IS WELLINGTON SINKING?

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Bruce Hayward's well referenced article "Is Auckland Sinking?" (Geoscientist Aotearoa/New Zealand Issue 4, November 2023) seeks an explanation of an apparent mismatch between the well-established tectonic stability around Auckland, and satellite observations of subsidence publicised by a government-funded research team known as the "SeaRise Project" in May 2022 (see Box).

Wellingtonians have been asking the same question as Bruce Hayward. As with Auckland, there is a plethora of science showing that, contrary to the SeaRise modelling, parts of the Wellington region have been rising out of the water throughout the late Quaternary, due to episodic seismic and aseismic processes (e.g., Pillans et al., 1995[1]; Beaven and Litchfield 2012[2]; Ninis et al., 2022[3]). However, the SeaRise news coverage, and the online 'tool'[6] (Fig. 1), suggested that parts of Wellington, such as Petone and Owhiro Bay, could be subject to sea level rise of 30 cm by 2040. Land subsidence, known as "Vertical Land Movement" or "VLM", is driving this accelerated rate, doubling the rate of relative sea level (RSL) rise.[7]. As Bruce Hayward found, the SeaRise claims appeared inconsistent with peer reviewed research and observations from around the region and warrant closer examination.

Queen's Wharf Wellington

Subsidence

Location 2502 on the SeaRise 'tool' is at Queen's Wharf Wellington, about 10 km from both Petone and Owhiro Bay. It is also the location of the Wellington Harbour Tide Gauge for which measurements are available online from 1944 courtesy of the Permanent Service for Mean Sea Level (PSMSL; Fig. 2). Analysis of the tide gauge data indicate that the average increase in monthly RSL observed by the tide gauge from 1944 to 2020 is 24.6 cm.

The NZ SeaRise Project

The NZ SeaRise: Te Tai Pari O Aotearoa programme was a $7.1 million, five-year (2018–23) research programme funded by the Ministry of Business Innovation and Employment-administered Endeavour Fund, involving a team of scientists from several institutions and led by Professor Tim Naish and Professor Richard Levy of the Antarctic Research Centre, Victoria University of Wellington. In 2022 the team received a further five-year grant of $13 million to extend its work.

The peak deliverable for the original SeaRise programme was an online tool providing projections of relative sea level rise at 2 km intervals around New Zealand's entire coast, out to 2150, with decadal milestones highlighted. The method utilised summed global projections for global (absolute) sea level rise from the Intergovernmental Panel on Climate Change (IPCC), with the team's estimates of local (tectonic, sediment compaction, etc.) vertical land motion. The latter has been primarily informed by an historic (2003–11) InSAR data set, with lesser reference to continuous GPS and tide gauge records.

The results were fast-tracked into the Ministry for the Environment's (MfE) 2022 "Interim guidance on the use of new sea-level rise projections" and the final version (MfE, 2024) was issued in February 2024[4]. It also featured in literature associated with the MfE's coastal adaptation ("managed retreat") consultation[5].

