9. DESIGN FLOOD MODELLING – SENSITIVITY ANALYSIS

9.1. Introduction

The following sensitivity analyses were undertaken for the 1% AEP event to establish an understanding of the variability of design flood levels that may occur if different conditions or parameters were adopted:

- *Climate Change (Sea Level Rise) (See Section)*: Sea level rise scenarios of 0.10m, 0.23m, 0.39m and 0.72m were assessed;
- *Climate Change (Rainfall Increase) (See Section)*: Sensitivity to rainfall/runoff estimates were assessed by increasing the rainfall intensities by 10%, 20% and 30%;
- *Time of Concentration*: Sensitivity to the coincidence between the rainfall flood hydrograph and the ocean flood hydrograph were assessed by varying the coincidence by ± 3 hours;
- *Manning's 'n' Roughness Value*: The hydraulic roughness values were increased and decreased by 20% across the catchment; and
- *Blockage*: Sensitivity to blockage of pipes and culverts was assessed for 0% and 100% blockage.

It should be noted that the parameters are not independent and adjustment of one parameter (such as the Manning's *n* value) would generally require adjustment of other values (such as impervious percentage) in order for the model to produce the same level at a given location. The aim of the sensitivity analysis is to give an estimate of the potential variability of design flood levels.

9.2. Background to Sea Level Rise

The *NSW Sea Level Rise Policy Statement* was released by the NSW Government in October 2009. This Policy Statement was accompanied by the *Derivation of the NSW Government's sea level rise planning benchmarks* (NSW State Government, 2009) which provided technical details on how the sea level rise assessment was undertaken. Additional guidelines were issued separately by OEH, including the *Flood Risk Management Guide: Incorporating sea level rise benchmarks in flood risk assessments 2010.*

The 2009 Policy Statement says that:

> *"Over the period 1870-2001, global sea levels rose by 20 cm, with a current global average rate of increase approximately twice the historical average. Sea levels are expected to continue rising throughout the twenty-first century and there is no scientific evidence to suggest that sea levels will stop rising beyond 2100 or that current trends will be reversed… The 4th Intergovernmental Panel on Climate Change in 2007 also acknowledged that higher rates of sea level rise are possible"* (NSW State Government, 2009)

Subsequent to the commencement of this Flood Study (and in progress), the NSW Government announced its Stage One Coastal Management Reforms on the 8th September 2012. As part of these reforms, the NSW Government no longer recommends state-wide sea level rise benchmarks for use by local councils, with councils having the flexibility to consider local conditions when determining local future hazards.

Accordingly, ESC, in partnership with Shoalhaven City Council, commissioned Whitehead and Associates (Environmental Consultants) Pty Ltd and Coastal Environment Pty Ltd to undertake the *South Coast Regional Sea-level Rise Planning and Policy Response Framework* Report. The exhibition draft was completed in July 2014.

The key scientific findings were summarised as:

- *There is no compelling reason to not adopt the projections of the Intergovernmental Panel on Climate Change (IPCC) as the most widely accepted and competent information presently available.*
- *Recent sea level rise trends offshore of New South Wales are similar to the global average.*
- *Recent changes in sea level have been very similar between Sydney and the Shoalhaven and Eurobodalla coasts.*
- *Future NSW sea-level rise will likely be similar to the global average with only minor variation.*

The report provided locally adjusted projections of sea level rise derived from the IPCC's Assessment Report 5. Within this framework four Representative Concentration Pathway (RCP) scenarios were prescribed. These were based upon pathways for atmospheric greenhouse gas and aerosol concentrations, combined with land use changes. The RCP's were denoted as RCP8.5, RCP6.0, RCP4.5 and RCP2.6 that were consistent with the W/m^2 of the radiative forcing increase comparative to the conclusion of the 21st century.

Table 20 shows the locally adjusted projections of sea level rise as extracted from the *South Coast Regional Sea-level Rise Planning and Policy Response Framework* Report.

Table 20: Locally Adjusted Projections of Sea-level rise for Shoalhaven and Eurobodalla

Year	RCP2.6			RCP4.5			RCP6.0			RCP8.5		
	Low	Middle	High	Low	Middle	High	Low	Middle	High	Low	Middle	High
2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2020	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03	0.02	0.02	0.03
2030	0.05	0.07	0.10	0.05	0.07	0.10	0.05	0.06	0.10	0.06	0.07	0.10
2040	0.10	0.12	0.16	0.09	0.12	0.16	0.08	0.12	0.15	0.11	0.14	0.17
2050	0.13	0.17	0.23	0.14	0.18	0.24	0.13	0.17	0.23	0.16	0.20	0.26
2060	0.15	0.21	0.30	0.18	0.24	0.32	0.16	0.22	0.30	0.21	0.29	0.37
2070	0.18	0.27	0.37	0.22	0.31	0.41	0.21	0.29	0.39	0.29	0.39	0.50
2080	0.21	0.31	0.44	0.25	0.38	0.51	0.25	0.36	0.50	0.35	0.49	0.64
2090	0.23	0.36	0.51	0.30	0.44	0.60	0.31	0.44	0.61	0.44	0.61	0.79
2100	0.25	0.41	0.58	0.34	0.50	0.69	0.36	0.53	0.72	0.53	0.74	0.98

ESC adopted the RCP6.0 High scenario at the Ordinary Council Meeting on the 25 November 2014.

