Revised wave wake criteria for vessel operation on the lower Gordon River

Tasmania

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Summary and main recommendations

Use of the lower Gordon River by commercial cruise vessels is subject to licence conditions supposed to minimise bank erosion by wave wake. The present criterion is a maximum wave hight of 75 mm as measured under standardised conditions however both monitoring and experimental work have shown that under many circumstances this is an inadequate safeguard against erosion. Small private vessels are not at present subject to any speed limit and may have disproportionately large impact.

This report finalises a draft circulated in December 2004 that was used to guide licensing of *Discovery* for operation on a trial basis in management zone two. It summarises geomorphological evidence that bank erosion by vessel wave wake can be avoided provided the height and period of the maximum wave do not exceed threshold values specified by a simple wash rule. Proposals include:

- a revised criteria for licensing of commercial operations (wash rule) and revision of speed limits for some existing vessels
- active discouragement of other boating visitors from travelling at a speed greater than approximately 5 knots
- revision of the *Lower Gordon River Recreation Zone Plan 1998*
- continued monitoring.

Relevant history

1985 Unusual erosion observed, speed limits introduced on some obviously affected reaches.
1989 Reaches upstream of Horseshoe Bend closed to commercial operations, remainder subject to 9 kt speed limit for commercial vessels and 6 kts for other vessels longer than 8 m.
1994 Commercial vessel speed limit reduced to 6 kts as dictated by 1989 decision, Gordon River Tourist Operations (Bingham) Inquiry, draft Lower Gordon River Recreation Zone Plan.
1995 Executive decisions were made against scientific advice to restrict the wave wake of any new commercial vessel to a maximum height of 30 mm and to measure vessel speed against land.
1997 Comprehensive wave wake measurement of cruise fleet, first NCB turbidity experiments, *Wanderer II* licensed on the basis that its wave wake was smaller than that of other vessels.
1998 Adoption of 75 mm maximum wave height criterion, *Gordon Explorer* identified as the vessel most likely to be causing erosion and its replacement recommended.
1999 *Wanderer III* was the first vessel licensed on the basis of maximum wave height predicted from scale model data.
2000 *Lady Jane Franklin* licensed, last monohull cruise vessel retired.
2002 Research shows wave height alone to be a poor indicator of erosion, power and energy should also be considered. *Adventurer* licensed a significant 0.5 kt too fast, turbidity logger installed.
2003 Wave energy and power considered when licensing *Lady Jane Franklin II* at 6.0 kts rather than the 6.5 kts at which it was predicted it would meet the 75 mm criterion.
2004 Turbidity logging demonstrates cruise vessels continue to cause erosion as earlier indicated by erosion pin monitoring. Draft version of this document used to guide licensing of *Discovery*.

Geoscientific background

The four fundamental properties of a water wave are height (vertical distance from crest to trough), period (time between successive crests), water depth and direction of propagation. The last is the most difficult to measure but may be estimated with sufficient accuracy for geomorphological purposes using simple numerical models of wave wake patterns. For many practical purposes water depth can be ignored if wave height is measured in (or recalculated to) deep water, with the depth defined as deep being a function of wave period. Measured wave height and period may be used to derive a number of other wave parameters such as length, energy, power, orbital velocities etc

Research by the Earth Science Section of NCB focussed upon the identification of wave wake influences on and thresholds to lower Gordon River erosion. There is strong theoretical and empirical evidence to indicate that sediment motion is not initiated until various wave parameters exceed threshold values. The maximum wave is therefore considered the most critical to the avoidance of erosion. Elevated turbidity adjacent to the bank following vessel passage is used as the indicator of threshold proximal erosion of cohesive banks in management zones 1 and 2. Wave power was found to have the strongest statistical correlation with turbid response.

Proposed management measure

The primary influence on the propensity of any vessel to cause erosion of a restricted channel is its speed. For vessels with known wave wake characteristics speed may be limited so that specified values of fundamental wave parameters remain below thresholds to erosion. The specification proposed here was originally formulated in Danish and has been adopted by regulatory authorities in Denmark, Sweden and New Zealand (at least) in order to manage the impacts of high speed coastal shipping (Croad and Parnell 2002). The wash rule is essentially a formula that gives wave height (H) for any period (T) so that power remains a constant: $H = H_b\sqrt{\frac{T_b}{T}}$.

