



Ministry for the  
**Environment**  
*Manatū Mō Te Taiao*

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# Coastal Hazards and Climate Change

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**APPENDICES**

New Zealand Government

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# Appendix A: Planning framework and relevant legislation

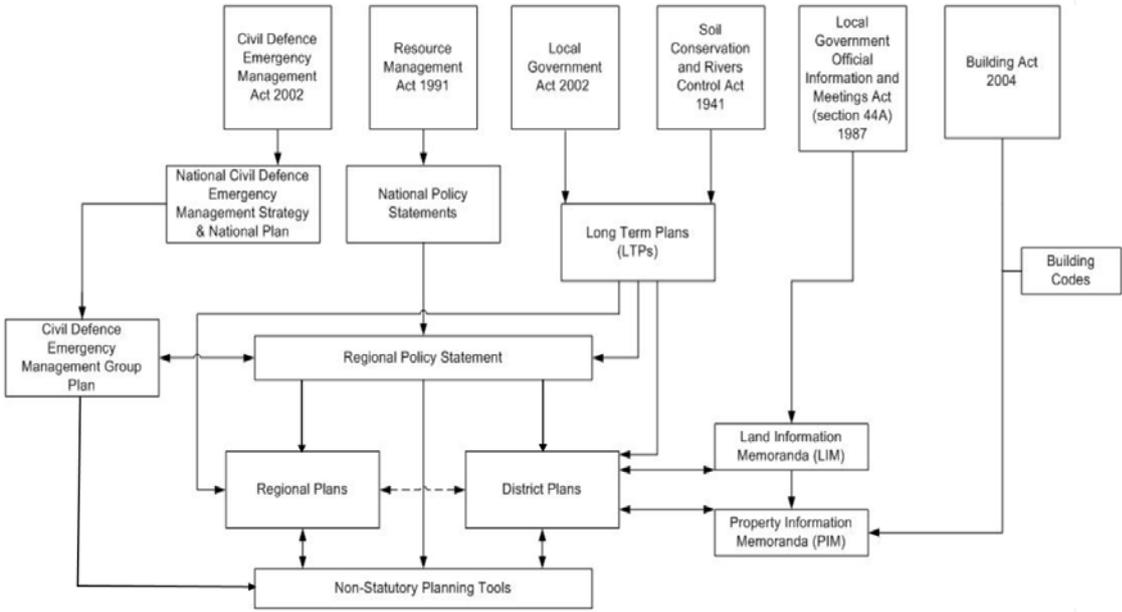
## A.1 Planning framework for managing natural hazards

Figure A-1 shows the key legislation for managing natural hazards in New Zealand and the key plans, statements and strategies prepared under the legislation. The legislation provides a range of responsibilities for national, regional, city and district agencies.

Regional policy statements play a central role in determining how local authorities manage natural hazards. They must meet the natural hazard management responsibilities under the Resource Management Act 1991 (RMA) and national policy statements (including the New Zealand Coastal Policy Statement 2010 (NZCPS 2010)), and may draw on councils' long-term plans developed under the Local Government Act 2002, Soil Conservation and Rivers Control Act 1941 provisions and civil defence emergency management (CDEM) group plans.

A number of other statutes that also have a bearing on natural hazards management are included in this appendix.

**Figure A-1: Relationship between statutory processes for managing natural hazards in New Zealand**



Source: Adapted from the [Quality Planning website](#)

## A.2 Resource Management Act 1991

Under the RMA, regional councils and territorial authorities have specific functions to manage natural hazards.

The purpose (section 5(1)) of the RMA is to promote the sustainable management of natural and physical resources. Sustainable management for the purposes of the RMA means:

...managing the use, development, and protection of natural and physical resources in a way, or at a rate, which enables people and communities to provide for their social, economic, and cultural well-being and for their health and safety, while:

- (a) sustaining the potential of natural and physical resources (excluding minerals) to meet the reasonably foreseeable needs of future generations; and
- (b) safeguarding the life-supporting capacity of air, water, soil, and ecosystems; and
- (c) avoiding, remedying, or mitigating any adverse effects of activities on the environment.<sup>1</sup>

The RMA provides for a hierarchy of planning instruments that give substance to the purpose of the Act (figure A-1).

Part 2 (purpose and principles) of the RMA identifies the preservation of the natural character of the coastal environment and the management of significant risks from natural hazards as matters of national importance. The requirements for managing the coastal environment are further clarified through the mandatory NZCPS 2010 (RMA sections 56–58). Regional policy statements and regional and district plans must comply with the Act and give effect to the NZCPS 2010. While there is no specific part within the Act that deals with coastal management and coastal hazards, the functions that are stipulated for regional and district councils require avoidance or mitigation of natural hazards.<sup>2</sup> For the purposes of the RMA, coastal hazards fall within the definition of natural hazards.<sup>3</sup>

Management of natural and physical resources under the RMA is guided by the principles set out in Part 2 of the Act and by objectives and policies in national and regional policy statements.

Section 6 sets out matters of national importance that must be recognised and provided for in exercising functions under the RMA, and includes:

- (a) the preservation of the natural character of the coastal environment (including the coastal marine area) ... :
- (b) the protection of outstanding natural features and landscapes from inappropriate subdivision, use, and development:
- (d) the maintenance and enhancement of public access to and along the coastal marine area ... :
- (e) the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, waahi tapu, and other taonga:
- (h) the management of significant risks from natural hazards.

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<sup>1</sup> Resource Management Act (RMA) section 5(2).

<sup>2</sup> Refer to sections 30(1)(c)(iv), 31(1)(b)(i).

<sup>3</sup> The definition of natural hazard in section 2 of the RMA is included in box A.1.

Section 7 of the RMA requires that particular regard must be had to a number of matters including:

- (a) kaitiakitanga:
- (aa) the ethic of stewardship:
- (c) the maintenance and enhancement of amenity values:
- (g) any finite characteristics of natural and physical resources:
- (i) the effects of climate change.

Section 7(i), which states that particular regard must be given to the effects of climate change, came into effect as a result of the Resource Management Act (Energy and Climate Change) Amendment Act 2004. This amendment is relevant to coastal hazard management and to the increasing need to plan for the effects of climate change that is already exacerbating coastal hazards in some areas.

Under the RMA, regional (or unitary) councils are responsible for managing the effects of activities within the 'coastal marine area' through a regional coastal plan.<sup>4</sup> Territorial local authorities are primarily responsible for managing activities on the landward side of the coastal marine area through a district plan.<sup>5</sup> Regional councils can also manage some land uses through a regional plan.

Although this coastal delineation suggests a concise management regime, coastal issues invariably cross the jurisdictional boundary of the mean high water springs (MHWS), so require an integrated management approach. Integrated management is fundamental to the RMA and is specifically required under sections 30(1)(a) (functions of regional councils), 31(1)(a) (functions of territorial authorities), 59 (purpose of regional policy statements) and 64(2) (preparation and change of regional coastal plans). Integrated management is reinforced in the NZCPS 2010, which applies to the 'coastal environment' and refers to both the coastal marine area and the land adjacent to the coast and subject to coastal influences. Section 64(2) of the RMA specifically provides that:

A regional coastal plan may form part of a regional plan where it is considered appropriate in order to promote the integrated management of a coastal marine area and any related part of the coastal environment.

The RMA requires councils to consult with other affected councils when preparing plans and regional policy statements.

The RMA also provides for combined policy statements and plans to be developed, including across local authority jurisdictions, both at regional and district level (section 80).

Natural hazard management functions and responsibilities are found in:

- section 30(1)(c)(iv) where regional councils have the function of control of the use of land for the avoidance or mitigation of natural hazards

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<sup>4</sup> RMA section 30(1)(d), section 64(1).

<sup>5</sup> RMA section 31.

- section 30(1)(d) where regional councils, in conjunction with the Minister of Conservation, have the function of the control of any actual or potential effects of the use, development or protection of land in the coastal marine area, including for the avoidance or mitigation of natural hazards
- section 31(1)(b)(i) where territorial authorities have the function of control of the effects of use, development or protection of land, for the purpose of avoidance or mitigation of natural hazards
- section 35 where all local authorities have responsibilities to gather information, monitor and keep records of natural hazards (to the extent that the local authority considers appropriate for the effective discharge of its functions)
- section 62(1) and (2) where the responsibilities for specifying objectives, policies and methods for the control of the use of land to avoid or mitigate natural hazards, or a group of natural hazards, must be allocated through statements in the regional policy statement. If no responsibilities are specified, the regional authority retains primary responsibility
- section 65(3) where a regional council must consider the desirability of preparing a regional plan when a threat from natural hazards 'arises or is likely to arise'
- section 106 where a territorial authority may refuse a subdivision consent, or grant it subject to conditions, if an assessment shows that there is a significant risk from natural hazards. Section 106(1A) helps clarify what must be taken into account in an assessment of risk in any situation
- section 220, which provides that conditions may be attached to subdivision consents to protect that land or any other land from natural hazards
- section 229, which provides that esplanade reserves or strips, required on subdivision of land, may have the purpose of protecting conservation values through mitigating natural hazards or maintaining or enhancing the natural functioning of the adjacent sea or river
- sections 330 to 331, which provide for emergency works in specific circumstances, including under the Civil Defence Emergency Management Act 2002.

## BOX A.1: KEY RESOURCE MANAGEMENT ACT 1991 DEFINITIONS (SECTION 2)

**Climate change** means a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

**Coastal marine area** means the foreshore, seabed, and coastal water, and the air space above the water:

- a) of which the seaward boundary is the outer limits of the territorial sea
- b) of which the landward boundary is the line of mean high water springs, except that where that line crosses a river, the landward boundary at that point shall be whichever is the lesser of:
  - i. one kilometre upstream from the mouth of the river; or
  - ii. the point upstream that is calculated by multiplying the width of the river mouth by five.

**Foreshore** means any land covered and uncovered by the flow and ebb of the tide at mean spring tides and, in relation to any such land that forms part of the bed of a river, does not include any area that is not part of the coastal marine area.

**Land** includes land covered by water and the air space above land.

**Marine and coastal area** has the meaning given in section 9(1) of the Marine and Coastal Area (Takutai Moana) Act 2011.

**Natural hazard** means any atmospheric or earth or water related occurrence (including earthquake, tsunami, erosion, volcanic and geothermal activity, landslip, subsidence, sedimentation, wind, drought, fire, or flooding) the action of which adversely affects or may adversely affect human life, property, or other aspects of the environment.

There are some notable aspects about how district and regional plans can give particular regard to natural hazard management and the effects of climate change in the coastal environment, as required under RMA sections 6 and 7. These include the following.

- Only regional policy statements, district plans and regional coastal plans are mandatory. Although regional councils may prepare other plans to fulfil their functions under RMA section 30, including those to control the use of land in relation to natural hazards, such plans are not mandatory for land outside the coastal marine area.<sup>6</sup>
- An activity cannot occur within the coastal marine area unless there is a resource consent or rule in a plan permitting it. This contrasts with most activities on the landward side of MHWS (RMA section 9), where an activity is permitted unless a rule controls or prohibits it (Harris (2004)). Therefore, it is critical that policies and particularly rules in district plans are carefully constructed to achieve intended community outcomes for land use in the coastal environment, to manage the effects of coastal hazards and climate change.

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<sup>6</sup> Although note that the primary responsibility for control of the use of land to manage natural hazards remains with regional councils unless assigned to the territorial authority through the regional policy statement.

- Land can be subject to both regional and district land use rules. Such provisions can work effectively together.

## BOX A.2: DISTRICT AND REGIONAL RULE SITUATION

District plan provisions are subject to limitations that reduce their ability to manage natural hazard effects in developed areas. Controls that limit buildings in a hazard area in district plan rules can prevent new buildings or significant extensions to existing buildings. However, 'existing use rights' generally apply to buildings in place before the coastal hazard rules came into effect, provided the building was 'lawfully established' (Resource Management Act 1991 (RMA) section 10). Even when a building has been partially or completely destroyed by coastal hazards, the existing use rights will allow the building to be rebuilt on the same general footprint, with the same character, intensity and scale.

Regional rules (under section 9(2) RMA) in such situations may be more effective for managing existing development. If controls on building in a coastal hazard area are contained in rules in a regional plan, then existing use rights do not apply and cannot be relied on to allow reconstruction or continued use of the building (section 10 and 10B rules providing for existing uses apply only to rules in district plans). Section 20A of the RMA provides that a use (including any associated structures), which would require a resource consent under a new rule in a regional plan, must seek a resource consent within six months of the rule becoming operative. While a resource consent to continue the use may be granted, it may be subject to appropriate conditions that could include the staged removal over time or other specific mitigation conditions. A consent can specify a duration of up to 35 years for the consent (section 123(d) RMA).

The issue of hazard management within district and regional planning documents was considered in the case of *Canterbury Regional Council v Banks Peninsula District Council* [1995] 3 NZLR 189, [1995] NZRMA 452 (CA) in which McKay J Court of Appeal noted:

It is true ... that natural hazard is not defined as being the consequence of the occurrence, but as the occurrence itself which has or potentially has the adverse consequence. What can be avoided or mitigated, however, is not the occurrence but its effect. Neither in s 30 nor in s 31 are the words 'effects of' used in connection with 'natural hazards'. This is for the simple reason that they would be otiose,<sup>7</sup> as the definition of 'natural hazard' incorporates a reference to effects. The word 'effects' would also be inappropriate in respect of s 30(1)(c)(i)-(iii). It is unnecessary and inappropriate to explain the language by reference to some subtle distinction between the respective functions of regional councils and territorial authorities.

It follows that the control of the use of land for the avoidance or mitigation of natural hazards is within the powers of both regional councils and territorial authorities. There will no doubt be occasions where such matters need to be dealt with on a regional basis, and occasions where this is not necessary, or where interim or additional steps need to be taken by the territorial authority. Any controls imposed can be tested by appeal to the (Environment Court), and inconsistencies are precluded by s 75(2).

<sup>7</sup> 'Otiose' means functionless.

A regime for managing hazards in the coastal environment is likely to work most effectively when clear responsibilities have been stated in the regional policy statement, clarifying the respective roles and responsibilities at regional and district level.

Some regional councils (eg, Bay of Plenty Regional Council, Hawke's Bay Regional Council and Environment Canterbury) have extended the geographical coverage of their regional coastal plans and provide policies and objectives to guide activities or control activities on land adjacent to the sea, as well as the coastal marine area. These provisions may establish setbacks, limit building and/or control building infrastructure (such as wastewater systems), which has the effect of controlling new buildings.

Such rules may allow existing uses to continue, but buildings damaged or destroyed by the action of the sea may not necessarily be rebuilt as of right.

Such regional rules for a coastal hazard zone provide the basis for, and are expected to have the long-term effect of, progressively rolling development back on a retreating shoreline – a managed retreat approach.

All plan provisions are subject to scrutiny through RMA Schedule 1 processes. They must also be subject to the section 32 evaluation process for their appropriateness, efficiency and effectiveness, as well as a risk assessment (in terms of the implications of acting or not acting) where uncertainty is concerned.

### **A.2.1 New Zealand Coastal Policy Statement 2010**

The NZCPS, gazetted in 2010, states policies to achieve the purpose of the RMA (see sections 56 to 58A) while managing the coastal environment. It is prepared under the RMA. The NZCPS 2010 is required to be 'given effect to' in district or regional plans, and must be had 'regard to' in decisions on resource consent applications. Regional policy statements, regional coastal plans and district plans must give effect to the NZCPS (sections 62(3), 67(3) and 75(3) of the RMA).

Policy 3 of the NZCPS 2010 directs a precautionary approach for decisions in the coastal environment when managing resources potentially vulnerable to climate change effects. It addresses the effects of activities on the coastal environment through guiding principles and specific policies. The provisions set out below are particularly pertinent to assessing response options to coastal hazards, including sea-level rise and other climate change impacts:

- Objective 1 and Objective 2, policies 1, 5, 11 to 17 – address features and components of natural and heritage character
- Policy 4 – integrated management
- Objective 6, policies 6, 7, 9 and 10 – consider appropriate subdivision, use and development in the coastal environment
- Policy 3 – address the precautionary approach towards proposed activities
- Objective 5, policies 24 to 27 – recognise natural hazards, and outline methods for managing coastal hazard risk (see box A.3)
- Objective 4, policies 18 to 20 – for maintenance and enhancement of public access and open space
- Objective 3, Policy 2 – Treaty principles, kaitiaki and tāngata whenua involvement in the management of coastal resources (Department of Conservation, 2010).

The Department of Conservation provides comprehensive implementation guidance for the NZCPS 2010 provisions (Department of Conservation, 2017).<sup>8</sup>

### BOX A.3: POLICIES 24 TO 27, NEW ZEALAND COASTAL POLICY STATEMENT 2010

#### Policy 24: Identification of coastal hazards

- (1) Identify areas in the coastal environment that are potentially affected by coastal hazards (including tsunamis), giving priority to the identification of areas at high risk of being affected. Hazard risks, over at least 100 years, are to be assessed having regard to:
  - (a) physical drivers and processes that cause coastal change including sea level rise;
  - (b) short-term and long-term natural dynamic fluctuations of erosion and accretion;
  - (c) geomorphological character;
  - (d) the potential for inundation of the coastal environment, taking into account potential sources, inundation pathways and overland extent;
  - (e) cumulative effects of sea level rise, storm surge and wave height under storm conditions;
  - (f) influences that humans have had or are having on the coast;
  - (g) the extent and permanence of built development; and
  - (h) the effects of climate change on:
    - (i) matters (a) to (g) above;
    - (ii) storm frequency, intensity and surges; and
    - (iii) coastal sediment dynamics;

taking into account national guidance and the best available information on the likely effects of climate change on the region or district.

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<sup>8</sup> [www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/policy-statement-and-guidance/](http://www.doc.govt.nz/about-us/science-publications/conservation-publications/marine-and-coastal/new-zealand-coastal-policy-statement/policy-statement-and-guidance/).

**Policy 25: Subdivision, use, and development in areas of coastal hazard risk**

In areas potentially affected by coastal hazards over at least the next 100 years:

- (a) avoid increasing the risk of social, environmental and economic harm from coastal hazards;
- (b) avoid redevelopment, or change in land use, that would increase the risk of adverse effects from coastal hazards;
- (c) encourage redevelopment, or change in land use, where that would reduce the risk of adverse effects from coastal hazards, including managed retreat by relocation or removal of existing structures or their abandonment in extreme circumstances, and designing for relocatability or recoverability from hazard events;
- (d) encourage the location of infrastructure away from areas of hazard risk where practicable;
- (e) discourage hard protection structures and promote the use of alternatives to them, including natural defences; and
- (f) consider the potential effects of tsunami and how to avoid or mitigate them.

**Policy 26: Natural defences against coastal hazards**

- (1) Provide where appropriate for the protection, restoration or enhancement of natural defences that protect coastal land uses, or sites of significant biodiversity, cultural or historic heritage or geological value, from coastal hazards.
- (2) Recognise that such natural defences include beaches, estuaries, wetlands, intertidal areas, coastal vegetation, dunes and barrier islands.

**Policy 27: Strategies for protecting significant existing development from coastal hazard risk**

- (1) In areas of significant existing development likely to be affected by coastal hazards, the range of options for reducing coastal hazard risk that should be assessed includes:
  - (a) promoting and identifying long-term sustainable risk reduction approaches including the relocation or removal of existing development or structures at risk;
  - (b) identifying the consequences of potential strategic options relative to the option of 'do-nothing';
  - (c) recognising that hard protection structures may be the only practical means to protect existing infrastructure of national or regional importance, to sustain the potential of built physical resources to meet the reasonably foreseeable needs of future generations;
  - (d) recognising and considering the environmental and social costs of permitting hard protection structures to protect private property; and
  - (e) identifying and planning for transition mechanisms and timeframes for moving to more sustainable approaches.

- (2) In evaluating options under (1):
  - (a) focus on approaches to risk management that reduce the need for hard protection structures and similar engineering interventions;
  - (b) take into account the nature of the coastal hazard risk and how it might change over at least a 100-year timeframe, including the expected effects of climate change; and
  - (c) evaluate the likely costs and benefits of any proposed coastal hazard risk reduction options.
- (3) Where hard protection structures are considered to be necessary, ensure that the form and location of any structures are designed to minimise adverse effects on the coastal environment.
- (4) Hard protection structures, where considered necessary to protect private assets, should not be located on public land if there is no significant public or environmental benefit in doing so.

Department of Conservation (2010).

## A.2.2 National policy statements

National policy statements are prepared under the RMA and enable central government to prescribe objectives and policies for matters of national significance that are relevant to achieving the purpose of the Act. They guide decision-making under the RMA at the national, regional and district levels and can, therefore, significantly affect resource management practices in New Zealand.

The Minister of Conservation is required to prepare a New Zealand coastal policy statement through a formal and public process, but other national policy statements (prepared by the Minister for the Environment) are optional. National policy statements can state policies and objectives on any issue that is of national importance and that is also relevant to promoting the sustainable management of natural and physical resources. Regional policy statements, regional plans and district plans must give effect to all national policy statements.

At the time of preparation of this guidance, a national policy statement for natural hazards is being considered. A framework for a risk-based approach has been investigated and published as a background document to further policy work for a future proposed national policy statement.<sup>9</sup>

The National Policy Statement on Urban Development Capacity, operative from December 2016, requires spatial planning to identify land which is suitable for development, particularly for urban areas in rapidly growing regions and districts, to underpin statutory planning through regional policy statements and regional and district plans.<sup>10</sup>

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<sup>9</sup> [www.mfe.govt.nz/publications/natural-hazards-management/risk-based-approach-natural-hazards-under-rma](http://www.mfe.govt.nz/publications/natural-hazards-management/risk-based-approach-natural-hazards-under-rma).

<sup>10</sup> <http://www.mfe.govt.nz/publications/towns-and-cities/national-policy-statement-urban-development-capacity-2016>.

### A.2.3 National environmental standards

National environmental standards are regulations issued under section 43 of the RMA.

They are legally enforceable and each council must enforce the same standard. In some circumstances, councils can impose stricter standards.

There are currently national environmental standards for air quality, human drinking water sources, electricity transmission activities, telecommunications facilities, and assessing and managing contaminants in soil to protect human health.

## A.3 Building Act 2004 and building regulations

The [Building Act 2004](#) addresses building work in the interests of ensuring the safety and integrity of a structure through its construction and subsequent use.

This focus is distinct from that of the RMA, which addresses the effects of that structure (or any activity within it) on the environment, and of the environment on that structure (or activity within it).<sup>11</sup> The Building Act is administered by the Ministry of Business, Innovation and Employment, primarily through district councils.<sup>12</sup>

Under section 71 of the Building Act, a building consent authority must refuse to grant a building consent for construction of a building, or major alterations to a building, if:

1. the land on which the building work is to be carried out is subject or is likely to be subject to one or more natural hazards; or
2. the building work is likely to accelerate, worsen, or result in a natural hazard on that land or any other property.

However, if the building work will not accelerate, worsen or result in a natural hazard on the land or on any other property, and the building consent authority is satisfied that adequate provision is made to protect the land and building work from natural hazards (section 71(2)), and it is reasonable, a consent must be granted. Where building consents are issued in such circumstances, including where a waiver or modification of the Building Code has been granted, the council must notify the Register-General of Land so the natural hazard concerned and the details of the waiver can be noted on the land's title.

Natural hazards include coastal hazards such as coastal erosion and inundation from storm tides and waves, which can combine with river and stream floods, overland flow or raised water tables (section 71(3)).

Buildings may require a land use consent under the RMA (where a building is located in an area in which buildings are controlled; where a permitted activity condition in relation to bulk or location is not achieved; or where a building is associated with a type of activity not provided for in the zone) as well as a building consent under the Building Act. If controls are imposed under both the RMA and the Building Act, all requirements apply. In this regard,

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<sup>11</sup> Where a building consent is sought, but a resource consent would also be required, section 37 of the RMA provides that the territorial authority must issue a certificate that prevents or limits the building work until necessary resource consents are obtained.

<sup>12</sup> Regional councils are responsible for building permits for dams. At present, all building consent authorities are territorial or regional councils, but the Building Act provides for private building consent authorities.

section 71(2)(a) of the Building Act may run counter to provisions developed under the RMA and regional and/or district plans.

Section 72 of the Building Act requires the granting of building consents if the work does not accelerate, worsen or result in a natural hazard, and if it is reasonable to grant the consent in respect of the natural hazard. If this waiver occurs, the Registrar-General of Land must be notified (or on behalf of the Crown, the relevant Minister and Surveyor-General must be notified, or in case of Māori land, the Register of the Māori Land Court) (section 73). Any notification must include the project information memorandum for the building consent, and the natural hazard(s) must be identified. Following this notification, an entry must be recorded on the certificate of title, noting that a building consent has been granted under section 72, and any particulars that identify the natural hazard concerned (section 74) must also be noted there. This record keeping allows for future owners of the land to be made aware of the natural hazard risk that may not be apparent at the time of purchase.

