Impacts of Recreational Boating on River Bank Stability: A Literature Review

Linda Huzzey and Darren Baldwin

The Murray-Darling Freshwater Research Centre
P.O. Box 991,
Wodonga, VIC 3698

An MDFRC Consultancy Report for
Murray Catchment Management Authority
315 Victoria Street,
Deniliquin, NSW 2710

May 2007

The Murray-Darling Freshwater Research Centre

Impacts of Recreational Boating on River Bank Stability. A Literature Review

Linda M. Huzzey and Darren S. Baldwin

May 2007

A report prepared for Murray Catchment Management Authority.

For further information contact:

Dr Darren Baldwin
Murray-Darling Freshwater Research Centre
PO Box 991, Wodonga, VIC, 3689
Ph (02) 60582300

E-mail: darren.baldwin@csiro.au

Cover Photograph: Murray River at Howlong, April 2007. Photo by Linda Huzzey

This report may be cited as:
Huzzey, L.M. and D.S. Baldwin (2007) Impacts of Recreational Boating on River Bank Stability. A Literature Review. Report for the Murray Catchment Management Authority. Murray-Darling Freshwater Research Centre, Wodonga, Victoria.

Table of Contents

EXECUTIVE SUMMARY

Recreational boat wakes have clearly been implicated in bank erosion in a wide variety of river types and sizes, both in Australia and internationally. Detailed studies of the rates of bank erosion and boat activity in river systems as different as the Gordon River (Tasmania), the Mississsippi River (USA), the Waikato River (NZ) and the Kenai River (USA) have all shown measurable impacts of recreational boats on the river bank stability. However even these studies have not always established the exact quantitative relationship between boat speeds, intensity or frequency of boat use, types of boats and the observable bank erosion. Studies have been conducted to develop predictive formulas for the size of wakes generated by a given boat size or speed; however these are not easily applicable in settings where there may be multiple boats operating at different speeds. Despite these limitations, in many places management responses have ensued and policies have been implemented, or are proposed, to limit boat speeds and otherwise minimize the impact of boat wakes.

On the Murray River there have been few studies examining the role of boat wakes but all studies to date suggest that other processes, specifically the seasonal cycle in flow rates in this highly regulated river, may in fact be equally or more significant than recreational boat use.

1. INTRODUCTION

Rivers are constantly dynamic and bank erosion is a natural part of the river system. Sediments are re-distributed along and across the channel by the currents and eddies, sometimes aided by wind waves. In meandering rivers, such as the Murray River below Lake Hume, channel positions change laterally by eroding on the outside of bends and depositing sediment in bars or ridges on the inside of bends. The vulnerability of streams to these natural changes depends on factors such as the particle size, stratification and cohesiveness of the bank materials, height and slope of the banks, type and density of the riparian vegetation, stream gradient, river stage and discharge, groundwater discharge, and wind waves. In many areas the inevitability of channel movements has been acknowledged and river managers are adopting the idea of allowing rivers to migrate freely within a defined corridor, an “erodible corridor”, rather than use traditional bank stabilization techniques (Piégay et al. 2005).

In addition to natural processes, human use of the riverine and riparian environment can cause bank erosion. Removal of riparian vegetation, dredging, de-snagging and modifications of the flow regime can all affect the bank stability (Abernathy and Rutherfurd 1999, Brooks 1999, Steiger et al. 2005). As noted in an earlier review of the overall impacts of recreational boating on water quality in lakes and reservoirs (Mosisch, Arthington 1998) the wake (or wash) from recreational power boating may also cause bank erosion. This assumption is implicit in many management guidelines and public information materials, e.g. Minnesota Department of Natural Resources (1993), Tasmanian Department of Primary Industries (2005). However, it has also been shown that recreational boating can make a significant contribution to regional economies. For example Boyle et al (1997) estimated that the direct annual expenditure on boating activities in Maine’s Great Ponds was about $US 640 million. Therefore, there is a clear tension between the potential damage to river channels through boating induced erosion and the economic and social benefits that can arise by allowing recreational boating.

This review describes studies which have attempted to clarify the exact connection between boat wakes and bank erosion. Many of the studies are essentially qualitative and observational, looking at the correlations between boat use and bank conditions at a given location. There are relatively few studies that have clearly linked boat wakes and bank erosion in a quantitative manner. In some studies turbidity has been used as an indicator of sediment transport, and thus bank erosion. This report will first discuss observational studies of boating activity and bank erosion at locations within Australia and internationally, with an emphasis on studies published in the last 20 years. It will then examine studies on the Murray River in particular, followed by an assessment of studies of boat wave dynamics which have been conducted to develop predictive formulas for boat wakes. It will then discuss how the role of boats on bank erosion is being incorporated into management and public use guidelines both within Australia and internationally and whether or not this is justified given our current knowledge. Finally it will outline a proposed methodology for examining the impact of recreational boating on river bank stability on the Murray River below Lake Mulwala.

2. PREVIOUS REVIEW ARTICLES

There have been very few review articles summarizing the role of boats on bank erosion in rivers. Mosisch and Arthington (1998) broadly examined the physical, chemical and biological impacts of recreational boating on rivers, lakes and reservoirs. With respect to wave action they discussed a number of earlier studies that had reported damage to the banks due to boat waves and wash. Many of those studies primarily looked at the effect of boat-generated waves on submerged aquatic vegetation and plants growing on the bank. Mosich and Arthington also included some of the early results of the studies on the Gordon River, Tasmania, and the study by Garrad and Hey (1987)[1]. They cited several investigations of power-boat induced erosion on Australian rivers by government agencies that found water skiing boats caused relatively small amounts of erosion when compared to other erosional processes (Hodges 1991, Victorian Dept. of Conservation and Environment 1991).

[1] See section 3 of this report for a more detailed discussion of these studies.

