▪ report

Lake Taupo Shoreline Erosion Study

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Prepared for

By

Beca Infrastructure Ltd

December 2006

3251438/TAA Rev F ▪ L2:66517

Revision History

Revision N°	Prepared By	Description	Date
A	Roddy Copeland	Draft for Client Review	20/2/2006
B	Roddy Copeland	Final Draft	12/4/2006
C	Roddy Copeland	PCG Comments incorporated	26/4/06
D	Roddy Copeland	Draft for GG approval. 2nd Cheal Survey and Wind/Lake Analysis inc.	24/8/06
E	Roddy Copeland	Final for Peer Review	28/9/06
F	Roddy Copeland	Final for Public Information	4/12/06

Document Acceptance

Action	Name	Signed	Date
Prepared by	Roddy Copeland	[signature]	5/12/06
Reviewed by	Stephen Priestley	[signature]	5/12/6
Approved by	Stephen Priestley	[signature]	5/12/6
on behalf of	**Beca Infrastructure Ltd**		

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Executive Summary

Background

This study forms part of the wider review and management planning for a comprehensive Lake Taupo Risk Management Strategy. The wider Strategy will look at future management of hazards associated with erosion of the shoreline, and flooding of lakeside areas and key tributaries.

The erosion component of the wider study deals with lakeshore erosion – investigating the causes of erosion and reviewing broad hazard and risk levels, and options for managing erosion in the future.

The processes and factors influencing erosion around the foreshore are complex and include both natural (e.g. geology, wind and waves, sediment inputs, tectonics) and human factors (development, structures, interruption of sediment supplies, control of lake levels, removal of vegetation, land use).

Understanding these influences on the lake is critical to the future planning and management of development along the lakeshore. Future planning should be looking towards the managing development in erosion areas, rather than being solely responsive to erosion issues as they arise.

This report summarises the findings from Stage 3 component of the Lake Taupo Erosion Study, and focuses on understanding the key contributing factors to erosion risk and the identification of erosion hazard levels around the lakeshore.

The next stage (Stage 4) of the study involves identifying whether any assets (properties, pipelines, reserves, ramps) are at risk, to enable development of a risk based strategy for managing the erosion hazard around the lakeshore. It will set out options for appropriate physical works and/or land use controls that may be necessary to manage any hazards and issues associated with erosion.

Objectives

The objectives of the overall study include:

- Determining key factors contributing to shoreline erosion
- Assessing the impact of structures in the littoral zone on erosion
- Production of erosion hazard maps, showing broad zones of erosion risk
- Development of a risk based management strategy for Lake the Taupo shoreline (subsequent stage)

Methodology

The methods used to assess the contributing factors to erosion and the extent of erosion risk around the lakeshore included:

- Review of available existing information relating to lake processes and erosion.
- Review of historical shoreline change (erosion / accretion) through analysis of:
  - Historical Orthophotography (aerial photography)
  - Historical survey plans
  - Recent surveys and beach profile monitoring
  - Photographs and reported erosion
- Field verification including site visit around the lake by boat
- High level assessment using of lake processes such as wind and wave height, longshore sediment transport rates.
- Detailed review of existing and natural lake level regime data. Including a combined analysis of lake level and wind coincidence.
- Analysis of other factors contributing to erosion e.g. geology, tectonic deformation (uplift and subsidence), impacts of land use and tributary management, reduction of sediment supplies due to dams, impacts of development and shoreline structures, operational considerations.
- An assessment of shoreline erosion hazard level was carried out characterising 44 broad shoreline units along the edge of Lake Taupo. This information was then used to produce a set of maps indicating the erosion hazard level .

Conceptual Erosion Processes

The Lake Taupo area is geologically young and dynamic with continuing tectonic and volcanic activity. The form of the lakeshore has naturally evolved over time as evidenced by historic landforms around the lake edge. Natural forces (including wind, rainfall, tectonics) continue to shape the lakeshore resulting in areas of erosion and accretion (land formation). Within the context of this natural change human influences have had an increasing impact. e.g. lakeshore development. The natural forces together with potential human influences need to be taken into consideration in future planning, forming the basis for informed decisions on management of the shoreline.

The physical processes that influence the form of a shoreline are complex and can be impacted by a number of natural and human influences. These include:

- The response of a shoreline to erosion is predominantly dependent on the shoreline geology. Hard or rock shorelines resist erosion, whereas soft or sandy shorelines are susceptible to erosion.
- Strong winds on the lake cause storm waves which refract and break on the shoreline at an angle, transporting sediment in the direction of the incident wave. This is referred

to as littoral drift. If this drift is not matched by sediment inputs to the system, such as sediment in the nearshore zone or from rivers, then the soft shoreline profile changes.

- Shorelines will tend to move towards a long term equilibrium profile/position based on reaching a balance of sediment inputs and littoral drift.
- Because the timing of storm wave events and sediment discharges from river systems, do not always coincide, the shoreline will naturally fluctuate. These short term fluctuations are natural shoreline responses and should not be seen as longterm erosion.

Main Conclusions

The following section includes summary headings and the relevant main conclusions from the study:

Limitations / Information Gaps

- Historically there has been very little information available relating to the lake processes affecting the shoreline or supporting data on erosion history. This has resulted in the development of the shoreline without regard to the natural fluctuations of the shoreline and the level of erosion risk, or implications of development on adjacent shoreline areas.
- The most significant gap in the information needed is long-term repeatable survey information on the profile of the shoreline. The collection of this data will allow better understanding of the longer-term trends and cycles in the position of shoreline.
- Additional information that would also contribute to better understanding of the processes driving erosion and the design of appropriate protection measures include: sediment budget modelling, wave height monitoring, and monitoring of performance of erosion control options.

Causes of Erosion

- The contributing factors to erosion vary considerably from site to site. The geological resistance to erosion, sediment supply and wind generated waves dominate the natural influencing factors for lake processes, but in their own right don't necessarily cause erosion where they system has come to equilibrium. Erosion is most evident during periods of high wind, coincident with high lake levels. In our opinion, providing quantified contributions for the various human factors is not practicable given the current information, the complexity of the shoreline processes, and variability for each specific location. The level to which some of the main factors are influencing erosion is indicative only and requires further long term data and site specific investigation for verification.
- Because the timing of storm wave events and sediment discharges from river systems, do not always coincide, the shoreline will naturally fluctuate. These short

term fluctuations are natural shoreline responses and should not be seen as long term erosion. Such fluctuations may be periodic and persist for 1 to 2 decades. From a shoreline management perspective, it is important to differentiate between shoreline fluctuations and long term erosion. It is also important to ensure development does not take place within these fluctuation zones.

Geology

- It is clear that the dominant geology at discrete points along the shoreline of Lake Taupo will largely determine the relative resistance of that point of shoreline to erosion. Those areas that have unconsolidated deposits such as pumice alluvium will be significantly more susceptible to erosion. Eastern and southern shorelines have a low resistance to erosion due to their geology (soft sediment pumice) and western and northern shorelines have a moderate to high resistance because of their more resistant geology(welded ignimbrite).

Wind

- Predominant wind direction and wave directions exert more energy on shorelines facing a west and southwest direction. These are often the shorelines that also have unconsolidated deposits

Tectonic subsidence

- Historical assessments indicate that the impact of subsidence and uplift is currently being offset by adequate sediment supplies and littoral drift, resulting in only minor impact on erosion in most areas. Depending on the availability of sediment in the future the potential for this to change remains.

Landuse / Soil Conservation

- Due to the highly permeable soils within much of the Lake Taupo Catchment it has been reported that the impact of land use on erosion is reduced because the amount of overland flow is minimal for most storm events. Higher levels of erosion occur during high intensity events when the pumice soils are easily eroded by surface flow. Sediment delivery to the lake shoreline is therefore episodic.

- It is considered that the impact of soil conservation works is unlikely to significantly increase the risk of shoreline erosion compared to predevelopment levels. In some cases such as the stabilisation of stream banks to prevent the river from naturally altering course, the lake may see a reduction in episodic large influxes of sediment from these events.

Development / Structures

- Localised erosion issues associated with structures such as ramps and groynes is widespread around lake Taupo. This is most prevalent in the areas around Taupo Township.
- Development in close proximity to the shoreline, within what may be natural shoreline fluctuation zones, has led to the placement of erosion control structures to protect individual properties.
- Many of the structures are not adequately designed and have resulted in adjacent erosion issues.
- Significant reductions in sediment supplies from hydro dams placed in rivers (e.g. Kuratau, Hinemaiaia) feeding Lake Taupo is likely to be contributing to potential erosion issues. Shorelines within the relevant sediment compartments might be expected to be impacted as they adjust to the reduced sediment inputs.

Operational issues and Maintenance

- Some current operational and maintenance practices associated with structures e.g. sediment removal from ramps need to be reviewed. Current practices such as those undertaken at the ramp at 2 Mile Bay where sediment that accumulates behind and on the ramp is removed from the lake may be contributing to down drift erosion issues. This practice should be reviewed to take into consideration the sediment deficit issues in the area.
- Other maintenance activities such as the removal of noxious plants from the shoreline of the lake also need to be reviewed taking into consideration their effect on erosion. When significant sections of vegetation are removed, replanting with suitable species should take place to mitigate any increase in erosion risk. Appropriate guidelines and the necessary consents should be developed to support this practice.
- Current operation of boats on the lake doesn't appear to be having a significant effect on erosion. However, the impact of boat wake on shoreline erosion should be considered if any significant changes to the type of boats or level of operation occur.

Lake Level Regime

Review of Data

Lake level analysis has shown that the control of the lake level results in periods when the lake is held higher than it would be naturally. Over the long term this is mostly balanced out by other periods when the lake level is drawn down below what it would have been naturally, resulting in similar annual lake level regimes. In addition the overall range of lake level under control is reduced with extreme lake levels no longer occurring.

However, more recently the record has shown that controlled lake levels have been held higher than natural during summer months, which can coincide with high wind events, increasing erosion risk.

Further more detailed points are set out below:

- Analysis of the last 10 year period of level data shows similar results to observations made by earlier studies, in which the actual and simulated water level regimes were similar.
- By reviewing the exceedence relationships for the recorded and simulated natural data sets for the last 3 and 5 year periods, it is apparent that the recorded maximum levels for these two periods are higher than the simulated uncontrolled maximum levels by about 100mm.
- Over the last 3 year period the summer actual recorded level exceedence was up to 200mm higher than the natural simulated regime for most of the level ranges. The increased recorded level does indicate an increase in the risk of erosion compared to the natural simulated levels.
- It should be noted that the review of shorter timeframes of the past few years will not necessarily be reflective of the longer-term trends. This will depend on short term variations such as weather patterns for those particular years, and control of the lake level.

Coincidence of high lake levels and wind events

The aim of this analysis was to determine if there is any significant difference in the correlation between strong wind and high lake water level events, for the simulated natural lake level regime and the recorded actual regime.

A 34 year wind-wave analysis has been conducted for two sites: Kuratau on the southwest of the lake and Waitahanui on the northeast. The results for areas influenced by similar prevailing winds will vary slightly but should have similar results. Three types of analysis were carried out, including:

  - A combined return period analysis for wind/wave runup and lake level,
  - A threshold analysis looking at the number of exceedences of high lake level and wind combinations.
  - Water level comparisons for the ten highest historical wind events for the period

Summary points include:

- The return period analysis showed a minor increase in the combined actual lake level and wind/wave runup values, however the differences between simulated and actual levels were considered to be minor and unlikely to significantly effect erosion risk.

- Under the controlled actual regime, the threshold analysis showed that for both Kuratau and Waitahanui there were typically more events exceeding the 'high end' lake level / wind event thresholds, indicating an increased risk of erosion.
- When analysing the dates of the events meeting the threshold limits there are long periods (10 years) where there are differing trends. Because of recent exceedences in the record this has resulted in more events under the controlled regime over the total period of record.
- Analysis of lake levels over the 34 years, for the highest wind events on record, did show that the extreme wind events have occurred more frequently during periods when lake levels are being held higher, increasing erosion risk. Although there appears to be a trend towards an increased coincidence of high lake levels and wind events with the controlled lake level regime, it is difficult to know whether lake level is a key erosion driver. This is due to the potential balancing effects of decreased maximum lake levels and the coincident availability of sediment supply.
- Analysis of the highest wind events on record showed that they do occur during the summer. For recent years where the actual summer level regime has been held higher than the natural regime, this increases the potential for high wind events during times when the lake level is higher than natural.

Hazard Assessment & Mapping Summary

For the purpose of this assessment the shoreline was divided into 44 broad units. The erosion hazard level of shoreline was then classified as very low, low, moderate or high. The breakdown of units was based on: changes in geology, land form and aspect, exposure to different levels of lakeshore process attributes, and reported / measured historical erosion trends. The assessment was carried out at a level that allowed only a broad characterisation of the shoreline, based on the available data and accuracy to which it could be reliably used. Localised areas of differing hazard levels may be present within the wider shoreline units.

It is important that the hazard levels allocated be reviewed over time and updated based on additional information as it is collected. Future use of the hazard level for planning purposes will also need to acknowledge the potential for more detailed studies altering the hazard level for specific sites.

The hazard assessment was carried out by undertaking a systematic review of available information (mapped on GIS / aerial photograph background) for each shoreline unit. In parallel to this a weighted attribute approach (using geology, historical erosion trends, tectonic deformation, wave height, and longshore sediment transport) was used to provide a tool for assisting in developing a consistent quantified approach to apportioning hazard levels.

It should be noted that although river mouths have not generally been identified as high erosion areas, they are naturally unstable and consideration of this should be accounted for separately.

A summary of the results is given below and erosion hazard areas shown on the attached map.

High Risk Units

Eight units are considered to be at high risk of shoreline erosion:

- Waikato River to Wharewaka Point (incl. Taupo Township), Waitahanui, Hatepe, Motutere and Te Rangiita along the eastern shoreline;
- Kuratau on the western shoreline; and
- Whangamata Bay (incl. Kinloch) and Whakaipo Bay on the northern shoreline.

All eight units are comprised of unconsolidated deposits, are likely to experience wave run-up at the higher end of the range and have historical incidents of erosion. Except for Whakaipo Bay all units have had a moderate to high degree of development, but there is more awareness of erosion in these areas.

Moderate Risk Units

- Some fifteen units were identified as being predominantly of moderate risk of shoreline erosion. These units are spread around the circumference of the lake, tending to occur in sedimentary bays comprising weak geology (unconsolidated deposits that readily erode).
- Some moderate risk units have experienced localised erosion cycles (e.g. Whareroa bay, Acacia Bay) but further work is needed to determine whether these are long term erosion trends (Note that a small section of foreshore at Whareroa in the vicinity of the boat ramp where significant erosion has occurred is identified on the hazard map.)

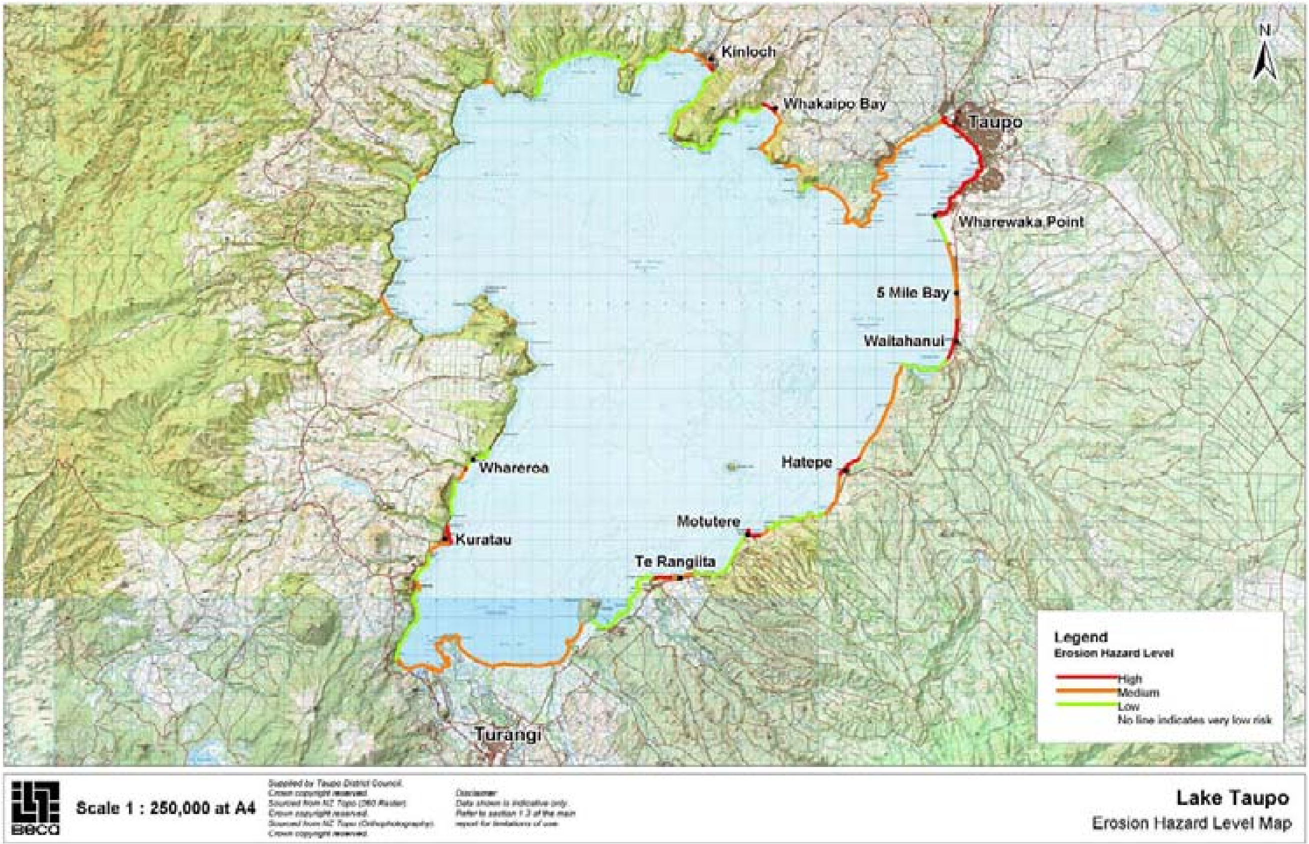
Low Risk Units

- Fourteen of the forty-four units were identified as predominantly having a low risk of shoreline erosion. The majority of the north western shoreline is plotted as low risk, dominated by the headlands which comprise dense volcanic flows and ignimbrites that are relatively resistant to erosion.
- Five units of low risk also occur along the eastern shoreline. This is likely due to the occurrence of accretion and/or the lack of reported erosion for some units.

