LAKE EPPALOCK SHORELINE EROSION

J. A. Davis

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COOPERATIVE RESEARCH CENTRE FOR
CATCHMENT HYDROLOGY

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PREFACE

The Waterway Management Program, within the Cooperative Research Centre for Catchment Hydrology comprises six projects in total, three first round projects (B1, B2, B4) and three projects initiated in 1997 (W1, W2, W3). Project B1 considered sources and control of sediment yield from catchments and streams. The study reported here considers the supply of sediment from erosion of shorelines in reservoirs, with particular attention paid to the Eppalock water supply reservoir in northern Victoria. This report was prepared by Jennifer Davis as a component of her postgraduate research. Her thesis research has focussed on the control of sediment delivery in water supply catchments. Both the results of the study, and the methods used will have more general application for other reservoirs.

Russell Mein
Director, Cooperative Research Centre for Catchment Hydrology

EXECUTIVE SUMMARY

Concerns were first raised about the contribution of lake shore erosion to the sedimentation of Lake Eppalock, in 1976 (Murley 1981) and although the lake is not in danger of losing a significant proportion of its capacity to sedimentation (Murley 1981), the impact of lake shore erosion warranted investigation. Such an investigation was carried out at Lake Eppalock in February 1996 as a part of a larger project designed to estimate a sediment budget for the entire Lake Eppalock catchment.

The analysis of the location and extent of lake shore erosion produced a number of conclusions.

1. Approximately 140,000 m^3 of material have been eroded from the shoreline at Lake Eppalock since the lake first filled, and assuming that this volume increased by 40 % once deposited, it is estimated that up to 196,000 m^3 of reservoir capacity is now occupied by this material. This is equivalent to a loss of only 0.06 % of reservoir capacity.
2. Heavily utilised boating areas on Lake Eppalock do not coincide with areas in which lake shore erosion is most severe, suggesting that whilst waves generated by speed boats are capable of initiating erosion, wind generated waves are the dominant causative agent.
3. Wind generated waves have been responsible for erosion on many of the steep, southern and western facing shorelines, where there is a long fetch.
4. It is currently not possible to identify whether or not lake shore erosion is an important source of sediment for turbidity in Lake Eppalock.
5. Shoreline erosion rates are probably in decline and pose no threat to reservoir capacity in the future.

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Trevor Cassidy (Goulburn-Murray Water-Lake Eppalock) for driving the survey boat;

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I would also like to thank the following organisations for their contribution to this study:

Coliban Water Laboratory for providing information about the domestic water supply system for Bendigo and Heathcote, as well as supplying turbidity data for Lake Eppalock and other Bendigo water supply storages.

The CRC for Catchment Hydrology for providing financial support;

Goulburn-Murray Water for providing the survey boat and lake level data;

The National Climate Centre for providing wind data from the Bendigo Prison climate station.

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1. INTRODUCTION

Following a survey of the silt lines in Lake Eppalock in 1976 concerns were raised regarding the contribution of lake shore erosion to sediment deposition within the lake (Murley 1981); a concern that is supported to some extent by the obvious erosion that can be observed along some sections of the shoreline. Shore erosion is an important component of the total sediment budget for Lake Eppalock and this investigation forms a small part of a larger project, assessing a sediment budget for the entire Lake Eppalock catchment. The assessment of this sediment budget is a component of the author's PhD project.

A survey of shoreline erosion was carried out at Lake Eppalock in February 1996 so as to quantify the contribution of lake shore erosion to the loss of reservoir capacity, and to investigate the spatial distribution of shoreline erosion. The survey methodology and results are described in this report and an estimate is made of the sediment contribution made by shoreline erosion. The factors that influence the location and severity of erosion at Lake Eppalock are investigated to help identify the best means of managing shoreline erosion at the lake. The issue of turbidity is also of paramount importance for the management of a water supply reservoir such as Lake Eppalock, and hence an attempt is made to determine the relationship between shoreline erosion and turbidity.

2. STUDY METHODOLOGY

Erosion along the shores of Lake Eppalock has tended to produce a distinctive 'notch-like' form with an upright face (or raw face) and a horizontal base (see Fig. 4.1). The technique used to locate and estimate shoreline erosion at Lake Eppalock simply involved mapping observed erosion by classifying the magnitude (volume) of erosion into one of three categories: negligible erosion, moderate erosion and severe erosion. The magnitude of erosion was classified by considering the height of the raw face of the erosion 'notch'. For each section of shoreline the average height of the raw face was estimated to be in one of three height ranges: 0-0.2 m; 0.2-1.5 m; and > 1.5 m (see Table 2.1) by visual inspection (not direct measurement). The heights were not directly measured because the survey was conducted from a boat on the lake, and the identified erosion categories mapped directly onto a 1:25,000 scale map of the lake.