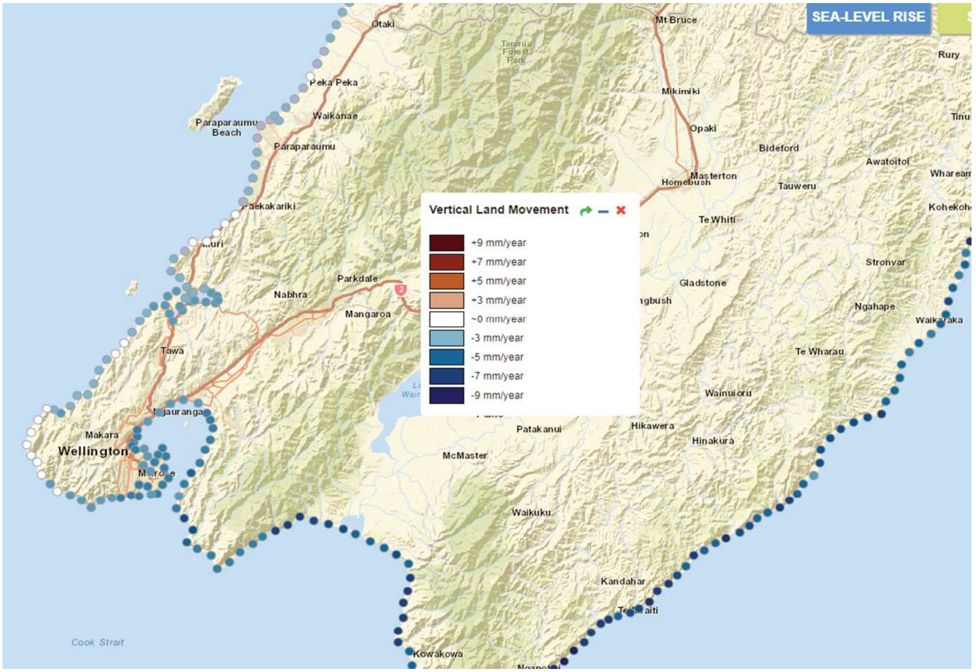

Figure 1: Screen capture of NZ SeaRise map of Vertical Land Movement for Wellington Region, 2003– 2011. From https://searise.takiwa.co/map/6233f47872b8190018373db9/embed

SeaRise record a 3.09 mm/yr subsidence rate between 2003 and 2011. This is consistent with the findings of Denys et al. (2020)[8] of an average interseismic subsidence rate in Wellington of ~3 mm/yr. But extrapolating that back to 1944 would suggest the VLM component of RSL alone would be 23.5 cm to 2021 across the 76-year data set. This leaves only 1.1 cm of sea level rise from the documented increase in absolute sea level (the height of the ocean surface above the centre of the Earth). Such a rate is well below established trends documented across the tide gauge record (e.g. Denys et al., 2020[8]) suggesting SeaRise's VLM component is far too high.

In reconciliation of the apparent mismatch, Denys et al. (2020)[8] explain that slow slip events (SSEs) have been responsible for an average of 0.8 mm/yr of uplift from 1997 through to the end of their data set in 2013. They conclude:

"subsidence is not steady state and to understand the VLM, it is the average rate for the duration of the TG [tide gauge] data (subduction plus uplift) rather than the actual subduction rate that we need to determine."

Adopting a longer data set to determine land movement trends, relevant for RSL projections, is recommended by Beaven and Litchfield (2012)[2]. They note that:

"SSEs modulate the interseismic vertical motion so that a measurement of land elevation change between two SSEs may be quite different from the rate averaged through many events (which is the rate of most interest for RSL predictions)".

This modulation, when coupled with other sources of uplift, may result in the cancellation or even the reverse of the subsidence predicted by the SeaRise modelling.

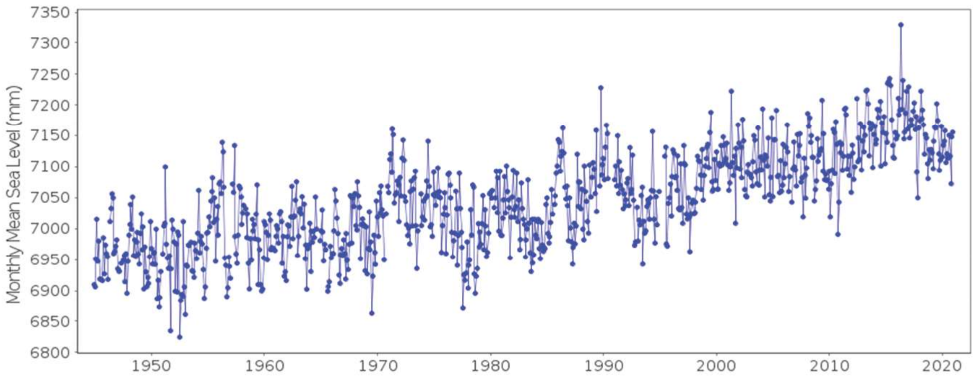

Figure 2: Monthly Mean Sea Level measured by the Queen's Wharf tide gauge in May 2022 with the level extended back in time. Source: PMSL web data - [221_high.png (900×360) (psmsl.org)]

For example, more recent work has been undertaken by NIWA, amongst others (e.g. Wallace, 2020[9]), on the nature and return times of SSEs as well as observations of uplift from other sources.

