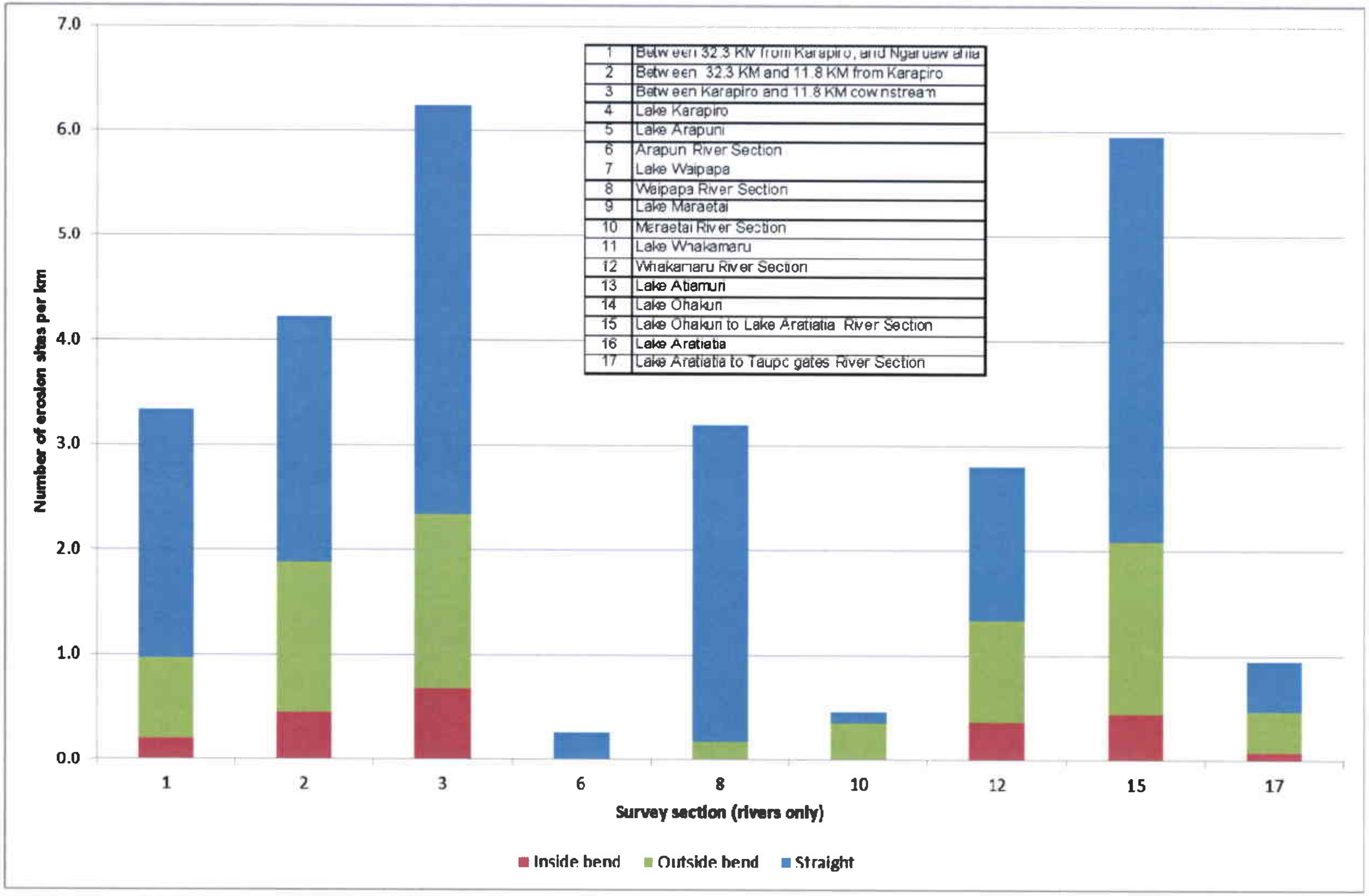

Figure 5.20: Graph of the morphology of erosion sites on river sections

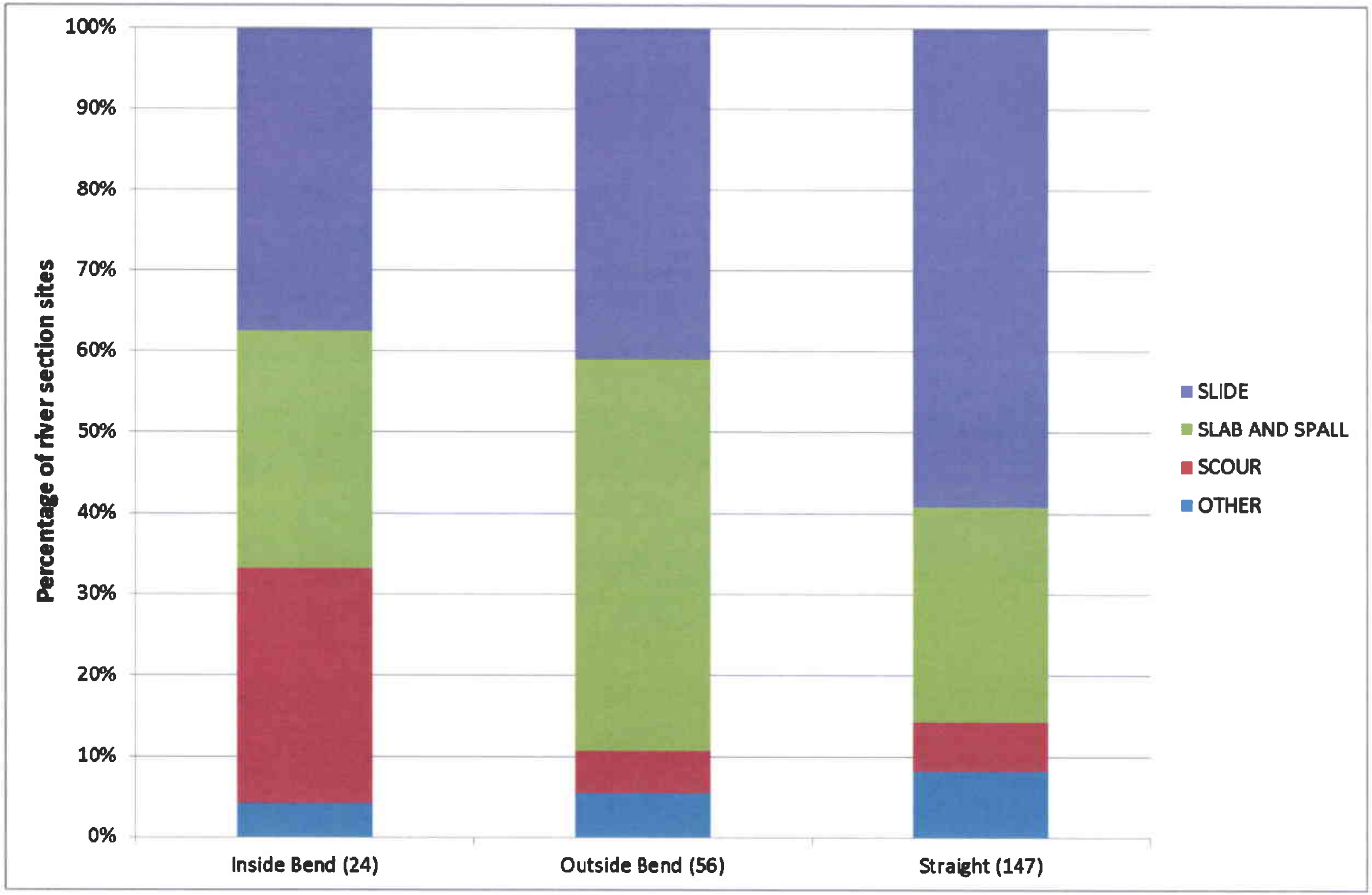

Figure 5.21: Graph of erosion failure types, by river morphology

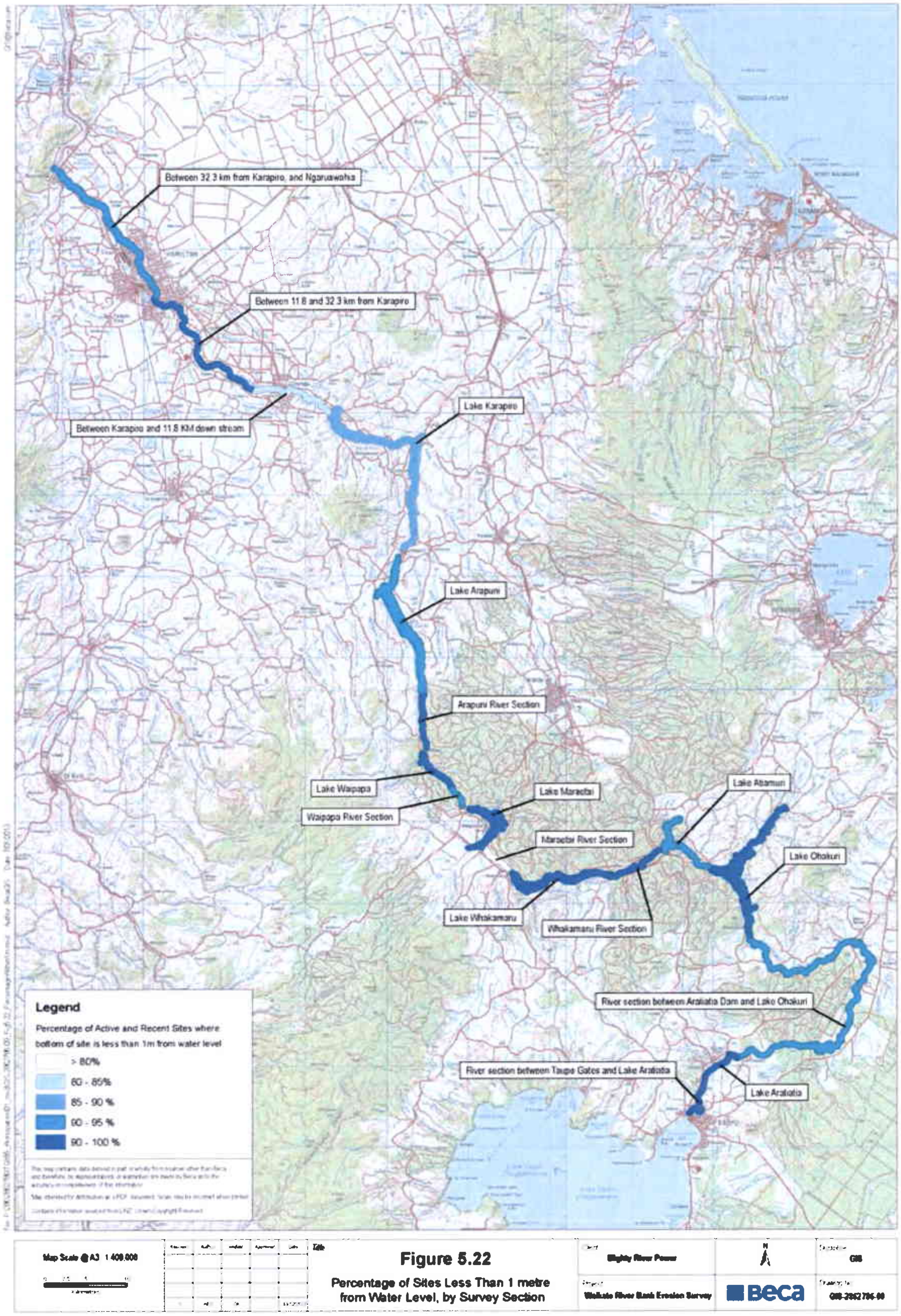

Figure 5.22: Percentage of sites less than 1m from water level, by section

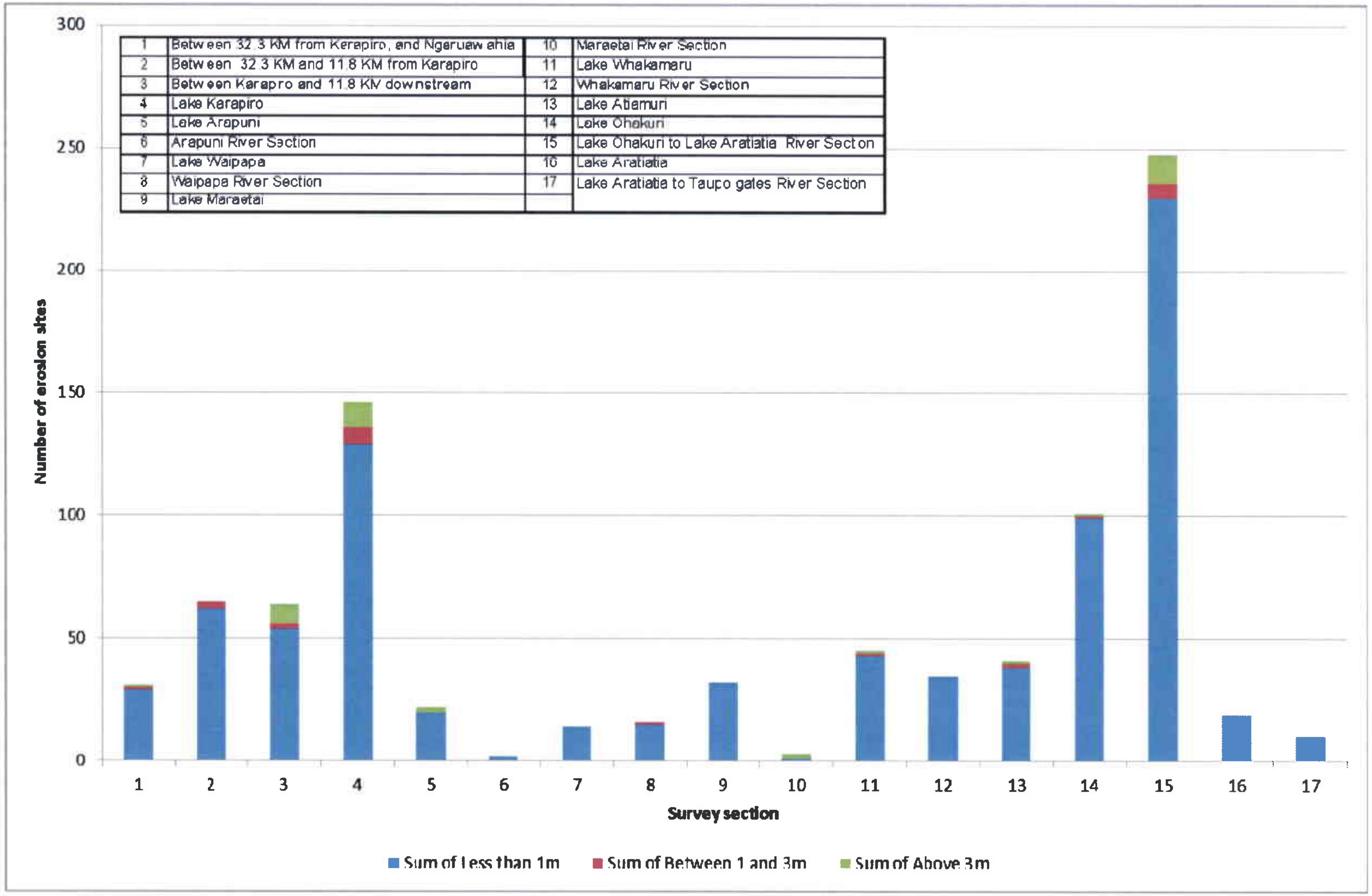

Figure 5.23: Graph of the lowest point above the surveyed water level, by survey section

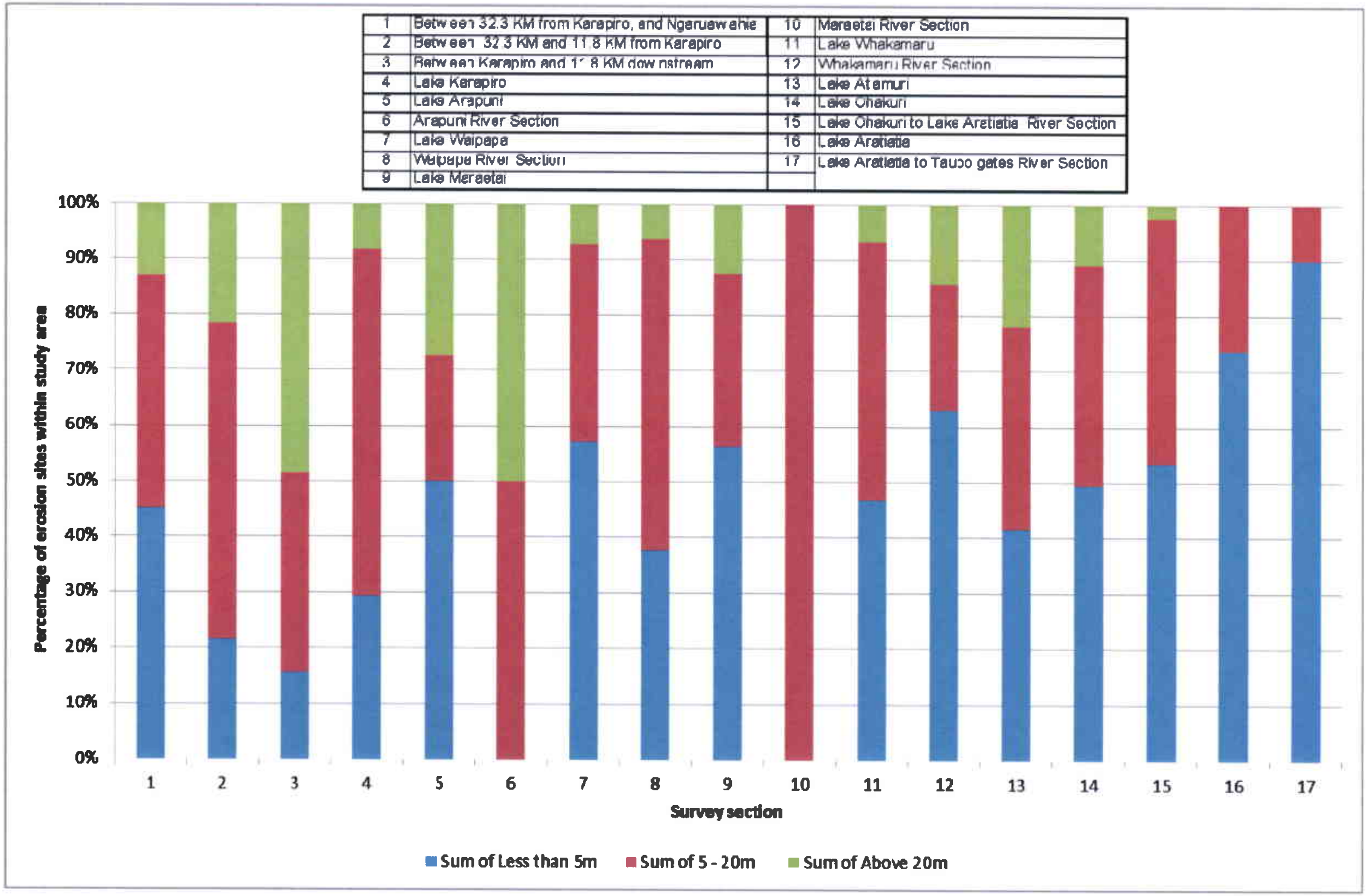

Figure 5.24: Graph of the position of erosion sites vertically on the bank above surveyed water level, by survey section