Building regulations, including the mandatory Building Code,<sup>13</sup> are made under and in accordance with the Building Act. Clause E1<sup>14</sup> of the Building Code aims to safeguard people from injury and property from damage by surface water<sup>15</sup> (which can be fresh water or water from the sea). Clause E.1.3.2 states that *surface water*, resulting from an event having a 2 per cent probability of occurring annually,<sup>16</sup> shall not enter *buildings*. The clause is usually applied in the form of a minimum building floor level for housing and residential–communal buildings, and it is a minimum standard. Box A.4 outlines the relationships between the Building Act and the RMA.

#### BOX A.4: RELATIONSHIPS BETWEEN THE RESOURCE MANAGEMENT ACT 1991 AND THE BUILDING ACT 2004

Under the Building Act, building work under a building consent cannot be undertaken until any necessary resource consents have been obtained (section 37).

Although district councils can exercise judgement about whether to allow a subdivision or development under the RMA, councils cannot abrogate responsibilities for avoiding or mitigating the effects of natural hazards and merely rely on the controls under the Building Act. The RMA process is important because the outcome of that process will generally decide whether a building can be sited in the relevant area in the first place.

Section 68(2A) of the RMA provides that regional or district rules may require performance criteria additional to, or more restrictive than, those under the Building Act for managing surface water to protect other property.

The Building Act, specifically sections 71 to 74, is particularly relevant where coastal (or other) hazards are discovered after subdivision has taken place (so RMA section 106 cannot be applied) or even emerge after development is already established, including in zoned areas. In some circumstances, waivers of the Building Code may be provided that allow for development subject to specified conditions, enabling the requirements of the Act to be achieved.

<sup>13</sup> The Building Act provides several routes to obtaining permits, including compliance with the regulations, through acceptable solutions and/or through verification methods and/or through alternative ways.

<sup>14</sup> [www.building.govt.nz/building-code-compliance/e-moisture/e1-surface-water/](http://www.building.govt.nz/building-code-compliance/e-moisture/e1-surface-water/).

<sup>15</sup> All naturally occurring water, other than sub-surface water, which results from rainfall on the site or water flowing onto the site, including that flowing from a drain, stream, river, lake or sea.  
[www.building.govt.nz/assets/Uploads/building-code-compliance/e-moisture/e1-surface-water/asvm/e1-surface-water-amendment-9.pdf](http://www.building.govt.nz/assets/Uploads/building-code-compliance/e-moisture/e1-surface-water/asvm/e1-surface-water-amendment-9.pdf).

<sup>16</sup> Annual exceedance probability or AEP (see appendix F).

A number of determinations have provided some clarity on the relationships that apply. The most relevant determinations made by the Ministry of Business, Innovation and Employment under the Building Act are:

- Determination No. 2004/08 – Protection of other property from coastal hazards. Issued 23 April 2004 (note: this determination applied the earlier natural hazard provisions under the Building Act 1991).
- Determination No. 2005/28 – Revisited protection of other property from coastal hazards. Issued 10 March 2005.
- Determination No. 2007/110 – Building consent for a house on land subject to coastal hazards. Issued 17 September 2007.

The full text for the determinations can be found at [www.building.govt.nz/resolving-problems/resolution-options/determinations/determinations-issued/](http://www.building.govt.nz/resolving-problems/resolution-options/determinations/determinations-issued/).

Summaries of these determinations can be found at: [www.niwa.co.nz/climate/information-and-resources/coastal-climate-change](http://www.niwa.co.nz/climate/information-and-resources/coastal-climate-change).

## A.4 Local Government Act 2002 and Local Government (Rating) Act 2002

The [Local Government Act 2002](#) outlines administrative and management responsibilities for regional and district councils, including for matters such as land management, utility services, recreation assets, transportation, and the associated provision of services. It also establishes the way territorial local authorities may collect financial contributions for funding the acquisition, maintenance and development of reserves and community infrastructure.

The Local Government Act 1974 requires stopped roads along the margins of the coast (along MHWS) to be vested in the district council as esplanade reserves (section 345(3)).

Community planning is a cornerstone of the 2002 Act, which requires communities to prepare long-term plans that set out community outcomes and longer term financial planning. These plans must include infrastructure strategies over at least a 30-year period, including provisions for their resilience in the face of natural hazard risks.

Local governments must meet specific consultation requirements when preparing long-term and annual plans, infrastructure strategies, and asset management plans or bylaws under the 2002 Act. These requirements are particularly significant for coastal strategies or other management plans that are adopted as part of the adaptation response to coastal hazards including climate change impacts.

Sections 16 to 18 of the Local Government (Rating) Act 2002 provide for establishing special rating areas or rating for special purposes subject to specific processes. These provisions can be used to fund projects and may be applied in coastal areas for adaptive management in the future.

## A.5 Soil Conservation and Rivers Control Act 1941

This legislation retains earlier objectives and responsibilities for catchment management and soil conservation, including “the prevention of damage by floods” and “the utilisation of lands in such a manner as will tend towards the attainment of the said objects” (section 10). The

legislation provides for administration of the objects of the Act<sup>17</sup> by regional and territorial authorities. It complements the powers in the Local Government Act 2002 for regional councils to make bylaws for flood protection and flood control works undertaken by, or on behalf of, a regional council. The Act allows for the taking of land under the Public Works Act 1981 when this is required to meet the Act's objectives, and provides for fair compensation.

## A.6 Civil Defence Emergency Management Act 2002

The Civil Defence Emergency Management Act 2002 (CDEMA) is intended to:

- improve and promote sustainable management of hazards
- encourage and enable communities to achieve acceptable levels of risk
- provide for planning and preparation for emergencies, and for response and recovery
- require local authorities, through regional groups, to coordinate planning and activities around reduction, readiness, response and recovery (the 4Rs)
- provide a basis for integrating national and local civil defence emergency management
- encourage coordination across agencies, recognising that emergencies are multi-agency events.

The CDEMA requires that a risk management approach be taken when dealing with hazards. It requires that this management is considered across the 4Rs – *reduction* (the avoidance and mitigation of risks) and *readiness for, response to, and recovery* from any event that may result in an emergency. When the risks associated with a particular hazard are being considered, both the likelihood of the event occurring and its consequences must be addressed.

The CDEMA provides a framework for regional and territorial authorities to plan and coordinate hazard management across their roles and responsibilities, alongside those of emergency and essential services providers. It can complement the Building Act 2004 and the RMA, particularly in managing impacts, during the readiness, response and recovery phases of an emergency (eg, evacuating an area, and providing welfare, when a hazard poses a direct threat to public safety).

This coordination of roles and responsibilities is achieved with the formation of civil defence emergency management (CDEM) groups comprising representatives from each of the territorial local authorities and the regional council within a region. The CDEMA (section 17(1)) outlines the functions of a CDEM group in relation to relevant hazards and risks. These include to:

- identify, assess and manage those hazards and risks
- consult and communicate about risks
- identify and implement cost-effective risk reduction.

The CDEMA (section 48) provides that each CDEM group must provide a CDEM group plan that must state the hazards and risks to be managed by the group and the actions necessary to do so. The CDEMA, therefore, anticipates that regional and territorial authorities will cooperate in managing hazards and risk, including coastal hazards.

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<sup>17</sup> Four objects of the Act are listed in section 10.

### **A.6.1 National Civil Defence Emergency Management Plan 2015**

The CDEMA also aims to establish and integrate national level hazard management (policy, functions and operational arrangements) with local level management. The National Civil Defence Emergency Management Strategy (2007) sets out the Government's vision, principles, goals and objectives for this management.

The National Civil Defence Emergency Management Plan 2015 and the supporting Guide to the National Civil Defence Emergency Management Plan 2015 outline the established operational arrangements across the 4Rs and the various areas of government, supporting organisations and community structures. Hazards covered under the Plan are the 17 classes of hazards in the [National Hazardscape Report](#) (2007), which include tsunami and coastal hazards (and recognition of sea-level rise and climate change effects).

Part 6 of the Emergency Management Plan relates to reduction and sets out the objectives, principles and methods for risk reduction. Reduction is described as steps that “involve identifying and analysing risks to life and property from hazards, taking steps to eliminate those risks if practicable, and, if not, reducing the magnitude of their impact and the likelihood of their occurrence to an acceptable level”, with the objective being “to take preventative steps to avoid or mitigate adverse consequences”.

The principles for reduction include to:

- achieve acceptable levels of risk through sustainable and practicable reduction measures to provide the best long-term solutions
- reduce the risks to communities from hazards, including a combination of the following measures:
  - modifying factors that affect the likelihood of an emergency where practicable to do so
  - modifying factors that affect exposure and vulnerability to consequences before, during and after an emergency
- take a precautionary approach to managing hazards and risks where there is:
  - scientific or technical uncertainty about a hazard or risk, or
  - potential for cumulative or cascading risks to arise.

Risk reduction is expected to be undertaken through the mainstream functions and activities of central and local government under their legislative and policy mandates (including all the statutes shown in figure A-1), and the risk management practices of agencies, private organisations and individuals. The Guide to the Plan (section 17 on reduction) also states a strong emphasis on local initiatives. As most hazard events are at a local or regional scale, individuals, communities and local government are considered best placed to decide on management options suited to them, for example, through land use planning requirements.

Other reduction activities outlined in Part 6 of the National Civil Defence Emergency Management Plan concern “the development, administration, and review of policy and regulation that facilitate reduction across society (eg, land use planning...and performance standards and codes for the design and construction of buildings and other structures)” and “the establishment, monitoring, and evaluation of policies and programmes across the social, economic, built, and natural environments that improve and promote the sustainable management of hazards and support increases in individual and community resilience to the risks that those hazards pose”.

The broad approaches to hazard management of the National Civil Defence Emergency Management Strategy and the Emergency Management Plan align with the United Nations International Strategy for Disaster Reduction (UNISDR). The Government has signed the declaration adopting the Sendai Framework 2015–30 and committed to implementing it as a way to enhance resilience to hazards from the local to the global level. Implementation requires shared involvement and cooperation across all areas of society, using and (where desirable) enhancing those institutional structures and processes already in place.

The CDEMA requires the Minister of Civil Defence to review the National Civil Defence Emergency Management Plan every five years. The next review is due by 2020. The National Civil Defence Emergency Management Strategy is currently under review with a revised strategy proposed for completion by 2018. The Sendai Framework requires reporting on progress on a biennial basis.

## **A.7 Reserves Act 1977**

The Reserves Act 1977 makes provision for the acquisition, control, management, maintenance, preservation, development and use of public reserves, and makes provision for public access to the coastline and rural areas. Administering bodies are generally required to prepare management plans for their reserves, which are open for public comment and review.

While the Reserves Act provides public use areas and access, these reserve areas may also be useful for providing buffers from coastal hazards. However, councils must manage reserves to fulfil their purpose(s) under the Reserves Act (whether historic reserve, scientific reserve, scenic reserve and so on). If buffer functions are not specifically mentioned in a reserve management plan, it is questionable whether reserve areas can be treated in this way by territorial authorities, because their buffering function may have an effect on their specified use for reserve or open space recreation. For example, the purpose of an esplanade reserve is defined in the RMA, which may include reducing coastal hazard risk. This purpose, if relevant, should be specified in the relevant reserves management plan.

## **A.8 Public Works Act 1981**

The Public Works Act 1981 deals with the rights of central and local government to acquire private land for public purposes including for reserves (within the meaning of the Reserves Act), and the procedures for acquiring and disposing of this land. The acquisition of land for reserve purposes is one way of providing for buffers and setbacks.

The Public Works Act covers procedures where the land is to be acquired by agreement or where it is to be compulsorily acquired.

## **A.9 Marine and Coastal Area (Takutai Moana) Act 2011**

Under this legislation (which repealed the Seabed and Foreshore Act 2004), the marine and coastal area is defined as the area bounded on the landward side by MHWS and on the seaward side by the outer limits of the territorial sea. At river mouths, the RMA definition is applied.<sup>18</sup> As outlined in Part 2 of the Act, the common marine area comprises the marine and coastal area, less freehold land within that area and conservation areas, reserves and national

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<sup>18</sup> Marine and Coastal Area (Takutai Moana) Act 2011 section 9.

parks. Any other land formerly owned by a local authority or the Crown was divested when the legislation became effective. Land in the common marine and coastal area is not and cannot be owned by anyone.

When, due to erosion, land of the Crown or a local authority moves seaward of MHWS, the title of that land is divested (unformed roads are not divested for a period of up to 15 years). If the Crown or a local authority acquires freehold land that has become part of the marine and coastal area, it becomes part of the common marine and coastal area.

Structures that are or come to be within the marine and coastal area are regarded as personal property, rather than an interest in land but are not part of the common marine and coastal area. The Crown is deemed to be owner of any abandoned structure in the common marine area and coastal area, unless the owner can be found.<sup>19</sup>

However, the Crown is not liable for any breaches committed in respect of the structure and any effects attributed to the structure, before the Crown became the deemed owner of the structure. The Crown is not liable for any health, safety or environmental issues associated with the structure.<sup>20</sup>

General access rights (subject to other legislation) are protected in the common marine and coastal area.

The legislation has not yet been tested for the status of land lost by erosion or inundation, the ability of local authorities to acquire such land other than by agreement, and the ability of the Minister of Conservation to adequately compensate local authorities.

## A.10 Local Government Official Information and Meetings Act (1987)

Section 44A (land information memorandum) is relevant for managing coastal hazards and climate change effects.

A person may apply to a territorial authority for the issue of a land information memorandum (LIM) in relation to matters affecting any land in the district of the authority. One of the matters to be considered when deciding what to include on a LIM is:

- (2)(a) information identifying each (if any) special feature or characteristic of the land concerned, including but not limited to potential erosion, avulsion, falling debris, subsidence, slippage, alluvion, or inundation, or likely presence of hazardous contaminants, being a feature or characteristic that
  - (i) is known to the territorial authority; but
  - (ii) is not apparent from the district scheme under the Town and Country Planning Act 1977 or a district plan under the Resource Management Act 1991.

There are no grounds for a territorial authority to withhold the information specified above or to refuse to provide a LIM where this has been requested. There is an increasing body of case law about natural hazard responsibilities.

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<sup>19</sup> Marine and Coastal Area (Takutai Moana) Act 2011, section 19.

<sup>20</sup> Ibid.

## Appendix B: Relevant court cases

Table B-1 summarises the key court cases relating to coastal hazards, application of the New Zealand Coastal Policy Statement 2010 and the effects of climate change on coastal hazards. The summary has been updated from cases covered in the previous guidance (Ministry for the Environment, 2008a, appendix 2). Table B-1 has links to the relevant case documents or decisions.

More detailed summaries of the main decisions and outcomes from these cases are at: [www.niwa.co.nz/climate/information-and-resources/coastal-climate-change](http://www.niwa.co.nz/climate/information-and-resources/coastal-climate-change).

**Table B-1: Summary of key court cases in relation to coastal hazards, application of New Zealand Coastal Policy Statement 2010, and climate change effects**

Case name	Year	Court	Key words	Issues under consideration	Link
<i>Judges Bay Residents Association v Auckland Regional Council and Auckland City Council A 72/98</i>	1998	Environment Court	Resource consent, natural hazards, sea level rise	Hazard protection measures and port development	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/1998/179.html?query=" judges%20bay"="">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/1998/179.html?query="judges%20bay"</a>
<i>Auckland City Council v Auckland Regional Council A 28/99</i>	1999	Environment Court	Resource consent, groundwater	Relevance of climate change information	<a auckland%20city%20council%20and%20auckland%20regional%20council"%20)"="" href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/1999/97.html?query=title(">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/1999/97.html?query=title("auckland%20city%20council%20and%20auckland%20regional%20council"%20)</a>
<i>Kotuku Parks Ltd v Kāpiti Coast District Council A 73/00</i>	2000	Environment Court	Subdivision, earthworks	Resource Management Act 1991 (RMA) section 106 and catastrophic coastal hazard events	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2000/210.html?query=Kotuku%20Parks">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2000/210.html?query=Kotuku%20Parks</a>
<i>Lowry Bay Residents Association v Eastern Bays Little Blue Penguin Foundation Inc W45/01</i>	2001	Environment Court	Consents, natural hazards	Relationship between Building Act 1991 and RMA in avoiding coastal hazards	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2001/170.html?query=" lowry%20bay%20residents%20association"="">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2001/170.html?query="lowry%20bay%20residents%20association"</a>
<i>Save the Bay v Canterbury Regional Council C6/2001</i>	2001	Environment Court	Coastal hazards, natural hazards	Hazard zone provisions within regional coastal environmental plan	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2001/20.html?query=" save%20the%20bay"="">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2001/20.html?query="save%20the%20bay"</a>
<i>McKinlay v Timaru District Council C 24/2001</i>	2001	Environment Court	Natural hazards, existing use rights	Existing use rights and the role of rules in regional and district plans	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2001/74.html?query=title(" mckinlay%20and%20timaru%20district%20council"%20)"="">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2001/74.html?query=title("mckinlay%20and%20timaru%20district%20council"%20)</a>
<i>Bay of Plenty Regional Council v Western Bay of Plenty District Council A 27/02</i>	2002	Environment Court	Coastal protection area, precautionary approach, sustainable management	Principles of hazard avoidance. Relationship between resource and building consents	<a bay%20of%20plenty%20regional%20council%20and%20western%20bay%20of%20plenty%20district%20council%20"%20)"="" href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2002/47.html?query=title(">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2002/47.html?query=title("Bay%20of%20Plenty%20Regional%20Council%20and%20Western%20Bay%20of%20Plenty%20District%20Council%20"%20)</a>
<i>Skinner v Tauranga District Council A 163/02</i>	2002	Environment Court	Hazard risk zones	Reasonable timeframe for coastal planning, use of precautionary approach for managing uncertainties	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2002/288.html?query=title(" skinner%20and%20tauranga%20district%20council"%20)"="">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2002/288.html?query=title("Skinner%20and%20Tauranga%20District%20Council"%20)</a>

Case name	Year	Court	Key words	Issues under consideration	Link
<i>Fore World Developments Ltd v Napier City Council W029/06</i>	2006	Environment Court	Subdivision, coastal erosion	Climate change information and use of the precautionary approach to account for uncertainties	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2006/120.html?query=Fore%20World">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2006/120.html?query=Fore%20World</a>
<i>Application by Tasman District Council – W047/2011</i>	2011	Environment Court	Plan change, coastal erosion, coastal inundation, subdivision	Immediate legal effect of rule in hazard areas	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2011/47.html?query=Tasman%20District%20Council%202011">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2011/47.html?query=Tasman%20District%20Council%202011</a>
<i>Environmental Defence Society v NZ King Salmon, Sustain our Sounds Inc Marlborough District Council, Minister of Conservation and Director General of Ministry for Primary Industries NZSC38/2014</i>	2013	Supreme Court	Plan change, resource consent, outstanding natural character	Interpretation of New Zealand Coastal Policy Statement (NZCPS) policies, and importance of strategic planning in giving effect to NZCPS	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZSC/2014/38.html?query=Environmental%20Defence%20Society">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZSC/2014/38.html?query=Environmental%20Defence%20Society</a>
<i>M and V Weir v Kāpiti Coast District Council, NZHC 3522/13 (interim), NZHC 43/15 (final)</i>	2013	High Court	Natural hazards, coastal hazards, land information memorandum (LIMs)	Information on LIMs	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZHC/2013/3516.html?query=Weir">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZHC/2013/3516.html?query=Weir</a> <a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZHC/2015/43.html?query=Weir">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZHC/2015/43.html?query=Weir</a>
<i>Carter Holt Harvey HBU Ltd v Tasman District Council W025/2013</i>	2013	Environment Court	Resource consent, coastal erosion, inundation	RMA section 106, importance of adequate access, and meaning of ‘avoidance’ of risk in relation to new development	<a carter%20holt%20harvey"="" href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2013/25.html?query=">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2013/25.html?query="Carter%20Holt%20Harvey"</a>
<i>Mahanga E Tu Inc v Hawke’s Bay Regional Council and Wairoa District Council W083/2014</i>	2014	Environment Court	Subdivision, consents, coastal hazard zones	Relevance of existing zoning and mitigation requirements	<a href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2014/83.html?query=" mahanga%20e%20tu%20inc"="">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2014/83.html?query="Mahanga%20E%20Tu%20Inc"</a>
<i>D and C Gallagher v Tasman District Council W245/2014</i>	2014	Environment Court	Subdivision, consent, coastal erosion, inundation, timescales	Coastal hazard investigations, timescale for planning, and application of NZCPS policies	<a gallagher"="" href="http://www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2014/245.html?query=">www.nzlii.org/cgi-bin/sinodisp/nz/cases/NZEnvC/2014/245.html?query="Gallagher"</a>

# Appendix C: IPCC assessments and representative concentration pathways

## C.1 IPCC climate change assessments

The Intergovernmental Panel on Climate Change (IPCC) is a scientific and intergovernmental body under the auspices of the United Nations, set up in 1988 at the request of member governments. The IPCC is dedicated to providing the world with an objective, scientific view of climate change and its political and economic impacts (see box C.1).

The IPCC released its Fifth Assessment Report (AR5) in 2013–14. The report comprises three detailed Working Group reports and an associated summary for policymakers along with an overall synthesis report for policymakers (IPCC, 2014a).

### BOX C.1: INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE



Fifth Assessment Report (AR5) (2013–14) in four volumes.

The IPCC was formed in 1988 by the World Meteorological Organization and United Nations Environment Programme to provide reliable scientific advice on climate change. The IPCC remit is to synthesise and communicate the current state of climate research to governments and policymakers at all levels, and it underpins negotiations at the United Nations Climate Conference – the United Nations Framework Convention on Climate Change (UNFCCC).

Approximately every six years, it has produced a full assessment of the current state of scientific knowledge on climate change and what it means. During this process, the IPCC produces four reports from three working groups (WGI: Physical Science Basis; WGII: Impacts, Adaptation and Vulnerability; WGIII: Mitigation of Climate Change) and an overall synthesis report for policymakers. These reports provide a coherent body of evidence and analyses that have been published either in peer reviewed scientific journals or other credible sources.

The Fifth Assessment Report (AR5) involved over 830 scientific authors from 85 countries and processed 142,631 review comments, with 42 governments providing reviews of the Synthesis Report.

Peer-reviewed literature up to the following cut-off dates was considered for AR5 (WGI: July 2012; WGII; August 2013; WGIII; October 2013). Website: [www.ipcc.ch](http://www.ipcc.ch).

The [2013 Working Group I – Physical Sciences report](#) (IPCC, 2013a) is a synthesis of peer-reviewed literature on observations and projections of climate change. The most relevant section is chapter 13 on ‘Sea level change’ (Church et al, 2013a). The [Summary for Policymakers](#) (IPCC, 2013b) provides a succinct summary of the extensive Working Group I report.

This was followed in 2014 by the [Working Group II – Impacts, Adaptation and Vulnerability assessment report](#) (IPCC, 2014c). The most relevant sections, from which material has been used in this guidance, are:

- Foundations for decision making (chapter 2) – (Jones et al, 2014)
- Adaptation planning and implementation (chapter 15) – (Mimura et al, 2014)
- Climate-resilient pathways: adaptation, mitigation, and sustainable development (chapter 20) – (Denton et al, 2014)
- Regional chapters: Australasia (chapter 25) – (Reisinger et al, 2014).

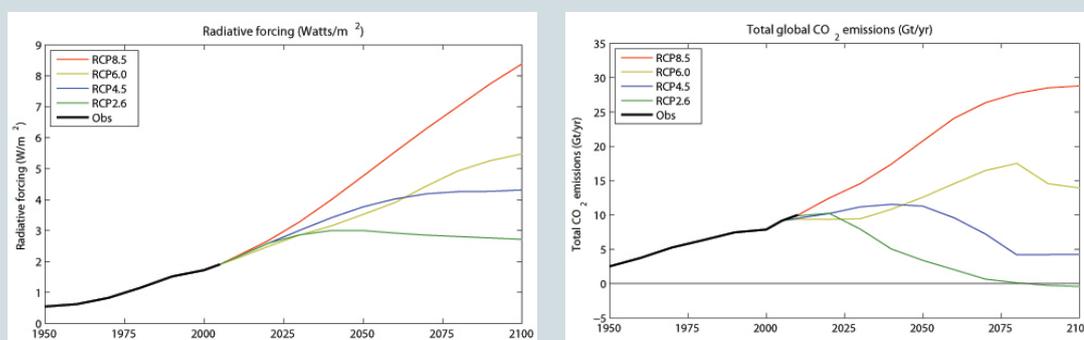
## C.2 Representative concentration pathways

The goal of working with scenarios is not to predict the future, but to better understand uncertainties in order to reach decisions that are robust under a wide range of possible climate futures (Moss et al, 2010).