Some general observations were made regarding the particle size distribution of the material deposited on the base of the 'notch' on separate field trips.

Table 2.1. Erosion Classification.

Erosion Category	Raw Bank Height
Negligible	0-0.2 m
Moderate	0.2-1.5 m
Severe	1.5 m and above

This method assumes that all of the shoreline erosion was above the water level on the day of the survey, which seems reasonable given that: i) the distinctive "notch" created by shoreline erosion was visible above the water level at all times; ii) substantial erosion below the notch was not observed by this author or the staff of Goulburn-Murray Water at Lake Eppalock (Cassidy 1996 Pers. Comm.) during autumn of 1995 when the storage reached its lowest level ever. It is, however, worth noting that this erosion measurement technique will have missed any "first fill erosion" that may have occurred. Such erosion may have taken place as the lake was first filling, eroding material below 1995 level. The importance of this omission and the assumptions made regarding on-going erosion are discussed in Section 5.1.

The approximate nature of the survey is highlighted by the fact that the bank height estimates were made by an observer from a boat on the lake, and that the erosion mapping was carried out using a base map at a scale of 1:25,000. Whilst this procedure does not provide accurate estimates of the volume of sediment eroded from the shoreline of Lake Eppalock it does allow areas of severe erosion to be identified and enables an assessment of the order of magnitude of erosion. This methodology is thus thought to be sufficient for the purposes of (i) identifying the spatial distribution of shoreline erosion at Lake Eppalock; and (ii) determining the relative contribution made by lake shore erosion to lake sedimentation.

3. RESULTS

3.1 Observations of Erosion Distribution

1. Moderate-severe erosion tends to be found where there is a long fetch, the shoreline topography is steep (10-20°) and on southern and western facing shores (Fig. 3.1). Where any one of these characteristics was absent erosion was negligible. The only location (see location D, Fig. 3.1) where this rule seems to fail is "The Strait" between the Metcalfe Pool and Campaspe Reach.

2. Trees along the shoreline have two roles. They help to resist erosion by absorbing some of the wave energy and binding the soil together, but tree falls were also responsible for displacing soil and exposing erodible material to wind and wave action thus destabilising sections of shoreline.

3. The local geology also influences erosion severity and location. Large sections of the lake shore are lined by loose rock material which is a natural feature of the local geology. The material is not packed tightly along the shoreline but scattered over much of the slope, at a variable density. In the areas where this material is sufficiently dense, so as to form a solid barrier against wave action (eg. southern side of Ja Ja Wurong Passage (location A, Fig. 3.1), parts of the Coliban (location B, Fig. 3.1) and Campaspe Arms (location C, Fig. 3.1)), erosion appears to have been mitigated.

4. Quite often the base of the "erosion notch", left on the shoreline by bank collapse, is armoured by gravel evacuated by the bank collapse. This armour would probably offer some protection to the base of the notch from wave action, if it had not already reached bedrock.

5. The height of the notch is controlled by the depth of soil and weathering, ie. the notch height is limited by the depth to bedrock.