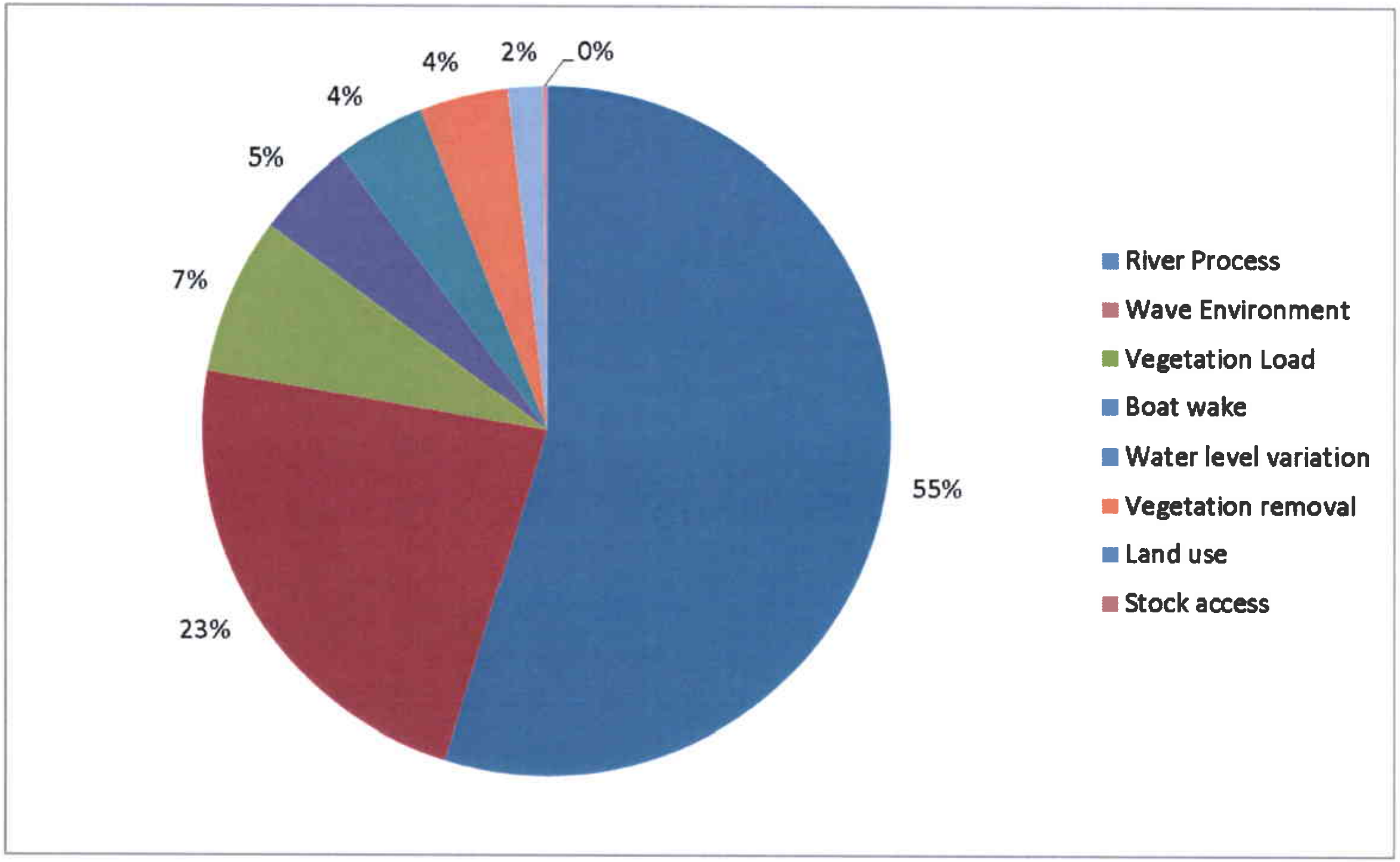

Figure 5.25: Graph of primary causative factors overall

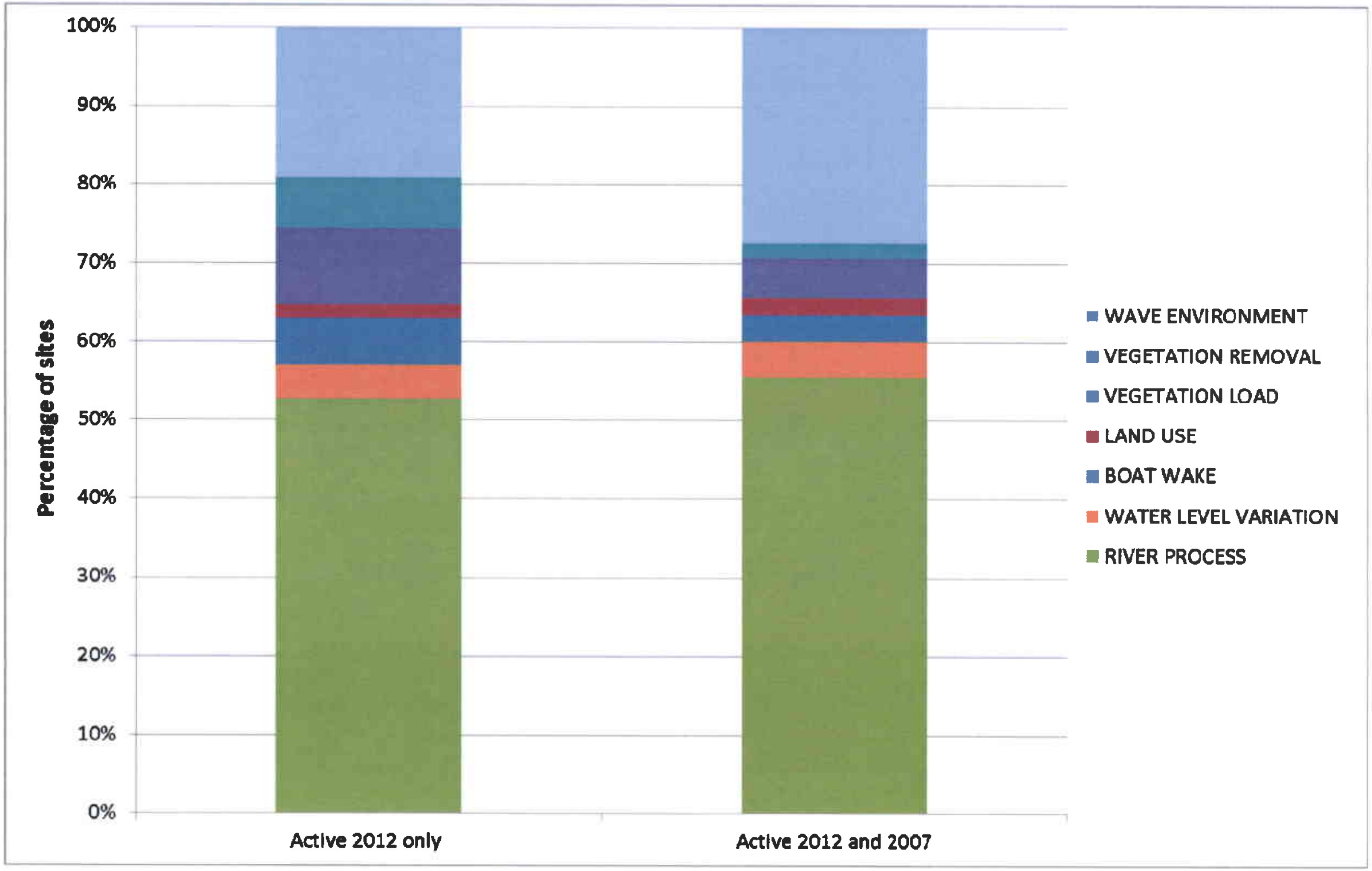

Figure 5.26: Graph of primary causative factors, by erosion activity age

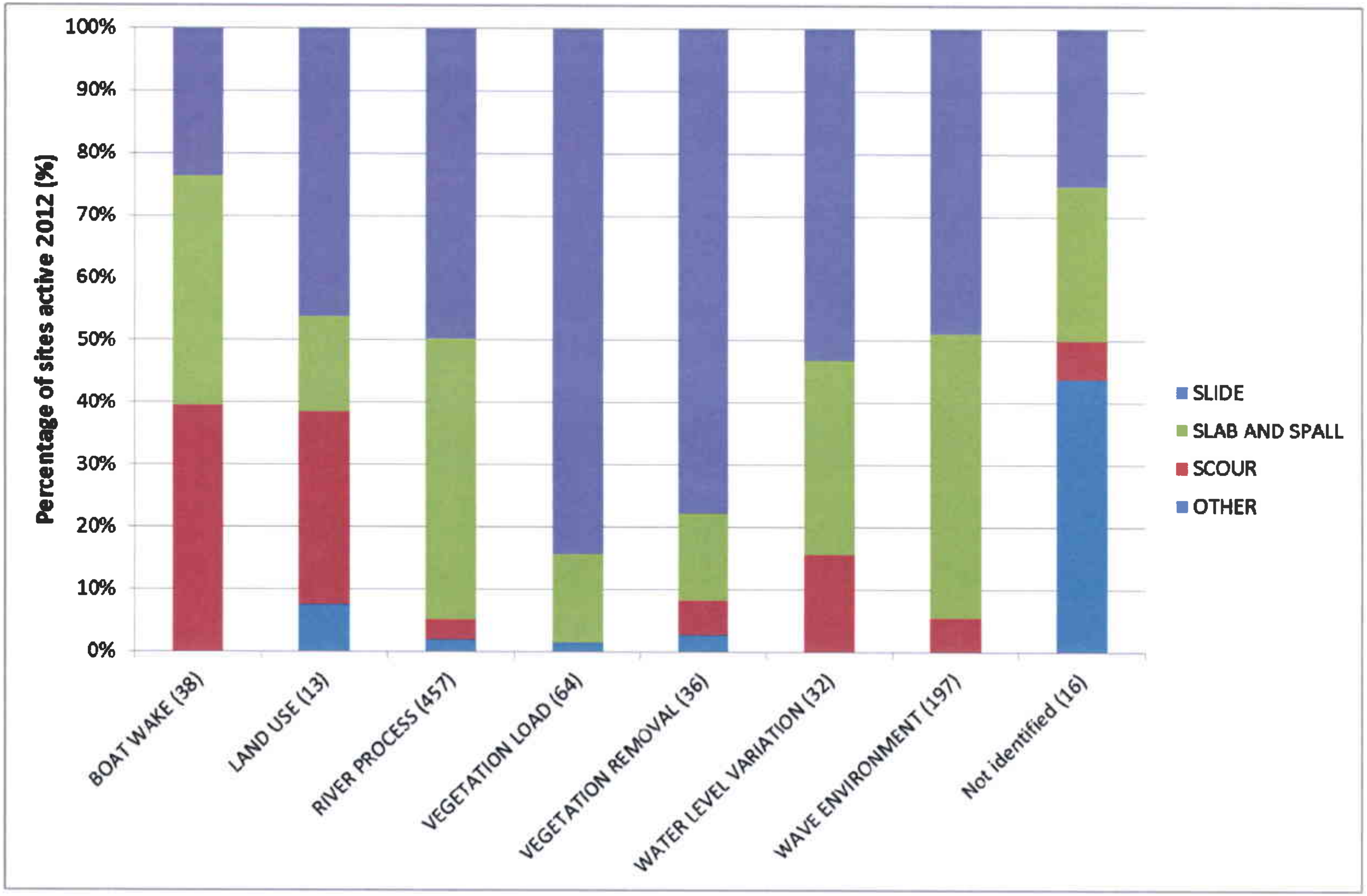

Figure 5.27: Graph of erosion failure types, by primary causative factor

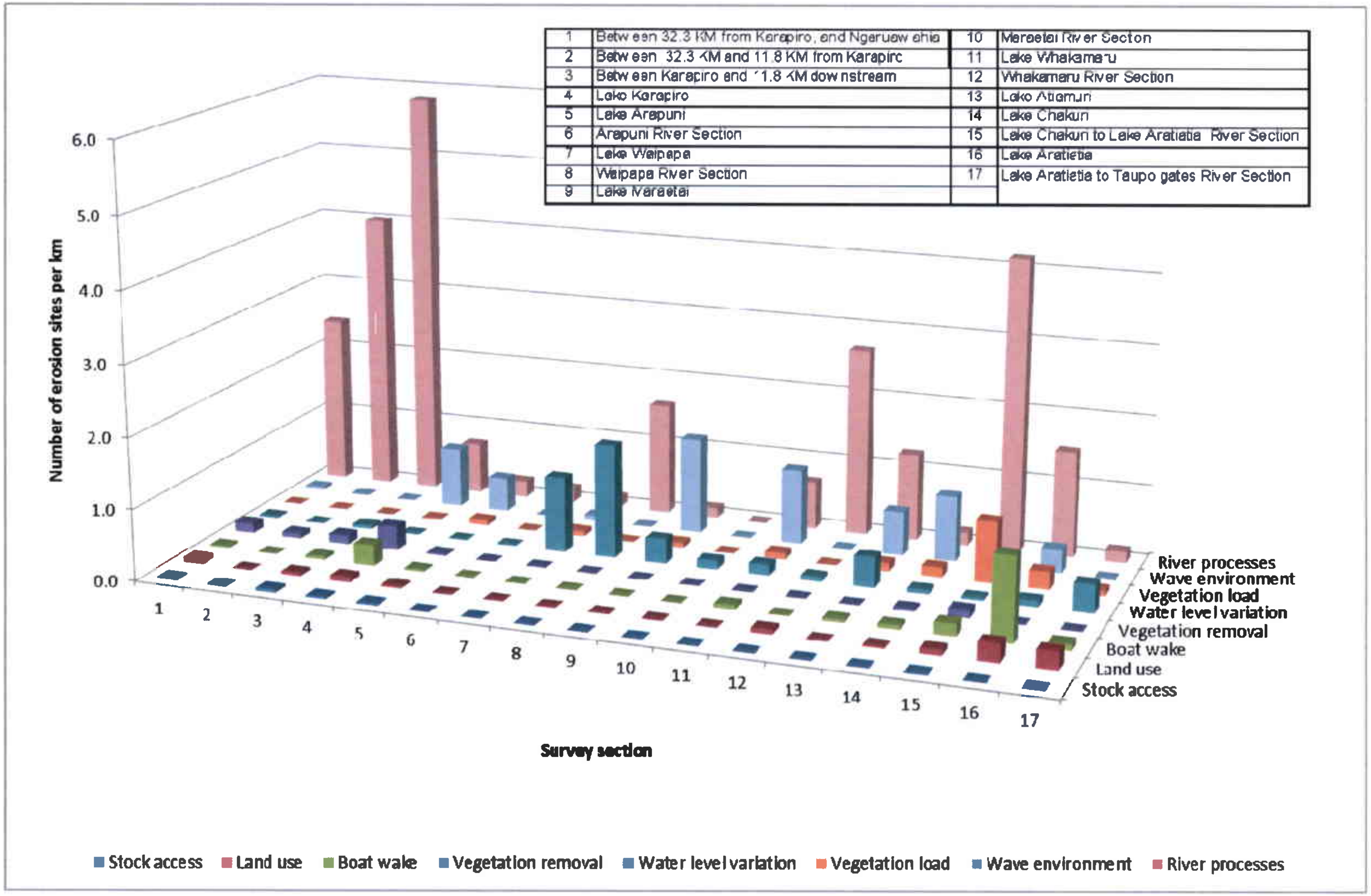

Figure 5.28: Graph of primary causative factors, by survey section

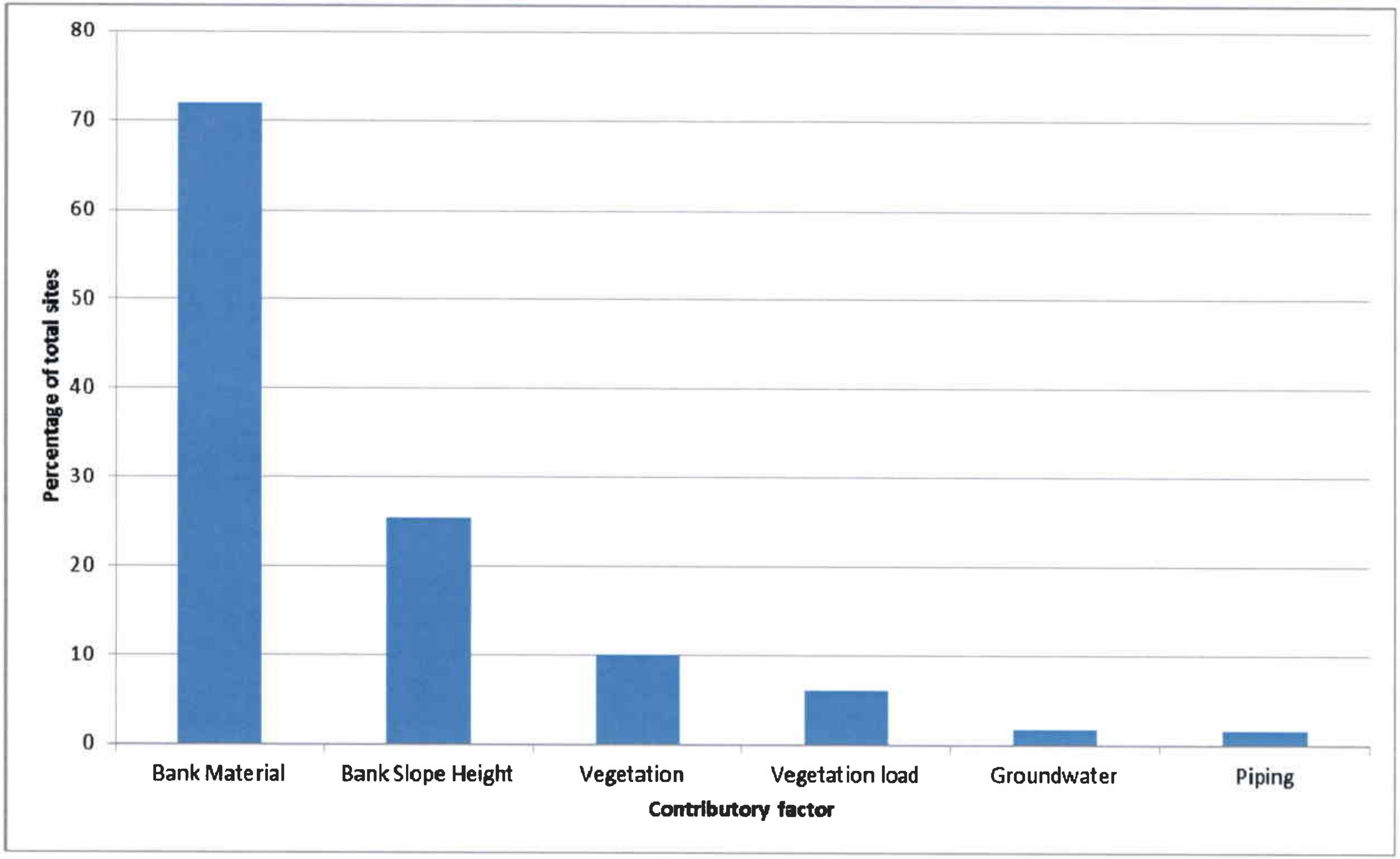

Figure 5.29: Graph of contributory factors identified overall

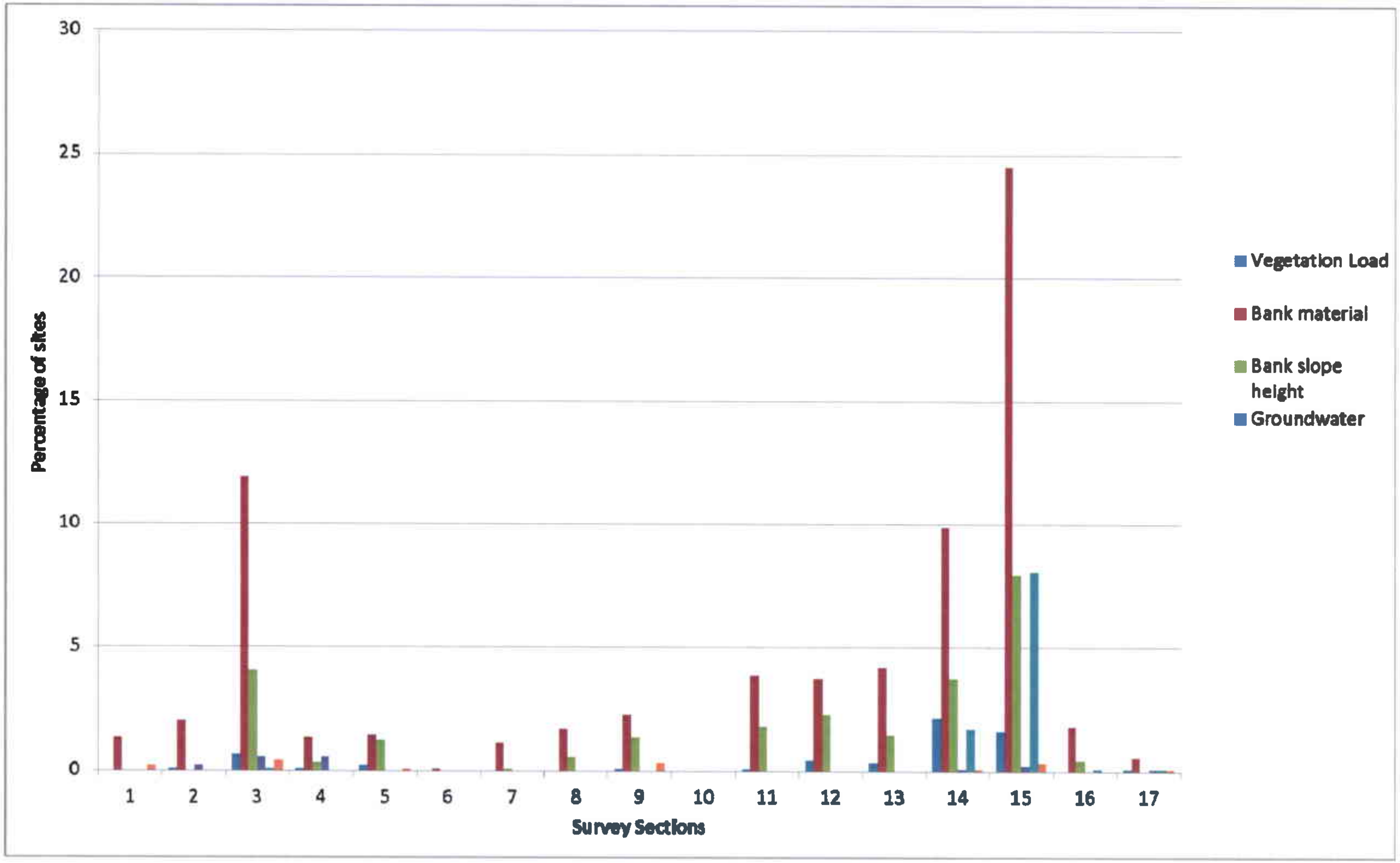

Figure 5.30: Graph of contributory factors, by survey section

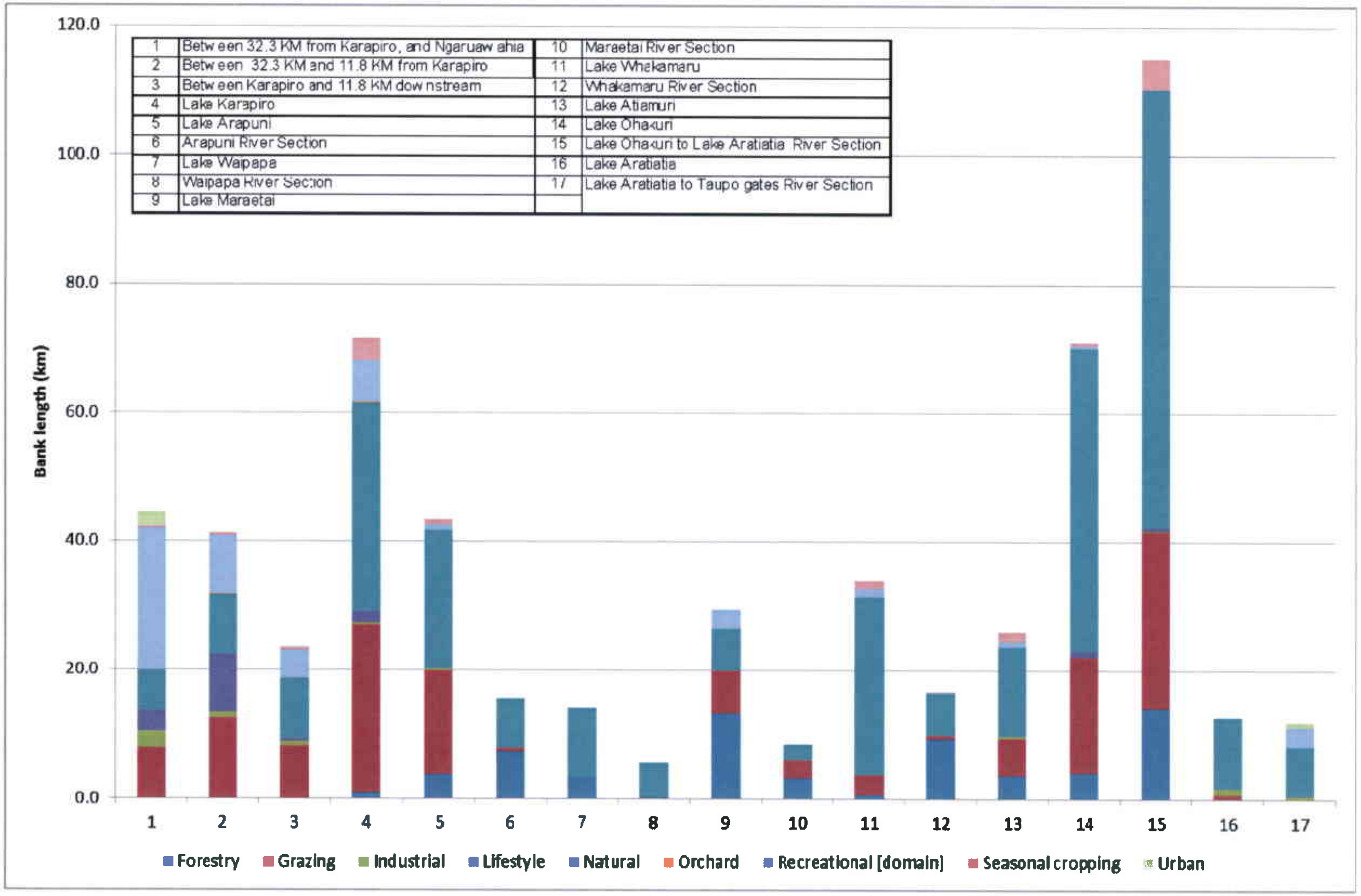

Figure 5.31: Graph of 2007 distribution of land-use categories at top of bank, by survey section

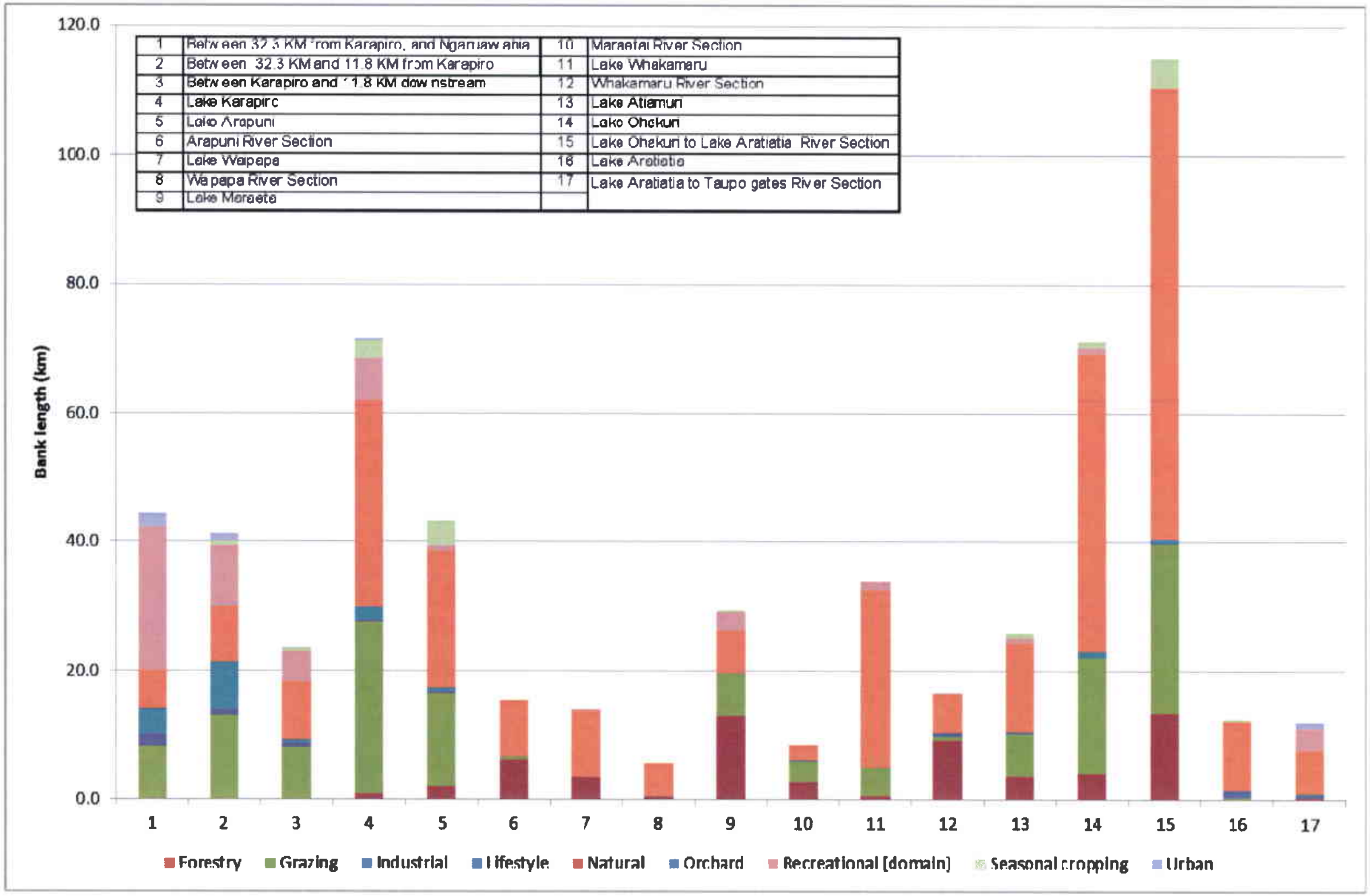

Figure 5.32: Graph of 2012 distribution of land-use categories at top of bank, by survey section

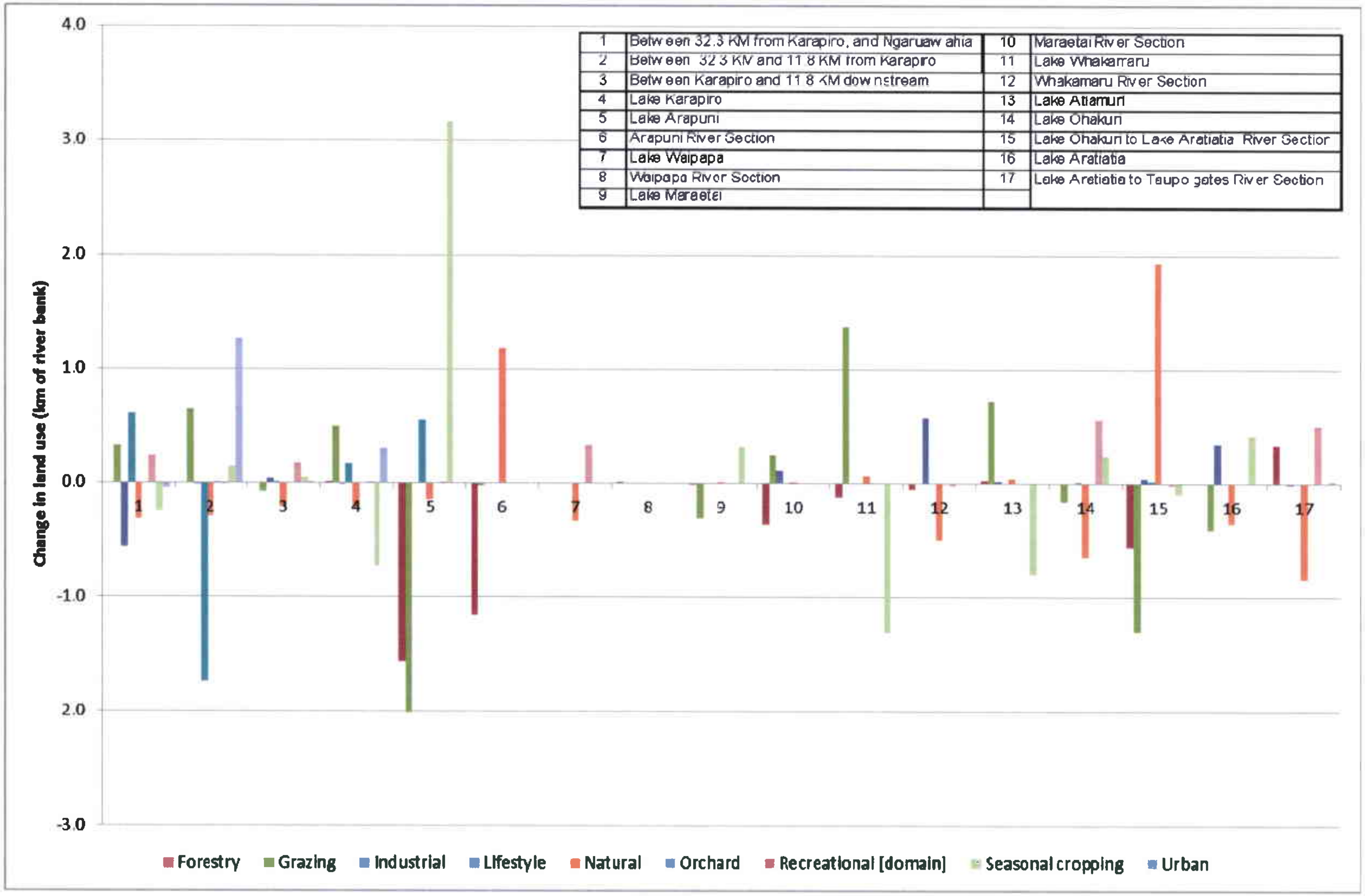

Figure 5.33: Graph of net change in land-use categories between 2007 and 2012, by survey section

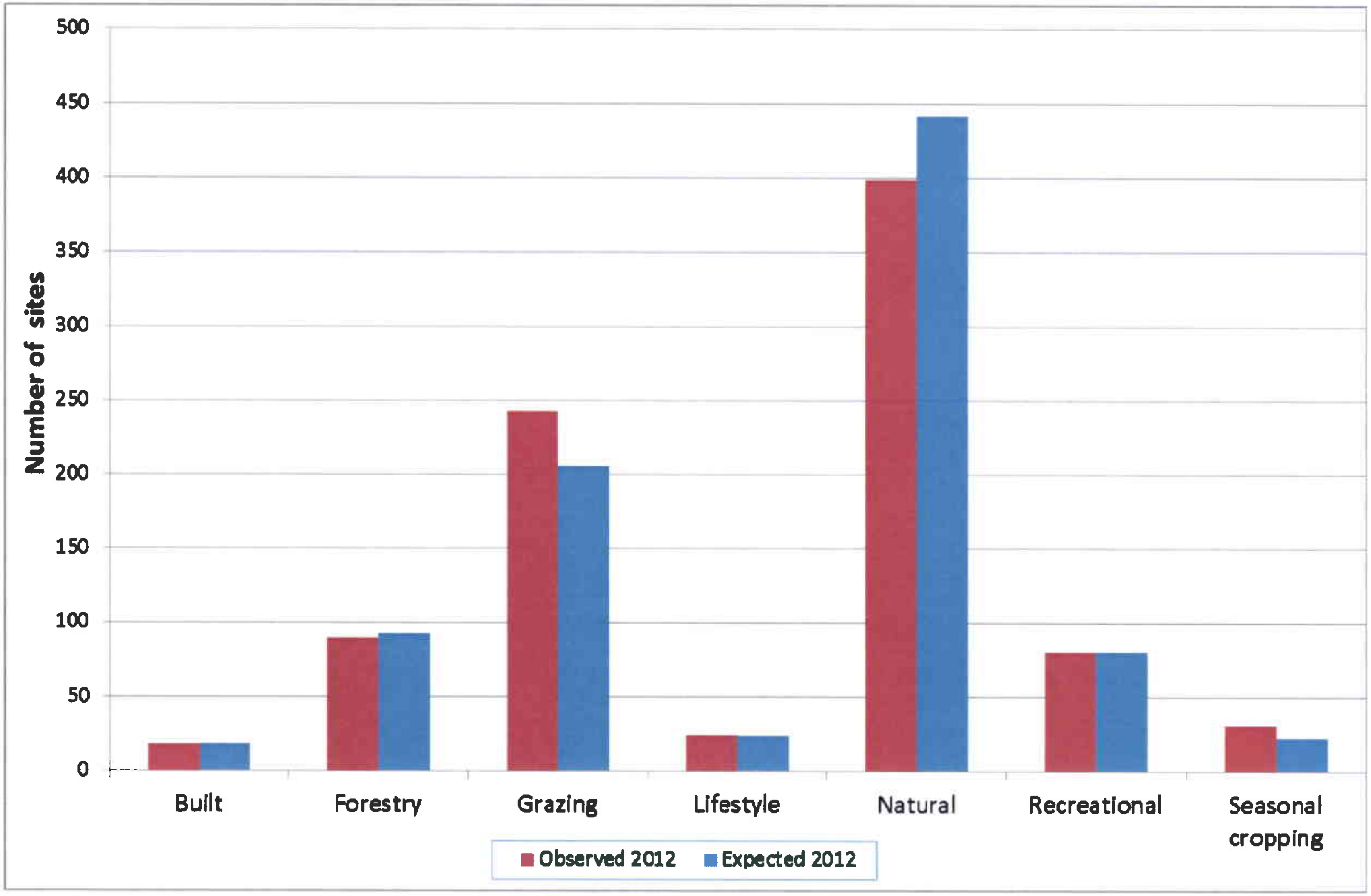

Figure 5.34: Graph of observed and 'expected' number of erosion sites, for all survey sections, by land-use category

