Proceedings of the Spatial Science Institute Biennial International Conference (SSC2007),
Hobart, Tasmania, Australia, 14-18 May 2007 (peer-reviewed paper)

MAPPING RELATIVE INUNDATION VULNERABILITY OF LAND PARCELS ON LOW-LYING GROUND: EXEMPLIFICATION WITH A PHOTOGRAMMETRICALLY-DERIVED DEM-BASED MODEL OF LAKES ENTRANCE, VICTORIA, AUSTRALIA

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ABSTRACT

Using the townscape of Lakes Entrance (Victoria, Australia) as a case study, it is shown how, via adoption of a suitable digital spatial data handling process path, a high-resolution bare earth terrain model suitable for flood and storm surge/storm tide inundation modelling of low-lying coastal townscapes can be derived photogrammetrically. Model applications refer mostly to urban area planning and include: a) possible future inundation extent estimation/prediction with individual land parcel resolution; b) current and future land-use planning; c) integration into local emergency services information systems and contingency planning; d) provision of rapid stakeholder 'mental map' stabilisation; e) promotion of public and private stakeholder consensus-building, and f) for immediate assessment (including land parcel attribute documentation and geographical partitioning) of the relative inundation risk implications for insurance purposes. The exemplification presented here indicates the emergence of new incentives for corporate spatial database building and integration in local government and other tertiary-level public-service agencies that are tasked with supporting integrated coastal zone management (ICZM) initiatives in Victoria.

BIOGRAPHY OF PRESENTER

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INTRODUCTION

The inundation of low-lying coastal land/water interface areas adjacent to coastal lagoons, tidal inlets or estuaries constitutes an ever-present threat (Ahmer *et al.*, 2005; Townend and Pethick, 2002). Many such areas have been settled with high-value real-estate. Inundation conditions in such coastal areas often become apparent during the convergence of what Tan *et al*. (2002) label as environmental ‘forcings’, primarily comprising of high influent catchment streamflows (caused by periods of extreme catchment rainfall), high coastal tidal and sea levels, and strong regional wind-effects which act to temporarily raise water levels in down-fetch lake or estuary areas. Inundation may also be sustained by extreme storm events, which can generate local or regional elevated sea level conditions known commonly as storm surges (refer Bird, 2000: 20-21; McInnes *et al*., 2005). Augmentation by highest astronomical tides (HAT) often exacerbates this problem. The Gippsland Lakes (situated in East Gippsland, Victoria, Australia) (refer Figure 1) is one such extensive coastal lagoon system whose shores harbour extensive low-lying areas subject to periodic inundation. At the Lakes Entrance township, urban development extends over an area that is currently classed as 'land subject to inundation' (DSE, 2006). Estimates of the 5% (1 in 20 year flood event), 2% (1 in 50 year flood event) and 1% (1 in 100 year flood event) Annual Exceedence Probability (AEP) flood levels for key locations around the Gippsland Lakes have been provided by Grayson *et al.*, 2004. This data has been deployed in support of digital inundation modelling of the Lakes Entrance township area, to provide accurate determination of the estimated maximum extents of any possible future inundation scenario.

