Forensic Analysis of the 1944 Datum Shift at the Wellington Tide Gauge

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INTRODUCTION

CORRECTLY INTERPRETING HISTORIC TIDAL RECORDS from tide gauges at New Zealand's ports takes on particular importance when determining long-term changes in mean sea level (MSL). Datum changes that can occur when gauges are renewed, replaced or reset cause particular problems. Such is the case with early sea level measurements in the Wellington harbour basin.

The first automatic tide gauge (TG) in Wellington was installed on Jervois Quay in 1887 (Adams, 1909). While it seems to have operated satisfactorily for a number of decades, in late 1944 it was replaced with a new gauge installed on the nearby Queens Wharf. The sea level data files archived by the former Department of Lands & Survey indicate that this new gauge began operation on 18th November 1944. It was Lands & Survey that had the responsibility for establishing regional/local mean sea level (MSL) height datums, both for mapping purposes and for infrastructural development (e.g., Jenks, 2006).

In the case of the Wellington MSL datum, correspondence files not only mention the installation of the new 1944 gauge, but also note an apparent, but unmeasured step change in Mean Tide Level (MTL)[1] of about 0.2 feet[2] concurrent with its installation. This indicates the possibility of a datum discontinuity or a datum offset when the gauge was installed. While not considered to be a vital matter at the time, the issue has gathered importance over the last few decades due to its influence on determining long-term sea-level change. Unfortunately, there is no record of the procedures followed when the new (1944) gauge was installed, nor any written comment as to how datum continuity might have been maintained and/or to what accuracy. All such records have been lost. The only data available are the measurements from the former TG on Jervois Quay (recorded as either annual MTLs or MSLs) and from the new TG at Queen's Wharf (recorded as hourly MSLs from 18 November 1944).

Due to this uncertainty, all the sea level trend analyses undertaken to date using the historical Wellington sea level data (e.g., Hannah, 1990), have included two datum offset parameters in the multi-variate least-squares solution for long-term trends, one for the period 1891-1944, and the other from 1945 – present day. The data from the old gauge on Jervois Quay have been assumed to be on a different datum from those collected after the 1944 Queens Wharf TG installation. Both datum parameters have been treated as unknowns and determined as part of the analysis. Because the annual MSL data file itself is discontinuous due to this datum offset, interpretation problems have been created for those unfamiliar with the issue and the analysis methodology.[3]

In this paper, various estimates for this datum offset are derived and a final value selected. It is intended that this value be applied to all pre-1944 data so as to move the entire MSL time series in Wellington to a single, continuous datum. This is little different to what has already been done to other annual MSL data sets (e.g. Auckland and Lyttelton) to compensate for their well documented datum changes.

Estimating the Datum Offset

Due to the lack of written documentation and the different data records available before and after the 1944 TG installation, some methods of determining a datum offset fail. Some analysis packages such as HECTOR (Bos et al., 2013) require homogeneous data throughout the time series while others simplify the process by using hourly tide data before and after the supposed datum discontinuity. Neither approach is applicable here. Furthermore, the situation is made even more complex due to the fact that Wellington not only has the usual inter-annual climate variability in sea-level records, but it is also a seismically and tectonically active region.

Taking these factors into account, three different approaches to the problem have been used. Because of the neglect of the unknown correlations between consecutive years of MSL or MTL data, the derived standard deviations will be indicative of the relative strength of each solution rather than an indication of their absolute value.

Approach 1. Using a Full Least Squares Analysis with an Abbreviated MSL Data Set.

The model used for this analysis is as documented in Hannah (1990). In the model a total of 9 parameters are used, two datum parameters (one for the period 1944-1981, and the other for the period 1945-1990), a sea level trend, the inter-annual anomalous response of MSL to annual mean barometric pressure and temperature changes, plus two parameters for the 8.6-year lunar tide and a further two parameters for the 18.6-year lunar tide.