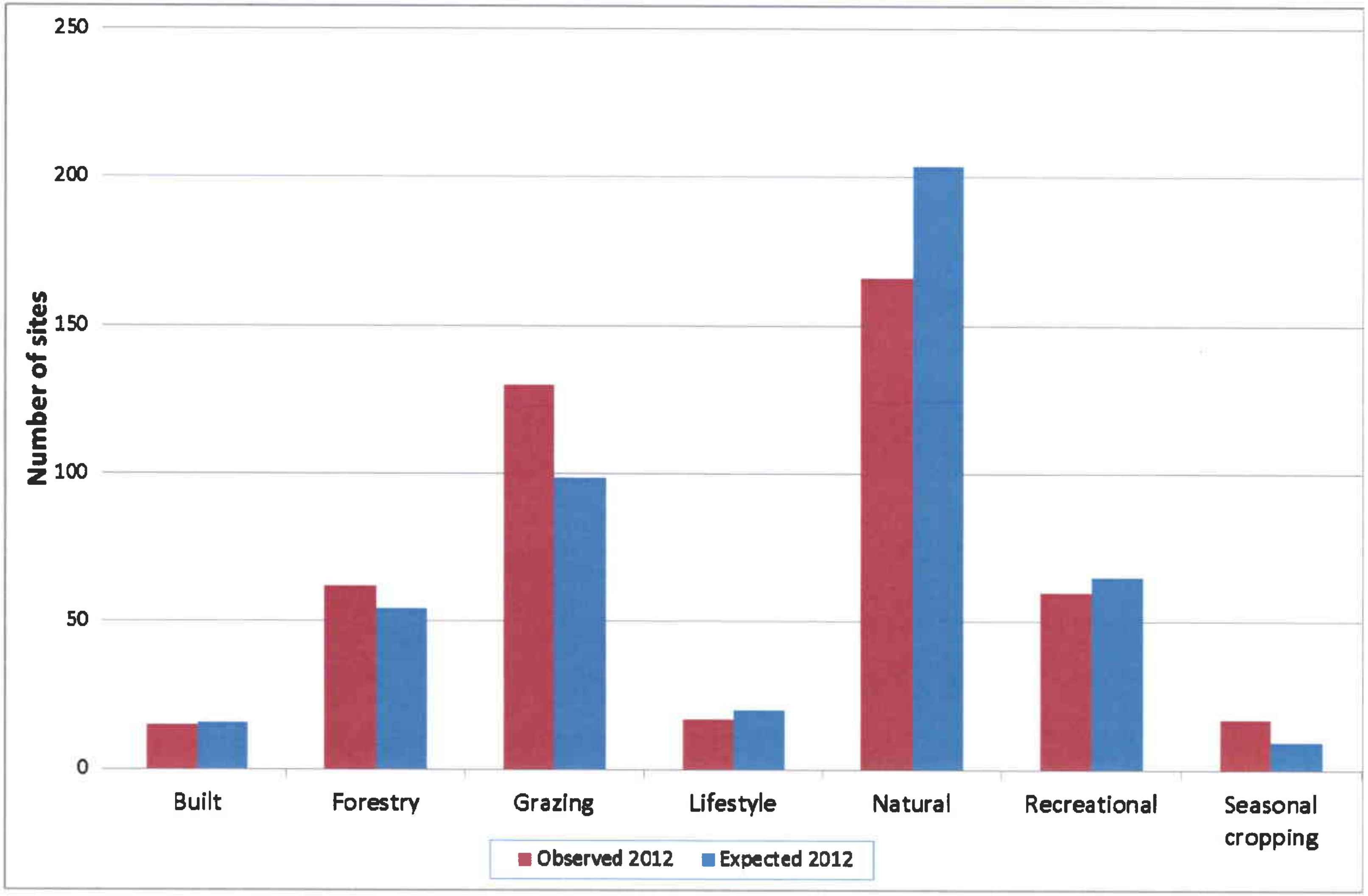

Figure 5.35: Graph of observed and 'expected' number of erosion sites for <u>river</u> sections, by land-use category

6 Comparisons with previous surveys

6.1 Comparison of methods

Prior to the start of the 2012 survey, the field parameters used in the two baseline studies were compared and evaluated, and a set of inventory parameters for 2012 was defined. The 2007 study (Taupo Gates to Karapiro) was completed after the 2006 study (Karapiro to Ngaruawahia), so it already included some additional and revised fields, as a result of the findings of the first survey. The 2012 inventory fields are generally the same as the 2007 survey. The sub-categories within each field have been refined in some cases, to aid in interpretation.

An Erosion Inventory Manual has been developed as part of this project to facilitate survey repeatability and improve comparability with future surveys.

The main difference between the 2007/2006 studies, and the 2012 study is the method used to determine the surface area of each erosion site. Previous surveys *estimated* the size of all features, whereas during the 2012 survey more detailed work was carried out to more accurately *measure* the features. This included calculating the area of erosion taking into account the inclined face of the bank, which may not have been considered during previous surveys. Table 6.1 presents the erosion area measurement and calculation differences between the surveys, and describes the similarities and differences between other key aspects of the surveys.

Table 6.1: Comparison of key inventory fields and calculation methodologies

Item	2006 Survey Method (Sections 1 to 3)	2007 Survey Method (Sections 4 to 7)	2012 Survey Methodology
Survey method	Boat based survey		
Study areas grouping for analysis	The same for all surveys		
Erosion site measuring tool	Estimated by a Geomorphologist		Measured using a laser rangefinder with accuracy of 0.3 m to 1 m, depending on the distance from the erosion site
Erosion site dimensions recorded	Estimated vertical height and average width		Maximum slope distance and maximum width using upstream and downstream bearings
Erosion site shape correction to calculate area	Not applied		A shape correction factor applied to allow for rounded features and various morphology
Handling of multiple erosion sites close together	Combined sites in close proximity	Generally did not combine adjacent sites in sections	Combined where immediately adjacent, or part of large scale feature
Potential errors in area measurement	Bank /erosion height estimated	Bank / erosion height commonly underestimated	Data recording errors, boat drift, obstruction from vegetation or slide debris
Description of causative and contributory factors	Assessed together	Separated into causative and contributory	Same list as 2007, minor refinement of categories

Land-use categories	Comments recorded as text, mainly on vegetation type.	Logged as particular land use categories	Similar as 2007, with a refined list of land-use categories
Geology	Free-text description of each site, including geology and geotechnical information	Determined for each site based on mapped geology.	Similar, but updated with new NZ terminology.
Engineering geology categories	Free-text description of each site, including geology and geotechnical information.	Set list of pre-defined engineering geology categories.	

6.2 Comparison of results

Comparisons with the results of the two baseline studies are discussed below. Some field parameters are more easily compared than others. Comparisons of erosion area and number of erosion sites are complicated by the different approaches taken.

6.2.1 Comparison of the number of erosion sites

A comparison of the number of erosion sites identified during the different surveys is shown as Figure 6.1 and in Table 6.2. This same metric is shown by kilometre of bank in Figure 6.2

In most sections, more erosion sites were identified in the 2012 survey than in the previous survey. The total number of sites has increased from 1176 to 1618 and the total number of sites defined as active or recent has reduced from 1,158 to 878. The details are not strictly comparable as slightly different approaches have been used in the surveys, and where previous surveys measured all erosion sites, the 2012 survey only measured sites > 3 m^2. In addition the 2008 survey (which covered sections 4 to 17) identified erosion in the same part of the river bank separately, whereas these were grouped together in the 2012 survey if they were part of the same overall erosion feature.

Overall, Figures 6.1 and 6.2 show that the number of active and recently active sites is similar to or slightly less than was recorded 5 years ago. It also shows that most of the new sites are active; however there are a small proportion of "newly recognised" recent sites and a few "newly recognised" older sites.

Table 6.2: Summary of identified erosion sites in 2006/2007 and 2012

Survey sections	Number of active erosion sites	Number of recent erosion sites	Number of older/ formerly recognised erosion sites	Active + recent sites/km	Total sites
Results of 2006/2007 survey					
1 to 3 (Karapiro to Ngaruawahia)	274[a]	101	18	3.4	393
4 to 17 (Taupo Gates to Karapiro)	783[b]	-	-	1.4	783
Total	**1057**	**101**	**18**	**1.8**	**1176**
Results of 2012 survey					
1 to 3 (Karapiro to Ngaruawahia)	95	62	311	1.5	468
4 to 17 (Taupo Gates to Karapiro)	654	67	429	1.3	1150
Total	**749**	**129**	**740**	**1.4**	**1618**

Notes:

a - Sites greater than 2 m^2 were identified in the 2006 survey of Sections 1 to 3, whereas sites > 3 m^2 were measured in the 2007 survey of Sections 4 to 17, and in the 2012 survey.

b -Sites were only defined as 'active' during the 2007 survey of sections 4 to 17.

6.2.2 Age / activity status of erosion sites

The size of erosion sites with respect to the activity status (age of movement) of the erosion is shown in Figure 6.3. The activity has been defined with respect to whether the site was active or recently active from 2007 until 2012 (i.e. on-going erosion sites), or in the 2012 survey only (i.e. new erosion sites). The figure clearly shows that the on-going erosion sites (active 2007 and 2012) are larger in area.

The mean areas of erosion sites with respect to the activity status is presented in Table 6.3 Comparison of means using a t-test (p-value <0.001) similarly shows strong evidence that the differences between mean areas are statistically significant.

Table 6.3: Summary of average erosion area for active sites in 2012 with respect to land-use change status

Age / activity status of erosion sites	Number of sites	Mean erosion site area (m^2)	Standard error
Active 2012 only	439	155	13
Active in 2007 and 2012	408	337	38
Area not measured	23		
Total*	870		

*The table excludes 8 of 878 sites surveyed in 2012 which were not categorised with respect to period they were active between 2007 and 2012

6.2.3 Area of erosion per site

The distribution of erosion area is highly skewed, with a large number of sites having a small surface area and a few sites having larger surface areas. This distribution pattern was identified in previous studies. The most comparable surveys to 2012 in terms of the size of sites measured are the Opus studies (Opus 1999, Opus 2000), which found 60 % of the sites are less than 100 m^2; the 2012 survey found 55 % of erosion sites are less than 100 m^2.

6.2.4 Total area of erosion

The total area of erosion is harder to compare due to the different approaches taken. Measurement of the erosion area in 2012 provides more accurate results than the method used previously. Table 6.4 compares the area of erosion between the different studies, showing a slight decrease in the area of erosion in Sections 1 to 3 (Karapiro to Ngaruawahia) and a significant increase in Sections 4 to 17 (Taupo Gates to Karapiro). Given that the number of sites identified in Sections 4 to 17 is relatively similar in 2007 and 2012, the difference is expected to be due to both changes in the measurement methodology, and to an increase in the extent of erosion at some sites (in particular sites in Section 4 and 15) where erosion has been on-going. This is discussed further below.

The 2012 approach, with measurement of the bank surface area, is expected to allow better comparison with future surveys.

Table 6.4: Comparison of area of erosion

Surveyed sections	Area of active erosion estimated in 2006/2007 (m^2)	Area of active and recent erosion measured in 2012 (m^2)
1 to 3 (Karapiro to Ngaruawahia)	43,846	35,240
4 to 17 (Taupo Gates to Karapiro)	36,984	173,033
Total	**80,830**	**208,273**

6.2.5 Comparison of erosion area by study section

A further more detailed comparison of the methods applied at specific erosion sites that are either large, or located on reaches with a significant number of erosion sites (sections 3, 4 and 15), is provided in Appendix A. Key findings are:

- In section 3 (river section from Karapiro to 11.8 km downstream): the number of erosion sites identified was the same in both surveys, with a similar distribution of area of erosion;

- Erosion sites in section 4 (Lake Karapiro) that have been examined have increased in bank length;
- Some erosion sites in sections 3 and 4 (Lake Karapiro and the river to 11.8 km downstream) have increased in height. This is in part a function of the survey methodology, where bank and erosion heights have previously been underestimated. For example at some sites in the 2012 survey the whole bank was assessed to have undergone shallow translational sliding, whereas the 2007 surveys have measured the scarp only and not the vegetated debris mass; and
- In section 15 (Aratiatia Dam to Lake Ohakuri), which has a significant proportion of the larger sites (such as Harpers Bend)), there has been a significant increase in erosion both in length and cross-sectional area since the 2007 survey.

It therefore appears that the erosion in sections 4 to 17 (Taupo Gates to Karapiro) has been underestimated in the 2007 survey, whilst there has been some over-estimation of area in the 2012 survey mainly due to data recording methodology and recording errors. In particular the under-estimation of bank height in 2007 compounds the under-estimation of area by the square of the error.

Whilst the 2012 method may over-estimate erosion in some cases, it is more repeatable and it is our view that future surveys will be more comparable using this refined method. In addition there has been a real increase in erosion during the last 5 year period in particular in sections 4 (Lake Karapiro) and 15 (Aratiatia Dam to Lake Ohakuri). This is supported by both the greater number of new erosion sites in these sections compared to other sections and the increase in the area of the larger sites in these sections.

6.2.6 Other changes to large sites

The increase in erosion of the large sites in section 15 (Aratiatia Dam to Lake Ohakuri) cannot be attributed to change of land-use to forestry, cropping or grazing, as these types of land-use have decreased since 2007 in this section of the river. The dominant land-use is 'natural ground' in this section, although there is a greater proportion of grazing, forestry, and seasonal cropping than in other sections. River and natural processes are the primary causative factor. Bank material is by far the most significant contributing factor. Vegetation load and bank height contribute proportionally more to erosion on this section of the river than other sections. It appears that it is a combination of a number of factors that have caused or contributed to greater erosion in this section, the most important of which is the combination of the banks being comprised of some of the youngest weakest soils while also being relatively high and steep.

An increase in erosion due to natural processes is also likely to be the case in sections 3 and 4 (Lake Karapiro and the river to 11.8 km downstream). Forestry and vegetation loads are not significant factors in these lower river sections. Groundwater and piping are more significant in these sections than other sections. As for section 15, the banks are also relatively high (section 3) and steep (section 4) compared to other sections.

6.2.7 Erosion rates

Erosion rates have previously been estimated by a number of methods. It was hoped that the 2012 survey would calculate erosion rate based on the volume of the erosion feature measured and estimated age (i.e. < 1 year, 1 to 5 years, > 5 years). However, the volume calculations proved inaccurate, with most of the erosion being shallow and within the error range of the measuring tool (i.e. < 1 m deep). For this reason a comparison of the proportion of erosion (area of erosion divided by the total estimated area of the bank) has been undertaken instead, similar to the previous surveys (2006/2007). As the bank heights have not been measured, this requires some assumptions. During the hearings for the Waikato Hydro System resource consent applications, Opus estimated the erosion rate using the length of erosion over the total length of the section measured. Table 6.5 compares erosion "rates" (determined by this methodology) between the current and previous studies.

Table 6.5: Comparison of the percentage of bank area that is eroding

Banks	2001 Opus Survey during consent applications	2006/2007 Baseline Survey	2012 Survey
Section 1 to 3 Karapiro to Ngaruawahia (all river, by area)	Not calculated	2 % (using 19.8 m bank height)	2 % (using 19.8 m bank height)
Section 4 to 17 Taupo Gates to Karapiro (river and lakes, by area)	Not calculated	2 % (using 4.8 m bank height)	9 % (using 4.8 m bank height) 3 % (using 19.8 m bank height)
Lake shore (by length)	2.6 %	Not calculated	Not calculated
River bank (by length)	4.4 %	Not calculated	Not calculated
Average of all sections	3.4 %	2 %	5 % (using 4.8 m bank height in sections 4 to 17)

The total bank area for sections 1 to 3 is estimated as 214 Ha using an average bank height of 19.8 m (URS, 2007) and for sections 4 to 17 the total bank area is estimated as 195 Ha using an average bank height of 4.8 m (Beca, 2008).

If a bank height of 19.8 m is used for Sections 4 to 17, then the 2012 percentage of bank area that is eroding in these sections is 3 %. Using this bank area, the erosion percentages are similar to those predicted by Opus as part of the resource consent application process. Using average bank height to calculate the erosion area is a simplification and this could be improved by measuring the actual bank height.

The background survey of 2001 showed that the proportion of erosion area per length of bank is greatest in the upper reaches (approximately from Lake Aratiatia) reducing downstream, with a slight increase between Karapiro and Hamilton. A similar trend is seen in this survey.

6.3 Comparison of causative factors

Background studies (Opus, 1999 and Opus, 2000) identified land-use change as having a significant effect on bank erosion, with combined agriculture and forestry assessed to be causing a third to a half of the erosion. The 2006/2007 baseline studies and this survey do not show this trend. The difference is likely to be due to the variance in the causative factors used between the erosion assessments and in particular the association of the land use at the top of the bank and the cause of erosion in the background studies. For example the Opus study found the upper river sections had 18.4 % forestry land use at the top of the bank and 18.4% of the sites have forestry as the main cause of erosion.

The distribution of causative factors was found to be similar to baseline (2006/07) surveys, if land-use practices include vegetation removal and loading as a single category (classification has been separated in the 2012 survey). The factors causing erosion have a similar distribution of primary causative factors identified by the baseline survey in the reservoirs and upper reaches compared with the 2012 survey, as shown in Figure 6.1 and summarised below:

- River and natural processes are the greatest primary causative factor of slope movement, being responsible for a little over 50 % of the active and recent movements observed in 2012 and 50 % in the 2007 baseline survey for Sections 4 to 17;
- Wave environment is the second most common factor triggering 20 % of the erosion in this survey. This is similar to the 23 % of erosion sites considered to be caused by wave environment in sections 4 to 17 2007 survey;
- Combining vegetation (both removal and loading) and land-use practices, there are 18 % of active sites in 2012 and 24 % of the active sites in the 2007 survey for sections 4 to 17; and
- Water level variation due to hydro-operations and natural variations are found to be a minor factor (4 %) in the erosion in 2012 and for sections 4 to 17 in 2007 (< 4 %).

Comparison with the previous survey for Sections 1 to 3 is difficult as that study combined the causative and contributing factors.

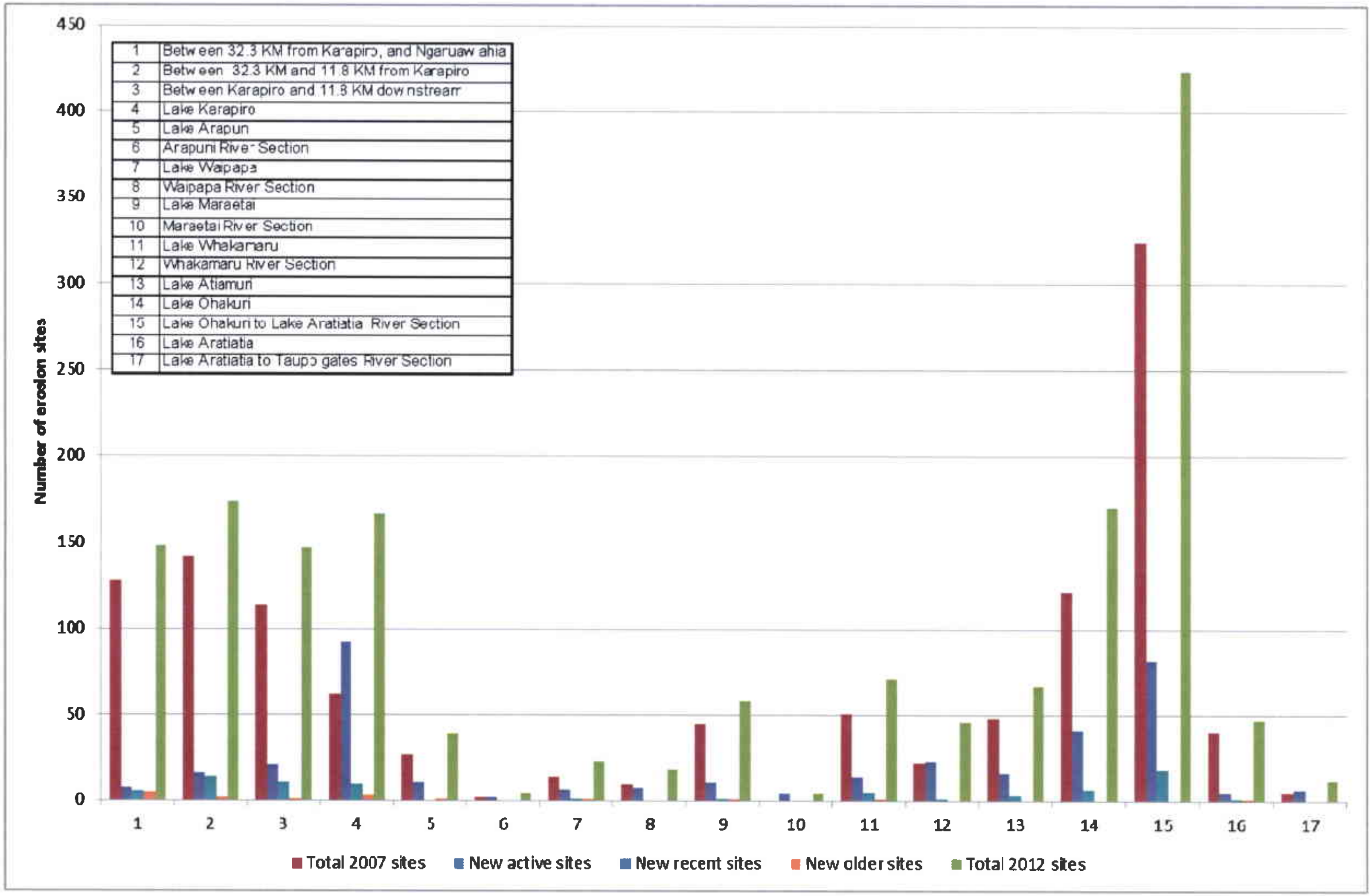

Figure 6.1: Graph comparing number of existing and new erosion sites from 2007 and 2012 surveys

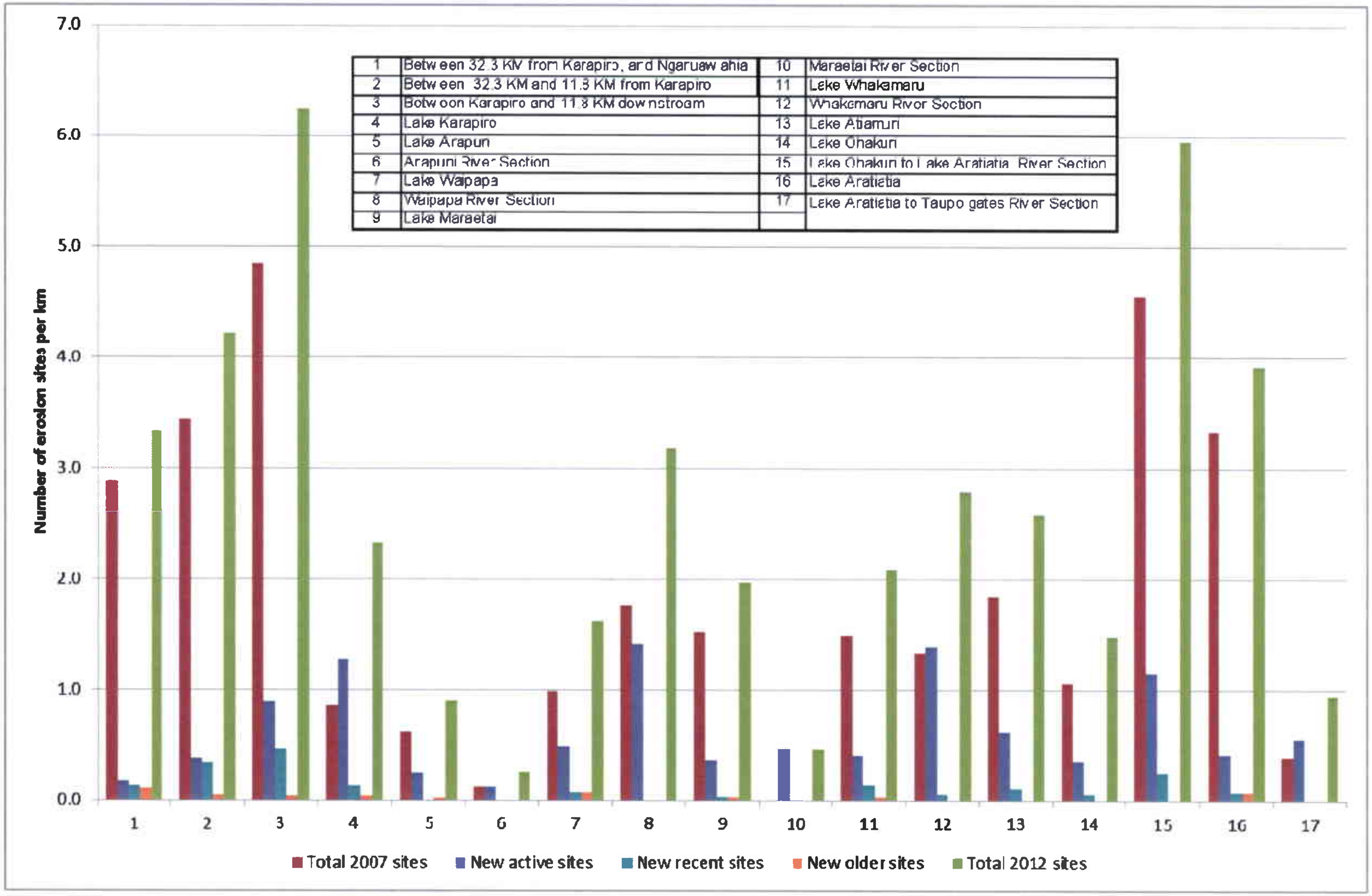

Figure 6.2: Graph comparing density of existing and new sites per kilometre from 2007 and 2012 surveys

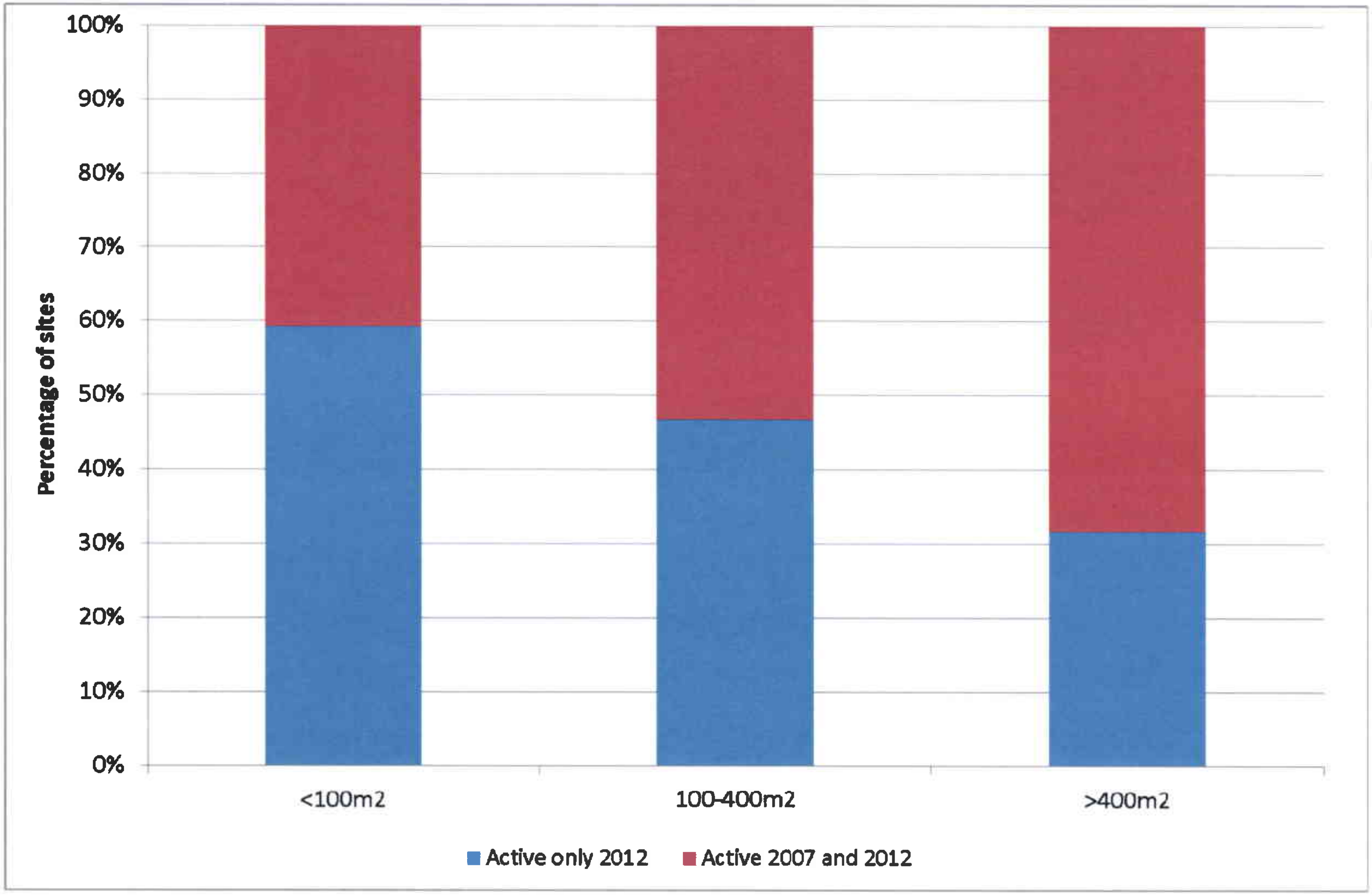

Figure 6.3: Graph showing the size of erosion sites, by age of erosion

7 Discussion and Conclusions

7.1 Erosion extent and distribution

This survey measured 878 active and recent erosion sites. This is a reduction in the number of active and recent sites from the baseline survey in which 1,158 sites were recorded.