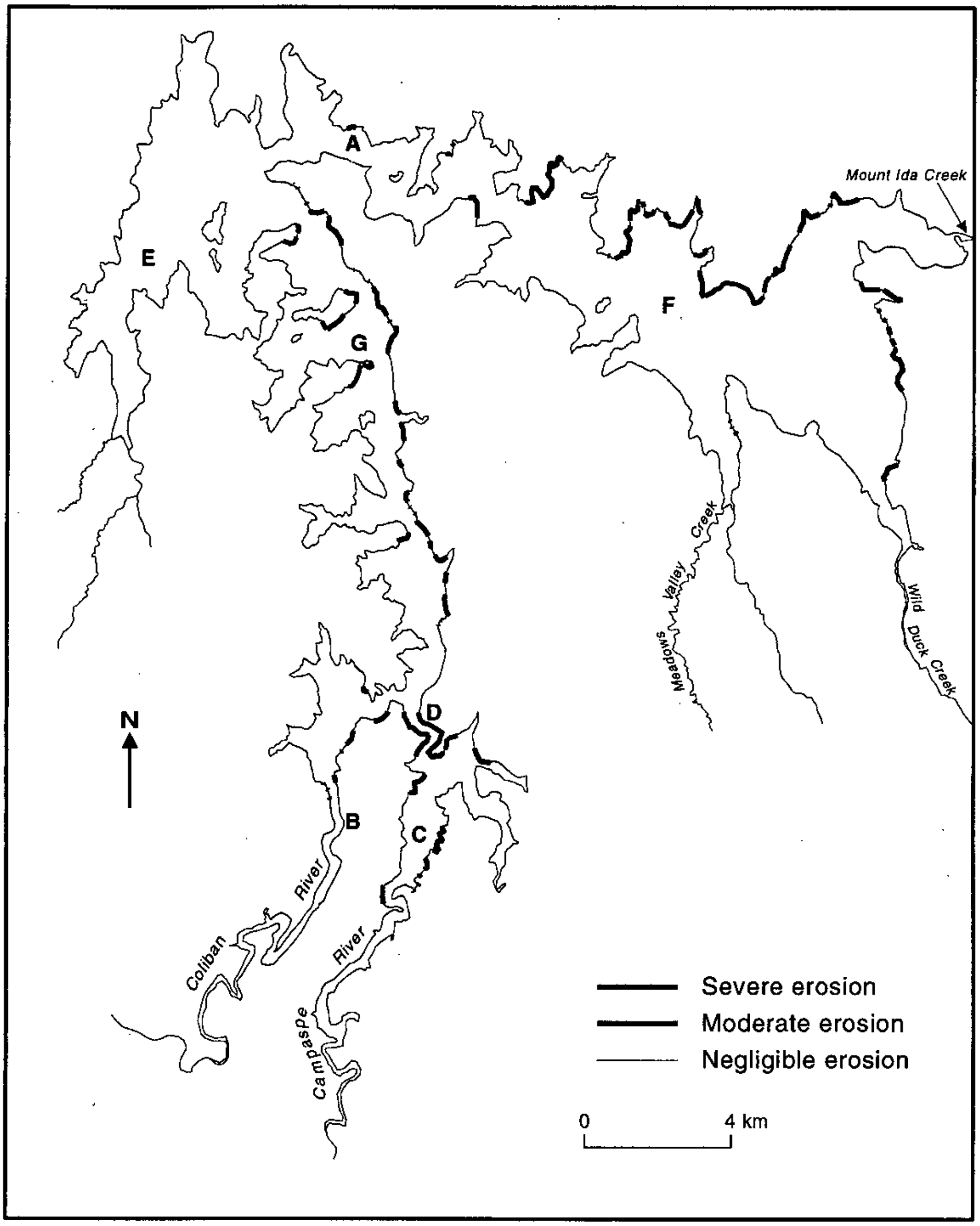

Fig. 3.1. Lake Eppalock Shoreline Erosion Map

4. ESTIMATION OF THE VOLUME OF SHORELINE EROSION

In order to simplify the calculation of the erosion estimate several assumptions have been made:

- a cross-section taken perpendicular to the shore, through the area where material has been eroded, is assumed to be triangular (see Fig. 4.1);

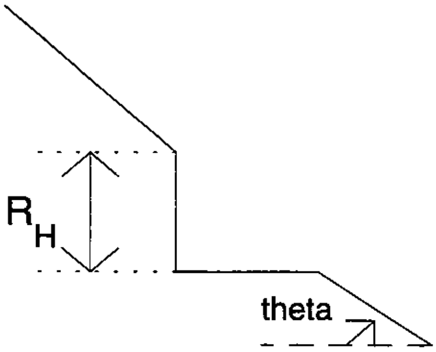

Fig. 4.1. A Simplified Cross-section of an Eroded Shoreline.

- R_H is equivalent to the raw height and θ equivalent to the slope angle;
- R_H is set for each erosion category (Table 4.1) and was estimated as the average raw height observed for each category;
- θ is set for each erosion category (Table 4.1) and was estimated as the average slope angle observed for each category.

Table 4.1. Estimated Erosion Variables.

Erosion Category	**R_H (m)**	**θ**
Negligible	0	-
Moderate	1	10^o
Severe	3	15^o

Based on the assumptions listed above the cross-sectional area was calculated for each class (Table 4.2). The length of shoreline pertaining to each class was then measured and the eroded volume estimated (Table 4.2).

Table 4.2. Estimated Erosion.

Erosion Category	**Cross-sectional Area (m^2)**	**Shoreline Length (km)**	**Eroded Volume (m^3)**
Negligible	-	130	0
Moderate	2.8	17	47,600
Severe	16.8	5.5	92,400
	Total	152.5	140,000

Therefore the estimated volume of material eroded from the lake shore is 140,000 m^3. Once the material is eroded and enters the reservoir it is "repacked" and thus can expand to be between 1.1 and 1.4 times its original volume (Sahu 1990). Consequently if we consider a worst case scenario in which the volume of material increases to 1.4 times its original volume, the volume of reservoir capacity that could have been lost is approximately 196,000 m^3. Hence the maximum percentage of reservoir capacity (312,000 Ml) lost to sedimentation derived from the shoreline is approximately 0.06%, indicating that the reservoir capacity lost to date due to shoreline erosion is almost negligible.