These studies did however acknowledge when power boats are turning or starting up they will make larger waves than when operating at high speeds (planing). The UK Centre for Economic and Environmental Development conducted a review of recreational impacts on UK Special Areas of (Marine) Conservation (UK CEED 2000). With regard to the effect of boat waves, they cited one earlier study by Zabawa and Ostrom (1980)[2] who found that the characteristics of the shoreline, (type of sediment, orientation and profile) will determine the actual impact of the boat-generated waves. Asplund (2000) conducted a literature review on the effect of motor boats on aquatic ecosystem for the Wisconsin Department of Natural Resources (USA)[3] and concluded that smaller rivers, where boats are operating close to the shore, and rivers with loosely consolidated or unvegetated banks, are the most susceptible to erosion. They also noted that there was very little information available on the combined effect of multiple boat wakes, or how much boat traffic a given shoreline can sustain.

3. REGIONAL STUDIES OF BOAT-RELATED RIVER BANK EROSION

3.1 Hawkesbury River, NSW

One of the earliest studies to investigate the impact of recreational boats on bank stability was conducted by the NSW Department of Public Works following public concern about the role of water skiing on bank erosion in the Hawkesbury River near Windsor (Lesleighter 1964). Using Manly Dam reservoir as a study site, near shore waves were measured as speedboats were run along straight lines at different speeds and different distances from shore. From this the amount of energy in a typical powerboat wave train was calculated and compared to the (estimated) amount of energy from wind waves in the Windsor section of the river, and the amount of energy which would be dissipated against the bank by the seasonal flood flows. Overall they found that the flood flows had much greater energy or power than either

[2] The report is now out of print and unavailable.
[3] The studies reviewed in Asplund (2000) are all discussed in Section 3 of this report

wake waves or wind waves. They also noted that bank erosion was present even in non-water skiing areas which further supported their conclusions that the primary cause of bank erosion was the large river discharges during flooding, and that there was no need to restrict speedboat activities.

3.2 Norfolk Broads, UK

The first detailed study of boat wakes and sediment transport was done by Garrad and Hey (1987) in the Norfolk Broads (UK) where increased turbidity and decreased aquatic macrophyte growth had been noted for some time. Suspended sediments were measured at 4 sites along the river: two in areas with no boats and two in navigable areas. At the sites with no boats there was no diurnal variation in suspended sediment; in contrast the sites where boats were present had a distinct diurnal variation in suspended sediment that did not correlate with tides or algal material but did correlate with the frequency and patterns of boat movements. Additional experiments, where a boat was driven past one of the turbidity sensors at different speeds, clearly showed a sudden increase in suspended sediment immediately following the passage of the boat, and that the maximum suspended sediment concentration was a function of boat speed. The implication from these studies was that propellers could entrain sediment from the bed and thus lead to sediment transport.

3.3 Gordon River, Tasmania, Australia

The results of Garrad and Hey (1987) were built on by Nanson et al. (1994) who conducted a study in May 1987 to examine bank erosion in the Gordon River, Tasmania. High speed tourist cruise boats started making regular day trips along the Gordon River, which is within the Tasmanian Wilderness Heritage Area, in the early 1980s and by 1985 the local Parks and Wildlife Service rangers had noticed that the river banks were starting to collapse. This was attributed to the cruise boats, and speed restrictions were introduced into some areas (Bradbury 2005a). The 1987 experiment was conducted over 2 days using the three tourist cruise boats operating on the river at that time running along river at varying speeds. Using erosion pins[4] measurements were made of bank retreat after each boat's passage. The bank at this location was almost vertical, about 2 metres high and comprised of sandy alluvium. Measurements were also made of the sediment transport and wave heights. Bed-load and suspended sediment were collected in sediment traps in the wash zone in front of the test bank. Waves were measured using a capacitance wave probe placed on the shoals close to the edge of the deep water channel; the data were analysed to obtain maximum wave height, significant wave height[5] and wave power. A high statistical correlation was found between wave height and both sediment transport and bank erosion. Plots of bank erosion versus maximum wave height showed there was clearly a threshold wave height beyond which the rate of erosion was much greater. As a result of this finding, a 9 knot speed restriction was placed on all boats greater than 8 metres in length in parts of the lower Gordon River and some parts of the river were closed to commercial traffic (Bradbury 2005a).

The erosion pin measurements started in 1987 were continued and expanded, and combined with detailed bank profiles and vegetation surveys, to monitor erosion a number of geologically different bank types along the river. The erosion pins were measured every 6 months and the bank surveys were done annually (Bradbury et al. 1995). The erosion rates decreased over the period 1987 through 1992 with the largest reduction following the introduction of speed restrictions and exclusion zones. However some measurable erosion was still occurring in all areas, especially those where the riparian vegetation had not re-grown. More significantly, erosion was found in areas that were, based on radiocarbon dating and geomorphic evidence, until very recently geologically depositional environments. It was estimated that it could be many years before the revegetation would be sufficient to contribute

[4] Erosion pins are small metal or wooden rods inserted horizontally into banks. Bank retreat is estimated from the changes in the length of the pin which protrudes from the bank.
[5] Significant wave height is the average height of the highest one-third of the waves.

to bank stability. In 1994 the commercial vessel speed was further reduced to 6 knots; the erosion rate was also reduced but was still measurable.

As a result of appeals by commercial boat operators, experimental studies were done to look at the threshold wave height that would cause bank erosion, rather than just focusing on boat speed. Erosion was assumed to be occurring if a plume of turbid water could be traced moving from the bank into deeper water following the passage of a cruise boat. From this work a permissible wave height of 75 mm, as measured in deep water 50 m from the vessel track, was incorporated into the commercial licence conditions. Continued experimental work at the same location showed that even with these wave heights some erosion is occurring if the high wake events have a great enough frequency or duration. Bradbury (2005b) used an optical backscatter sensor to measure turbidity at 15 second intervals over a year. The resulting data showed repeated episodes of high turbidity than can be clearly attributed to boat wake waves. Overall it was found that at least 80% of the high turbidity events occurred at times when the most likely cause was a cruise vessel.