Active and recent erosion frequency is less than or equal to 3.5 sites per kilometre of bank, with an average of 1.4 sites per kilometre. The surveyed sections with the greatest frequency of bank erosion are:

- Section 3, between Lake Karapiro and 11.8 km downstream;
- Section 4, Lake Karapiro; and
- Section 15, Lake Ohakuri to Lake Aratiatia.

When the erosion is normalised by bank length, sections 3 (Karapiro to 11.8 km downstream), 8 (Waipapa River), and 15 (between Aratiatia Dam and Lake Ohakuri) have the greatest amount of erosion per kilometre of river bank, however the data for section 8 may be biased because of its short length (just over 5 km).

There are significantly more erosion sites per kilometre length of river bank (proportional 63 % of sites occupy river banks compared to lake banks) than lake bank (proportionally 36 % of sites occupy lake banks) when normalised by kilometre length. A similar trend is observed when comparing area of erosion with 20% more erosion (active and recent) by area occurs on river sections than on lake sections.

The distribution of the total area undergoing bank erosion is highly skewed to a few sites. Only 61 sites have an area greater than 500 m^2, and these comprise more than 50 % of the total erosion recorded. There are 19 sites (2 % of the total) that are 2,000 m^2 or more in area, comprising some 30 % of the total erosion.

The total area affected by erosion has significantly increased in sections 4 to 17 (Taupo Gates to Lake Karapiro) compared to the baseline survey (from approximately 37,000 m^2 to 172,000 m^2) and there has been a decrease in erosion area in sections 1 to 3 (Karapiro to Ngaruawahia), from approximately 44,000 m^2 to 33,000 m^2. The change in area in part reflects the change in survey methodology. However, some of the larger existing erosion sites were found to have increased in size over time. These observations are supported by the statistical increase in erosion site size over the period that erosion has been recorded.

7.2 Susceptibility and contributory factors

The study confirms the conclusions of the baseline survey that there is a strong relationship between the amount of erosion, bank material type, and geological conditions. Some 60 % of the erosion sites are comprised of younger and weaker materials derived from the Taupo and Oruanui eruptions (less than 26,000 years old) and 97 % of the erosion occurs within these and the soil-like deposits (both alluvium and non-welded ignimbrites) derived from older eruptions from the Taupo Volcanic Zone.

The slope height, slope angle, and bank material were divided into five classes (Class A to E) to assess the combined effect of bank geometry and material type which are often inter-related. The vast majority (about 90 %) of recent and active sites occur in either Class A or B, both of which are comprised of unconsolidated weak soils, differentiated by variable bank morphology. Almost 50 %

of the sites are identified as within low banks (typically < 1 m high) with slopes generally of less than 60 °. This indicates that overall the bank height and bank slope are not a significant contributing factor to the frequency of erosion sites, but the unconsolidated weak nature of the soils is. However, it does appear that the sections that have a combination of high banks and/or steep slopes and very weak erodible soils (sections 3, 4 and 15) have proportionally more erosion.

There is a correlation between erosion type and slope bank class, where smaller slabbing and spalling type movements are more common in high steep banks (Class B) and slides are more common in low shallower banks (Class A).

Three times as many erosion sites occur along straight sections of river than occur along outside river bends and very few erosion sites occur on inside bends. No statistical variation was found when comparing erosion type with river bank morphology, except for a disproportionately higher number of scour erosion type sites occurring on inside bends (which might be expected). There was no statistical variation with river bank aspect and erosion frequency. The majority of the erosion (greater than 90 % of sites) extend to or within 1 m of the river level at the time of the survey.

7.3 Causative factors

The distribution of primary causative factors is similar to that identified by the baseline survey. In the lower reaches, comparison is difficult due to the difference in recording of contributory/causative factors in the 2006 study. The following conclusions can be made regarding causative factors:

- River and natural processes are by far the greatest primary causative factor that has triggered movement, being the primary factor in over 50 % of the active and recent movements observed in 2012;
- Wave environment is the second most common factor triggering 20 % of the erosion, being more widespread in the Lake sections (4 - Karapiro, 9 - Maraetai, 11 – Lake Whakamaru, and 14);
- Vegetation (both removal and loading) is the next most common factor at 16 % of active and recent sites in 2012. There is a greater proportion of sites attributed to vegetation load in section 15 (between Aratiatia Dam and Lake Ohakuri) compared to other sections. Vegetation removal is a significant primary causative factor in section 4 (Lake Karapiro); and
- The large active erosion sites > 2000 m^2 have increased in size since the baseline survey. A detailed study of the large sites in section 15 (river section between Aratiatia Dam and Lake Ohakuri) indicates that the increase in erosion cannot be attributed to land-use change. River and natural erosion processes, and vegetation loads were the primary causative factors for the large sites in this section. Bank materials were found to be contributing factors.
- Land-use and boat wakes are primary causative factors in just over 5 % of the erosion in 2012.
- Water level variation is a minor causative factor being attributed to less than 5 % (68 erosion sites) of the total sites and 4 % of active and recent erosion in the 2012 survey. This is comparable with previous surveys which also showed approximately 4 % of erosion sites were caused by water level variations.

7.4 Consideration of land-use changes

Land use has not been found to be a significant causative factor in either of the baseline surveys or this survey. However, land-use has influenced erosion:

- Grazing and seasonal cropping are associated with a slightly greater proportion of erosion sites than other land-uses;
- On river sections, there is a greater frequency of erosion sites where forestry, grazing, and cropping are land-uses than at where other land-use is recorded; and

- The percentage of sites where vegetation load and vegetation removal are the primary causative factor has increased since the baseline survey. In particular, loading from dead tree trunks (and loss of erosion protection provided by living trees) from the felling of pine forests along the bank crest, is a more significant erosion trigger than wind throw and root prising of live trees.

7.5 Comparison with previous studies

Overall, the number and frequency (number of sites per kilometre length of bank) of active and recently active sites is similar to or slightly less than that recorded 5 years ago.

The area of erosion has however increased, in particular in the sections from Lake Karapiro to Taupo Gates (section 4 to 7). This increase mostly reflects difference in survey methodology and previous inaccuracies (the 2007/2008 survey has under-estimated bank height which compounds the under-estimation of area by the square of the error). In addition, an increase in area of erosion has been observed since the last survey, as shown by both a statistical review of large sites that exhibit on-going erosion (active 2007 and 2012) and a review of individual large erosion sites.

The proportion of erosion area per area of bank remains the same (2 %) for sections downstream of Lake Karapiro (sections 1 to 3). There has been an increase in the proportion of erosion area for sections upstream of Lake Karapiro (sections 4 to 17). The proportion has been affected by the average bank height used in the previous studies. If the same assumptions are made for the bank height as used in sections 1 to 3, then overall erosion is 3 %, similar to that predicted.

The background survey of 2001 showed a similar trend in erosion area distribution as the 2012 survey, with greater erosion occurring in the upper reaches (approximately from Lake Aratiatia) reducing downstream, with a slight increase between Karapiro and Hamilton.

The ranking of causative factors recorded in the 2012 survey is similar to that of the 2007 (sections 4 to 17) survey. Categories for causative factors varied in the 2006 survey of sections 1 to 3.

7.6 Conclusions

The 2012 Waikato bank erosion survey created a comprehensive database of existing, recent, and older/ previously recognised sites, to enable tracking of erosion in the Waikato Hydro System over time. An Erosion Inventory Manual was developed to define the inventory parameters and enable consistency in the survey methods in future surveys. The method of measuring the area of each erosion site was improved in 2012, however this has complicated comparison of the total area of erosion between studies. Assessments in the number of sites, spatial distributions, causative/ contributory factors, and correlations between various inventory parameters show that:

- There are less erosion sites compared to the baseline surveys (878 active and recent erosion sites compared with 1,158);
- The frequency of active and recent erosion is, on average,1.4 per kilometre throughout the study area, ranging from 0.1 to 3.4 sites /km per section;
- The greatest density of erosion sites is in sections 3 (Karapiro to 11.8 km downstream), 8 (Waipapa river), and 15 (Aratiatia Dam to Lake Ohakuri), although it is noted that the data for section 8 may be biased because of its short length (just over 5 km);
- The frequency of erosion (sites per kilometre length) has generally decreased since the previous survey, except in sections 4 (Lake Karapiro) and 15 (river section between Aratiatia Dam and Lake Ohakuri);
- The total area of erosion has decreased in the river sections from Karapiro to Ngaruawahia and increased in the sections from Karapiro to Taupo Gates. Much of this variation is thought to be due to variations in survey methods

- A significant increase in erosion area has occurred in sections 4 (Lake Karapiro) and 15 (river section between Aratiatia Dam and Lake Ohakuri);
- Some sites have increased in size, particularly the largest erosion sites;
- River and natural processes are by far the greatest primary causative factor that has triggered movement, being the primary factor in more than half of the active and recent movements observed in 2012;
- The bank materials are the most significant contributory factor, with most (60 %) erosion sites occurring in loose unconsolidated soils (pumice sands) and 90 % occurring in alluvial and non-welded volcanic deposits from the last two major eruptive events of Taupo and Oruanui.
- In section 15 there is a correlation between young, very weak bank materials and steep, higher slopes and this may explain the greater erosion in this section compared to elsewhere;
- Water level variation is a minor causative factor, being attributed to 4 % of the total active and recent erosion in the 2012 survey;
- On average, erosion is occurring over 5 % of the banks, which would appear to be a slight increase from previous studies, although this may partly be attributed to differences in the survey method.

Applicability

This report has been prepared by Beca on the specific instructions of our Client. It is solely for our Client's use for the purpose for which it is intended in accordance with the agreed scope of work. Any use or reliance by any person contrary to the above, to which Beca has not given its prior written consent, is at that person's own risk.

Should you be in any doubt as to the applicability of this report and/or its recommendations for the proposed development as described herein, and/or encounter materials on site that differ from those described herein, it is essential that you discuss these issues with the authors before proceeding with any work based on this document.

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Appendix A

Comparison of erosion between 2007 and 2012 at large sites

ID	HISTORIC SITE NAME	SECTION NAME	2012 HEIGHT (M)	2007 HEIGHT (M)	2012 LENGTH (M)	2007 LENGTH (M)	2012 AREA (M2)	2007 AREA (M2)	2012 LANDUSE	2007 LANDUSE	2012 PRIMARY CAUSAL FACTOR	2007 PRIMARY CAUSAL FACTOR	2012 CAUSAL FACTORS: OTHER
407	12	Lake Karapiro	8.75	4	212		1854	60	Seasonal cropping	Grazing	VEGETATION REMOVAL	Land use	

The area of this site measured by the 2012 survey is greater than that estimated during 2007, partly due to the measured height being twice that estimated during 2007.

ID	2012 PHOTOS	2007 PHOTOS
407	 	

ID	HISTORIC SITE NAME	SECTION NAME	2012 HEIGHT (M)	2007 HEIGHT (M)	2012 LENGTH (M)	2007 LENGTH (M)	2012 AREA (M2)	2007 AREA (M2)	2012 LANDUSE	2007 LANDUSE	2012 PRIMARY CAUSAL FACTOR	2007 PRIMARY CAUSAL FACTOR	2012 CAUSAL FACTORS: OTHER
1036	641	Lake Ohakuri to Lake Aratiatia	33.2	15	303		10060	3000	Seasonal cropping	Natural	RIVER PROCESS	River processes	Water Level Variation

These photos indicate that the bank height was under-estimated during the 2007 survey. The 2007 area should therefore be at least 6000 m^2.

ID	2012 PHOTOS	2007 PHOTOS
1036	 	

ID	HISTORIC SITE NAME	SECTION NAME	2012 HEIGHT (M)	2007 HEIGHT (M)	2012 LENGTH (M)	2007 LENGTH (M)	2012 AREA (M2)	2007 AREA (M2)	2012 LANDUSE	2007 LANDUSE	2012 PRIMARY CAUSAL FACTOR	2007 PRIMARY CAUSAL FACTOR	2012 CAUSAL FACTORS: OTHER
1076	681	Lake Ohakuri to Lake Aratiatia	29.45	15	156		4602	450	Forestry	Forestry	RIVER PROCESS	Land use	

These photos indicate that the bank height was under-estimated during the 2007 survey. The 2007 area should therefore be at least 1000 m^2, and possibly more if the length of the erosion feature was also under-estimated.

ID	2012 PHOTOS	2007 PHOTOS
1076	 	

ID	HISTORIC SITE NAME	SECTION NAME	2012 HEIGHT (M)	2007 HEIGHT (M)	2012 LENGTH (M)	2007 LENGTH (M)	2012 AREA (M2)	2007 AREA (M2)	2012 LANDUSE	2007 LANDUSE	2012 PRIMARY CAUSAL FACTOR	2007 PRIMARY CAUSAL FACTOR	2012 CAUSAL FACTORS: OTHER
1077	682	Lake Ohakuri to Lake Aratiatia	30.49	8	145		4417	480	Forestry	Forestry	RIVER PROCESS	River processes	

These images also indicate that the 2007 height was greatly under-estimated. The 2007 area should therefore have been at least 1,800 m^2 and possibly more if the length of the feature was also under-estimated.

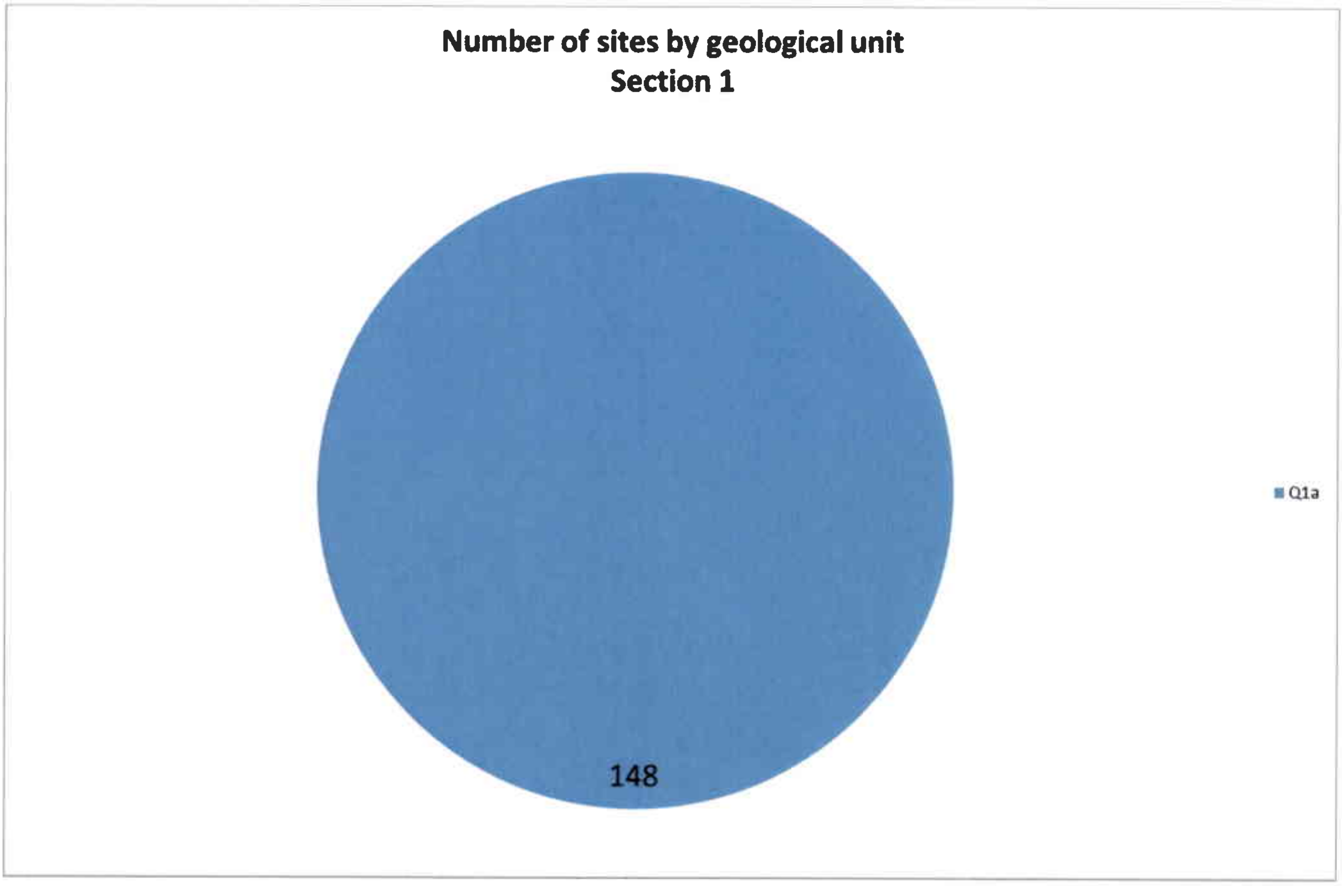
ID	2012 PHOTOS	2007 PHOTOS
1077	 	

ID	HISTORIC SITE NAME	SECTION NAME	2012 HEIGHT (M)	2007 HEIGHT (M)	2012 LENGTH (M)	2007 LENGTH (M)	2012 AREA (M2)	2007 AREA (M2)	2012 LANDUSE	2007 LANDUSE	2012 PRIMARY CAUSAL FACTOR	2007 PRIMARY CAUSAL FACTOR	2012 CAUSAL FACTORS: OTHER
14	L - 2.5 - A	Between Karapiro and 11.8 KM downstream	34.47	10	20	25	698		Grazing	Grazing	RIVER PROCESS		

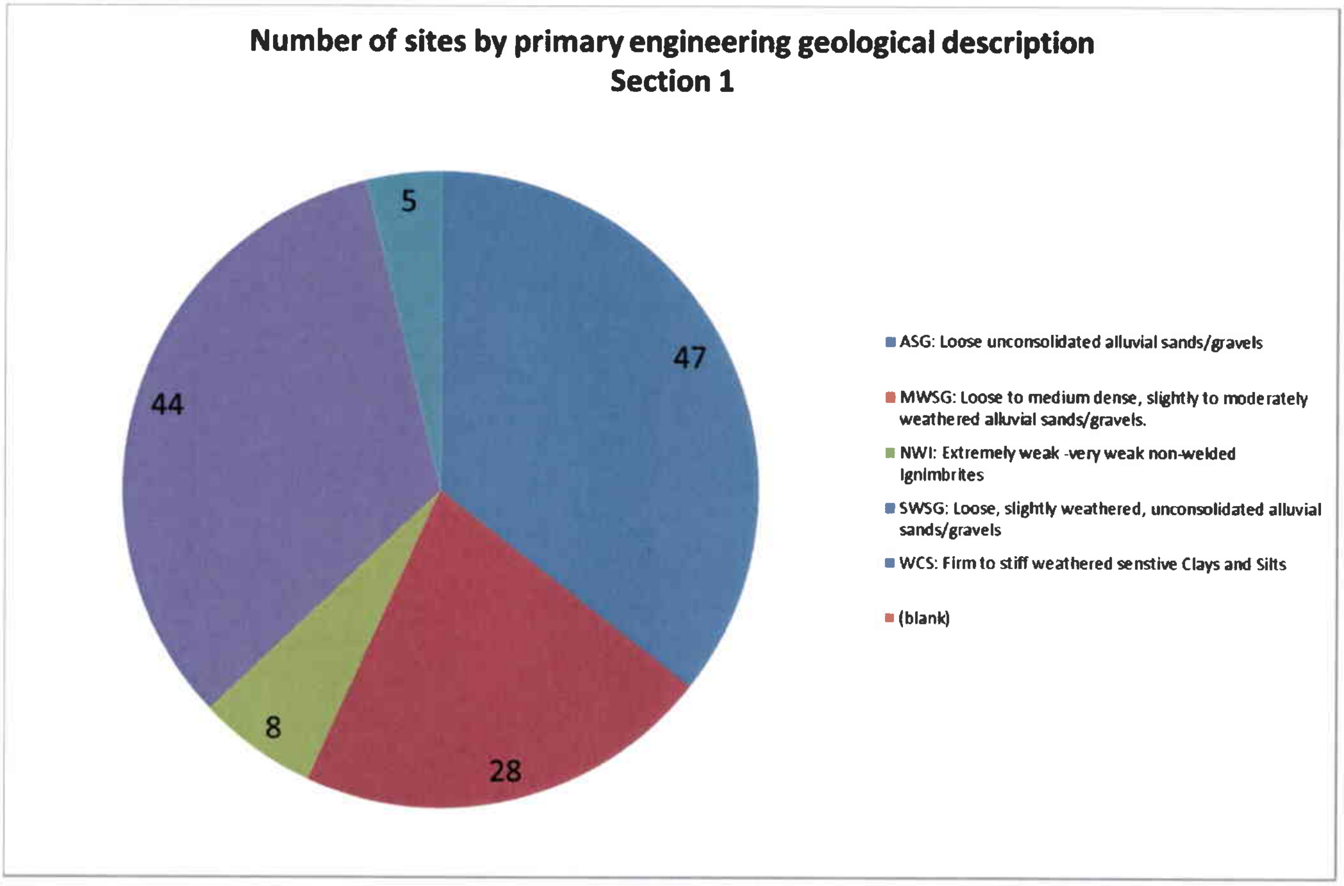
ID	2012 PHOTOS	2007 PHOTOS
14		

Appendix B

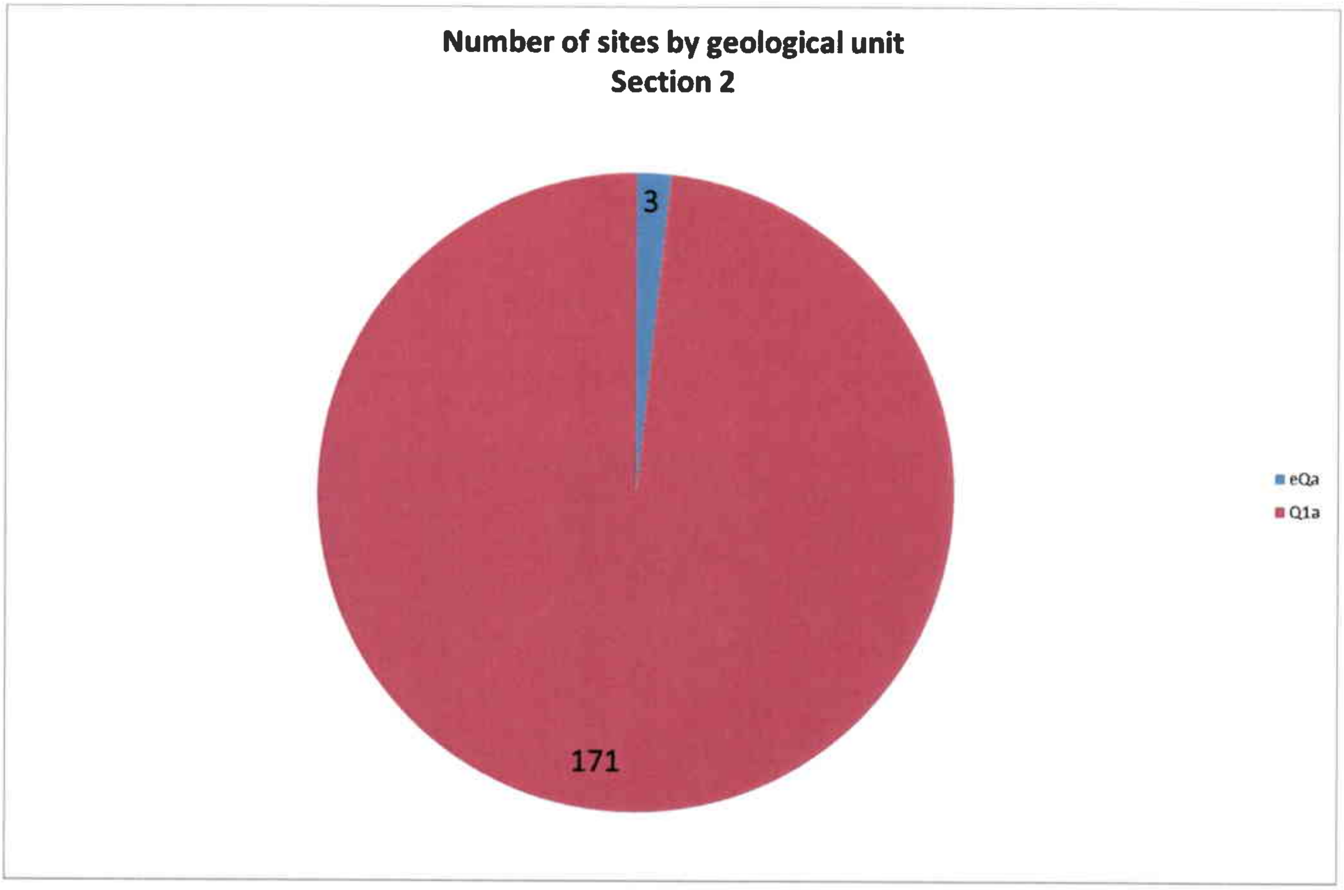
Spatial distribution of the mapped geology and engineering geologic units