NIWA advised the Greater Wellington Regional Council regarding RSL in a 2018 client report[10]. Like Denys et al. (2020)[8], the authors were cautious about estimating VLM based solely on transitory subsidence. Their longer data sets were from 23 Global Navigation Satellite System (GNSS) sites around the region between 2008 and 2018, and from 1998 to 2018 for three sites, including Queen's Wharf. Relevant to the SeaRise modelled subsiding trend, they state:

"The net effect is that the subsidence due to the subduction of the Pacific plate under the Australian plate and coseismic displacement to date was mostly cancelled out by the current day Kaikoura earthquake postseismic deformation and the upwards ratcheting effect of the SSEs."

Figure 3 is a chart showing VLM at the GPS site at the Wellington airport, 5 km from the Queen's Wharf tide gauge, where uplift from Kaikōura and other sources clearly prove NIWA are right. Wallace (2020)[9] documents similar uplift on the Kapiti Coast with GNS Science reporting that the Kapiti Coast had been subject to uplift of up to 1 cm in the first half of 2023 alone[11].

These sources of uplift have likely occurred previously and are likely to recur. But they were not observed in the short-term inter-seismic SeaRise dataset and accordingly are not modelled in their projections. Consequently, the SeaRise projections of future VLM are biased towards subsidence in the Wellington area.

Projections

The SeaRise projections of RSL rise at the Wellington Harbour Tide Gauge, Queen's Wharf (Fig. 4), are similarly erroneous when compared to observations. The SeaRise online tool projects RSL rise from 2005 through to 2150, with decadal milestones, based on the IPCC's analysis of the response of absolute sea level to various emission pathways: from the lower pathway known as SSP1-1.9 through to the 'very unlikely'[12,13,14,15] highest pathway of SSP5-8.5. To these estimates are added the local VLM component projected by SeaRise.

The first milestone is 2020, where we now have measured data to test the model. At site 2502, which is at Queen's Wharf, using a realistic emission pathway, SSP2-4.5, SeaRise estimate with 'medium confidence' an overall rise in relative sea level of 11 cm, which without the VLM component, reduces to 6 cm, inferring a VLM component of −5 cm (P50 values).

During the same 15-year period the tide gauge recorded an increase of RSL of only 2 cm, which includes VLM (Source: [https://psmsl.org/data/obtaining/rlr.monthly.data/221.rlrdata]). The SeaRise methodology of adding IPCC estimates of absolute sea level rise to local rates of subsidence results in an over-estimation of around 550% for this site. This exaggerated rate is replicated around the region.

