RAISING TOMORROW'S INFRASTRUCTURE – KEEPING DUNEDIN ABOVE SEA LEVEL RISE

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ABSTRACT

Dunedin has many low lying areas, increasingly threatened by the sea due to climate change effects. The Dunedin City Council's concern was to develop a workable policy that set minimum floor levels for new buildings above the predicted maximum sea level.

There are many dynamic and poorly defined elements that make up sea level. Storm surge, tidal effects, tsunami and sea level rise itself. A large number of reports, sometimes conflicting, on the topic had to be taken into account.

The challenge was to develop minimum floor level rules for tomorrow's infrastructure that took into account all these variables yet gave simple definitive answers. Additionally, it has to be easy to update these rules as new information comes to hand.

This paper describes the methodology that achieves all these goals: definitive floor levels, acknowledgement of local variations, and a means to simply update without affecting credibility.

The ultimate validation was the wide public acceptance of the policy when announced as front page news. Even though minimum floor levels were raised significantly from previous levels, there was acceptance from insurers, the real estate industry, and the ratepayers.

The methodology developed is adaptable to any coastal community in New Zealand

KEYWORDS

Buildings, minimum floor levels, sea level rise, climate change.

1 INTRODUCTION

During the early 1990's, following Local Government amalgamation, the Dunedin City Council (the Council) realised the need for a floor level policy relating to residential development at coastal and harbour locations between Waikouaiti and Taieri Mouth. At the time, a review of the normal tidal range and extreme tide (storm surge) events was undertaken and a single minimum floor level with an approximate freeboard of 300mm above the highest recorded sea level of 101.86 metres (OMD) was recommended by the Council's Building Control office. The recorded extreme tide levels were at the Dunedin gauging station in the Upper Harbour.

The recommended minimum floor level was 102.15 metres, the datum being the Otago Metric Datum (OMD) (viz. Dunedin Vertical Datum 1958 minus 100.00 metres). This is recorded as Map 23 on The Council's Hazard Register and was last updated on 27 August 2001.

The recommended minimum floor level was intended specifically for domestic residential buildings but has been used for other types of buildings. It has been applied at various locations along the Dunedin coast without adjustment for local effects (e.g. wave run-up or 'tidal bore' concentration), and without consideration of the predicted sea level rise during the life of a building. The recommended minimum floor level was intended not to be applicable at riparian sites where flood levels, in a 1% Annual Exceedence Probability (AEP) event, would exceed the effects from coastal hazards.

In 2011, the Council engaged MWH to review its minimum floor level policy and to recommend a methodology for determining minimum floor levels that take account of predicted sea level rise. The review considered the

Council’s regulatory obligations, guidelines and other information about climate change and predicted sea level rise, and factors that contribute to the level of the sea.

2 RESEARCH

2.1 LEGISLATION

Building Act

The Building Act 2004 (s72) requires that a building consent authority issue a building consent for building work on land that is at risk from coastal hazards, or any other hazard, provided the building complies with the Building Code and the building itself does not accelerate, or worsen, or extend the hazard to another property (MfE, 2008a). (Consent under Section 72 does require that an entry is to be made on the relevant certificate of title in accordance with Sections 73 and 74 of the Act).

The Building Act (s71) requires that a building consent authority refuse a building consent if: the land is subject to one or more natural hazards; or the building work is likely to accelerate, worsen or result in a natural hazard on that land or any other property – unless adequate provision has been or will be made to protect the land, the building work, or other property from the natural hazard (Building Act 2004).

Building Regulations

Surface Water

The Building Regulations (Clause E1 Surface Water) state that buildings shall be protected from surface water ingress from events having a 2% annual probability of exceedence (viz. a 50 year level of protection). The associated acceptable solution Clause E1/AS1 states that suspended (timber) and slab on ground floors shall be 150mm above the surrounding ground but does not nominate a freeboard value above surface water. A Building Industry Authority (BIA) Determination 99/005 referred to a 500mm freeboard above a 1% Annual Exceedence Probability (AEP) flood level.

Building Life

The Building Regulations (Clause B.2: Durability) require building elements to function for not less than 50 years.

An Environment Court decision on a zone change application (ref. W029/06) referred to a 100 year timeframe when considering coastal issues. The BIA determination similarly identified this timeframe for hazard mitigation.

Thus, building elements should be designed to function for a period of greater than 50 years, and such a period may be 100 years or more.

Resource Management Act 1991 (RMA) -Subdivision and Land Use Consents

RMA Section 7 *Other matters* of the RMA includes:

In achieving the purpose of this Act, all persons exercising functions and powers under it, in relation to managing the use, development, and protection of natural and physical resources, shall have particular regard to—

(i) the effects of climate change:

RMA (s106) requires a regulatory authority to review natural hazards when assessing subdivision consent applications. Where a land use consent is required to build, a hazard assessment may be required.