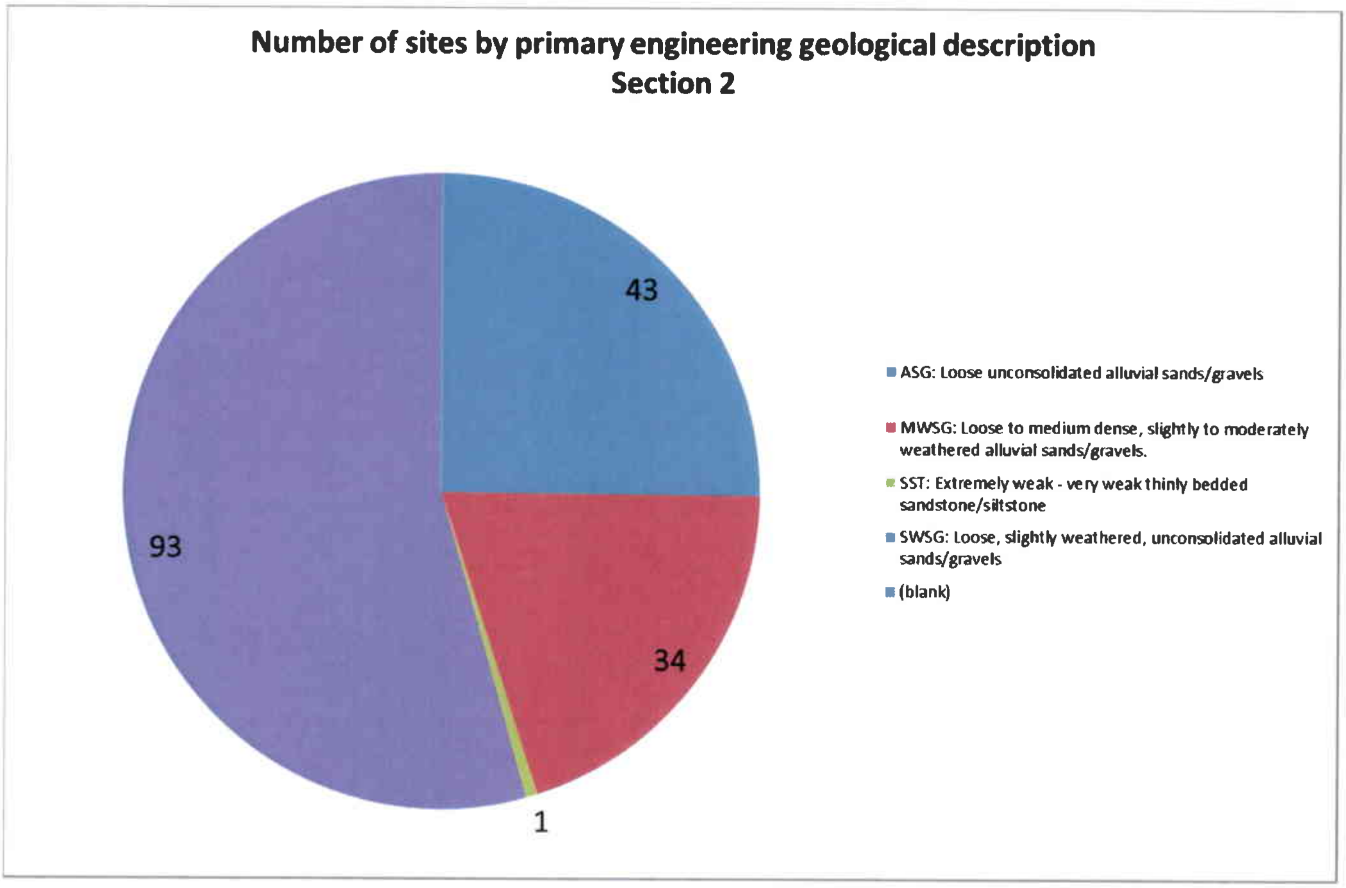


Number of sites by geological unit
Section 1
148
Q1a

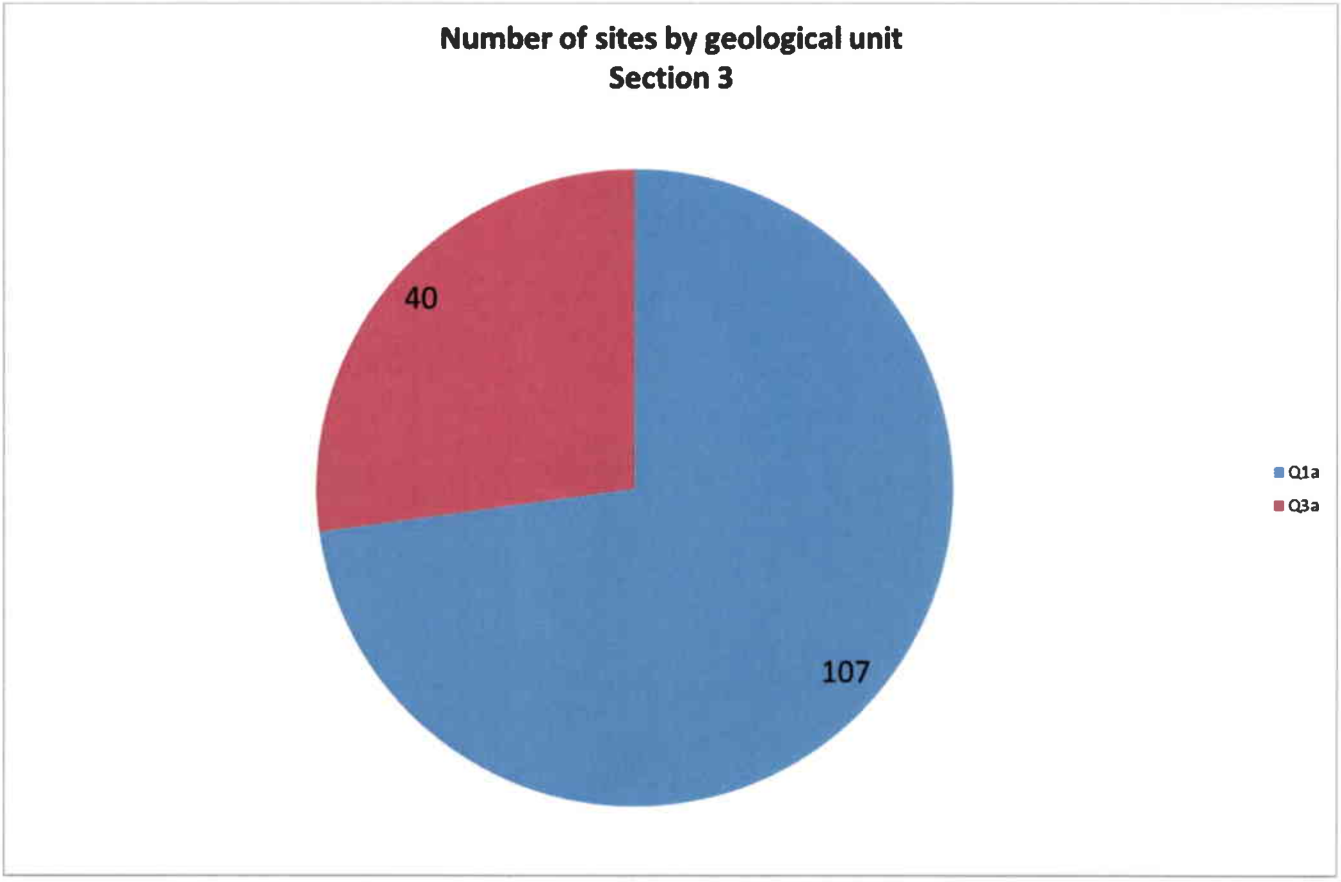


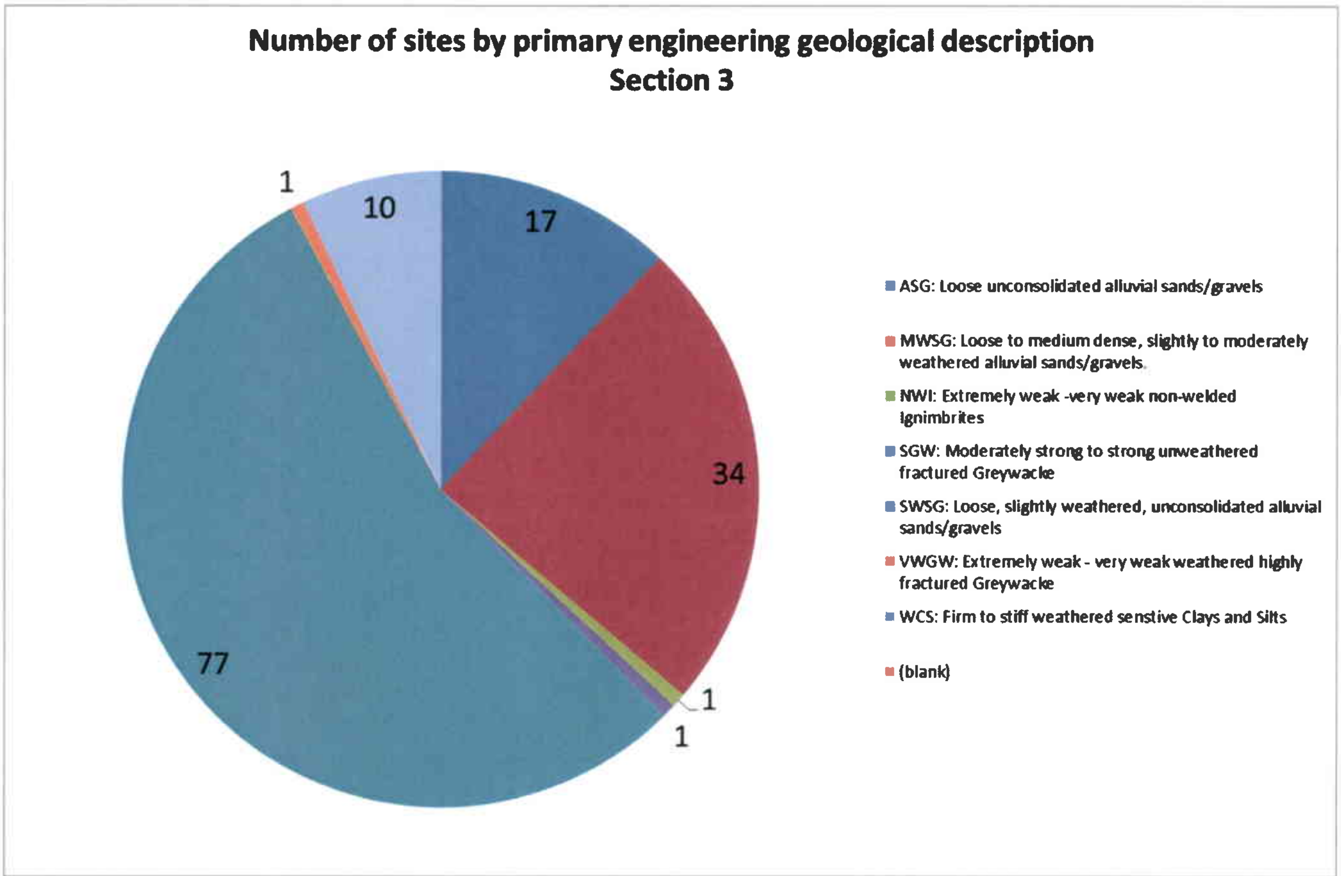
Number of sites by primary engineering geological description
Section 1
5
47
44
8
28
ASG: Loose unconsolidated alluvial sands/gravels
MWSG: Loose to medium dense, slightly to moderately weathered alluvial sands/gravels.
NWI: Extremely weak -very weak non-welded Ignimbrites
SWSG: Loose, slightly weathered, unconsolidated alluvial sands/gravels
WCS: Firm to stiff weathered senstive Clays and Silts
(blank)





Note: Geological units are taken from maps, engineering geology from field observations. Where the engineering geology could not be observed, this is not identified.





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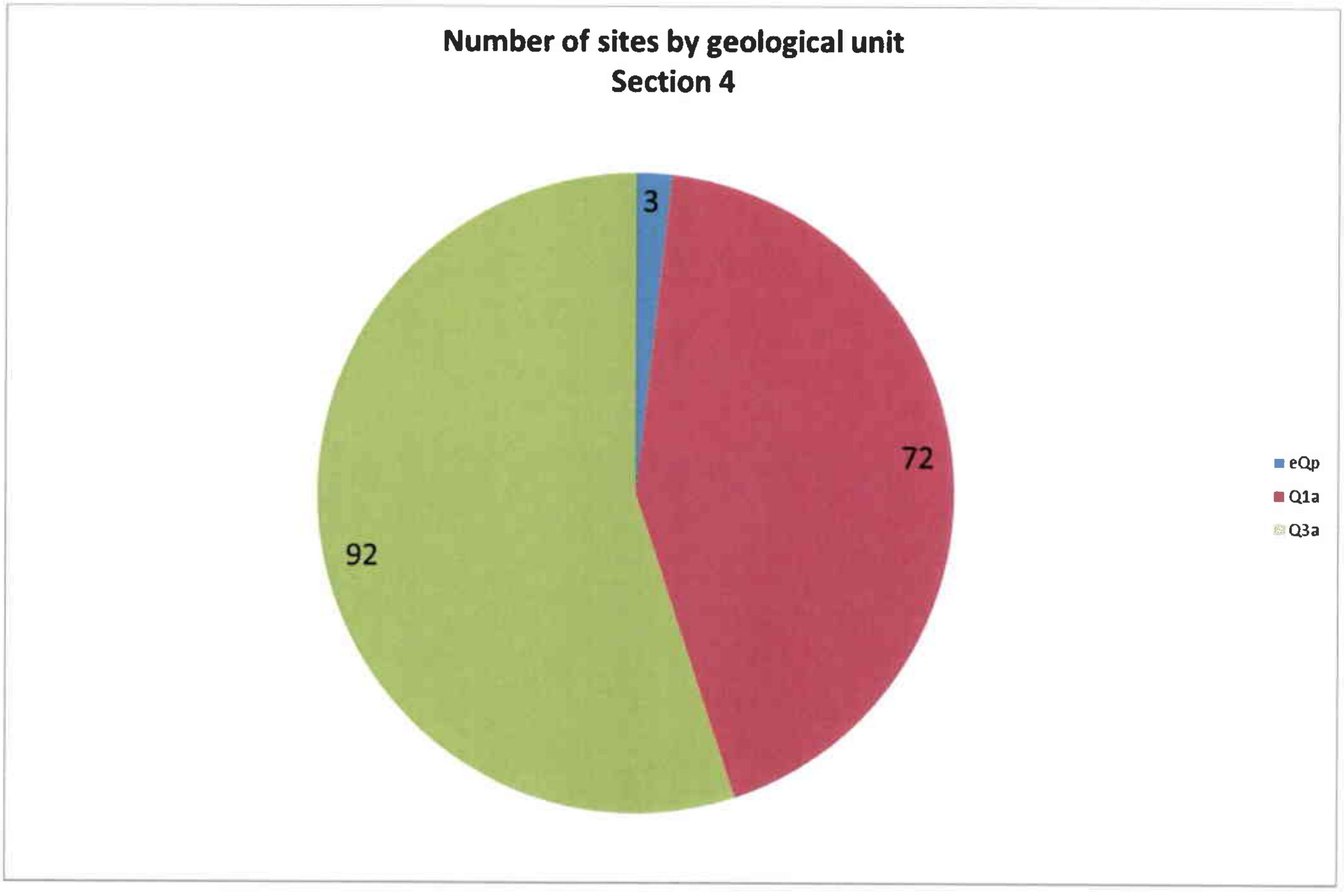

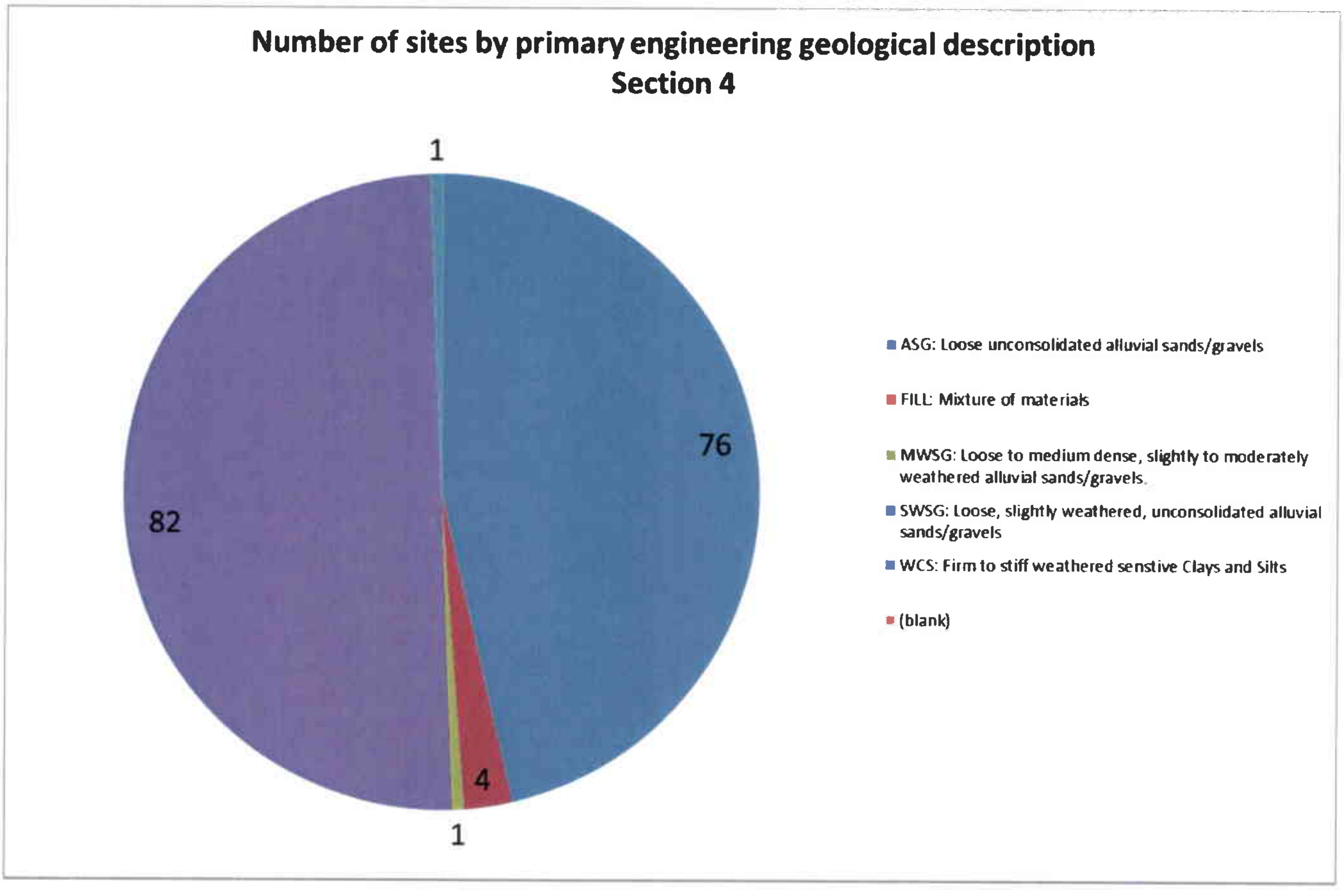

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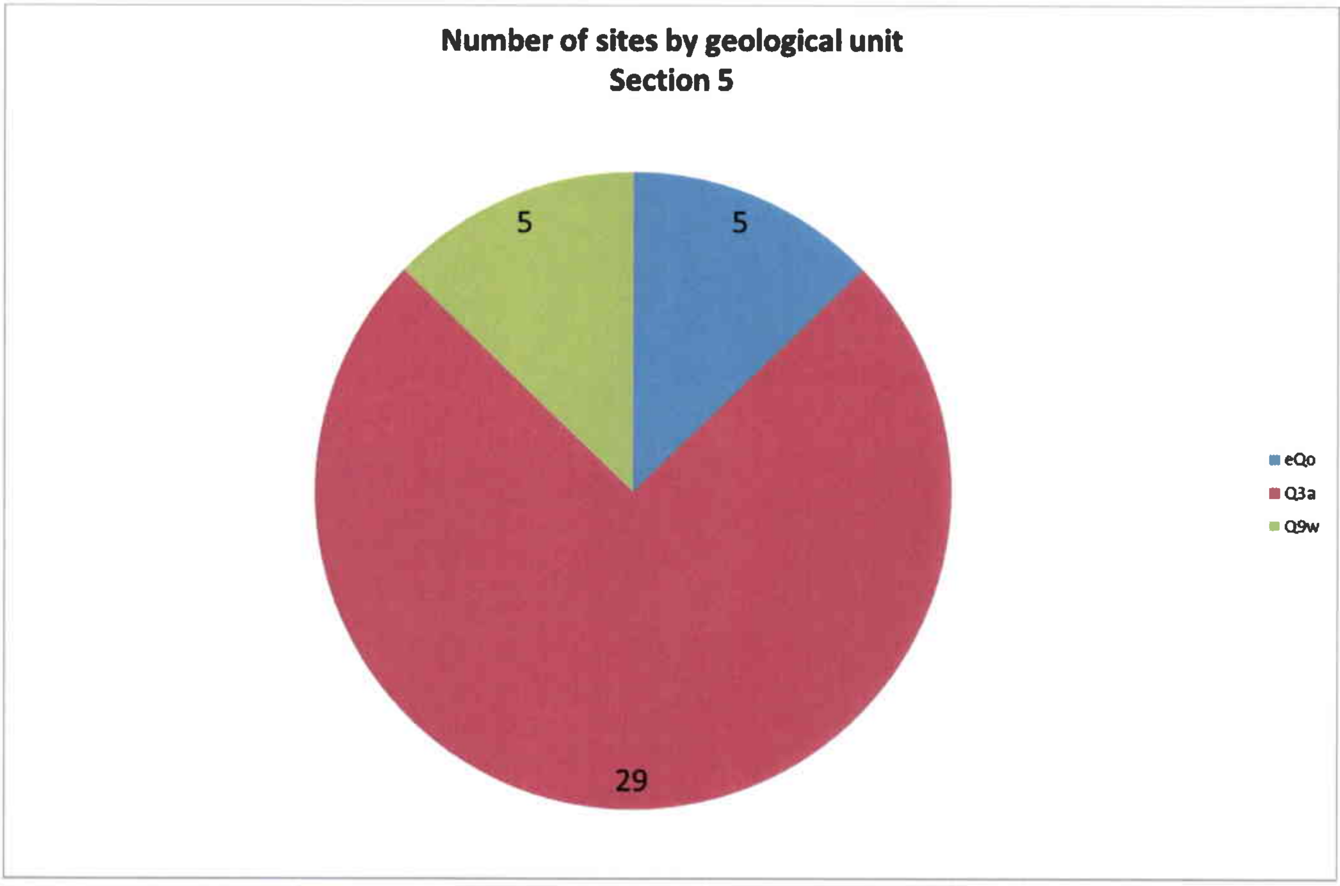

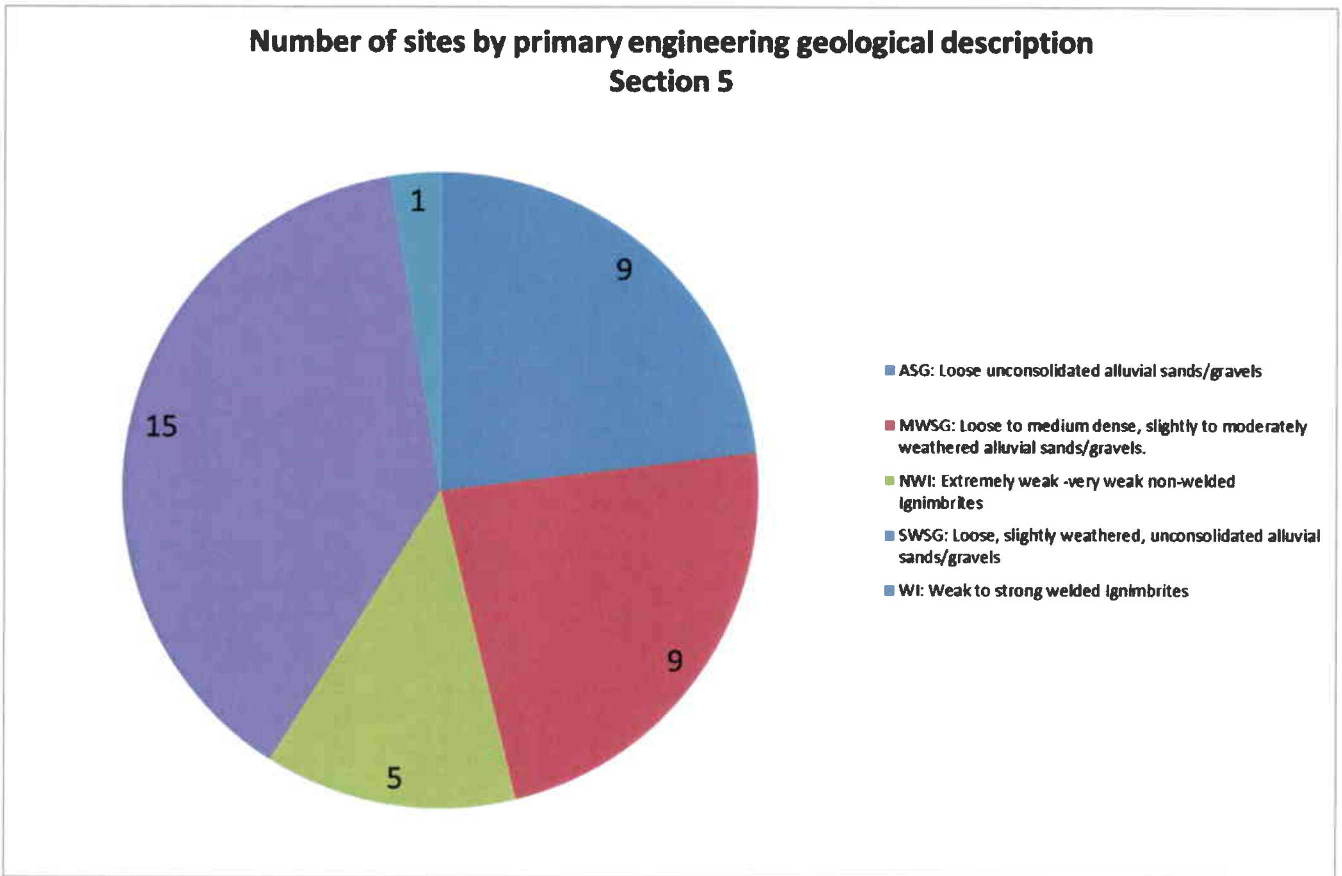

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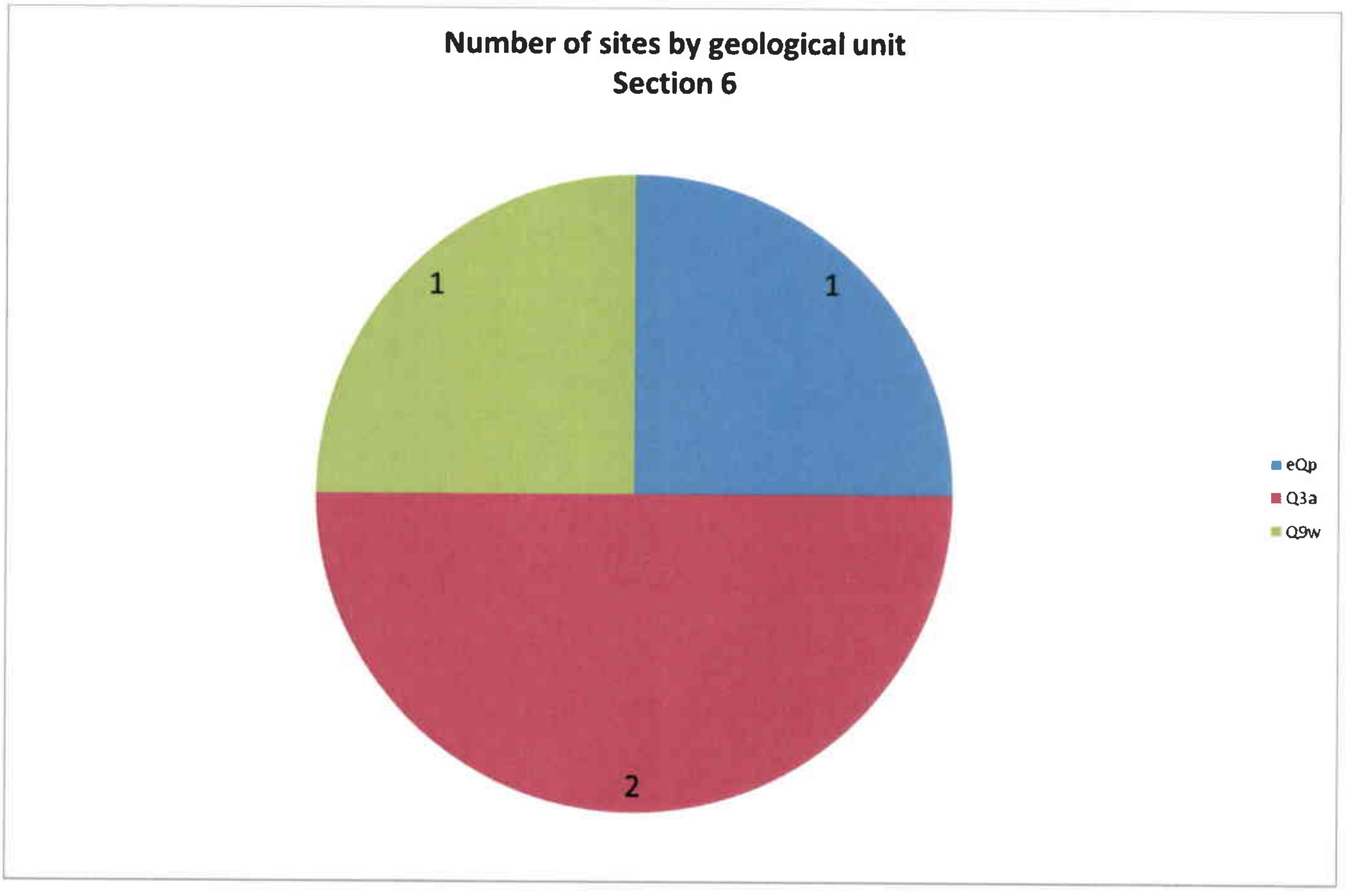