Very Low Risk Units

- Seven of the forty-four units were identified as being of predominantly very low risk of shoreline erosion. Excluding Te Anoputarua Headland (southwest of Te Rangiita) all of these areas occur along the western shoreline of Lake Taupo (making up approximately 50 % of this shoreline). The very low risk rating is in large due to the presence of strong, erosion resistant geology (dense volcanic flows and welded ignimbrites).

Lake Taupo Erosion Hazard Summary Map



1 Introduction

1.1 Background

This study forms part of the wider review and management planning forming the Lake Taupo Risk Management Strategy. This wider Strategy investigates hazards associated with erosion of the shoreline, inundation of the shoreline and flooding of key tributaries, and management of flooding downstream of the lake. The focus of this component of the wider study is the erosion of the lakeshore, including investigating the causative factors, carrying out a review of hazard and risk levels and developing a strategy for managing shoreline erosion at Lake Taupo.

With 622 km2 in area Lake Taupo is the largest lake by area in New Zealand. The Lake Taupo area is a geologically young and dynamic area and experiences continuing tectonic and volcanic activity. The form of the lakeshore has naturally evolved over time as evidenced by significant historic landforms around the lake edge. Natural forces (including wind, rainfall, tectonics) continue to shape the lakeshore resulting in areas of erosion and accretion.

Within the context of this natural change, human influences have more recently also had an increasing impact on the form of the lakeshore. As areas around the lake are developed there have been significant changes to the environment including: land use changes within the catchment, development on the foreshore, structures such as groynes and ramps, increases in the volume of water entering the lake due to diversions, dams installed on some of the main incoming rivers and upgrade works to the outlet to allow the lake to be used more effectively for hydroelectric power generation on the Waikato.

As we plan for the future of lake Taupo, the inevitable natural forces of erosion and accretion together with potential human influences need to be taken into consideration and form the basis for informed decisions on the management of the shoreline.

1.2 Objectives

The summary of the objectives of this study include:

- Determining key factors contributing to shoreline erosion
- Assessing the impact of structures in the littoral zone on erosion
- Production of erosion hazard maps, showing broad zones of erosion risk
- Development of a risk based management strategy for Lake the Taupo shoreline (subsequent stage)

For a more detailed list of the objectives and scope refer to the project brief in the Appendices.

1.3 Limitations

This report is based upon the scope and sources of information made available for this study. This report is therefore based on the accuracy and completeness of the information provided at the time of the review. Beca cannot be held responsible for any misrepresentation, incompleteness or inaccuracies provided within that information. Should any other information become available, then this report should be reviewed accordingly.

Opinions and conclusions are based upon our understanding and interpretation of current information, and should not be constituted as legal opinions. This report should not be copied or used for any purpose other than was originally intended, nor used by any other parties without the approval of a Director of Beca. Should this report be used by Third Parties, whether authorised or otherwise obtained, Beca accepts no liability for any reliance placed on this report nor its use by any party for any purpose other than as identified.

1.4 Peer Review

The Stage 3 report has been subject to a formal independent peer review undertaken by Tonkin & Taylor (T&T). The review has found the methodology undertaken for the report to be sound and identified a number of useful and constructive suggestions which have largely been adopted in this version. The final peer review letter is attached in Appendix H.

1.5 Structure of the Report

To assist with putting the remainder of the content of the report in context an upfront section on erosion processes and sediment budgets has been included. This is followed by a summary of the review of previous studies providing a more substantial background to this study. The subsequent sections then look in more detail at the contributing factors to erosion and the assessment and mapping of erosion risk.

The following bullets set out the structure for the remainder of the report.

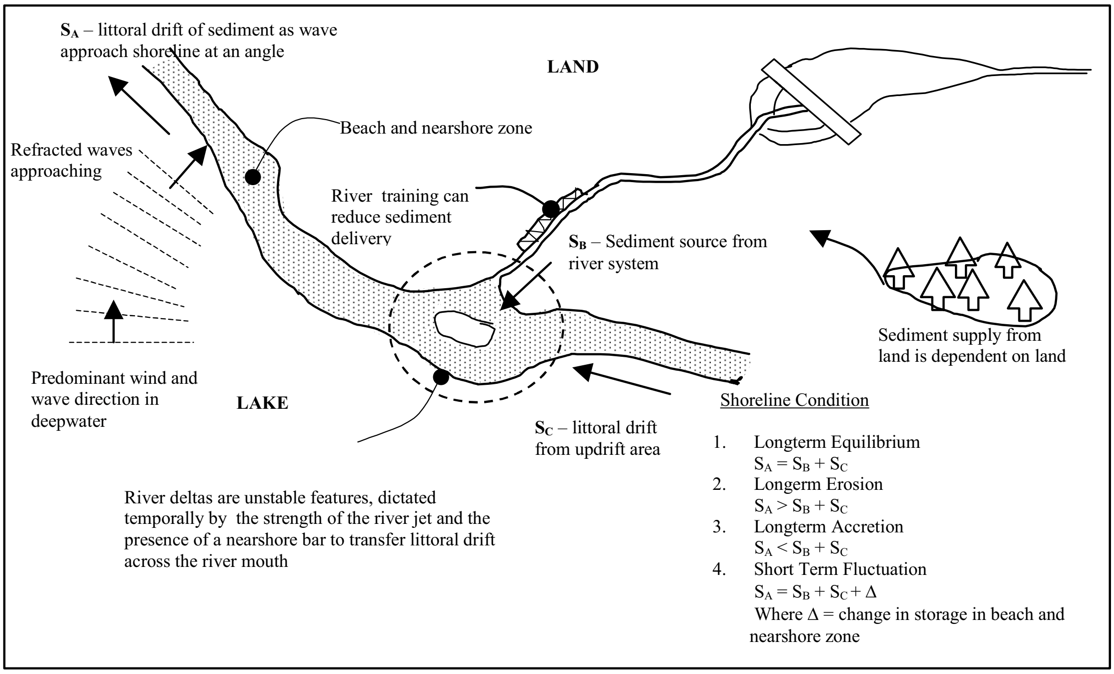
- Section 2 – Background concepts on erosion processes
- Section 3 – Summary of previous studies and available data
- Section 4 – Analysis of natural and human factors contributing to erosion
- Section 5 – Methodology for assessing erosion risk and hazard mapping
- Section 6 – Gaps in existing information
- Section 7 - Conclusions

2 Conceptual Erosion Processes

The response of a shoreline to erosion is dependent on the shoreline geology, which broadly falls into 3 categories: hard rock; soft rock or clayey banks; and soft shorelines (ie sand or unconsolidated material). From a shoreline management perspective, hard rock shorelines do not erode. Soft rock or clayey bank shorelines potentially erode but to a lesser degree than soft shorelines. When erosion occurs the landform is lost as it cannot recover. Often a soft shoreline forms at the base of soft rock or clayey bank shorelines. The following is a general discussion on erosion processes of soft shorelines. See Figure 2.1

Strong winds on the lake cause storm waves which refract and break on the shoreline at an angle, transporting sediment in the direction of the incident wave. This is referred to as littoral drift. If this drift is not matched by sediment inputs to the system, such as sediment in the nearshore zone or from rivers, then the shoreline profile changes. If the drift is greater than the sediment inputs, erosion occurs. Conversely if the drift is less than the sediment inputs, accretion occurs. Transfer of sediment from river mouths and the nearshore zone is a complex process.

Figure 2.1 Shoreline Sediment Processes



Because the timing of storm wave events and sediment discharges from river systems, do not always coincide, the shoreline will naturally fluctuate. These fluctuations are evidenced by the backshore areas being eroded and then later on recovering. These short term fluctuations are natural shoreline responses and should not be seen as longterm erosion.

Such fluctuations may be periodic and persist for 1 to 2 decades. From a shoreline management perspective, it is important to differentiate between shoreline fluctuations and long term erosion.

Sediment delivery from a catchment is mainly dependent on rainfall, particularly severe events which result in floods, which in turn result in land and river erosion. The magnitude of erosion is also dependant on land use and land management practices. Contemporary practices such as river training, protection such as fencing off from livestock and creation of reservoirs, tend to reduce sediment delivery.

If shoreline protection measures, such as reclamations or groynes are installed within the shoreline fluctuation zone then such measures can result in downdrift erosion. See Figure 2.2 a - c for an illustration of these erosion processes and possible responses.

Based on some of these concepts some over all conclusions that could be made about shoreline erosion on Lake Taupo are:

- More erosion of land results when storm waves occur with elevated lake levels.
- Erosion can be more focused on the shoreline with lesser fluctuating lake levels.
- Many shoreline protection measures are located in the natural shoreline fluctuation zone.
- Subsidence caused by longterm tectonic movement will cause accelerated shoreline erosion.
- Land and river erosion supplies sediment to the lake system which is a sink for sediment, i.e. overall the lake system is accreting. Whilst the lake as a whole is accreting, the significant water depth and other processes mean that the lake edge may still be eroding. This erosion is however likely to be localised. Moreover surplus sediment can be stored in the nearshore system as a buffer for severe stormwave events and to balance the mis-match between storm wave erosion and sediment supply.
- Lake Taupo erosion rates are generally less than occurs on exposed ocean beaches.

Various factors contribute to the potential for erosion along the shores of Lake Taupo. Natural processes include the geology of the lakeshore and the natural lake and shoreline influences such as wind and waves, sediment inputs from rivers, and the extent to which the shoreline has come into equilibrium with the environment. Human influences can also have a significant impact on the potential for shoreline erosion through both catchment activities such as landuse, the manipulation of river flows into the lakes and lake levels, river protection work as well as more local effects through development and structures disrupting the equilibrium and dynamics of sediment movement and budgets.

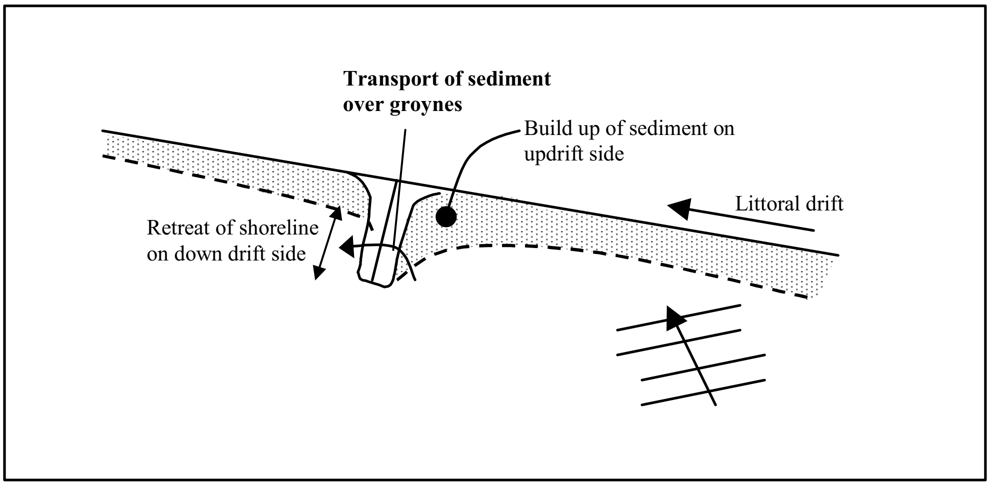


Figure 2.2a: Short Groynes (eg. boat ramps)

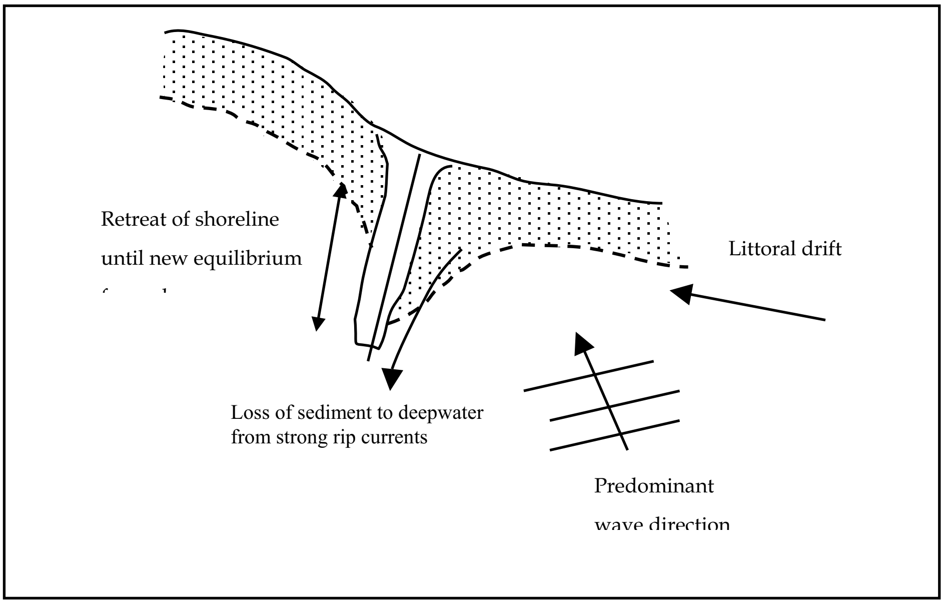


Figure 2.2b: Long Groynes (eg causeways, headlands)

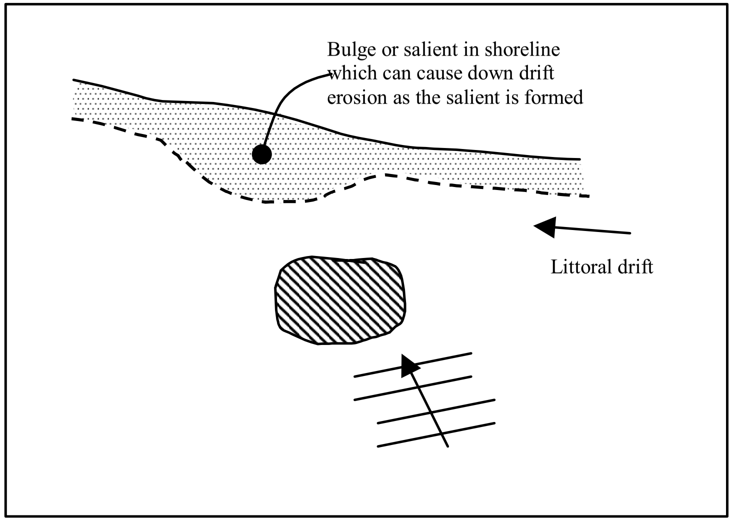


Figure 2.2c - Offshore reef or island (with salient)

