ANALYSIS OF PRE/POST FLOOD BATHYMETRIC CHANGE USING A GIS
A CASE STUDY FROM THE GIPPSLAND LAKES, VICTORIA, AUSTRALIA

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In late June 1998, a damaging flood event occurred at Lakes Entrance (Victoria, Australia), which was partly due to retardation of floodwater flow through the Gippsland Lakes artificial entrance by the level of flood-tide delta sediment accretion in the Entrance and Reeves Channels. Analyses of digitised three-dimensional hydrographic datasets allowed the extent of pre and post-flood event bathymetric change to be visualised and also quantified.

Despite the introduction (post-1998 floods) of engineered sediment management regimes in the Entrance and Reeves Channels, flood-tide delta accretion has continued. This sediment accretion potentially increases the vulnerability of infrastructure in low-lying areas of the Lakes Entrance township to any future Gippsland Lakes flood events.

INTRODUCTION

Coastal lagoons, tidal inlets and estuaries throughout the world exhibit a variety of hydrodynamic conditions, and can be considered ‘interface’ areas between upstream processes, coastal processes and climatic influences. In Australia, they are valued for a variety of reasons, including provision of areas sheltered enough to be suitable for port and harbour installation and associated developments, some of which refer to high-value real estate. Due to the hydrodynamic and physiographic processes that operate within contributing catchment areas and coastal zones, the potential for the occurrence of natural hazards, including flooding of low-lying coastal infrastructure, is ever-present (e.g. see Day, 1999).

One such location where ports facilities co-exist with settlement on the shores of a modified coastal lagoon system is at Lakes Entrance, Victoria, Australia. Here, an artificial entrance for the Gippsland Lakes was first opened in 1889, allowing shipping to pass from Bass Strait, across the extensive swash-aligned Holocene sandy barrier (e.g. see Bird, 1978; Thom, 1984) known for its famous Ninety Mile Beach, and into the comparatively-sheltered waters of the back-barrier lagoon system, known as the Gippsland Lakes. Since 1889, and particularly since the mid-1970s, channel sedimentation has caused port authorities to devote much time and expense to maintaining channel navigability (e.g. see DNRE, 1998; Wheeler, 2005; Wheeler and Peterson, 2005a; Wheeler and Peterson 2005b).

In June 1998, a heavy rainfall event (for example, in the order of 284.6 mm in 24 hrs, at Club Terrace, East Gippsland, 24 June 1998—e.g. see BOM, 2005) in the easternmost sections of the Gippsland Lakes catchment produced heavy flooding at Lakes Entrance. In attempting to escape through the artificial entrance to Bass Strait, floodwaters which were generated from this
rainfall event were retarded by an accumulation of flood-tide delta sands in the Reeves and Entrance Channels. Analysis of environmental conditions prevailing at the time of the June 1998 floods reveal that floodwater levels were sustained not only by channel constriction, but by a convergence of environmental forcings (e.g. see Tan et al. 2002). Vulnerability to further such flooding can be better assessed if the nature and relative significance of the combined forces are known. Most readily documentable in these terms is information on the nature and persistence of channel infilling under current catchment and coastal management regimes.

June 1998 floodwaters inundated low-lying areas of the Lakes Entrance township, in the process causing much damage to urban and business infrastructure. Since this time, development of high value urban infrastructure has increased in the area previously affected by flooding. Whilst any new construction plans referring to areas classed as ‘subject to inundation’ are subject to building regulations that specify building height above the Australian Height Datum (AHD) (Vic. Building Regulations, 1994), already established properties remain at vulnerable elevations.

Digital capture and analysis of pre and post-Gippsland Lakes flood event hydrographic datasets (for January and July 1998) for the Entrance, lower Hopetoun and Reeves Channels allows the extent of immediate post-event bathymetric change to be visualised and quantified. Analysis of later hydrographic charts (May 1999, July 2000 and January 2005), and of aerial photography, allows comparisons to be made in respect to longer-term post-flood bathymetric changes in these channels.