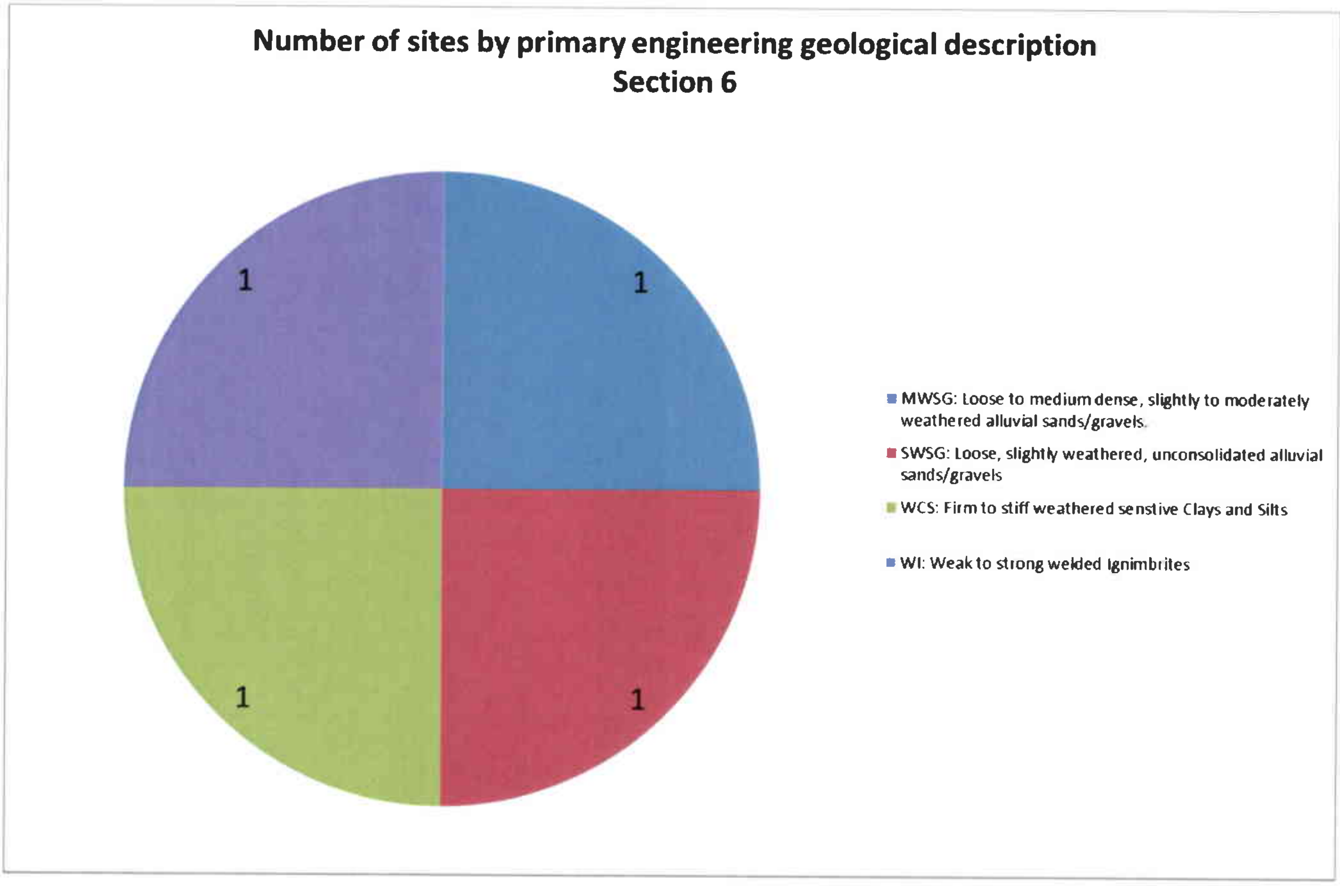

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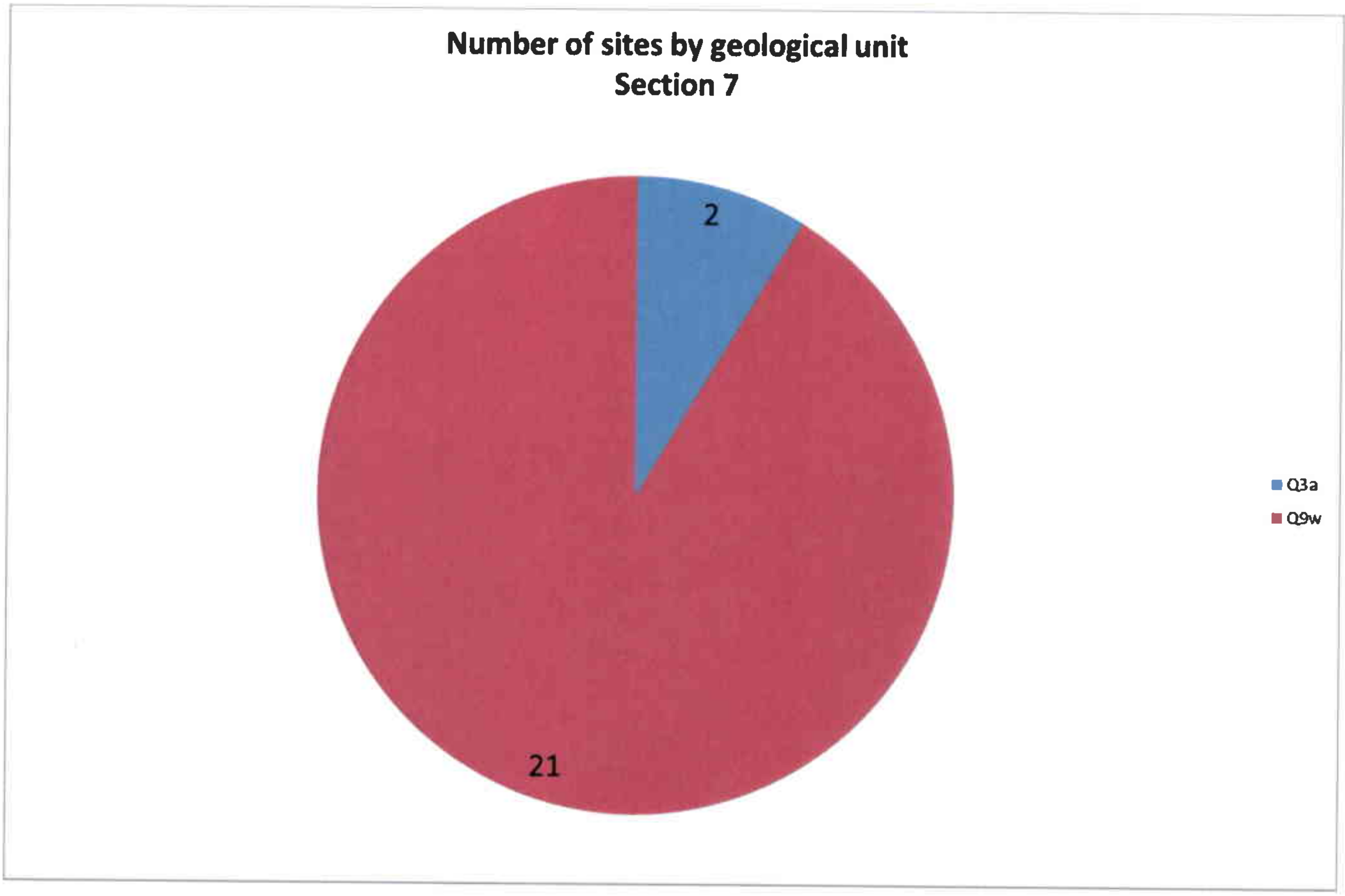

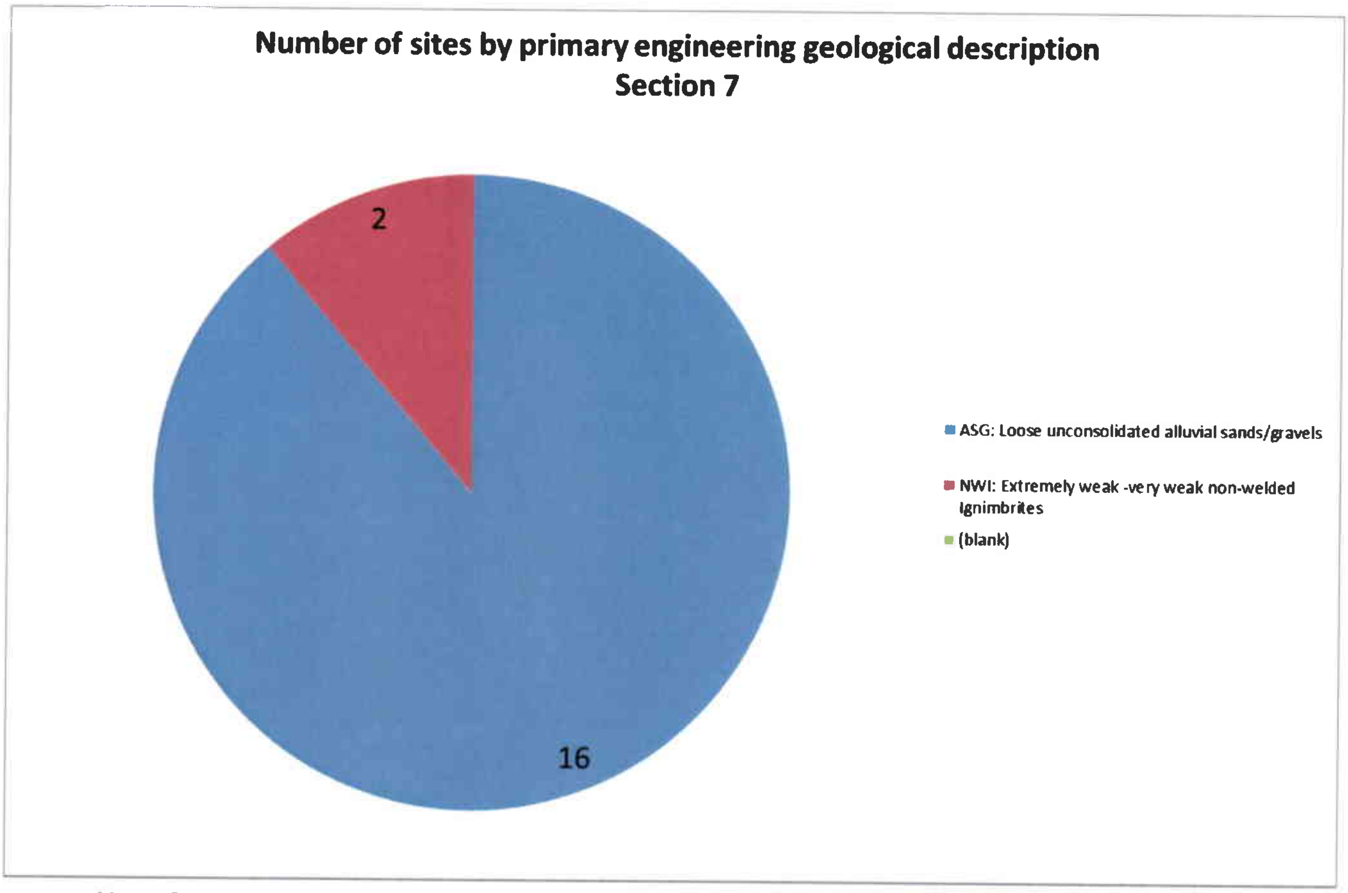

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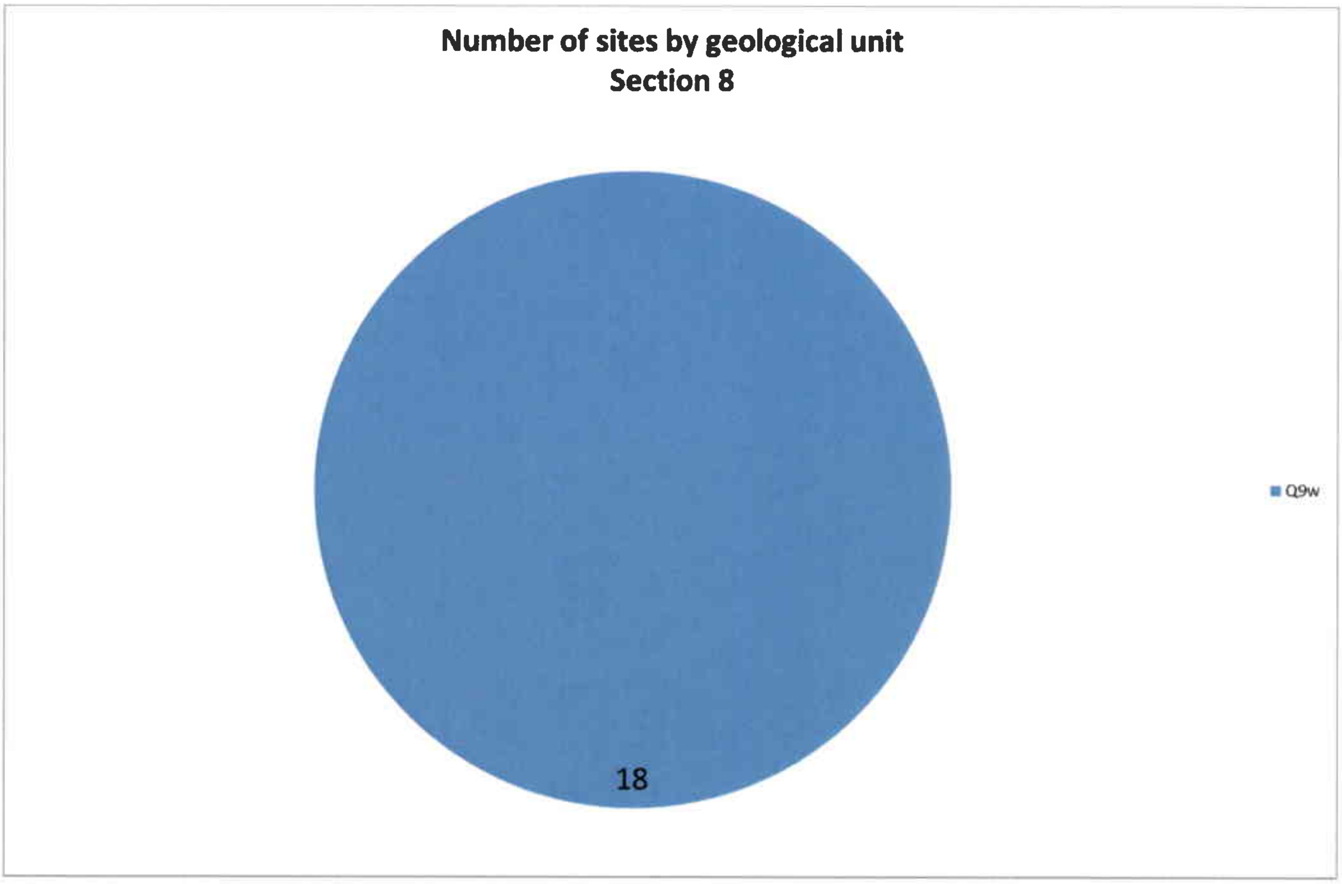

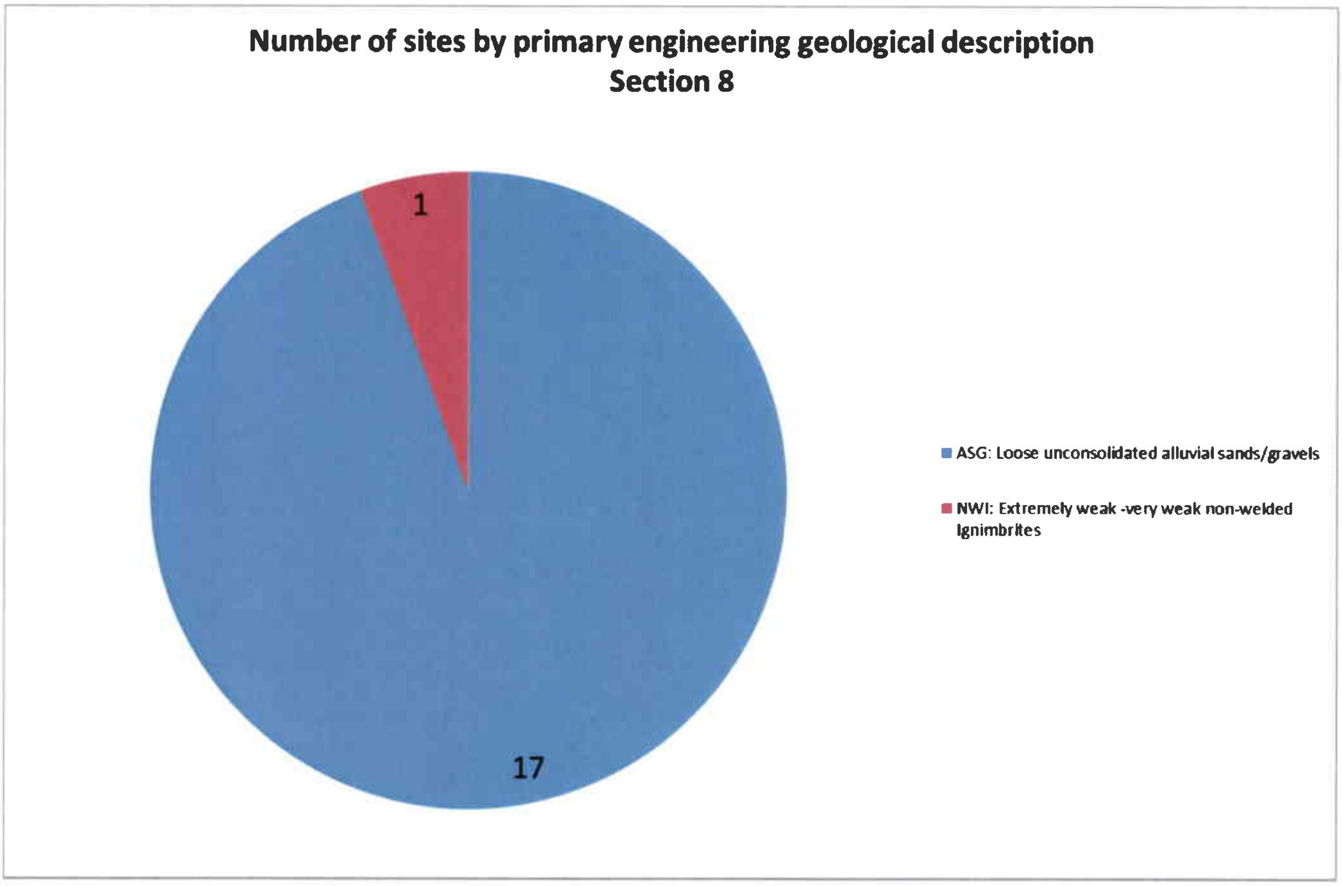

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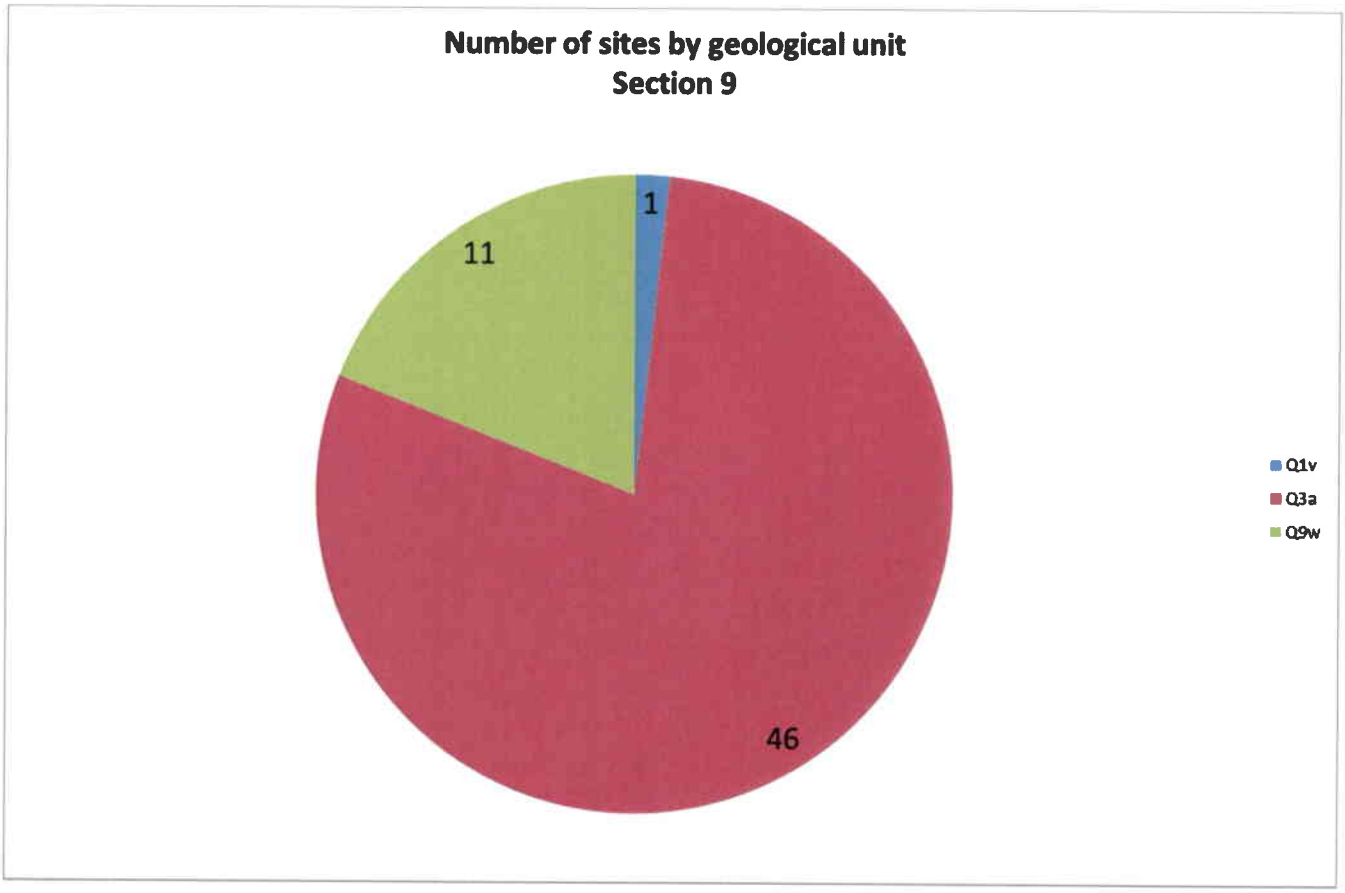

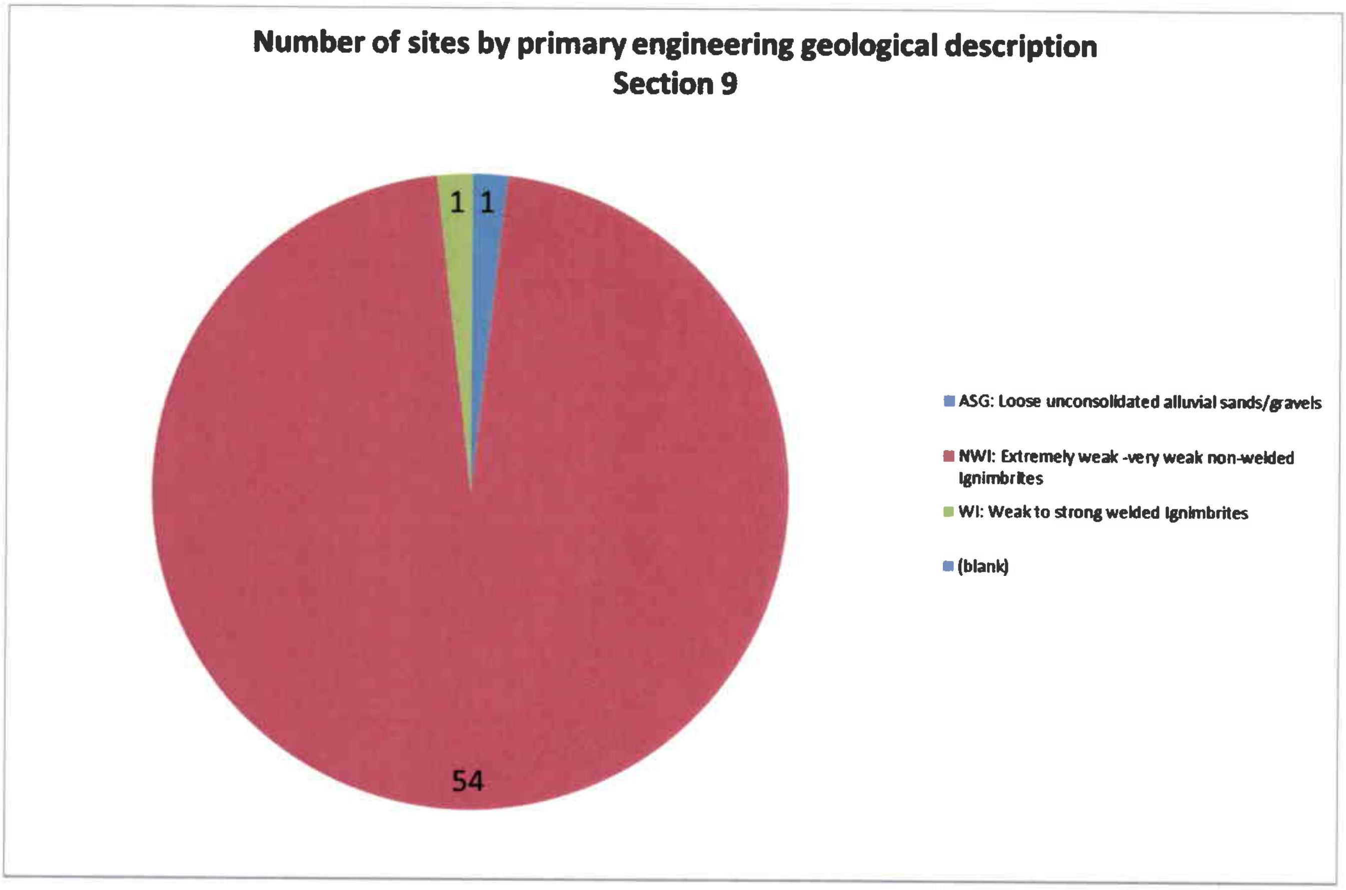

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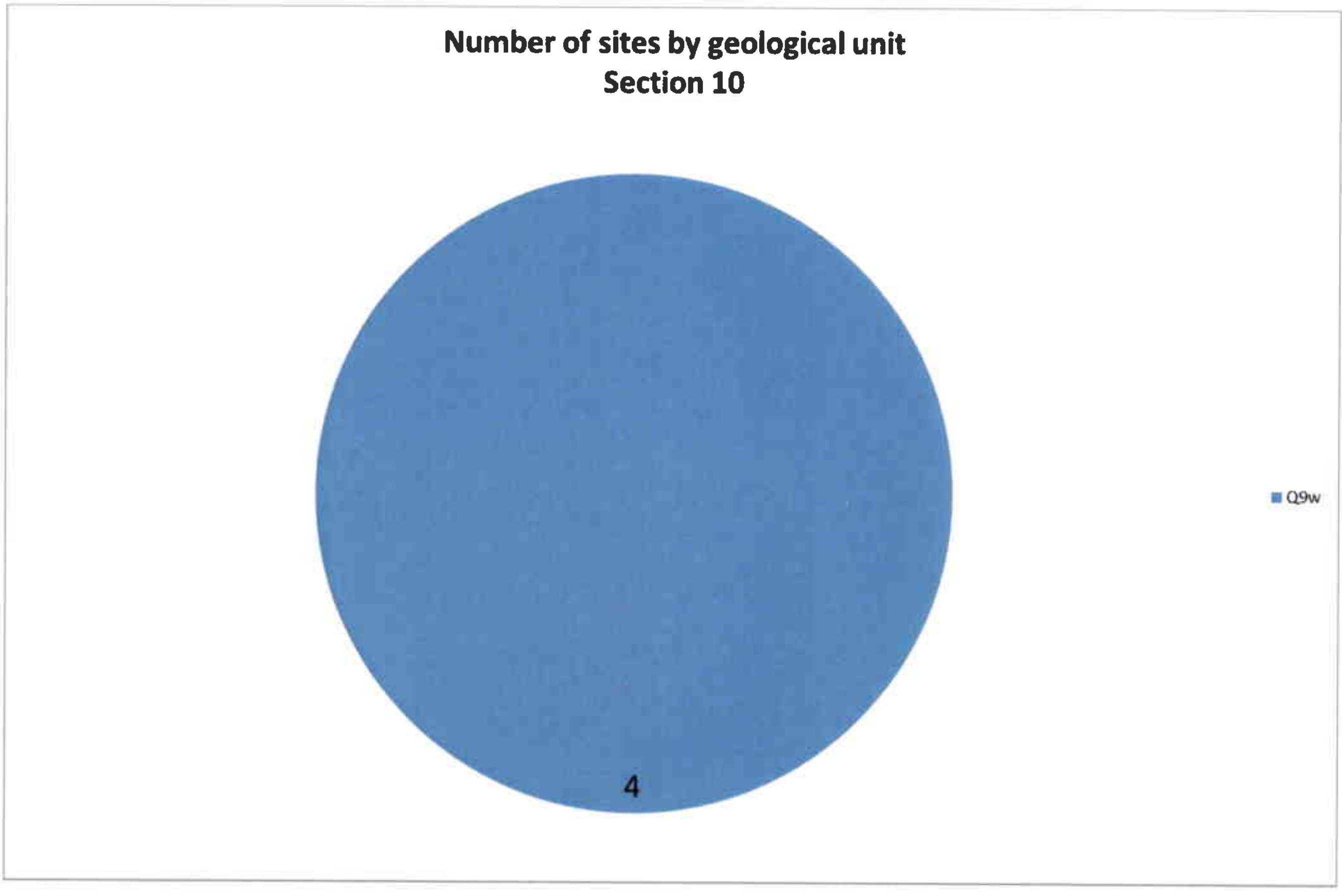