To enable consistent climate change projections to be derived for the IPCC AR5, four representative scenarios of future radiative forcings were developed. These are called representative concentration pathways (RCPs) (Burkett et al, 2014; Moss et al, 2010; van Vuuren et al, 2011). Box C.2 outlines the background to developing the RCPs from integrated assessment models that include social, economic and other factors (eg, demographics, land use changes).

### BOX C.2: REPRESENTATIVE CONCENTRATION PATHWAYS – EMISSION SCENARIOS USED IN THE IPCC AR5

**Figure C-1: Global radiative forcing and associated carbon dioxide emissions, including land use (around 9 per cent of total) and fossil fuels, for representative concentration pathways with historic values from 1950**



Data source: RCP Database(v2.0) <http://tntcat.iiasa.ac.at:8787/RcpDb/>

Four representative scenarios of future radiative forcings were developed for the IPCC AR5, called representative concentration pathways or RCPs (Collins et al, 2013; Moss et al, 2010; van Vuuren et al, 2011).

Radiative forcing, expressed in watts per square metre ( $W/m^2$ ), is the change in the balance between incoming insolation (solar) and outgoing energy radiated back up in the atmosphere caused by changes in atmospheric composition, including aerosols and greenhouse gases, such as carbon dioxide.

The background to the words are respectively (van Vuuren et al, 2011):

- *representative* – signifies that each of the RCPs represents a larger set of emission and mitigation scenarios in the literature and was selected to have different forcing targets
- *concentration* – used instead of emission rates, emphasising that concentrations of greenhouse gases (or associated radiative forcing) are the primary output of the RCPs, for input to climate models
- *pathway* – referred to as pathways, but not specific scenarios or forecasts. They are internally consistent sets of time-dependent forcing projections that could potentially be realised with more than one underlying socio-economic scenario.

The numbers after RCP denote the radiative forcing reached by 2100 (left-hand plot above).

RCPs were developed using integrated assessment models that typically include economic, demographic, energy and simple climate components. The emission scenarios they produce are then run through a simple model to produce time series of greenhouse gas concentrations that can be run in climate–ocean models. The requirements of plausibility and consistency have been assured by basing the RCPs on published scenarios of these integrated assessment models (van Vuuren et al, 2011).

As a set, these four RCPs represent, or are compatible with, the full range of emission scenarios available in the scientific literature (up to 2010–11), with and without climate policies. Limitation to four scenarios makes running long multiple climate–ocean model simulations more tractable by concentrating on a few representative scenarios, and use of a smaller suite makes it easier for users to assimilate model outputs.

Each of the RCPs primarily covers the period 1850 (end of Industrial Revolution) to 2100 AD.

Note: The RCPs should be considered plausible and illustrative, but **do not have probabilities attached to them** (Collins et al, 2013).

Table C-1 lists the essential characteristics of each RCP and the anticipated global mean surface temperature increases by 2081–2100 relative to a 1986–2005 baseline.

**Table C-1: Representative concentration pathway descriptions and inputs and outputs**

RCP	Description	Radiative forcing (W/m <sup>2</sup> )	CO <sub>2</sub> concentration (ppm CO <sub>2</sub> eq)	Global mean temperature in 2081–2100 (likely range* °C)
RCP8.5	Continued high-emissions baseline trajectory with no effective emissions mitigation and a rising radiative forcing pathway – emissions stabilised only after 2100, but radiative forcing continues rising until around 2250. Highly energy-intensive scenario as a result of high population growth (around 13 billion by 2100) and lower rate of technology development.	8.5	~1370	2.6–4.8
RCP6.0	Moderate emission mitigation pathway, with initial reductions, but gradually rising again peaking around 2080. Stabilisation of emissions to around 6 W/m <sup>2</sup> soon after 2100. Population peaks at around 10 billion later this century.	6	~850	1.4–3.1
RCP4.5	Moderate emission mitigation pathways peaking around 2050 and gradually declining, with stabilisation of radiative forcing to around 4.5 W/m <sup>2</sup> by 2100. Population peaks at around 9 billion later this century.	4.5	~650	1.1–2.6
RCP2.6	Peak and decline in global emissions occurs around 2020, rapidly reducing to zero-net global emissions by last quarter of this century and thereafter possible negative emissions (requiring some removal of carbon from the atmosphere). Population peaks at around 9 billion later this century.	peaks at ~3 (2040–50), declining to 2.6 by 2100	~490 peak**	0.3–1.7

Note: CO<sub>2</sub> = carbon dioxide; ppm CO<sub>2</sub> eq = parts per million of carbon dioxide equivalent; W/m<sup>2</sup> = watts per square metre; ~ = around

\* Range between 5 per cent and 95 per cent of all climate model simulations, relative to base period 1986–2005 (table SPM.2, IPCC, 2013b).

Note: Add around 0.6°C to these projections relative to the 1986–2005 baseline (IPCC, 2013b) to derive temperature rises from the start of the industrial era, which were used as the baseline for targets in the Paris Conference of the Parties (COP21) climate change agreement.

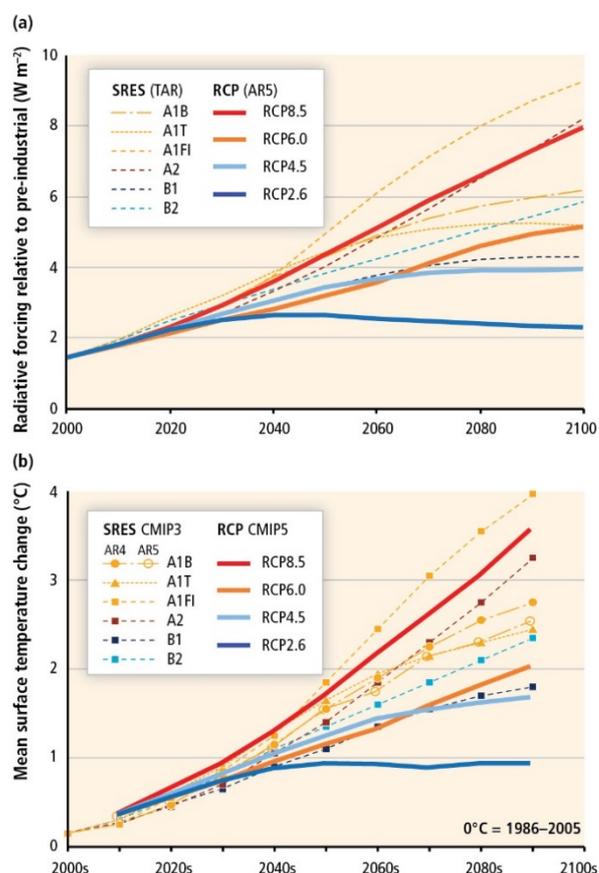
\*\* Average global atmospheric carbon dioxide reached 400 parts per million in 2016.

'Zero net emissions' is part of the lowest RCP2.6 pathway for the latter quarter of this century. This refers to the case where total global emissions of long-lived greenhouse gases<sup>21</sup> are fully offset by removals by forest sinks, industrial removal processes or other forms of carbon capture and storage so there is no net flow of emissions of long-lived gases to the atmosphere on an annual or period basis (Leining and Kerr, 2016). This would be accompanied by significant reductions in emissions of short-lived gases.

## Previous SRES emission scenarios

The 2007 IPCC Fourth Assessment Report (AR4) used emission scenarios from an IPCC Special Report on Emission Scenarios<sup>22</sup> known as SRES scenarios. These were superseded by RCPs in the 2013 IPCC AR5, described above. Figure C-2 shows both SRES and RCP scenarios for radiative forcing and temperature projections, to enable a comparison for reports or papers that use either scenario set. This guidance uses only the more recent RCP scenarios.

**Figure C-2: Comparison of SRES and RCP global emission scenarios (radiative forcing and temperature) used for the IPCC AR4 and AR5 respectively**



Note: AR4 = Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC); AR5 = Fifth Assessment Report of the IPCC; CMIP = Coupled Model Intercomparison Project; RCP = representative concentration pathway; SRES = Special Report Emissions Scenarios; TAR = Third Assessment Report of the IPCC;  $W m^{-2}$  = watts per square metre. The thick lines denote the RCPs and dashed lines the SRES scenarios. Source: Burkett et al, 2014, figure 1-4

<sup>21</sup> The major greenhouse gases are carbon dioxide ( $CO_2$ ), methane ( $CH_4$ ), nitrous oxide ( $N_2O$ ), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride ( $SF_6$ ). Conventionally, methane is considered a short-lived gas and the others long-lived gases. The 2006 IPCC *Guidelines for National Greenhouse Gas Inventories* identify other greenhouse gases that could be included if they become relevant to New Zealand.

<sup>22</sup> [www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf](http://www.ipcc.ch/pdf/special-reports/spm/sres-en.pdf).

# Appendix D: Background science on sea-level rise and projections

## D.1 Ocean, ice and sea-level rise observations

As a result of sustained warming of the atmosphere through the enhanced greenhouse effect from emissions since the Industrial Revolution, the ocean and land–ice environments have been gradually changing. Relevant headline observations by the Intergovernmental Panel on Climate Change (IPCC) on coasts, oceans and ice environments are summarised in box D.1.

The increase in annual mean air temperature for New Zealand over the period 1909 to 2015 was 0.98°C, or a rate of 0.92°C per 100 years (NIWA, 2016), which is slightly higher warming than the global average of 0.85±0.2°C from 1880–2012 (IPCC, 2013b).

### BOX D.1: IPCC FIFTH ASSESSMENT REPORT SUMMARY STATEMENTS ON OBSERVATIONS OF COASTAL, OCEAN AND ICE ENVIRONMENTS

- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90 per cent of the energy accumulated between 1971 and 2010 (*high confidence*), with only about 1 per cent stored in the atmosphere.
- Glaciers have lost mass and contributed to sea-level rise throughout the 20th century.
- It is *very likely* that the rate of ice mass loss from the Greenland ice sheet has substantially increased over the period 1992 to 2011, resulting in a larger mass loss over 2002 to 2011, than over 1992 to 2011. The rate of ice mass loss from the Antarctic ice sheet, mainly from the northern Antarctic Peninsula and the Amundsen Sea sector of West Antarctica, is also *likely* larger over 2002 to 2011.
- It is *very likely* that the mean rate of global averaged sea-level rise was 1.7±0.2 millimetres per year between 1901 and 2010, 2.0±0.3 millimetres per year between 1971 and 2010, and 3.2±0.4 millimetres per year more latterly (between 1993 and 2010). Tide gauge and satellite altimeter data are consistent regarding the higher rate during the latter period.
- The rate of sea-level rise since 1850 has been larger than the mean rate during the previous 2000 years (*high confidence*). Over the period 1901–2010, global mean sea level rose by 0.19±0.2 metres.

Source: IPCC Summary for Policymakers from Working Group I (IPCC, 2013b) and IPCC Synthesis Report (IPCC, 2014a)



Source: Dan Zwartz

These global and regional increases in surface temperature, along with wind and ocean circulation, drive most of the processes that affect sea-level rise.

## D.2 Contributors to sea-level rise (global, regional and local)

Several factors have contributed to global, regional or local rise in sea level in the recent past and are likely to have an impact into the foreseeable future. Different response times apply to these factors. The main contributors are (Chambers et al, 2016; Church et al, 2010; Milne et al, 2009; Reager et al, 2016; Rietbroek et al, 2016; Slangen et al, 2014):

- Warming of ocean waters, mostly in the 0–2000 metre depth layer. As the ocean warms, the water density decreases thereby increasing the **volume** of the ocean. With the exception of low-lying areas, most of the world’s shorelines constrain lateral inundation – when coupled with the great depths of the ocean, most of the volume expansion is expressed as an increase in the height of the water column and therefore a rise in the surface sea level. This thermal expansion arises from the cumulative effect of all increased ocean temperatures throughout the water column. It is one of the major contributors to sea level change during the 20th century.
- **Water mass** added to the oceans from melting or break up of land-based ice stores (ie, the cryosphere) such as land-based glaciers, ice caps and polar ice sheets (particularly Greenland and West Antarctica). The contribution of additional water mass is accelerating and in the long term will be the largest component of sea-level rise as ice sheets diminish.

Note: Because coastal fringing polar ice shelves and sea ice already float in the ocean, they only have a minor contribution to sea-level rise when they break up and melt (due to the slight increase in volume from the less dense freshwater ice melt relative to the large volume of saline ocean water). However, polar ice shelf collapse contributes to sea-level rise indirectly, by reducing the buttressing of the ice sheet flows off the polar continents, thereby accelerating ice sheet flow into the ocean (Paolo et al, 2015).

- Changes in composition or flowpaths of the main **ocean currents** and associated changes in wind patterns. These features are also substantially influenced by natural climate variability, as evident by the regional differences in sea-level rise during the satellite era (since 1993), as shown in figure D-1.
- Changes in the net storage or discharge of **terrestrial freshwater**, for example, groundwater and river extraction, reservoirs, changes in global rainfall and evaporation from climate variability such as El Niño and La Niña.
- Global sea level change can also be caused by **ocean basin changes** through such processes as seafloor spreading and ongoing post-glacial readjustment of the Earth’s crust since the last Ice Age (on average the Earth’s seafloor has subsided slightly).

As ice sheets progressively melt they redistribute mass across Earth, inducing regional changes in the gravitational pull on ocean levels (known as a ‘**gravitation fingerprint**’). Following loss of ice mass from an ice sheet, the regional gravitation pull reduces, relaxing the mean level of ocean waters near the ice sheet, leading to compensating increases in sea levels much further afield, such as in the opposite hemisphere (Bamber et al, 2009; Hay et al, 2014; Mitrovica et al, 2011).<sup>23</sup>

- **Vertical land movement** (uplift or subsidence), which can significantly transform ocean sea-level rise locally – especially important is ongoing subsidence that increases the effective sea-level rise (see box D.2).

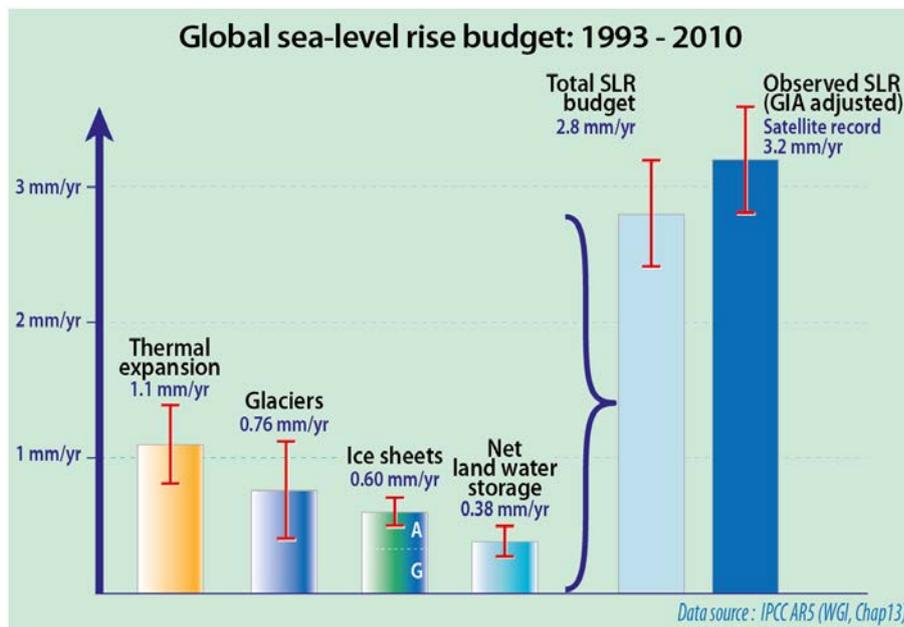
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<sup>23</sup> For New Zealand, large losses of ice sheet mass in Antarctica will contribute a lower gravitational component of sea-level rise, more so at the south end of New Zealand nearer Antarctica, but conversely a higher component derived from reduced gravity from Greenland ice sheet losses – see Ackerley et al (2013).

The combined effect of individual contributors to recent observed sea level change from IPCC Fifth Assessment Report (AR5) is shown in figure D-1. This is based on the satellite era since 1993 (up to 2010), when measurements of ocean sea level and global gravity changes (through the GRACE satellite) enabled a closer match of the sea level budget in relation to the observed response.

A recent update covering the period from 1993 to 2013 by Chambers et al (2016) found that the sea-level rise budget from the sum of contributors closed to within 0.2 millimetres per year (mm/yr) of the global trend. Forty per cent of the trend was from thermal expansion and 60 per cent from an increase in ocean mass (eg, glaciers, ice cap, ice sheets, hydrology), with an acceleration in the contributions from polar ice sheets over the last decade.

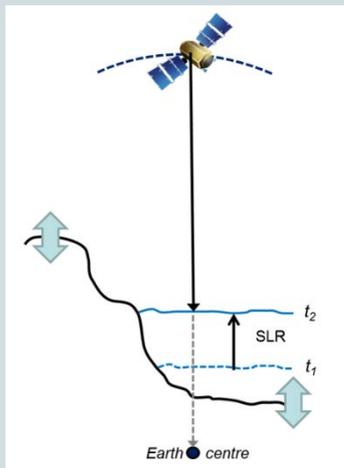
**Figure D-1: Contributors (month/year) to the sea-level rise budget over the satellite era from 1993 to 2010**



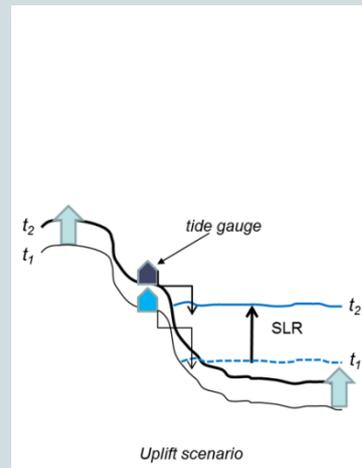
Note: Ice sheet contributions arise from Antarctica (A) and Greenland (G). The red bars denote the uncertainty range on the estimated contributions or observations. GIA = glacial isostatic adjustment; mm/yr = millimetres per year; SLR = sea-level rise.

Source: IPCC Fifth Assessment Report, chapter 13 (Church et al, 2013a)

## BOX D.2: ABSOLUTE AND LOCAL SEA-LEVEL RISE



Absolute (eustatic) sea-level rise



Local (relative) sea-level rise

**Absolute** or eustatic sea-level rise (SLR) is the rise in the average ocean surface elevation measured from the centre of the Earth. It is the variable that is simulated in global models to generate future projections and also for Intergovernmental Panel on Climate Change assessments.

**Local** (relative) SLR is the local change in sea level relative to the land at a specific point on the coast, measured by a sea level gauge. The gauge measures the combined effect of absolute SLR for the regional sea and other regional and local processes, for example, oceanographic circulation patterns, hydrology cycles (water use and storage), and local and/or regional vertical land motion (subsidence or uplift). Consequently, local SLR varies between coastal regions.

If local processes affecting local SLR remain similar through time (excluding earthquake events), then the rising absolute sea level from warming oceans and ice melt will increasingly dominate the local SLR in the future. For example, the present vertical land movement in Wellington, generated by inter-seismic subsidence of 1–2 millimetres per year (mm/yr), is not too dissimilar to the present global absolute SLR of around 2–3 mm/yr. However, if it were to remain the same until 2100, it would diminish in relative importance as absolute SLR rates reach around 10 mm/yr.

A common misunderstanding is that sea level gauges on land are not suitable for measuring the 'actual' SLR at a location or region, because the record is affected by vertical land movement and other localised oceanographic processes. However, **it is the local or relative SLR, directly measured by the tide gauge that needs to be adapted to locally (not the absolute rise of the ocean)**. For example, if the land is subsiding, the local SLR will be higher than the absolute rise (see figure 16 in chapter 5) or vice versa for uplift.

To convert local SLR into absolute SLR, for scientific purposes (eg, contributing to international databases for calibrating climate–ocean models and tracking the ocean SLR against representative concentration pathway projections), and to quantify the ongoing rate of vertical land movement, continuous GPS (cGPS) recorders are co-located on land near the gauge site. Although Land Information New Zealand supports a limited network of 'coastal' cGPS stations within the GeoNet monitoring network, more sites should be co-located with key sea level gauges to improve the quality of information on vertical land movement at the coast.

GeoNet cGPS network: [info.geonet.org.nz/display/equip/New+Zealand+Continuous+GPS+Network](http://info.geonet.org.nz/display/equip/New+Zealand+Continuous+GPS+Network).

## Recent sea-level rise during the satellite era (since 1993)

Sea surface heights measured by radar altimeters on a series of satellite missions since 1993 (eg, TOPEX/Poseidon; Jason 1, 2, 3; Sentinel-3) have provided a consistent and continuous coverage of sea level across the oceans.

Based on the CSIRO analysis,<sup>24</sup> the trend in global mean sea level from 1993 to January 2016 is  $3.3\pm 0.1$  mm/yr, but sea-level rise is not distributed equally across the globe (figure D-2). In particular, the western Pacific (including New Zealand) has exhibited considerably larger rises in sea level over the 23-year satellite era than the eastern Pacific.

Around New Zealand, from 1993 to 2015 inclusive, the trend for the absolute sea-level rise in the wider exclusive economic zone ocean waters has been  $4.4\pm 0.87$  mm/yr,<sup>25</sup> compared with the trend of  $3.0\pm 0.1$  mm/yr for the same analysis on the global dataset – both without including any glacial isostatic adjustment or GIA (M Hadfield, NIWA, pers. comm.). The comparison of trend is shown in figure D-3. As expected, regional subsets of ocean sea level exhibit more natural variability than the smoother global average, as shown in figure D-3, with the Inter-decadal Pacific Oscillation (IPO) shift around 1999 obvious in New Zealand sea level.

These regional differences in sea level in the Pacific are influenced by variability in ocean wind patterns generated by climate modes, such as the 20- to 30-year IPO and the two- to four-year El Niño–Southern Oscillation (ENSO) (eg, Han et al, 2016). This inequality in patterns of sea-level rise across the Pacific is projected to be amplified under future sea-level rise, including the increasing emergence of the gravitational fingerprint as ice sheets become unstable (Perrette et al, 2013; Slangen et al, 2012).

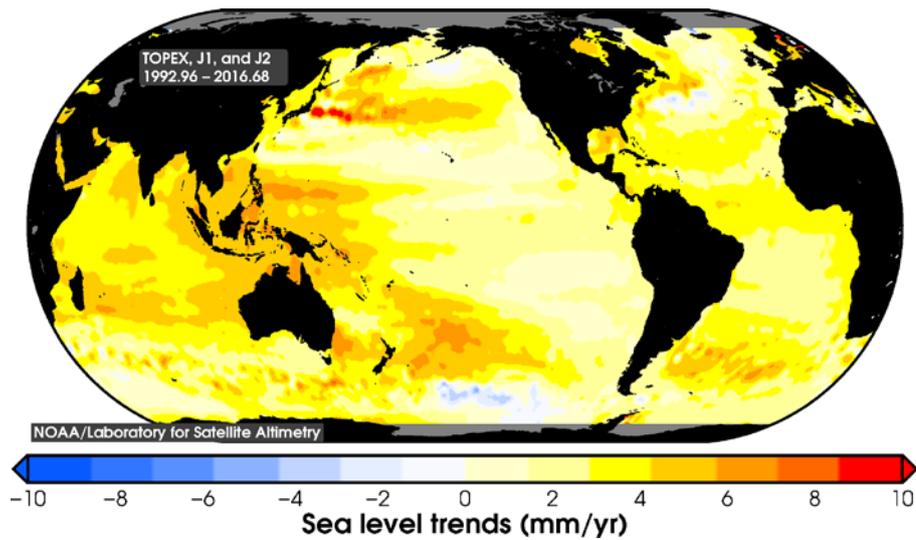
The sea level response in the southwest Pacific is clearly influenced by variability from climate modes, which currently partially masks the background trend derived from climate change. The degree of climate variability in different regional seas also extends the monitoring time required, before acceleration of the climate change signal becomes clearly evident. A statistically significant acceleration in sea-level rise is likely to emerge from the climate–system variability within regional seas around the Pacific (including New Zealand) in the next few decades (Fasullo et al, 2016), but the variability could also be influenced by climate change (see Marcos et al (2016) for a summary).

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<sup>24</sup> See [www.cmar.csiro.au/sealevel/sl\\_hist\\_last\\_decades.html](http://www.cmar.csiro.au/sealevel/sl_hist_last_decades.html).

<sup>25</sup> Standard deviation incorporates effect of a lag-one autocorrelation of 0.878 on monthly averages.