Herein, the 2030, 2050, 2070 and 2100 projections were investigated as they relate to strategic planning horizons, to assess the sensitivity to projected sea level rise on the catchment's flood behaviour. The projected sea level rise values were 0.10m, 0.23m, 0.39m and 0.72m respectively.

9.3. Background to Increased Rainfall

The Bureau of Meteorology has indicated that there is no intention at present to revise design rainfalls to take account of the potential climate change, as the implications of temperature changes on extreme rainfall intensities are presently unclear, and there is no certainty that the changes would in fact increase design rainfalls for major flood producing storms. There is some recent literature by CSIRO that suggests extreme rainfalls may increase by up to 30% in parts of NSW (in other places the projected increases are much less or even decrease); however this information is not of sufficient accuracy or certainty as yet (NSW State Government, 2007).

Any change in design flood rainfall intensities will increase the frequency, depth and extent of inundation across the catchment. It has also been suggested that the cyclone belt may move further southwards. The possible impacts of this on design rainfalls cannot be ascertained at this time as little is known about the mechanisms that determine the movement of cyclones under existing conditions.

Projected increases to evaporation are also an important consideration because increased evaporation would lead to generally dryer catchment conditions, resulting in lower runoff from rainfall. Mean annual rainfall is projected to decrease, which will also result in generally dryer catchment conditions. The influence of dry catchment conditions on river runoff is observable in climate variability using the Indian Pacific Oscillation (IPO) index (Westra et. al., 2009). Although mean daily rainfall intensity is not observed to differ significantly between IPO phases, runoff is significantly reduced during periods with fewer rain days.

The combination of uncertainty about projected changes in rainfall and evaporation makes it extremely difficult to predict with confidence the likely changes to peak flows for large flood events within the catchments under warmer climate scenarios.

In light of this uncertainty, the NSW State Government (2007) advice recommends sensitivity analysis on flood modelling should be undertaken to develop an understanding of the effect of various levels of change in the hydrologic regime. Specifically, it is suggested that increases of 10%, 20% and 30% to rainfall intensity be analysed.

9.4. Results

9.4.1. Tidal Inundation

The extent of the HHWS tidal inundation (without rainfall) does not vary significantly for the 2030 and 2050 tidal horizons, with a slight extension within the tidal flats located to the north of Mossy Point and south of George Bass Drive. The 2070 and 2100 tidal horizons extend further into the tidal flats and further along Lynch Creek and Candlagan Creek.

9.4.2. Sea Level Rise

The constricted channel width of Candlagan Creek and the Tomago River at the confluence with the ocean resulted in peak flood level increases less than the corresponding sea level rise increase. In the 2030 scenario the peak flood levels increased by 0.06 m (in which sea levels were increased by 0.10 m), in the 2050 scenario the peak flood levels increased by 0.15 m (in which sea levels were increased by 0.23 m), in the 2070 scenario the peak flood levels increased by 0.26 m (in which sea levels were increased by 0.39 m) and in the 2100 scenario the peak flood levels increased by 0.51 m (in which sea levels were increased by 0.72 m).

9.4.3. Rainfall Increase

A rainfall increase of 10% resulted in increases to peak flood levels by up to 0.2 m along Candlagan Creek, Tomago River and through the township of Mogo. The peak flood levels within Broulee were found to increase by up to 0.1 m, although within Tomakin the peak flood level impact was less than 0.01 m.

A rainfall increase of 20% resulted in increases to peak flood levels by up to 0.4 m along Tomago River and increases of up to 0.3 m along Candlagan Creek and through the township of Mogo. The peak flood levels within Broulee were found to increase by up to 0.2 m and within

Tomakin the peak flood level impact was up to 0.1 m.

A rainfall increase of 30% resulted in increases to peak flood levels by up to 0.6 m along Tomago River and increases of up to 0.4 m along Candlagan Creek and through the township of Mogo. The peak flood levels within Broulee were found to increase by up to 0.2 m and within Tomakin the peak flood level impact was up to 0.1 m.

It should be noted that increases in rainfall are such that the 1% AEP event with a rainfall increase of 30% results in runoff approximately equivalent to a 0.2% AEP event under present day conditions.

9.4.4. Time of Concentration

Varying the time of concentration by ± 3 hours resulted in decreases in peak flood levels of up to 0.2 m within Tomago River (from the mouth of the river to upstream of the George Bass Drive Bridge). From upstream of the George Bass Drive Bridge to the junction of Tomago River with Jeremadra Creek, the peak flood levels were found to decrease by up to 0.1 m. Along Candlagan Creek, the peak flood levels decreased by up to 0.1 m.