H_b and T_b may be any benchmark combination of H and T and have elsewhere been chosen to differentiate the wake characteristics of conventional and high speed ships. When empirically determined benchmark values appropriate to the lower Gordon are used the formula is effective in delineation of the threshold of turbid response to wave wake (figure 1). It also provides allowance for the tendency of wave period to increase with waterline length, meaning tests conducted with one vessel can be used to predict the geomorphic impact of another solely of the basis of the latter's wave wake characteristics.

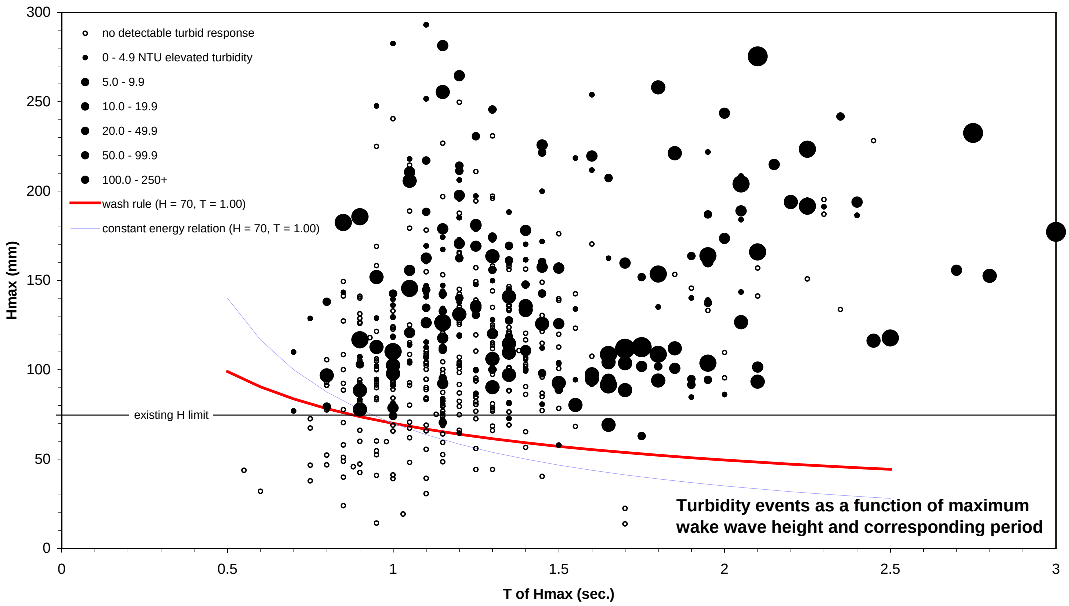

Figure one: measured elevation of turbidity resulting from wave wake impact on some representative estuarine and alluvial banks in zones 1 and 2 of the lower Gordon River as a function of the fundamental characteristics of the maximum wave. Data acquired from 583 experimental runs using 12 different vessels at sites near Timms Eddy, Tuan Gaby Flats, Kathleen Sound, Heritage Landing, Expectation Reach and Eagle Creek. Legend error due to an apparent limitation of MS Excel.

Brief geoscientific discussion

Bank form, material properties, water level and salinity all influence erosional processes. Muddy shoals at the foot of the bank scarp are considered the most universally sensitive part of the bank landform assemblage. These are most vulnerable to wave action at low water level since for any given wave the bed is then subject to faster non-breaking orbital motion and an increased chance of scour by breaking waves. Upon suspension sediment may then be transported away from the bank by either subsequent waves or river currents, to settle at a depth from which it is unlikely to be restored to the bank landform by other processes. The shoal muds are typically dominated by clay minerals and/or organic particulates with settling times controlled by flocculation state. Simultaneously low water level and salinity is therefore regarded as the highest risk condition. Water level and salinity conditions as monitored at the time of data acquisition were not necessarily those under which erosion was most likely to occur.

Turbidity monitoring indicates wave wake remains a significant operator of geomorphic process. Small vessel and scheduled cruise wave wake events often attain turbidity values in excess of 50 NTU, ten times the Australian drinking water quality guideline. Over a 5 m wide shoal from 1 – 0 m depth this represents suspension of 170 g of sediment per m of bank. If all that sediment were to be removed from the shoal by the action of subsequent waves and river current the landform surface would be lowered by an average of 28µm. Unmeasurable by itself, but given a long term vertical alluviation rate of 1.4 mm/yr indicated by radiocarbon dating (Bradbury *et al* 1995) and the compaction that occurs during sediment storage this is estimated to represent erosion of some 5 days worth of average sedimentary input. The reversal of geomorphic process from deposition to erosion is considered more significant than the absolute magnitude of erosion.