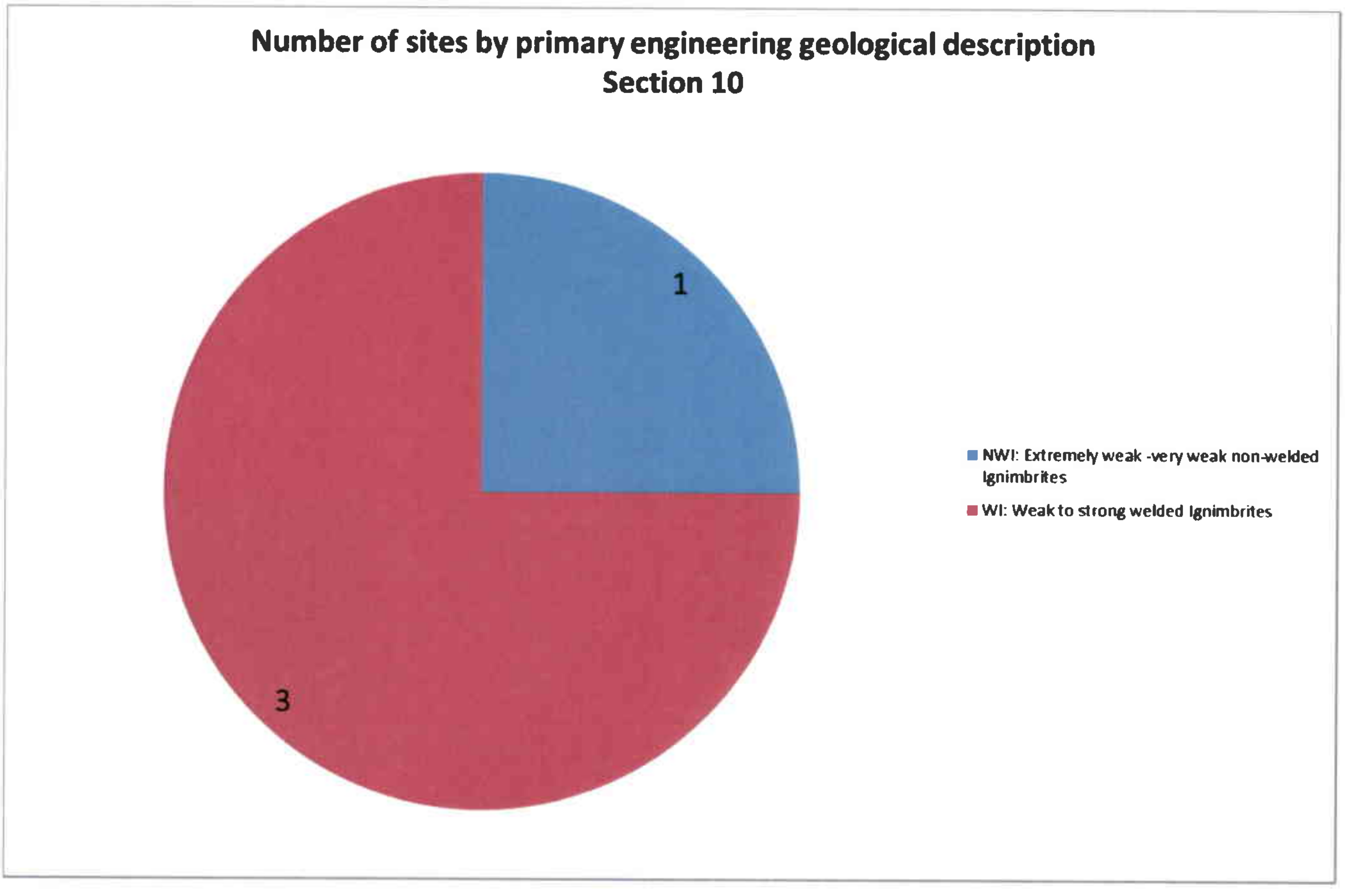

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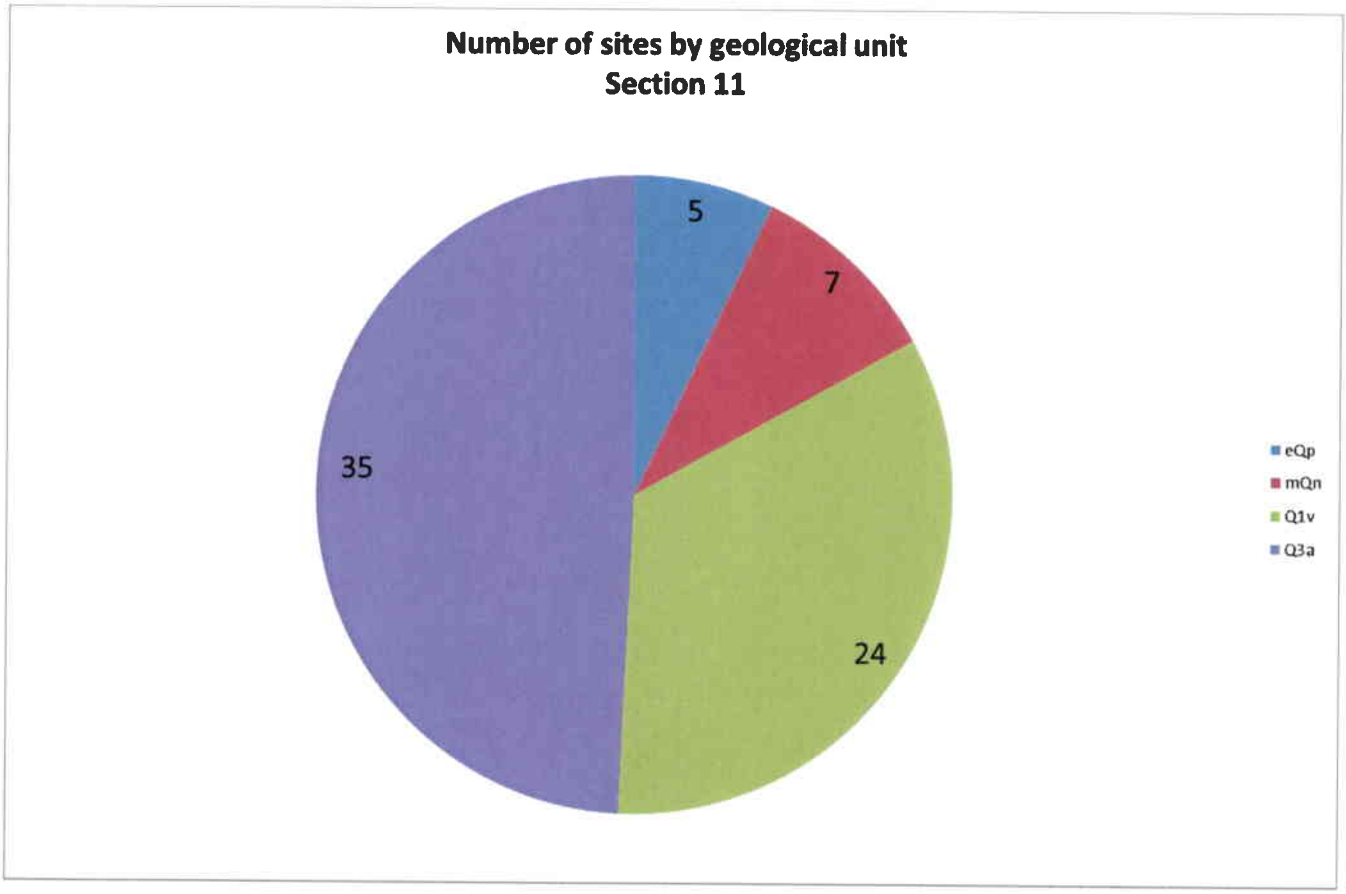

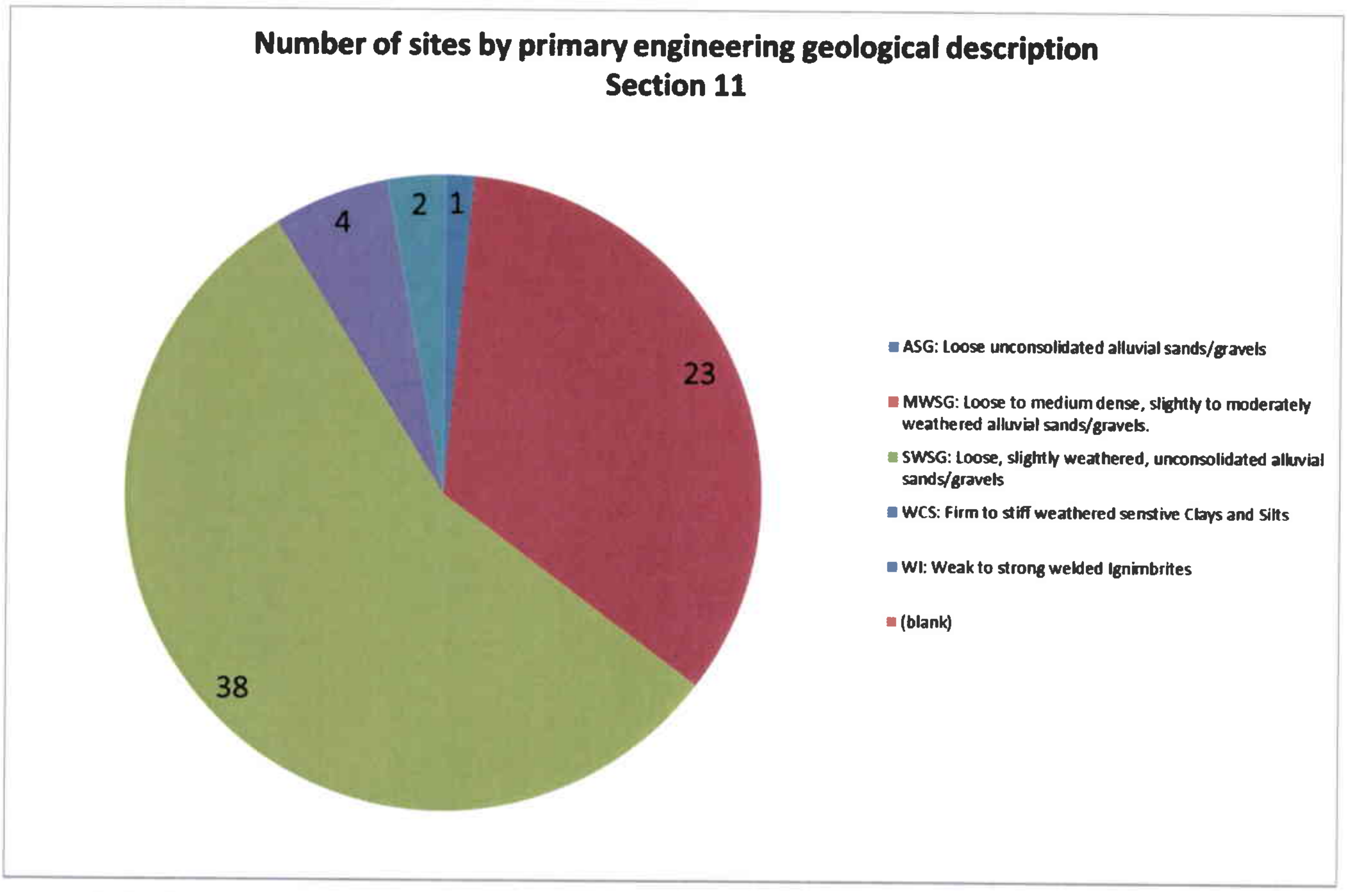

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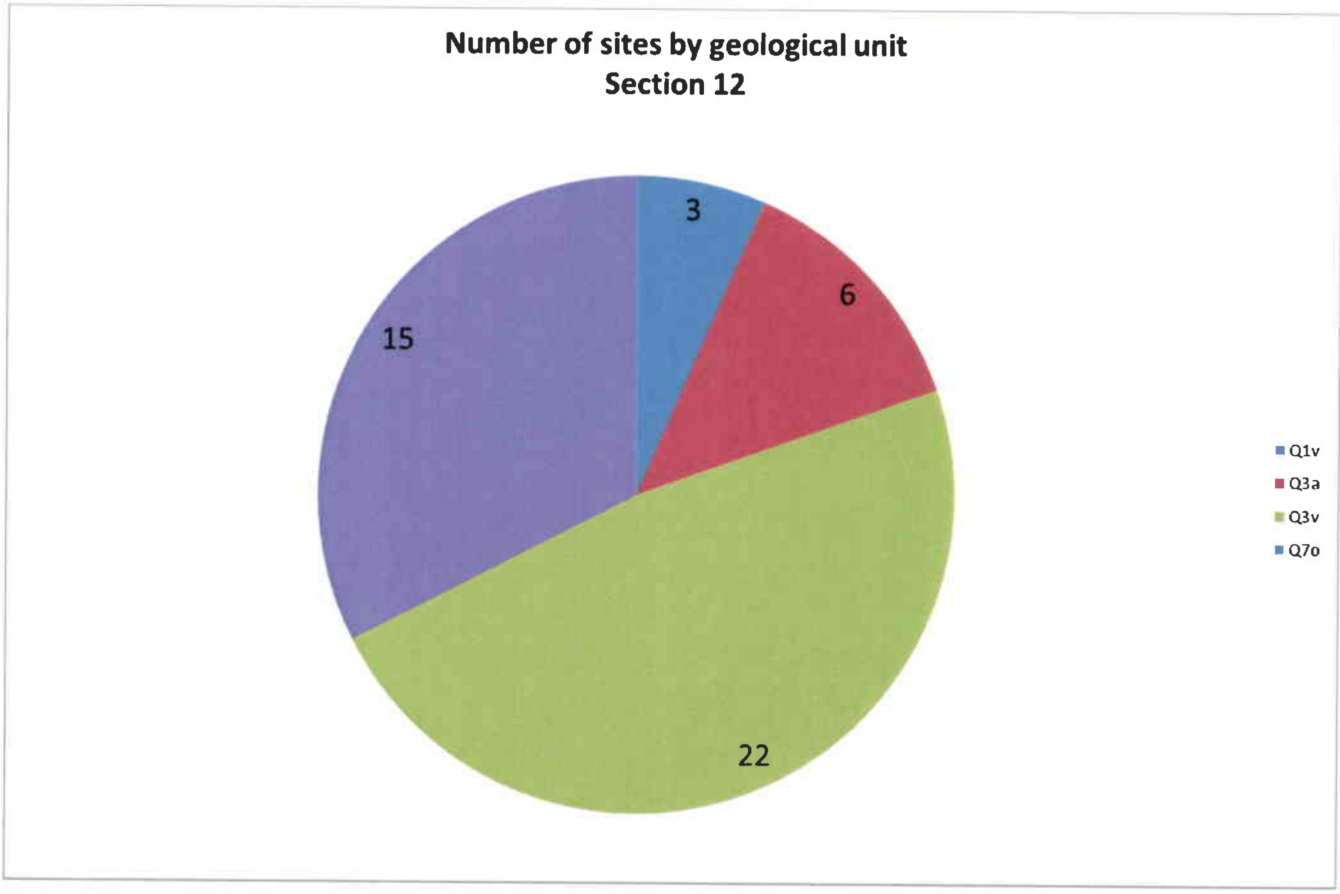

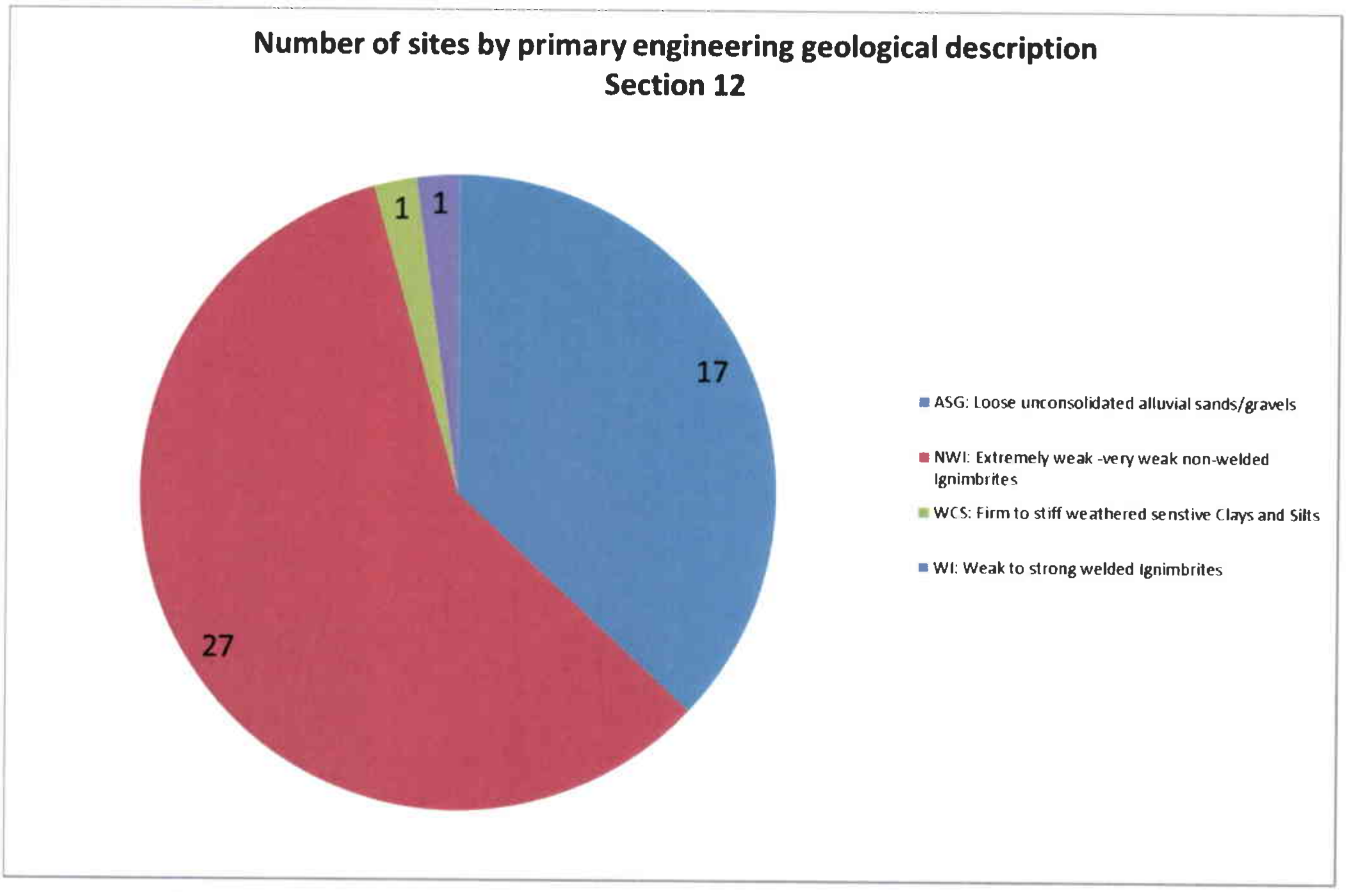

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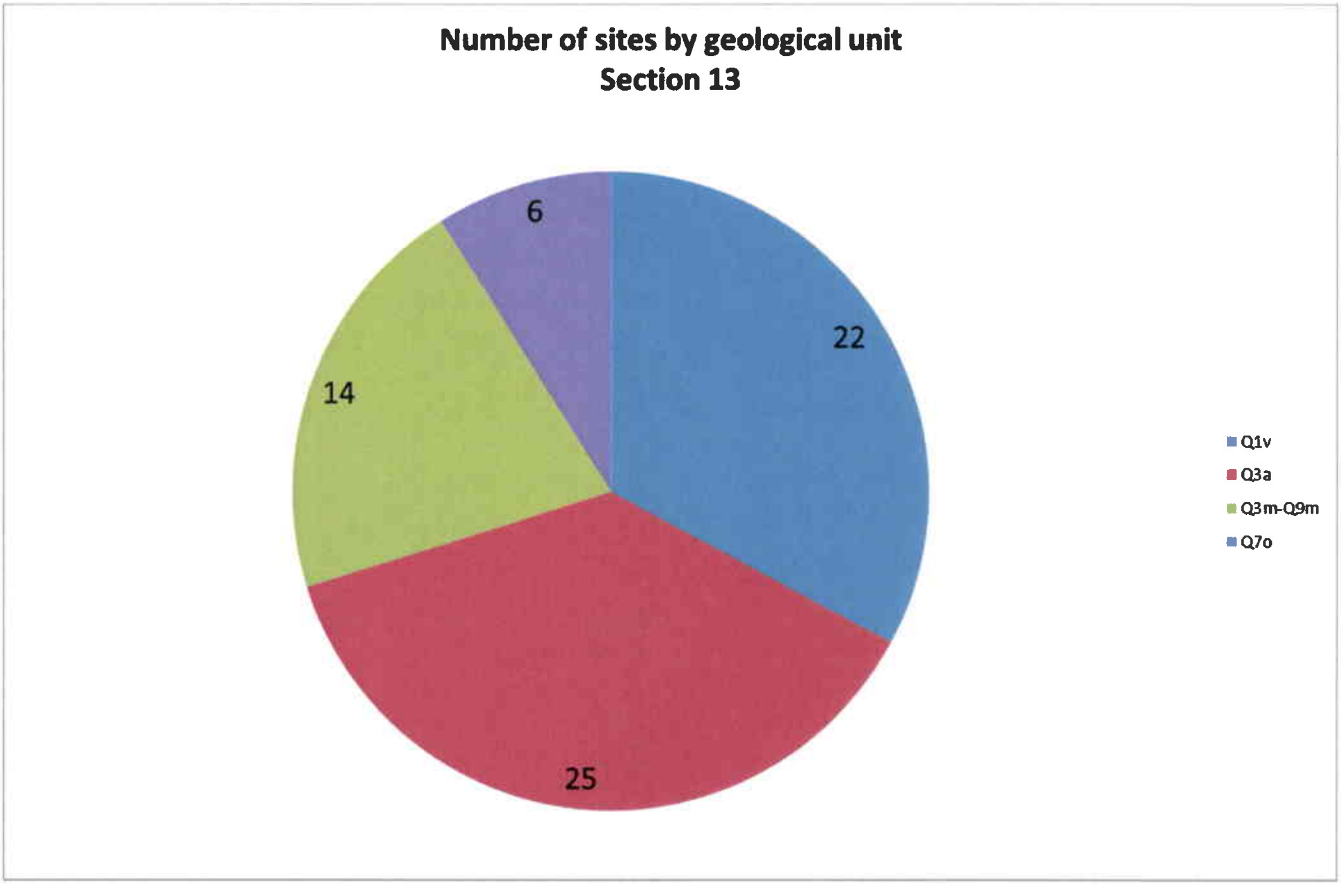

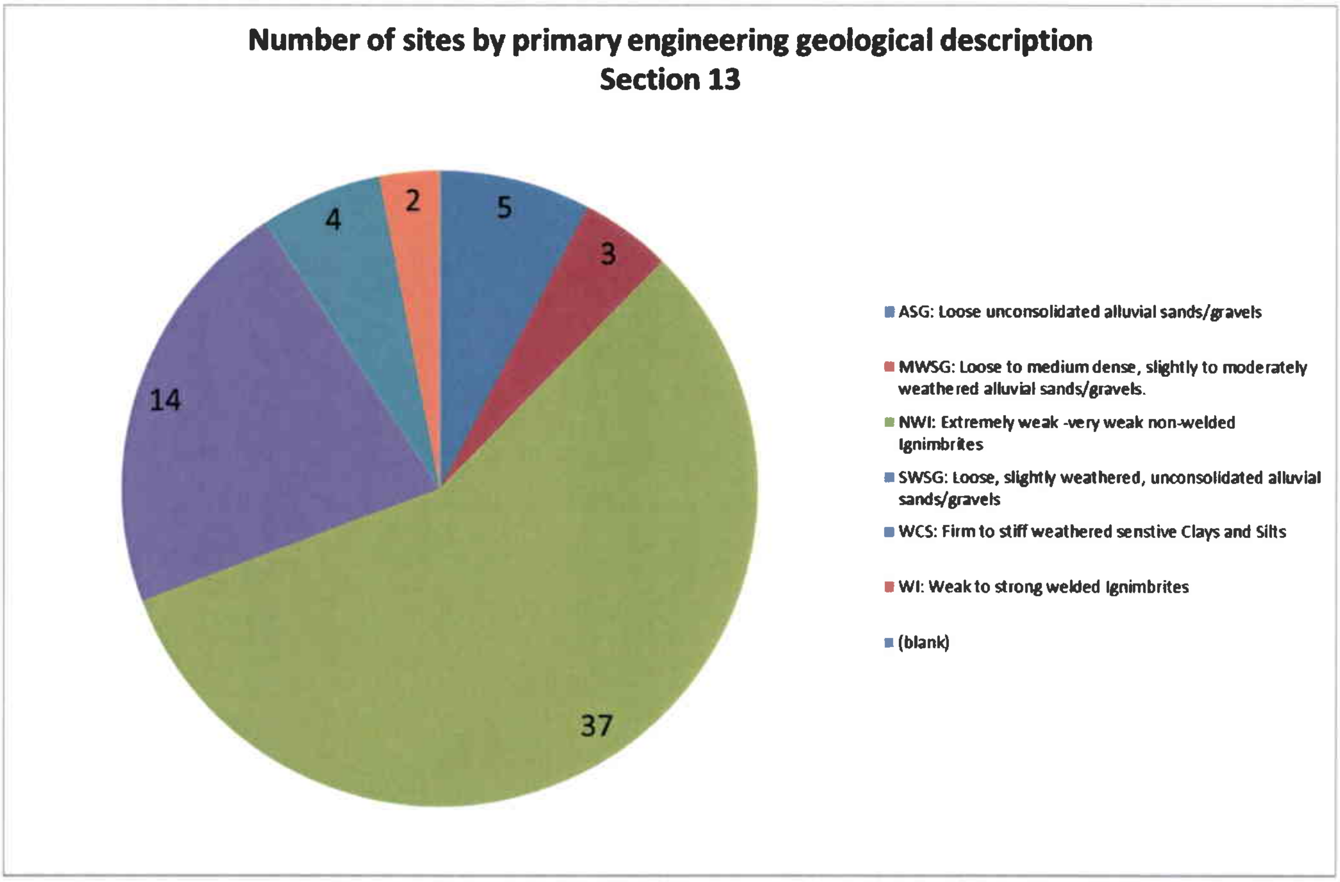

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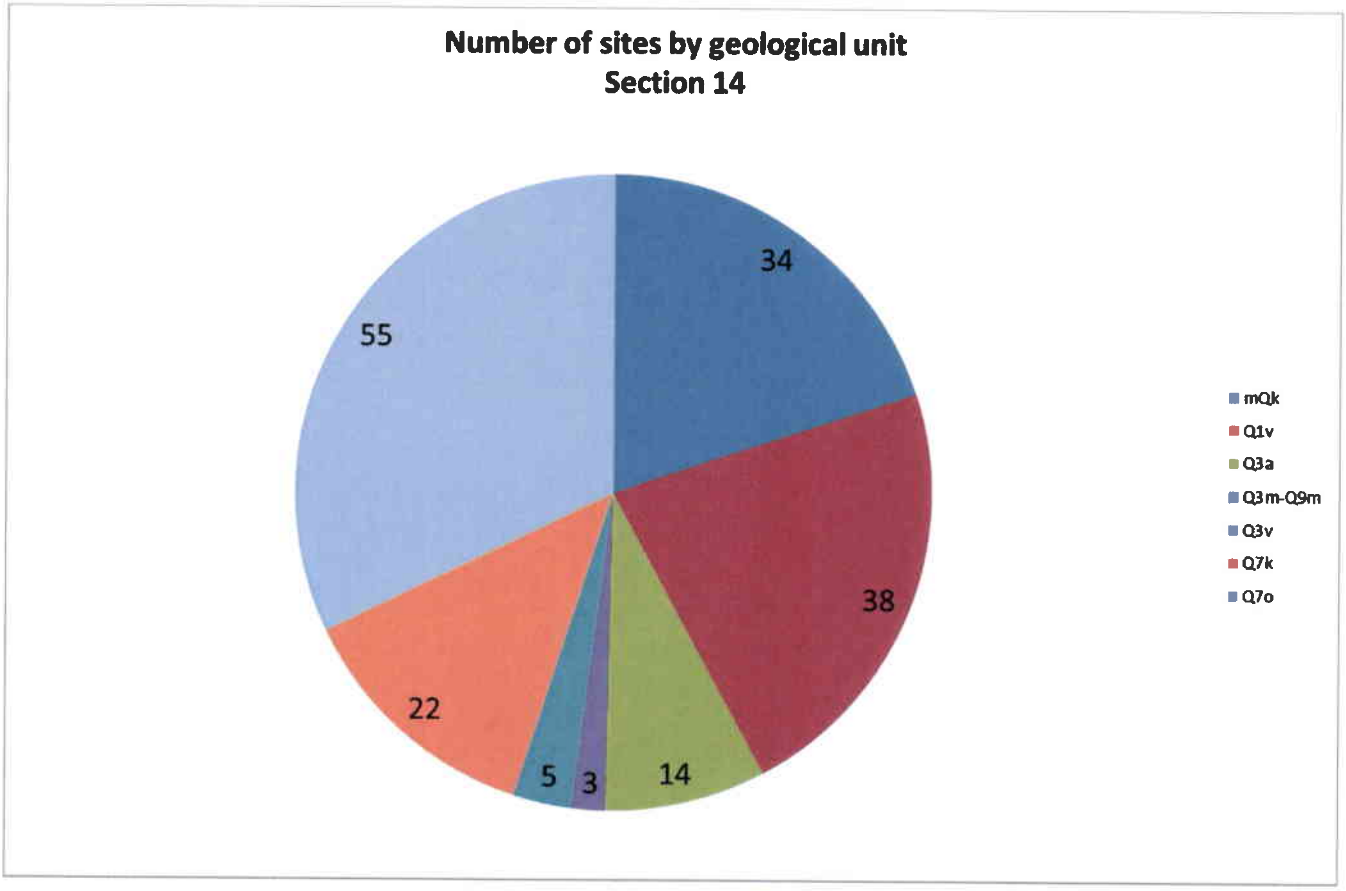