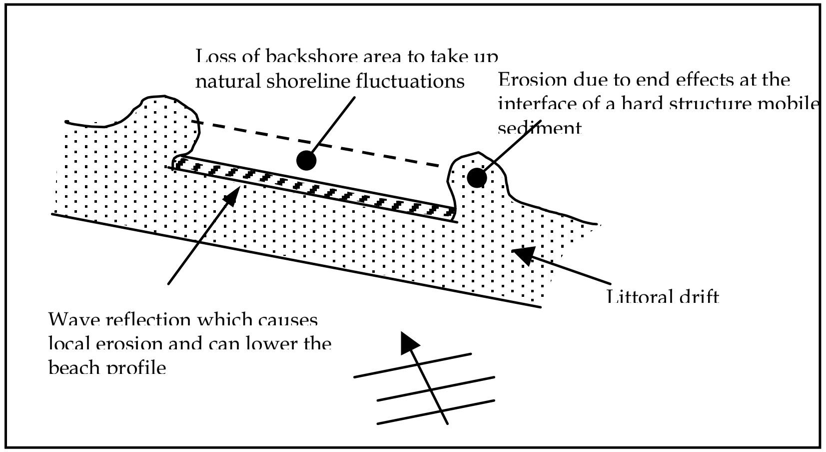


Figure 2.2e: Shore Parallel Walls

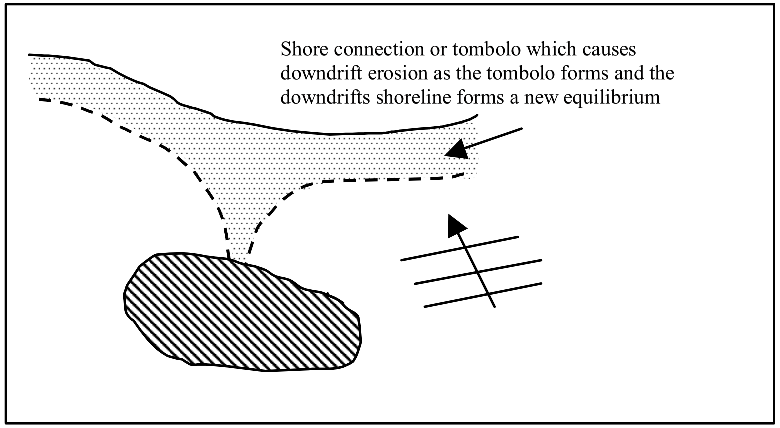


Figure 2.2d: Offshore Reef or Island (with Tombolo)

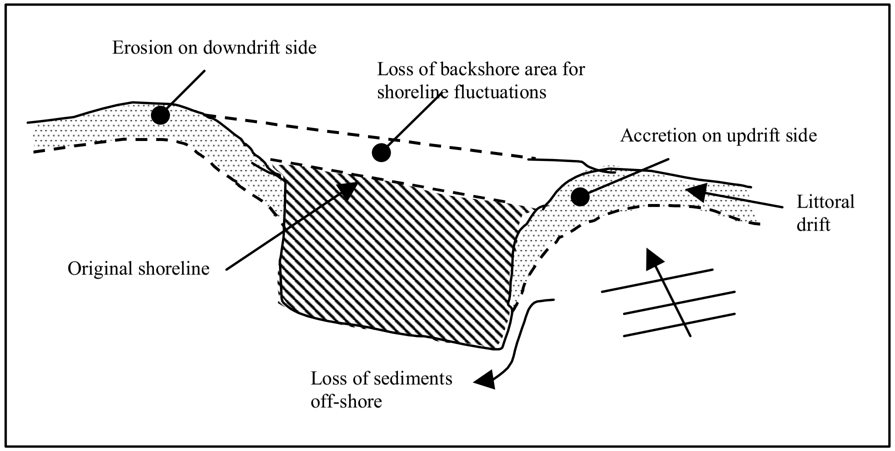


Figure 2.2f: Reclamation

2.1 Sediment Budgets

The conceptual model of sediment budgets is a useful way of demonstrating some of the fundamental erosion concepts. Additionally, to gain a more in depth understanding of erosion processes at a particular locations, a sediment budget should be developed. This is not a minor undertaking. The initial task is to divide the lake system into littoral cells or compartments, i.e. reaches of the shoreline over which sediment supply and transport is independent from other cells. This is usually achieved by identifying the predominant wave directions, equilibrium shoreline alignments, significant sediment sources, land promontories, such as headlands, which direct sediment offshore, and self contained embayments. Refer to Figure 2.3.

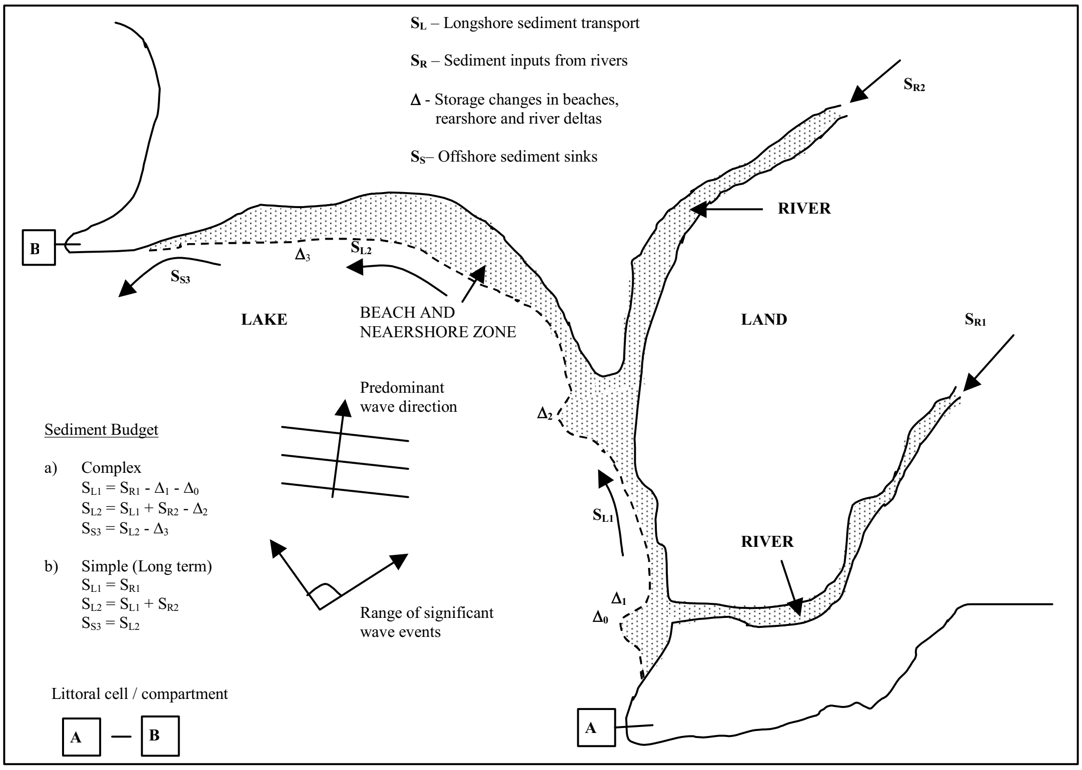
Once the sediment compartment is identified the balance of sediment coming into the system is compared with the amount moving along the shoreline, being deposited or eroded, and the amount leaving the system. For a particular length of shoreline that is at equilibrium, and not accreting or eroding, the following would be the case:

Sediment moving along the shoreline (littoral drift away from the location) **=**

Sediment inputs from rivers **+** Littoral drift from updrift areas

If there is a longterm imbalance and the sum of the incoming sediments is less than what is being moved along the shoreline then erosion would be expected.

Figure 2.3 – Sediment Budget Components



To assess this, for each littoral cell a sediment budget is established for sediment supplies or inputs, sediment sinks (areas where sediment leaves the system such as being directed off shore into deep water), littoral drift and changes in sediment storage of the beach and nearshore zone. None of these components can be accurately measured. Sediment inputs from rivers can be established from hydrological flow data and sediment rating curves, with an assessment for bedload. This gauging and recording is usually conducted for representative catchments and extrapolated for nearby catchments. In addition, bathymetric surveys in reservoirs can provide a good gauge on sediment capture of their upstream catchments. Sediment sinks, say upstream of land promontories, can be measured by bathymetric and beach surveys but offshore sinks can only be inferred.

Littoral drift cannot be directly measured. Usual practice is to develop a wind / wave model, calibrated and verified by field data. Wave data at the shoreline can be used to estimate littoral drift from a suite of sediment transport algorithms. The selected algorithm should be appropriate to lake processes and have peer support for its application, supplemented by our understanding of the geomorphology and sediment characteristics.

Changes in the sediment storage of the beach system can be obtained from regular beach profiles which are the most useful for quantifying shoreline erosion. Changes in the nearshore zones can be measured by less frequent bathymetric surveys. Estimation of overall sediment budgets is illustrated in Figure 2.3. A short term budget, which would provide information on the variability of the results is complex and requires a significant amount of field information on changes in storage. If the littoral cell is in equilibrium, with only small changes in storage, then the budget can be simplified from information on sediment inputs and littoral drift estimates. Results are usually expressed in tonnes per year and cubic metres per year.

3 Review of Existing Information

Stage 1 of this study focused on the review of existing information relating to shoreline processes and erosion for Lake Taupo. This review focused on identifying the processes and contributing factors to erosion, and the conclusions that could be made regarding historical and future erosion.

Historically there has been very little information available relating to the lake processes affecting the shoreline or supporting data on which to base further analysis. This has often resulted in the development of the shoreline without regard to the natural fluctuations of the shoreline and the level of erosion risk, or implications of development on adjacent areas.

3.1 Existing Reports

The most significant addition to the knowledge about the lake processes resulted from a report by NIWA entitled *Lakeshore geomorphic processes, Lake Taupo*, October 2000[1], prepared for Mighty River Power (MRP) as part of the consenting process. This report covered key topics such as wind and wave analysis, sediment compartments and budgets, historical erosion using aerial photographs, and analysis of the lake level regime. A companion report to the NIWA report was produced by Kirk and Single[2] which focused on the impact of structures on the shoreline, and in particular within Taupo Bay. Additional lake level analysis has also been carried out by Opus[3, 4] also for MRP. Recently some site-specific studies have also been carried out, providing additional information on specific areas. These include a study carried out at Waitahanui for MRP (Tonkin & Taylor, 2004[5]), and a report in support of the Kinloch Marina expansion (Raudkivi, 2005[6]).

Environment Waikato[17] had previously classified erosion hazard along the Lake Taupo shoreline, identifying a high-risk area along the eastern shoreline and small pockets of the southwestern and northwestern shoreline. The areas of high-risk correlate to areas mapped as unconsolidated deposits, conversely areas of low risk correlate to resistant volcanic flows and ignimbrite.

3.2 Historical Shoreline Change

Accurate information relating to historical shoreline change at Lake Taupo is limited. Historical shoreline change is typically assessed using:

- Aerial photos or orthophotography,
- Repeatable beach profile surveys, ideally over a period of between 15 to 20 years,
- Historical survey plans, and
- Field Verification.

The following sections summarise the available information from orthophotography, survey information, and information collected during a site visit.

3.2.1 Orthophotography

- Historical erosion and accretion was assessed by NIWA[1] (1940 to 1976, 1993) and this study (1938, 1946, 1962, 1983, 1993, 1999, 2003 to 2004) using orthophotography, with an assumed error of ± 10m.
- The accuracy of identifying shoreline change through the use of orthophotography is therefore limited, and makes interpretation of areas with less than 10m of change difficult. The accuracy was limited by the ability to accurately register points on the older aerial photographs and then rectify these with the NZ Map Grid, lens distortion, image quality, and the ability to identify a common ‘shoreline’.
- Accretion ranging from 5 m to 200 m is estimated for 5 Mile Bay (north), Te Rangiita, Stump Bay, Tongariro Delta, Waihaha Bay and Kinloch. Note the area of accretion at the scale of 200m[1] relates to the Waimarino river mouth where the progradation of the shore was up to (12m/yr), during pulses of limited duration. Field evidence verifies that these areas are experiencing accretion. Accretion results from a continuous sediment supply to an area where fluvial (river) processes are more dominant than lacustrine (lake) processes. It is therefore emphasised that human activity (i.e. construction of dams, breakwaters, groynes etc) which disrupts the sediment balance and/or fluvial-lacustrine balance, could impact the current trend.

- Erosion is not as easily identified from orthophotography as:
  - The magnitude of shoreline change is generally of the same order as the uncertainty (i.e. < 10 m);
  - Reported erosion is often a short term response / event and therefore may not be picked up by the time frame of the aerial photography; and
  - The area of shoreline affected is often localised (i.e. immediately adjacent to structures).
- It is therefore important that areas identified as having experienced erosion are verified by field inspection
- Orthophotography indicated long-term erosion of up to 5 m along parts of the foreshore between Taupo Township and Wharewaka Point. Erosion was not detected in some areas (i.e. Four Mile Bay etc) where it is known to have occurred in response to shorter-term events. These short-term events are not detected, highlighting the importance of field verification and the need for long term monitoring of beach profiles to pick up short-term fluctuations as well as longer-term trends.
- Erosion (up to 5 m based on locations of large trees relative to the shoreline seen of the site visit as on aerial photos) is indicated for the length of shoreline extending from south of 5 Mile Bay to Waitahanui. Residents allege up to 15 m of residential property loss. Erosion at this scale could not be confirmed one way or the other from the aerial photographs.
- The limited accuracy possible with the historical photographs and the scale of erosion present means there is a need for other ways of determining shoreline change. The collection of additional data is therefore important, with beach profile monitoring being the most accurate.

3.2.2 Beach profile monitoring

Historically there has been very little beach profile monitoring carried out around Lake Taupo. This has resulted in a significant gap in one of the most dependable sources of information for recording and analysing shoreline change. During 2004, Taupo District Council commissioned a survey at key locations around the lake where erosion had been reported. Cheal Consultants undertook this survey. Refer to plans in Appendix A for locations of surveyed beach sections.

At the start of the Lake Taupo Erosion Study, only this single survey had been undertaken. However, this survey could be compared to historical data taken from local survey plans. The historical lake edge, as taken from relevant historical survey of local areas, was marked on the November 2004 beach profiles. Cheal's confirmed that this lake edge was defined by the location of the contour level of 357.015 at that time.

In March 2006 (while this study was under way) Cheal Surveyors conducted a second beach profile survey repeating the locations carried out in 2004.

The following sections and tables in Appendix A, provide a summary comparison of the recent shoreline changes between the 2004 and the 2006 surveys, as well as historical changes prior to 2004 based on the 2004 survey and the historical survey plan information plotted by Cheal. Erosion rates are based on the relative location of the 357.015m contour – taken to represent the historic lake edge boundary.

Although comparisons will be made between the 2004 and 2006 surveys, the results must be treated with a note of caution. The pre-2004 rates are based on long term averages and take no account of short-term trends or processes; the 2004-06 rates are the opposite, representing only short-term trends within a fixed time period. Note should also be made of the different times of survey; the 2004 survey was conducted in spring and the 2006 survey in autumn, and therefore may reflect seasonal changes.

Discussion

The shoreline changes taken from the survey comparisons were generally consistent with reported erosion and that identified by orthophotography. The long-term analysis at Kinloch has a greater margin of error due to the accuracy of the surveying at the time of the original survey plans (1928/1961). As the resulting measured change is within the margin of error, it is not possible to accurately calculate the actual change, however the overall change is small. Cheal indicated that there is little error expected for Wharewaka, Five Mile Bay, Waitahanui and Motutere, as these sections run parallel with the highway and have more accurate survey plans. Refer to Table A1 in appendix A for supporting data.

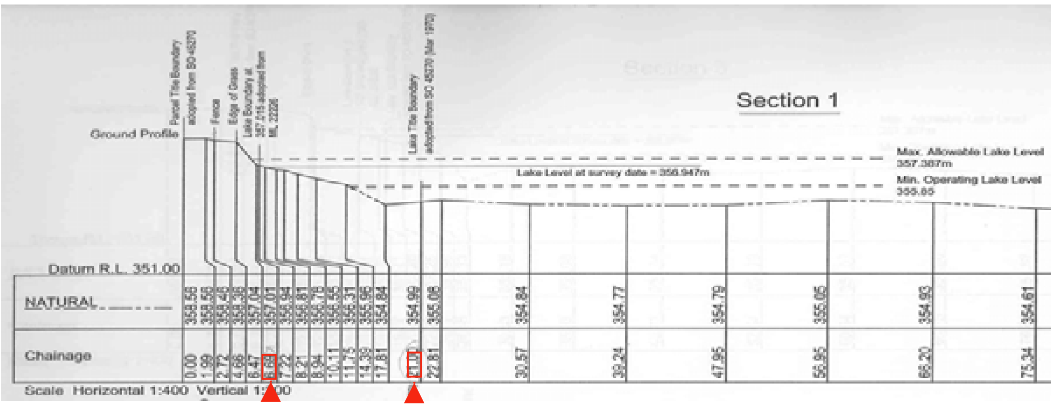
The following points summarise some of the observations:

- At Kinloch, section 1 had historically shown significant accretion, with sections 2-4 showing little change. Comparing the 2004 and 2006 surveys, the Kinloch sections all show accretion, however since the 2004 survey, rock protection had been built at the location of section 2. Accretion rates appear to be increased. There are no significant changes in the beach gradients between 2004 and 2006.
- Comparisons cannot be drawn for the section surveyed at Acacia Bay as a rock wall has been constructed at the section since the 2004 survey.
- At Wharewaka, the historic trends are maintained over the 2004-6 time period, but as with other sections the rates are considerably greater for the 2004-06 period than pre 2004. The changes are similar to those seen during the site visit, where section 3 (towards the Lake) is eroding and sections 1 and 2 appear to be accreting. An increased volume of material can also been seen in the nearshore bathymetry(section 1).
- The survey at Five Mile Bay shows consistency in erosion along the three sections, but as with other sections the rates for the 2004-06 period are much greater than the historical rates. Section three also shows a significant change in gradient, with the 2006 profile four times steeper than the 2004 profile. All sections show a significant increase in the amount of material in the nearshore and extending up to 40m off shore.
- The Waitahanui Beach profiles generally show consistency in action, with erosion occurring at most sections. However, no recent erosion is evident for the first section closest to the river. All the 2006 profiles show a steeper gradient, some increasing by 100%. Erosion rates are not significantly greater than the pre 2004 data. Increased bed levels are also apparent offshore.