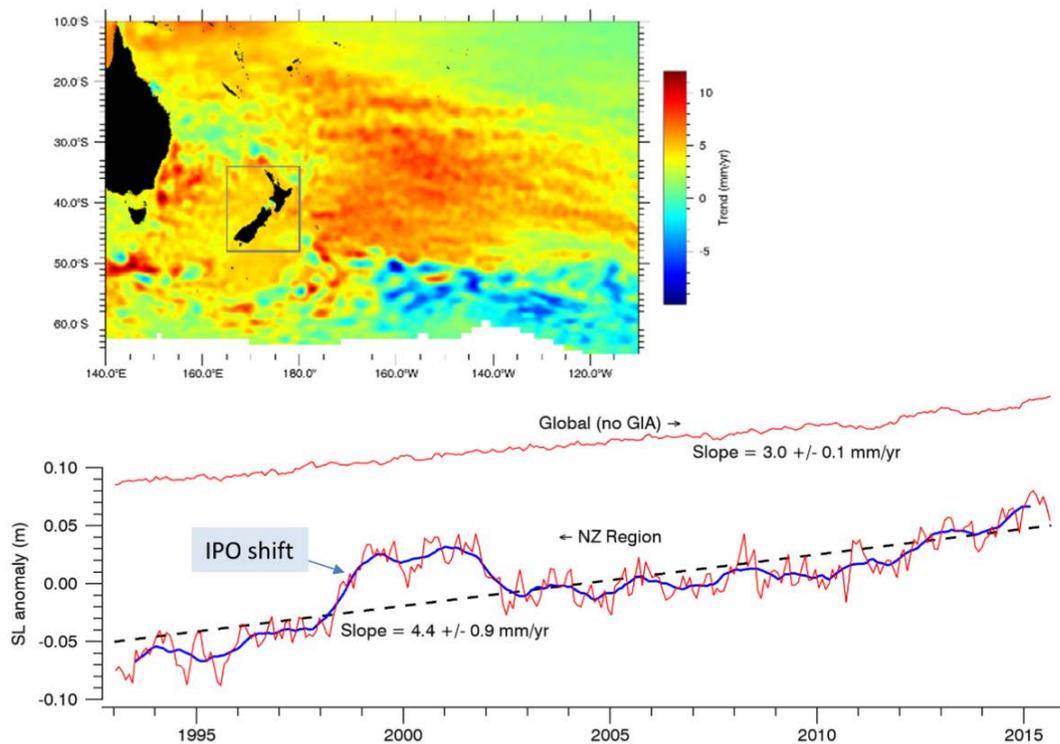
**Figure D-2: Map of regional patterns of sea-level rise (month/year) from 1993 to August 2016**



Note: Local trends estimated using data from TOPEX/Poseidon, Jason-1 and Jason-2, which have monitored similar ground tracks since late 1992. An inverted barometer adjustment has been applied, but not the glacial isostatic adjustment effects on the geoid or Earth's crust.

Source: NOAA/NESDIS Center for Satellite Applications and Research

**Figure D-3: Regional New Zealand sea trend in sea level from 1993–2015 compared with the global average (both without glacial isostatic adjustment)**



Note: GIA = glacial isostatic adjustment; IPO = Inter-decadal Pacific Oscillation; mm/yr = millimetres per year; NZ = New Zealand; SL = sea level. Map shows contour plot of linear trends (mm/year) and inset box is the area from which gridded altimeter data was extracted for the New Zealand seas trend. Blue line in lower panel is a running one-year average.

Source: [AVISIO delayed-time gridded altimeter dataset](#); analysis M Hadfield, NIWA, pers. comm., 2016

## D.3 Approaches to sea-level rise projections

Uncertainties in climate projections arise from natural variability, uncertainty around the rate of future emissions and the resulting climate response. Uncertainties also occur because representations of some known processes remain unrefined and because some processes are not included in the climate–ocean and ice sheet–ocean models (IPCC, 2013a, see FAQ 1.1).

The term ‘projection’ is used in two senses in the climate change literature. In general usage, a projection can be regarded as any description of the future and the pathway leading to it (ie, not a ‘prediction’). However, a more specific interpretation has been attached to the term ‘climate projection’ or ‘sea-level rise projection’ by the IPCC, which refers specifically to model-derived estimates of future climate. Projections are also used in the context of developing future population and economic pathways or scenarios.

There are fundamental limits to the precision with which temperatures and sea-level rise can be projected into the future, because of the chaotic nature of the climate system and the complex interactions with ocean and ice environments.

Furthermore, decadal-scale projections are sensitive to prevailing conditions – such as the temperature of the deep ocean or ice sheet dynamics – that are less well known. Some natural variability over decadal periods arises from interactions between the ocean, atmosphere, land, biosphere and cryosphere (ice environments). This variability is also linked to phenomena such as the two- to five-year ENSO and longer climate cycles, such as the 20- to 30-year IPO (which influences New Zealand climate and mean sea level), and similar climate cycles in other oceans (IPCC, 2013a, FAQ 1.1).

There is no single, well-accepted technique for projecting future sea-level rise – each has strengths and weaknesses, and no perfect approach for anticipating future conditions exists.

Four approaches are used by scientists for developing projections for surface temperature, sea-level rise, mass losses from ice stores and other climate variables.

### Process-based models

Process-based models are complex numerical models that simulate the dynamic processes and interactions between the atmosphere, oceans, land surface, ice – plus energy from the sun, and that increasingly detail the influence of clouds, rainfall, evaporation and sea ice. The model outputs focus on estimating climate trends or changes (eg, typically comparing statistical measures over a decade or more from ensembles of multiple simulations).

Examples are the models from the [Coupled Model Intercomparison Project–Phase 5](#), known as CMIP5 models. These process-based models were used to develop the global temperature and sea-level rise projections in the IPCC AR5 (Collins et al, 2013). Examples of process-based ice-sheet models coupled to climate–ocean models are provided by DeConto and Pollard (2016) and Joughin et al (2014). These models were calibrated with extensive measurements of gravity (ie, change in mass of the ice sheets) by the GRACE satellite and polar ocean measurements.

### Semi-empirical models

In relation to projections of sea-level rise, these models are based on more simplified functions that estimate sea level response to a forcing driver, such as global surface temperature or

radiative forcing with gain and lag parameters, and can include shorter term fluctuations.

Examples include:

- using historical relationships between global sea level and surface atmospheric temperature, assuming the relationship holds into the future (eg, Jevrejeva et al, 2012; Moore et al, 2013; Rahmstorf et al, 2012)
- combinations of equations for the response to surface temperature of each contributor to sea-level rise such as ice sheets, glacier and thermal expansion (eg, Mengel et al, 2016). These are subsequently ‘trained’ using historic temperature and sea level data, which includes paleo information combined with the modern instrumental record. This recent approach targets each contributor to sea-level rise, providing more realistic projections.

Note: Sea-level rise projections, based on semi-empirical models at the time of compiling the IPCC AR5, were significantly higher than process-based model estimates (Church et al, 2013a). However, more recent studies with more complex approaches that include expert elicitation (eg, Mengel et al, 2016), align more closely with process-based models and the IPCC AR5 projections.

## **Structured expert panel or elicitation approaches**

Inclusion of uncertainties in climate and sea level projections, variously called model, structural or deep uncertainty, take the scientific community outside the zone of what can be predicted using process-based and semi-empirical models (Oppenheimer et al, 2016). This applies particularly to non-linear polar ice sheet and ice shelf responses, where the complex processes and feedback mechanisms that cause sea-level rise are not completely understood. Further, thresholds or instabilities that could result in irreversible or runaway reductions in ice sheet volumes for the different RCPs lead to deep uncertainty at the upper-end projections (or upper tail of the probability distribution).

Consequently, to complement the physically based model approaches, structured expert judgement through panels or elicitation with a larger group of experts has been used. A similar approach was used to assess uncertainty and confidence descriptors in the IPCC AR5.

Examples of this approach to estimating contributions from polar ice sheets to sea-level rise projections are the expert panel approaches of Bamber and Aspinall (2013) and Horton et al (2014). The former was critiqued by de Vries and van der Wal (2015) who criticised the decision not to elicit estimates of the total sea-level rise from ice sheets, but only ask the experts about the individual sea level trend contributions at 2100 from the largest three ice sheets (Greenland, West and East Antarctica). Bamber et al (2016) responded that, while experts differ greatly in their ability to quantify uncertainty accurately and informatively, the superiority of performance-based combinations is amply attested.

## **Probabilistic approaches**

Probabilistic approaches use a Monte Carlo simulation technique to ‘sample’ many thousands of times from probability distributions for each contributing component to sea-level rise, derived from various sources including measurements, expert panel elicitation or science community assessments and process-based models. Example probabilistic-based global projections were derived by Jevrejeva et al (2014) and Kopp et al (2014), and for Antarctica specifically by Little et al (2013).

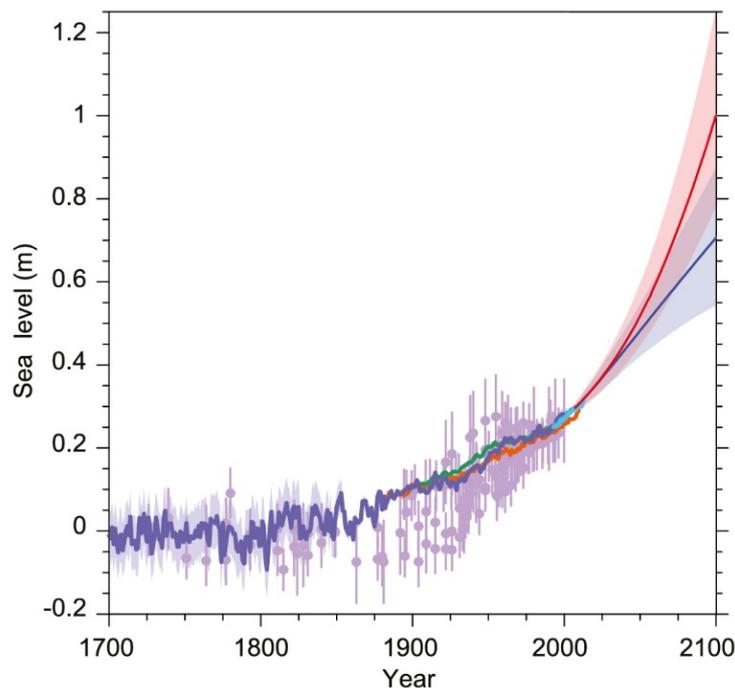
The probabilistic approach used by Kopp et al (2014) combined process-based IPCC AR5 modelling approaches with the expert panel findings of Bamber and Aspinall (2013) for the upper-end ice sheet projections (or tails), providing projections for RCP2.6, 4.5 and 8.5, with probability distributions for sea-level rise for each RCP.

## D.4 Projections in context with historic observations

After relative stability in sea level in the past 2000–3000 years of the late Holocene, with small rates of sea level change of up to plus or minus 0.2 mm/yr (Kopp et al, 2016), sea level began to rise in the late 1800s or early 1900s, as shown in figure D-4 from IPCC AR5. This upwards trend has been analysed by several researchers (eg, Church et al, 2010; Kemp et al, 2011; Kopp et al, 2016; Meyssignac and Cazenave, 2012; Milne et al, 2009).

Sea-level rise projections covering the lower and upper RCP2.6 and RCP8.5 scenarios, derived from a synthesis of process-based models in IPCC AR5, are also shown in figure D-4, highlighting the accelerating trend likely to occur over the rest of this century and beyond.

**Figure D-4: Compilation of paleo, sea level gauge data and projections for global sea-level rise**



Note: Paleo salt-marsh sea level data (purple dots), three sea level reconstructions from tide gauge data (blue, orange and green), satellite altimeter data (bright blue line since 1993) and central estimates and likely ranges for projections of global mean sea level for RCP2.6 (blue) and RCP8.5 (red) scenarios, **all relative to pre-industrial sea level**.

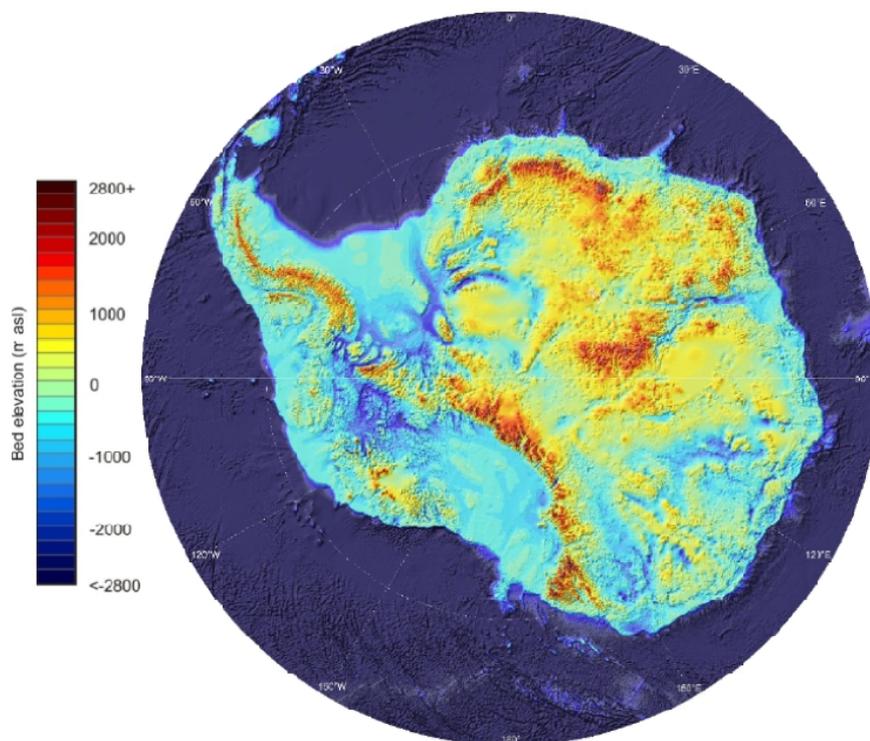
Source: Figure 13.27, Intergovernmental Panel on Climate Change Fifth Assessment Report, Church et al (2013a)

## D.5 Emergence of polar ice sheet instabilities

Recent observations of the ice mass covering Greenland and mainly West Antarctica, through satellite measurement of gravity (mass) changes and airborne radar surveys, have revealed areas of accelerated mass loss in regions of both continents (eg, Morlighem et al, 2014; Paolo et al, 2015; Rignot et al, 2014; Velicogna et al, 2014).

Bedmap2 is an Antarctic mapping project that also measured the bedrock elevations under the ice. Surveys show that the volume of ice contained in the Antarctic ice sheet is 27 million cubic kilometres, with a potential to ultimately contribute to sea-level rise by 58 metres (Fretwell et al, 2013), and reveal substantial areas of Antarctica where the ice is grounded on bedrock well below sea level (figure D-5).

**Figure D-5: Bedrock topography of Antarctica, with elevations (metres) relative to present mean sea level**



Note: West Antarctica is to the left and the Ross Shelf is in the centre bottom.

Source: Fretwell et al, 2013 – with permission

Large portions of the West Antarctic ice sheet are grounded on bedrock below sea level at the coast (grounding line<sup>26</sup>). There are no major bedrock obstacles that would prevent the ice sheets becoming unstable following further retreat and draw down into the entire interior basin, which is well below present sea level as shown in figure D-5 (Feldmann and Levermann, 2015; Fretwell et al, 2013; Rignot et al, 2014). Such processes, if already initiated, would lead to further sizeable and irreversible commitments to sea-level rise (DeConto and Pollard, 2016; Golledge et al, 2015; Trusel et al, 2015).

The IPCC AR5 predicted up to a metre of sea-level rise by 2100 for the upper end of the likely range for the RCP8.5 scenario – but it did not anticipate any significant contribution from Antarctica. Recent journal publications (eg, DeConto and Pollard, 2016; Feldmann and Levermann, 2015; Golledge et al, 2015) indicate that instabilities and onset collapse of the Antarctic ice sheets (mainly in West Antarctica) are more vulnerable to a warming climate than was anticipated when developing the IPCC AR5. However, a study by Ritz et al (2015) found a more restrained contribution from Antarctica ice sheets of 0.3 metres sea-level rise by 2100

<sup>26</sup> The point at where the ice sheet is grounded on solid rock at the coast, marking the transition from the floating part (or shelf) that already contributes to global sea levels (ice shelf) to the grounded ice sheet on land that is yet to contribute.

for the A1B scenario (similar to RCP6.0 – see [appendix C](#)) but indicated that ice sheet instabilities could be initiated in the Amundsen Sea area of Antarctica this century.

While updating studies undertaken since the IPCC AR5, a review by Clark et al (2015) concluded that ice loss from the polar ice sheets by 2100, offset by mass gains in East Antarctica and a slightly reduced melt from glaciers in some regions (eg, Alaska), together indicate that sea-level rise will still lie within the ‘likely range’ (two-thirds probability) of the AR5 projections. In a more recent review, Slangen et al (2016b) found that recent studies on Antarctica indicate a wider upper spread in sea-level rise projections from ice sheets than the IPCC AR5 range, with ultimately sea-level rise reaching up to a few metres per century beyond 2100 for higher emissions scenarios. Using a more complex process model of Antarctic ice shelf instabilities, DeConto and Pollard (2016) determined projections at the upper end and even beyond the several tenths of a metre (decimetres) in the IPCC AR5 (Church et al, 2016).

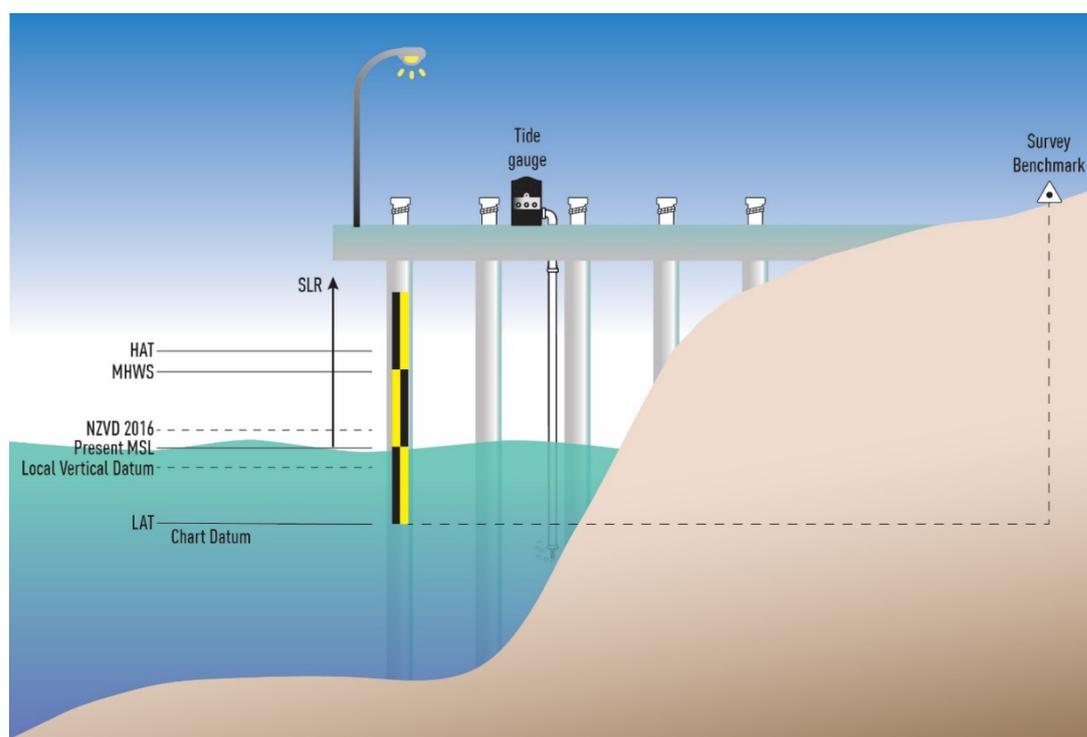
Overall, considerable (deep) uncertainty remains in the timing and extent of the critical contribution to sea-level rise from polar ice sheets and the degree of instability in-region. But what is becoming clearer from these studies is the emergence of a more skewed tail distribution (toward the upper range of possibilities) of sea-level rise projections beyond 2100 that is primarily driven by the ice sheet contributions (Kopp et al, 2014; Slangen et al, 2016b).

The adaptive pathways planning approach and stress testing of plans and major new infrastructure contained in this guidance are designed to work around this deep uncertainty.

## Appendix E: Baseline mean sea level for locations around New Zealand

Sea-level rise projections in this guidance should be added to the local and regional mean sea level, which have been averaged, where possible, over the same baseline period (1986–2005) used for the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) projections (IPCC, 2013a). This ‘grounds’ the future sea level to a vertical datum of the locality or region or the national New Zealand Vertical Datum 2016 (NZVD2016) (figure E-1).

**Figure E-1: Schematic of mean sea level and relationship to various vertical datums and additional sea-level rise**



Note: Local Vertical Datum is specific to each region(s) and is gradually being superseded by a national New Zealand Vertical Datum (NZVD2016). HAT = highest astronomical tide; LAT = lowest astronomical tide; MHWS = mean high water spring tide.

Table E-1 lists the average mean sea level (MSL) over the baseline period 1986–2005 (or the nearest available record over several years) for sites around New Zealand, both relative to the relevant local vertical datum and the national NZVD2016.<sup>27</sup>

For example at Tararu (Firth of Thames), using table E-1, a 1 metre sea-level rise would raise the MSL to an elevation of  $1 + 0.183$  metres = 1.18 metres above Moturiki Vertical Datum–1953 (MVD-53), or  $1 + (-0.129)$  metres = 0.87 metres above NZVD2016. Storm tide water levels would then be added to these future MSL elevations in the relevant datum.

<sup>27</sup> See [www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/new-zealand-vertical-datum-2016-nzvd2016](http://www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/new-zealand-vertical-datum-2016-nzvd2016).

**Table E-1: Mean sea level (MSL) at New Zealand locations averaged over the approximate 1986–2005 baseline (used by IPCC) for adding on sea-level rise projections**

Gauge site	Averaging period (available data)	MSL (m; local vertical datum)	MSL (m; NZ Vertical Datum 2016)
Auckland (Waitemata)	1986–2005	0.110 [AVD-46]	–0.222
Wellington	1986–2005	0.164 [WVD-53]	–0.224
Lyttelton (post-quake)	1986–2005	0.123 [LVD-37]	–0.266
Dunedin	1986–2005	0.076 [DVD-58]	–0.301
Marsden Point	1986–2005	–0.116 [OTP-64]	–0.201
Whangarei	1999–2006	–0.078 [OTP-64]	–0.182
Onehunga	2001–2008	0.219 [AVD-46]	–0.065
Tararu (Thames)	1993–2005	0.183 [MVD-53]	–0.129
Tararu (Thames)	1993–2005	0.193 [AVD-46]	–0.130
Moturiki Island	1986–2005	0.069 [MVD-53]	–0.129
Tauranga	1987–2005	0.068 [MVD-53]	–0.131
Gisborne	2004–2010	0.168 [GVD-26]	–0.170
Napier	1989–2005	0.016 [NVD-62]	–0.177
Port Taranaki	1986–2005	0.155 [TVD-70]	–0.143
Nelson	1986–2005	0.080 [NVD-55]	–0.249
Picton	2005–2008	0.015 [NVD-55]	–0.296
Westport*	1999–2008	0.288 [LVD-37]	–0.090
Timaru	2002–2005	0.143 [LVD-37]	–0.195
Port Chalmers	2000–2005	0.014 [DVD-58]	–0.316
Bluff	1998–2005	0.131 [BVD-55]	–0.183

\* Based on mean sea level from the modern gauge (G Rowe, Land Information New Zealand, pers. comm., 2016).

Note: Mean sea level provided in the relevant local vertical datum and in NZVD2016. The baseline period varies due to availability of data.

As sea level rises, the updated average MSL can be tracked relative to the baseline MSL in table E-1. This can be done by analysing recent annual MSL from the nearest gauge data or from the Land Information New Zealand (LINZ) website which is updated annually (usually for 18–19 year averaging periods). These updated MSL values for standard ports are listed in the LINZ Nautical Almanac or provided at [www.linz.govt.nz/sea/tides/tide-predictions/standard-port-tidal-levels](http://www.linz.govt.nz/sea/tides/tide-predictions/standard-port-tidal-levels). The periods of observation for MSL are at [www.linz.govt.nz/sea/tides/tide-predictions/standard-port-periods-observation](http://www.linz.govt.nz/sea/tides/tide-predictions/standard-port-periods-observation).

These published MSL values are relative to the port chart datum (which is around the lowest low tide) or otherwise the gauge zero datum. Table E-2 lists the offsets to be subtracted from the measured MSL values for the various gauges to convert these MSL values into levels in the relevant local vertical datum or NZVD2016.