2.2 POLICY AND GUIDELINES

Council Climate Change Predications Policy

The Council adopted a Climate Change Predictions Policy in 2006. This policy was updated in September 2011.

With regard to sea level rise, the 2006 policy gave a mean sea level rise of 0.33m up to 2050 and 0.66m up to 2100. The 2011 policy gave sea level rise of 0.3m up to 2040, and 0.8 to 1.6m up to 2090.

Ministry for the Environment 2008, 2009

The Ministry for the Environment (MfE) has produced reports about climate change. Three of these are:

- Coastal Hazard and Climate Change: A Guidance Manual for Local Government in New Zealand' (MfE, July 2008a)
- Preparing for Climate Change: A guide for Local Government in New Zealand'(MfE, July 2008b)
- Preparing for Coastal Change: A guide for Local Government in New Zealand' (MfE, March 2009).

MfE 2009 identifies coastal hazards likely to be exacerbated by climate change and provides planning advice for territorial authorities. It makes reference to the Intergovernmental Panel on Climate Change (IPCC) predictions and recommends:

For planning and decision timeframes out to the 2090s (2090 – 2099):

a. *A **base** value seal level rise **of 0.5m relative to the 1980-1999 average** should be used, **along with***
b. ***An assessment of the potential consequences from a range of possible higher sea-level rises** (particularly where impacts are likely to have high consequence or where additional future adaptation options are limited). At the very least, all assessments should consider the consequences of a mean sea-level rise **of at least 0.8m** relative to the 1980-1999 average.*

The emphasis in the extract above is given in the document. The document discusses the need for hazard avoidance. Developments in Dunedin requiring subdivision and land use consents will be subject to such assessments: infill residential development not subject to consent under the Resource Management Act will not be. Risk mitigation including hazard mapping and minimum floor level construction will be necessary for these developments.

The document contains relevant case law. Some decisions refer to the need to recognise the changing coastal environment and to adopt a 100 year time frame when permitting development.

2.3 OTHER INFORMATION

Climate Change Impacts on Dunedin, Professor Blair Fitzharris, March 2010

Professor Fitzharris was commissioned by the Council to assess climate change impacts on Dunedin. As part of that assignment he reviewed material published by the IPCC, the MfE, and the National Institute for Water and Atmospheric Research (NIWA).

He referred to the IPCC's (Fourth Report) upper limit of 0.6 metres sea level rise to 2090 but recommended that a projected sea level rise of at least one metre by 2090 would be prudent for impact and planning exercises.

Intergovernmental Panel on Climate Change (IPCC)

A recommendation of the IPCC for planning beyond 2100 is to adopt a rise of 10mm per annum.

Otago Regional Council Storm Surge Modelling Study (NIWA 2008)

This study considered nine locations within Dunedin's territory at risk from extreme sea levels - a combination of tide, storm surge, wave set-up and wave run-up. The report noted that the storm surge effect includes the influence of low barometric pressures and wind induced wave action on the level of the sea. Wave set-up is the larger scale effect of storm winds and wave run-up is the localised short-term breaking wave phenomenon at any shore (ref. MfE Factsheet 1, March 2009, Components of sea level).

The report noted the significant range in storm surge levels predicted along the Otago coast and the significant added effect of wave run-up at some locations. Karitane, Purakanui, Long Beach, and Taieri Mouth were identified as low lying and at greater risk from the overall effects of storm surges. Unlike tsunami events the storm surges are likely not to have sufficient energy to travel up river or overland to any extent.

The report tabulated storm surge values for 100 and 500 year return period events and average and maximum wave run-up values at specified locations. Storm surge heights in north of the Otago Peninsula are generally lower than the south. The range for the 100 year period is 1.66 to 1.98 metres above MLOS.

Wave run-up values range from 0.22 metres north of the Peninsula to 0.47 metres south.

Included in the NIWA report are figures for each of nine locations showing for various return periods the extent of inundation. The NIWA report noted that it did not address potential dune erosion when considering the risk of inundation in South Dunedin.

Otago Regional Council Tsunami Inundation Study (NIWA 2008)

The tsunami report identified near-field sources (in particular the Puysegur Fault) and far-field sources (South America) with the former likely to produce the greater wave height but the source providing the greater frequency of events (100 year return period). Also considered were less active faults (Akatore) and tsunami generated by submarine landslide events. The report provided a single height prediction for the near field events and both 100 and 500 year return period predictions for the far-field events. Because of the shielding effect of the Otago Peninsula the maximum heights for near-field events were significantly higher south of the Otago Peninsula than north of it.