- The Motutere Bay 2004-06 profiles are consistent with the pre 2004 historical assessment of erosion for the first five sections, although the rates are much higher. Further north where the historical analysis had shown erosion and accretion, similar processes were found to occur between the 2004-06 surveys. The rates were again higher.

At Kuratau, from Section 7, Te Rae Point and Southwards there was a historical trend of accretion. Te Rae Point and sections 1 and 4 are still showing accretion but sections 2, 3 , 6 and 7 are showing minor erosion between 2004 and 2006. Further northwards towards the Kuratau River mouth the historical pre 2004 trend of erosion has continued, with the rates of erosion showing a significant increase. With the exception of section 8 all profiles show a decrease in profile area (beach volume) between 2004 and 2006, indicating that even in sections showing accretion based on the position of the shoreline, there is an overall loss of beach sediment.

Figure 3.1 – Example of Section from Cheal Surveys



3.2.3 Field Verification

A site visit by boat was undertaken on 12 August 2005. The weather conditions were fine and the lake level was approximately 356.65 m RL (or approximately 600 mm below operational maximum). The following section provides a brief summary of some of the observations during that visit. A more complete record of observations and photos taken can be found in Appendix B.

- Significant erosion had previously been identified along the Taupo foreshore cliffs[8]. This was evidenced during the elevated lake levels of July 1998 (357.48 m RL, compared to maximum control level of 357.25 m RL[7]) that resulted in 0.5 m to 1 m of horizontal erosion, with 17 sites requiring remediation[8]. The site visit confirmed localised erosion as indicated by the presence of beach scarps, erosion protection structures (groynes, seawalls, geotextiles) and the retreat of the beach profile by up to 6 m around infrastructure such as outfalls and boat ramps.
- Erosion in this area is likely enhanced by human activities such as dams and diversions that reduce the sediment load within rivers and/or structures such as groynes that disrupt lacustrine processes such as long-shore transport[8, 9]. A series of some 50 groynes and natural rock formation between Wharewaka Point and Taupo Township

is believed to be starving Taupo Township of sediment thus accelerating shoreline erosion.

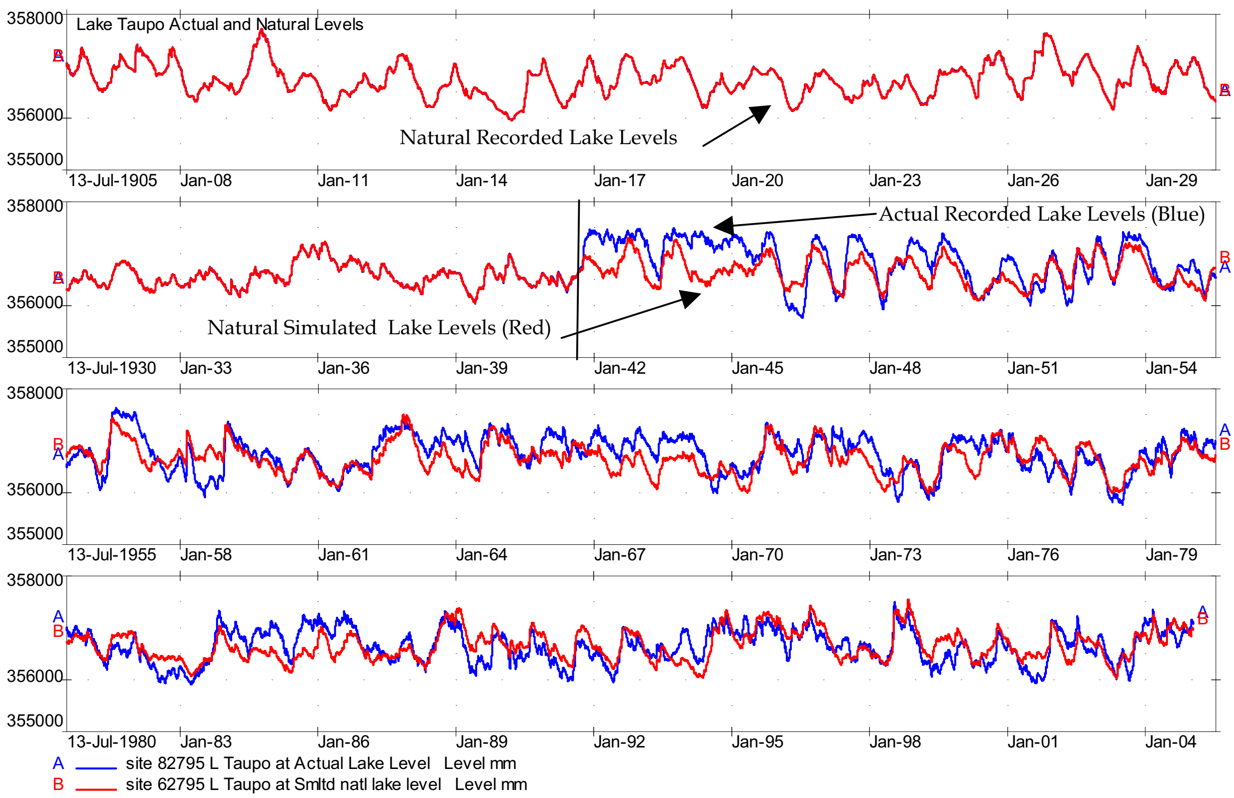
- From 5 Mile Bay South to Waitahanui the retreat of the grass line about stormwater outfalls suggests in the order of 3 to 4 m of erosion in a 30 year period. A small scarp about 0.2 to 0.5 m in elevation is also observed at the beach crest, reportedly due to the erosion event of 2004. Erosion is also evidenced at Waitahanui, by the occurrence of exposed tree roots in front of the campground (also detected in aerial photographs) and by the retreat of the shoreline to the north of private boat ramps.
- At Motutere, Waitetoko and Te Rangiita, severe erosion is reported after short-term events (such as February 2004) however both sites are reported to recover quickly. Some 2m of lateral build up on the south side of a recent boat ramp was observed at Waitetoko. At Te Rangiita rock is being moved from seawalls and deposited in front of houses further along the shoreline.
- At Pukawa Bay (western side of the lake) there is an 8m lateral difference in the shoreline and approximately 1.3 m vertical difference in the relative level of the lake to either side of a concrete boat ramp. As at Waitahanui, the roots of a large tree are exposed also suggesting the occurrence of erosion. This erosion does not pose an immediate threat, as the houses are set back from the shoreline, however this site may require further monitoring.
- Both accretion and erosion are occurring at Kuratau. Accretion takes the form of delta formation at the river mouth to the north. To the south of the river mouth, a scalloped erosion pattern is occurring along the beach, with retreat occurring between “headlands” formed by willow trees. Some 10 m of retreat is observed, although surveys (Chris Todd, pers comm.) indicate losses of up to 20 m.
- Localised erosion occurs at Kinloch, due to the marina breakwater. This erosion is only recent, when retreat of the shoreline towards the poplars was observed following the 2004 storms.
- It is noted that all erosion reported occurs along lengths of shoreline dominated by unconsolidated deposits.

3.3 Review of existing Lake Level Regime Information

Since September 1941 when the Lake Taupo Control was commissioned utilising the new outlet arrangement there have been various factors that have influenced the lake level regime. Figure 3.2 shows the recorded (blue) and simulated uncontrolled (natural – red) lake levels for the period between 1905 to 2004. Until 1941 the lake level regime was considered natural and was governed by rainfall within the catchment and the capacity of the outfall into the Waikato. The two most significant changes to the physical operation and capacity of the system and the volume of water reaching Lake Taupo were the upgrading of the outlet arrangement and the diversion of additional water to Lake Taupo as part of the Western and Eastern diversions associated with the Tongariro Power Development (TPD) (1971 and 1979 respectively). Since these have taken place the primary controlling factors affecting the lake level have been the amount of rainfall, and the influences of controlling how the lake levels are managed including the use of the lake for hydroelectric power generation and flood prevention.

The control of lake levels has been primarily associated with the control of the outlet gates for hydro electric purposes downstream. However, the flows entering Lake Taupo due to the TPD are significant and contribute about 25% (Opus 99)[3] of the total flows entering the lake. Due to the significant increase in capacity of the outlet gates allowing these flows to pass, focus has generally been on the operation of the control gates for downstream hydro purposes as the controlling factor, however the additional incoming flows still contribute to the system.

Figure 3.2 – Recorded and simulated uncontrolled lake levels (1905 – 2004) (Actual Lake Levels shown in Blue, Natural simulated levels shown in Red) (Levels are based on 24 hour averages)



As a part of the consenting process for the use of Lake Taupo for hydroelectric power generation storage, and due to concerns that the use of the lake as a storage reservoir was causing a change to the water level regime resulting in adverse effects to lakeshore erosion, there has had a greater level of analysis on this topic. A large amount of this work was undertaken for MRP[10] as evidence for their consent applications, which was carried out around 1999 - 2000. The findings from most of these reports generally confirm that the lake level regime in recent times is similar to the natural simulated regime, with reduced extreme high levels. In general our review of these past analyses found that they provide a true reflection of the impact of the lake level regime. Further additional analysis and comment is provided in Section 4.

Some of the conclusions from these studies are included below:

Tongariro Power Development (TPD) - Effects on the Waikato - Opus, 1997 [4].

Report presents statistical data on mean, minimum and maximum monthly flows, flow distribution curves and annual minimum and maximum flows. Report shows that generally the storage available in the lake has been greater than prior to the TPD (ie lake levels have been held lower), however this isn't caused by the TPD but happens to be a result of lake level controls implemented and outlet control.

"The trend of increased operational storage corresponds with a trend of generally lower lake levels since 1968. However, the trend in natural inflow has generally increased since 1986, and particularly since 1987."

Lake Taupo and Waikato River Levels and Flows - Opus 1999 [3].

The report finds that "The duration plots are very similar over the lake level range 356.3 m (10 percentile value) to 356.65 m (50 percentile value). Outside this range the effect of the controlled lake regime is to keep the controlled lake level record lower than the natural lake level record by up to 0.1m. "

Lake levels were also compared for different historical operating regimes for the lake. Figure 4.7 in the Opus report shows the proportion of time that lake level was below a particular threshold value. The report makes the following points following examination of the plots.

"Except during the war years (1941-1945), Taupo levels under lake control have been held fairly close to the uncontrolled fluctuation range, …", "Variations from the Pre Gate Control situation are at most in the order of 200-250mm with more variation evident in the pre TPD Diversion than in the post TPD diversion regime. It appears therefore, that apart from during the war years, management of Lake Taupo levels has succeeded in maintaining a controlled lake level regime close to the natural regime. "

"Lakeshore Geomorphic Processes, Lake Taupo" NIWA, Hicks et al 2000 [1]

Under control since 1946 the maximum level has been at 357.25 mRL. "This represents a contraction of maximum elevations by 0.52m, a fact that is significant in considering shoreline erosion since it occurs mainly under storm wave action at high lake levels." The minimum is set at 355.85mRL giving a range of 1.4m.

Referencing the Hicks 2000 report, the following relevant points were made:

- Since October 1979 the lake has been at high levels (above 357.20m) for less time than was the case under "natural conditions" in the period prior to control,
- The lake has spent greater time at low levels (below 356.4m) than was the case in the pre-control period.
- The percent of time in the range of 356.4m –356.6m decreased by about 12%, and;
- The percent of time in the range of 357.0m 357.2m was increased by about 9%.

Hicks [5] shows that the over the last 20 years of data the percentage of time that the lake has been held at higher level has decreased from 34% to 21%. Generally the lake levels fall within a 0.8m band centred on 356.6m.

In terms of seasonality the lake is typically lower in the winter and higher in the spring. Examination of monthly water levels by Hicks [5] shows that the lake is often kept at higher levels than natural for specific periods of time. Although over the longer term the resulting distribution is similar to natural conditions. The extremely high lake levels of the natural record have been avoided, under control.

The report observes that all shoreline erosion involves the net loss of sediments. As the control of the lake levels have produced reduced extremes and therefore should be inhibiting additional erosion rather than increasing it. Erosion hazards occur most strongly when lake levels are high and strong wind create large waves, these conditions occur naturally, and the development of the control of the gates reduces the probability of this occurring rather than increasing it.

Hicks [5] also reviewed the coincidence of wave run-up and lake levels to test if the lake level regime under control changed the joint probability resulting in higher "absolute run-up levels" being produced. It was concluded that, " …lake level control has not significantly affected the shore erosion hazard due to storm waves occurring at high lake levels."

" Lake Taupo Hydrology Review, A Report Prepared for the Waitangi Tribunal." Hamilton, D. 2005 [11].

More recently a review/audit of the evidence provided to the Waitangi Tribunal was undertaken by David Hamilton[11]. The conclusions from this review included the following:

"Over the last 10 years the lake has operated at or below the pre-control gate lake level distribution for the May to November period" and " about 0.1m above the pre-control lake level distribution for most of the December to April period except at the high end (85%-100%) where it has not reached the natural maximum levels."

He confirmed that the earlier analysis by Freestone (H29) shows realistic results and that 'the seasonal pattern was similar to the natural situation and peak levels slightly lower."

4 Gaps in existing information and recommendations for further data collection

The most significant gap in the current information needed to better understand the process acting on the Lake Taupo Shoreline and their effects is long-term repeatable survey information on the beach profiles of the shoreline. The collection of this data will allow better understanding of the longer-term trends and cycles in the position of shoreline locations. It will eventually allow differentiation between areas where the shoreline is experiencing shorter-term fluctuations and those areas where erosion is a long-term trend. This information is important for both developing set back distances if appropriate, as well as designing structures in the littoral zone. Collection of nearshore bathymetry information, particularly around river mouths would also be useful.

Additional information that would also contribute to better understanding of the processes include: additional verified wave modelling of the lake, in conjunction with a sediment budget model with known rates of erosion / accretion and inferred sediment transport from the wave model, also monitoring of performance of erosion control management measures, wave height monitoring. More information on the density, size and movement of the specific sediments found in the lake relative to standard coastal sediments and the associated coefficients.

These items are discussed further in Appendix C, including recommendations for additional monitoring.

5 Further Analysis and Assessment of Factors Contributing to Shoreline Erosion

The following sections discuss the results from the high level assessment of some of the primary potential influences on lakeshore erosion.

5.1 Geology

5.1.1 Geologic History

Lake Taupo is situated near the southern end of the Taupo Volcanic Zone (TVZ), a NNE-SSW trending zone of volcanism that extends from the Bay of Plenty to Ohakune. Volcanism has occurred from 5 main caldera centres within the TVZ, of which Taupo is one. The TVZ is also an area of high heat flow and thin crust, extensional faulting and shallow earthquakes. Deeper earthquakes result from the subduction of the Pacific Plate beneath the Australian.

Pre-historic caldera forming eruptions are thought to have occurred from the Taupo centre since 320,000 years ago, however the basic shape of Lake Taupo is a result of the Oruanui eruption (and subsequent collapse) some 22,000 years ago. The southern part of the lake is mostly formed through tectonic activity on regional structures.

The most recent Taupo eruption (1,820 years ago) and ensuing caldera collapse formed the Waitahanui Basin (deepest, northern basin of Lake Taupo) [12]. Erupted material blocked the pre-existing outlets for several decades raising the level of the lake by approximately 34 m (terraces at this elevation can be seen along the eastern shoreline) before a new outlet was formed.

5.1.2 Geologic Formations

The 1:250,000 geologic map[13] for the Taupo area identifies 11 different geologic formations occurring along the shoreline of Lake Taupo, these units are summarised in Table 5.1. For the purpose of this study these units can be grouped on the basis of their relative resistance to erosion (Figure 5.1).

Unconsolidated (i.e. uncemented) alluvium and volcanic deposits (low resistance to erosion) dominate the eastern and southern shoreline. Soils in this area readily experience deep and accelerated erosion[12]. The western and northern shoreline comprises mainly volcanic lava flows, domes and welded ignimbrite (moderate to high resistance to erosion). A map summarising the grouped units is shown in Figure 5.1. Local features and boundaries are indicative only and may not be accurately mapped.

The geology of the Lake Taupo catchment has a significant influence on flood run-off generated from a given rainfall. The permeable nature of the ash and pyroclastic material that mantles the catchments draining to Lake Taupo, suppresses flood-peak runoff, which is typically 10 % of storm rainfall. This compares to 50 to 60 % runoff of storm rainfall in the Waipa Catchments[3].