5. CAUSES, IMPLICATIONS AND THE FUTURE OF LAKE SHORE EROSION

5.1 Wave Generated Erosion

First Fill Erosion

First fill erosion was not measured for two reasons. The first being that it is extremely difficult to measure, being below the water level most of the time. The second reason it was not considered relates to the fact that information on this component of erosion was not deemed necessary given the aims of this report. This investigation was designed to determine what impact lake shore erosion has had on the lake, in relation to capacity loss, and the best strategy for managing this problem. Whilst the omission of first fill erosion from the calculation of capacity loss may result in the underestimation of capacity loss to shoreline erosion, these volumes are so small in comparison with the lake capacity (less than 1%) that such an omission has little bearing on the overall result, ie. lake shore erosion has not significantly impacted on the lake's capacity. With regard to recommending strategies for managing this capacity loss first fill erosion is irrelevant because it only occurs once. Thus from this perspective it is only on-going shoreline erosion that is of interest.

On-going Shoreline Erosion

On-going lake shore erosion occurs where wave action erodes the banks, undercutting the slope and causing bank failure. The waves initiating erosion may be generated by power boats or by wind.

Wave Generation by Power Boats

If waves generated by power boats were important in determining the location and severity of erosion at Lake Eppalock then one would expect there to be a strong correlation between heavily utilised boat areas and erosion. However the heavily utilised boating areas indicated on Fig. 3.1 by locations E, F and G, do not coincide with many of the areas with severe erosion. This observation however, does not mean that power boat generated waves are not capable of initiating shoreline erosion at Lake Eppalock, it is simply that other important factors influencing shoreline stability such as topography and vegetation, are overriding. There is in fact at least one example of powerboat generated wave erosion in Lake Eppalock at "The Strait" (location D, in Fig 3.1). This erosion can be attributed to power boats because the confined nature of "The Strait" would restrict the generation and entry of wind generated waves.

These observations suggest that wind generated waves cause much of the shoreline erosion at Lake Eppalock, and consequently the relationship between wind generated waves and shoreline erosion will now be investigated.

Wind Generated Waves

Sediment movement occurring along shorelines is driven primarily by wave action, and thus sediment movement is a function of the energy of waves arriving at the shoreline

(CERC 1984). Consequently an understanding of littoral processes requires knowledge of wave climate, i.e. the distribution of wave height, period and direction throughout the year (CERC 1984). Such wave characteristics are generally determined by local winds, as well as the 'recent history of winds in the more distant parts of the same waterbody' (CERC 1984, p. 4-29). In small waterbodies, such as Lake Eppalock, local winds are the main source of energy for waves and thus erosion processes. Local winds, therefore, are the primary wave generation mechanism at Lake Eppalock, and thus erosion resulting from waves on the shoreline of the lake, is a function of wind velocity, duration and fetch (CERC 1984).

The significance of wind generated waves for shoreline erosion at Lake Eppalock can, therefore, be investigated by using physical data to determine which parts of the lake would be subject to wave action with the most energy, most frequently. These localities can then be compared with the observed erosion sites. Such an analysis provides a means for determining the physical characteristics that have an overriding influence on shoreline erosion at Lake Eppalock.

In order to determine the areas of shoreline subject to significant wave action it is first necessary to identify the wind direction/s for which wind velocities and durations are greatest. By also checking the lake levels that correspond with these winds it will be possible to identify at what elevation/s erosion has been focussed. To carry out this analysis lake level data and raw wind data were obtained. Wind data were obtained from the Bendigo Prison climate station (1957-1991). Although the climate station is approximately 25 km north-west of Lake Eppalock the wind data are still considered to be representative of conditions at Lake Eppalock (Senior BOM Forecaster 1996 Pers. Comm).

The raw wind data consist of two daily readings (9 am and 3 pm) between 1957 and 1987, and seven daily readings (3 am, 6 am, 9 am, 12 pm, 3 pm, 6 pm, 9 pm) for 1987-1991; where each reading consists of a wind speed and direction. Thus it is not possible to determine wind duration. This analysis will therefore, only be able to identify the locations where wind generated waves are driven most frequently by high velocity winds, which limits the value of the analysis.

To standardise the raw wind data for the analysis the data file was edited so that only 9 am and 3 pm observations where included for the length of record used. The wind data file was then combined with the weekly lake level data to produce a single data file containing an estimate of the lake level (based on available weekly levels), and wind direction and speed at 9 am and 3 pm for each day between October 1963 and October 1991. The starting date coincides with the first time the lake filled to full supply level, whilst the finish date coincides with the final day wind observations were made at the Bendigo Prison site.

Initially all of the data were used to determine the most frequent wind direction and lake level. This exercise was then repeated for data corresponding to wind velocities of 20 km/h and over, and again for wind velocities of 40 km/h and over. This approach was taken because it was not possible to identify an appropriate threshold wind velocity, i.e. a critical wind velocity for generating waves capable of initiating erosion. Hence prevailing wind direction and lake levels were identified for a range of wind velocity groupings.