Geographic Information Systems (GIS) technologies have allowed such coastal zone changes (and attendant problems) to be two and three-dimensionally modelled, analysed, monitored and displayed (e.g. see van der Wal and Pye, 2003, and Hennecke et al. 2004). Such digital spatial data handling can be deployed in situations where monitoring of channel bathymetry by ports management authorities is required. By deploying such information in the coastal zone, the efficiency and effectiveness of coastal management may be considerably augmented.

THE STUDY AREA: LAKES ENTRANCE AND THE GIPPSLAND LAKES

The 390 square kilometre coastal lagoon system known as the Gippsland Lakes is located between 200 and 265 kilometers east of Melbourne, Victoria, Australia (refer Figure 1). The lagoon system is made up of three main interconnected ‘lakes’ (Lakes Wellington, Victoria, and King). These lakes include many smaller arms and channels. The contributing catchment has an area of over 20,000 square kilometres, and from this catchment, the Thomson, Latrobe, Macalister, Avon, Mitchell, Nicholson and Tambo Rivers discharge into the Lakes (refer Figure 2). The contributing catchment is divided into areas of management jurisdiction. Major catchment management agencies include the East and West Gippsland Catchment Management Authorities, the Gippsland Coastal Board, Gippsland Ports, and Southern Rural Water.

An artificial outlet to Bass Strait was opened in June 1889 to provide a reliable shipping link between Melbourne and the townships of Bairnsdale and Sale (e.g. see Bird and Lennon, 1989). It is situated at the township of Lakes Entrance near the easterly extremity of the lagoon system (refer Figure 3). The progressive development of Lakes Entrance into one of Australia’s major fishing ports (refer Figure 4) sustains the need to maintain a safe, navigable entrance to the Gippsland Lakes.
This aspect is one which has necessitated the management of channel sedimentation in the artificial entrance area, primarily to allow the safe passage of commercial fishing vessels from their anchorage in the Cunninghame Arm into Bass Strait. For ports management bodies, the challenge of maintaining this navigability has varied over the history of the artificial entrance.

Figure 1 The Gippsland Lakes, Victoria, Australia – Location

Figure 2 The Gippsland Lakes catchment
Figure 3 The Gippsland Lakes artificial entrance and the township of Lakes Entrance
Photograph by the author, 2005

Figure 4 Commercial fishing vessels at Eastern Harbour, Cunninghame Arm, Lakes Entrance
Photograph by the author, 2005
The location of the area digitally modelled using GIS (ESRI ArcGIS 9) is depicted at Figure 5. The study area includes the artificial entrance channel (called the Entrance Channel), and the lower section of the Hopetoun and Reeves Channels. Various coastal engineering structures are present within the study area, including seawalls (refer Figure 6) and groynes (refer Figure 7), and these have been emplaced primarily in order to direct ebb-tidal flows through the artificial entrance in attempts to enhance sediment scouring across the flood and ebb-tide deltas (Bird and Lennon, 1989).
Figure 6 Seawall along the Reeves Channel at Bullock Island
Photograph by the author, 2005

Figure 7 Rigby Island groynes
Photograph by the author, 2005
METHODOLOGY

TIN models were created from analogue to digital conversion of hydrographic charts, sourced from Gippsland Ports Authority archives, for the time period January 1998 to January 2005 (see Table 1). By way of the data flow path shown in Figure 8, the following outputs have been generated:

A. time-series digital elevation models (DEMs), from which changes in the nature and distribution/bulk of the flood tide delta could be visualised and also used for;
B. time-series volumetric quantification of morphometry changes (by use of the ‘Cut and Fill’ function), and;
C. time-series mapping of morphological change distribution.