Based on the turbidity measurements it was recommended (Bradbury 2005c) that the method of restricting vessel operations by maximum wake wave height be replaced by an application of the “wash rule”, which considers a combination of wave height and period. This method had recently been applied by the Marlborough Sounds Council, NZ to shipping in Marlborough Sounds (Croad and Parnell 2002). The wave heights and periods generated by any boat will vary with speed (as well as the shape and size of the hull), thus the various speeds which are permissible for each boat will be determined as part of the licensing process. In addition to these new methods applicable to commercial boats, it was also recommended that all recreational vessels be limited to 5 knots. The lower Gordon River continues to be a popular tourist destination and has always been particularly susceptible to erosion by boat wakes because it is naturally subject to a very low energy wind wave climate. Recently an extensive education program, using websites, brochures and posters was started to inform the public about the impact of boat wash on the river banks.

3.4 Upper Mississippi River system, USA

Studies of recreational boating impacts on the Upper Mississippi River were studied by Johnson (1994) in a section of the river near Red Wing, Minnesota, which is subject to high levels of recreational boat use and had documented bank erosion. A nearby channel (Wisconsin Channel), which has very similar riverine and geomorphic characteristics but minimal boat use, was used as a control. The river banks along the section studied were visually classified into areas with high, moderate or low erosion rates based on shoreline features such as exposed roots and steep-cut banks. It was found that more than 50% of the main channel was experiencing high erosion as compared to less than 5% in the control channel. Quantitative shoreline survey transects were done at 5 locations – 3 along main channel and 2 in the control channel. The study transects were on inside and outside bends, and along a straight stretch of the channel. Surveys were done approximately 4 times per year for 3 years (spring 1989 – summer 1992). The results showed greater shoreline recession along the main channel at all transects regardless of geomorphic position (one location had 14 ft (4.3 m) of shoreline recession over 3 years). The erosion observed could not be due to a natural geologic re-positioning of the channel as the Mississippi River is a mature river and has been approximately stable in this region over the past 100 years. An erosion rate was calculated by estimating the area of bank material lost between successive surveys; higher erosion rates occurred during the recreational boating season. The largest rates of erosion occurred in 1991 and 1992 when the river's water levels were higher than usual most of the boating season. This was interpreted as being because the wave energy was not dissipated against a sloping shore but against the upper steeply-sloped portion of the bank.

This study also measured turbidity in water samples taken from 3 depths over two 1-day periods and a 5-day period during summer 1991. Turbidity levels varied during the day with maximum values during early to mid afternoon, which were also peak boating times. Turbidity profiles were also taken over one day across the whole channel, and showed that the higher turbidity values extended from the shoreline out to the edge of the deeper navigation channel. Overall this study concluded that impacts from recreational boats, due to their greater number and larger wake wave heights, were greater than from commercial vessels, and that they were the major contributing influence for the documented high rate of shoreline erosion. They were also considered directly responsible for the elevated turbidity levels which adversely affect the aquatic ecosystem. Repeated transect surveys in the same locations in 1997 and 2003 confirmed that the rate of shoreline recession in these areas has continued.

Between 1995 and 2000 Minnesota Department of Natural Resources studied the recreational boating impacts in the St. Croix River (Mississippi River Landscape Team 2004). Fourteen sites were surveyed twice a year. Eleven sites experienced net erosion, and three sites had net deposition. The sites with net deposition all had no boat waves and no foot traffic trampling the shoreline vegetation. These surveys were supplemented by experiments with controlled boat runs in the river using various sized boats at different speeds. Maximum wave heights and suspended sediment (measured in sediment traps) were recorded as the boats were passing, and it was found that a wave height of 0.4 ft (122 mm) was the threshold size for sediment mobilization from the banks. This height was frequently exceeded by recreational boats. This study concluded that human induced impacts are frequently causing the loss of vegetative ground cover and shoreline erosion along the St. Croix River.

The report by the Mississippi River Landscape Team (2004) also noted that river stage is a contributing factor to wake-caused stream bank erosion along the Upper Mississippi River. When the river levels are high, in this case meaning bankfull down to 2-3 ft (0.6 – 0.9 m) above the normal low summer levels, the wake waves strike the steep upper banks and tree root zones which are easily eroded, causing soil to wash into the river and loss of riparian forest habitat. These higher water levels do not occur frequently during the summer but when they do it is a particularly problematic because that is the time of greatest recreational boating activity. Public advisories requesting voluntary no-wake operation have been posted along the river but with little effect or cooperation. The largest waves come from large V-hulled craft operating at high horsepower. They conclude that a primary element for river planning in the Upper Mississippi River system must be control of wakes for all motorized craft, especially during the high flow stages.

3.5 Kenai River, Alaska, USA

Bank erosion along the Kenai River in Alaska has been reported since the early 1980s. Parts of the river have been closed to power boats since 1986, and in other areas there are restrictions on boat motor size or the number of people on board (i.e. the weight of the vessel) in addition to no-wake zones. The primary boat users are recreational and sport salmon fishers. The first quantitative study to examine the relationship between boat use and bank erosion was done over a one-year period, August 1995 to September 1996 by the United Sates Geological Survey (Dorava and Moore 1997). The purpose of the study was to estimate the amount of erosion caused by boat wakes. This was done by correlating boat activity with measured bank erosion, and also by conducting a controlled experiment measuring boat wakes under different boat operating conditions. The sites selected for this study were protected from human access, and thus there was minimal trampling of the bank and the primary anthropogenic influence on bank erosion would be from boat wakes. Ten sites were used; all had erosion pins installed to measure bank erosion, three had wake gages to measure wave and water levels. The three most up-river sites were in a segment of the river where motorized boats are prohibited and thus were used as controls. The erosion pins were generally installed in the upper bank just below the roots of the overlying vegetation and were spaced 25 to 100 ft (7.6 to 30.5 m) apart. There were up to 7 erosion pins per site. Erosion pins were measured when installed (Aug 1995) and then again the following spring, and about once a month through the 1996 summer season. The maximum amount of bank recession measured from the erosion pins was greatest in areas with boating activity compared to the control sites. Amounts varied between 6 and 45 inches (0.2 and 1.1 m) over the one-year study whereas the erosion rates in the control (no boats) sites were 10 to 12 inches (approximately 0.3 m). Some of the eroded sites were along the inner bank of a river bend which should have been depositional. Wave-generated undercutting of the bank was commonly observed.