Bank landforms have been significantly modified by wave wake over the past 2 decades and might now be considered hypersensitive to its effects. Continued wave wake influence upon geomorphic process means the system cannot respond naturally to sea level rise. Although the predicted global rate of sea level rise may be unprecedented the local rate of change is unlikely to be extraordinary as coasts and estuaries are often tectonically submergant. Continued Neogene uplift of Tasmania in general and the valley west of First Gorge in particular may at least partially offset eustatic rise. Further estuarine infill would be expected with sea level rise but the present wave wake influence may be enough to tip the system towards broadscale erosion of Holocene landforms upon inundation.

The benchmark values H_b = 70 mm and T_b = 1.00 sec. that determine the position of the wash rule curve in figure one were chosen because they are central to the spread of the experimental data and provide a tight envelope to the distribution of experimentally induced turbidity events. The position of the curve therefore in effect allows for the empirical worst case in terms of bank sensitivity to wave wake. The experiment sites include some of the more sensitive lower Gordon estuarine and alluvial banks known so in terms of qualitative geomorphology the proposed benchmark values are appropriate to safeguard at least most of banks in zones 1 and 2. Only one site near the Spence River confluence was found to be more sensitive, with results summarised in figure two. Geomorphological evidence suggests that similarly sensitive sites occur near Lake Morrison and the southern (upstream) end of Limekiln Reach.

These high sensitivity sites are far enough upstream that surface water can be reliably expected to be of low salinity so they are considered most vulnerable to wave wake whenever water level is below about 0.4 m by the Heritage Landing gauge board. Such low water level may occur as the result of barometric depression at almost any time of below average river discharge and becomes more likely with decreasing discharge. Due to the operation of the Gordon power station low water can be difficult to predict but typically occurs during periods of low flow and light winds.

The constant wave power dictated by the zone one wash rule benchmark values is 4.7 W/m, within rounding error of the threshold 5.0 W/m determined by other means. It might be argued that wave energy may be more significant than power. The corresponding constant energy relation is $H = H_b \frac{T_b}{T}$ and generates a steeper curve than the constant power wash rule. An energy rule using any combination of H_b and T_b either within the range of experimental data or matching the previously proposed 10 J energy threshold was found to provide a poorer fit to the results than does the power based rule.

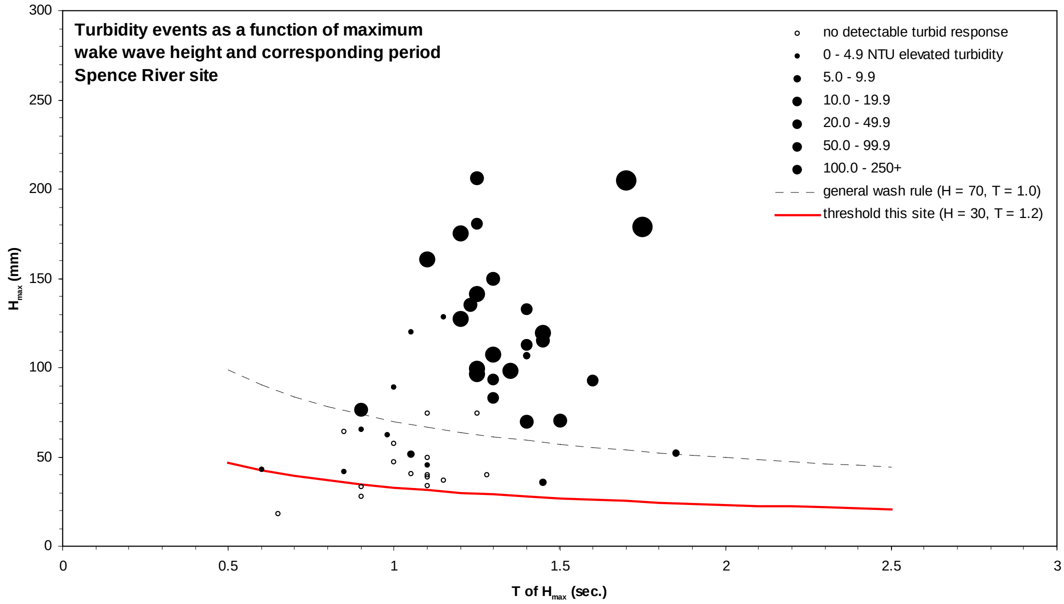

Figure two: measured elevation of turbidity resulting from wave wake impact on the high sensitivity alluvial bank site near the Spence River confluence.