9.4.5. Manning's Roughness

Peak flood levels were found to decrease across the catchment with decreased Manning's Roughness values. Within Candlagan Creek and Tomago River the peak flood levels decreased by up to 0.3 m.

Increased Manning's Roughness values were found to increase peak flood levels across the catchment. Within Candlagan Creek and Tomago River the peak flood levels increased by up to 0.3 m.

9.4.6. Blockage Assumptions

The hydraulic model was relatively insensitive to the assumption of no blockage of the culverts and pipes. Upstream of Dunns Creek Road, the no blockage scenario resulted in small sections of decreased peak flood levels, up to 0.1 m. Within the township of Broulee, the no blockage scenario resulted in decreased peak flood levels up to 0.02 m.

The 100% blockage scenario resulted in minor impacts across the catchment and slightly more impacts in the vicinity of the blocked infrastructure. Upstream of Dunns Creek Road and along Lynch Creek and Candlagan Creek where the Princes Highway crosses, the peak flood level was found to increase by up to 0.2 m. Within the township of Broulee, the 100% blockage scenario was found to increase peak flood levels by up to 0.1 m.

10. DISCUSSION – FLOOD BEHAVIOUR

A number of flood mechanisms have been investigated; including mainstream flooding, overland flooding and tidal inundation. Tidal inundation or storm surge occurs when atmospheric conditions result in higher sea levels, such as king tides. Mainstream flooding is when water levels rise up from rivers and creeks that have reached capacity. Overland flooding is the rainfall runoff as it travels downward to either a creek/river or underground drainage network.

10.1. Tomakin

The township of Tomakin is subject to different flood mechanisms across different areas. The area to the west of Sunpatch Parade and north of Parks Parade is predominantly subject to tidal inundation and mainstream flooding. The area to the east of Sunpatch Parade is subject to overland flooding.

10.2. Mossy Point

Similar to Tomakin, Mossy Point has a variety of flood mechanisms present. North of River Road is predominantly tidal inundation and mainstream flooding. The remainder of Mossy Point is subject overland flooding.

10.3. Broulee

Broulee drains in two directions; to the north and to the south. From Iluka Avenue overland flow travels north to Candlagan Creek, with properties adjacent to Candlagan Creek subject to tidal inundation and mainstream flooding.

South of Iluka Avenue, the township of Broulee is subject to overland flooding that drains south. This area is relatively flat, with slopes less than 0.5%, which results in flood water not draining away as fast as it would on a steeper slope. Additionally, the vegetated dunes that border the township to the east and south present a hindrance to overland flow discharging into the ocean.

10.4. Mogo

The township of Mogo is predominantly subject to mainstream flooding. Areas downstream of Tomakin Road, including Mogo Zoo, are also within the tidal affectation area.

11. PRELIMINARY FLOOD PLANNING AREAS

11.1. Background

Land use planning is considered to be one of the most effective means of minimising flood risk and damages from flooding. The Flood Planning Area (FPA) identifies land that is subject to flood related development controls and the Flood Planning Level (FPL) is the minimum floor level applied to new developments within the FPA.

The process of defining FPA's and FPL's is somewhat complicated by the variability of flow conditions between mainstream and local overland flow, particularly in urban areas. The more traditional approaches typically having been developed for riverine environments and mainstream flow.

Defining the area of flood affectation due to overland flow (which by its nature includes shallow flow) often involves determining at which point it becomes significant enough to classify as "flooding". The difference in peak flood level between events of varying magnitude may be minor in areas of overland flow, such that applying the typical freeboard can result in a FPL greater than the Probable Maximum Flood (PMF) level.

The FPA should include properties where future development would result in impacts on flood behaviour in the surrounding area and areas of high hazard that pose a risk to safety or life. Further to this, the FPL is determined with the purpose to decrease the likelihood of over-floor flooding of buildings and the associated damages.

The Floodplain Development Manual suggests that the FPL generally be based on the 1% AEP event plus an appropriate freeboard. The typical freeboard cited in the manual is that of 0.5 m; however it also recognises that different freeboards may be deemed more appropriate due to local conditions. In these circumstances, some justification is called for where a lower value is adopted.

Further consideration of flood planning areas and levels are typically undertaken as part of the Floodplain Management Study where council decides which approach to adopt for inclusion in their Floodplain Management Plan.

11.2. Methodology and Criteria

The methodology used in this report was as follows:

- 2070 sea level rise scenario peak flood levels trimmed to exclude areas with peak flood depths less than 0.15 m;
- Freeboard of 0.5 m applied;
- waterRIDE software used to calculate extent of 2070 scenario plus freeboard;
- Properties with greater than 10% of the cadastral lot (total land area of a property) inundated selected.

11.3. Results

The results from the aforementioned process identified 1,609 properties for inclusion in the preliminary flood planning area.

A sensitivity analysis was undertaken to determine how many additional properties were identified under the 2070 sea level rise scenario comparative to the existing sea level scenario. In the existing sea level scenario, 1,605 properties were identified, which is four less than the 2070 sea level rise scenario.

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