The results are presented below in tables 5.1 & 5.2.

Table 5.1. Wind Range and Direction Frequency Data. Totals in table are the sum of the total number of observations (9 am and 3 pm) corresponding to each category.

Wind Direction	**Wind Range**		
	> 0 km/h	**> 19.9 km/h**	**> 39.9 km/h**
N	1206	80	4
NE	2313	61	2
E	1713	60	6
SE	2360	293	32
S	2724	428	22
SW	2725	365	32
W	2644	480	61
NW	2580	334	45

Table 5.2. Wind Range and Lake Level Frequency Data. Totals in table are the sum of the total number of observations (9 am and 3 pm) corresponding to each category.

Lake Level AHD (m)	**Wind Range**		
	> 0 km/h	**> 19.9 km/h**	**> 39.9 km/h**
185-185.9	222	15	1
186-186.9	332	9	0
187-187.9	300	23	2
188-188.9	569	99	13
189-189.9	1812	240	16
190-190.9	2815	281	35
191-191.9	2707	262	18
192-192.9	2712	284	31
193-193.9	6078	795	80
> 193.9	718	93	8

These data are also presented graphically in figures 5.1 & 5.2.

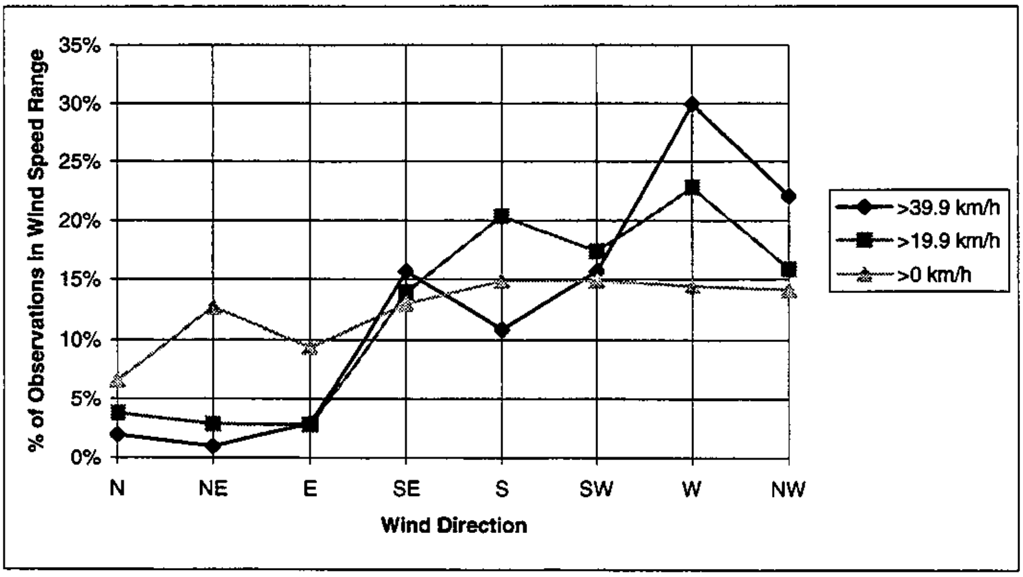

Figure 5.1. Wind Range and Direction Frequency Data.

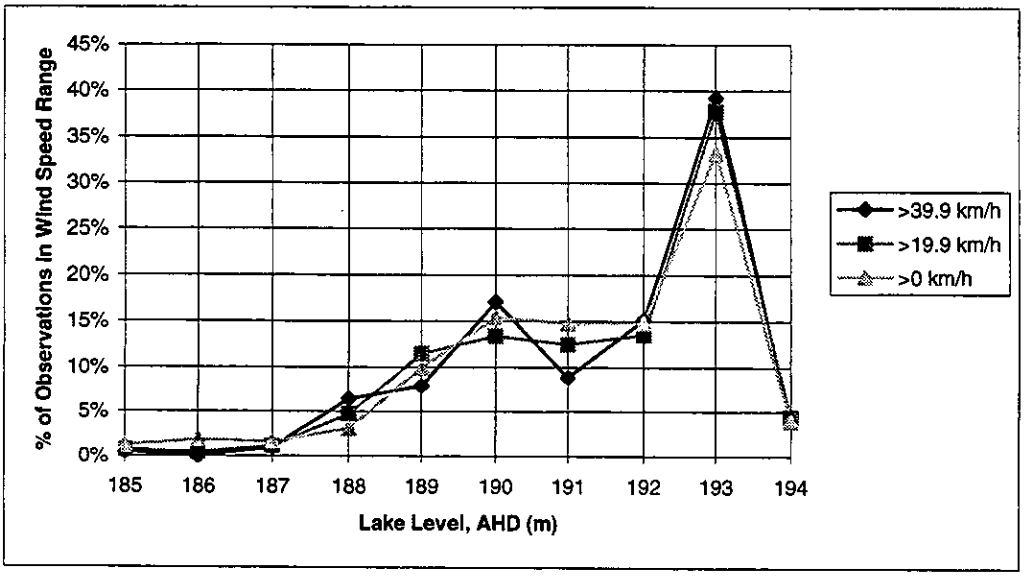

Figure 5.2. Wind Range and Lake Level Frequency Data.