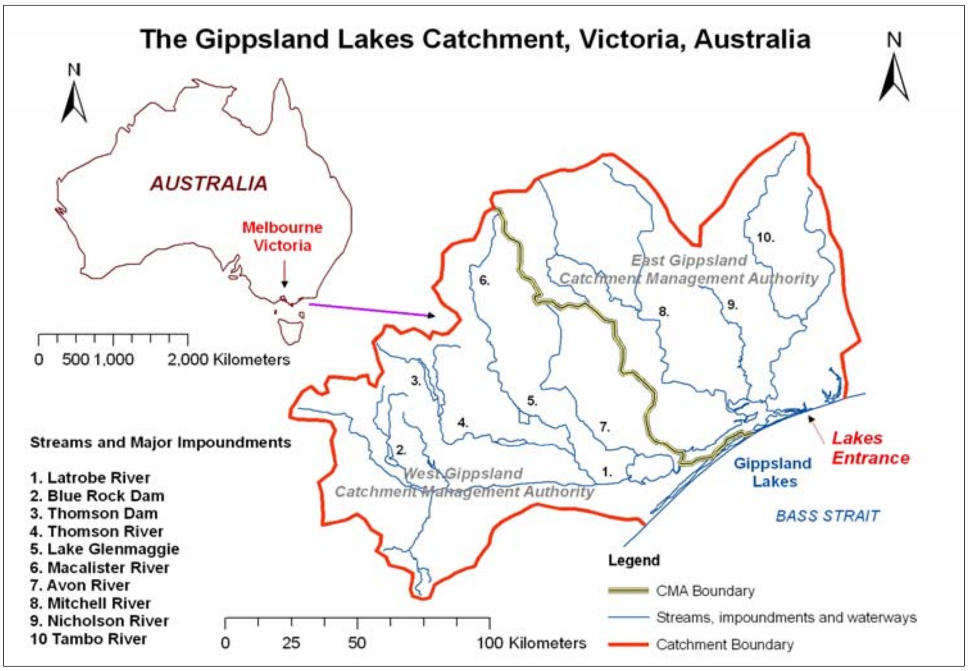

Fig.1: The Gippsland Lakes catchment, Victoria

Exemplified in this case study are the use of digital photogrammetry methods for digital elevation model (DEM) extraction, and subsequent high-resolution two and three-dimensional inundation event scenario modelling for the Lakes Entrance townscape. Whilst the utility of DEM extraction via digital photogrammetry methods for inundation extent modelling has been previously exemplified (e.g. see McMahon *et al*., 2005), the modelling approaches taken in this case study reflect the adaptation required during data handling to address the particular difficulties faced when attempting to develop an accurate 'bare-earth' DEM for a coastal low-lying (<1.8m AHD) urban landscape, where negligible primary height data (e.g. contours, spot heights) are available for inclusion into the data process flowpath. The accurate spatial evaluation of coastal zone urban inundation risk with individual 'land parcel' resolution, can provide spatial decision support for inclusion in local council planning processes. Such data can also be deployed to provide a rational basis for the development of coastal inundation management policy, including emergency response contingency planning, and public flood awareness and education (refer Reeve, 1998, and Buckle, 1999). Additionally, insurance companies must fully understand the estimated frequency and extent of the inundation risks they may insure (Sanders, 2005). An understanding of relative inundation risk to individual properties is essential in order to set an insurance premium (IAG, 2005).

THE STUDY AREA – THE LAKES ENTRANCE TOWNSHIP

Fig.2: The Lakes Entrance township

Lakes Entrance, situated in the East Gippsland region of Victoria, Australia (refer Figure 2), is located adjacent to the Gippsland Lakes artificial entrance. Engineered through a Holocene sandy barrier formation (refer Bird, 1965) over an extended period in the late nineteenth century, this artificial outlet replaced a natural coastal lagoon entrance to the Gippsland Lakes, whose outlet location migrated between 5-8 kilometres to the east of the artificial entrance. The history of European settlement in the region surrounding the current Lakes Entrance urban area has been synthesised in detail by Bird and Lennon (1989). In 1878, the first suburban allotments in the present Lakes Entrance area were surveyed. The progressive development of the Lakes Entrance urban townscape has taken place upon low-lying land, which Bird (1965: 41) terms an inner-sandy barrier. Since its original deposition as an extensive outer sandy barrier across a marine embayment at a Late Pleistocene stage, this inner-barrier has been dissected by subsequent denudation, and protected from swell wave attack by the development of an outer Holocene sandy barrier formation since the culmination of the Flandrian Transgression at approximately 6000 years B.P. (refer Bird, 2000). As a fossil barrier, it persists to the present as a chain of islands, extending seaward of the marginal bluff that marks the pre-depositional interglacial marine limit.