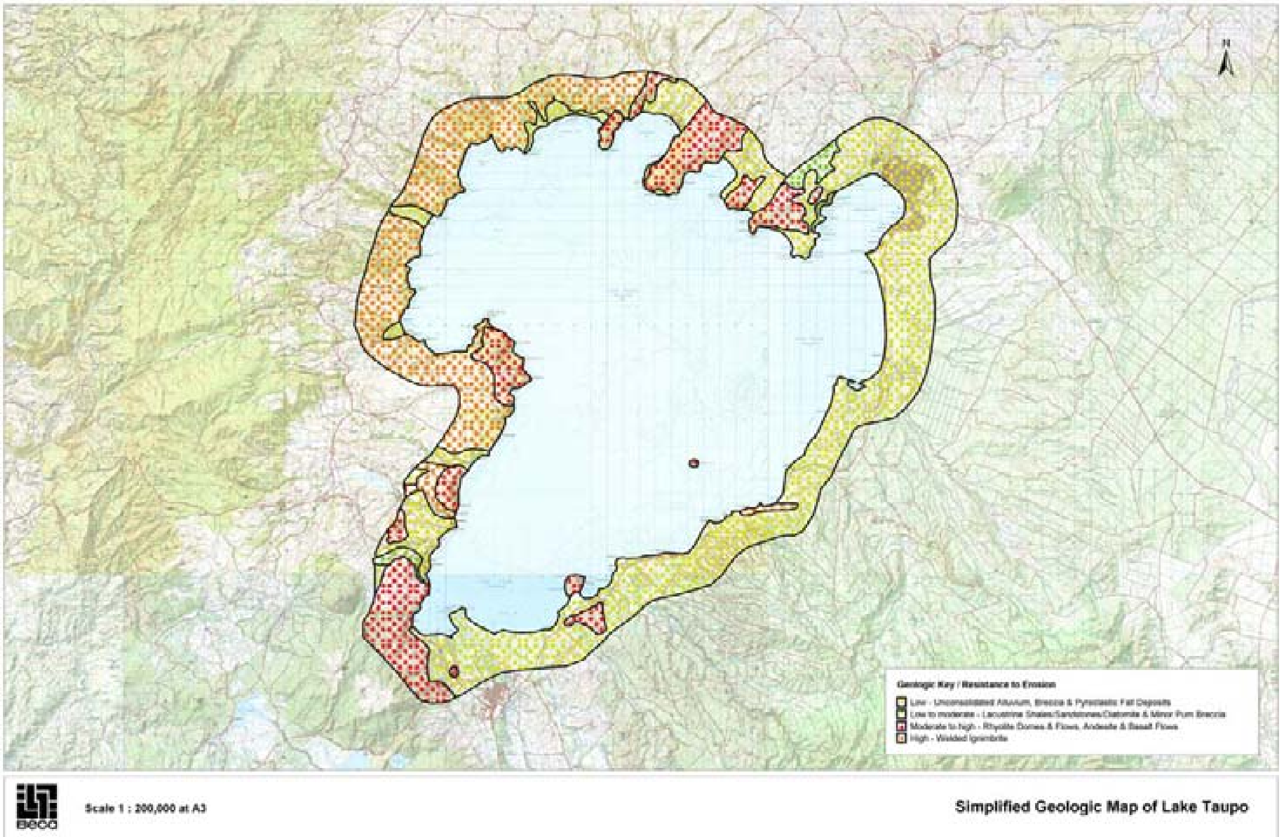
The Taupo Fault Belt (TFB) runs from Waihi to just west of Taupo Township and incorporates a number of active fault traces, hence the horst and graben structure of the northern shoreline, where blocks of land have been downthrown creating a depressed valley (graben) bounded by raised land (horst) on either side.

Table 5.1: Summary of Geologic Units

Relative Resistance To Erosion	Geologic Unit	Description	Occurrence
Low	Taupo Pumice Alluvium (TPA)	Unconsolidated pumice alluvium and ignimbrite (186 AD eruption), weak, uncemented, non cohesive	South-eastern shoreline, down faulted blocks, bays
	Waitahanui Breccia	Unconsolidated pumice breccia/lapilli tuff fan	Eastern shoreline underlying TPA, Otuteto Pt
	Haparangi Rhyolite Pumice	Pyroclastic & ash beds, pumice breccia, lapilli, ash, avalanche and nu'ee ardante (uncemented)	Rangatira Point
Low to Moderate*	Huka Formation	Upper lake beds & minor pumice breccia Lower thin bedded lacustrine shale, sandstone and diatomite	Acacia and Pukawa Bay
Moderate to High	Haparangi Rhyolite	Small spherulitic, pumiceous and lithoidal domes and flows	Te Rangiwha Pt
	Karangahape Basalt	Basalt flows	Karangahape Cliffs
	Haparangi Rhyolite (older)	Small spherulitic, pumiceous and lithoidal domes and flows	Northern shoreline, Werohanga Pt and Karangahape Cliffs
	Kakaramea Andesite	Andesite flows	Waihi
High	Rangitaiki & Whakamaru Ignimbrites	Welded, crystal vitric tuff, prominent quartz crystals, pale grey	North-western shoreline and isolated outcrop between Hatepe and Jellicoe Pt
* Dependent on exact nature of unit i.e. unconsolidated breccia vs. sandstone			

It is clear that the dominant geology at discrete points along the shoreline of Lake Taupo will largely determine the relative resistance of that point of shoreline to erosion. Those areas that have unconsolidated deposits such as pumice alluvium will be significantly more susceptible to the potential erosion.

Figure 5.1 – Map showing grouped geologic formations



5.2 Geomorphology

5.2.1 Eastern Shoreline

The landforms occurring along the shoreline are a function of the dominant geology at each site. The eastern shoreline (unconsolidated alluvium) is characterised by low pumice cliffs and gently sloping (< 7°) topography due to the relative ease of erosion. As the deposits are easily eroded a steady supply of sediment is deposited in the near shore resulting in a gentle sloping bathymetry[1, 12,13].

Historical higher lake levels can be seen forming low-level terraces along the eastern and northeastern shoreline. Accretion is also evidenced by delta formation at the mouths of major rivers i.e. Tongariro.

5.2.2 Western and Northern Shorelines

The southwestern shoreline (resistant andesite flows) is defined by the Waihi Fault and comprises steep (26 to > 35°) cliffs. The northwestern bays are also characterised by steep cliffs (26 to 42°), a result of the welded ignimbrites that dominate this area. The resistance of these two rock types to erosion ensures continuation of the steep cliffs below water level with steep near-shore bathymetry [1,12,13]. This steep bathymetry tends to prevent waves from breaking instead leading to wave reflection.

5.3 Tectonic Deformation

Due to Lake Taupo's position with respect to the TVZ and the TFB, both long-term continuous deformation (due to regional activity and warping) and instantaneous (earthquake) events can occur resulting in relative uplift or subsidence of one part of the lake to another, potentially affecting relative lake levels.

5.3.1 Continuous Deformation

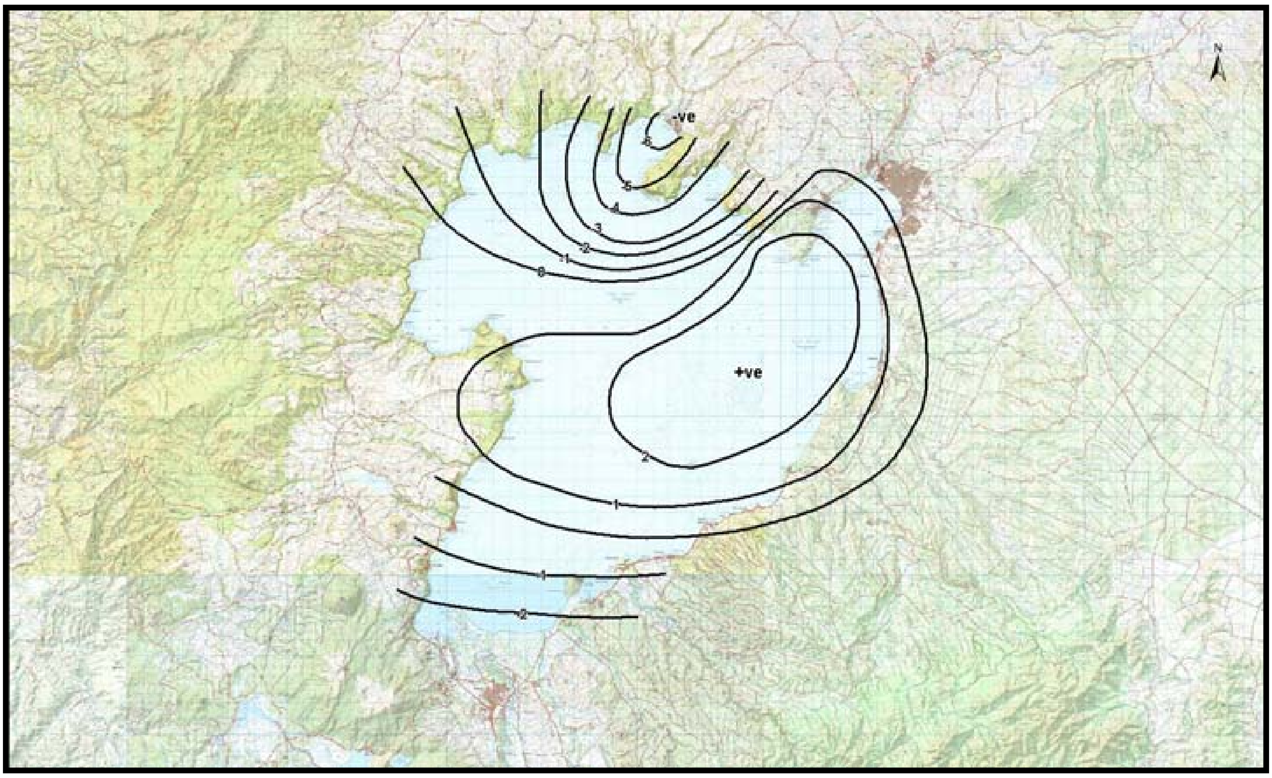
A significant change in deformation direction and rates has occured within the last 20 years[9]; therefore both the shorter-term and longer-term deformation rates will be discussed. Without the evaluation of more recent (last 5 years) GPS data, it will be assumed that current and projected deformation will follow the short-term trend.

Short-Term (Last 20 Years)

The current average rate of deformation for Lake Taupo is 6 – 9 mm/yr, based on data collected between 1979 and 2001[9]. Deformation during this period is dominated by minor uplift on an area centred over the Horomatangi Reef (including Acacia Bay to Hatepe and along the shoreline from Kuratau to Karangahape Cliffs) relative to the northern and southern ends of Lake Taupo (Figure 5.2).

Significant subsidence was recorded at Kinloch (mean annual deformation rate of –6.3 mm/yr), with a further 13 mm of subsidence recorded between December 1999 and March 2001.

Figure 5.2 - Short Term Mean Annual Deformation Rates (mm,) ***after Hancox, 2001***



Long Term (Since 186 AD)

Longer-term deformation is also characterised by a broad area of relative uplift (4 – 5 mm/yr) centred over the lake and relative subsidence of the Turangi - Waihi area. It is significant to note that the subsidence of Kinloch has only occurred within the last twenty years, the long-term trend was for uplift along the northern shoreline. Therefore if the current trend of subsidence continues, in the long term this could cause issues at Kinloch.

5.3.2 Instantaneous Deformation

Previous earthquakes in this area have been known to cause up to 1 m uplift/subsidence. An earthquake could result in instantaneous vertical movement and if near to the shoreline may create a heightened wave (tsunami), as a direct result of the event causing localised erosion.

5.3.3 Conclusions Which Can Be Drawn

- Near-continuous deformation occurs with subsidence of the northern and southern shorelines relative to the central Horomatangi Reef which is rising;
- This deformation is likely to continue;
- Subsidence will result in shoreline inundation, increasing the wave run-up elevations and erosion potential leading to undercutting and collapse of low pumice cliffs;
- Uplift could result in lower relative lake level / higher cliff height and therefore may promote instability of unconsolidated deposits having an increased height; however the increase in available sediment associated with uplift for beach areas is generally considered to reduce the risk of erosion.
- Earthquakes may cause instantaneous vertical movement of land; a resultant tsunami could lead to localised erosion; and
- Historical assessments[2] indicate that the impact of subsidence and uplift is currently being offset by adequate sediment supplies and littoral drift resulting in only minor impact on erosion in most areas. Depending on the availability of sediment and the longer term trends in the future the potential for this to change remains.
- Continued monitoring and confirmation of current trends should be reviewed on a regular basis.

5.3.4 Wind and Waves

The wind and the waves generated along the available fetches provide the primary energy driving the processes resulting in erosion, and therefore it acts as one of the primary controls over where erosion risk lies.

NIWA[1] reviewed and analysed the wind data from various sources around Taupo. Their findings showed that the dominant westerly wind is present for all seasons, although there is some variability. The resultant effect of wave generation can be seen from the plots of wave height produced by NIWA using their Lakewave hindcast model as a part of the 2000 study, as well as for the updates using this model carried out for this study. The results from long term analysis of wave energy shows that shores exposed to the west and southwest experience the greatest wave energy[1] .The models also show a corresponding increase in the long shore sediment transport potential for these shores.

Historical seasonal patterns were identified by NIWA[1], including the windiest months being spring (September, October, November) and the autumn and winter (March through August being the calmest.

As a part of this current erosion study NIWA were commissioned to rerun their Lakewave model developed for the 2000 study. The run included the last 5 years of wind data and allowed revised outlet files to be produced giving high level information on wave heights, sediment transport and divergence which was used along with other information during the assessment of shoreline erosion hazard levels. Maps included in Appendix E show examples of plots for Longshore Sediment Transport (LST) Divergence, and RMS (Root Mean Square) Breaker Height, we produced using the NIWA data. Due to some of the limitations associated with available calibrated information to put into the model, such as sediment transport rates and coefficients, the model is primarily useful for observing trends rather than actual values. Development of more localised detailed sediment budget models in conjunction with wave modelling would assist in defining more accurate values.

5.4 Impacts of Land Use and Tributary Management

In addition to those activities that directly impact on the lake foreshore, there is the capability for activities within the Lake Taupo wider catchment to affect the sediment budget for the lakeshore and therefore influence the potential for erosion. The following sections discuss the potential influence that landuse, catchment management practices and structures such as fences, bank protection and dams may have on the erosion risk for Lake Taupo.

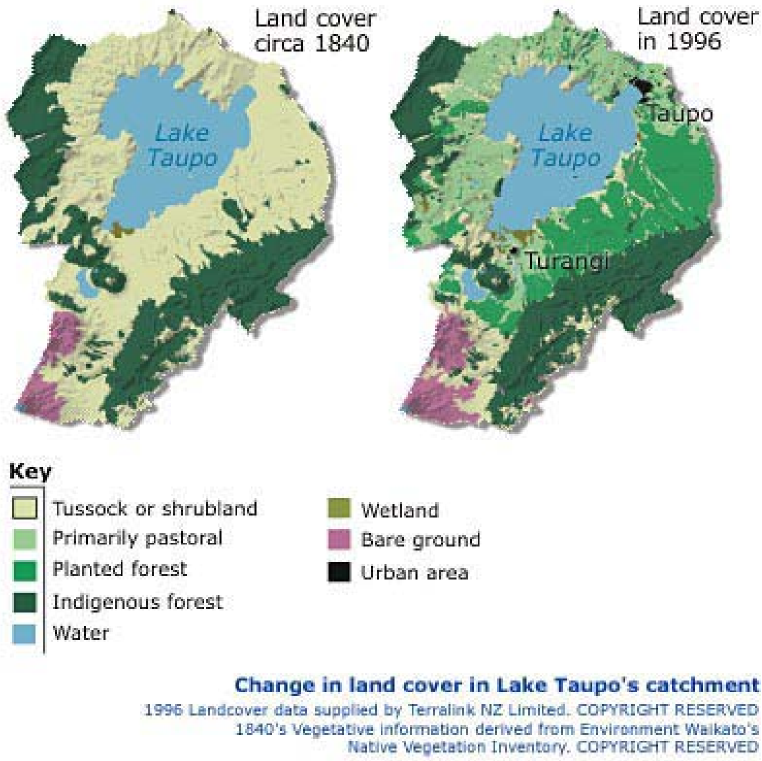
Due to the Environment Waikato initiatives associated with soil conservation and tributary management through programmes such as Project Watershed, there is a reasonable amount of information on land use type, soil erosion potential and the conservation works associated with these. There is limited information, however, on the relationship of these activities on the sediment budgets entering the rivers or Lake Taupo. Many of these initiatives are aimed at preventing soil loss and therefore have the potential to reduce sediment supplies to the rivers and subsequently to the lake sediment compartment systems, impacting the equilibrium. The goal of the schemes is to usually bring back the amount of erosion to natural levels as opposed to stopping it altogether.

5.4.1 Land Cover

The current land cover as reported by Environment Waikato is listed and shown in the land cover map below. This map also shows the land cover circa 1840.

- Pasture (18 percent).
- Production forestry (18 percent).
- Native vegetation, scrub and other land uses (41 percent).
- Lake (19 percent).
- Bare ground (four percent).