Wave amplitudes were tabulated for the three predictions noted above. To determine a total wave height, the amplitudes should be added to a typical mean high water spring (MHWS) tide level of 0.9 metres.

Tsunami events particularly at river mouths and upstream reaches of the rivers represented a much greater risk due to the ‘tidal bore’ effect. Taieri Mouth, the Lower Taieri Plain, Green Island adjacent to the Kaikorai Estuary, and State Highway 1 in the vicinity of the Waikouaiti River would be at risk of inundation and wave damage.

The Otago Harbour was identified as at low risk from tsunami events because the harbour entrance provides significant damping of waves from near or far-field sources. Predicted wave heights were 0.150 metres for near field and 0.5 metres for far field events (an event in mid-19th century apparently lifted boats onto land).

The report identified six locations within Dunedin. Figures were generated showing the extent of inundation at each location for the three predicted events. The sequence of wave fronts and associated times of arrival were stated for each event. The maximum heights were noted for the near-field and the far-field events with a 500 year return period. For locations outside the harbour the far-field 500 year predictions were in the range 2.1 to 2.5 metres above the MLOS. Generally levels were lower north of the Peninsula.

Historical Sea Level Rise - Prof John Hannah, Otago University School of Surveying

In public lecture (12 July 2011) entitled ‘Sink or Swim’, Prof Hannah produced results of his research on the Mean Level of the Sea in Dunedin over the last 90 years. He said that, whilst fluctuations over a cycle of 20-40 years were evident, the trend in sea level rise over the last 90 years was 1.7mm per year and there was no evidence of acceleration. This correlates well with the global mean, which Prof Hannah stated to be 1.8mm/yr.

3 METHODOLOGY

3.1 OVERVIEW

The project methodology identified sea level components as follows.

1. Mean level of the sea (MLOS). MLOS is increasing owing to global warming.

2. Storm surge, which is the increase in sea level (excluding the effects of waves) due to low barometric pressure and winds blowing either onshore or alongshore over the ocean (with the coast on left).

3. A freeboard height to mitigate the risk of damage to underground services and floor elements (particularly timber floors) and provide a safety margin against intrusion of water.

4. A 'Base Level' to apply to buildings at coastal and harbour sites; the level to include the present day MLOS plus an allowance for storm surge plus the freeboard.

5. A Climate Change Effects (CCE) Factor. A height that allows for predicted sea level rise, and the increase in other effects (eg. storm surge) that are predicted as a result of climate change. This factor requires continual review as global and local trends become apparent.

6. Local Affect (LA) Factors, which may be relevant, to mitigate effects that include: wave run-up during storm events; site specific tsunami exposure; 'tidal bore' effects in rivers; and any lifelines importance factor applying to the specific building.

Where subdivision or land use consent is required, the Council may require a more detailed site specific assessment of natural (coastal) hazards, and may subsequently grant consent subject to mitigation measures relevant to the location, which may include the specific siting of a dwelling within the lot and a 'site specific' minimum floor level.

3.2 BASE LEVEL

Overview

MfE (2008a) defines the components of sea level as: mean level of the sea (MLOS); the predicted astronomical tide; storm surge; storm tide; wave set-up; and wave run-up. The proposed Base Level has been determined from three of these components, namely:

- MLOS (which includes sea level rise to date)
- Present day tidal range for mean high water springs (MHWS)
- Storm surge height (excluding local wave run-up effects)
- Freeboard.

Climate change effects (CCE Factor) need to be added to the Base Level as does a Local Adjustment Factor (LA Factor). The 'Base Level' should be the first value considered for any building consent application at a coastal location and the other factors added where appropriate.

Level Datums

There are a number of datums for Dunedin in use at present or that have been used historically.

- Dunedin Vertical Datum 1958. 0m DVD was intended to reflect mean sea level when established in 1958. This was evidently based on the previous 20 years data of sea level, which we now know to have some variation in it (ref Prof John Hannah, 'Sink or Swim' lecture 12 July 2011; sea level rise in NZ over the last 90 years has averaged 1.7mm/year, but varies over a 20-40 year cycle). The 'Dunedin Vertical Datum' is situated at an inner harbour gauge site, and further information can be found at http://www.linz.govt.nz/geodetic/datums-projections-heights/vertical-datums/mean-sea-level-datums.
- Otago Metric Datum, 0m on the Dunedin Vertical Datum is 100m on OMD. This has been a convention in the surveying profession for probably the last 30 years, but no definitive reference could be found to prove the translation from DVD to OMD. Therefore 100m OMD is approximately (not exactly) mean level of the sea.
- Chart datum (sometimes known as Zero on the Tide Predictions, an approximation of low tide. 0m on the Chart Datum is 99.01m on OMD (99.009 precisely)).
- City datum. 0m on the City Datum is 86.668m on OMD. Again, this translation is commonly used, but a definitive reference to prove it could not be found.