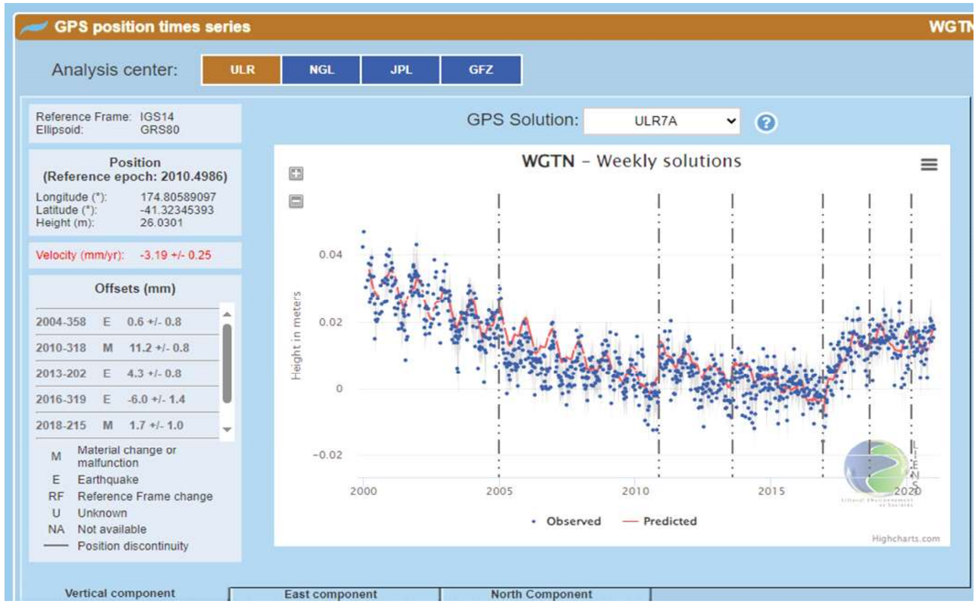

Figure 3: Screen capture of GPS measurements located at Wellington airport. [Source: https://www.sonel.org/spip.php?page=gps&idStation=898]

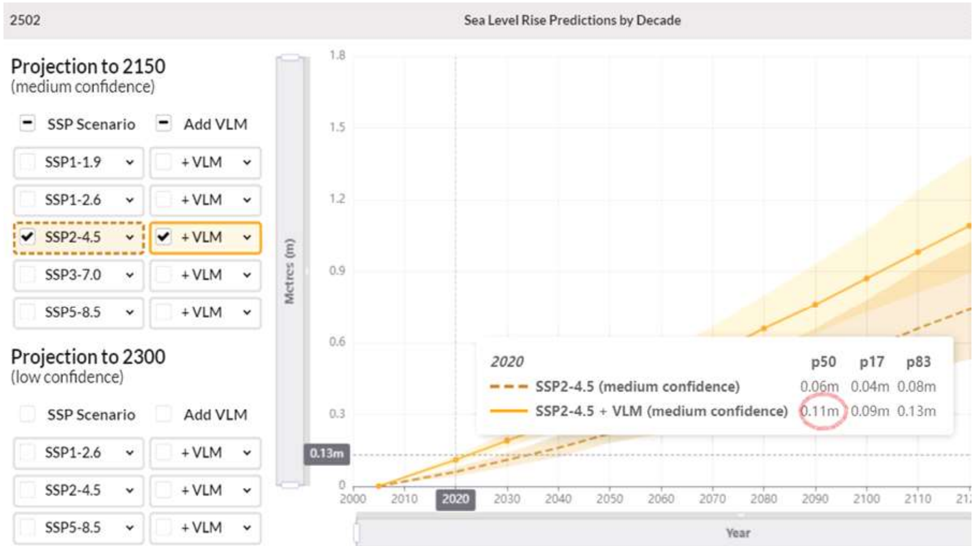

Figure 4: Screen capture of the SeaRise online tool for site 2502 highlighting the 11 cm projected RSL at 2005 – 2020 which reduces to only 6 cm without the VLM component (as at 25 January 2024 available at [https://searise.takiwa.co/map/6233f47872b8190018373db9/embed]).

The adoption of this novel methodology adds complexity to an otherwise simple analysis. For example, an alternative straightforward method of predicting future RSL is to fit a statistical model to the long-term relative sea level records and extrapolate the model into the future to provide a forecast. Figure 5 shows an Autoregressive Integrated Moving Average (ARIMA) model that accounts for the serial autocorrelation of sea level data and non-stationarity due to an underlying acceleration of sea level rise. The ARIMA model was fitted to the data from 1901 to 2004 (red dashed line), and used to forecast sea level rise from 2005 to 2030 with 95% confidence limits (upper limit black dotted line, lower limit orange dotted line). The observed RSL for 2005–2021 are also plotted (black line), and it is evident that the ARIMA forecast has predicted annual sea levels reasonably well up to 2021. The expanding separation of the confidence limits with time also restricts the utility of longer duration extrapolations.