The data from the wave gages were used to estimate the size of the boat wakes, and their energy relative to the energy imparted by the stream flow on the banks. The gages were simple float systems with a continuous chart recorder. Comparison of the boat wake energy and the tractive energy from the stream requires some assumptions to estimate the amount of the total tractive energy of the river that is expended (dissipated) against the shoreline. Given the simplifying assumptions, caution needs to be used when interpreting the results; also the data were collected when the Kenai River flow was unusually low. However the authors found that at the three sites where boat wakes were measured, the boat wakes contributed 80% of the energy impacting the banks. Even if the exact numbers are subject to error, this suggests that under some flow conditions boat wakes can potentially contribute a significant amount of energy in the Kenai River.

The study also used visual observations of boat types and numbers of boats. These data were collected by a combination of local volunteers (residents) as well as Alaska State agency employees. Correlating the observations collected on boat activity (size, number etc.) with the recorded waves indicated that “a wide variety of wake sizes were generated by boats of similar size and carrying similar numbers of passengers, depending on how the boat was operated on the river” (Dorava and Moore, 1997, p.48). A controlled boat experiment was also conducted; boats of varying loads and distance from the bank were run at maximum speed along the river and the maximum wave height recorded for each. They found that the wake height increased with boat load (number of passengers), the wake height measured at the bank decreased if the boat was run along course further from shore, and that V-hull boats generated larger wakes that flat-bottomed or inflatable boats.

A follow-on study looked at the effectiveness of two kinds of erosion barriers that had been used in the Kenai River (Dorava 1999). To do this they ran controlled tests on several sites along the river. At each site they ran a 20 ft (6.1 m) flat bottomed boat along a defined course 75 ft (22.9 m) from the bank at the same speed. The boat was run both upstream and downstream, 10 passes each way; there were no other boats present. Each test was run initially with no bank protection and then run with erosion barriers in place. Measurements were made of the waves and the suspended sediment just in front of the bank. The results clearly showed that the erosion barriers (“biologs” and spruce trees) both attenuated the waves and reduced the amount of sediment eroded from the bank which indirectly showed the role of boat wakes in eroding the banks.

In 2005 a much more detailed study of boat use and bank recession in the Kenai River was conducted to try and determine the relative contribution of boat wake erosion to total bank erosion (Maynord et al. 2007). The field study was done over 4 days, 19-23 July, timed to coincide with peak boating activity around the late run of Chinook (salmon). Data were collected at 5 sites along an 11 mile section of the river; bank cross sections and wave data were collected at 4 of the sites; boat counts were taken at all of the sites. Measurements were also made of the discharge and velocity across the stream. The boat counting was done from 0700 to 1900 over the 4 days. Information was collected on boat operation mode (either planing, bow-up, or no-wake), boat position within the river channel (middle or sides), direction of travel (upstream or downstream), number of people in the boat and the boat type (V-hull, flat, other). The counting was done by observers working in teams of 2 for 6 hour shifts. At all sites recorded at least 30 boats/hour (some had more than 80 boats/hour), most boats were operated in the planing mode, the boats were primarily going upstream[6], more than 70% of the boats were V-hull, almost half of the boats carried 5 people, and there was very little difference in boat frequency over the day.

The wave measurements were used to determine the total wave climate, which included wind waves, and thus the data could not be used to determine the effects of any single boat. Total wave energy was calculated from measured wave heights, period and water depth. The authors estimated, based on the grain size of the bank material, that the threshold wave height which would be necessary to initiate erosion was 0.25 ft (76 mm). Wave data were collected for the four 12 hour observation periods. The records were broken into 30 minute intervals and band-pass filtered; wave energy for each 30-minute interval was summed and divided by the number of boats to calculate the wave energy per boat. The same calculation was also done using only waves greater than the threshold value of 0.25 ft (76 mm).

From this study no clear correlation was found between boat wave energy and measured bank recession rates. The wave results showed that when considering only the higher waves (>0.25ft or 76 mm), the energy per boat was greater after a certain threshold traffic level was reached suggesting that high rates of boat traffic have a greater impact than the same number of boats spread over a longer time period. Part of the explanation is wave interference, which can create larger and more complex waves, and as the traffic increases the boats slow down and are no longer planing, and thus are making larger wake waves. The estimated energy from boat waves varied between 20% and 60% of the computed energy at the bank due to streamflow during the measurement period. The authors noted that areas with higher boat wave energy may have higher turbidity levels near the bank and that the energy may be sufficient to prevent the colonization of some (stabilizing) plant species. The results only further emphasise that the importance of boat wave energy is both spatially and temporally variable, and that on an annual basis,

[6] Salmon fishing in this area is done while drifting downstream; the boats then motor back upstream and drift down again, repeatedly throughout the day.

river currents may still be the largest factor influencing overall bank stability in the Kenai River.

3.6 Waikato River, New Zealand

McConchie and Toleman (2003) studied wake wave characteristics and suspended sediment concentrations at several locations along the Waikato River over a range of flow conditions. The sampling was done at 8 sites along the river under 2 different flow regimes (high, low). The sites had different bank characteristics: different sediment type, steepness, and vegetation cover. At all sites wave trains were generated in a controlled event by a 5 metre jet boat travelling both upstream and downstream approximately 15 metres from the bank. The boat was run at 2 speeds, a displacement speed (10 km/h) and a planing speed (approx 50 km/h). The wave amplitudes were measured with pressure sensors attached to poles driven into the bed and sampling at 4 Hz. Measurements were made at 3 or 4 locations within 7 m of the bank. Suspended sediments were also sampled. The authors used time series analysis to separate the boat wake waves from the background (wind) waves. Wave characteristics obtained from this analysis were wave number, wave amplitude and energy, and the duration of the wave train or packet of waves. The maximum wave amplitude was found to be the most useful data.