The level datum previously recommended to the Council and adopted by MWH for its review was **the Otago Metric Datum (OMD)**.

Mean Level of the Sea

The mean level of the sea (MLOS) in 2011 is 1.09 metres above chart datum. Therefore, relative to the chart datum of 99.01 metres, the MLOS in 2011 was 100.10m in terms of OMD.

Predicted Astronomical Tide

The mean high water springs level (MHWS) is 2.18 metres above chart datum (ref. LINZ 2008) and therefore 101.19 metres above OMD.

Although the highest astronomical tides (HATs) predicted during the 19 year astronomical cycle will exceed the MHWS by about 0.2 metres, these extreme figures were not used to determine a minimum floor level. This is because it was considered an unreasonable double jeopardy to assume that the maximum predicted storm surge event will happen at the same time as a maximum astronomical tide event.

The tidal ranges elsewhere along the Dunedin coastline vary from those at the Dunedin Inner Harbour gauge site. For example, the MHWS range is plus 200mm near Taieri Mouth and minus 200mm near Waikouaiti (ref. NIWA Storm Surge Study, June 2008, Fig 2.2). Storm surge and tsunami heights reported by NIWA are however relative to a single MLOS height.

Storm Surge

Storm surge has been determined on the basis of:

- The present day mean level of the sea (MLOS) of 100.10 metres (OMD)
- The Otago Region Storm Surge Modelling Study (NIWA, June 2008).

The recommended storm surge height above present day MLOS is 2.0 metres. This includes allowance for the storm surge continuing through a high tide cycle.

Therefore, the storm surge height is 102.10 metres. The previous maximum storm surge level was 101.86 metres, recorded in 1980 at the Dunedin tide gauge.

This storm surge figure is higher than the highest predicted astronomical tide figure. Therefore it is storm surge that drives minimum floor level, not predicted high tides.

Freeboard Height

The previously adopted freeboard height was 0.3 metres to floor level. This provided an allowance for avoiding inundation of the floor substructure (particularly a timber floor) and underground services at the building platform. Also, it was intended to provide an allowance against local effects (e.g. wave action from boats and vehicles) and the uncertainty associated with a District minimum floor level.

The minimum freeboard to the floor level stated in the Building Regulations (Clause E1/AS1) is 0.15 metres above highest adjacent ground level (which could be inferred to be the ponding level).

The more conservative height of 0.3 metres, which was previously adopted by the Council, was proposed.

Summary of Base Level Components

In terms of Otago Metric Datum, the Base Level comprises:

Mean Level of the Sea, 2011	100.10m
Astronomical Tide	Less than STORM SURGE, so not added
Storm Surge	2.0m
Freeboard	0.3m
Final Height	**102.40m**

3.3 CLIMATE CHANGE FACTOR

Overview

The proposed methodology included quantitatively defining a Base Level. This level is a “global” minimum floor level that does not include predicted future effects or local circumstances. To this Base Level is added an allowance for Climate Change Effects (CCE), as discussed in this section. Then a further adjustment is made to take account of localised factors, Local Adjustment Factor.

Climate Change Effects considered were:

- Increased storm surge
- Increased rainfall intensity
- Sea level rise.

Increased Storm Surge

MfE (2009) states:

> *We know that changes to individual storm conditions are likely, particularly in their intensity. It is less certain what these changes mean for the magnitude or frequency of storm surges, and how storm-tide levels will change. You can assume that storm-tide levels will rise only due to an increase in mean sea level rise, until further research and monitoring suggest otherwise.*

Therefore, a zero effect from storm surge on the Climate Change Factor was adopted for the present. This assumption will be a subject of regular review.

Increased Rain Fall

While climate change is predicted to increase the maximum intensity of rainfall events, this will not have an effect on sea level in general. Therefore, a zero effect on the Climate Change Factor from increased rainfall was adopted

However, there may be an effect on tidally-affected flood zones such as at Henley. This would be accounted for by the Local Adjustment Factor.

Increase in Sea Level

The Building Regulations have a requirement that certain building elements, including floors, function for not less than 50 years. A '50 year' allowance for sea level rise as a minimum allowance has been investigated.

Minimum Requirement for 50 Years (2060)

<u>MfE 2008 and 2009</u>

An extract about the rate of sea level rise from MfE (2009) is presented below.

We recommend that for planning and decision timeframes out to the 2090s (2090–2099):

1. a base value sea-level rise of 0.5 m relative to the 1980–1999 average be used, *along with*
2. an assessment of potential consequences from a range of possible higher sea-level rise values. At the very least, all assessments should consider the consequences of a mean sea-level rise *of at least 0.8 m* relative to the 1980–1999 average.