Conclusion

Bruce Hayward's piece concludes by offering possible explanations for why the SeaRise modelling is at odds with established Holocene records pertaining to Auckland. For Wellington, the explanation is clear: SeaRise's short-term, inter-seismic, data set has not recorded the episodic uplift associated with near and far earthquakes or slow slip events—both of which have recurred periodically. Over the medium term (>30– 100 yrs) these can cancel out the predicted subsidence. Over geologic time frames they result in net uplift.

More recent research, presented at the GSNZ 2023 Conference (Stern et al., 2023[16]), suggests that satellite measurements may be biased towards subsidence. They advise using the tide gauge to test GNSS measurements. I agree.

The SeaRise model, (Naish et al., 2022, submitted[17]) has not yet passed peer review but has been embraced by the Ministry of the Environment and is being adopted by coastal City and District Councils for town planning purposes. But with question marks around the model's accuracy for Auckland and now, Wellington, perhaps it is time to revert to the tried and trusted tide gauges as our best approach to measure medium-term RSL and estimate forward rates.

Meanwhile, I'd be interested to hear from other members who have similar concerns about the seeming inconsistency of the SeaRise VLM rates or projections with established trends in your region. ■

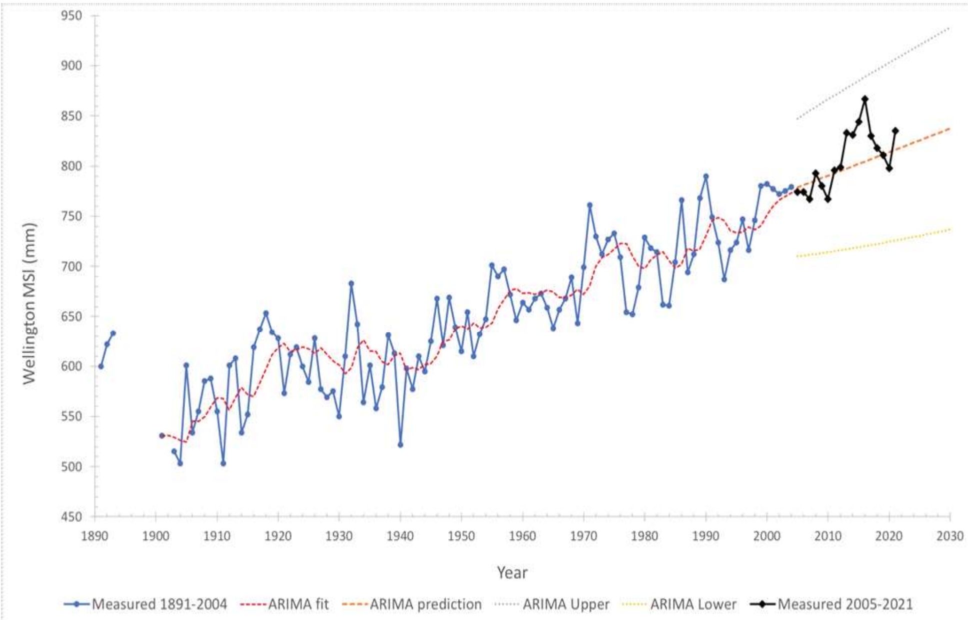

Figure 5: Annual mean relative sea level at Wellington from 1891 to 2021 using data from Bell & Hannah (2012)[18], updated with data from the Permanent Service for Mean Sea Level (PSMSL) and LINZ tide gauge site WLGT sensors 40 & 41. An ARIMA model was fitted using R functions auto.arima and forecast provided by the package forecast. The upper and lower bounds for the forecast correspond to 95% confidence limits.

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