The results varied a great deal between sites because of their different physical characteristics. Maximum wave heights were up to 133 mm which is much larger than the background wind waves on this river. Faster boat speeds created larger, higher energy waves. However there was no simple relationship between the boat wake wave height and distance from shore; this varied for each different sample site depending on the bed profile. Overall they found that the interaction of a range of site-specific factors including bed profile, bank material and vegetation affect the wave characteristics and erosion potential. The authors noted that although boat wakes are larger and higher energy than the wind waves, the duration of the wakes is less than background conditions, and overall found that it was not easy to generalize about the effect of boat wakes on bank erosion in the Waikato River.

3.7 Murray River, Australia

The only experimental study to date that has looked specifically at the role of boating activity on bank erosion in the Murray River was a study conducted by Erskine et al. (1993) for the Murray Darling Basin Commission. This study aimed to look broadly at the extent and nature of channel changes between the Hume Dame and Lake Mulwala. Using both historical and more recent data the authors found that there had been changes in both channel width and depth, and that observed rates of widening were greater between 1977 and 1993 than in the previous century. In the study area 22% of the banks appeared to be eroding and typically had an erosion notch at the level of maximum regulated flow. The channel widening was primarily attributed to the flow regulation, which has changed the flow regime and resulted in prolonged moderate level flows which have greater cumulative stream power and saturate more of the bank sediments. An erosion notch forms at this water level; the sediment at or below the water level may be removed by the stream flow, causing subsequent collapse of the bank material above the notch. Secondary causes of the channel widening that were considered were de-snagging, loss of riparian vegetation and wave action from boats.

In response to public concerns that that speed-boats cause considerable bank erosion, the investigation by Erskine et al. (1993) conducted a field study to investigate the effect of (water skiing) speed boats on bank erosion. The boat study was done over Easter weekend, 1992 (Friday 17th April to Monday 20th April) in a 2 km reach just downstream of the 8 knot speed restriction zone at Corowa. This area included a large bend and a variety of bank sediments. During the boat study the river was about 1 metre lower than its normal irrigation stage, and the water level stayed constant and low during the experiment. Lines of erosion pins were put down the bank at nine equally spaced locations around the meander bend. The pins were placed from 1 metre above to 1 metre below the water level. Whole bank profiles were also measured and sequential photographs of the bank were taken at one site. The amount of change in bank profile that occurred overnight was taken as the non-boat effect on bank erosion and deposition. The wave heights from speed boats were estimated as being generally greater than 50 mm, which are large enough to erode fine sand. They estimated that each boat wake generated about 15 of these sized waves; they observed more than 500 passages of speed boats on Easter Saturday and Sunday. Wind waves in this reach, given the limited fetch, were estimated as less than 20 mm.

No measurable erosion or deposition was found at any of the pin lines overnight, therefore the authors assumed that any observed changed were due to boat waves. Along the boat study area the amount of erosion was highly variable. At some sites an erosional step developed at the water level and then moved back upslope. The largest such notch was 16 m long, 300 mm high and eroded back 1 m over the 2 days. Other notches were smaller (typically less than 100 mm) and did not migrate as far. The material removed from these erosional features was partly deposited on the lower bank. The size of the step was larger on the banks comprised of sands with inter-bedded lenses of silts and clays; the erosion was least where the bank was just sand. A trench dug across the bank below the quasi-permanent erosion notch showed that much of the sediment had been recently deposited, thus the boat-related erosion observed in this study was not removing original bank material. It may however have been accelerating the downstream movement of the sediment from the lower banks. The erosional step caused by the boat activity over the study period was still visible several weeks later and was larger than the steps caused by pauses in the (continued) fall of the regulated river flow. As this study was done when the flow levels were lower than normal irrigation stage, the authors surmised that under normal summer conditions the boat wakes would be attacking the upper banks of the river and may contribute to the development of the flow-related notch. This study did demonstrate measurable impacts on the bank from the speed boat wakes. However the authors concluded that control of water skiing would not control bank erosion throughout the Hume Dam to

Lake Mulwala region, but recommended that in areas with high levels of boating activity, stabilization with vegetation or rock would be effective an effective erosion control.

The view that, in the Murray River, boat-related bank erosion is secondary to erosion due to other factors such as flow regulation was first expressed by Rutherfurd (1991), and has been incorporated in subsequent reports by Tilleard et al. (1994), Thoms et al. (1998), Rutherfurd (2000) and Gippel and Lucas (2002). Southwell and Thoms (2004) conducted a detailed geomorphic study of the bank erosion along the Murray River in the vicinity of Echuca and found that, within the six 5km-long study areas, almost half of the banks were being actively eroded. The banks adjacent to an area used extensively by wakeboarding vessels showed the most active bank erosion. Overall they found that areas with higher boat use and/or less vegetation had more bank erosion, and areas with vegetated banks and restricted boat speeds had the least bank erosion. This study was based on visual assessment of the bank condition, and where bank erosion was observed it was classified according to the mechanism of bank instability. The two most frequent methods of bank failure were slumping and notch development.