Grayson *et al.* (2004) relate that there are limited historical observations of flood levels at Lakes Entrance, with three occasions being recorded over the past century when water heights of 1.6-1.7 metres AHD were experienced. The Victorian Flood Management Strategy (DNRE, 1998: 74) identifies the flood event of 1952 (1.8m AHD) as being the largest on record. The most recent inundation event at Lakes Entrance occurred in late June 1998, and was caused by heavy sustained rainfall in the eastern sections of the Gippsland Lakes catchment (Rooney, 1998). Further, McInnes and Hubbert (2001) have identified a strong correlation between such extreme water levels at Lakes Entrance, the passage of cold fronts across Bass Strait, and the presence of East Coast and Tasman low pressure systems. 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. The highest water levels in the past 25 years at Lakes Entrance (1.3 m AHD - Grayson *et al.* 2004) were sustained during this flood event, and water levels of above 0.8 m AHD were sustained for a period of three days (Tan *et al.*, 2002). McMaster (1998) relates that the water levels at Lakes Entrance reached their maximum height when the peak of the spring (flood) tide through the artificial entrance met the outgoing floodwaters on the evening of 24 June 1998. Damages in the East Gippsland region from resultant flooding totalled $AU 77.5 million (Yeo, 2002).

INUNDATION SCENARIO RECOMMENDATIONS FOR LAKES ENTRANCE

Much of the terrain upon which the Lakes Entrance township has developed is situated below 1.8m above Australian Height Datum (AHD). With reference to the estimated Annual Exceedence Probability (AEP) inundation heights that have been recommended by Grayson *et al.* (2004: 6) (refer Table 1), it is clear that varying areas of the Lakes Entrance townscape would be at risk of inundation under these estimated future scenarios. Estimated future storm surge/tide return heights modelled by McInnes *et al.* (2005) (for the Ninety Mile Beach at Lakes Entrance), may also cause inundation of sections of the Lakes Entrance townscape. However, McInnes *et al.* (2005) suggest that elevated sea levels at the open coast and within the Lakes would only be comparable for longer-lived and more extreme events.

Tab. 1: AEP levels for Lakes Entrance.

AEP Scenario	Lakes Entrance Inundation Height
5% (1:20 year)	1.3 m AHD
2% (1:50 year)	1.6m AHD
1% (1:100 year)	1.8m AHD

Maps of ‘land subject to inundation’ (LSIO) at Lakes Entrance are part of the East Gippsland Planning Scheme (DSE, 2006). The Victorian Government defines the LSIO as an area that can be ‘used as an interim measure to identify flood-affected areas where detailed information to define the floodway is not available’ (VPP, 2000). According to the East Gippsland Planning Scheme (EGPS) (2006: Clause 44.04), the purpose of the LSIO is to a) implement the State Planning Policy Framework and the Local Planning Policy Framework, including the Municipal Strategic Statement and local planning policies; b) identify land in a flood storage or flood fringe area affected by the 1 in 100 year flood, or any other area determined by the floodplain management authority; c) ensure that development maintains the free passage and temporary storage of floodwaters, minimizes flood damage, is compatible with the flood hazard and local drainage conditions and will not cause any significant rise in flood level or flow velocity; d) reflect any declaration under Division 4 of Part 10 of the Water Act (1989), where a declaration has been made, and e) protect water quality in accordance with the provisions of relevant State Environment Protection Policies, particularly in accordance with Clauses 33 and 35 of the State Environment Protection Policy (Waters of Victoria).

Whilst the current LSIO for the Lakes Entrance township area is designed to represent the 1 in 100 year inundation extent (1.8m AHD), estimated inundation extents of recommended 1 in 20 and 1 in 50 year inundation heights, are not able to be visualised by stakeholder groups. Spatial data handling offers the chance to construct a digital base-model of the bare-earth terrain for Lakes Entrance, to provide ‘user-defined’ inundation scenario modelling. Kunapo (2005) suggests that deployment of high resolution, land-parcel scale bare-earth DEMs is a pre-requisite for spatial decision support in Local Government Area (LGA) planning. Results from this type of modelling can potentially be utilised to better understand the nature of estimated inundation extents under recommended future inundation scenarios for Lakes Entrance.

METHODOLOGY

As Sties *et al.* (2000) note, DEMs have traditionally been produced either by survey methods, or by the use of stereo photogrammetry methods. Whilst the use of airborne LiDAR data for DEM extraction is now commonplace (e.g. see Reurebuch *et al*., 2005), there is an absence of LiDAR data for the project study area. There also exists a lack of both contour and spot-height data for the study area contained in the Victorian Spatial Data Infrastructure (VSDI) database, and within the spatial databases of local management agencies. Thus, for the purposes of this research, stereo photogrammetry methods offered the only available alternative for the development of an accurate bare earth DEM for inundation extent modelling. A concise project data and information flow path as used in this project is provided at figure 3.