The accuracy concerns with the use of Grid DEMs referred to by Chang (2004: 147) led to the development and use of only TIN DEMs for the analysis reported in this paper. Upon completion of initial TIN DEM construction, all models were converted to layer files in ESRI ArcMap to reflect the same depth value colour ramp. Direct visual comparison between models is facilitated by use of common georeference and depth legend.

Ultimately, it is the ‘Cut and Fill’ function that enables convergence of all data processing for derivation of model-dependent net time-series volumetric flood-tidal delta change. Using this tool, the bathymetric contours of a pair of TIN DEMs can be compared so that volumetric (m³) differences can be estimated, and bathymetric change derived. Construction of a Cut and Fill ‘analysis mask’ (consisting of a polygon shapefile constructed in ArcCatalog and ArcMap) allowed uniform sections of the study area to undergo Cut and Fill analysis. Thus, time-series DEMs of similar bathymetric coverage could be readily compared to one another, revealing the amount of net sediment gain or loss between successive hydrographic surveys. The analysis mask used in this study is depicted at Figure 9.

It should be noted that all area and volumetric figures derived from Cut and Fill analysis of study area DEMs are model dependent. Inherent and introduced data errors may well have affected the accuracy of the input data (DEMs). The proximity of hydrographic data survey timings and locations are basically undocumented, and this is a variable factor that should be considered when assembling data on net volumetric change. The seasonal timings of hydrographic surveys must also be noted, because the relative significance of dynamic environmental forcings/regimes (and their effects upon channel bathymetry and sediment volumes) will differ between surveys. Thus, a linear volumetric gain/loss trend between DEM ‘snap-shots’ should never be assumed.
Table 1 Chart and analogue to digital conversion details for individual hydrographic charts

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<tr>
<th>Date of Survey</th>
<th>Survey Method</th>
<th>Chart Datum</th>
<th>Scan Res.</th>
<th>GCPs Used</th>
<th>Average RMS Error</th>
<th>Data Point Quantity</th>
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Figure 8 Concise project data flow path
RESULTS

THE 1998 FLOOD EVENT: DESCRIPTION, VISUALISATION AND SPATIAL ANALYSIS

The rainfall event that led to the June 1998 floods at Lakes Entrance (refer Figure 10) was largely confined to the catchments of the unregulated eastern rivers (Tambo, Nicholson, Mitchell), which are situated closer to the artificial entrance area than the now highly regulated western rivers (Thomson and Latrobe). Rooney (1998) relates that during this event (June 22-24, 1998), heavy sustained rain over Gippsland was caused by the development of an intense low pressure system near the coast of New South Wales. This low pressure system displayed the typical characteristics of a Type 2 Australian East Coast Cyclone (e.g. see Sturman and Tapper, 2001, 192) and moved south along the coast from NSW into the East Gippsland region. Research by Tan et al. (2002) found that streamflows from eastern rivers dominated Gippsland Lakes inflows over the course of this event, contributing a combined flow of 320,000 ML/day. This resulted in the highest water levels for the past 25 years at Lakes Entrance (+1.2 m AHD). Levels of above 0.8 m AHD were sustained for a period of three days. Further, and as McMaster (1998) relates, the water level reached this maximum height (+1.2 m AHD) when the peak of the incoming spring tide met the outgoing floodwaters on the evening of 24 June 1998. Thus, damaging flooding of low-lying areas in the Lakes Entrance township was sustained (refer Figure 11). It is clear that such a combination of forcing factors can re-occur in the future, and that the only factor which might be readily reversed is the net increase in volume of the flood-tide delta.
Figure 10 Heavy floodwater discharge at the artificial entrance, late June 1998
Courtesy East Gippsland News, (June 1998) Bairnsdale, Victoria