The data in Table 5.1 (Fig. 5.1) indicate that the distributions of direction observations for the >19.9 km/h and >39.9 km/h wind range categories, were similar. These distributions suggest that winds with a velocity greater than or equal to 20 km/h and winds with a velocity greater than or equal to 40 km/h tend to originate from the south-east (135^{o}) through to north-west (315^{o}). Whereas the wind direction frequency histogram for all non-zero velocity wind observations suggests a more even distribution of wind directions. It is apparent from the data that winds are as likely to originate from any direction, except possibly the north (0^{o}). Overall these data indicate that winds may blow from almost any direction, however, higher velocity winds tend to originate from the south-east, south, south-west, west and north-west.

Wind-lake level frequency patterns were similar for all three wind speed categories (see Table 5.2 and Fig. 5.2). The data indicate that 30% to 40% of non-zero wind observations in all three wind range categories coincided with a lake level between 193 and 194 m AHD. This is more than double the number of observations made in the next most frequent lake level category. Thus the data clearly indicate that when winds are blowing at Lake Eppalock the lake level is most likely to be between 193 and 194 m AHD.

Whilst these results are limited by the fact that wind duration data are not available they would suggest that if wind generated waves were responsible for shoreline erosion at Lake Eppalock one would expect to find erosion predominantly on south and west facing shorelines, between 193 and 194 m AHD. These predicted erosion localities coincide with some of the observations made during this investigation. The data presented in Fig. 3.1 show that severe erosion is found on the southern and western facing shorelines. Observations discussed in Section 2, indicate that an erosion notch was observed at approximately 193-4 m AHD, and major erosion has not been observed at lower levels. Thus the distribution of shoreline erosion observed at Lake Eppalock, both in the horizontal and vertical planes, can generally be explained by lake levels and the local wind climate.

Exceptions to these general spatial patterns of erosion are, however, evident and can be explained by the influence of other factors. For example it is evident in Fig. 3.1 that severe erosion also coincides with areas with a large fetch, ie. of at least 500 m, and up to 1500 m in some cases. Where the fetch is much less than this severe erosion is not found, regardless of the direction the shoreline is facing. The influence of fetch was predicted in the discussion preceeding the analysis.

The areas affected by severe erosion are also locally, quite steep, which can impact on erosion in three ways: i) it means that immediately adjacent to the shore the lake will be relatively deeper, and hence wind generated waves will have higher energy; ii) in the event that the slope is undercut by erosion it will be less stable and more likely to collapse, evacuating a large amount of material; and iii) evacuated material is more likely to be transported down into the lake and not sit at the shoreline and protect the bank by dissipating wave energy.

From this brief analysis it is possible to conclude that much of the more severe erosion at Lake Eppalock can be attributed to wind generated waves initiating bank collapse on steep, southern and western facing shores in areas in which the fetch is large.

5.2 Important Environmental Factors for Lake Shore Erosion

Whilst the main factors controlling lake shore erosion at Lake Eppalock have been identified in the previous section, this section summarises the influence of all environmental factors on shoreline erosion at Lake Eppalock. Intuitively the environmental factors controlling shoreline erosion can be identified as: climate, topography, vegetation, geology and human impacts. These factors are also interrelated.

Climate: Climate plays a role in determining the location and extent of erosion at Lake Eppalock, with regard to prevailing wind direction, speed and duration. As discussed in Section 5.1, wind speed and duration influence wave energy and hence erosive energy, whilst wind direction influences the location of erosion. Thus lake shore erosion at Lake Eppalock tends to be most severe along south and west facing shorelines, ie. those shorelines facing the prevailing wind direction (see Fig. 3.1).

Topography: Topography determines the fetch and the off-shore depth which influence wave energy and hence the erosive energy available. However, topography also influences erosion resistance by playing a part in determining slope stability, ie. where the slope is steep it is more vulnerable to collapse once undercut by wave action. The influence of topography at Lake Eppalock is clearly evident with severe erosion coinciding with areas of shoreline with relatively steep slopes (as observed in Section 3.1) and substantial NE-SW and N-S fetch (see Fig. 3.1).