Management implications

Commercial cruises

Both maximum wave height and its corresponding period vary with vessel speed so for assessment and licensing purposes the proposed wash rule can be used in the same manner as the existing 75 mm maximum wave height criterion. That is, to set a maximum permissible speed based upon the measured or reasonably predicted wave wake characteristics of any particular vessel. The management aims of the *Lower Gordon River Recreation Zone Plan* 1998 should be used to define the limit of acceptable geomorphic disturbance and any appropriate factor of safety.

A new commercial vessel could be licensed for operation at a nominal speed at which wash rule compliance under operational conditions is to be reasonably expected at least 90% of the time. Date and time stamped turbidity monitoring records (collected in partial series since December 2002) may be used to test predictions of geomorphic impact according to vessel wave wake characteristics (Bradbury 2005). Compliance of existing vessels can and should be assessed and their maximum permitted speed adjusted if necessary..

The introduction of catamaran hull forms to Gordon River service has seen a progressive increase in vessel size, particularly in terms of waterline length. Longer vessels may generate longer waves, with the implication that vessel length may eventually become a limiting factor. Potential vessel operators should be advised to include wash rule compliance as part of their design or purchasing specifications.

Wave wake is a hydrodynamic phenomenon and as such varies with vessel speed through the water. However existing licences inappropriately permit vessel speed to be measured by GPS, that is against a geospatially fixed reference. Currents of 0.7 – 0.8 kt have been reported off Heritage Landing under otherwise unexceptional conditions (McRea 1997) so prediction of potential geomorphological impact must consider GPS based measurement of vessel speed subject to some ±1.0 kt error. Any such error necessitates application of an appropriate factor of safety as a 1.0 kt reduction in permitted speed.

Sensitive sites

A small number of sites within zone 2 are particularly vulnerable at low water level, which typically occurs under navigationally ideal conditions of low flow and light winds. That is, when it may just be possible to operate 'Wanderer class' vessels at less than 5 kts, as necessary to achieve the lower wash rule benchmark values of 30 mm and 1.2 sec. for H_{max} and corresponding T respectively. Wave power acting on the bank would also be reduced if increased vessel – bank separation were to be maintained. AMC advice may be sought on a vessel specific basis to determine operational conditions least likely to cause erosion of high sensitivity sites. However it does appear probable that regular vessel passage past these sites would at least occasionally cause detectable disturbance to geomorphic process unless a speed of around 4 kts can be maintained when necessary. The only commercial tourist vessels presently permitted to use zone 2 are *Stormbreaker* and *Discovery*. Further permission for commercial use of zone two should only be considered with extreme caution, at least until results of the present *Discovery* trial are known.

Private boats

Management effort has focussed principally upon limiting the wave wake of larger commercial vessels, with the result that the relative impact of non-commercial river traffic has become increasingly significant in recent years. Turbidity monitoring indicates that private vessels may have greater geomorphic impact than proportionate to visitor numbers.

Private boats less than 8 m long are subject only to a general MAST by-law that prohibits speeds in excess of 5 kts within 60 m of any shoreline or bank. As the lower Gordon estuary is for the most part greater than 120 m wide those boats that travel near the centre of the river are not at present subject to any speed limit. However passage of a small, fast boat anywhere on the riverine estuary can have a significant impact even upon the further bank.

For many hydrodynamic purposes a vessel's speed must be considered with respect to its waterline length as quantified by the dimensionless length Froude number, $F_L = \dfrac{V}{\sqrt{gL}}$ where V = vessel speed, L = waterline length and g is acceleration due to gravity. Values of F_L in excess of 0.5 are generally considered representative of high speed, meaning small vessels don't have to travel particularly fast to generate a wake pattern characteristic of high speed. Regardless of size high speed vessels typically generate long period waves without analogue in the natural lower Gordon wave climate. Efficiency of wave propagation through deep water is proportional to period so long waves can transfer with little loss of energy over the scale of the lower Gordon waterbody the significant proportion of high speed propulsive power spent on wavemaking. This then hits the banks with a lot of geomorphic power.