4. BOAT WAKE STUDIES

The results of observational investigations of the relationship between boat wakes and bank erosion made at a given location (e.g. Nanson et al. 1994, Dorava and Moore 1997, Misssissippi Landscape Team 2004) can be difficult to use in a predictive manner in another river. Can engineering studies of boat characteristics provide any insight? Studies of vessel design and wake wash characteristics for large vessels, especially high speed ferries (e.g. Stumpo et al. 1999), are not applicable to recreational boats. The most comprehensive studies of waves generated by small boats were conducted by Maynord (2001, 2005). The aim of these studies was to develop equations for estimating wave height, and thus wave energy, generated by small boats used in a planing and semi-planing mode[7]. Past theoretical studies were combined with a field study conducted on Johnson Lake (near Soldotna Alaska) on 23-28 July 2000. The lake provided a controlled environment – no other boats (and boat wakes) were present, there was not any wave reflection from the shore due to its size and the presence of shoreline vegetation, and there were no currents. Four different boats were used – 2 flat bottomed, 2 V-hull; they varied in size from 4.9 to 6.1 m long. The boats were run along parallel to the shore at different speeds, and different motor and loading configurations, with 5 replicates of each run. Boat speed was measured by a GPS on board and wave heights were recorded using capacitive sensors on a wave staff. Considering all the various combinations of boat type, speed and power over 400 tests were run. The results showed that in general the wave heights decreased with distance from the boat; the wave heights at maximum power depended on the load in the boat and the actual power used; and V-hull boats caused larger waves than flat-bottomed boats at maximum power. From these results, and those of prior studies, a general wave equation was developed which predicts the maximum wave height at a horizontal distance from the boat (x) based on the deadrise[8] angle, the volume of water displaced by the boat, and the displacement Froude number[9]. For a given boat and boat speed, wave heights will decay with distance from the boat at a rate of $x^{-0.42}$. Applying this equation requires knowledge of boat dimensions and boat speeds, thus it may not be easy to use in a regulatory manner given the variety of possible recreational boat types and sizes.

A similar predictive criteria was sought by Macfarlane and Cox (2004) in order to develop vessel operating criteria for a section of the Noosa River which is relatively undisturbed with good riparian vegetation, but has been experiencing increasing amounts of erosion due to boat wash from recreational boats and small tourist vessels. The authors considered that using only maximum wave height was too simplistic and instead considered a

---

[7] Semi-planing is when the lift force on the bottom of the boat causes it to partially rise out of the water; the bow is generally high in the water and large waves are generated. Also called semi-displacement or ploughing.
[8] Deadrise angle is a measure of the angle between the bottom of the boat and horizontal.
[9] The displacement Froude number is proportional to the vessel speed divided by the volume of water displaced by the boat.

combination of height, period and energy of the maximum waves. Based on data collected in the Gordon River by von Krusenstierna (1990) they looked at the relationship between energy per unit height of the deep water (wake) waves, wave period, and amount of bank erosion, and from this proposed a critical wave energy value that would limit bank erosion in the Noosa River. Formulas were developed in terms of waterline length, energy of the maximum waves and vessel speed which would satisfy the criteria. However the authors did note that if a blanket speed limit is preferred, that a speed limit of 5 knots along the river would limit the boat wash energy below the erosional level. This latter criteria was incorporated in the Noosa River Plan (Noosa Council 2004).

5. MANAGEMENT RESPONSES

Several government agencies and local councils, both in Australia and internationally, have implicitly assumed that recreational boats cause bank erosion and published public information materials on the topic. In the USA fact sheets published by the Minnesota Department of Natural Resources (1993) and the Oregon State Marine Board (2003) list bank erosion as one of the impacts of recreational boat wakes and include guidance on how boat operators can reduce boat wakes. The Canadian Department of Fisheries and Oceans (2006) includes a 5 page document on their website clearly implicating boat wakes in the shoreline erosion along the St Lawrence River near Montreal. Within Australia examples are the 4 page leaflet published by the Tasmanian Department of Primary Industries and Water (2005) which includes illustrations of wake wave patterns when boats are operated in a displacement, transitional and planing mode, as well as recommendations as to how boat operators can avoid damaging the banks. The Southeast Queensland Healthy Waterways Partnership (2005) website lists boat wakes was as a factor contributing to streambank erosion in the Noosa River.

On behalf of the Port Stephens Council, GHD Pty. Ltd. conducted a year-long study of bank erosion at 14 sites along the Williams River, New South Wales

(GHD 2006). Only one of the sites monitored showed measurable erosion over the study period, and the exact cause of that erosion was not able to be clearly identified. However the authors reported that while doing the study they visually observed boat wakes causing increased turbidity and bank erosion, specifically removing sediment that had fallen from the upper bank to the waterline. As a result they recommended that a Boating Management Plan be developed for the Williams River and that a no-wake zone be implemented in some sections of the river. A study of the Macleay River by Cohen (2005) found that boat waves contributed to bank erosion at several locations along the river and recommended to the Kempsey Shire Council that a more detailed study be conducted to determine quantitatively the relative contribution of wind and boat waves in the lower Macleay River.

6. CONCLUSIONS

All the studies reviewed in this report have shown that recreational boating can lead to river bank erosion. However, beyond that simple statement it is difficult to generalise about the relationship between recreational boating and erosional processes. The relative energy generated by recreational boat waves can be measured and are often found to be larger than the normal wind waves for a given reach of the river. However computing the energy of these waves relative to the total energy impacting the stream banks is difficult and where it has been done, it has been found that the river flow impacts on the bank are greater than boat or wind waves except in very localized areas. The actual wave climate generated by recreational boating activity is very difficult (or almost impossible) to model. Studies have shown that, for a single boat, the wake waves will depend on boat size, hull shape, speed and weight (passenger load). The combined effect of multiple wakes and boats turning has never been modelled but would need to be considered in future research. Other factors also need to be considered. For example, studies in the Mississippi, Kenai and Murray Rivers have all inferred that the vulnerability of the banks to erosion varies with river level (stage). Furthermore many studies have shown that where the riparian vegetation is absent or reduced (which could be due to floods as well as human impacts) that bank erosion is more likely to result. Interestingly, the most common management response has been to impose speed restrictions. Whilst these restrictions do reduce the boat wake wave energy, and potentially reduce erosion, there are multiple factors contributing to bank erosion and so reducing boat speeds may not eliminate bank erosion. The cover photo of this report shows a case in point. It was taken in a 4 knot speed restriction zone near Howlong on the Murray River. The photo clearly shows that the river bank is undergoing active erosion.