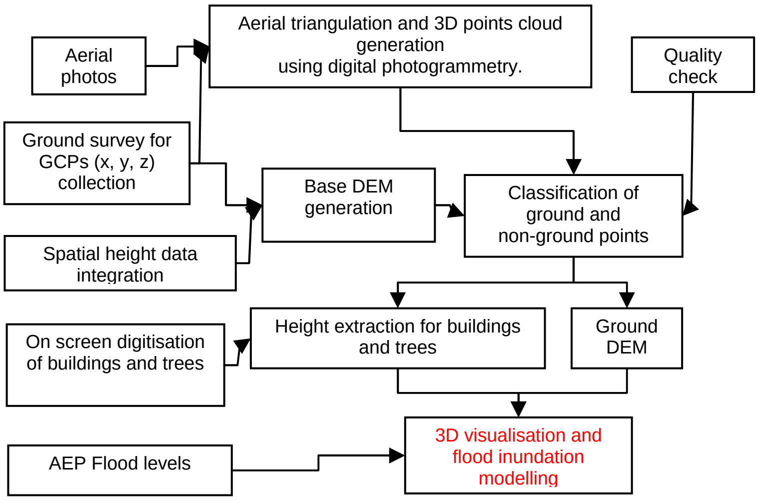

Fig.3: Study Process Flow Diagram

For DEM building, collection of the most credible vertical measurements (‘z’ values) for ground control points (GCPs) is crucial (Kunapo *et al.*, 2005). Typically, this data is not readily available in the same information flows used to assemble ‘x’ and ‘y’ information. Field work was carried out to obtain GCPs using real time kinetic (RTK) GPS. Once GCPs were defined and the aerial triangulation performed, 3D point clouds were generated. These 3D point clouds included non-ground objects which were separated to develop the ground DEM. The process flow diagram identified by Kunapo (2005) was implemented to generate the base DEM for this study area, and a similar process was applied for initial filtering of ground and non-ground points. Due to the questionable accuracy of the spatial height data with which the base DEM was made, further validations were applied. Validation of the DEM was carried out via manual survey methods using a ‘dumpy’ level and staff from permanent survey marks. Twenty-four random locations were surveyed over different areas of the study area, and the results obtained were cross-checked with the bare-earth DEM (refer Table 2). Manual validation also allowed certain GCP locations to be ‘height-checked’ with relation to known permanent survey marks, thus providing confidence in the GCP height values obtained via dGPS survey.

Using ArcGIS, on-screen digitisation was carried out to digitise buildings and trees from the ortho-photo, and the classified 3D point cloud was used to extract feature heights. From the resultant bare-ground DEM was derived study area 0.1m contours, and inundation extent polygons for each inundation scenario as required.

Tab. 2: Recorded differences between manual survey and bare-earth DEM

Location	Difference +/- (mm)	Location	Difference +/- (mm)
1	31	13	43
2	-14	14	-3
3	-42	15	-21
4	3	16	-18
5	36	17	37
6	-9	18	-44
7	13	19	-3
8	-13	20	-7
9	4	21	-3
10	81	22	-10
11	14	23	-76
12	38	24	7

APPLICATION OF THE DEM

Inundation modelling refers to a uniform elevation of water heights in the North Arm, the Cunninghame Arm and the Reeves Channel surrounding the Lakes Entrance township, to the level of the recommended Annual Exceedence Probability (AEP) scenarios (refer Table 1). However, floodwater behaviour in an urban environment (e.g. refer Hingray *et al*., 2000; Tanguy *et al*., 2001; Aronica and Lanza, 2005) impose more complexity upon scenario modelling than can be represented by simple application of AEP levels. The duration of each respective flood height 'peak', which would be sustained by a combination of environmental forcings, will also influence the area of maximum inundation extent. For instance, and as Grayson *et al*. (2004: 26) remind us, tidal effects play a critical role in determining the duration of flood height peaks.