Figure 11 Floodwaters at the Sherwood Lodge Motel, Lakes Entrance, 25 June 1998
Courtesy G. Kyriakou
Visualisations representing the hydrographic chart compiled on 23 January 1998 (pre-floods) (refer Figure 12) show that throughout the Entrance, Reeves and lower Hopetoun Channels, depths are shallow. A visualisation denoting (via depth shading) all depths of under 1.5 meters (Chart Datum – 0.537 m below AHD) shows clearly the location of shallow water areas (refer Figure 13). A well-developed flood-tidal sand accumulation area between Rigby and Bullock Islands is present, with a shoaling area extending across the Reeves Channel at this point. In addition, well developed flood-tidal sediment depositional areas are clearly evident in the Reeves Channel immediately upstream of the entrance to the North Arm. The Entrance Channel is also very shallow, and a large sand spit in the Entrance Channel (adjacent to the western entrance pier head) has developed (refer Figure 14 and 15). This sand body clearly constricts the Entrance Channel at this point.

**Figure 12** Oblique 3D visualisation of TIN DEM for 23 January 1998. Reeves Channel in foreground, Entrance Channel in background, facing southeast from above Kalimna towards Bass Strait

**Legend**

<table>
<thead>
<tr>
<th>Depth Range</th>
<th>Color</th>
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<tr>
<td>-1.000 - -0.5</td>
<td>Light green</td>
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<tr>
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<tr>
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<tr>
<td>-17.000 - -16.5</td>
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</table>
Figure 13 Depth shading of 2D DEM visualisation for 23 January 1998 (all depths shallower than –1.5 m CD coloured yellow)
Figure 14 3D visualisation of sediment accumulation adjacent to western entrance pier head in the Entrance Channel, January 1998
Following the high water levels of June 1998, a hydrographic survey of the study area was undertaken over 30 June - 1 July 1998. Reference to the derived post-flood DEM visualisation at Figure 16 shows that Rigby Island shorelines have retreated, and the tidal scour holes at Groynes 1 and 2 have deepened. Major flood-tidal depositional areas along the Reeves Channel remain (or have been re-deposited after floodwaters subsided during flood-tides). Sediment scouring has taken place along the seawall at Bullock Island. Considerable sediment scouring has also taken place along the lower Hopetoun Channel above its confluence with the Entrance Channel. Floodwaters have considerably deepened the Entrance Channel, and removal of the sand spit near the western entrance pier head has taken place.

Cut and Fill analysis of DEMs shows that between 23 January 1998 and 30 June - 1 July 1998, a net estimated 169,772 m³ of sediment was removed from the study area channels, to a large extent due to the scouring effects of floodwaters (refer Table 2).

<table>
<thead>
<tr>
<th>DEM Interval</th>
<th>Volumetric Gain (m³)</th>
<th>Volumetric Loss (m³)</th>
<th>Net Vol Gain/Loss (m³)</th>
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<td>232043</td>
<td>-169772</td>
</tr>
<tr>
<td>30 Jun / 1 Jul 1998 – 3 May 1999</td>
<td>255797</td>
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</tr>
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<td>23 Jan 1998 – 17/18 Jan 2005</td>
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Table 2 Sediment loss/gain, Entrance and Reeves Channels, 23 January – 1998 to 17/18 January 2005
Figure 16 3D TIN DEM visualisation of Reeves and Entrance Channels for 30 June/1 July 1998 (post-floods). Reeves Channel in foreground, Entrance Channel in background, facing southeast from above Kalimna towards Bass Strait
POST-1998 MORPHOLOGICAL CHANGE

By May 1999, some ten months after the June 1998 flood event, volumetric analysis using Cut and Fill reveals an estimated net total of 188,671 m$^3$ of sediment had been re-deposited in the channels, which more than replaced the documented sediment losses following the June 1998 flooding (refer Table 2). Visualisation of three-dimensional oblique DEM images for May 1999 also supports this volumetric data, with evidence of extensive channel infilling apparent (refer Figure 17). Similar analysis of the July 2000 DEM reveals that between May 1999 and July 2000, an estimated 14,679 m$^3$ loss of sediment took place (refer Table 2 and Figure 18).