For longer planning and decision timeframes beyond the end of this century, we recommend an additional allowance for sea-level rise of 10 mm per year beyond 2100.

Table 1 summarises these baseline sea-level rise recommendations to guide the risk assessment processes for shorter planning and decision timeframes over the 21st century. Further guidance on what numbers to use for planning for future sea-level rise is found in section 2.3 of the source report.

Table 1: Baseline sea-level rise recommendations for different future timeframes, in metres relative to the 1980–1999 average.

TIMEFRAME	BASE SEA-LEVEL RISE ALLOWANCE (m)	ALSO CONSIDER THE CONSEQUENCES OF SEA-LEVEL RISE OF AT LEAST: (m)
2030–2039	0.15	0.20
2040–2049	0.20	0.27
2050–2059	0.25	0.36
2060–2069	0.31	0.45
2070–2079	0.37	0.55
2080–2089	0.44	0.66
2090–2099	0.50	0.80
Beyond 2100	10 mm/year	

The recommended minimum allowance for 2060 (ie a 50-year period from now) was 0.31 metres. Also, it was recommended that the consequences of a sea level rise of 0.45 metres be considered for this period.

Blair Fitzharris

The Blair Fitzharris report (2010) recommended that, "at this time, projected sea level rise of at least 1 metre by 2090 would be prudent for impact and planning exercises. The science in this area is currently inconclusive and needs to be followed closely by Council so as to continually adjust this estimate".

DCC 2011 Policy

The Council's Climate Change Policy is for a seal level rise for Dunedin of 0.3 metres by 2040 and a minimum sea level rise of 0.8 metres by 2090. The sea level rise for 2060 may be interpolated as 0.5m.

Summary

Given a 0.45-metre seal level rise by 2060 as MfE's recommended minimum consideration and a 0.5-metre sea level rise by 2060 as an interpolation of the Council's climate change policy (2011), it was considered appropriate and consistent that 0.5-metre allowance for sea level rise be adopted as the minimum for the Climate Change Effects Factor.

Additional Allowance for Increased Design Life

If the life of a building is expected to extend beyond 50 years, then an additional allowance for the minimum floor level should be added to the minimum allowance.

MfE (2008a, 2009) advise that "*For planning and decision timeframes beyond 2100 where, as a result of the particular decision, future adaptation options will be limited, an allowance for sea-level rise of 10 mm per year beyond 2100 is recommended*.......".

The rate of sea level rise between 2060 and 2090 given by MfE is approximately 10 mm per year (base level rise is 6.7 mm per year and rise for minimum considerations is 12 mm per year). The rate of sea level rise between 2060 and 2090 deducted from the Council's Climate Change Policy 2011 is 10 mm per year.

It was proposed that the adopted rate of sea level rise after 2060 be 10mm per year.

Summary

It was proposed that a minimum allowance for the Climate Change Effects Factor be 0.5 metres and that that the Climate Change Factor be increased by 10 mm per year after 2060.

3.4 LOCAL ADJUSTMENT FACTOR

Overview

The Local Adjustment Factor (LA) was proposed as the third and final Factor, which enables the minimum acceptable floor level at any particular site to be determined. The LA Factor takes account of local, and/or project specific matters that would be inappropriate to apply generally.

It was beyond the scope of the MWH work to investigate the LA Factor in detail. However the scope did include providing comment on any factors that should be included for consideration as a result of the research undertaken. Therefore, the comments provided were not comprehensive.

The Council's Climate Change Policy (2011) included a projected sea level rise of between 0.8 and 1.6m for the year 2090. The figure of 0.8m is accounted for in the proposed methodology by the Climate Change Effects Factor.

It was proposed that an allowance for sea level rise to 2090 greater than 0.8 m should be considered as part of the Local Adjustment Factor. It was considered that such an allowance would be applicable when considering Building Classification and Risk. For example, a more conservative allowance for sea level rise would be used for a building/project where the consequences of a sea level rise greater than the Climate Change Effect Factor would be unacceptably severe.

Special Zones

Special Zones may be created where higher (or lower) levels of protection against the effects of sea level rise and other coastal hazards can be considered. This may be because specific protection works are in place, or conversely it may be because the consequences of inundation are greater or less than average.

South Dunedin has in place a system to convey stormwater to the open sea or to harbour outlets. It was predicted that there will be greater difficulty with time in controlling groundwater levels throughout South Dunedin.

A LA Factor may be adopted accordingly for such zones.

Building Classification and Risk

A number of building types including domestic garages and commercial workshops have been and may in the future be constructed at locations subject to a risk of inundation. For future consent applications, the Council may again accept a lower floor level (negative LA Factor), or may grant a waiver of any minimum floor level requirement.