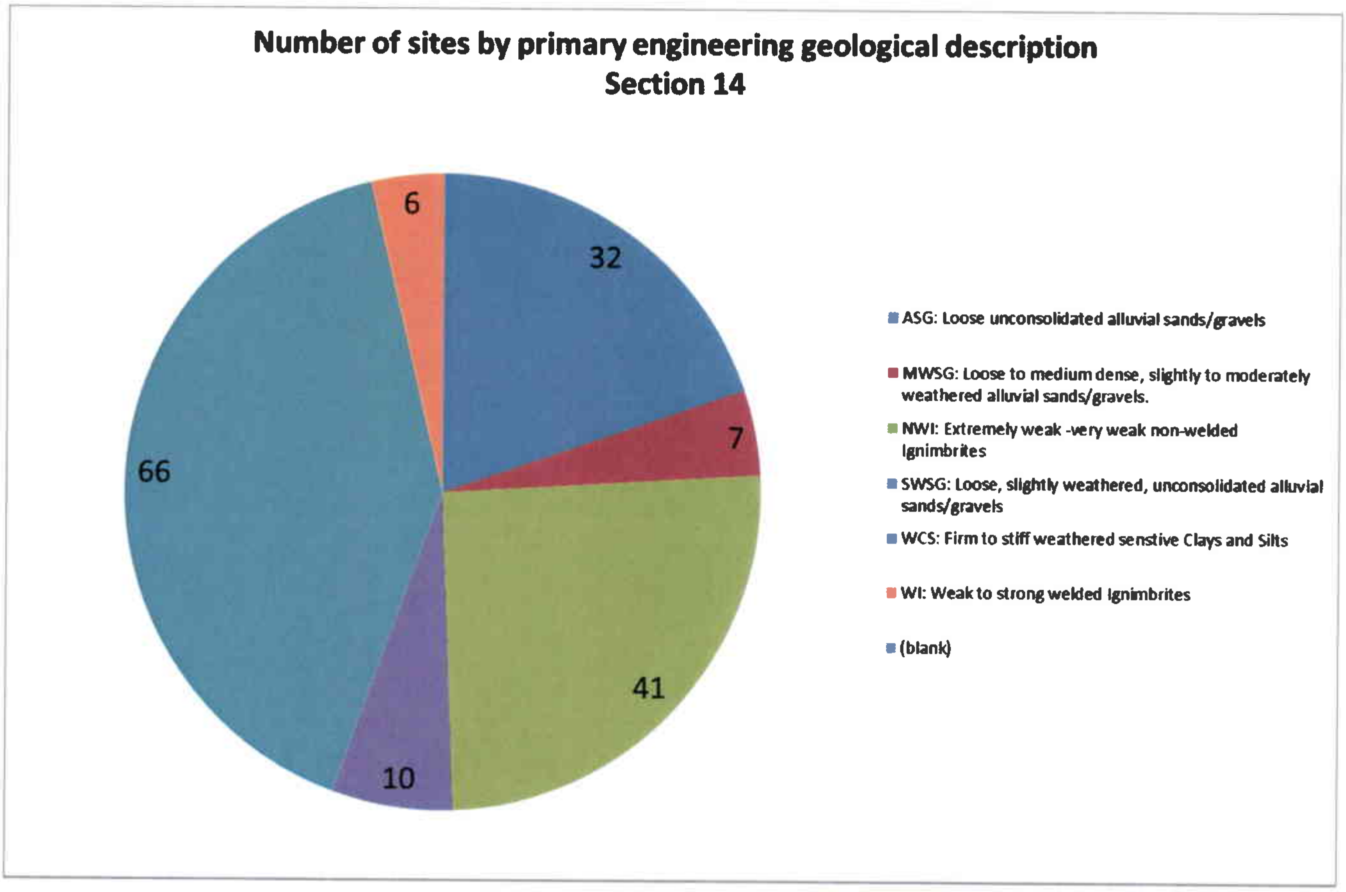

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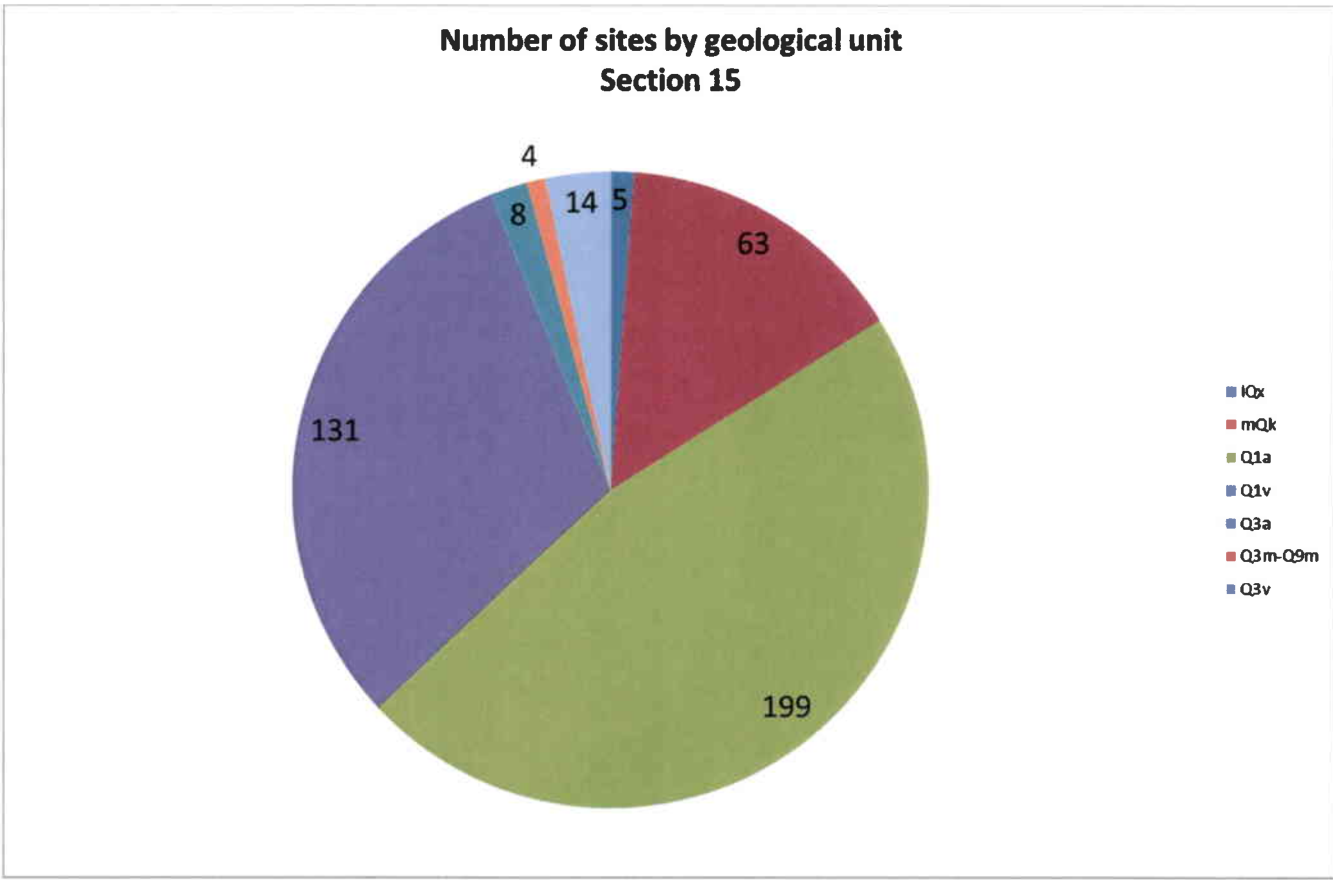

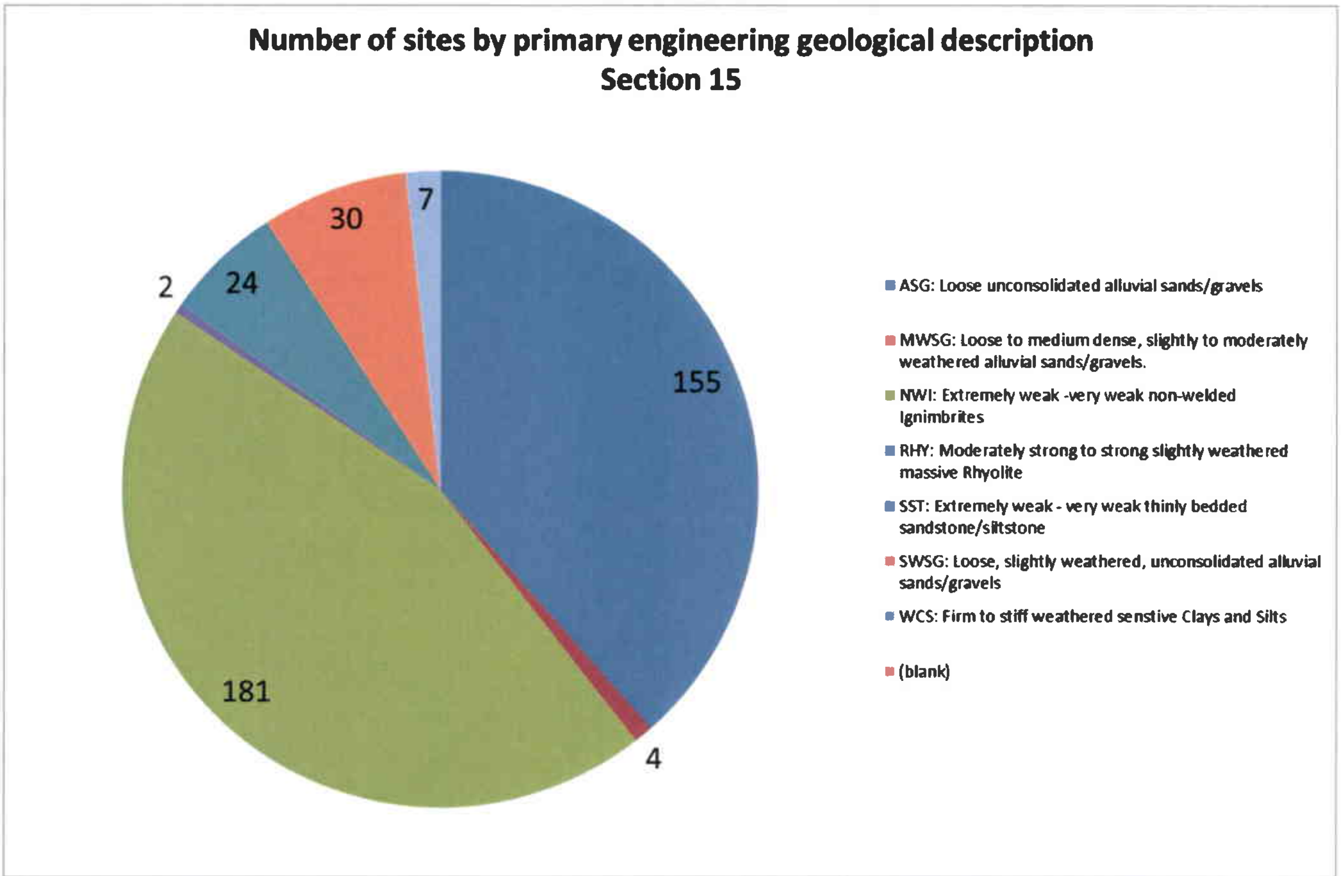

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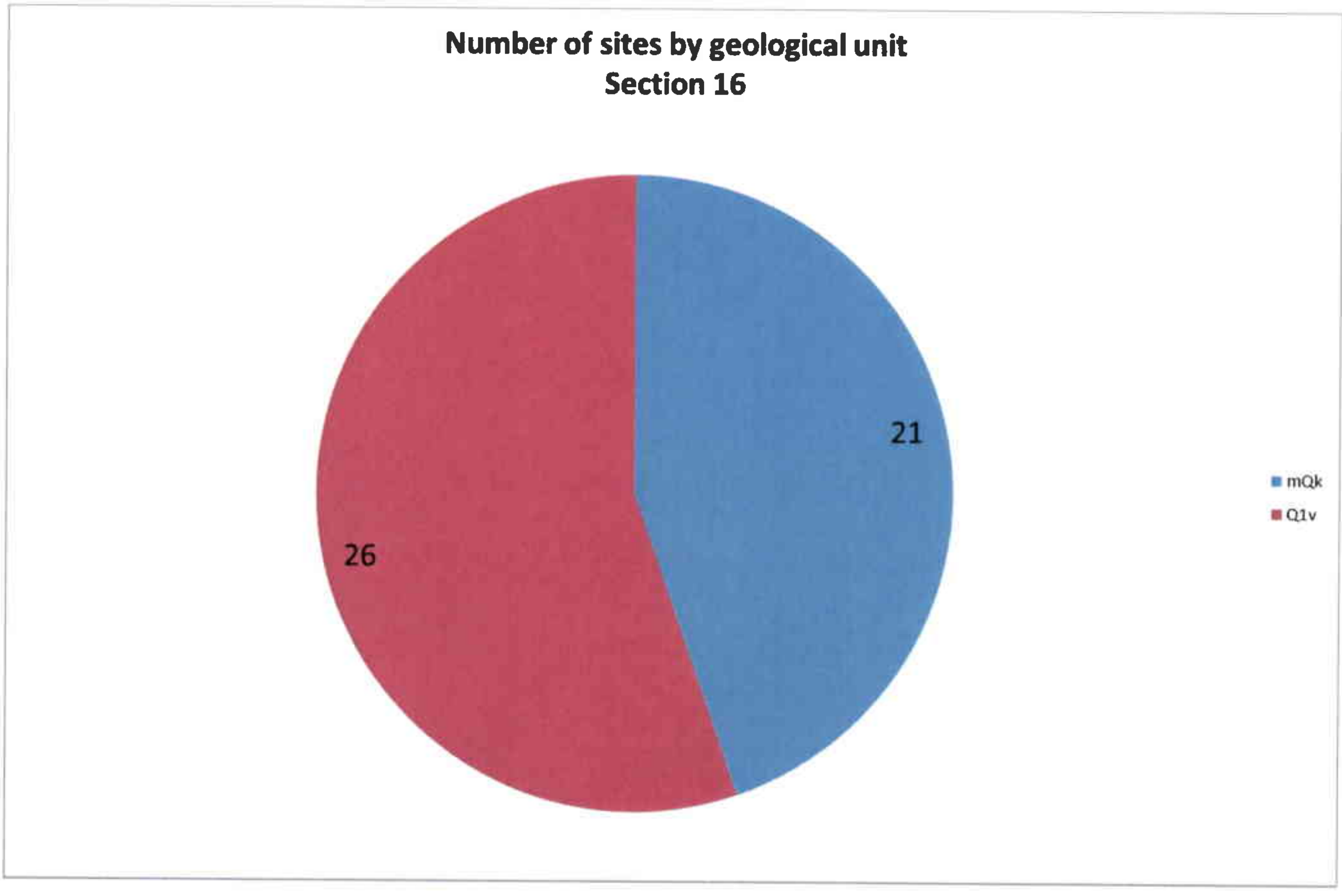

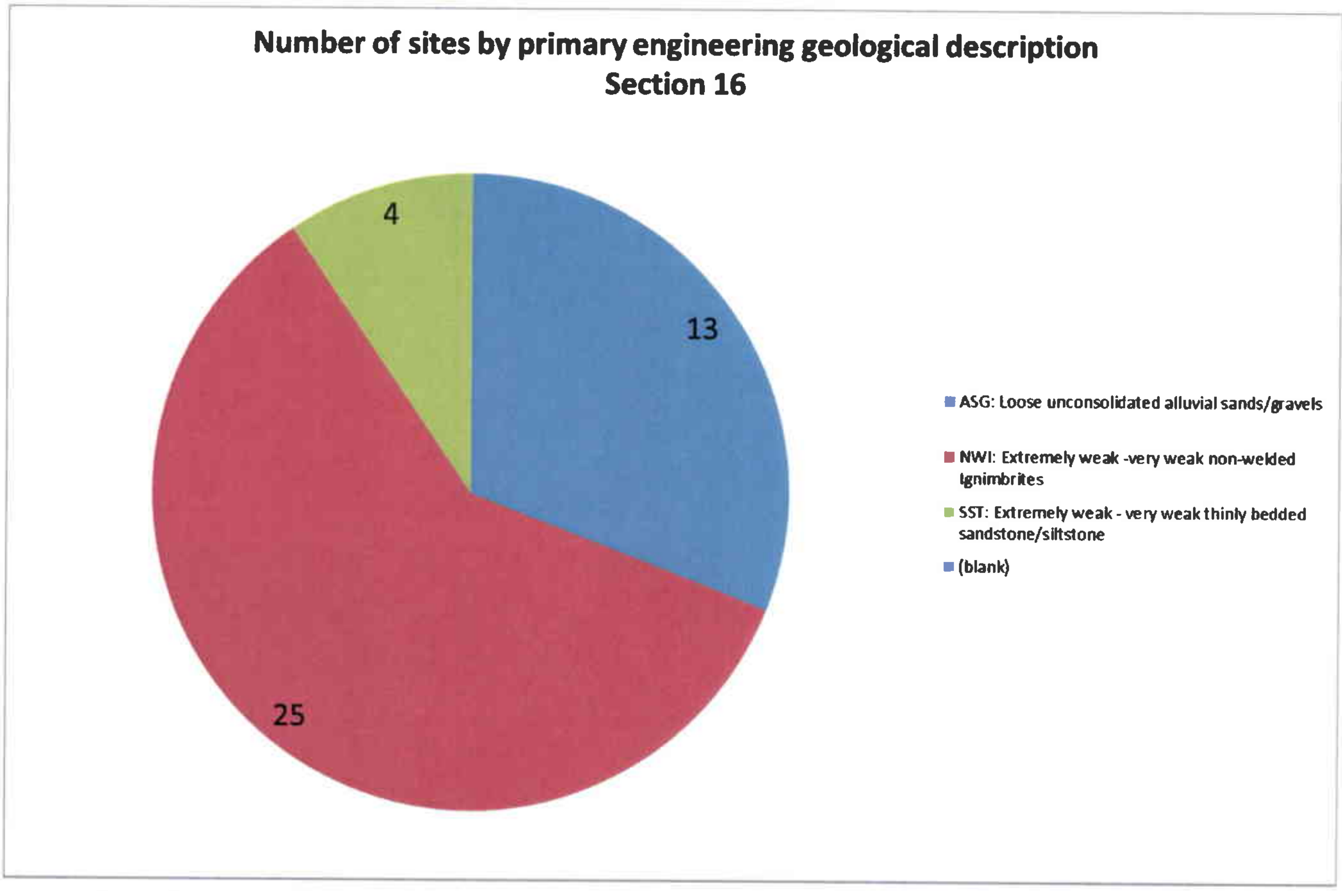

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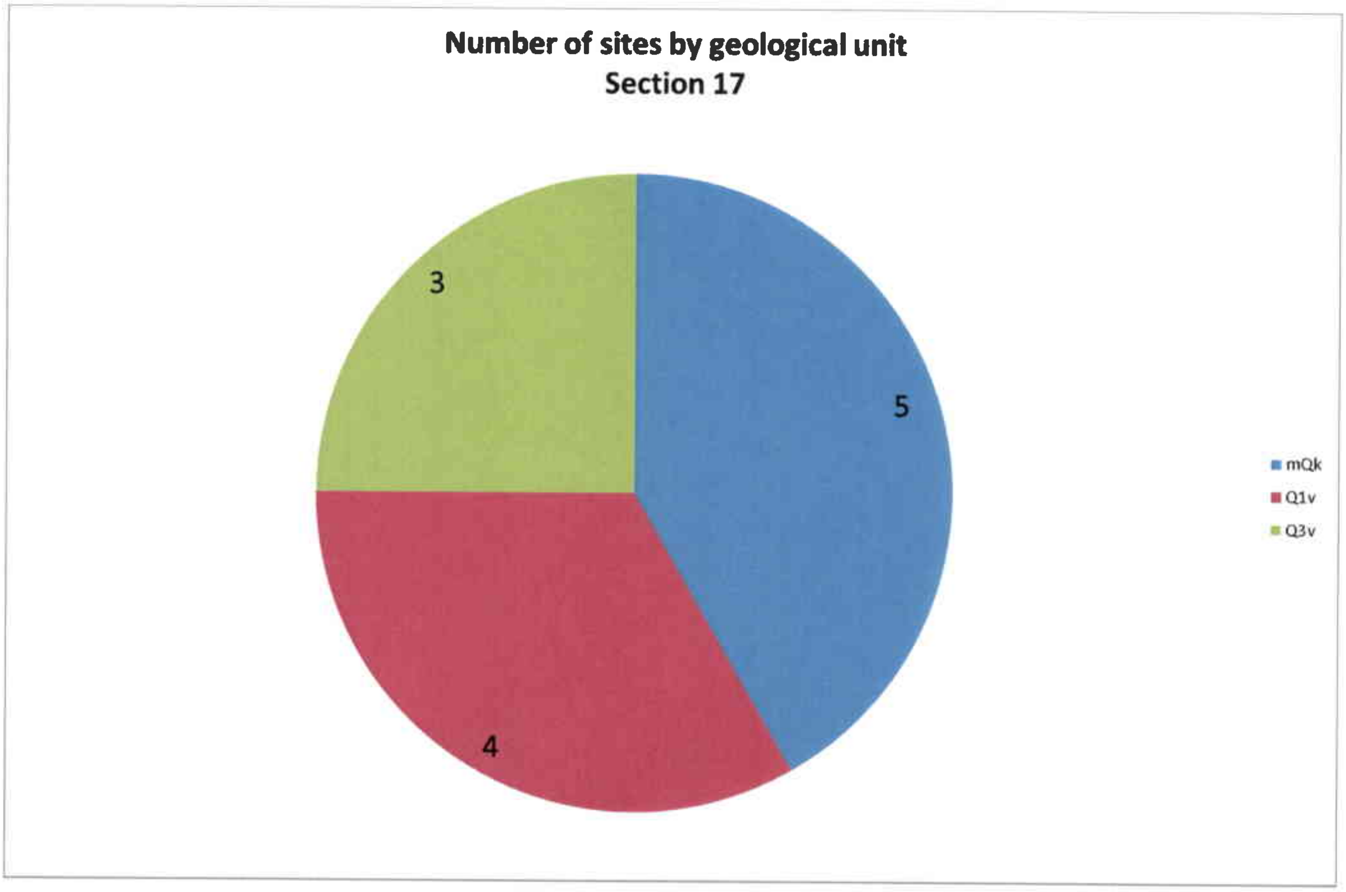

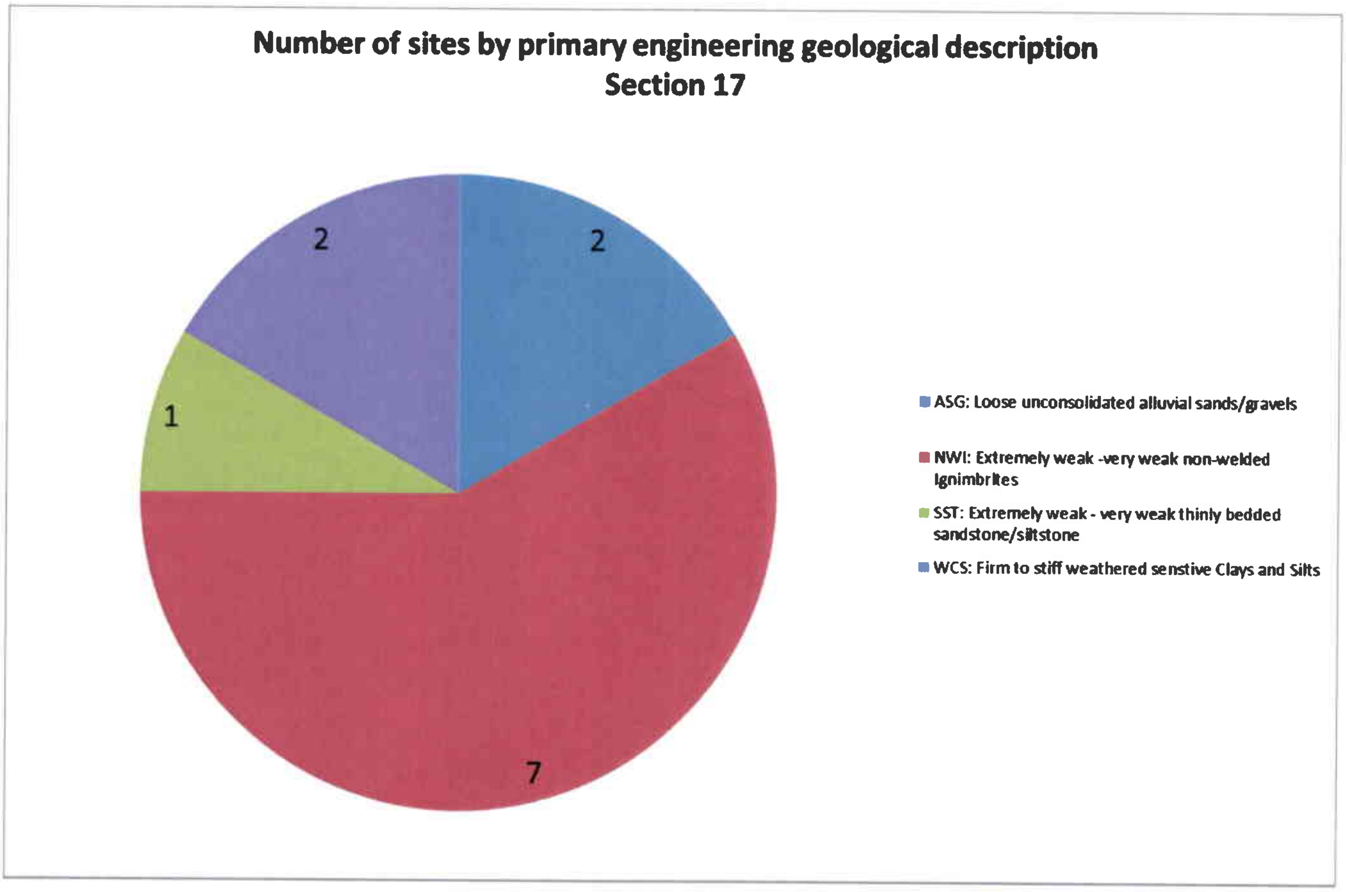

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