Figure 5.3 – Comparison of land cover change for the Lake Taupo Catchment

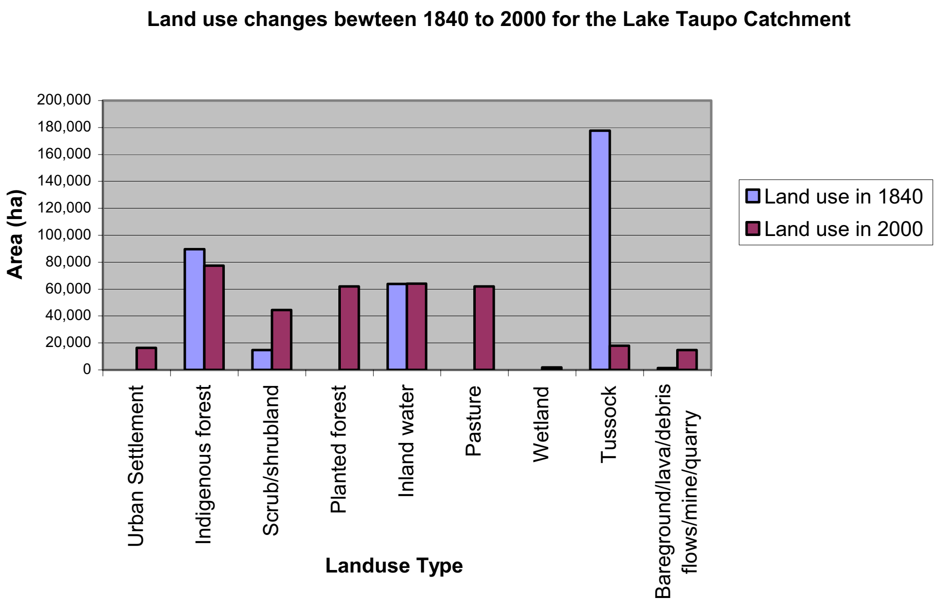


An assessment of land use change by Environment Waikato resulted in the reported changes shown in Table 5.2 and Figure 5.4 below. The most notable changes have been the reduction of Tussock country and the conversion to pasture, plantation forestry and the increase in urban development.

Table 5.2 – Changes in land use between 1840 and 2000

Lake Taupo Catchment Land Cover Changes (from Environment Waikato)		
	Landcover areas in hectares	
Land use description	**Land use in 1840**	**Land use in 2000**
Urban Settlement	0	16,308
Indigenous forest	89,622	77,429
Scrub/shrubland	14,637	44,540
Planted forest	0	61,939
Inland water	63,759	64,015
Pasture	0	61,947
Wetland	0	1,848
Tussock	177,744	18,000
Bareground/lava/debris flows/mine/quarry	1,479	14,849
Totals	**347,241**	**360,875**

Figure 5.4 – Chart of land use change between 1840 and 2000



It is clear from previous studies that land cover type can have a significant impact of the soil loss from land areas. Table 5.3 below taken from work carried out by Campell (1945)[15] in Hawkes Bay gives an indication as to the variability of erosion magnitude from different vegetation cover types.

Table 5.3 - Field Measurements of Surface Erosion Magnitude (Campell 1945)

Vegetation cover type	Surface erosion magnitude (tonnes/ha/event)
Forest	<0.01-0.29
Scrub	0.11-0.29
Pasture (depending on slope, intensity of grazing and herbage removal)	0.07-4.42
Devegetated, eroded or bare ground	5.60-14.57

Comparing these rates to the changes to land use over time reported earlier, shows that for changes such as the increase in pasture there would be a likely increase in the soil loss from those land areas. However the increase of planted forest will provide reduced sediment loads for most of the lifecycle of the forest.

Due to the highly permeable soils within much of the Lake Taupo Catchment it has been reported that the impact of land use on erosion is reduced as the amount of overland flow is minimal for most storm events[5]. Schouten (1980)[16] found that even during the period between 1955-1980 when there was significant clearing of scrub and original forest that was converted into grassland and pine forests there was little impact on sediment loadings in streams. This is sometimes countered by higher levels of erosion during high intensity events when the pumice soils are easily eroded by surface flow. There has been, however anecdotal evidence that in some catchments where increased flows occurred the streams could cope with the additional flows that led to bank erosion[1]. The availability of significant amounts of ash from volcanic eruptions can significantly increase the sediment levels for the short to medium term following the eruptions.

Landuse changes leading to increased development and associated stormwater discharges to soakage in the rearshore of the lake have been reported [(2)] to be effecting groundwater levels along localised areas of the foreshore. The reported significance of this is that it may reduce the beaches ability to absorb wave energy leading to increased loss of beach material. Specific examples of this were not identified during this study, but may be occurring.

5.4.2 Tributary Management

The primary effects of tributary management on the erosion potential for the lakeshore relates to the effect on the sediment being supplied to those beach systems. The aim of most of these programmes is to reduce the soil loss from the catchment. This has the potential to conflict with potential sediment deficits to the shoreline of Lake Taupo.

Significant effort is being put into the management of soil conservation programmes throughout the Taupo Catchment. Soil conservation programmes include:

- tree planting on hills and stream banks
- retiring land
- fencing gully areas and waterways to prevent stock access.

Within the Taupo Catchment it is estimated that 131 km (7.3 percent) of waterways are either actively eroding or have high potential to do so. In addition, 13 percent of the Lake Taupo Catchment (36,694 ha) is classified as land at risk[14].

Environment Waikato[17] has classified erosion hazard along the Lake Taupo shoreline, identifying a high-risk area along the eastern shoreline and small pockets of the southwestern and northwestern shoreline. The areas of high-risk correlate to areas mapped as unconsolidated deposits, conversely areas of low risk correlate to resistant volcanic flows and ignimbrite. This study expands on this and incorporates other influences such as historical erosion and lake and shoreline processes.

The scope of the Regional soil conservation works to combat this as defined on the Environment Waikato website includes:

Table 5.4 – Taupo Catchment soil conservation works

Land retired (ha)	5,145
Fencing (km)	1,125
Planting (ha)	4,252
Structures	86
Water supply systems	41
Replacement value($ million)	15.20

Goals for managing these risk areas include works for the following:

- five percent of the zone's streambank length (identified by the field survey)
- 90 km of total streambank which will need to be protected.

The aim for these works will be to reduce sediment losses by 50 percent from treated areas over 20 years, and 90 percent over 40 years.

5.4.3 Discussion

Whilst there is a reasonable level of information on the soil conservation initiatives with the lake Taupo Catchment, we have not found any direct relationship to the volume of sediment reduction and the potential impact on shoreline processes for the lake.

Many of the catchment conservation programmes are aimed at mitigating the impacts of development with in the catchment, such as the fencing of waterways to prevent cattle from disturbing the banks. In many cases the result of these programmes will be to return the levels of streambank erosion back towards levels prior to development / disturbance. It is therefore considered that the impact of these soil conservation works is unlikely to be significantly increasing the risk of shoreline erosion compared to predevelopment levels. As mentioned earlier the purpose of these structures is to return the level of erosion to pre development levels. In some cases such as the stabilisation of stream banks to prevent the river from naturally altering course, the lake may see a reduction in periodic large influxes of sediment from these events. However, as in some cases these large influxes can be followed by periods of reduced sediment input from the river the longer term effect of this is reduced.

5.5 Reduction of sediment supplies due to dams

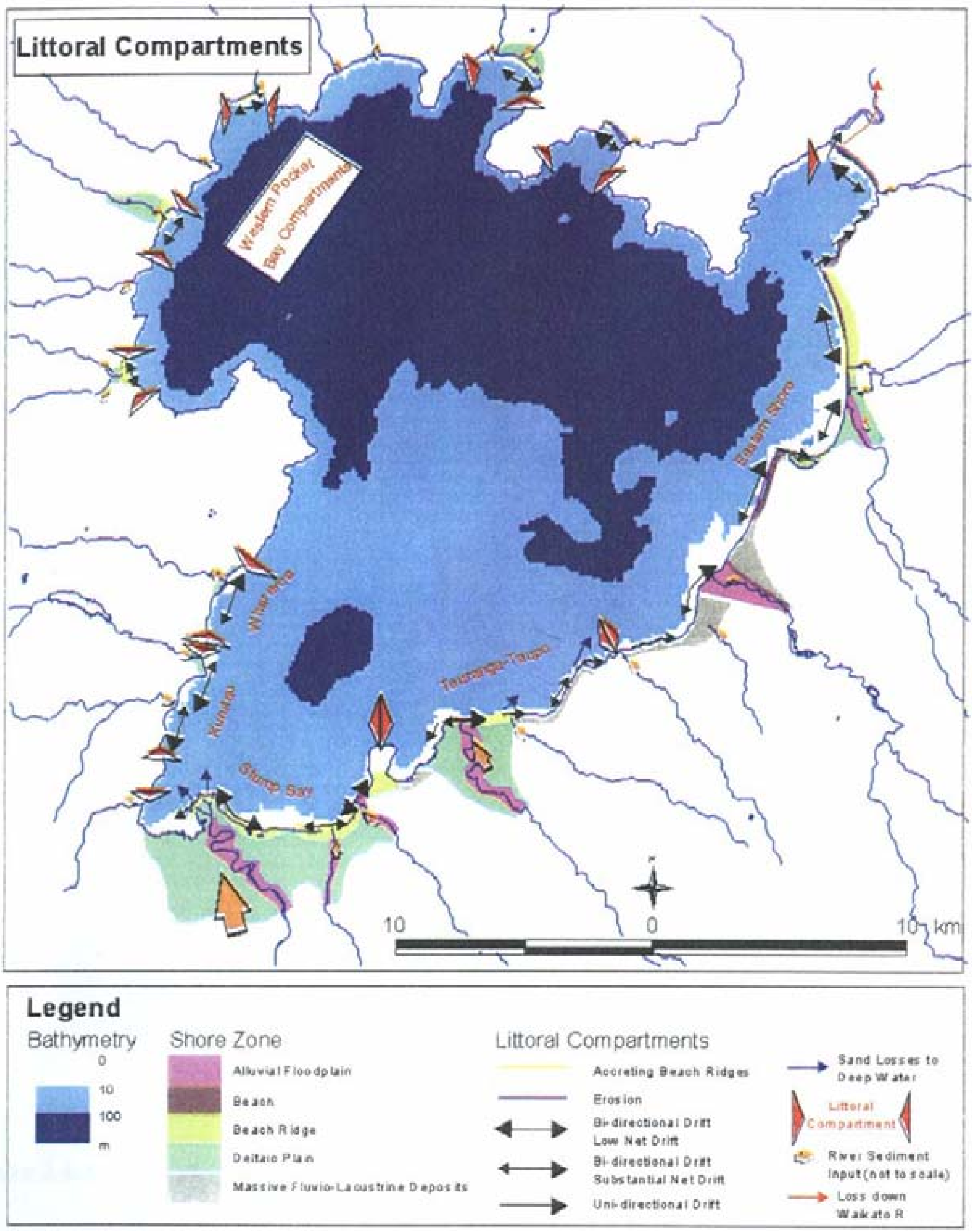
The greatest inputs of sediment into the lake come from the catchments along the southeastern shore[1], a breakdown of estimates can be found in the NIWA 2000 report. This report estimates of the total suspended sediment load at approximately 192,000 t/yr, of that total amount sand and gravel inputs account for about 148,000 t/yr. Some 60% of this is derived from the Tongariro.

The sand and gravel loads are more significant to beach formation as much of the smaller sediment will pass out into the middle of the lake where it will be deposited. Thus not contributing significantly to the sediment budget as it will be lost from the system.

It is important to acknowledge that although the majority of sediment comes from the Tongariro, the impact of the sediment from the Tongariro is limited to the littoral compartment associated with the river. Therefore sediment inputs from the Tongariro will not impact on other compartments such as by Waitahanui or Taupo Bay etc.

The extent of the main sediment compartments around Lake Taupo were identified by NIWA[1], and a figure from their report depicting the extent of the littoral compartments and the longshore directional movement of sediment is shown in Figure 5.5 below.

Figure 5.5 – Littoral Compartments defined by Niwa[1].



Possibly more significant to specific catchments has been the construction of dams on several of the main rivers entering lake Taupo, including the Hinemaiaia, Kuratau and Tongariro rivers. Based largely on work carried out by Schouten[16] and estimates of on the sediment loads from catchments upstream of the dams, NIWA reported the following estimates for reductions in sand and gravel loads reaching Lake Taupo[5]. The post dam figures are based on the sediment derived from the catchment areas downstream of the dams. Further discussion here is limited to Kuratau and the Hinemaiaia.

Table 5.5 - Changes in sand and gravel loads due to dams

River	Natural Load t/yr	Post-dam Load t/yr	Reduction in Load t/yr	Percentage Reduction
Hinemaiaia	9900	1560	8340	84%
Kuratau	5230	1610	3620	69%
Tongariro	108600	89000	19600	18%

Additional information of the estimates for the Hinemaiaia were also found based on work carried out by T. Marshall of the Waikato Valley Authority and estimates of the volume of sediment removed from the 'HA' Reservoir[18], which is the furthest upstream of the three reservoirs built, by surveying the reservoir floor. The following table summarises the estimates of sediment retained by the 'HA' reservoir.

Table 5.6 – Estimates for sediment retained by HA Reservoir

Time Period	Rate (m^3/year)
1952 -1966	8,821
1966 -1978	7,042
1980 - 1993	2,692
1993 - 1998	10,000

The variations in the volumes were largely attributed to influences of the intensity and duration of large storm events during those periods, on the highly erodible pumiceous soils. The eruption of Mount Ruapehu in October 1995 also would have increased loads during that period.

5.5.1 Hinemaiaia

There have been three dams built on the Hinemaiaia as part of the Hydro-Electric Power Scheme (HEPS), HA, HB, HC built in 1952, 1966 and 1981 respectively. HA is located the furthest up stream and due to its size HC and HB are not considered likely to remove much of the material which passes through HA.

The Hinemaiaia is one of the main sediment sources for the Eastern shore sediment compartment as defined by NIWA[1], additional sources also include the Waitahanui Stream and the White Cliffs. This compartment extends north all the way to the Waikato River. Much of the foreland that Hatepe has been formed on has been sourced from the river. As shown above the construction of the dams has significantly reduced the amount of sediment reaching the lake. The wave climate has the capability to transport sediment both north and south, however there is a net northward drift.

Previous studies and analysis of historical erosion haven't identified significant erosion within the immediate areas around the river mouth. However, a phase of erosion was considered to be expected as reported by NIWA[1], as they considered that as the sediment distribution by the waves continues, with less sand replacing what has been moved the shoreline will be impacted. Its overall impact may be subdued due to the significant sediment source stored in the nearshore zone, such as off the White Cliffs and river deltas.

The reduction of sediment from the Hinemaiaia may be contributing to sediment deficit issues further north at Waitahanui and into Taupo Bay. A report by Tonkin & Taylor for Mighty River Power[5] indicated that the likely cause of erosion at Waitahanui was a reduction in sediment supply. The reduction was partly attributed to the (84%) reduction from the Hinemaiaia, however it also was considered that erosion cycles were likely due to the "episodic and lumpy" natural supply regime that occurs in nature. NIWA[1] also considered the erosion at Waitahanui to be short term, rather than a long-term trend with low amplitude accretion / erosion cycles likely. Possibly rectifying a historical bulge, created when the houses were developed or from a historical large sediment input from the Waitahanui Stream. Also contributing to the reduced sediment supply is a reduction in the level of erosion of the White Cliffs, south of Te Kohaiakahu Point. NIWA attribute this mainly to re-vegetation.

5.5.2 Kuratau

The Kuratau River is the main sediment source for the 'Kuratau sediment compartment' as defined by NIWA[1] , and may be the source for the foreland that has been built on, and a large subaqueous delta on the edge of the steep lake basin. The Kuratau dam was constructed on the Kuratau River in 1962, and estimated reduction in sand and gravel load is approximately 69%[(1)]. As was the case with Hatepe, erosion at Kuratau might be expected in the long term as the foreland adjusts to the reduced sediment supply[1]. Further analysis on the causes is required, for example through a sediment budget analysis.

Historically aerial photos and comparisons to historical surveys show the lakeshore towards the point at Kuratau as accreting. Closer to the river mouth aerial photos didn't detect any significant change, however the comparison of the recent beach profile survey done by Cheal's to the historical lake edge showed significant erosion since the survey plan from 1963 and this is confirmed by the recent Cheal survey in 2006. Certainly in recent times there is clear evidence from site visits of this erosion occurring.

Historically the large delta in front of the river mouth may have been providing a source of continued sediment to the Kuratau foreshore, to top up the reduced supply coming from the river. The closest beach profile section by Cheals has shown a significant loss of material up to 200m out from the shoreline in this location. The ability for continued supplementation from the delta may have been reduced as this source has been used up, leading to the more recent reports of erosion.

Significant infilling of the river mouth on the true right bank approximately 25m up river has been observed. Historically boats were able to sail in an area that now has large sand bars. The relationship of this to the change in regime of the river, including any reduction in peak flows due to the dam has not been determined at this stage.

Further detailed information of the bathymetry in this area and how it changes over time would allow a better understanding of the dynamics of this area and assist in a sediment budget calculation.

It appears there were historical plans for erosion control measures along Kuratau following the development of the dams. There is anecdotal evidence that they were installed, however, there doesn't appear to be any remains on site.