Notes:

- 1 Instructions for converting between vertical datums (LINZ): [www.linz.govt.nz/data/geodetic-services/coordinate-conversion/online-conversions/instructions-for-carrying-out-online-height-conversions](http://www.linz.govt.nz/data/geodetic-services/coordinate-conversion/online-conversions/instructions-for-carrying-out-online-height-conversions)
- 2 Online vertical height conversions: <http://apps.linz.govt.nz/coordinate-conversion/index.aspx?Advanced=2&test>

**Table E-2: Offsets to subtract from the measured mean sea level at various gauges around New Zealand to convert to the local vertical datum and New Zealand Vertical Datum 2016**

Gauge site [datum]	Local vertical datum	Offset (m) to subtract from mean sea level (chart datum or gauge zero) → local vertical datum	Offset (m) to subtract from mean sea level (local vertical datum) → NZ Vertical Datum 2016
Auckland (Waitemata) [Chart datum]	Auckland Vertical Datum [AVD-46]	1.743	0.332
Wellington [Chart datum]	Wellington Vertical Datum [WVD-53]	0.915	0.388
Lyttelton (post-earthquake) [Chart datum]	Lyttelton Vertical Datum [LVD-37]	1.241	0.389
Dunedin [Chart datum]	Dunedin Vertical Datum [DVD-58]	0.9914	0.377
Marsden Point [Chart datum]	One Tree Pt Vertical Datum [OTP-64]	1.676	0.085
Whangarei [Gauge zero]	One Tree Pt Vertical Datum [OTP-64]	1.91	0.104
Onehunga [Chart datum]	Auckland Vertical Datum [AVD-46]	2.201	0.284
Tararu (Thames) [Gauge zero – TVD-52*]	Moturiki Vertical Datum [MVD-53]	-0.118	0.312
Tararu (Thames) [Gauge zero – TVD-52*]	Auckland Vertical Datum [AVD-46]	-0.1278	0.323
Moturiki Island [Gauge zero]	Moturiki Vertical Datum [MVD-53]	1.487	0.198
Tauranga [Chart datum]	Moturiki Vertical Datum [MVD-53]	0.9622	0.199
Gisborne [Chart datum]	Gisborne Vertical Datum [GVD-26]	1.052	0.338
Napier [Chart datum]	Napier Vertical Datum [NVD-62]	0.9243	0.193
Port Taranaki [Chart datum]	Taranaki Vertical Datum [TVD-70]	1.815	0.298
Nelson [Chart datum]	Nelson Vertical Datum [NVD-55]	2.2401	0.329
Picton [Gauge zero]	Nelson Vertical Datum [NVD-55]	0.725	0.311
Westport [Chart datum]	Lyttelton Vertical Datum [LVD-37]	1.762	0.378
Timaru [Chart datum]	Lyttelton Vertical Datum [LVD-37]	1.3005	0.338
Port Chalmers [Chart datum]	Dunedin Vertical Datum [DVD-58]	1.016	0.420
Bluff [Chart datum]	Bluff Vertical Datum [BVD-55]	1.609	0.314

\* Tararu Vertical Datum – 1952

# Appendix F: Hazard occurrence probabilities and timeframes

The probability, or likelihood, of events (eg, a coastal hazard occurrence) are commonly expressed in terms of:

- their **annual exceedance probability (AEP)**, which is the chance of at least one such event magnitude or level being reached or exceeded in any one year
- their **average recurrence interval (ARI)**, also commonly known as **average return period**, which is the **average** time interval between events that reach or exceed such an event magnitude, when averaged over many occurrences, that is, a very long period with many such events (some events may occur close together while for others there may be a long gap between similar events)
- the expected average **number of exceedances (N)** of events that reach or exceed such an event magnitude in a given timeframe.

The term ARI has two potential pitfalls when communicating likelihood:

- 1 the likelihood is expressed in years, which makes it prone to confusion with the planning lifetime
- 2 such terminology is commonly misinterpreted – for example, a 100-year return period event only occurs once in a 100-year period, therefore assuming that because one large event has just occurred the average recurrence interval will pass before another such event. When another such event occurs in the period then the calculations are questioned.

ARI and AEP are related by the following equations.

The *encounter probability* (or *design risk*),  $E$ , is related to ARI by:

$$E = 1 - \left[ e^{(-1/ARI)} \right]^L, \text{ (Pugh, 1996)} \quad (1)$$

where  $L$  is the timeframe over which the encounter probability is being assessed. The probability  $E$  of a hazard event occurring increases as the timeframe  $L$  being considered increases. When the encounter probability is assessed over a one-year period, then  $L = 1$  giving the annual exceedance probability or AEP:

$$E = 1 - e^{(-1/ARI)} \quad (2)$$

Probabilities (eg,  $E$  and  $AEP$ ) are expressed as a number between 0 and 1 or as a percentage (0 – 100 per cent). The smaller the probability, the less likely the particular event will occur in a given timeframe, such as a year. For example a storm tide level with a 2 per cent AEP (or 0.02) means there is a 2 per cent chance in any year of that water level being equalled or exceeded.

The average recurrence interval is related to AEP by:

$$ARI = \left( \frac{-1}{\log_e(1 - AEP)} \right) \quad (3)$$

which, for an ARI **greater than about 10 years**, simplifies to approximately:

$$ARI = 1 / AEP \text{ (for } ARI \geq 10 \text{ years or } AEP \leq 10\% \text{ or } 0.10) \quad (4)$$

So an AEP of 2 per cent (0.02) is equivalent to a 50-year average recurrence interval and a 1 per cent AEP (0.01) is the same as a 100-year average recurrence interval.

Common AEPs and their equivalent ARIs are summarised in table F-1.

**Table F-1: Common annual exceedance probabilities (AEPs) and their equivalent average recurrence intervals (ARIs)**

AEP (0–1)	AEP (%)	ARI (years)
0.005	0.5% chance of being exceeded in any year	200
0.01	1% chance of being exceeded in any year	100
0.02	2% chance of being exceeded in any year	50
0.10	10% chance of being exceeded in any year	10
0.18	18% chance of being exceeded in any year	5
0.39	39% chance of being exceeded in any year	2
0.63	63% chance of being exceeded in any year <sup>28</sup>	1

Over a particular period (eg, a structure design life, mortgage term or planning timeframe), the likelihood of exceedances  $E$  (%) of an extreme event of a specified AEP magnitude within a given timeframe ( $L$ ) is summarised in table F-2, with colour shading according to likelihood rating.<sup>29</sup>

**Table F-2: Likelihood of one or more extreme events of a specified annual exceedance probability magnitude within a given timeframe**

$E$ (%) AEP	Time horizon (years): design life, planning timeframe, mortgage term → $L$								
	2	5	10	20	30	50	100	200	500
0.39 (39%)	63%	92%	99%	100%	100%	100%	100%	100%	100%
0.18 (18%)	33%	63%	86%	98%	100%	100%	100%	100%	100%
0.10 (10%)	19%	41%	65%	88%	96%	99%	100%	100%	100%
0.02 (2%)	4%	10%	18%	33%	45%	64%	87%	98%	100%
0.01 (1%)	2%	5%	10%	18%	26%	39%	63%	87%	99%
0.005 (0.5%)	1%	2%	5%	9%	14%	22%	39%	63%	92%

<sup>28</sup> Note, for a one-year average recurrence interval event, the annual exceedance probability or chance of occurring in any year is not 100 per cent (ie, not certain to occur each year), because there is a finite chance that magnitude event may not occur for a few years.

<sup>29</sup> Note that  $E$  never truly reaches 100 per cent but becomes increasingly close to 100 per cent (for practical purposes) at small annual exceedance probability and long lifetimes.

The % exceedance ( $E$ ) in the above table for a time horizon ( $L$ ) is calculated from an AEP (input as a decimal probability) using equation 5 (which is equivalent to equation 1):

$$E(\%) = 100 \times [1 - (1 - AEP)^L] \quad (5)$$

The chance that an event in percentage terms with a given average recurrence interval will occur within the time horizon above can be summarised in a number of ways, for example, using likelihood rating such as in table F-3 (Burkett et al, 2014; box 1-1). The same colour scheme is applied as in table F-2.

**Table F-3: Quantitative terminology for likelihood**

Likelihood rating	Probability that a hazard event with a given annual exceedance probability will occur within the design life or planning timeframe (%)
Virtually certain:	≥ 99% probability of occurrence
Very likely:	≥ 90% probability of occurrence
Likely:	≥ 66% probability of occurrence
About as likely as not:	33–66% probability of occurrence
Unlikely:	≤ 33% probability of occurrence
Very unlikely:	≤ 10% probability of occurrence
Exceptionally unlikely:	≤ 1% probability of occurrence

If the exceedance statistic is to be used to estimate *risk* (ie, the combination of *likelihood* ( $P$ ) and *consequence* (eg, the damage cost of each event)) then knowing only the probability of *one or more* events occurring (as calculated for  $E$ ,  $AEP$  or  $ARI$ ) may not be sufficient – an estimate of the expected number of exceedances,  $N$ , in the time horizon, as in table F-4, is generally more useful (Hunter, 2012):

$$N = -\log_e(1 - AEP) \times L \quad (6)$$

**Table F-4: The expected number of exceedances in a given time horizon**

$N$ (Number)	Time horizon (years): design life, planning timeframe, mortgage term → $L$								
$AEP$	2	5	10	20	30	50	100	200	500
<b>0.63</b> (63%)	2	5	10	20	30	50	100	200	500
<b>0.39</b> (39%)	1	2.5	5	10	15	25	50	100	250
<b>0.18</b> (18%)	0.4	1	2	4	6	10	20	40	100
<b>0.10</b> (10%)	0.2	0.5	1	2	3	5	10	20	50
<b>0.02</b> (2%)	0.04	0.1	0.2	0.4	0.6	1	2	4	10
<b>0.01</b> (1%)	0.02	0.05	0.1	0.2	0.3	0.5	1	2	5
<b>0.005</b> (0.5%)	0.01	0.025	0.05	0.1	0.15	0.25	0.5	1	2.5

Note: AEP = annual exceedance probability. Shaded cells have expected exceedances of less than one event in the time horizon – but this does not imply an event will not happen.

These measures of probability can be combined in various ways to show likelihood of extreme events.

## Examples using the tables

The Building Code (Surface waters: Clause E1.3.2) specifies a minimum standard of 2 per cent AEP for setting floor levels in relation to surface water inundation.

A 2 per cent AEP (or 50-year ARI) magnitude event has a 45 per cent chance of occurrence within a 30-year period (eg, mortgage term), so inundation can be described as ‘about as likely as not’ over the mortgage period, if the floor level was built to the minimum 2 per cent AEP flood level. On average, we could expect ( $N =$ ) 0.6 (or less than one) such event to occur within a typical 30-year period.

This might be translated for a hypothetical example as, “over the duration of your mortgage term it is about as likely as not that your house will be inundated by a coastal storm event reaching at least floor level – in fact, we expect the need to undertake flood repairs is evenly poised between not happening or occurring once in that period”.

For the same floor level (designed for 2 per cent AEP), but considering a longer possible lifetime of 100 years for the house, there would be an 87 per cent chance of the floor being flooded within the 100-year period, so inundation can be described as ‘likely’. On average, we could expect ( $N =$ ) 2 such events to occur within (an average) 100-year period.

The likelihood rating table can also be used in the process to set the risk tolerance for an appropriate probability of occurrence for coastal erosion in determining the landward boundary of an erosion hazard area or hazard setback line (see case study F (Northland region) – chapter 6; section 6.6).

## Appendix G: Dynamic adaptive pathways planning approach

The dynamic adaptive pathways planning (DAPP) approach (Haasnoot et al, 2013)<sup>30</sup> is an exploratory model-based planning tool that helps design strategies that are adaptive and robust over different scenarios of the future. It has been developed as an analytical and assessment approach for making decisions under conditions of uncertainty. Effective decisions must be made under conditions of unavoidable uncertainty (Dessai et al, 2009).

In the context of rising sea levels, where conflicting values prevail for coastal areas, the consequences of decisions can be profound and may be impossible to reverse. This will result in activities that are locked in to the place and space, thereby reducing the ability of decision-makers to adapt to future conditions. Costly adjustments that have distributional consequences on different groups within society may result.

The DAPP therefore focuses on keeping multiple pathways open into the future – this helps alleviate irreversible decisions and reduce the risk of being wrong when making decisions in the present. It does this by making transparent future actions that can be taken, should actions today prove insufficient to meet objectives.

The DAPP approach can also be used to facilitate iterative decision-making involving both decision-makers and stakeholders. The approach has been used increasingly for implementing climate-resilient pathways for water management in situations of uncertainty; its application to a problem of compounding coastal hazard risk resulting from sea-level rise is particularly helpful for decision-makers.

Within the DAPP, a plan is conceptualised as a series of actions over time (pathways). The essence of the approach is the proactive planning for flexible adaptation over time, in response to how the future actually unfolds. The DAPP approach starts from the premise that policies and decisions have a design life and might fail as the operating conditions change (Kwadijk et al, 2010).

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<sup>30</sup> Based on two complementary approaches for designing adaptive plans: ‘adaptive policymaking’ and ‘adaptation pathways’, which Haasnoot et al (2013) originally called ‘dynamic adaptive policy pathways’. The term dynamic adaptive pathways planning is used for the more generic approach used in this guidance.

### Questions used in the dynamic adaptive pathways planning process

The set of questions below is used to prompt consideration of: the changing risk over a long timeframe and different strategies that would meet long- and short-term adaptation objectives under different coastal climate change scenarios and their risk profiles.

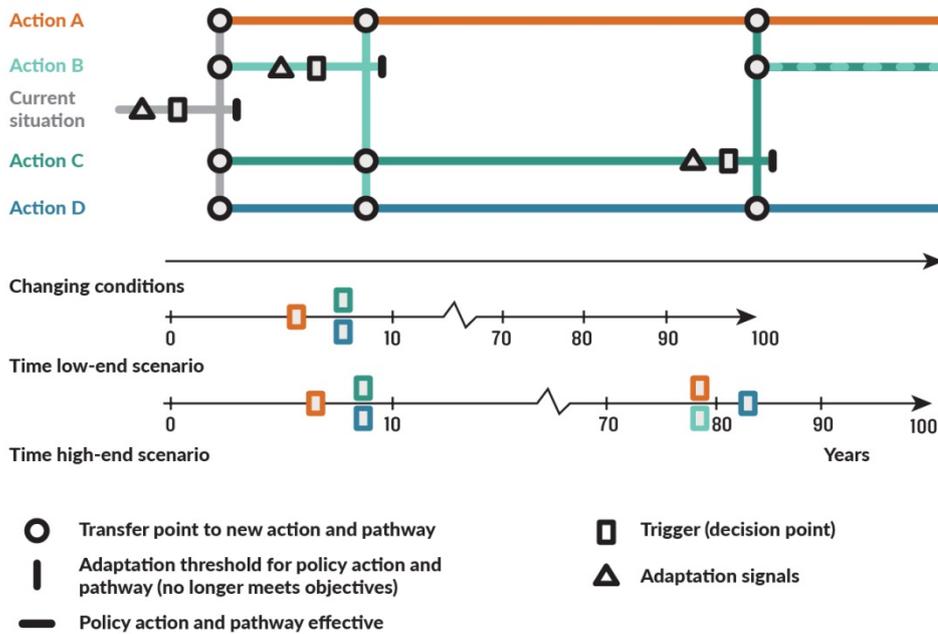
- What are the first impacts we will face as a result of climate change?
- Under what conditions will current strategies become ineffective in meeting objectives?
- When will alternative strategies be needed given that implementation has a lead time?
- What alternative decision pathways can be taken to achieve the same objectives?
- How robust are the options over a range of future climate scenarios?
- Are we able to change path easily and with minimum disruption and cost?

The options and alternative pathways and triggers (decision points) can be drawn using iterative processes by technical advisors, decision-makers and with communities as input to the adaptation decision-making process. An example is shown in figure G-1. For details on the application of the approach see sections 9.3–9.4 and the case study (box 18).

Once actions or options fail, additional or other actions are needed to achieve objectives, and a series of pathways emerges; at predetermined trigger points the course can change while still enabling the objectives to be achieved. By exploring different pathways, and considering whether actions will lock in those options and not enable adjustments in the future, thereby creating path dependency, an adaptive plan can be designed that includes short-term actions and long-term options.

The plan is monitored for signals that indicate when the next step of a pathway should be implemented or whether reassessment of the plan is needed. The signals can be those defined by thresholds in the physical processes and socially defined triggers that reflect the tolerability of the adverse consequences by the community affected by the sea-level rise or coastal hazard.

**Figure G-1: Example of a pathways map**



Note: See chapter 9 for an explanation.

Source: Adapted from Haasnoot et al (2013); Hermans et al (2017)

The resulting pathways can be tested for robustness with respect to a number of assumptions and parameters, for example: different climate change scenarios (using sea-level rise scenarios set out in chapter 5 or hazard assessments in chapter 6); the discount rate; earlier or later decision review dates, and variations in the costs of the adaptation options and in expected losses. Robustness tests can be done on a number of complementary options; for example, structural options may become unaffordable and may need to be supported by planning and regulatory options, targeted rates and insurance.

When applied to flood adaptation planning in the Hutt River catchment (see box 18), it was noted that the annual exceedance probabilities (AEPs) and related river flows were based on Poisson distributions, which assume a known mean and variance, even though the historic record is too short to establish these reliably. A form of conjugate or extreme value distribution may better reflect the uncertainty around the mean and variance. This is one reason why, for sea-level rise assessments as set out in this guidance, it is important to test for robustness and earlier onset using the upper-end ( $H^+$ ) sea-level rise scenario (section 5.7), thereby better reflecting the upper-end uncertainty.

# Appendix H: Simulation game process (Sustainable Delta Game)

Simulation games have been used to understand the interplay between human activities and water management decisions for some time. More recently, their use has focused on (social) learning about uncertainty, training water managers, education and engagement, increasing cooperative behaviour where there is high complexity, particularly where stakeholder and community interests are diverse and where values drive different perspectives on climate change (Harteveld, 2012; Hoekstra, 2012; Runmore et al, 2016; Valkering et al, 2012; Van der Wal et al, 2016; Van Pelt et al, 2015).

By experiencing decision-making under uncertainty in the 'safe' test environment of a simulation game that is facilitated independently, adaptive pathways planning for climate change adaptation can be better understood and acted upon. This has been tested and demonstrated in New Zealand (Lawrence and Haasnoot, 2017). It also enables the social and political conditions to be addressed that create decision-making challenges in uncertain and changing conditions (Wise et al, 2014).

These conclusions are based on: framing risk through experience of decision-making under conditions of uncertainty (Van Pelt et al, 2015); by locating possible future risk in the present as an experienced risk (Evans et al, 2014; Kousky et al, 2010); framing activities with respect to their lifetime (Kwadijk et al, 2010); and providing facilitated spaces for learning about uncertain and changing risk conditions relevant to the decision-making context (Tschakert and Dietrich, 2010).

The Sustainable Delta Game,<sup>31</sup> initially developed for the Netherlands, simulates a decision setting in a river catchment that helps participants learn about preparing for managing water resources under extreme events for an uncertain future. The game can be used to:

- experience the future and its uncertainties
- raise awareness of adaptive management
- raise awareness of the role of negotiation and collaboration
- reflect on policy decisions
- discuss robust and flexible policy actions.

The game has been played by water managers, scientists, students and diplomats in several developed and developing countries. This game has now been tailored for three different New Zealand river settings (an east and west coast South Island river and a North Island river) and for coastal settings. The tailoring to New Zealand situations was funded by Deltares, the Netherlands, the New Zealand Climate Change Research Institute, Victoria University of Wellington, the Greater Wellington Regional Council, Wellington City Council and Tasman District Council.

Details about the game are available at: [www.deltares.nl/en/software/sustainable-delta-game/](http://www.deltares.nl/en/software/sustainable-delta-game/).

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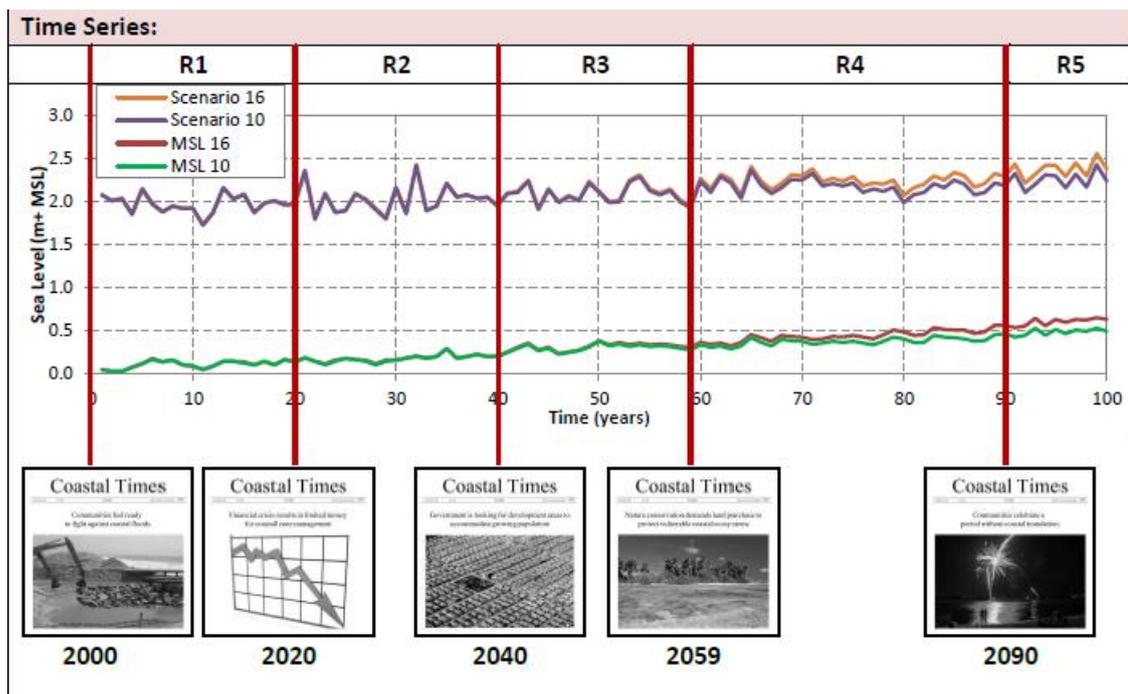
<sup>31</sup> Contact Dr J Lawrence at New Zealand Climate Change Research Institute (Victoria University of Wellington) for access to the game ([judy.lawrence@vuw.ac.nz](mailto:judy.lawrence@vuw.ac.nz)).

In the game, groups of participants in several teams develop a sustainable management plan for a river or coastal area by setting a vision, choosing policy actions, negotiating these policy actions with other teams and having them simulated at several time points over a 100-year period.

As the future unfolds, the participants experience what happens in the river and its catchment or the coastal area. Was there a flood or a drought event? What is the opinion of the community? How do socio-economic conditions change? What happens upstream? Do the water policies need to be adapted?

With simulations based on environmental models (Haasnoot et al, 2011) and transient scenarios (Haasnoot et al, 2015), participants get direct feedback on their policy actions. In addition, impacts of floods and droughts, support of inhabitants, economic growth and impacts on nature need to be taken into account when deciding on responses that may be included in the adaptive water management plan. Several scripts for game sessions are available. Each script includes a climate change scenario, context, relevant newspapers and citizen perspectives for different situations. Figure H-1 displays an example of part of a script: the river inflows, newspapers and the different time periods that are played in each round.

**Figure H-1: Part of a script for a game session, showing two sea-level rise transient scenarios, the game rounds (time slices and newspapers)**



Note: m+MSL = metres above mean sea level.

Source: Sustainable Delta: New Zealand Coastal World Guide Tainui, Deltares 6 April 2016

The simulation model (for details, see Haasnoot et al (2012)) is implemented in PC Raster (Van Deursen, 1995). It describes the cause–effect relationships within the water system based on results of more complex hydrological and impact modelling previously applied on the Rhine delta. The model was checked for internal consistency and for plausibility of the outcomes by expert judgement. The effects of different transient climate change scenarios (Haasnoot et al, 2015) are considered through changes in river discharge that cover typically flood and drought situations. For the New Zealand version of the game, the river inflows were scaled because local rivers are much smaller relative to the Rhine River. The model then calculates the effects of flood events on river water levels, probability of levee (stopbank) failure, flood damage and

impacts on agriculture and biodiversity. This model was adapted for New Zealand by removing the navigability modules and adding impacts and actions for agriculture.

After the simulation game, the participants and facilitator reflect on what happened during the simulation as the storyline developed and on the adaptation pathway that emerged. They discuss what triggered this pathway, how it could be improved and what it could mean in practice using the following questions.

- Did you behave in a more reactive or proactive way?
- At what point in the game did you identify the need for a change in strategy?
- What arguments did you use to change the strategy?
- Which uncertainties did you experience?
- What was the role of negotiation with the other teams?
- In hindsight, would you have played the game differently?
- What did you learn from the game session?
- Other comments?

In this context, different possible futures are considered and the path dependency, robustness and adaptive capacity of actions are discussed. The game primarily has learning objectives, but it can change behaviour, which then influences how adaptive pathways are subsequently developed.