Local residents who have experienced prior flooding events at Lakes Entrance relate that the inundation of some low-lying township areas occur, in the first instance, due to rising lake waters 'backing up' the stormwater pipe network, and discharging into terrestrial areas (e.g. streets) via stormwater inlets (e.g. grates, roadside gutter stormwater pit inlets), before lake levels reach heights sufficient to 'overtop' seawalls or breach shoreline areas (Goff Pers.Comm., 2006). A survey of specific areas of the current urban stormwater pipe network at Lakes Entrance, where flooding is known to occur, has shown that 'backflow' and discharge of lake water through stormwater inlets is the cause of initial inundation of low-lying areas. Accordingly, modelling results presented in this paper reflect the theoretical *maximum extents* for respective inundation scenarios, which may or may not be reached by floodwaters due to a) water heights surrounding the township not being uniformly elevated by environmental forcings; b) the proximity of low-lying areas to stormwater pipe and road networks, which may act as a ‘conduit’ for the travel of floodwaters from the lakes; c) the amount of direct rainfall falling at the Lakes Entrance township, which may cause ‘pooling’ of water in low-lying areas and possibly contribute to failure of the stormwater network; d) the complex nature of urban environment floodwater behaviour, and e) the duration of flood height ‘peaks’.

The highest inundation extent for the late-June 1998 Lakes Entrance floods have been listed as respectively 1.3m AHD by Grayson *et al.* (2004), and 1.2m AHD by Tan *et al.* (2002). In comparison, the West and East Gippsland Catchment Management Authorities (CMAs) list the maximum flood height experienced at Lakes Entrance during this event as 1.6m AHD (WGCMA, 2006). The derived two and three dimensional visualisations for the 5% AEP estimated inundation event (1.3m AHD) may closely approximate (in some townscape areas) the actual 1998 flood event highest inundation extent. Comparisons of the modelled inundation extents with the highest actual 1998 flooding extent would be possible at certain locations if suitable oblique or aerial photography of this event existed. However, as many of the photographs of the 1998 floods that do exist have no annotation denoting the timing of image capture, it is impossible to estimate the approximate inundation height depicted in the images. However, for indicative purposes, some images taken during the 1998 inundation event can be compared to the 5% AEP estimated inundation extent derived through modelling. Such comparison provides scope for limited validation of the bare-earth DEM as used for base-modelling. Other historical evidence in the form of information (photographs and anecdotal evidence) from a *Lakes Post* article, published after the flood event (22 July 1998), correlates with sections of the inundation visualisation.

Scenario visualisation (refer Figure 4) shows that large areas of the western end of the township would be more affected by a 1.3m AHD inundation scenario than would the eastern areas of the township. Analysis shows that inundation patterns closely follow both the stormwater pipe and roads network. Clearly, at this flood height, inundation of many township areas would firstly take place via floodwater discharge from stormwater inlet grates and kerbside inlets, prior to the overtopping of seawalls and breaching of shorelines by floodwaters. As the modelled horizontal inundation extent increases in response to vertical flood height increases (from 1.3m AHD to 1.6m AHD, and beyond to 1.8m AHD; refer Figures 5 and 6), further analysis shows that the stormwater pipe network again acts as a ‘conduit’, allowing floodwater inundation of inner townscape areas. Inundation patterns again follow the relatively lower-lying road networks via kerb and channelling.

DISCUSSION

A primary use of data and information presented in this paper relates to applications in support of integrated coastal zone management (ICZM) initiatives (see Cicin-Sain and Knecht, 1998). In this instance, the sharing and ‘integration’ of flood inundation data and information is required between relevant public and private sector coastal zone stakeholders for future coastal area planning and management. The East Gippsland region is positioned within the jurisdiction of the Gippsland Coastal Board (GCB), a regional agency provided for by the Victorian Coastal Management Act (1995), and tasked with both vertical and horizontal coastal zone stakeholder integration. Derived two and three-dimensional model visualisations reported in this paper can support future

ICZM initiatives by providing an effective spatial communication to public and private stakeholders of the nature of estimated inundation extents, or any other ‘user-defined’ flood height scenario. In this way, stakeholder ‘mental-map’ stabilisation can occur (Gould and White, 1974), and stakeholder consensus-building can be promoted (Poitras *et al*., 2003). Correia *et al.* (1998:212) suggest that stakeholder perception and participation are important components of flood hazard awareness and control measures, and to achieve the necessary consensus, the public must be involved in decision-making processes. Eves (2004: 85) suggests that continued public flood awareness in inundation-prone areas is extremely important, due to post-inundation event decrease in public flood awareness, and a loss of public appreciation of flood event impacts. Jankowski *et al*. (2001:125) suggest that activities likely to benefit from support are exchange of opinions and arguments, and potential aggregation of individual solutions into a consensus-based decision.