Data supplied by Slurry Systems Marine Pty. Ltd. (2005) indicates that between January 1999 and January 2005, various sediment management regimes (encompassing ‘sand transfer’ (refer Figure 19) and ‘sand bypass’ operations) removed a recorded 996,886 m$^3$ of sediment from the Entrance and Reeves Channels. It should also be noted that during the period January 1999 and October 2001, whilst a recorded 143,636 m$^3$ of sediment was removed from Channels in suction dredging operations by Slurry Systems Marine, the Gippsland Ports dredger Sandpiper was also employed in dredging operations (refer Figure 20). During this period, the Sandpiper possessed no form of volumetric measuring equipment (SSPL, 2005) and thus, it is likely that a greater total volume of sediment than is recorded would have been removed from the channels.

Over 17–18 January 2005, a hydrographic dataset of the study area was compiled by Gippsland Ports. This dataset was subsequently digitised and compared to the June 2000 DEM for Cut and Fill volumetric change analysis. Results show that a net estimated 92,289 m$^3$ of sediment deposition had taken place over the period (refer Table 2), despite the large total of sediment removed from the inner channels via sediment management strategies over this period. Visual DEM analysis of the 2005 model supports volumetric findings (refer Figure 21). Depth shading analysis of the 2005 DEM, revealing all depths under 1.5 m CD, shows in clear detail the increased extent of flood-tide delta shoaling areas (refer Figure 22).
Figure 17 3D TIN DEM visualisation of Reeves and Entrance Channels for 3 May 1999. Reeves Channel in foreground, Entrance Channel in background, facing southeast from above Kalimna towards Bass Strait.

Legend

-0.500 - 0
-1.000 - -0.5
-1.500 - -1
-2.000 - -1.5
-2.500 - -2
-3.000 - -2.5
-3.500 - -3
-4.000 - -3.5
-4.500 - -4
-5.000 - -4.5
-5.500 - -5

-6.000 - -5.5
-6.500 - -6
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-7.500 - -7
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-21.500 - -21
-21.780 - -21.5

ANALYSIS OF PRE/POST FLOOD BATHYMETRIC CHANGE ARTICLES
Figure 18 3D TIN DEM visualisation of Reeves and Entrance Channels for 14-15 July 2000. Reeves Channel in foreground, Entrance Channel in background, facing southeast from above Kalimna towards Bass Strait.
Figure 19 Lakes Entrance Sand Transfer System

Figure 20 The Gippsland Ports cutter-suction dredger Sandpiper, operating in the Cunninghame Arm, May 2004
Photograph by the author
Figure 21 3D TIN DEM visualisation of Reeves and Entrance Channels for 17/18 January 2005. Reeves Channel in foreground, Entrance Channel in background, facing southeast from above Kalimna towards Bass Strait.
Figure 22 Depth shading of 2D DEM visualisation for 17/18 January 2005 (all depths shallower than –1.5 m CD coloured yellow)
SUMMARY OF OVERALL FLOOD-TIDE DELTA SEDIMENT GAIN/LOSS – JANUARY 1998 TO JANUARY 2005

Volumetric comparison between the January 1998 and January 2005 DEMs shows that a net 107,591 m³ of sediment had been deposited over this time period (refer Table 2). Locations of overall sediment gain and loss within the Entrance and Reeves Channel flood-tide delta over this time period can be viewed in the resultant generated Cut and Fill diagram (refer Figure 23). Comparative two-dimensional DEM visualisations showing bathymetric evolution within the channels over the period January 1998 and January 2005 are provided at Figure 24.