Buildings containing 'lifelines' facilities, such as communications equipment, hospitals, water treatment plants and other essential services and infrastructure, should be identified and the LA Factor specifically assessed. Should the consequences of inundation adversely affect such buildings or the functions within them (eg the plant and equipment), a higher allowance for sea level rise than provided by the Climate Change Factor should be applied as a component of the Local Adjustment Factor.

Topographical Effects

Topographical effects including exposure to wave run-up at open sea beach locations during storm surge or tsunami events and exposure to 'tidal bore' effects in rivers during tsunami events require specific assessment. Reference should be made to the ORC commissioned Tsunami and Storm Surge reports (NIWA 2008) for detailed hazard maps and an appropriate LA Factor determined.

Different Freeboard

The Environment Court has favoured freeboard heights in flood plains as great as 0.5 metres, although the circumstances for this have not been researched. Further, there may be local circumstances where a reduction of freeboard can be made from the 0.3m recommended for the Base Level.

It was envisaged that there are situations where coastal defences may occasionally be overtopped by waves. Additional freeboard or specific drainage provisions for buildings protected by such seawall may be required.

Dwellings and On-site Effluent Disposal

Recent developments at a number of coastal communities had hinged upon the feasibility of on-site effluent disposal systems. Concerns related to the potential impact on the disposal systems of raised groundwater levels likely to result from the effects of sea level rise. Site specific assessments were recommended where new dwellings cannot be connected to reticulated foul sewerage systems. The viability of residential development at such locations may be in doubt depending upon the SLR Factor and present day ground levels so determination of a minimum floor levels could be irrelevant.

Tsunami Tidal Bore Effects

The Otago Regional Council (ORC) commissioned Tsunami Inundation Study identified individual wave amplitudes to be in the range 2.4 to 2.5 metres above MLOS south of the Otago Peninsula and 2.2 metres above MLOS north of the Otago Peninsula in a 500 year AEP, 'far field', seismic event. The study also provided predictions for 'near field' events but made clear the 'far field' events were of higher probability.

Although these 500 year AEP tsunami heights are greater than for the 100 year AEP storm surge predictions, the determination of the 'Base Level' recommended adoption of the more likely upper bound storm surge value. In other words, Tsunami is no worse than storm surge.

There may be places where the local tsunami hazard is greater than the standard allowance described above. This may be due to the local topography, both above and below the waterline. Identification of such areas can be included as a component of the LA Factor.

Therefore tsunami, in general, is considered no greater a threat than storm surge. However the ORC tsunami study identified locations including the Taieri River and lower Taieri Gorge where the energy from a tsunami event could be sufficient to send a 'tidal bore' through the gorge, affecting West Taieri settlements such as Henley. Provision should be made to review development and appropriate minimum floor levels, although in many sites the 1% AEP flood level may well govern floor levels in such areas.

As and when any other such locations are identified, an appropriate LA Factor should be introduced.

Wave Run-up

Storm surge wave run-up heights range from 0.25 metres at Waikouaiti up to 0.45 metres at Taieri Mouth. The LG Factor should therefore be +0.45 metres north of the Peninsula and +0.25 metres for the harbour and locations south of the Peninsula and these values should be applied where wave run-up exposure exists.

Table 7.1 provides guidance on the locations most at risk, where wave run-up should be considered as a component of the LA Factor.

Coastal Erosion

The risk of coastal erosion being exacerbated by rising sea levels and other climate change effects has been referred to by Fitzharris and others. The Otago Coastline includes areas prone to rapid erosion. They include areas of raised beach terrace (ref. Geology of the Dunedin Area, IGNS 1996), sand spits within the Otago Harbour (e.g. Harwood), open sea locations (e.g. Warrington), and rocky shorelines capped with loess soil deposits (e.g. alongside Brighton Taieri Mouth Road).

Also, localised areas of sedimentary and metamorphic rock formations are at risk of relatively high rates of coastal erosion and similarly these should be identified as part of any site specific hazard assessment.

Backwater

In some locations, such as the examples listed below, minimum floor level will be affected by a combination of flooding due to storm, and tide. There will be a backwater curve that will add to the sea level. In these location there is potential for the appropriate minimum floor level to be higher than the Base Level plus CCE Factor.

Potential locations are the lower reaches of the Waikouaiti, Waitati, and Taieri Rivers, Kaikorai Stream and Otokia Creek.

For floor level assessments at these locations, the flood level should be determined either by using historical data or by calculation of catchment characteristics. Much of 'at risk' Taieri Mouth is situated outside the Council's territory, but Henley is within Dunedin and could be at risk in the event a tsunami struck Taieri Mouth. The Momona Airport is within the West Taieri flood protection scheme so not directly at risk from coastal events.

