4. Relative sea-level rise and planning implications

Relative sea level is the effective change in sea-level rise related to the land on which our coastal development lies. If the elevation of the coastal margin is slowly changing (up or down), then relative sea-level changes will be the sum of changes in both sea level of the ocean and the vertical movement of the landmass. For instance, when the ground sinks lower (subsidence), the rising sea level can reach higher (Figure 1) and further inland if the land is low-lying. Subsidence will also worsen rising groundwater levels where they are already influenced by tides and sea-level rise, even if coastal flooding is not yet a risk.

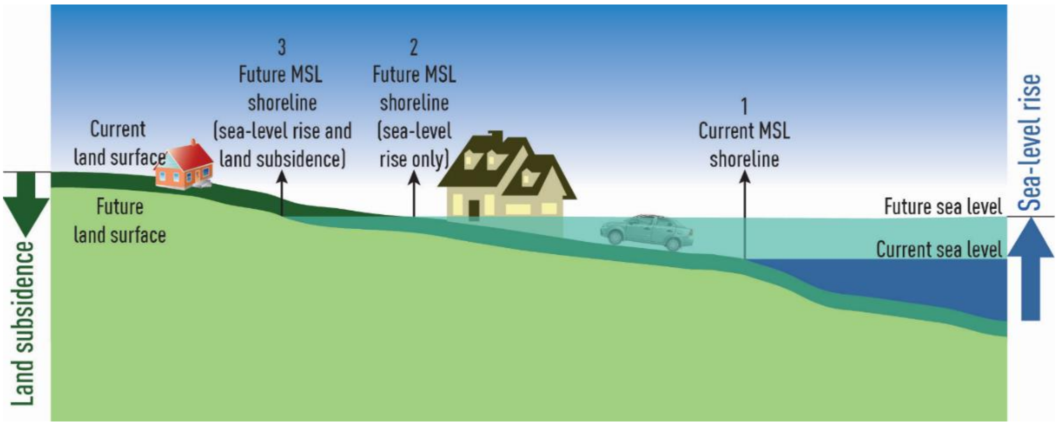

Figure 1: *Effect of relative sea-level rise on the shoreline at mean sea level (MSL) when coastal land subsides over time (red arrow). Source: MfE coastal hazards guidance[1], A Wadhwa, NIWA.*

Several processes can affect land elevations. Aotearoa-New Zealand sits astride a tectonically active boundary between the Pacific and Australia crustal plates. This situation can generate earthquakes that rupture and distort the land surface, while in between earthquakes (which may be many decades or centuries apart), the land may be sinking or rising due to elastic deformation from the widespread influence of locking and slow-slip along the Hikurangi Subduction Zone. This ongoing subsidence effects eastern and southern North Island as well as the northern half of the South Island. Other causes of vertical land movement at the coast are from ongoing compaction of deep sediment layers (e.g., Hauraki Plains), groundwater pumping or the ongoing compaction of land reclaimed from the sea or estuaries.

Projections for vertical land movement around Aotearoa-New Zealand

Through the recent analysis[2] of continuous GNSS/GPS monitoring stations and satellite radar data (see Box below), estimates of local vertical land movement rates (mm/year up or down) for the period 2003–2011 are now available from NZ SeaRise on the Takiwā platform[3] at 2-km spacing along the entire coastal margin of Aotearoa–New Zealand. Around our coastline, the vertical rates of movement (excluding earthquakes) vary widely from a rapid subsidence rate of 8 mm/year (southern Wairarapa) to an uplift of 5 mm/year (near Pikowai–central Bay of Plenty). However, many coastal locations have low rates below 1 mm/year.

For now, these recent vertical land movement rates (over a relatively short period for 2003–2011), are extrapolated into the future. These rates (uplift, subsidence or stability if little change) are added into projections of the rise in ocean sea level to provide a relative sea-level rise (relative to the landmass) that is unique to each location.[3]

Over planning timeframes of at least 100 years (as required for decisions on coastal development), it is the ongoing trend in vertical land movement that needs to be considered – not banking on a future earthquake that may raise or lower the coastal margin dramatically (as it did in the 2016 Kaikōura earthquake). Vertical land movement may well change over time, which is why it is important to keep monitoring not only the rise of ocean level but also how quickly the land is moving up or down. Tide gauges monitor the net effects of changing ocean and land levels simultaneously, aided in a few places by co-locating GNSS/GPS stations that measure vertical land movement separate from what the ocean is doing (see Box).

Relative sea-level rise projections and planning implications

When planning adaptation at the coast to rising sea level, it is the relative sea-level rise we need to adapt to, as we consider the impact on assets and infrastructure that sit on the landmass. If the landmass is subsiding, this makes the height of the rising sea level worse (Figure 2). The rise in the adjacent ocean level (dashed line) is unaffected by the gradual land subsidence locally in this example. The NZ SeaRise projections for relative sea-level rise are available at 2-km intervals around our coast[3], which combine the future projections for vertical land movement and the rise in ocean levels for several climate-change scenarios. An important caveat is whether the future rate of vertical land movement changes from that measured in the period 2003–2011. Ongoing monitoring of how the land moves up or down (see Box below) is critical to keep relative sea-level rise projections grounded.