7. PROPOSED FIELD STUDY

The Murray Catchment Management Authority has noted that there is significant high-speed recreation activity along the Murray River and is concerned that this activity, particularly wake-boarding, is contributing to bank erosion. As the review of the literature indicates, it is often very difficult to disentangle the effects of recreational boating from other erosion processes. The following section outlines the approach we propose to examine this issue.

Historically, the Murray River Channel has moved across its floodplain – therefore erosion and deposition are not unnatural phenomenon for the river. However the river has been highly modified from its natural state. The river is highly regulated, with almost constant high flow (at or near bank-full) during the irrigation season and significantly reduced flows at other times. Snag removal, to allow for navigation, has resulted in a decrease in the channel ‘roughness’ and has led to both more uniform and faster flows. Grazing by domestic stock has removed much of the understorey riparian vegetation that helped maintain bank stability. Each of these factors can lead to enhanced bank erosion. Disentangling the impact of recreational boating from these other factors will require use of ‘control’ and impacted sites. Because we cannot stop boating activity in sections of the river (true control sites) we will uses sections where boating activity has been modified. A preliminary assessment of suitable locations has been undertaken for the Murray River between Lake Hume and Torrumbarry Weir. Summer irrigation flows upstream of Lake Mulwala are particularly fast and would probably confound the study so only sites downstream of Lake Mulwala were considered. Enforceable restricted boating zones (4 knot, 8 knot, no-wash and no-ski zones) exist in reaches of the river adjacent to the townships of Cobram, Tocumwal and Echuca. These zones will be used as control sites.

Bank Profiles: At least 18 sites with the speed exclusion zones and 18 sites with boating activity will be selected (with equal weighting to sites on the inside and outside of river bends). Permanent benchmarks will be established at each site and the bank profile surveyed in June 2007 and again in April/May 2008 (i.e. after the period of peak boating activity). A set of erosion pins will also be deployed at each site and will be monitored at least four times during the study period. Soil physical characteristics will also be determined at each location.

Impact of individual boat passages: During a period of high boating activity (Summer School Holidays) we will monitor two sites for the impact of individual boats – one site in a speed exclusion zone and one site where boating is occurring. Boat type (skiing, wake boarding and fishing) and activity (planing/non-planing; number of skiers; number of passengers) will be assessed visually. Relative boat speed will be determined by time taken to pass two set points. Wave height, shape and speed will be determined using a wave staff with built in logger. Suspended sediment generation will be determined using both suspended sediment traps and turbidity loggers.

Outcomes: By comparing bank erosion in speed restricted zones with areas used for boating the proposed methodology will provide a framework for the assessment of the relative importance of high speed recreational to other causes of bank erosion. Looking at wave characteristics from individual boat passages will then allow an assessment of the relative impacts of different types of boats.

8. REFERENCES

Abernathy, B. and I. Rutherfurd (1999) Riverbank Reinforcement by Riparian Roots. Proceedings of the 2nd Australian Stream Management Conference, Adelaide, South Australia.

Asplund, T.R. (2000) The effects of motorized watercraft on aquatic ecosystems. Wisconsin Department of Natural Resources, Bureau of Integrated Science Services, Madison, WI. PUBL-SS-948-00

Bradbury, J. (2005a) Lower Gordon River erosion – history and lessons learned. Department of Primary Industries and Water, Tasmania www.dpiw.tas.gov.au/inter.nsf/WebPages/LJEM-6J289T?open

Bradbury, J. (2005b) Lower Gordon River turbidity monitoring, April 2003 – December 2004. Department of Primary Industries and Water, Tasmania www.dpiw.tas.gov.au/inter.nsf/WebPages/LJEM-6J289T?open

Bradbury, J. (2005c) Revised wave wake criteria for vessel operation on the lower Gordon River. Department of Primary Industries and Water, Tasmania www.dpiw.tas.gov.au/inter.nsf/WebPages/LJEM-6J289T?open

Bradbury, J., P. Cullen, G. Dixon and M. Pemberton (1995) Monitoring and management of streambank erosion and natural revegetation on the Lower Gordon River, Tasmanian Wilderness World Heritage area. *Environmental Management* **19(2)**:259-272.

Brooks, A. (1999) Lessons for River Managers from the Fluvial Tardis. Proceedings of the 2nd Australian Stream Management Conference, Adelaide, South Australia.

Canadian Department of Fisheries and Oceans (2006) Erosion and boat wakes. http://www.marinfo.gc.ca/en/plaisance/index.asp

Cohen, T. (2005) The geomorphology of the Macleay River estuary. A report to the Kempsey Shire Council. http://www.kempsey.nsw.gov.au/estuarymanagement.htm

Croad, R. and K. Parnell (2002) Proposed Controls on Shipping Activity in the Marlborough Sounds. Consultants report to the Marlborough District Council. http://www.marlborough.govt.nz/documents/summarylist.cfm

Dorava, J.M. (1999) Effectiveness of streambank-stabilization techniques along the Kenai River, Alaska. U.S Geological Survey, Anchorage, Alaska, Water Resources Investigations Report 99-4156.

Dorava, J.M. and G.W. Moore (1997) Effects of boatwakes on streambank erosion, Kenai River, Alaska. U.S Geological Survey, Anchorage, Alaska, Water Resources Investigations Report 97-4105.

Erskine, W.D., I.D. Rutherfurd, J.J. Sherrard and J.W. Tilleard (1993) River Murray and anabranches between Hume Dam and Lake Mulwala: Investigation of river channel changes, Ian Drummond and Associates, unpublished Consultant's report to the Murray-Darling Basin Commission, Canberra.

Garrad, P.N. and R.D. Hey (1987) Boat traffic, sediment resuspension and turbidity in a broadland river. *Journal of Hydrology*, **95**:289-297.

GHD, 2006, Williams River Bank Erosion Study. A consultants report to the Port Stephens Council (http://portstephens.local-e.nsw.gov.au/environment/1273/38747.html).