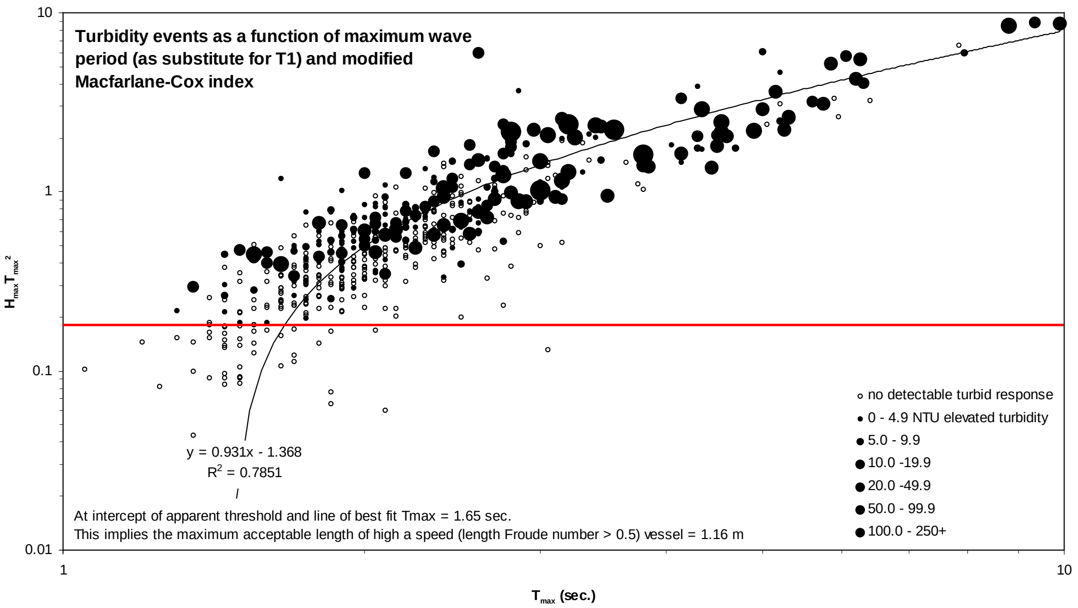

Figure three: Determination of the maximum acceptable length of a high speed vessel by the modified Macfarlane and Cox (2003) method.

Macfarlane and Cox (2003) have developed a wave period based method to determine the maximum acceptable length of a high speed vessel from any empirical measurement of wave wake induced erosion. Their method uses the period of the initial wake wave however the comparable value maximum period is more readily determined and has been used here. By applying this slightly modified method to the Gordon River data for cohesive banks it was found that the maximum acceptable length for a high speed vessel in zones one and two is less than 1.2 m (figure three). In other words a strong suggestion that operation of any practical vessel at high speed is likely to cause erosion of these banks. A blanket 5 kt speed limit on non-commercial vessels is considered the simplest prohibition of high speed operation.

Recommendations in detail

Monitoring
Adaptive management of Gordon River erosion over the past two decades has presented a rare opportunity for experimental geomorphology. It is predicted that application of these recommendations would greatly assist achievement of the management aim of no erosion by wave wake. However that hypothesis requires testing by continued monitoring of turbidity for identification of impact events (two sites are presently instrumented) and erosion pins (about 40 sites) to maintain the broader context of geomorphological process.

Recreational vessels
An approximate 5 kt speed limit should be applied in an appropriate manner to all non-commercial vessels. A general guide to low wake boating in Tasmania with specific reference to the Gordon has been prepared, approved for publication by the General Manager RMC and endorsed by IFC and AMC. Layout and design are in progress and a print run of some 22 000 has been funded via WHACC. MAST have agreed to distribute the brochure to all 23 500 registered boat owners in Tasmania enclosed in a periodic mailout but at a cost of $2 900. Hydro Tasmania have agreed to sponsor half of that amount but further funding is required to cover distribution of an extended print run. As a matter of priority a poster version should replace the outdated and inappropriate 1992 guide mounted on the wall of Boom Camp.

Commercial tourist operations
For normal operations in management zone one it is recommended that the simplistic 75 mm maximum wave height criterion is replaced with a specifically modified version of the Danish wash rule.

Although an elegant concept the wash rule must necessarily be expressed in terms of an equation,

acceptable $H_{\max} \leq 70\sqrt{\frac{1.00}{T_{H_{\max}}}}$,

which may then be plotted as a limit defining line on a graph of maximum wave height and corresponding period.