At Kuratau the land that some of the development has occurred on, has been formed by historical sediment brought down and deposited by the Kuratau River, either through flooding or shoreline accretion. Generally the built up area is set back from the shoreline at present which will act to protect the properties, as it can allow time for further monitoring and natural fluctuations to occur. However, more recently this buffer zone has reduced significantly towards the river mouth.

5.6 Impacts of Lake Level Regime

5.6.1 Previous investigations and analysis

As set out in Section 2.4 there have been various investigations into the lake level regime comparing the current regime to that prior to the commissioning of the outlet control (1905 - 1941), as well as comparisons to a 'simulated uncontrolled' regime which models the simulated natural condition for all historical periods. The comparison to the natural simulated regime is the most relevant as it should allow for any variations in weather trends.

There appears to be a general consensus from the analysis undertaken up to 2000 that the lake level regime of recent times has been operated close to the simulated natural conditions. Any variations have been considered minor and have not been associated with contributing significantly to erosion. Further than this the control of the lake levels has reduced the maximum lake levels as compared to pre-control by about 0.52m[1]. As shoreline erosion appears to primarily manifest itself during periods of high lake levels and increased wind, in some cases the control of the lake has been considered to actually reduce the potential for erosion [4].

A review and audit of earlier lake level analysis was carried out by David Hamilton[11] for the Waitangi Tribunal in 2005. Hamilton's analysis included the use of more recent data up through 2004, and concluded that the earlier analysis by NIWA (2000) and the conclusions "that over recent decades, lake level control has not increased the risk of shore erosion or back shore flooding above what would have occurred with out lake level control are considered sound." He does however point out that over the last 10 years for the period between December to April the lake level distribution has been about 0.1m above the pre-control distribution, with the exception of levels at the high end (85-100%) where it hasn't reached the maximum levels.

5.6.2 Further analysis and recent short term trends

As a part of this study we reviewed some of the earlier analysis and undertook some further analysis using data up to January 2005. We were also requested to look at the most recent periods to assess if there have been any changes to previous conclusions.

The primary means of the additional analysis was the use of exceedence plots of the lake levels for different time periods. These plots show the percentage of time the lake was below the corresponding level. The time periods reviewed included but not limited to:

– Pre-control Gates – July 1905 – October 1941

Simulated uncontrolled 'natural', an actual recorded for the following periods:

– Post TPD developments	October 1979 – January 2005
– Last 10 Years	January 1994 – January 2005
– Last 5 years	January 2000 – January 2005
– Last 3 years	January 2002 – January 2005
– Full year for 2004	

Seasonal analysis was also carried out for Summer (December to April) and Winter (May to November) for the above periods.

Some of the relevant exceedence plots have been attached in Appendix D along with some annotated comments. The main conclusions from this analysis are listed below:

Review of last 10 years of data

- Over most level ranges the recorded level over the last ten years has been similar to the longer period post the TPD. (Figure 1 – Appendix D)
- All periods following the pre-control gates have had reduced maximum levels. (Figure 1) This is primarily due to the maximum level control agreements that have been enforced, and have been made achievable by the increased capacity of the gates.
- Recorded levels for the last 10 years spent less time at high levels (>357.1) than the simulated uncontrolled levels for the same period and Pre-gate control. (Figure 4)
- Recorded levels for the last 10 years had lower maximum levels compared to the simulated uncontrolled levels for the same period and Pre-gate control. (Figure 4)
- Recorded levels for the last 10 years spent more time at the lower levels (<356.5) than the simulated uncontrolled levels for the same period and Pre-gate control. (Figure 4)

Review of last 5 and 3 years of data

- For the last 3 and 5 year periods the simulated uncontrolled levels have had lower maximums and spent less time at levels above 357.0, as compared to the last 10 year period and Pre-gate control (Figure 3).
- The last 3 and 5 year periods have spent similar times at the highest levels (> 357.1) and had lower maximums as compared to the last 10 years, by about 150mm(Figure 2).
- Recorded levels for the last 5 years spent less time at high levels (>357.0) than Pre-gate control levels. However recorded levels spent more time at the upper range of levels than

the than the simulated uncontrolled levels for the same period, by up to approximately 50mm. (Figure 5)

- The maximum level recorded (357.35) over the last five years exceeded the simulated uncontrolled maximum level (357.25) by approximately 100mm. (Figure 5)
- Recorded levels for the last 3 years spent less time above 357.1 than Pre-gate control. (Figure 6)
- However, the recorded exceedance curve for the last 3 year period shows approximately 10% more time spent at mid to high levels (356.7 – 357.1) than the simulated uncontrolled. (Figure 6)
- The maximum level recorded (357.34) over the last three years exceeded the simulated uncontrolled level (357.25) by approximately 90mm. (Figure 6)

Seasonal Comparisons

- Over the last 10 years for summer months (December – April), the actual recorded levels were similar to the natural simulated regime, with recorded exceedence curve being slightly over the simulated curve for levels between 356.8 and 357.1. (Figure 7)
- Over the last 10 years for summer months (December – April), the actual recorded levels were above the Pre-gate control by approximately 50-100mm except at levels above 357.1. (Figure 7)
- Over the last 10 years for winter months (May – November), the actual recorded exceedence plots were at or below Pre-gate control and natural simulated levels. (Figure 8)
- Over the last 3 years for summer months (December – April), the actual recorded levels exceedence was up to 200mm higher than the natural simulated regime and Pre-gate control for most level ranges. (Figure 9)
- Over the last 3 years for summer months (December – April), the actual recorded maximum levels were approximately 100mm higher than simulated maximums, however still well below the Pre-gate control maximums. (Figure 9)

Review of 2004 data

- The exceedence plots for 2004 for recorded and simulated uncontrolled lake levels are similar with greater levels of fluctuations due to the short timeframe. (Figure 12)
- The recorded maximum lake level for 2004 was approximately 100mm higher than the simulated uncontrolled levels, however still below the Pre-control gates levels. (Figure 12)
- The recorded lake level exceedence plot for summer months of 2004 (December to April) was above simulated uncontrolled plot for all lake levels, by up to 200mm. (Figure 11)
- The recorded maximum lake level for summer 2004 was approximately 100mm higher than the simulated uncontrolled levels, however still below the Pre-control gates levels. (Figure 11)

- The recorded lake level exceedence plot for winter months of 2004 (May to November) was below simulated uncontrolled plot for most lake levels, by up to 100mm. (Figure 13)

5.6.3 Discussion

Analysis of the last 10 year period of level data shows similar results to observations made by earlier studies, to the effect that the lake level regime over this period is unlikely to have significantly increased the risk of erosion due to a modification of the lake regime. With reduced maximum levels this may reduce the risk of erosion in some cases.

Analysis of the last 5 and 3 years worth of data with exceedence plots shows some instances where the recorded lake level regime has been held higher than the simulated uncontrolled (natural) regime. It should be noted that the review of shorter timeframes such as these will not necessarily be reflective of the longer term trends, and will be more susceptible to short term variations such as weather patterns for those particular years. If these trends were to continue it may be expected to effect the longer term trends of erosion.

By reviewing the exceedence curves (Figure 5 & 6 in Appendix D) for the recorded and simulated uncontrolled data sets for the last 5 and 3 year periods, it is apparent that the recorded maximum levels for these two periods are higher than the simulated uncontrolled maximum levels by between 90 – 100mm. The time spent at higher water levels (>357.0) was greater for the recorded data than the simulated levels, with the recorded exceedence curve being higher by about 50mm. It is worth noting that the 3 and 5 year exceedence curves and the time spent at the higher levels are still below that of Pre-gate control, as well as the 10 year recorded curve for the highest levels (>357.15). It appears that while the recorded levels for the last 3 and 5 years, follows the same trend of spending less time at the higher lake levels (Figure 2 & 3), as modelled for the simulated uncontrolled levels for these periods, the relative decrease is not as significant and therefore this results in the recorded levels remaining higher than the simulated uncontrolled data. This short-term trend may have been caused by a lower amount of rainfall through this period.

The seasonal variation of lake level exceedence for the last 10, 5 and 3 years, and 2004 was also reviewed. (Figures 7-13) For the last 10 year period the winter levels are generally below the simulated uncontrolled levels throughout the curve. For summer months the 10 year recorded exceedence curve is between 50 –100mm above the Pre-control gate curve up to a level of 357.0, but was similar to the simulated uncontrolled regime for this period.

As the time periods review were made shorter and more recent the difference between seasonal regimes becomes more apparent with summer recorded levels remaining high. Over the last 3 year period the actual recorded level exceedence was up to 200mm higher than the natural simulated regime for most of the level ranges. (Figure 9)

When reviewing shorter time periods throughout the full record of data this occurrence of recorded level being higher than the simulated natural levels is not unique. However, as identified by NIWA[1], while there are discreet times when the lake level is held higher than it would be naturally, the longer-term statistics show that these periods are balanced out and there is minimal overall increase in levels and therefore erosion risk.

This study has not verified the accuracy of the model that creates the simulated uncontrolled regime. This accuracy and relevance of this model is critical to the reported changes from the simulated uncontrolled regime. There is also a potential that reducing the lake level variation may focus the wave energy on a more narrow band of bank leading to a greater risk of erosion. The applicability of this to Lake Taupo has not been determined at this stage.

The occurrence of high lake levels particularly in late summer reflects the our current understanding of the MRP operational regime where the lake levels are held high at the end of the summer in preparation for increased power consumption demands of the winter. During the winter months the lake levels are then managed at lower levels which balances the yearly exceedence regime to one which is similar to the natural annual regime.

From historical analysis it appears that this timing of holding the lake levels higher during summer does not coincide with periods with higher average wind speeds. However, the coincidence of high lake levels and high wind events should also be reviewed. This additional analysis is described below.

5.7 Coincidence of high lake levels and wind events

As part of the stage three study, an analysis of wind and wave events around the lake has been conducted. The aim of this analysis was to determine if there is any significant difference in the correlation between strong wind and high lake water level events, for the simulated natural lake level regime and the recorded actual regime. This analysis has been conducted for the entire period of available wind data – namely January 1972 to May 2006 using 3 hourly average wind speeds. Wind data was used from the Taupo Aerodrome as it provided the longest set of frequent data. Local variances, particularly evident in the southern part of the lake, will therefore not be represented. Further detail and tables associated with this analysis can be found in Appendix G.

The wind-wave analysis has initially been conducted for two sites: Kuratau on the southwest of the lake and Waitahanui on the northeast. These two sites have been chosen, as they are both known areas of recent erosion and are affected by different prevailing winds: northeast wind at Kuratau and southwest wind at Waitahanui. Other north-eastern shores will vary slightly but will perform similarly to the Waitahanui results. Analysis has made use of supplied still water level (SWL) lake data. This is made up of two different data sets - one representing the actual recorded lake level and the second the simulated natural lake level, which represents a modelled lake regime pre lake outlet control. These data sets were provided by NIWA.

Three separate analyses have been carried out at each of these sites:

- An estimation of absolute water levels for different return periods, for both the actual and simulated lake level data. (In this report absolute water levels are defined as the sum of both the estimated wave run-up and SWL),
- An analysis of the coincidence of strong wind events (e.g. greater than 20 knots) and still water levels (e.g. greater than 357.0m), and

- An analysis of water levels corresponding to the ten strongest wind events for the period of record.

5.7.1 Discussion

Lake level analysis reported in preceding sections has shown that the control of the lake level results in periods when the lake is held higher than it would be naturally. Over the long term this is mostly balanced out by other periods when the lake level is drawn down below what it would have been naturally, resulting in similar lake level regimes. In addition the overall range of lake level under control is reduced with extreme lake levels no longer occurring. Whilst annual lake level regimes are also similar, seasonal differences are apparent, with higher than natural lake levels occurring in the late summer months, and lower than natural levels occurring in winter and spring.

Review of previous wind analysis conducted by NIWA (2000) shows average wind speeds to be typically highest in spring, when the lake level is typically lower, and calmer in summer and autumn, when lake level is typically higher. The analysis of coincident wind and lake level events in this report indicates that the majority of the top ten highest wind events on record at Waitahanui have actually come in late summer to early autumn, and have corresponded with a high 'actual' still water level (SWL) that shows significant difference from the simulated level.

Reported erosion around the lake has been largely attributed to a limited number of events when the lake level is high, and there are strong winds. Further analysis of these types of events was therefore undertaken.

Return Period Analysis

The return period analysis of daily absolute lake level (the combination of SWL and wind generated wave run up), over the 34 years of data showed that for Waitahanui and other areas exposed to the southwest wind, that for any given return period, the absolute runup level was higher. The level difference is considered to be minor and therefore unlikely to significantly affect the erosion potential.

For Kuratau the actual levels are greater than the corresponding simulated levels for return periods up to 25 years, while they are lower for return periods over 50 years. The level differences at Kuratau are also minimal and unlikely to significantly affect the erosion potential.

Threshold Analysis

The threshold analysis looked at the number of high lake level (above 357.0m) and high wind events (above 20 knots). There were more events under the actual controlled regime than there would have been under the simulated natural regime for both Kuratau and Waitahanui. This finding was also the case for a higher lake level of 357.2 and wind events of 20 knots. This shows that for these infrequent high lake level and wind events the actual controlled regime has resulted in a greater number of onerous events compared to the natural regime. Where the shoreline is more susceptible to high lake level and high wind events this would indicate an increased risk of erosion under the controlled regime. This analysis is dependent on the threshold set, but a sensitivity analysis has shown similar findings for a range of events (see Table 3 – Appendix G).

However, when analysing the dates of the events meeting the threshold limits (Figure 1 and 2 Appendix G) there are long periods (10 years) where there are differing trends. Over the total period of record this has resulted in more events under the controlled regime, however this may be simply a reflection of the influence of the recent trend rather than a long term variance.

High wind events

A third approach to looking at the data was to focus on the 10 events over the record with the highest wind speeds, and compare the simulated and actual water levels. For a southwest wind, primarily affecting the north and eastern shores, the wind events more frequently occurred during periods when the actual lake level was held above the natural level, in some cases by between 200mm to 650mm. For these top 10 events the potential for erosion due to the control of lake levels would therefore be considered higher.

This is however balanced in some cases (for example the 1998 erosion event) where the actual lake level was lower than the natural simulated level. In this case had the natural regime been in place it would be expected that the erosion would have been more significant.

The recorded occurrences of very high wind events during times when the actual lake level was higher than natural indicate an increase in erosion risk. The relative increase in risk is difficult to determine due to the periodic nature of some of the trends, the balancing effects of decreased maximum lake levels, and the potential presence of other underlying factors such as the availability of sediment supply.

5.8 Impacts of development and shoreline structures

As well as indirect human influences on the lakes such as those discussed in Section 4, the impact of structures within the littoral zone has also significantly contributed to the erosion problems at Lake Taupo. The impacts of these structures has been identified in a number of reports[4,11,16] but forms the primary focus of a report by Kirk and Single (Land and Water Studies) in 2000[11] which was produced as a companion report to the NIWA 2000 Lakeshore Processes report[4].

Although the Kirk and Single report discusses various locations around Lake Taupo it focuses on the significant level of development and the effects around the township of Taupo. It describes the state of much of the bay as subject to "chronic erosion", and attributes this primarily due to effects "on beach sediment budgets and by inappropriate construction of large number of shore-parallel (eg: walls, bulkheads and revetments) and cross-shore structures (eg: groins and ramps)."

The report largely attributes the chronic erosion of the beaches of Taupo Township to the deficit in sediment supply due to the construction of a large field of 50 groins built since the 1940's along the shore between Wharewaka Point and the Sea Scout building. Some of these structures appear to be natural rock formations. It also states that sediment yields from the catchments have been reduced due to the damming of rivers and afforestation.

More localised erosion is also developing as a secondary consequence of erosion control structures both in Taupo Township as well as other locations such as Waitahanui. This is often due to inadequate designs or a lack of understanding of shoreline processes in the area. Kirk and Single also identified more than 100 boat ramps almost all of which are creating beach erosion on the downdrift shores.

During our site visit many of these structures were observed along with adjacent erosion. Generally the erosion associated with the boat ramps was localised to the near downdrift shoreline.

In locations such as Taupo Township, Waitahanui, and Four Mile bay reserve part of the problem relates to development that has occurred too close to the shoreline, with out allowing for natural fluctuations of erosion and accretion cycles. In some cases development may have pushed out into the lake and natural processes are attempting to rectify the change and bring the shoreline back into equilibrium.

5.9 Operational Considerations

Some current operational practices associated with structures such as sediment removal from boat ramps need to be reviewed, taking into consideration their impact on erosion. Current practices such as those undertaken at the ramp at 2 Mile Bay where sediment that accumulates behind and on the ramp is removed from the ramp and taken out of the lake are contributing to the sediment deficit in down drift areas of Taupo Bay. This material should be replaced down drift of the ramp.

Other maintenance activities such as the removal of noxious plants from the shoreline of the lake also need to be reviewed taking into consideration their effect on erosion. When significant sections of vegetation are removed, sufficient stabilisation through replanting with suitable species should take place to mitigate any increase in erosion risk.