Gippel, C.J. and R. Lucas (2002) River Murray Action Plan, Yarrawonga to Echuca: Review of Fluvial Geomorphology and Recent Environmental Changes. Unpublished consultant's report to the Goulburn Broken Catchment Management Authority.

Hodges, R. (1991) Riparian damage from boating. *Australian Planner* **29**:101-106.

Johnson, S. (1994) Recreational boating impact investigations, Upper Mississippi River System, Pool 4, Red Wing Minnesota. Report by the Minnesota Department of Natural Resources, Lake City, Minnesota for the National Biological Survey, Environmental Management Technical Center, Onalaska, Wisconsin, February 1994. EMTC 94-S004. 48 pp. + appendixes (2pp.)

Lesleighter, E.J. (1964) Hawkesbury River – The effect of speedboat activities on bank erosion. NSW Department of Public Works, Rivers and Harbours Branch, Report No. 164, 12pp.

Macfarlane, G. and G. Cox (2004) The development of vessel wave wake criteria for the Noosa and Brisbane Rivers in Southeast Queensland. In; Coastal Environment V, incorporating Oil Spill Studies (C.A. Brebbia, J.M. Saval Perez & L. Garcia, Editors), WIT Press.

Maynord, S.T. (2001) Boat waves on Johnson Lake and Kenai River, Alaska. US Army Corps of Engineers Report ERD/CHL TR-01-31.

Maynord, S.T. (2005) Wave height from planing and semi-planing small boats. *River Research and Applications*. **21**:1-17

Maynord, S.T., D.S. Biedenharn, C.J. Fischenich and J.E. Zufelt (2007) Boat Wake Induced Bank Erosion on the Kenai River, Alaska. Draft Report January 2007 http://www.borough.kenai.ak.us/KenaiRiverCenter/Publications/BWS_Phase_II.pdf

McConchie, J.A. and I.E.J. Toleman (2003) Boat wakes as a cause of riverbank erosion: a case study from the Waikato River, New Zealand. *Journal of Hydrology(NZ)* **42(2)**:163-179.

Minnesota Department of Natural Resources (1993) Mississippi River bank erosion and boats: Facts and solutions. Public information sheet published on http://www.dnr.state.mn.us/safety/boatwater/publications.html

Mississippi River Landscape Team (2004) Shoreline and water quality impacts from recreational boating on the Mississippi River. Minnesota Department of Natural Resources report. http://www.dnr.state.mn.us/aboutdnr/reports/impacts_mississippi.html

Mosisch, M.D. and A.H. Arthington (1998) The impacts of power boating and water skiing on lakes and reservoirs. *Lakes & Reservoirs: Research and Management* **3**:1-17.

Nanson, G.C., A. von Krusenstierna and E.A. Bryant (1994) Experimental measurements of river-bank erosion caused by boat-generated waves on the Gordon River, Tasmania. *Regulated Rivers: Research and Management* **9**:1-14

Noosa Council (2004) The Noosa River Plan. http://www.nrw.qld.gov.au/land/planning/pdf/noosa_river_plan.pdf

Oregon State Marine Board (2003) Watching your wake: A boater's guide http://www.boatoregon.com/Library/WatchWake.pdf

Piégay, H., S.E. Darby, E. Mosselman and N. Surian (2005) A review of techniques available for delimiting the erodible corridor: A sustainable approach to managing bank erosion. *River Research and Applications* **21**:773-789

Rutherfurd, I.D. (1991) Channel form and stability in the River Murray: a large, low energy river system in Southeastern Australia. Unpublished PhD thesis, Department of Geography and Environmental Science, Monash University.

Rutherfurd, I.D. (2000) Some Human Impacts on Australian Stream Channel Morphology. In: River Management: The Australasian Experience (S. Brizga and B. Finlayson, editors), John Wiley and Sons Ltd.

Southeast Queensland Healthy Waterways Partnership (2005) Noosa Catchment web page http://www.healthywaterways.org/about_seq_catchments_noosa.html

Southwell, M. and M. Thoms (2004) Bank erosion along the River Murray: Processes, causes and management options. CRC for Freshwater Ecology Report, 33pp.

Steiger, J., E. Tabacchi, S. Dufour, D. Corenblit and J-L Peiry (2005) Hydrogeomorphic processes affecting riparian habitat within alluvial channel-floodplain river systems: A review for the temperate zone. *River Research and Applications* **21**:719-737.

Stumpo, S., K. Fox, F. Dvorak and L. Elliot (1999) The prediction, measurement and analysis of wake wash from marine vessels. *Marine Technology* **36(4)**:248-260.

Tasmania Department of Primary Industries and Water (2005) Guide to low wave wake – “Wake up Slow down”. Leaflet published on http://www.dpiw.tas.gov.au/inter.nsf/Attachments/LJEM-6J96XQ?open

Thoms, M. P. Suter, J. Roberst, J. Koehn, G. Jones, T. Hillman and A. Close (1998) Report of the River Murray Scientific Panel on Environmental Flows. Murray Darling Basin Commission Report, 168pp.

Tilleard, J.W., W.D. Erskine and I.D. Rutherfurd (1994) Impacts of River Murray Flow Regulation on Downstream Channel Morphology. Proceedings of the Hydrology and Water Resources Symposium, Adelaide, The Institute of Engineers, Australia, National Conference Publication 94/14, Vol.3, 409-415.

UK CEED (2000) A review of the effects of recreational interactions within UK European marine sites. Report prepared for the UK Marine Special Areas of Conservation project by the UK Centre for Economic and Environmental Development, 264pp.

Victorian Department of Conservation and Environment (1991) Findings of the investigation into the use and management of the Bridgewater Public Park Reserve. Victorian Department of Conservation and Environment, Melbourne.

von Krusenstierna, A. (1990) River bank erosion by boat-generated waves in the lower Gordon River, Tasmania. Master of Science thesis, Department of Geography, University of Wollongong.

Zabawa, C. and C. Ostrum (1980) The role of boat wakes in Arundel County, Maryland. Maryland Coast Report Number 5, USA.