The constants are empirically determined benchmark values of maximum wave height (70 mm) and its corresponding period (1.00 sec.) as may be readily measured under standardised conditions. Routine wave wake characterisation may therefore be used to set the maximum speed of commercial vessels so that known thresholds to erosion are not exceeded. In other words, potential operators would only be required to submit exactly the same information for assessment as has been acceptable for the past 7 years. Implications for the existing Gordon River commercial fleet are summarised in table one.

When assessing vessels and setting speed limits some allowance must be made for operational variability from the nominal speed. Acceptance of a vessel for operation might reasonably be based upon prediction that it would comply with the wash rule at least 90% of the time during steady operation under conditions of relatively light wind and river current. Wave wake is a hydrodynamic phenomena and as such the critical measure is the vessel's speed through the water. River currents on the order of one kt can be reasonably expected to occur at so GPS based speed estimates must be considered subject to ±1 kt error, with the sign dependent upon direction of travel with respect to the current. There is no intrinsic geomorphological factor of safety in the wash rule so GPS based speed measurement errors necessitate a compensatory reduction in the permitted speed if erosion is to be avoided whenever a vessel travels upstream against a significant current.

Table one: Implications of these recommendations for existing vessels. WHC = World Heritage Cruises, SMC = Strahan Marine Charters, GRC = Gordon River Cruises, PWS = Parks and Wildlife Service, WCYC = West Coast Yacht Charters.

Adventurer WHC	Despite argument to the contrary regarding predicted impact due to excessive wave power this vessel was licensed strictly according to the 75 mm maximum wave height criteria (P. Williams pers. comm.). It is now implicated by turbidity monitoring as a regular cause of geomorphic impact. Full scale data held by DPIWE suggest wash rule compliance would be achieved most of the time if the permitted speed was reduced from 5.5 to 5.0 knots. This should be verified by checking against model data held by AMC before any agreement is formalised.
Discovery WHC	This vessel is already licensed for management zones one and two and speed limited according to the proposed wash rule but its predicted zero impact remains unconfirmed (to be reported separately).
Fairway SMC	Full scale wave wake measurements acquired by DPIWE were used to assess this vessel and indicate no operational change is necessary for wash rule compliance.
Lady Jane Franklin II GRC	Licensed with consideration of wave power and not just maximum wave height, this vessel should comply with the wash rule at its presently permitted speed (believed to be 6.0 kts). However turbidity monitoring clearly shows it causes a significant proportion of total impact. Either it is consistently operated within 50 m of the monitoring site or at speed exceeding 6.0 kts. Or there is an error with prediction of its maximum wave based upon model tests. The only evidence is for the last: the displacement used for model testing (as specified by the naval architect) is anomalously more than 30% lighter than the 'Wanderer class' average after rescaling to constant LWL. More thorough review is required to determine the speed necessary for wash rule compliance.
Shearwater PWS	This vessel is too short and subject to variation in displacement and trim due to loading to reliably achieve wash rule compliance at any practicable speed. As the primary test vessel used to determine erosion thresholds at many sites its impact is well known and like that of recreational boats can be minimised by sensitive operation.
Stormbreaker WCYC	Wave wake was characterised at full scale by AMC in 1995. About half the data is archived only as raw probe voltage and calibration coefficients are unrecorded, but may be recoverable by comparison with runs for which both voltage and water surface elevation records exist. More thorough review is required to determine wash rule compliance.
Wanderer II WHC	Available wave wake characterisation is relatively poor but data from other 'Wanderer class' vessels may be rescaled by AMC according to waterline length. More thorough review is required to determine wash rule compliance.

There exists in management zone two a small proportion of high sensitivity sites that are particularly vulnerable if water level is lower than about 0.4 m by the Heritage Landing gauge board. Appropriate benchmark values are then H_b = 30 mm and T_b = 1.20 sec. Initial results from monitoring of operation of *Discovery* and tenders in zone two on a trial basis will shortly be analysed and reported. It would not seem appropriate to authorise further commercial use of zone two in the interim.

Revision of Lower Gordon River Recreation Zone Plan 1998

The recommendations made here are based upon significant advances in understanding of the controls on wave wake erosion. This was foreseen when the present plan was written and allowance was made for revision within five years or as appropriate. These recommendations should be incorporated into a revised plan and guidelines for vessel wave wake characterisation and assessment.

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