Local government and emergency management agencies may utilise derived inundation extent maps to help plan for inundation event scenario response. As Buckle (1999:21) relates, to achieve effective service provision, emergency managers need a clear understanding of the phenomena that they must potentially deal with. A greater understanding of estimated inundation extent scenarios can enable relevant managers to develop strategies, such as emergency ‘action plans’,

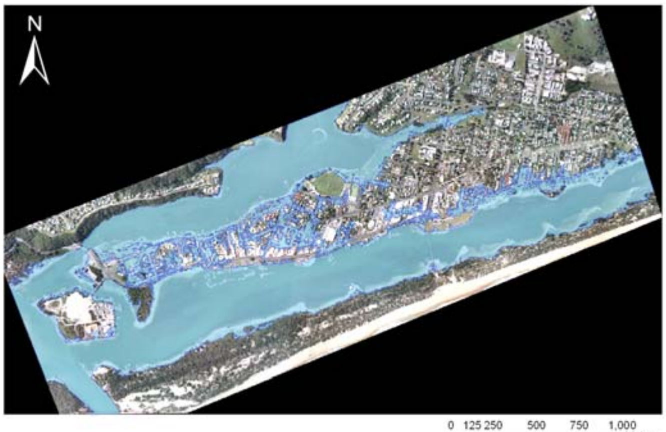

Fig. 4:
Lakes Entrance Township - 5% AEP (1:20 year) Inundation Extent (1.3m AHD)

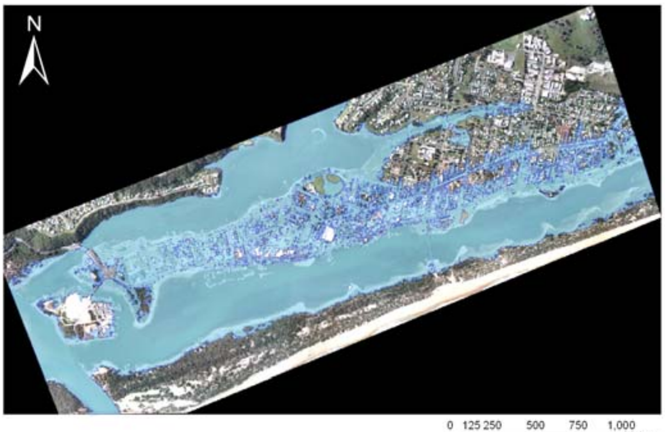

Fig. 5:
Lakes Entrance Township - 2% AEP (1:50 year) Inundation Extent (1.6m AHD)

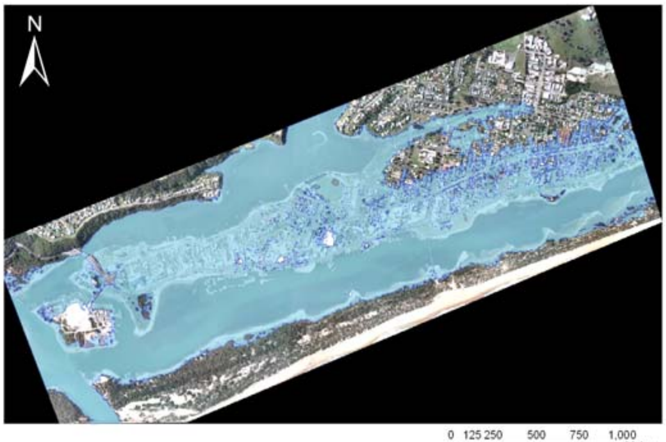

Fig. 6:
Lakes Entrance Township - 1% AEP (1:100 year) Inundation Extent (1.8m AHD)

for maximising public awareness and safety. Further stakeholder consensus-building regarding future potential contingency planning and flood mitigation strategies can be facilitated by deployment of inundation scenario mapping.