By using this approach, the game supports a number of objectives. For example, it helps participants:

- learn about water and coastal system processes
- learn about adaptive policy-making, adaptation thresholds and adaptation pathways
- experience a decision-making process within a changing environment full of uncertainty
- discuss the use of scenarios for planning and sustainable water and coastal management
- discuss and develop innovative solutions for addressing changing risk profiles.

It can be used by technical advisors, elected politicians (decision makers) and in community engagement settings.

# Appendix I: Examples of engagement approaches

## Managed Retreat: Project Twin Streams (Waitakere City, New Zealand)

### Setting

The Lower Oratia catchment is located in the former Waitakere City in Auckland. Flood and stormwater issues escalated during the 1990s, leading Auckland Regional Council to propose a moratorium on development if these water issues were not addressed. Waitakere City Council responded by developing the Project Twin Streams 2002, which ran for 10 years, to reduce flood risk and improve the ecological functioning of the waterways.

### Project Twin Stream

At the outset, the Council decided that it would not use compulsory acquisition through the Public Works Act 1981 for the properties affected; rather it adopted a voluntary approach to any property purchase and at a fair market price. Secondly, it decided on an inclusive participatory process including property owners and community representatives (eg, politicians, the media and local Māori) consistent with its Eco City status and Agenda 21, and to avoid hard engineering works. This approach recognised the significant impacts on property owners.

Before any communication with property owners about land purchase, the Council developed an engagement plan. The plan was developed using consultants experienced in public engagement who met regularly with the Council and project staff to ensure a consistent and coordinated plan. The key elements of the engagement were:

- 1 Preparing all engagement materials before any contact with property owners (eg, letters to individuals, detailed information and mapping of flooding history and impacts, property purchase processes, call centre scripts, and factsheets) and pre-prepared key messages.
- 2 The normal operating mode was to help the property owners, to share ideas (including those proposed by property owners), to avoid rushed decisions and to ensure equitable decision-making processes.
- 3 Information on impacts was detailed and contextualised to include the causes of flooding, the range of possible responses and the nature of future impacts likely in climate affected scenarios.
- 4 Briefing of stakeholders, including relevant Council departments, politicians, cultural representatives, legal representatives and other elected representatives.
- 5 Initial letters delivered to affected property owners.
- 6 Media briefings and subsequent regular press updates, to limit media coverage of issues before discussions with property owners.
- 7 Appointments organised with property owners (owners who did not make an appointment received follow-up telephone calls).

- 8 Face-to-face visits with all affected property owners in a given locale, in the same week. (Initial visits with individual property owners were conducted by two staff to ensure a mix of technical and social skills and to illustrate flooding impacts at the site.)
- 9 Local 'drop-in' days were organised within two weeks of the initial letters.
- 10 The project team gave regular updates to stakeholders (eg, politicians, community groups, the media) to manage potential risks associated with any incomplete or inaccurate information.

## Outcomes

Seventy-eight full purchases and 78 part purchases (with parts of properties purchased) were negotiated to allow for floodplain redesign. While the Council objectives were for a managed retreat outcome, this was achieved by linking to environmental, social, economic and cultural goals. As a result, the social fabric of the community was strengthened by new public resources (eg, parks, cycle ways and walkways) and accommodating those who moved to other areas.

## Lessons for engagement

Addressing significant risks to people and property through adaptation can require significant change. Recognising and responding to individual circumstances and emotional needs (eg, fear, anger, stress, excitement, confusion) when developing response options and their implementation is essential for those affected and for the success of the plan.

This example demonstrates the efficacy of an approach grounded in building the knowledge of the people affected, having periods for engagement that extend to meet their needs and being able to negotiate equitable and individualised solutions while meeting the wider Council objectives.

In addition, this case also shows the importance of engaging with people who may influence and/or advise the decision-makers (eg, politicians, the media, legal advisors and community associations).

Sources: Atlas Communications & Media Ltd (2011) [Project Twin Streams case study: Largescale property purchase without recourse to compulsory purchase](#) and Vandenbeld and MacDonald (2013)

## Western Bay of Plenty: 'Not Just a Storm in a Tea Cup' campaign

Since 2011, Waihi Beach in the Western Bay of Plenty has frequently been subjected to coastal flooding, with significant and costly damage to private and public property. Western Bay of Plenty District Council and its community have been exploring and understanding the issues together. The steps in the process were as follows.

- 1 Defining the problem they were trying to solve. In February and early March 2014, the Council sat down with the community over ‘a cup of tea’. As one Council staff member put it:

Whether you’ve experienced flooding on your property or not, whether you live in Athenree, Pio Shores or down at the beach, you need to have a say. Whatever the solution ends up being, it will come from the community and it will affect you.
- 2 Eleven community workshops were held over this two-month period, leading up to the Council’s three-yearly long-term plan (LTP) review in 2015. At this review, major funding decisions on a preferred stormwater option for Waihi Beach, were to be made.
  - Workshop attendees were asked to write down on Post-it notes what issues were created for the community and property owners when it flooded.
  - Issues were grouped into themes: infrastructure, maintenance, regulation, planning, people and individual responsibility, funding and finance.
  - As the workshops progressed, the discussion moved from discussing impacts to identifying solutions.
  - In this way, the community’s voice was heard.
- 3 A process of deliberative democracy followed, by generating the framing and focus of the LTP.

The positive outcomes of the engagement were community buy in, raising community interest, generating a sense of council-led community empowerment and education in the wider community on coastal flood issues. The process also allowed Council staff to tap into local knowledge and ‘reality check’ elements of the LTP, before it went to the full Council for deliberation.

Lawrence J et al, 2016. Synthesis Report RA4: Enhancing capacity and increasing coordination to support decision making. Climate Change Impacts and Implications (CCII) for New Zealand to 2100. MBIE contract C01X1225. 74 pp. Available from <http://ccii.org.nz/outputs/>.

## Takaka River Flood Hazard Project: Tasman District Council lessons learned about community engagement

### Setting

The Takaka township is located on the floodplain of the lower Takaka River in Golden Bay, Tasman District. Climate change projections identified that the present day 200-year average recurrence interval (ARI) size event could become a 100-year ARI event by the year 2090. The township has continued to develop over the preceding three decades, and both river and landform changes have altered the local flood risk. The following steps were taken to investigate the risk and to engage with the community before examining response options.

### Information and its communication

- 1 The Council commissioned modelling of the flood hazard for events up to the 200-year ARI using Light Detection and Ranging (LiDAR) contour data. This confirmed a moderate to high flood hazard for some parts of the township and medium to very high hazard for much of the surrounding rural land. Eight risk reduction options were identified for the township, including zoning and building controls and flood flow-path protection.

Modelling (DHI MIKE21) and WaterRide display software were used for preliminary investigation of several of these options including structural protection methods and river gravel management. Static maps for peak flood depth and velocity, difference mapping (primarily used for scenario comparison) and depth x velocity hazard maps, as well as animations of modelled floods, were created.

- 2 The Council decided to use the 200-year ARI as a proxy for including climate change within hazard assessments to inform long-term planning decisions. The Council also excluded the effects of an existing structural defence, effectively using a worst case scenario. There was an apparent acceptance of this approach for assessing hazard risk for long-term planning. Nevertheless, the Council acknowledged the potential for challenge depending on how this information was used, leading it to initiate a public engagement programme that incorporated several methods, including those listed below.
  - Communicating the modelling results to the local community at a public open day, through local media and on the Council’s website, to initiate discussion on the hazard and potential responses to the risk.
  - Static poster displays and PowerPoint presentations using both flood maps and animations to visually communicate the hazard and outline the potential response scenarios.
  - A terminology guide was provided including short explanations of Annual Exceedance Probability (AEP) and Average Recurrence Interval (ARI), the relationship between the two, and highlighting that multiple extreme events could occur close together in time.
  - A summary of the assessment of flood risk to asset management and development planning (modified from *Preparing for Future Flooding*, Ministry for the Environment (2010)). The flood risk was defined using several methods including ARI, AEP and expressions of chance; for example, there is around a 1 in 4 chance of a 100-year ARI sized event occurring in the next 30 years, or a 63 per cent chance that an asset with a 100-year life span will experience a 100-year ARI event (see table F-2 in [appendix F](#)).
  - Animations, proved very useful for quickly communicating the scale of the hazard, as well as comparisons between response scenarios and the impact of climate change on future flooding hazard.
  - There were very different perceptions and acceptance of the hazard risk and the response options, dependent on a wide variety of factors, including:
    - sector of the community (urban versus rural)
    - previous experience of major flooding (whether in Takaka or elsewhere)
    - residence time in the community (long time or recent newcomers)
    - past experiences with, and level of trust of, the Council
    - amount of fixed assets likely to be affected (eg, pastoral farmers versus kiwifruit orchardists)
    - impacts (adverse versus beneficial) on properties from potential risk response scenarios
    - perceptions of affordability and sustainability of response options
    - consideration of adverse effects elsewhere – on community and environment.
  - Maximising engagement with stakeholders – for smaller communities, property mail-outs may achieve better engagement than advertisements using local media and community networks.

- Get to know the community – it is useful to understand the variety of personal experiences and circumstances within the community because these impact on the perception of hazard and risk. This is particularly important where there has been a long history of flooding and/or coastal hazards, or bad experiences with local authorities have occurred, because trust needs to be built as a first step.
- It is important to allow sufficient time for people to absorb the information when communicating hazard risk – this will enable them to achieve an understanding of risk and climate change implications.
- It is invaluable to provide opportunity for the community to discuss their concerns and question flood and river management experts at face-to-face meetings.
- Separation of hazard and response discussions will also help reduce the amount of information being presented at once.
- Flood hazard maps and animations of modelled flood events are effective tools for quickly communicating flood hazards and comparisons of potential responses. Communicating risk using both ARI, AEP concepts, as well as chance expressions, helps people to understand the risk in context.
- Subsequent to the initial round of public engagement, further discussions with community representatives have indicated a preference for ‘living with the risk’ and using existing building regulations, rather than resource management planning or structural responses to extreme flood events (100-year ARI plus). Contributing factors included affordability, potential effects on development and recognition that physical protection methods and ongoing residual risks will have adverse effects. There is also interest in examining structural and asset management responses to smaller sized flood events (10- to 20-year ARI) in the future.

Lawrence J et al, 2016. Synthesis Report RA4: Enhancing capacity and increasing coordination to support decision making. Climate Change Impacts and Implications (CCII) for New Zealand to 2100. MBIE contract C01X1225. 74 pp. Available from [ccii.org.nz/outputs/](http://ccii.org.nz/outputs/).

## Coping with coastal erosion at Muriwai Beach through a staged implementation plan

### Setting

Muriwai Beach is one of the Auckland Region’s most popular beaches (Turbott and Stewart, 2006). However, since the 1960s, it has been eroding at a rate of around 1 metre per year. Continued landward retreat of the dunes put regional park infrastructure, including a car park, the surf club tower and roads, at risk. Historical attempts to mitigate erosion, including: a seawall constructed by the Army 20 years ago to protect one of the car parks and, more recently, gabion baskets and rock armouring to stop erosion where the road and boat ramp enter the beach, had failed. The local community and stakeholders had a strong desire to retain local infrastructure but not compromise the highly valued natural character of the area.

### Process

The Auckland Regional Council employed an independent facilitator to work with the community and stakeholders to develop an agreed solution. Notably, no private coastal property was at risk. A process was established where all voices were heard, including the local community, council, wider community groups and surfers.

The groups entered into the process without preconceived solutions. The process used facilitation, dialogue, negotiation and joint problem solving. Use of an independent contractor enabled issues of historical distrust between locals and the Council to be mitigated.

## **Outcome**

The result was a jointly negotiated and staged implementation plan that included critical decision points. Triggers for action were principally related to the timing of actions, such as relocating or realigning local infrastructure – these were developed by the community and supported by the Council. This plan was formalised in 2004 and the A car park, a road and the surf club were relocated inland.

The approach followed allowed for the unpredictable nature of coastal erosion. It also provided sufficient time to obtain the resource consents required to relocate and realign infrastructure, and for the community and beach users to adapt to the managed change. An additional benefit was an improvement in the relationship between the Council and the community and stakeholders, with the reserve managed in a more inclusive manner, giving the local community more say over what happens at its beach.

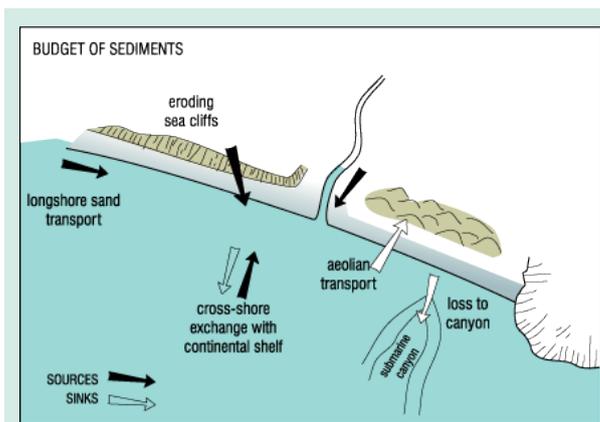
Sources: Blakett et al (2010a); Turbott and Stewart (2006)

# Appendix J: Supplementary information

These sheets provide additional information on elements of coastal processes.

## 1 Coastal erosion

In its natural state, the coast recedes or advances (apart from cliffs) in response to sediment supply, climate and ocean conditions. Coastal accretion is where the shoreline builds out. Coastal erosion becomes a hazard when human activity or settlement is threatened by a temporary or permanent cutback of the shoreline.



Typical sediment **sources** to nearshore coastal systems:

- longshore transport into area
- input from rivers
- wind (aeolian) transport onto beach
- erosion of sea cliffs
- onshore transport
- beach nourishment
- trapping of sand by dune vegetation.

Typical sediment **losses** from nearshore coastal systems:

- longshore transport out of area
- wind transport away from beach
- offshore transport (eg, storms, swell, currents)
- abrasion
- sand extraction
- hard defences (wave reflection off structure)
- dams and reservoirs trapping river sediments.

Source: Komar (1998)

Changes in the position of the coastline result from a complex interaction of different natural factors and processes.

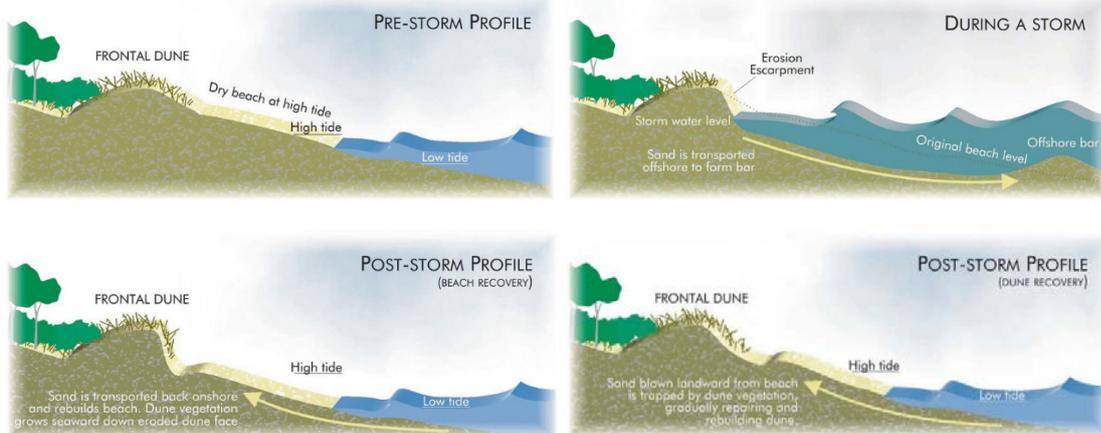
- Interactions and influences of hydrodynamic driving processes – these include swell, sea waves, tides, storm surge, currents, storm sequences and the effect of climatic variability, for example, El Niño–Southern Oscillation and Inter-decadal Pacific Oscillation. Climate change will affect each of these processes.
- Geomorphology – that is, the characteristics of the coastal margin (eg, beach and barrier type, sediment characteristics, geological controls, such as headlands and islands) – and how these characteristics respond to, and interact with, hydrodynamic processes. For example, spits are often unstable and prone to large and long-lived changes in the position of the coastline.
- Sediment budget – rate and relative balance of sediment supply and losses at the coastline (see adjacent box).
- Crustal loading and tectonic factors influencing vertical land movement – coastal uplift or subsidence.
- Sea-level rise.

Because many factors are involved in coastal erosion, shoreline change from sediment ‘redistribution’ in a nearshore beach system will *not* be consistent year after year in the same location.

Erosion and accretion can occur in a cyclic pattern, ranging in timeframes from seasonal up to several decades (particularly on sandy coastlines). They can also occur in a series of episodic steps related to storm events; there may be little change for many years and then rapid cutback may occur during a storm or a sequence of storms. Even over short distances of coast, patterns of erosion and accretion can vary, producing, for example, erosion hotspots linked to the occurrence and movements of nearshore sand bars.

Coastal erosion occurs over timescales that range from individual storms, through annual and El Niño cycles, up to long-term retreat at decadal or century scales (eg, due to climate change and higher sea level). Normal practice therefore deals with erosion on two timescales: *short-term fluctuations* (days to a few months, including storm cutback) and *long-term trends* (seasonal to decades or centuries).

Coastal erosion processes are complex and variable, making it difficult to estimate future coastal erosion at a specific place. Adequate data and historic information about shoreline changes and sediment budgets are needed, along with an understanding of how vulnerable the coast is to climate change.



Typical response of a natural sand beach–dune system to erosion during a storm event and the subsequent build-up of the beach and dunes over the following months (and even years). Source: Dune Restoration Trust of New Zealand

### Typical ranges of coastal erosion rates

Feature	Storm response (short term)	Long-term erosion rates
Sandy beaches	Highly variable even within a locality, and can be 10-plus metres during an extreme storm.	Highly variable even in a locality but generally less than 5 metres per year.
Spits	Extremely variable, with storm-related movements of 100-plus metres at the ends of unstable spits.	Extremely variable, with storm-related fluctuations typically dominating long-term trends. Fluctuations can be of the order of 200-plus metres.
Gravel	Can be up to 5–10 metres during extreme storms, with stable periods between storms.	Generally less than 1 metre per year on average, but can be 2–3 metres per year in more vulnerable locations, particularly where the land backing the gravel barrier is low-lying, or where the longshore supply is interrupted.

### Typical ranges of coastal erosion rates

Estuarine shores	Highly variable, dependent on storm wave direction and timing with high tides. Changes can be in the order of tens of metres during storm conditions, but can vary substantially over short distances.	Variable over short distances, with erosion tending to occur as a series of storm-related steps. On average less than 2 metres per year and up to 5 metres per year at some vulnerable locations, for example, where channels cut in.
Cliffs	Highly variable depending on the geological characteristics and hydraulic processes in the area. Negligible for hard rock cliffs but can be substantial on unconsolidated cliffs, particularly if land slipping also occurs.	On unconsolidated cliffs, average rates tend to be in the range 0.5–1 metre per year, but higher in localised hotspots. Mudstone cliff retreat up to 0.3 metres per year and harder sandstone cliffs at 0.01–0.02 metres per year.

Human intervention can also markedly alter or control natural coastal sediment processes, through:

- catchment activities, for example, land use practices, urbanisation, dam construction, water abstraction (affects sediment supply from land sources via rivers and streams)
- dredging of tidal entrances and harbour channels (affects sediment movements in coastal systems)
- sand or gravel extraction from the coastal marine area (removes sediment from the nearshore system)
- coastal protection works, for example, groynes, breakwaters, artificial reefs, seawalls (which all affect the natural buffering, movement and distribution of nearshore and beach sediments)
- beach nourishment or nearshore replenishment (adds sediment to the beach and nearshore system)
- permanent modification of coastal margins, for example, dune removal, vegetation removal or change, reclamations, waterways, wharves and marinas (affects the natural movement of beach and nearshore sediments).

## 2 Coastal storm inundation

Coastal storm inundation is an acute natural event arising from extreme weather events (storms, waves or swell from distant storms) in which normally dry but low-lying coastal land is flooded occasionally. Storm-related coastal inundation occurs when high tides (mostly during spring or perigean tides) combine with:

- storm surge – the temporary (hours to days) increase in mean sea level (MSL) over and above the predicted tide height, due to a combination of strong onshore winds and low barometric pressure
- waves and swell – through a combination of wave setup (an increase in the water levels landward of surf zone) and wave runup over the upper beach, which can overtop low coastal barriers
- monthly MSL (higher than average monthly mean sea level (due to climate cycles and variability)).

**Storm tide** is used to describe the total sea level formed from the combination of tide, plus month-to-month variability in MSL, plus storm surge during storm conditions. During storm events, the likelihood and magnitude of coastal inundation is highly dependent on the coincident occurrence or timing of spring high tides, storm surge and wave conditions. For example, the peak of the storm surge will not always coincide with the highest wave conditions and the time of a high spring tide. Around New Zealand, they will be correlated in some way, owing to various factors:

- certain weather conditions, such as the tracking of extra-tropical cyclones or low-pressure systems close to New Zealand's coast, which could produce both high wave conditions and high storm surge. As storm surge in New Zealand is relatively modest compared with the astronomical tide (which is completely independent of meteorological conditions), however, correlation with extreme wave conditions may not be that high (particularly on the west coast, where the tide range is higher)
- wave heights that are limited by water depth in shallow water. In this case, there can be a high correlation between high water level and higher wave conditions.



Hauraki Plains inundated (May 1938)  
Source: RNZAF

The biggest storm tide events last century occurred close together in 1936 and 1938, with a similar-sized event in Auckland occurring on 23 January 2011.

The Great Cyclone of 1–2 February 1936, with barometric pressures down to 970 hPa and ferocious winds and waves, came on the back of a very high perigean spring tide and caused widespread coastal inundation damage along the east coast of the North Island. Coastal roads were washed away, a house fell into the sea at Te Kaha, while the sea swamped houses 100 metres inland at Castlepoint (the sea breached the coastal dunes). A month later, on 25–26 March 1936, an easterly gale produced by a low depression combined with extremely high perigean spring tides to cause damage and sea flooding in the Auckland region.

Two years later, on 4–5 May 1938, more than 1600 hectares of the lower Hauraki Plains (pictured) were flooded at depths of 0.5–1.3 metres, through a combination of spring tides and northeast gales that caused a large storm surge and accompanying waves. Several breaches of the shoreline stopbank occurred from Waitakarau to Kopu. The inundation was exacerbated by heavy rainfall.

More recently, Auckland experienced a similar magnitude storm event on 23 January 2011 (2.38 metres AVD-46), with more extensive coastal storm inundation, being 0.11 metres higher than the 1936 event. This caused deeper coastal flooding, including houses and road closures. Most of the difference in peak water level for these similarly sized storms is attributable to the additional sea-level rise of 0.12 metres in the period since 1936.

Sources: Brenstrum (1998); [www.ohinemuri.org.nz/journals](http://www.ohinemuri.org.nz/journals) (Sept 2009); Stephens et al (2013)

The area and depth of inundation also depends on how the high storm tide and wave conditions actually inundate an area (ie, their flow path). This depends on the physical characteristics and topography of the upper parts of the beach or estuarine shoreline and immediate coastal locality. Typical flow pathways include:

- direct inundation of flowing ‘green water’, where the storm tide plus wave setup level exceeds the elevation of the land; typically occurs where the coastal barrier is reduced or absent (including human modification), such as along estuarine and sheltered coastlines or along river margins
- inundation due to the breaching of a natural barrier, such as a gravel ridge or narrow dune field (with low-lying land behind it), or a human-made defence such as a stopbank or revetment; breach flooding is more likely to occur on open sections of coast exposed to larger waves and swell
- wave overtopping (from wave splash and spray – as distinct from ‘green water’) of a natural barrier, such as a gravel ridge or narrow dune field, or coastal protection such as a stopbank or seawall; typically occurs due to wave or swell conditions coinciding with a high tide or storm tide, with inundation volumes greater on more exposed open sections of coast.



Coastal inundation at East Clive, south of Napier, on 16 August 1974 was caused by a persistent heavy swell coinciding with high tides. This resulted in the gravel barrier being overtopped and the low-lying land behind being inundated. Two hundred homes were affected.

Source: Ministry of Works and Development, Napier (now NIWA)

River flooding of coastal and estuarine margins, and stormwater flooding of low-lying areas, can be exacerbated by high tides or storm tides. In relatively flat, low-lying coastal margins (eg, the Lower Heathcote River in Christchurch, South Canterbury plains, Hauraki Plains, Ahuriri in Napier), land may stay flooded with seawater for several days after an extreme event. Beside physical and corrosion damage to buildings, infrastructure and electrical services, inundation by seawater has a drastic effect on vegetation and pasture production for several months.