Figure 23 Areas of sediment gain/loss derived through Cut and Fill volumetric analysis, Entrance and Reeves Channels, 23 January 1998 – 17/18 January 2005

Author
Figure 24: Comparative two-dimensional DEM visualisations of Entrance and Reeves Channel bathymetric change, January 1998 – January 2005.
DISCUSSION

Analysis of the five DEMs for the seven-year period 23 January 1998 – 17/18 January 2005 shows a marked net sediment accretion trend within the study area. Much sediment was removed following the June 1998 flood event, however in the ten months elapsed between the collection of successive hydrographic datasets (July 1998 – May 1999), rapid sediment accretion took place. Between May 1999 and July 2000, minimal net removal of sediment took place within the channels. The interval spanning July 2000 and January 2005 again saw net flood-tide delta sediment accretion take place, despite extensive engineered management efforts to remove sediment from the area. Both visual and volumetric analysis has shown that the flood-tide delta is now even more voluminous (and the water across it shallower) than it was in January 1998.

Catchment environmental and management changes (especially over the past 30 years – e.g. see Wheeler, 2005) such as stream regulation and inter-regional water transfer (via the Thomson Dam), irrigation scheme expansion (at the Macalister Irrigation District), and entirely documentable falling rainfall trends, has caused a reduction in the level of streamflow inputs to the Gippsland Lakes. This reduction has caused the significance of ebb-tide flows at the artificial entrance to diminish. Clearly, new trends in bathymetric sedimentological equilibrium would be expected to emerge with any alteration to the relative significance of ebb and flood tidal flow at the artificial entrance area.

It has been well documented that increased sedimentation at coastal lagoon/inlet entrances will result from loss of streamflow augmentation to ebb-tide flows (e.g. see Bird, 1967; Bird, 1984; Bird, 2000; Davies, 1980; Pethick 1994; Smakhtin, 2004). In other coastal areas of Australia, the effect of catchment streamflow reduction at tidal delta areas has been documented. A case study by Bourman et al. (2000) exemplifies this phenomenon. Progressive fresh water appropriation in the Murray-Darling catchment for agriculture has reduced Murray River estuary fresh water inflows by 75%. Extensive accumulation and consolidation of flood-tidal deltaic deposits has been the result.

Another potential contributor to flood-tide delta accretion is sediment management regime changes, in this case after the deployment of the side-cast dredger April Hamer, which has been almost permanently operational in the artificial entrance area since 1977. The dredging methods of the April Hamer across the ebb-tide delta in Bass Strait (refer Figure 25) are considered by Bird (2000, 238) to enhance flood-tidal delta nourishment within the inner channels. In sediment transport terms, the side-cast dredging operation promotes continued suspension of sediment throughout the water column, which simulates the sediment entrainment effect of high wave energy conditions at the ebb-tidal delta (even in calm sea conditions) during dredging operations. Thus, the scope for flood tide entrainment to augment the volume of the flood-tide delta is enhanced.

Research on Gippsland Lakes artificial entrance flood-tide delta accretion by Wheeler (2005), Wheeler and Peterson (2005a), and Wheeler and Peterson (2005b) for the period 1889-2005 shows that an inexorable growth in the flood-tide delta is apparent: slow during the period 1889-1975 (in the survey interval that encompasses the Macalister Irrigation District development and expansions between 1924-1959 (SRW, 2005)), and faster since the introduction of the April Hamer and the commencement of large-scale inter-regional water transfers after the commissioning of the Thomson Dam in 1983 (refer Table 3). Evidently, significant modification to sediment
transport and depositional processes at the artificial entrance area occurred over the relatively short time period between 1975 and 1985. The continuation of this rapid flood-tide delta accretionary trend to January 2005 indicates the importance of sediment management and catchment inflow regimes to the nature of the flood-tide delta form created at any time.