Vegetation: Vegetation, in the form of trees appears to have both a stabilising and destabilising influence on shoreline erosion. In a number of areas trees appeared to increase the resistance of the shoreline to erosion, binding together soil and absorbing some of the wave energy. However in some places tree-falls have destabilised sections of the shore. Nevertheless, overall, vegetation appears to play an important role in stabilising the shoreline.

Geology: Geology impacts on shoreline erosion by influencing the resistance of the shoreline to erosion and the depth of weathering. At Lake Eppalock there is a lot of loose rock evident on the ground surface, which can not only absorb some of the wave energy, but also protect the soil from wave action. Consequently where this material is sufficiently dense, so as to form a solid barrier against wave action, eg. the southern side of Ja Ja Wurong Passage (location A, Fig. 3.1), parts of the Coliban (location B) and Campaspe Arms (location C), erosion is mitigated.

The depth of weathering effectively determines the maximum height of the notch and so influences the severity of erosion, however the influence of this characteristic at Lake Eppalock was not investigated in detail.

Human Impacts: At Lake Eppalock there are two main ways in which humans impact on lake shore erosion. The first is related to changes in vegetation resulting from human occupation and, as was discussed above, vegetation does play an important role in stabilising the shoreline. Whilst the relationship between human induced vegetation change and shoreline erosion at Lake Eppalock was not clearly evident, it seems probable that changes in shoreline vegetation caused by human occupation have the potential to modify the impact of shoreline erosion.

The second way in which humans impact on shoreline erosion at Lake Eppalock is through the use of power boats on the lake. It is unlikely that power boat generated waves have played a significant role in determining the location and extent of shoreline erosion at Lake Eppalock, as discussed previously, however there is at least one site where erosion may be attributed to this source alone.

5.3 Shoreline Erosion and Lake Turbidity

Also associated with erosion is turbidity and thus the issue of water quality; hence erosion in a water supply reservoir such as Lake Eppalock can have multiple impacts. Although this study did not seek to directly address the issue of turbidity in Lake Eppalock as it is related to lake shore erosion, this issue is sufficiently important to warrant brief examination.

The data presented in this report relate specifically to the volume of material contributed by shoreline erosion to lake sedimentation and it was assumed in the calculations that all the material eroded from the shoreline has been deposited on the lake bed. However some percentage of sediment transported into the lake will remain in suspension in the lake water resulting in a certain level of turbidity. Thus in terms of effective lake management it is important to determine whether or not lake shore erosion is an important source of material for lake turbidity.

This issue may be addressed by considering Welsh and Stewart's (1991) work on turbidity in Lake Eppalock. From a detailed analysis of weekly rainfall, inflow and turbidity data for the period 1983-1988, Welsh and Stewart (1991) concluded that turbidity in the lake can be directly related to material released from the shoreline during rainfall events, as well as inflow from the Coliban River. Although these conclusions were drawn from an extensive analysis the results still need to be viewed cautiously because as a simple comparison of more recent data from Coliban Water reveals, lake turbidity levels are a function of not only recent inflows, but also past inflows. The graph (Fig. 5.3) indicates that mean annual turbidity in the weir pool is a function of the total rainfall for the previous year and is apparently not related to total rainfall in other years, including the current year. This may be indicating that the lake has a residence time of about 1 year, which agrees with a mean residence time of 1.5 years, calculated by dividing reservoir capacity by average annual inflow.

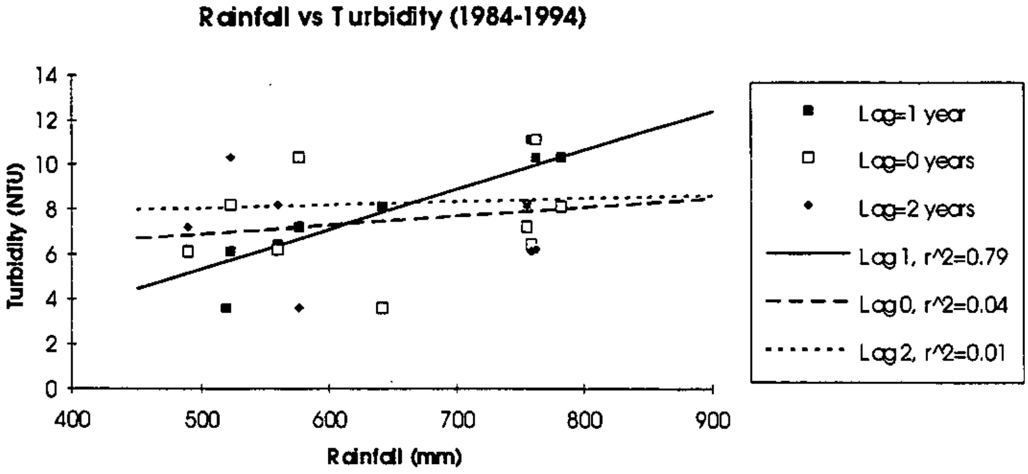

Fig. 5.3. Mean Annual Lake Turbidity vs Annual Rainfall (Heathcote).