Whilst any new real-estate developments within planning zones classed as ‘areas liable to flooding’ at Lakes Entrance are subject to building regulations that specify a building height of 300mm above any flood levels declared under the Water Act (1989), or otherwise determined by the floodplain management authority (unless the authority consents to a lower floor level) (Vic. Building (Interim) Regulations, 2005: 85-7), many extant properties are clearly at vulnerable elevations. The Victorian Planning Provisions (2000) relate that: ‘flooding risk must be considered in planning decisions to avoid intensifying the impact of flooding through inappropriately located uses and developments. Areas affected by flooding should be identified on planning scheme maps, and appropriate controls on the use and development of land introduced through the use of the flood zone and overlays…. Local floodplain development plans should also be prepared and incorporated into the planning scheme to guide decision-making on applications for development on land in the flood zone or overlay’.

Objective number four of the East Gippsland Planning Scheme (EGPS) (DSE, 2006) ‘Identification of Development Constraints Policy’ (Clause 22.09) states it must be ensured that ‘urban and rural areas liable to inundation by the 1 in 100 year flood are identified, and that land use and development in these areas are managed to reduce risks of damage to buildings and works, or of impeding flood flows and free passage of water’. Further, the Development Constraints Policy recognises that appropriate designation of areas subject to flooding/inundation is required in the planning process, and states that: ‘many parts of the Shire are susceptible to flood risk…. Inappropriate use or development in flood-prone areas may lead to effects on the behaviour of floodwaters, as well as damage to structures, roads and communications infrastructure’. Whilst one of the stated objectives of the Development Constraints Policy is to identify and manage land affected by the 1 in 100 year flood, the respective 1 in 20 and 1 in 50 year inundation extents have not been identified and implemented in the EGPS to date.

These respective derived estimated inundation extents can be used for identification of potential hazards to infrastructure. For instance, the inundation of unsealed sewer system manhole covers and individual property overflow relief gullies (see AS/NZS 3500.2.2 2003) may allow floodwater ingress to the sewerage system, and may also permit raw sewage egress to coastal waters. Any illegal cross-connection at property level between the sewerage system and stormwater system can also allow raw sewage egress to coastal waters via stormwater inlets (e.g. kerbside grates or stormwater pits) during inundation events. The Victorian State Planning Policy Framework (2006) stipulates that: ‘planning and responsible authorities should ensure that land-use activities potentially discharging contaminated runoff or wastes to waterways are sited and managed to minimise such discharges and to protect the quality of… estuaries and marine environments’. Clause 35 of the Environment Protection Act (1970) also deals with sewerage management. Areas ‘at risk’ of floodwater ingress to the sewerage system, or sewage egress from the system, can be identified by overlaying Lakes Entrance sewerage system data upon the respective inundation visualisations, thus offering scenario mapping which can provide further spatial decision support opportunities for planning and management agencies.

Smith (2002) suggests that the insurance industry regard flood maps as the most valuable single piece of information, and that to be truly useful, these maps must extend to the level of the worst case event, i.e. the probable maximum flood (PMF). Bodycott and McLuckie (2002:165) relate that excluding abnormal events such as dam break, there are four different causes of flooding in a building. These are listed as due to a) the breakage of pipes or storage tanks, b) water entry from above (e.g. storm damages); c) water rising from ground level due to localised urban runoff, and d) flooding from a stream or channel purely as the result of upstream runoff. The Australian insurance industry has previously insured the losses in categories ‘a’, ‘b’, and ‘c’, however category ‘d’ has traditionally been denied insurance coverage. In Lakes Entrance township areas, it has been established that initial property inundation and damage by floodwaters may be caused by backflow of estuarine waters via the stormwater pipe network. This situation may also, in parallel, contribute to a failure of the stormwater discharge system should heavy, extended rainfall be experienced at the Lakes Entrance township area. Thus, a considerable level of uncertainty currently exists for insurance providers, LGA planners and property owners alike, regarding i.) the initial cause of flooding, and ii.) the relative apportioning of blame to *storm*waters or *flood*waters for inundation damages (i.e. flood causes categories ‘c’ and ‘d’). Eves (2002) relates that in Australia, all building and building contents insurance contain an exclusion clause for any damage caused by natural flooding, if the habitable floor level of the property is below the 1 in 100 year flood level. This scenario remains a major problem in Australia, as a recent assessment by the Insurance Australia Group (2005) suggests: 160,000 Australian homes are currently at risk from a 1 in 100 year flood, with many homes built in areas where flood frequency is higher than 1 in 20 years. Deployment of land-parcel resolution inundation extent mapping for Lakes Entrance is one method by which the relative flood risk to individual properties may be estimated, providing the potential for individual property flood insurance premiums to be determined according to relative levels of flood risk.