Settlement Due to Liquefaction

Recent experience from the Christchurch earthquake has shown that where liquefaction occurs, settlement will also occur, and such settlement can be significant. Resurveying of Christchurch will reveal the magnitude of settlement that has occurred, and from this a Local Adjustment Factor for Dunedin may be able to be determined.

The DCC Hazard Register identifies some areas subject to liquefaction and these are generally low lying, meaning that any settlement could be significant with respect to minimum floor levels.

On-Site Effluent Disposal

The Council may require site specific assessments for individual building consent applications where on-site effluent disposal to ground is proposed in low lying areas such as Harwood.

Assessment of LA Factor

Quantifying the LA Factor was beyond the scope of the MWH work. However, a methodology for an initial check as to whether a LA Factor may be applicable and should be quantified was suggested, as given in Table 1.

Table 1 : Hazards and Local Adjustments

Location	Extent of Development at Risk	Storm Surge Wave Run-up Hazard	Tsunami 'Tidal Bore' Hazard	Erosion Hazard
Waikouaiti Beach	large	high	low	low
Karitane Estuary	large	moderate	low	low
Karitane Beach	large	high	high	high
Waikouaiti River	large	low	low	low
Warrington/ Evansdale	moderate	low	Moderate / Low	low
Waitati Township	large	low	low	low
Purakanui	small	low	low	low
Long Beach	large	high	high	moderate
Aramoana	large	moderate	low	Low
Te Ngaru to Careys Bay	large	low	low	moderate
Harwood to Harington Point	large	low	low	high
Papanui Inlet	small	low	low	moderate
Hoopers Inlet	small	low	low	moderate
Tomahawk	high	moderate	High	moderate
St Kilda to St Clair	high	high	low	high
Waldronville	small	moderate	low	moderate
Kaikorai Estuary	small	low	low	low
Westwood to Ocean View	large	high	low	moderate
Brighton / Otokia Creek	large	low	low	low
Brighton to Taieri Mouth	small	moderate	low	moderate
Henley	moderate	low	Moderate	low

4 DISCUSSION

4.1 REVIEWS

The Council invited the Otago Regional Council (ORC) and Tonkin and Taylor (T&T) to comment on the MWH report entitled Methodology for Determining Minimum Floor Levels 2011 (2011 Report).

Both the Tonkin and Taylor and ORC reviews generally supported the methodology and made comment on how Local Adjustment Factors should be developed.

4.2 CONSULTATION

A front page article in the Otago Daily Times, 30 November 2012, reported the Council's announcement of changes to minimum floor levels, with increases up to 1.2 metres, and that these were based on the MWH report. The article reported comments by representatives of the Real Estate Institute of New Zealand, the Insurance Council, the Otago Master Builders Association, community boards, and the ORC. The comments were generally supportive of the changes.

4.3 FURTHER INFORMATION

More recently, the IPCC has released its fifth assessment report. A summary of New Zealand findings was produced by the New Zealand Climate Change Centre. Findings relevant to setting minimum floor levels include:

- Global sea level rise by 2100 of about 0.5-1 metre above 1086-2005 average in a high carbon world, or 0.3-0.6 metre if there is rapid decarbonisation.

- Even if temperatures peak and decline, sea level is predicted to continue to rise for many centuries

- Sea level rise around New Zealand may be up to 10% higher than the global average.

This information supports the need for regular reviews of any adopted minimum floor level.

5 CONCLUSIONS

The MWH review resulted in a recommended methodology for determining minimum acceptable floor levels for buildings in coastal areas of Dunedin City. The methodology is summarised in Figure 1 and is summarised as follows.

- A minimum acceptable floor level is determined as the sum of a Base Level, a Climate Change Effects Factor, and a Local Adjustment Factor.

- The review established that the present day mean level of the sea (MLOS) in terms of the Otago Metric Datum is 100.10 metres.

- The recommended Base Level is 102.40m in terms of the Otago Metric Datum. This comprises an allowance of 2.0m for storm surge and a freeboard height of 0.3 metres.

- The recommended Climate Change Effects Factor is 0.5m for a building with a design life up to 2060, with an additional 10mm for every year after 2060 where the life of a building extends beyond 2060. Because of the uncertainty about the rate of sea level rise, it was recommended that the Climate Change Effects factor is reviewed after each relevant government policy or guideline update, or at least every five years.

- A Local Adjustment Factor should be considered. Such a factor will take into account matters that are specific to the local physical setting, to the life and use of the building, the design life of a building, and any mitigating circumstances. These matters include Tsunami. The Council may require a building consent application to include a site specific assessment of coastal hazards in order that an appropriate LA Factor can be calculated.