In their work, Welsh and Stewart assume that correlations between rainfall and turbidity are representative of shoreline input, which can be justified by the fact that they found no lag (at a weekly time step) between the rainfall event and the turbidity response. However this assumption limits shoreline source areas to those areas in the vicinity of the dam wall because material released from areas distant from the dam wall must be subject to travel times similar to those calculated for the tributary inflows, eg. Coliban River: 1-3 weeks (Welsh and Stewart 1991).

The purported influence of the Coliban River on lake turbidity levels should also be viewed cautiously because although one study in 1980 (based on one measurement for low, medium and high flow) found the Coliban River to have the highest suspended solids concentration and load (Interdepartmental Committee on Lake Eppalock 1981), another has noted the influence of Wild Duck Creek (Drew 1983).

Another piece of evidence which argues against Welsh and Stewart's conclusion that lake shore erosion is an important source of material for turbidity in the lake, is that lake shore erosion has contributed less than 5% of the sediment deposited in the lake (Davis 1996).

This discussion clearly illustrates the complex nature of the relationship between sediment sources and lake turbidity. No dominant source of lake turbidity can be clearly identified, and thus it is not possible to determine the impact of lake shore erosion on turbidity in Lake Eppalock.

5.4 Predicting the Future of Shoreline Erosion

Like many forms of erosion lake shore erosion can be most severe following a major disturbance, eg. such as a change in base level (filling of a reservoir). Following such disturbances the system tries to find a new equilibrium position (Graf 1977) and over time, as the system approaches equilibrium, erosion rates tend to slow (Bull 1975). Hence, given that Lake Eppalock first filled over thirty years ago one would expect that rates of lake shore erosion would probably now be in decline. Evidence of this can be found at the lake where many of the "erosion notches" are now protected from wave action to some extent. The bases are armoured or have reached bedrock thus wave energy is dissipated, and the raw erosion faces have moved back from the lake edge, away from the wash zone and hence they are now less likely to be under cut.

Over time, as material accumulates at the base of the erosion face the gradient of the raw slope may decline and it may be stabilised by vegetation. Consequently the shoreline erosion rates measured at Lake Eppalock over its first thirty years are probably a maximum and erosion rates in the future will be lower than these. Given the fact that the lake has lost only a minor percentage of its capacity due to shoreline erosion (approximately 0.06%) in its first thirty years, and assuming that erosion rates will decrease in the future it is apparent that lake shore erosion does not pose a threat, by itself, to the capacity of the reservoir.

In terms of treating lake shore erosion to address the issues of capacity loss and erosion there are two options:

1. Do nothing, because as was described above the lake shore is probably beginning to stabilise and so the worst of the erosion has probably finished;
2. Rock beaching appears to be the most effective means of protecting a raw bank. Such action may be warranted where, for example, undercutting is threatening a road.

Shoreline erosion can also pose a threat to water quality by increasing turbidity. Lake Eppalock not only supplies water for irrigation, but also provides water for domestic use (Dept Water Resources 1989), and thus a deterioration in water quality in the future could necessitate the construction of a water treatment plant (Coliban Water 1996 Pers. Comm.). It is, however, not clear as to what the main source of turbidity is for Lake Eppalock, ie. the lake shore or the catchment via the tributaries. If turbidity levels in Lake Eppalock in the future do become of concern to management it may be necessary to initiate an investigation to determine the main source of the material responsible for the high turbidity levels, to allow appropriate management actions to be implemented.

6. CONCLUSIONS

Investigation of the volume and location of lake shore erosion at Lake Eppalock resulted a number of conclusions.

1. Approximately 140,000 m^3 of material has been eroded from the shores of Lake Eppalock since the reservoir first filled, and assuming that this material could expand to 1.4 times the original volume once deposited in the lake, it is possible that up to 196,000 m^3 (0.06 %) of reservoir capacity could have been lost due to the deposition of this material in the lake.
2. Heavily utilised boating areas on Lake Eppalock do not coincide with areas in which lake shore erosion is most severe, suggesting that whilst waves generated by speed boats are capable of initiating erosion, wind generated waves are the dominant causative agent.
3. Wind generated waves have been responsible for erosion on many of the steep, southern and western facing shorelines, where there is a long fetch.
4. It is currently not possible to identify whether or not lake shore erosion is an important source of sediment for turbidity in Lake Eppalock.
5. Shoreline erosion rates are probably in decline and pose no threat to reservoir capacity in the future.

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