Over the longer-term, climate change and associated sea-level change scenarios, and regional land subsidence hold many potential consequences for low-lying Gippsland coastal settlements, including Lakes Entrance. Global mean sea level is expected to rise by 3-30 cm by 2040, and 9-88 cm by 2100 (IPCC, 2001). Walsh *et al*. (2004) relate that sea level rise may a) accelerate the erosion of coastal margins; b) diminish the effectiveness of the buffer provided by the beach, and c) cause an increased incidence of coastal flooding, either by increasing the height of storm surges, or by acting as a higher seaward barrier restricting the escape of flood waters caused by excessive runoff. Any concurrent lowering of coastal land due to subsidence may exacerbate the effect of sea level rise and coastal flooding scenarios. Coastal subsidence in Gippsland is a direct consequence of fluid extraction from the Latrobe Aquifer by Bass Strait oil and natural gas extraction, and of onshore Latrobe Valley open-cut brown coal mining operations (GCB, 2006). There is a significant risk that ongoing lowering of fluid levels in the Latrobe Aquifer will result in land subsidence along the Gippsland coast of between 1-2 metres over the next 70 years (GCB, 2006). Holzer and Johnson (1985) relate that other urban areas in the world have experienced significant flood events due to land subsidence caused by fluid extraction. Further scope for flood hazard uncertainty can be mentioned; Wheeler (2005) suggests that at Lakes Entrance, a potential barrier to Gippsland Lakes floodwater egress through the artificial entrance to Bass Strait has been caused by channel constriction, due to the progressive accretion of flood-tide delta sands. Whilst on 10 November 2005 the Victorian State Government announced an $AU31.5 million package to ‘install a sand management system to keep the Lakes Entrance port open’ (Vic. Govt. 10 Nov 2005), whether the proposed sand management program (Gippsland Ports, 2006) will be either effective or sustainable in the long-term, to maintain a channel system of sufficient depth to allow future Gippsland Lakes floodwater egress to Bass Strait, remains to be seen.

CONCLUSION

The relative estimated inundation extents for AEP scenarios can be seen as exemplifying the deployment of GIS technologies in support of ICZM initiatives. Within the overall context of ICZM, it is clear that GIS has the potential to act as an important tool not only for coastal inundation risk assessment, but also in support of many coastal planning and management issues and problems. In this case, the two and three-dimensional inundation visualisation generation capacity can be used to provide relevant ‘user-defined’ information to all coastal zone stakeholders. In the absence of both LiDAR data and detailed VSDI data, digital photogrammetry is clearly an option for DEM building. In this case, detailed mapping of flood inundation extents is a pre-requisite for i) land parcel inundation hazard assignment, for example, as a probable maximum flood (PMF) mapping system for flood-risk appraisal with land-parcel resolution, and for inclusion in LGA planning schemes for use in future land-use planning; ii) sewer-network asset re-design in the face of changing estuarine hydrology, and iii) stormwater pipe network re-design to remove the estuarine flooding risk that is currently posed to areas of the Lakes Entrance township. Additionally, potential uses of such information refer to stakeholder flood awareness and education, and for emergency services contingency planning. At Lakes Entrance, it is clear that public and private stakeholder integration and consensus will be increasingly required in the future, to plan for the combined effects of climate change, estimated storm surge/tide and flood inundation scenarios, and regional subsidence. These (and other) coastal zone challenges provide future incentives and opportunities for spatial database construction, analysis, maintenance, and data sharing by agencies tasked with ICZM, both in Gippsland and in Victoria.

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