Human interventions can also exacerbate coastal storm inundation hazards through:

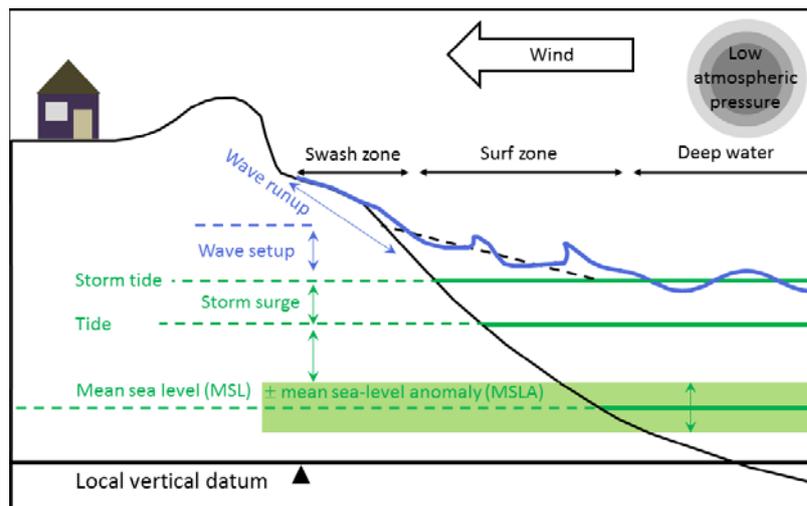
- river training works (straightening, stopbanks) that increase river levels at the coast
- poorly designed coastal protection structures that exacerbate loss of the beach adjacent to the structure or increase exposure to wave runup and overtopping
- coastal property development in inundation-prone areas (low-lying estuary margins or shorefront areas without an adequate buffer), or roads or other infrastructure that block overland flows
- inadequate drainage capacity behind coastal berms, seawalls or revetments (including roads)
- physical removal, reduction or damage to natural coastal barriers, such as sand dunes and gravel barriers (eg, lowering access ways, removing vegetation, trimming or removing dunes)
- permanent modification of coastal margins (eg, waterways, canals, marinas, boat ramps, reclamation).

#### **‘Red-alert’ tide days (‘king tides’)**

Dates for the year when predicted high tides reach the highest levels can be found at [niwa.co.nz/our-science/coasts/tools-and-resources/tide-resources](https://www.niwa.co.nz/our-science/coasts/tools-and-resources/tide-resources). These large tides prime exposed low-lying coastal areas for potential coastal inundation, even if modest storm surge or wave conditions were to occur.



### 3 Components of coastal sea level



Components of coastal sea level. Source: NIWA

The elevation that the sea reaches at a shoreline is determined by the following components.

- 1 Mean sea level (MSL) – the average (mean) level of the sea over a defined period, usually 18–20 years, relative to a vertical datum (see [supplementary information sheet 10](#) on datums). MSL continues to rise due to climate change, and this rise is accelerating.
- 2 The mean sea-level anomaly (MSLA) is the variation of the non-tidal sea level about the longer term MSL on time scales ranging from months to several years, due to climate variability. MSLA is influenced by longer term climate fluctuations related to seasonal effects (annual cycle), the El Niño–Southern Oscillation and the Inter-decadal Pacific Oscillation (IPO). Seasonal sea levels are a few centimetres higher in late summer and early autumn (and a few centimetres lower in winter and early spring). During El Niño phases, sea levels tend to be depressed, and during La Niña phases, sea levels tend to be higher. IPO in its negative phase, which started in 1999, can increase sea levels by up to 5 centimetres.
- 3 The astronomical tide is the largest contributor to sea-level variability. Tides result from the gravitational attraction of the moon and sun, they are deterministic and can be forecast well ahead (including ‘red-alert’ tide days). The tide oscillates about the combined MSL and MSLA for any given month.
- 4 Storm surge is the increase in regional sea level (excluding the effects of waves) due to low barometric pressure (the ‘inverse barometer’ effect) and winds blowing either directly onshore or alongshore with the coast on the left (see [supplementary information sheet 6](#) on storm surge). Conversely, high pressure and winds blowing offshore, or alongshore with the coast on the right, tend to depress sea level below the predicted tide.
- 5 Storm tide is the term used to describe the temporary rise in sea level offshore of the wave breaker zone. Storm tide is the combination of the above four components (MSL plus MSLA plus tide plus storm surge).
- 6 At the shoreline, the maximum vertical elevation reached by the sea is a combination of the wave setup landward of the wave-breaking zone and wave runup (or swash). These act on top of the storm tide level. Both wave setup and runup are highly variable even over a short length of coast, varying according to the type of beach, the beach slope, the backshore features and presence of coastal defence structures.

## 4 Tides around New Zealand

Tides are generated by gravitational forces exerted by both the sun and moon on the Earth's oceans. Ocean tide waves then propagate onto the continental shelf and into estuaries and harbours, modified by:

- wave shoaling (where the tidal wave slows down and increases in tide range in shallower waters)
- friction from the seabed and constrictions such as estuary entrances, river mouths and straits.

New Zealand's tides are categorised as semi-diurnal (approximately twice daily; every 12 hours and 25 minutes). Tides can be predicted for many years in advance (see resources box below).

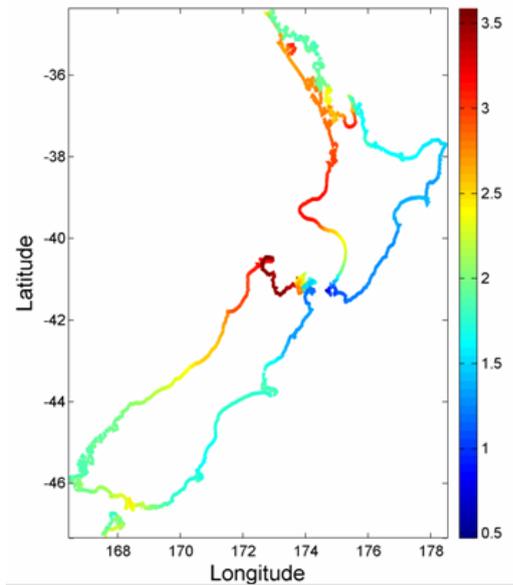
The spring tide range (the difference between high and low waters around the full and new moons) varies around New Zealand, reaching 3.5–4 metres on the west coast, but only 1–2 metres on the east coast.

A tide mark commonly used to characterise high tides is mean high water spring (MHWS), which is also used to define the coastal planning boundary ([supplementary information sheet 5](#) Mean high water spring).

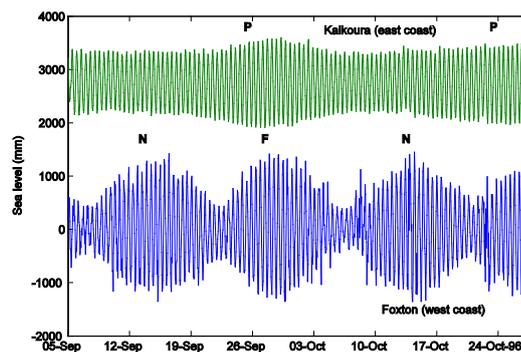
MHWS is traditionally calculated for nautical purposes as the long-term average of the highest high tide that occurs just after every new [N] and full [F] moon (ie, spring tides, with a spring-neap-spring tide cycle occurring around every fortnight. See Foxton tide in plot). Normally, only about 10–15 per cent of all high tides would exceed such an MHWS mark.

New Zealand tides along the central–eastern coasts do not fit with the commonly used nautical MHWS definition. For example, at Kaikoura (as shown), nearly 43 per cent of high tides exceed the nautical MHWS level.

This is due to the small difference between the two-weekly neap and spring tides along the central–eastern region because the solar ( $S_2$ ) tide is weak. Instead, the higher tides on the east coast peak once a month (around 27.5 days), when the moon's elliptical orbit is closest to the Earth (ie, when the moon is in its perigee [P]).



Spring tide range (in metres) around the coast of New Zealand. Source: NIWA



Comparison of tide characteristics between Kaikoura (east coast) and Foxton (west coast). P= perigee, N= new moon and F= full moon.

The largest high tides cluster around dates when a full or new moon coincides with the moon in its perigee (peaking approximately every seven months). These tides are classed as perigean spring tides ('king tides'), which can be predicted and publicised well ahead as red-alert tide days, when coastal inundation of low-lying areas could easily occur if adverse weather conditions are present (see [supplementary information sheet 2 Coastal storm inundation](#)).

#### **Tide prediction resources**

Official tide predictions at standard and secondary ports: [Tide predictions](#) | Land Information New Zealand (LINZ).

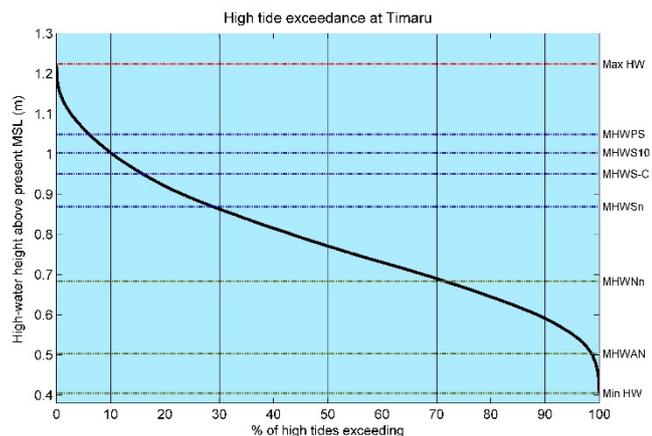
Open coast and exclusive economic zone tide predictions for up to one month at any location around New Zealand for any time period since 1830: [www.niwa.co.nz/services/online-services/tide-forecaster](http://www.niwa.co.nz/services/online-services/tide-forecaster).

## 5 Mean high water spring

The position of mean high water spring (MHWS) is important because it is used to delineate the landward jurisdictional boundary of the coastal marine area under the Resource Management Act 1991 and the Foreshore and Seabed Act 2004.

Defining MHWS is not straightforward, however, because it depends on whether an accurate or pragmatic determination is required. It is more complex on open coasts, where persistent wave setup must be factored in on top of the tidal component for a realistic MHWS boundary.

Several quantitative and qualitative definitions of MHWS level are in use:



An exceedance curve of all high tides for a 100-year period at Timaru, showing the different levels relative to the present mean sea level (MSL) for different definitions of MHWS: MHWSn (traditional approach); MHWS-10 – level exceeded by 10 per cent of high tides; MHWS-C – LINZ cadastral level; MHWPS – mean high water perigean spring tide. Also shown are neap high tide markers MHWNn (nautical definition) and MHWAN (mean high water apogean-neap) and the Max and Min High Water.

- *MHWSn*: the traditional nautical approach is based on a quantitative ‘tidal harmonic’ definition of MHWS, typically<sup>32</sup> as the average of pairs of successive high waters in a 24-hour period in each semi-lunation (approximately every 14 days) at new and full moon, or in mathematical terms the sum of  $M_2$  (lunar) and  $S_2$  (solar) tide constituents. For central areas of the eastern coast of New Zealand ([supplementary information sheet 4 Tides around New Zealand](#)), however, this definition results in high tides that exceed the MHWS level much more frequently than would be pragmatic for defining the boundary of the coastal marine area (eg, plot above for Timaru).
- *MHWPS*: this upper-level MHWS is related to the higher perigean spring tides that occur in clusters for a few months, peaking around every seven months when a full or new moon coincides with the moon’s perigee (‘king tides’). These are calculated as the sum of  $M_2$  (lunar),  $S_2$  (solar) and  $N_2$  (lunar elliptical) tide constituents. Around New Zealand, this tide height is exceeded by between 5–10 per cent of all high tides.
- *MHWS-10*: based on an appropriate percentile (eg, 10 per cent) of all the high tides that would exceed an MHWS level. Provides a more consistent approach nationally (eg, Bell et al, 2015 – report for the Parliamentary Commissioner for the Environment).
- *MHWS-C*: provided for surveyors for cadastral purposes, based on the next 18.6-year period.<sup>33</sup>
- *Natural indicators*: a range of natural indicators can be used to provide a qualitative assessment of MHWS, including toe of the dune, toe of the cliff, edge of vegetation, highest line of driftwood, tide marks on fence posts, and for estuaries, the seaward edge of glasswort (*Salicornia australis*) or other salt marsh plants.<sup>34</sup> On open coasts, these

<sup>32</sup> Bell (2010).

<sup>33</sup> [www.lin.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/tidal-level-information-for-surveyors](http://www.lin.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/tidal-level-information-for-surveyors).

<sup>34</sup> Baker and Watkins (1991).

markers implicitly include wave setup and runup effects, while driftwood lines and tide marks can also be influenced by the last elevated storm tide level.

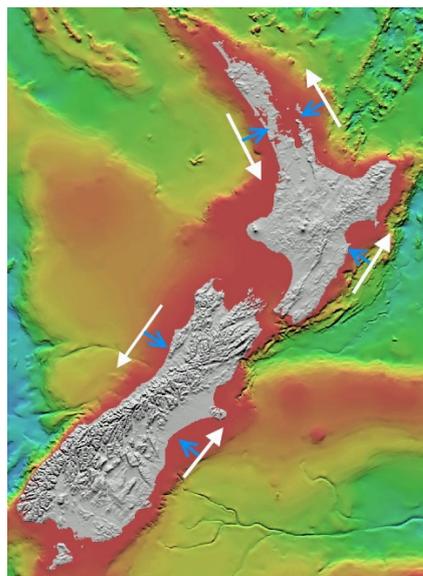
Both Land Information New Zealand and the Environment Court have emphasised that there is no single definitive method to establish a natural boundary such as MHWS; the method used will depend on the particular issue under consideration and natural characteristics of the location.

As sea level rises, and effects of coastal erosion and more frequent inundation occur, the MHWS boundary will migrate landward and so require more frequent monitoring of its position.

## 6 Storm surge

Storm surges are temporary increases in ocean and estuary water levels, associated with storm conditions that last over periods of hours to days. Storm surge is produced by a combination of two weather and ocean processes:

- 1 low barometric pressure allows sea level in a region (100 square kilometres or more) to rise above the pre-storm sea level. This is known as the 'inverted-barometer' effect and results in around a 1 centimetre rise in sea level for every 1 hPa drop in barometric pressure below the mean annual barometric pressure. Annual mean pressure: 1015–1016 hPa in upper North Island, 1014 hPa in central New Zealand and West Coast, 1013 hPa in Canterbury, 1012 hPa (Otago–Southland)
- 2 strong, persistent winds blowing either onshore or alongshore, with the coast on the left (due to the Coriolis effect), cause water to 'pile up' against the coast. Similarly these winds can 'hold up' water levels in estuaries via the inlet.



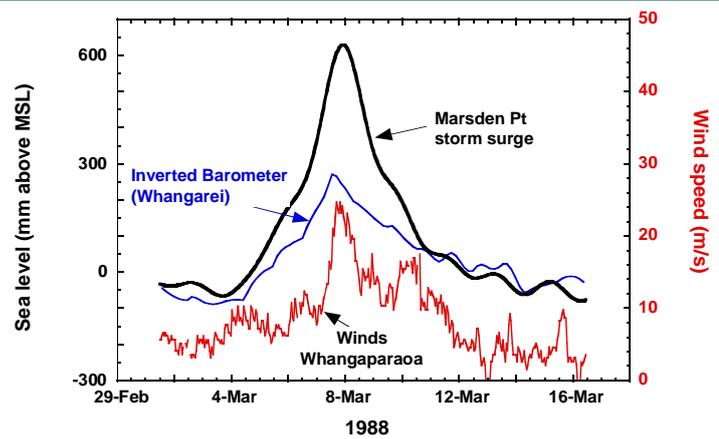
Alongshore wind directions (white) around New Zealand that contribute onshore water level setup (blue) to storm surge at the coast.

The mix of both the wind and inverted barometer effects can vary widely, depending on the type of weather system. During ex-tropical low-pressure systems, which experience clockwise rotation of the winds around the pressure system, the inverted barometer effect generally contributes at least 50 per cent or more to the storm surge height impacting the New Zealand east coast. Low-pressure troughs associated with blocking highs produce prolonged winds blowing over large fetches, however, and these can produce large wind-driven surges with relatively small inverse-barometer components, for example, a 0.8 metre wind-surge at Tararu (Firth of Thames) on 12 June 2006.

Storm surge height rarely exceeds 0.6 metres on open coasts around New Zealand (the largest recorded being a 0.97 metre surge (on 12 June 2006 at Tararu in the semi-enclosed Firth of Thames)), and is much smaller elsewhere. Storm surge heights can be higher in some estuaries and harbours, however. The largest recorded is a 0.90 metre storm surge in Kawhia Harbour on 6 May 2013, followed closely by 0.88 metre in Tauranga Harbour during Cyclone *Giselle* in April 1968. So the coincidence of storm surge with high spring or perigean tides is still the main factor that determines whether a high storm surge will cause inundation problems.

Cyclone *Bola*, one of the most damaging cyclones to hit New Zealand in recent decades, tracked southwards over New Zealand in early March 1988.

At Marsden Point, the storm surge measured over 0.6 metre (black line). At the peak of the storm surge, approximately 50 per cent was due to the inverted barometer effect (blue line), with the remainder due to the influence of the strong east-north-east winds (red line).



Note: mm = millimetres; MSL = mean sea level; m/s = metres per second.

### Storm tide and storm surge monitoring

Monitored sea level and storm surge data for the last five days at 16 sea level monitoring sites around the New Zealand coast: [www.niwa.co.nz/our-services/online-services/sea-levels](http://www.niwa.co.nz/our-services/online-services/sea-levels).

## 7 Waves

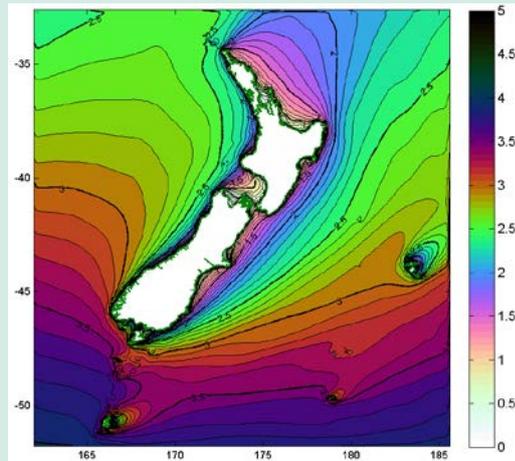
Waves around New Zealand's open coast are generated from two sources (and often co-exist):

- locally generated waves, caused by local winds over a finite fetch of tens to hundreds of kilometres
- distantly generated (swell) waves, formed in the wider Pacific Ocean or Southern Ocean.

Waves are defined by their *significant wave height* ( $H_s$ ), or the average height of the highest 33 per cent of waves over a certain period, the *wave period* ( $T_m$ ) – the average time between successive waves – and the wave direction.

Offshore wave conditions around New Zealand can be subdivided into four major zones in terms of open-coast wave exposure:

- *south-facing coasts (Fiordland to Catlins, South Island)*: an extremely high-energy wave zone (mean  $H_s = 3\text{--}4$  m;  $T_m = 10\text{--}12$  s; SW–W). Waves are typically steep, indicating a zone of active wave generation, but also contain a sizable swell component from the Southern Ocean
- *western New Zealand coasts*: a high-energy wave zone (mean  $H_s = 2\text{--}3$  m;  $T_m = 6\text{--}8$  s; SW–W). The waves are steep and respond to the regular passage of weather systems across the Tasman Sea
- *eastern New Zealand, up to East Cape*: a moderate- to high-energy wave zone (mean  $H_s = 1.5\text{--}3$  m;  $T_m = 6\text{--}9$  s; S). Sheltered from prevailing westerly winds by the New Zealand landmass, but exposed to southerly winds and swell. Wave steepness is variable, indicating a mixture of swell and local wind sea
- *north-eastern North Island (East Cape to North Cape)*: a low-energy lee shore (mean  $H_s = 1\text{--}2$  m;  $T_m = 5\text{--}7$  s, N–E). Wave steepness is variable. Highest waves occur during ex-tropical cyclones or as swell that is generated by Pacific cyclones well out to the north-east of the North Island.

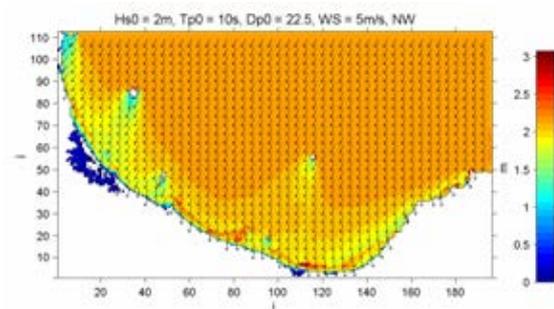
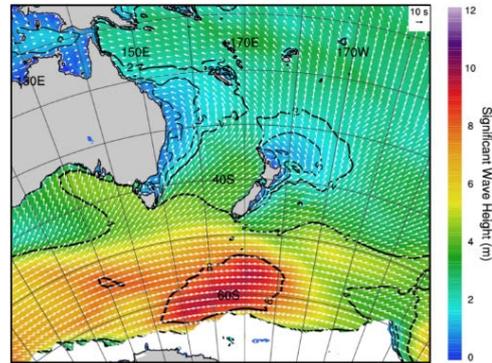


Forty-five-year average of the significant wave height ( $H_s$ ) in metres around New Zealand, based on a deep-water wave model. Source: NIWA

In estuaries and harbours, waves are mostly generated by local winds, and their height is limited by the wind fetch and the depth of water. Fetch is the distance downwind of continuous open water, with long fetches allowing the wind to build up larger waves. Wind waves in estuaries and harbours can still cause erosion and inundation hazards, particularly during very high tides or storm tides.

Little monitoring of wave conditions has been carried out around New Zealand. Consequently, to assess wave climate and derive probabilities of extreme wave conditions, computer models are used to *hindcast* wave conditions from past wind conditions over a sufficient period of time (decades). Two types of model are typically used:

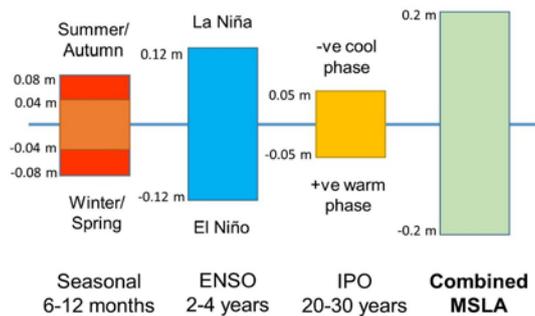
- deepwater wave models that simulate oceanic wave conditions over a large part of the Southern and Southwest Pacific oceans (right, upper figure) based on global and regional wind fields
- nearshore wave models (eg, SWAN) that simulate the changes in deep-water wave conditions as the waves approach the shore brought about by wave refraction, diffraction and shoaling. These models cover a small regional area and are driven by deep-water wave conditions on the offshore boundary and local winds over the region being modelled (eg, right, lower figure for the Bay of Plenty – note the wave shadows behind offshore islands).



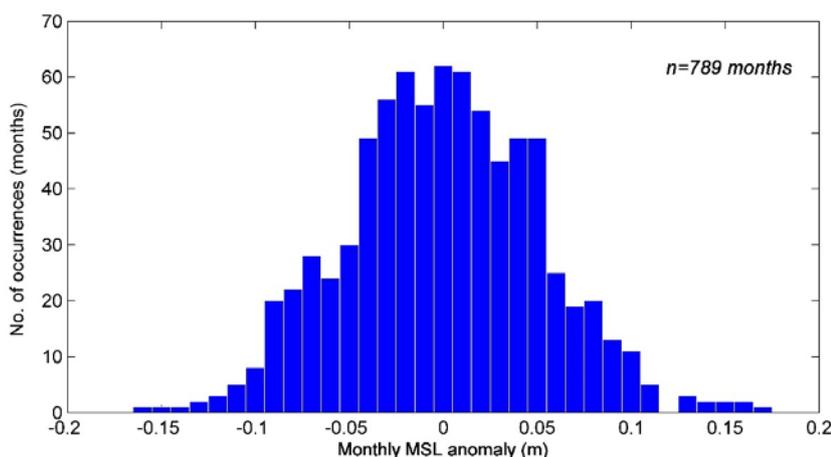
## 8 Long-period mean sea level fluctuations

Longer term fluctuation or anomaly (lasting at least a month) in the monthly mean sea level (MSL) is also an important component when assessing coastal inundation and erosion hazards. These fluctuations are typically related to:

- persistent weather patterns, for example, storminess, depressed pressure or anticyclonic conditions over a month
- annual (seasonal) heating and cooling cycle caused by the influence of oceanic currents and the sun on the ocean; MSL tends to be higher in late summer and autumn and, over a year, can fluctuate around plus or minus 0.04 metres on average around New Zealand, but up to plus or minus 0.08 metres in some years
- interannual two- to four-year El Niño–Southern Oscillation cycles; MSL is usually depressed during El Niño phases, and higher during La Niña phases, with fluctuations of up to plus or minus 0.12 metres on both east and west coasts of New Zealand
- twenty- to 30-year Inter-decadal Pacific Oscillation (IPO) cycles; the rate of sea-level rise in New Zealand tends to be higher during the initial negative (cool) phases of IPO and have a lower increase during the positive (warm) phases of IPO. The IPO facilitates sea-level fluctuations in New Zealand of up to plus or minus 0.05 metres. The IPO has been in a negative phase since about 1999 but may be switching to the positive phase.