The results from this paper hold particular interest for all catchment stakeholders, in particular for Gippsland Ports and for the Gippsland Coastal Board. The growth of the flood-tide delta has imposed progressively greater demands on the dredging programme, and clearly, the shallowing effect of the balance of forces converging at the flood-tide delta is no longer to be mitigated within the present publicly funded maintenance dredging programme. It is apparent that continuation of these management strategies into the future (as proposed by Gippsland Ports (2005) in their recently released Draft Long-Term Management Plan for Dredging) will not significantly reduce the flood-tidal delta volume. The failure of mitigation strategies between January 1999 and January 2005 to reduce the size of the flood-tide delta, despite the documented removal of nearly 1,000,000 m$^3$ of sediment, supports this finding.
The observed and quantified development of the flood-tide delta since the June 1998 catchment flood event also holds particular implications for future catchment management. Cut and Fill analysis shows that there has been an increase of $107,591 \text{ m}^3$ in delta volume over the time period January 1998 to January 2005 (refer Table 2), and visual depth shading analysis shows the nature and extent of delta growth over this period (refer Figures 13 and 22). It is clear that this documented flood-tide delta expansion and consolidation increases the vulnerability of infrastructure in low-lying areas of the Lakes Entrance township to future Gippsland Lakes catchment flood events. When viewed in the context of climate change and anticipated impacts, Gippsland Lakes catchment flood events may become increasingly prevalent. Climate change predictions by the CSIRO suggest that in Gippsland, extreme daily rainfall events may become more intense and frequent (DSE, 2005).

The application of results reported in this paper is relevant for future Gippsland Lakes catchment Integrated Coastal Zone Management (ICZM) (e.g. see Cicin-Sain and Knecht, 1998). Integration is clearly called for, and is long overdue in this instance, because the flood-tide delta

<table>
<thead>
<tr>
<th>Calendar Year</th>
<th>Inflows to Thomson Reservoir (ML)</th>
<th>Total Downstream Releases from Thomson Reservoir (ML)</th>
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<tr>
<td>1984</td>
<td>219000</td>
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<tr>
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<td>46500</td>
</tr>
<tr>
<td>2003</td>
<td>210500</td>
<td>46500</td>
</tr>
</tbody>
</table>

Table 3 Thomson Dam water transfers and downstream discharges, 1984-2003 (all figures rounded to nearest 500 ML) after Melbourne Water (2004)
CONCLUSIONS

Two and three-dimensional DEM visualisation and ‘Cut and Fill’ volumetric modelling shows flood tide delta accretion in the Entrance and Reeves Channel has continued after the June 1998 Gippsland Lakes catchment flood event, despite the deployment of engineered sediment management regimes. This net sediment accretionary trend in the channels to January 2005 indicates that only restoration of the ebb-flow dominance (e.g. by restoring the streamflow input to the lakes from the catchment) and/or significant engineering input is likely to reverse this accretionary trend. Implications for future management refer to the need for reducing accretion, and for effective removal of flood-tide delta sediments, to facilitate future catchment floodwater escape through the Reeves and Entrance Channels to Bass Strait.

In that it is probably impossible for Gippsland Lakes catchment authorities to reinstate natural catchment streamflow regimes in the future (so as to enhance ebb-tidal sediment scouring), the use of coastal engineering options will no doubt be proposed. The most sustainable strategies in these terms will surely be those that utilise and harness existing natural processes currently in operation. Clearly, sediment supply linkages between the offshore ebb-tide delta in Bass Strait, and the flood-tide delta, must be negated to create a sustainable sediment management regime.

Adoption of a three-dimensional modelling approach has been shown here to 1) yield more potential for future bathymetric monitoring than can the use of analogue hydrographic charts, and 2) create potential for a much greater stakeholder understanding of coastal issues. Digital spatial data handling and spatial analysis in any future decision support is clearly called for.
ACKNOWLEDGEMENTS

The assistance of the following organisations and individuals is gratefully acknowledged: Gippsland Ports, for primary hydrographic data provision; academic staff at the Centre for GIS, School of Geography and Environmental Science, Monash University, Melbourne; Gippsland Ports staff Mr Bertrand Smedts, Ms Gail Bolding, Mr Alan Smith and Mr Peter Hinksman; Mr Ray Wheeler for aerial photography acquisition; and the two academic referees of this paper.

REFERENCES