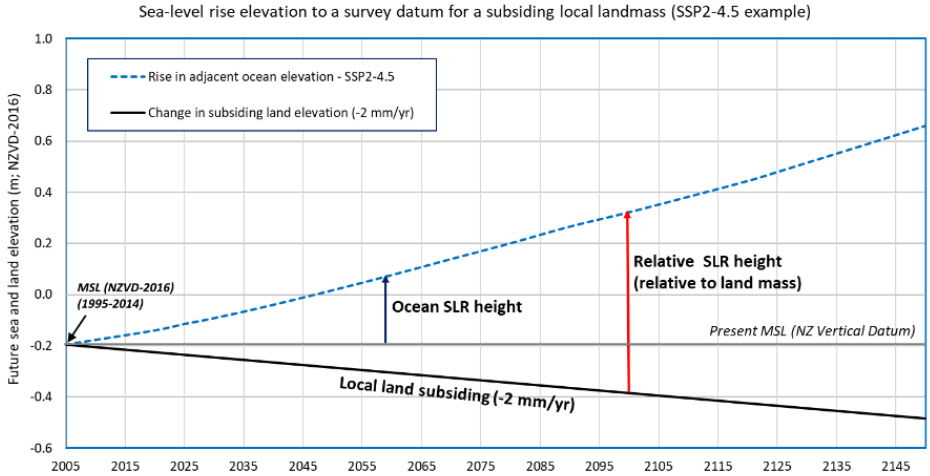

Figure 2: *Schematic of relative sea-level rise (SLR) for a subsiding coastal area for one climate-change scenario (see Primer #2), which is a height relative to the sinking landmass (red arrow). To convert heights of relative sea-level rise projections (zeroed at 2005), to a survey elevation, add a mean sea level of the recent past (1995-2014) in terms of a survey datum (e.g., NZ Vertical Datum -2016 in this example).*

For planning and assessing risk for coastal adaptation strategies, the implications for subsiding coasts are:

- If subsidence is present locally (e.g., 2 mm/year), this will bring forward in time when a specific sea-level rise threshold will be reached. Towards the end of this century, for a low-emissions scenario, this subsidence rate brings forward the threshold by ~2-3 decades, while a high emissions scenario would be ~1–2 decades earlier (less because the rise in ocean levels would be more substantial).
- There is a widening uncertainty in both ocean sea-level rise and vertical land movement. Therefore, rather than second-guess a scenario to plan for now, it is far better to adopt a dynamic adaptive approach and in tandem track how relative sea-level rise progresses for timely adaptation.

Monitoring and estimating vertical land movement rates

In the past, the main way of measuring vertical land movement was through regular surveying of levels on individual survey benchmarks. With the advent of satellites, measurements of land elevation over time can be done over much wider areas. Initially, the US Global Position System (GPS) comprising 24 satellites was the first network that became operational in 1993. Further satellite systems were deployed by different agencies and countries (e.g., GLONASS, Galileo and Beidou) – so generally these systems are now known as a global navigation satellite system (or GNSS) rather than specifically GPS. Now permanent receiver and antenna GNSS stations continuously measure and record horizontal and vertical land movement. Since 2002, GeoNet (with Land Information NZ and EQC funding) have built an extensive GNSS network[4], proving very useful for monitoring land deformation under ongoing tectonic processes and helps update vertical land movement of benchmarks nationally.

Vertical land movement rates over time (excluding earthquakes) are essential for producing projections of relative sea-level rise. However, only some of the GNSS stations in GeoNet are located at the coast and only the tide gauges at the four main-centre ports have a GNSS station alongside.

To fill these large gaps in coverage along the coast, the NZSeaRise project has extracted VLM rates, averaged over the period 2003–2011, based on Interferometric Synthetic Aperture Radar (InSAR)[5] observations from the Envisat satellite[6] operated by the European Space Agency. These InSAR satellite data were adjusted to align locally with GNSS station records in each area to build a consistent set of vertical land movement rates at 2 km spacing around our coastline.[3]

[1] MfE: https://environment.govt.nz/publications/coastal-hazards-and-climate-change-guidance-for-local-government/
[2] Working paper: Significance of vertical land movements at convergent … https://www.searise.nz/publications
[3] https://www.searise.nz/maps-2
[4] https://www.geonet.org.nz/data/gnss/map
[5] https://www.esa.int/Applications/Observing_the_Earth/Widening_Envisat_s_InSAR_view
[6] https://earth.esa.int/eogateway/missions/envisat