Persistent weather patterns and seasonal to long-period climate cycles could alter the monthly mean sea level anomaly (MSLA) in New Zealand by up to plus or minus 0.2 metres relative to the background MSL. Such outer-limit combinations of MSLA would occur infrequently and last for only a short period of months, however.



Distribution of monthly mean sea level (MSL) anomaly (about the linear trend in sea-level rise) from the Wellington Harbour sea level gauge from December 1944 to December 2011. The MSL anomaly ranged between  $-0.16$  metres and  $+0.17$  metres about the average linear trend. Highest monthly anomaly occurred during October 1989, coinciding with the strong La Niña episode of 1988/89, lower than normal barometric pressure ( $1005.8$  hPa compared with the long-term mean of  $1013$  hPa) and more northerlies. Data source: Greater Wellington Regional Council

## 9 Sea-level rise

Global sea level has fluctuated considerably over millennia, ranging from a few metres above present when the climate was warmer about 125,000 years ago, to more than 120 metres lower than present during the last glacial maximum 20,000 years ago. In the modern era, sea level began to rise around the latter half of the 1800s, and steadily increased at a rate in the range of 1.4–1.9 millimetres/year during the 20th century. In the satellite era (since 1993), global mean sea level has risen 3.3 millimetres/year. The increase is due partly to natural climate variability and partly to acceleration in sea-level rise due to warming of the atmosphere and oceans.

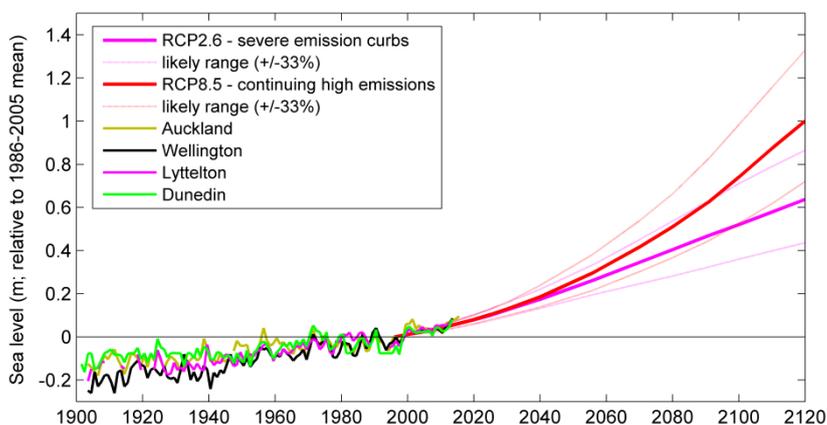
Key drivers of the rise in sea level are:

- thermal expansion from warming ocean waters
- additional water mass added to the ocean from glaciers, ice sheets and net freshwater runoff

Local sea level change may be different to the global average, and relative sea level change also includes the effect of vertical land movement.

Across New Zealand, the average relative sea-level rise (based on 10 gauge sites) for the 100 years up to 2015 was  $1.8 \pm 0.2$  millimetres per year (see plot for four main ports).

Locally, adaptation to the relative sea-level rise is required – not the global average rate. Projections of future sea-level rise are usually global, however. So for New Zealand, offsets need to be applied to projections for differences in the regional-ocean response for the Southwest Pacific (eg, an additional 0.05 metre by the 2090s) and local vertical land movement (which can be measured by continuous GPS recorders).



Relative sea-level rise for New Zealand's four main ports since 1900 (using annual means) spliced with RCP2.6 and RCP8.5 global sea-level rise projections (IPCC, Fifth Assessment Report).

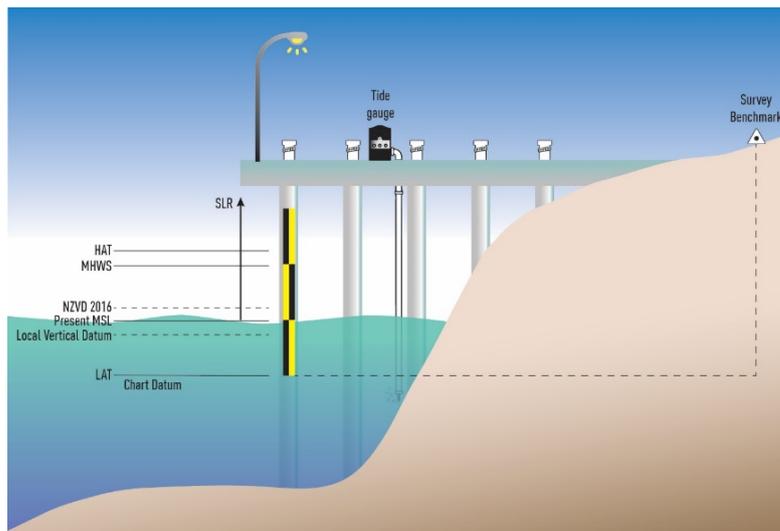
IPCC projections (in the Fifth Assessment Report) of global sea-level rise by 2100 cover a range of around 0.3–1.0 metre above the 1986–2005 average level, depending on the level of future greenhouse gas emissions. The range in sea-level rise projections is much narrower in the near-term to 2060 (0.2–0.4 metre).

In the more distant future, it is virtually certain that sea level rise will continue beyond 2100, with sea level rise due to thermal expansion to continue for many centuries. Sustained global warming of 2–4°C could lead to the near-complete loss of the Greenland ice sheet over a millennium or more, causing a global mean sea level rise of about 7 metres, in addition to any contribution from Antarctica. Abrupt and irreversible ice loss from a potential instability of marine-based sectors of the Antarctic ice sheet in response to climate forcing is also possible.

### **Commitment to sea-level rise**

Recent studies suggest that cumulative global emissions to date have already committed the Earth to an eventual 1.6–1.7 metres of global sea-level rise (SLR) relative to the present level, if no further net global emissions were to occur from now. Due to inertia in the climate–ocean–ice system, the period for this SLR commitment to be fully realised is uncertain (could be a century or more), but the time extends out considerably if severe curbs on global emissions, in the next few decades, can limit global temperature rise to less than 2°C.

## 10 Vertical datums and mean sea level

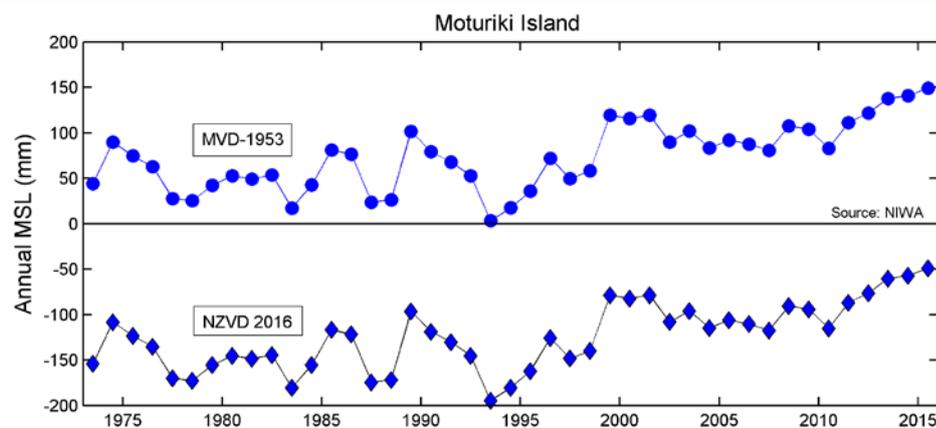


Schematic of the typical relationship between chart datum, the local vertical datum and New Zealand Vertical Datum 2016 (NZVD2016) in relation to present mean sea level (MSL).

Various tide levels are also shown (LAT = lowest astronomical tide; HAT = highest astronomical tide, and MHWS = mean high water spring). SLR = sea-level rise.

The three main vertical datums that are used for navigational purposes and on land for surveying and engineering purposes are:<sup>35</sup>

- *chart datum* (CD) – used for navigation and for hydrographic charts. It typically refers to a level below which low tides seldom fall (or lowest astronomical tide – LAT). Most port tide gauges are set to CD.
- *Local vertical datum* (LVD) is one of the around 13 regionally based vertical survey datums. They were based on sea-level data collected over several years (mostly 1920s to 1950s). Sea level has risen in the intervening period, which means an offset above the LVD is now required to tie in the present mean sea level.
- *New Zealand Vertical Datum 2016* (NZVD2016) – new national vertical datum developed by Land Information New Zealand in 2016, based on an improved representation of the geoid (undulating gravity field) across New Zealand.



Plot of annual mean sea level (MSL) at Mount Maunganui (Moturiki Island) above the relevant local vertical datum (Moturiki MVD-1953) and the New Zealand Vertical Datum 2016 (NZVD2016) (lower panel) 1972–2015. Zero on the vertical axis is the datum for both. Present-day MSL is higher than the local vertical datum owing to the effects of sea-level rise over the 65 years since that local datum was defined, while present sea level is below the new NZVD2016.

<sup>35</sup> [www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums](http://www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums).

### **Tide marks for cadastral and engineering design purposes**

Land Information New Zealand provides tide marks at standard ports for engineering and cadastral surveying, based on tide predictions for the next 19 years, while tide marks for navigation are based on predictions for the coming year only: [www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/tidal-level-information-for-surveyors](http://www.linz.govt.nz/data/geodetic-system/datums-projections-and-heights/vertical-datums/tidal-level-information-for-surveyors).

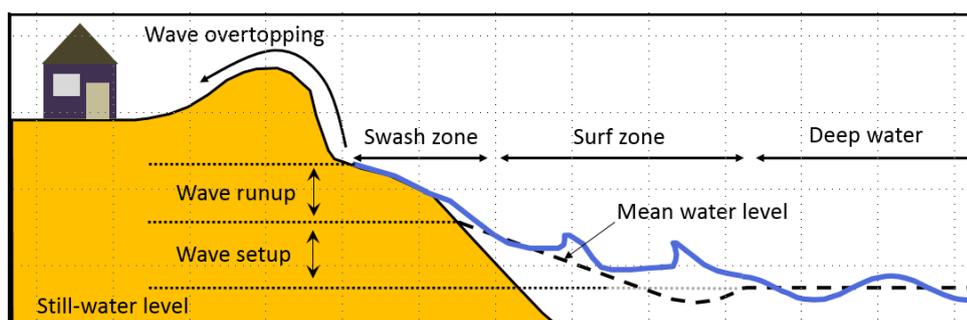
## 11 Wave setup, runup and overtopping

Waves contribute to coastal inundation hazards by three consecutive processes:

- wave setup – after incoming waves break, the average level of the water inside the surf zone to the beach is set up higher than the sea level offshore from the breaker zone
- wave runup – the extra height that broken waves reach as they run up the beach and adjacent coastal barrier (natural or artificial), until the wave energy is finally expended by friction and gravity
- overtopping – the spill-over of waves as they reach the crest of the coastal barrier (photo) or defence structure, resulting in flooding of the land and properties behind the barrier. Depending on the overtopping flow and character of the barrier, the barrier may breach, increasing the potential for further inundation. Wave spray or splash over a coastal defence structure can be hazardous for transport networks, but volumes are relatively small compared with overflowing ‘green water’.



Source: R Bell, NIWA



Schematic of wave setup, runup and overtopping. Source: NIWA

*Wave setup* is influenced by the offshore wave height and wave period, together with the nearshore seabed shape (profile). Wave setup is an integral component of the total water level that could cause direct or near-continuous inundation of green water onto coastal land. The combined storm tide plus wave setup level is therefore important for direct, and potentially rapid and extensive, coastal inundation.

*Wave runup* and *overtopping* at any coastal locality is usually quite site specific, depending on factors such as beach slope, roughness of the beach (sand, gravel or large rocks), wave height, exposure to ocean swell, how close inshore waves can penetrate before breaking, and the characteristics of the land above the beach (eg, dunes, seawall, low cliffs). Wave runup constitutes a short-term fluctuation in water level relative to wave setup, tidal and storm surge time scales, and is unlikely to cause substantial inundation other than in a few tens of metres of the dune or berm crest. Surface water can accumulate quickly over time from wave overtopping and splash if stormwater drainage or soil permeability is limited, however.

Waves also play a major role in causing coastal erosion by:

- the runup of high-energy storm waves, resulting in erosion of the dune or cliff toe
- mobilising large quantities of sediment between the beach and nearshore bars – gentle swell and more quiescent waves following a storm usually help in replenishing a beach by slowly combing sediment back onto the beach; the sequencing of storms and high wave and swell activity is also an important factor
- varying the rate of longshore movement of sediment (the alongshore drift is due to waves approaching the coast at an angle to the shoreline) – erosion can occur in this situation, especially if the drift is predominantly in one direction, allowing a structure or natural feature to trap sediment behind it but ‘starving’ the down-drift coast.

## 12 El Niño–Southern Oscillation and Inter-decadal Pacific Oscillation

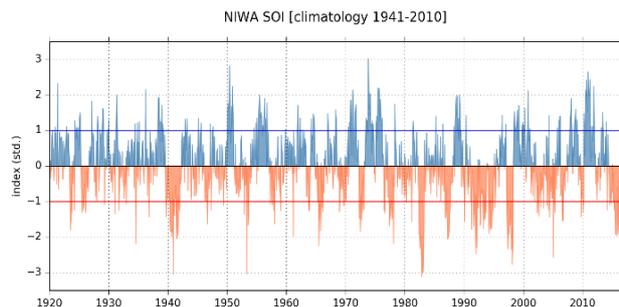
Natural fluctuations in New Zealand’s (and the Pacific’s) climate are influenced by two key natural cycles operating over timescales of years: the El Niño–Southern Oscillation (ENSO) and the longer Inter-decadal Pacific Oscillation (IPO). These natural phenomena operate over the entire Pacific Ocean and beyond, in response to changes in ocean temperature, prevailing trade winds and the strength of the subtropical high-pressure belt. El Niño and La Niña occur irregularly over about two-to-seven years, with each phase lasting from nine months to two years. There can be large variability in the intensity of individual events (also dependent on the prevailing IPO phase).

During **El Niño** conditions, New Zealand experiences:

- more westerly winds – cooler seas
- slightly high wave conditions off the south-west coast of the South Island
- depressed mean sea level
- lower likelihood of ex-tropical cyclones.

During **La Niña** conditions, New Zealand experiences:

- more north-easterly winds – warmer seas
- slightly higher wave conditions off the north-east coast of the North Island
- higher mean sea level
- higher likelihood of ex-tropical cyclones.



ENSO is measured in terms of the east–west pressure difference, the Southern Oscillation Index (SOI), which is a scaled form of the difference in mean sea-level pressure between Tahiti and Darwin relative to the mean (1941–2010). Plot shows monthly SOI values since 1920. El Niño occurs when the SOI is persistently lower than –1 and La Niña when the SOI is persistently greater than +1; that is, above or below the lines. Source: N Fauchereau, NIWA

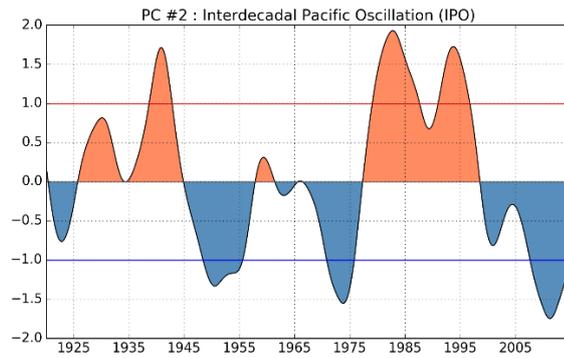
The IPO is a long-lived Pacific-wide natural cycle that causes relatively abrupt ‘shifts’ in climate patterns in the Pacific Ocean, which can last for two-to-three decades. Overall, the IPO’s spatial pattern of sea-surface temperature in the Pacific resembles that of ENSO, but IPO is decadal in scale (compared with interannual for ENSO). As a result, relatively long data records are required to define and understand the IPO. It is strongest in the northern Pacific, but affects the entire Pacific, including New Zealand’s climate and oceans. Since 1920, there have been two warm, or positive (1924–44 and 1977–98), and two cold, or negative (1945–76 and 1999–present), IPO phases. Changes in the phase are associated with abrupt shifts in North Pacific atmospheric pressure and mean sea level, and contrasting fluctuation patterns in temperature, pressure and atmospheric circulation between the eastern and western Pacific. Recent indications suggest the IPO may be switching back to a positive phase.

**During positive IPO** New Zealand experiences:

- more intense El Niño events
- reduced rate of rise in mean sea level
- tendency for beaches to accrete on eastern coasts.

**During negative IPO** New Zealand experiences:

- more intense La Niña events
- increased rate of rise in mean sea level
- more easterlies and north-easterlies
- tendency for beaches to erode on eastern coasts (eg, 1970s storms).



IPO is defined by an index based on more than 10-year patterns of sea-surface temperatures (SST) in the Pacific. The IPO changes phase every 20–30 years.

Source: N Fauchereau, NIWA

## 13 Tsunami

The word tsunami is used internationally, and is a Japanese word meaning 'harbour wave' or waves. Tsunami are generated by several geological disturbances, particularly:

- large seafloor earthquakes, in which significant deformation (uplift or subsidence) of the seafloor occurs
- submarine landslides in canyons or scarps (which may be triggered by an earthquake)
- volcanic eruptions (eg, underwater explosions or caldera (crater) collapse, pyroclastic flows and atmospheric pressure waves)
- large coastal-cliff or lakeside landslides
- meteorite (bolide) impact (rare).

Tsunami can be classified either by the distance from their source to the area impacted or, more relevant for emergency management purposes, the travel time to the impacted area. For New Zealand, three categories are typically defined:

- local source event – within 60 minutes travel time (could affect several tens of kilometres of coast or more)
- regional source event – within one-to-three hours' travel time (could affect a region or several regions)
- distant (remote) source event – longer than three hours' travel time (could affect many regions).

Tsunami wave characteristics at the coast can vary substantially, depending on several factors, including: the generating mechanism; the location, size and orientation of the initial source (disruption); source-to-locality distance; and local seabed and coastal margin bathymetry and topography. The timing and height of high tide with the tsunami peak waves are also important factors in determining the extent and magnitude of inundation. Sea-level rise will also exacerbate tsunami inundation and increase flow depths (relative to present day for the same event).

Tsunami waves differ from the waves we normally see breaking and running up the beach, particularly in the length or period between wave crests and their landward reach. The time between successive tsunami wave crests can vary from several minutes to an hour, rather than several seconds. As tsunami waves reach shallow coastal waters, they slow down, shorten and steepen rapidly, sometimes reaching heights over 10 metres at the shoreline and potentially inundating up to a few kilometres inland. In the large recent (Magnitude 9 or



The last major remote source tsunami to hit New Zealand shores was the Chile tsunami of 1960 – photo shows the Port of Gisborne. Maximum crest-to-trough wave height reached 5.35 metres in Lyttelton Harbour, fortunately around low tide. The tsunami caused damage at many locations along the east coast (eg, Ahuriri Bridge, Napier).



The remains of a small house north of Gisborne that was destroyed by a 10-metre local source tsunami in March 1947. Three people rode out the tsunami in the house, while two others ran up the hill with water at their heels. Pouawa, where the bridge was destroyed, is in the distance. Source: *Weekly News*, 2 April 1947

greater) megathrust events (2004 Indian Ocean; 2011 Tohoku, Japan), tsunami runup heights reached to around 30–40 metres in some areas.

Shallow bays and harbours tend to focus the waves and cause them to be amplified (or resonate) and slosh back and forth, especially if the tsunami wave period matches the natural resonant period of the water body. Tsunami waves that overtop or breach natural coastal beach ridges and barriers can surge considerable distances inland in low-lying areas (hundreds to thousands of metres), depending on the wave height at the shoreline, wave period and topographic characteristics and development of the coastal area.

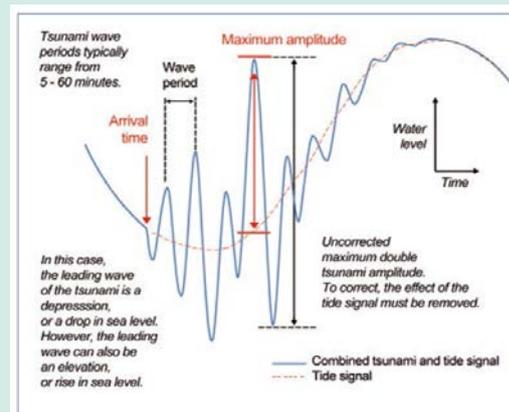
### Key tsunami definitions

**Tsunami period** (minutes) – the time between successive tsunami wave peaks. Periods can fluctuate during the course of a single event and vary between different locations in the same region. Periods are usually in the range of a few minutes (eg, for a relatively small 'local source' tsunami) and up to an hour for a large 'distant source' tsunami.

**Tsunami amplitude** (metres) – the height of the tsunami wave crest above the instantaneous sea level (tide level) at the time of arrival. The wave amplitude is far from constant, and it increases substantially as the wave approaches the shoreline. It is the 'height' used in tsunami warnings and alerts, and the average return period tsunami hazard at the shore line (maps below).

**Tsunami wave height** (metres) – as for storm waves, the vertical crest-to-trough height of waves or double tsunami amplitude. It is generally used in conjunction with measurements from a sea level gauge to express the maximum tsunami wave height near shore.

**Tsunami runup** (metres) – a more useful measure; the vertical inundation elevation the seawater reaches above the instantaneous sea level at the time of the tsunami (including the tide). This measure still has the drawback that it depends markedly on the type of wave, the local topography and development density, so it is site specific.



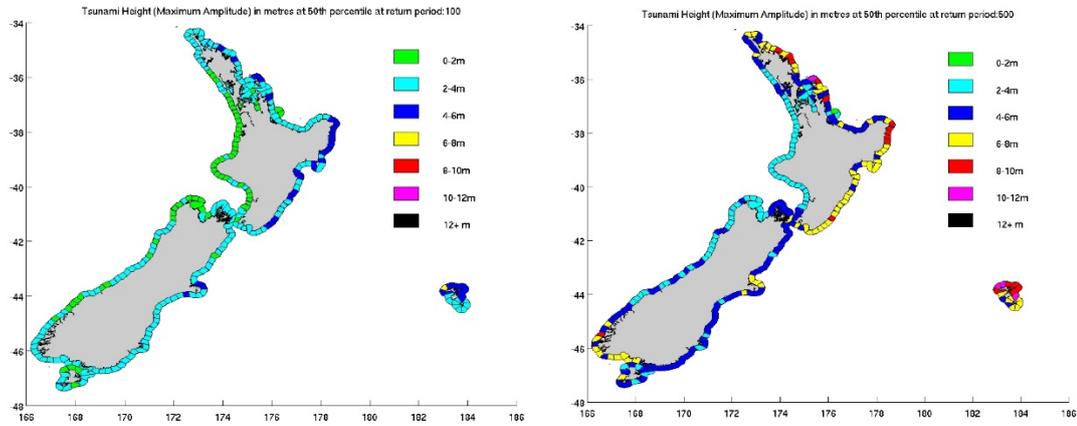
Source: Intergovernmental Oceanographic Commission (2016).

The arrival of a tsunami wave-train (ie, it typically is not just one wave) can be observed as an initial drawdown (recession) of the level of the sea (much faster than the tide), but could be the opposite (an initial quick rise in sea level). Which one depends on the pattern of the seafloor deformation on each side of the rupture (eg, for an earthquake, this depends on the area and vertical and horizontal direction of movement of the rupture).

The waves that propagate towards the coast seldom break before reaching the nearshore area and appear to have the whole ocean behind them. Other tsunami occur as an advancing breaking wave front or bore, which is the type of wave most people associate with a tsunami. Inundation of the coastal margin continues until maximum runup height is reached, after which the water temporarily recedes. The outrushing waters resulting from temporary wave

recession can produce even higher current speeds and scour than the uprush wave, as the flood waters gravitate to the lowest point in the coast

For the same wave height at the shore, a longer-period tsunami wave-train, such as generated by a remote source (eg, from South America), will generate larger inundation volumes than a shorter-period wave (eg, a local source) of the same wave height.



Tsunami heights (maximum tsunami amplitude) in metres around New Zealand for average recurrence intervals of: (left) 100 years, (right) 500 years. Note: these are median estimates from the probabilistic modelling results. Source: Power (2013)<sup>36</sup>

<sup>36</sup> See also [www.civildefence.govt.nz/assets/Uploads/publications/GNS-CR2013-131-Tsunami-Report-Full.pdf](http://www.civildefence.govt.nz/assets/Uploads/publications/GNS-CR2013-131-Tsunami-Report-Full.pdf).