Current operation of boats on the lake doesn’t appear to be having a significant effect on erosion. However, the impact of boat wake on shoreline erosion should be considered if any significant changes to the type of boats or level of operation occur.

Appropriate guidelines should be set for these activities, and where necessary consents may need to be obtained to allow the work to proceed.

5.10 Key locations and summary of contributing factors

The contributing factors to erosion vary considerably from site to site. The geological resistance to erosion, sediment supply and wind generated waves dominate the natural influencing factors for lake processes, but in their own right don’t necessarily cause erosion. Erosion is most evident during periods of high wind, coincident with high lake levels. In our opinion, providing quantified contributions for the various human factors is not practicable given the current information, the complexity of the shoreline processes, and variability for each specific location. The qualitative effects of some of the contributing factors are summarised in Table 5.7. A brief discussion of some of the key locations is set out below. This is followed by Table 5.8 that sets out some of the main factors influencing erosion at some key locations. The level to which they are influencing erosion is indicative only and requires further long term data and site specific investigation for verification.

Table 5.7 – Potential human effects of factors influencing erosion

Factor	Influence*	Comment
Development	Negative	When within shoreline fluctuation zone
Sediment Reduction – Dams etc	Negative	Confined to sediment compartment
Land use	Positive	Changes increasing sediment loads – pasture etc
	Negative	Changes decreasing sediment loads – minor - river fencing
Structures	Negative	Generally localised – small negative
	Negative	Taupo Bay – widespread, interrelated with development
Water Level	Negative	When held at higher levels more of the time
	Positive	Reduced maximum levels

*negative indicates a contributing factor to erosion

The following areas have experienced erosion cycles in recent years and therefore are briefly highlighted further here. There are other areas which may also be experiencing erosion but are not discussed further here. For example at the Southern end of the lake there is significant variation in the shoreline around Turangi and the Tongariro Delta. Various lengths of this area undergo significant erosion and accretion cycles, largely influenced by the significant amount of sediment coming from the Tongariro Delta. Caution should therefore be taken in all areas where the underlying geology makes the shoreline susceptible to erosion.

5.10.1 Taupo Bay

The Tapuaeharuru Bay shoreline extending from Wharewaka Point to the Waikato river forms a sub-compartment of the wider Eastern Shore compartment identified by NIWA[1]. The Eastern Shore compartment extends South to Bulli Point and also at the Waikato River to the North. Historically two of the main sediment sources into the wider compartment have been the Hinemaiaia River and the White Cliffs. In recent times the inputs have been reduced due to the dams on the Hinemaiaia, and revegetation of the White Cliffs[1]. Refer to Figure 5.6.

Sediments from these sources and other smaller streams work their way northwards along Five Mile Bay, where along the northern end there has been historical accretion. Some sediment is lost out of the system as it is driven offshore at Wharewaka Point, the remainder feeds into Four Mile Bay. A number of other smaller streams also add sediment to the system, the largest being the Waipahihi[1]. The available sediment within the compartment is sparse and moves northwards along a series of small sub-compartments that are interrupted by multiple groins, both man made and natural. Ultimately sediment is lost down the Waikato River, where it is pulled in by the current.

Some of the key issues and observations regarding Tapuaeharuru Bay include:

- Erosion in multiple places was evident during July 1998 high lake level episode.
- The shoreline is generally formed from geology with low resistance to erosion.
- Historically there has been significant modification to much of the shoreline, including alteration of the shape, installation of shore parallel and perpendicular erosion structure. Many of these structures do not meet good practice for shoreline structures and therefore are in some cases causing erosion downdrift or at either end.
- There has been significant development within what is likely to be a natural fluctuation zone for the shoreline.
- The approach to managing the shoreline of Tapuaeharuru Bay will require special attention. The development of a consistent approach to any hard protection where it is necessary is recommended.
- As part of a long term strategy, including some masterplanning, the redevelopment of beaches in key areas should be considered. The development of equilibrium pocket beaches may require further structures to contain the beach.
- Other factors such as sediment removal, vegetation removal, and increased high lake level/wind events are also contributing to erosion in some areas.

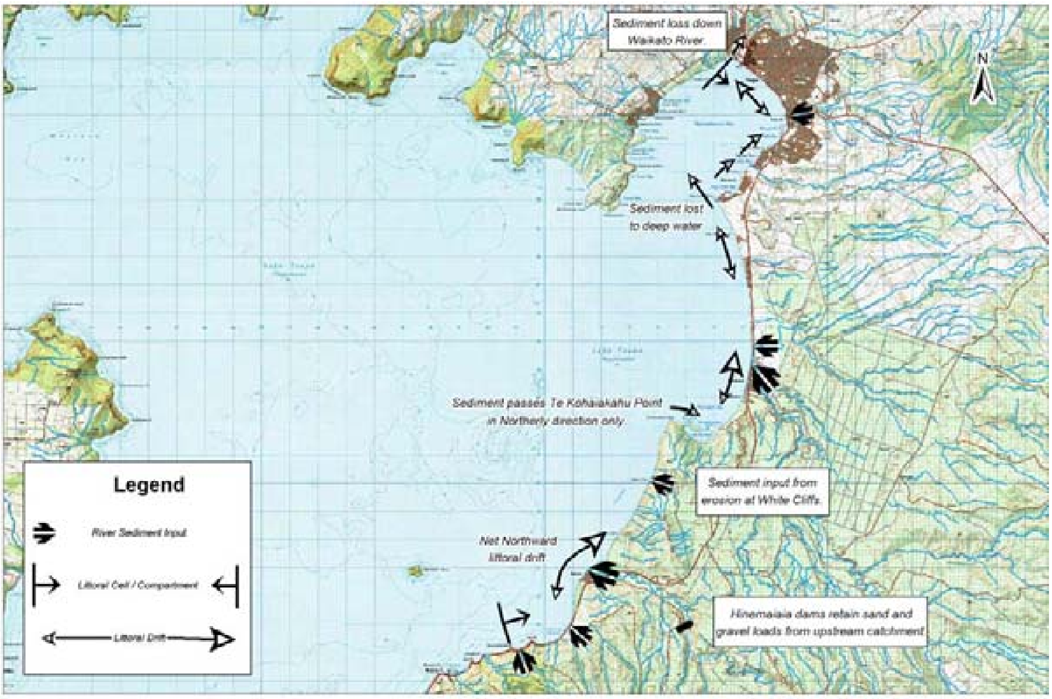


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Fig. 5.6 - Eastern Shore Sediment Compartment

5.10.2 Waitahanui

The development areas around Waitahanui are at the Southern end of the Five Mile Bay sub-compartment[1], and therefore are also within the Eastern Shore compartment. The main sediment sources are therefore the Hinemaiaia, White Cliffs and the Waitahanui Stream. Sediment is capable of being transported both North and South, however there is a net northward drift, as is evidenced by the bar at the Waitahanui Stream mouth. Refer to Figure 5.6.

Some of the key issues and observations regarding Waitahanui include:

- Erosion in this area has largely been attributed to a lack of sediment from up drift areas,[5] as well as possible rectification from a historical bulge formed by a large influx from the Waitahanui Stream for land development in the area.
- Causes of reduced sediment supply include; reduced supplies due to the dams on the Hinemaiaia, re-vegetation of the White Cliffs[1], and natural fluctuations in sediment cycles[5].
- Comparison of historical survey plans of the lake edge and the recent Cheal beach profile survey show erosion of up to 0.41m/yr adjacent to the river mouth, the rate lessening as you head south away from the river.
- The mouth of the Waitahanui, like most streams or rivers is a dynamic area, this can be seen by the cycles that the river mouth and spit go through where the discharge location can move up to several hundred metres north of the location where it breaks into the river. Areas in the immediate proximity to the river mouth could therefore expect cyclical periods of erosion and accretion as the river and lake processes work in their own cycles.
- Development within or close to the likely fluctuation zone has also meant there has been the construction of hard, shore parallel erosion protection measures of various forms along this stretch of shoreline. Some of these structures are causing erosion problems at either end, adding secondary erosion issues.
- Analysis of the highest wind events over the period of record showed an increased occurrence of high wind events during periods when the lake level was higher than it would have been naturally. However, reduced maximum water levels under the actual lake level regime may be considered to reduce erosion risk.

5.10.3 Kinloch

Kinloch is situated in the Whangamata Bay, which forms a pocket bay compartment that acts independently of adjacent bays. The main sediment inputs into the bay are from the Otaketake and Whangamata Streams. Large influxes of material are reported[1] to have been in flushed into the bay during development in the 60's and 70's. Much of this material appears to have been trapped behind the groin at the marina entrance, where the land has accreted almost 40m. [7] The net littoral drift is towards the East as evidenced by the build of this sediment.

Some of the key issues and observations regarding Kinloch include:

- Recent erosion episodes immediately to the east of the marina entrance during high lake levels have been attributed to sediment bypassing this length of the shoreline. This is due to the presence of the groynes at the marina entrance[6] as well as a reduction in the sediment entering the system.
- The Kinloch area has had a shorter-term trend of tectonic subsidence, and since 1979 has been dropping approximately 7mm on average compared to Acacia Bay. Although this doesn't appear to be causing major issues at present, if this trend continues it may cause problems in the long term.

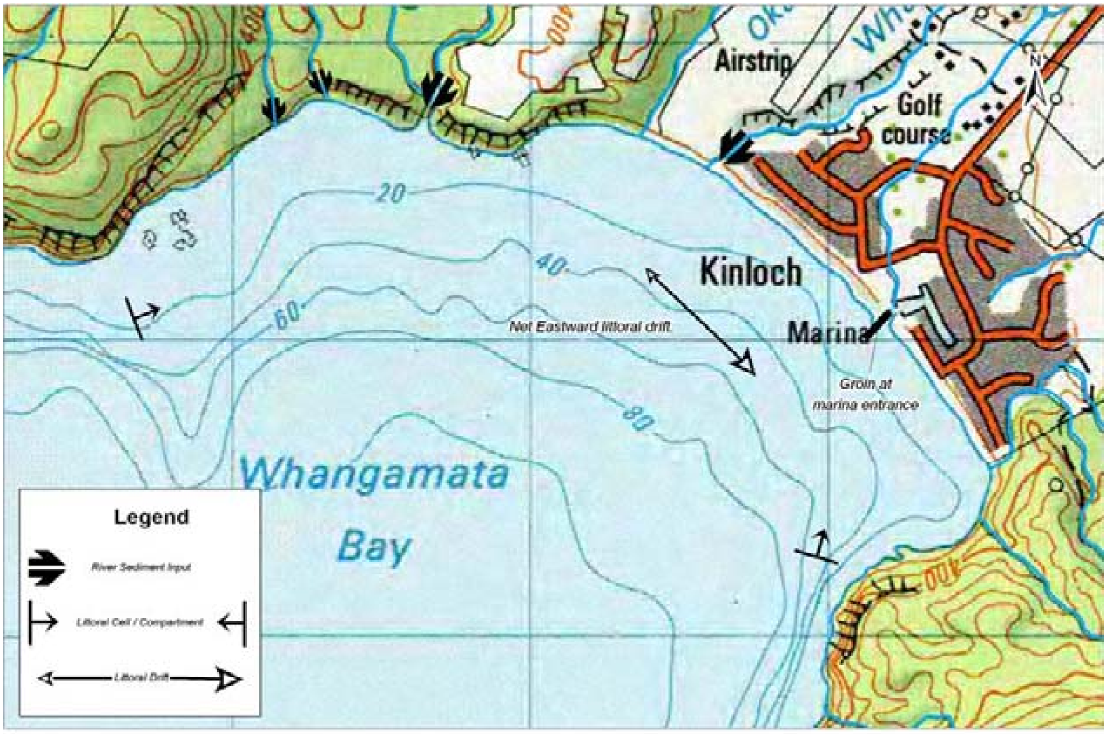

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Fig. 5.7 - Whangamata Bay Compartment (Kinloch)

5.10.4 Kuratau

The Kuratau compartment spans from Pukawa in the South to Werowanga Point in the North, where there is deeper water at either end of a narrow shelf[1]. The main sediment source into the compartment is the Kuratau River, although this has been significantly reduced since the construction of the Kuratau dam in the early 1960's. The Kuratau foreland was formed by these sediment inputs. The net longshore sediment transport is South, however movement of sediment is capable in both directions. Refer to Figure 5.8.

Some of the key issues and observations regarding Kuratau include:

- Historical aerial photographs indicate accretion of the Kuratau foreland as you move away from the river mouth.

- Comparison of historical survey plans to the Cheal beach profile survey showed erosion of up to 20m since 1963.
- Recently over the past years evidence of a retreating shoreline has been identified, particularly nearer to the river mouth. The nature of the shoreline makes it susceptible to erosion at higher lake levels.
- Kuratau has the benefit of a buffer zone that has ensured that the development of houses has been set back from the shoreline. This buffer zone allows time to monitor longer term trends and develop a considered response to erosion. However, this buffer area is now reduced significantly towards the river mouth and in some areas quite low-lying and therefore is prone to flooding.
- The construction of the Kuratau dam has decreased the sand and gravel loads to the lake by an estimated 69%[1]. A reduction of this amount is likely to have an effect on the equilibrium of the system and the sediment budget.
- Better understanding of the sediment budget and available material will assist in determining the significance of the reduction in sediment supply.
- Longer term (34 years) analysis of the 10 highest wind events showed a decrease in the likelihood of the highest wind events corresponding with high lake levels. Short term analysis (last 5 years) showed an increased occurrence of the highest wind speeds and higher than natural lake levels. This may not, however, be reflective of longer term trends.

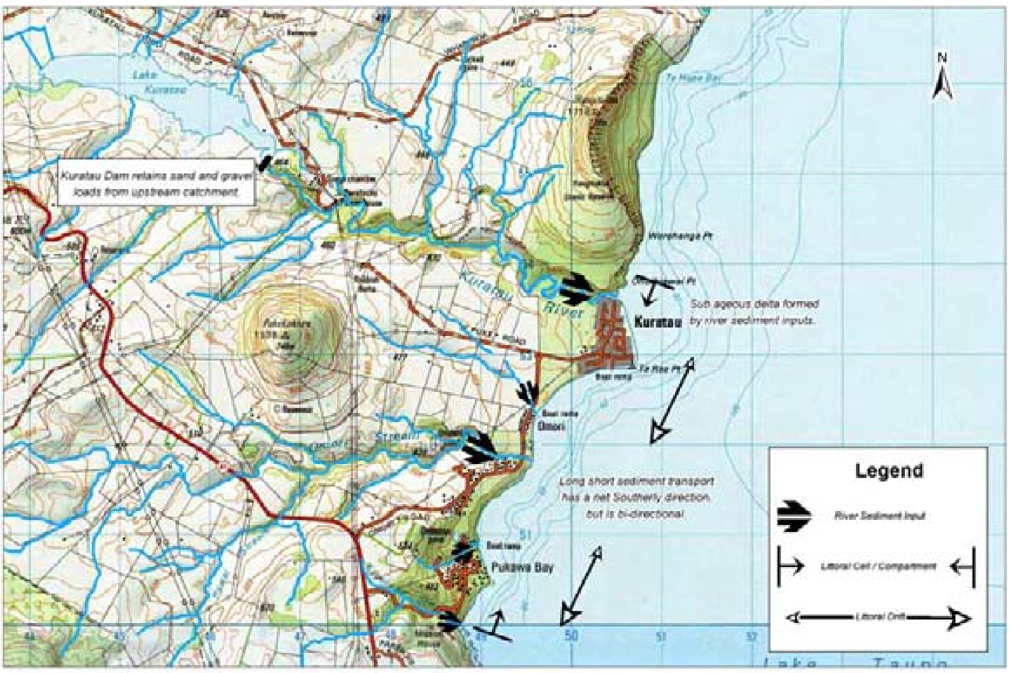

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Fig. 5.8 - Kuratau Compartment

Table 5.8 - Summary of identified contributing factors at some key locations

	Identified Main Factors Contributing to Erosion				
Location	**Natural Processes(a)**	**Catchment mgmt (b)**	**Structures / Development (c)**	**Lake level regime (d)**	**Comments**
Taupo Township to Wharewaka Pt					(a) Natural weathering of cliffs, natural shoreline fluctuations (c) Development in fluctuation zone. Structures trapping sediment including groins and natural features/secondary erosion effects/ (c) less sediment arriving from Hinemaiaia, White Cliffs.
Waitahanui					(a) Natural shoreline fluctuations. (c)Reduced sediment supplies due to the Hinemaiaia Dam and White Cliffs. Development in fluctuation zone.
Kuratau Foreland					(a) Natural shoreline fluctuations. (c) Reduction in sediment due to Kuratau dam.
Kinloch					(a) Natural subsidence (c) Groin at marina mouth.

Minor Factor — Significant Factor

Natural Processes(a) – Includes natural fluctuations in shoreline profile, tectonic deformation, weather patterns and rainfall etc

Catchment Management(b) – Includes soil conservation works, river training, land use etc

Structures / Development (c) – Includes shore parallel and perpendicular structures, development within a fluctuation zone, Dams reducing sediment supplies.

Lake level regime (d) – Influence on erosion due to combination of lake level durations at certain levels with wind event causing wind waves.