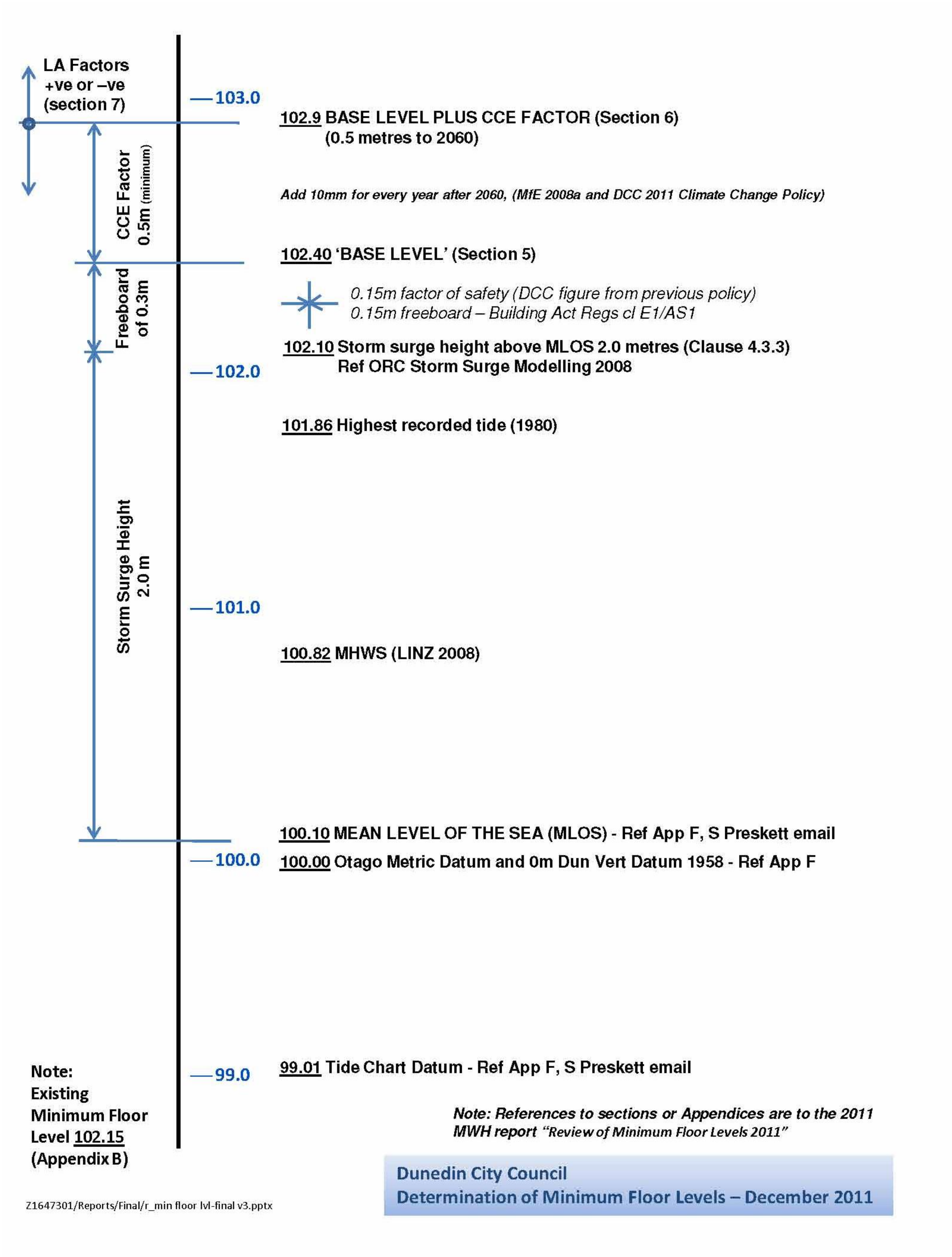
- In the absence of a LA Factor, the minimum acceptable floor level is the Base Level plus the Climate Change Effects Factor. The resulting minimum acceptable floor level for a building with a life less than or equal to 2060 is 102.90m.

The methodology is applicable for use with any isolated or community buildings in coastal New Zealand.

The Council’s announcement of changes to minimum floor levels (on the basis of the MWH report with an increase of 750mm above the previous minimum level), which potentially affects many households, was generally accepted by the community.

Establishing minimum floor levels is important for building consent authorities given their regulatory responsibilities. The methodology presented provides a rigorous foundation for assessing hazards associated with climate change and sea level rise, and has applications which include the development of second generation district plans. Importantly, the methodology is structured to enable adjustment in response to the dynamic climate change and sea level rise situation.

Figure 1:



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