The data set selected extended from 1891-1990. The aim here was twofold. Firstly, to have approximately equal years of data on the same datum (i.e., the number of years of pre-1944 data to be very close to the number of years of post-1944 data). Secondly, to avoid possible data complexities caused by slow slip inter-seismic events that are known to have occurred from 1997 onwards (Denys et al., 2020).

The two datum parameters determined from the least-squares analysis (with standard deviations in brackets) for the two epochs are as follows:

1891 – 1944	0.541 (0.010) m
1945 – 1990	0.576 (0.020) m

Datum Change = 0.035 (0.022) m.

While this method of analysis gives both the flexibility to weight any given year of MSL data according to its quality, plus the ability to model many of the systematic effects found in these types of datasets, it has a number of weaknesses. Firstly, it assumes that there has been a single linear MSL trend throughout the period covered by the data set. It further assumes that there have either been: i) no significant non-linear effects (due, for example, to unknown tectonic motion); and ii) that the length of the data sets has allowed them to effectively bridge the inter-annual climate variability that arises mainly from the dominant 2–4 year El Niño Southern Oscillation (ENSO) and the smaller 20-30 year Inter-decadal Pacific Oscillation (IPO) influences on annual MSL (Hannah & Bell, 2012).

Approach 2. Use of the Two Lunar Nodal Tide Cycles both Before and After Nov. 1944.

In this approach MSL is calculated for the full 19-year lunar nodal-tide cycle prior to November 1944 and the full lunar cycle after November 1944. In the absence of any bias created by short-term climate-cycle variability, the difference between the two numbers, once adjusted for any assumed linear rise in MSL, should reflect the datum change. However, there is likely to be some bias from the IPO which has a 20–30 year periodicity. A previous analysis of the climate-cycle variability in annual MSL time series of the 4 main ports in New Zealand was undertaken by Hannah & Bell (2012). Here a reconstructed sea-level principal component (or Empirical Orthogonal Function EOF) was extracted from the de-trended data. Their Figure 4 indicates that the annual MSLs, arising from climate-cycles such as ENSO and the IPO, appear to be higher in the 19 years after 1944.Taking a mean of this EOF (Mode 1) over the two 19-year periods (1926-1944 and 1945-1963) for Wellington, results in a slightly higher bias in MSL in the latter period by 0.02 m over the former period. The following were calculated:

MSL $_{(1926\text{-}1944)}$ = 0.594 (0.008) m with a mid-point of 1934 (EOF-1 = –0.019 m)

MSL $_{(1945\text{-}1963)}$ = 0.671 (0.007) m with a mid-point of 1953 (EOF-1 = +0.0012 m)

Difference = 0.077 (0.011) m, EOF-1 difference = 0.02 m.

However, the simple linear MSL trend from 1891–1945 = 0.7 (± 0.42) mm/yr or, 13 (± 8.0) mm over a 19-year tidal cycle.

Datum Change = 0.077 m – 0.02 m (ΔEOF-1) – 0.013 m = 0.044 (0.014) m.

While this approach depends upon an assumed constant linear sea level trend over the period of the analysis, the relatively short time (19 years) renders it relatively weakly dependent upon the accuracy of that number. For example, an error of 0.5 mm/yr in the linear trend would equate to an error of 9.5 mm in the derived datum offset. This approach, however, eliminates many of the disadvantages of the first approach.

Approach 3. Comparison with MSLs at Lyttelton and Auckland

In this approach a direct comparison is undertaken between the 1944 and 1945 MSLs at Wellington with those at Auckland and Lyttelton. While simple, this approach not only depends upon consistency of bias between the MSLs as recorded at the three tide gauges, but it also relies heavily upon the accuracy of the specific annual MSLs used.

The calculated values are as follows:

	MSL Wellington	MSL Auckland	MSL Lyttelton
1944	0.595 (0.04) m	1.890 (0.025) m	0.969 (0.025) m
1945	0.640 (0.03) m	1.901 (0.025) m	0.978 (0.025) m
Diffence	+ 0.045 (0.05) m	+0.011 (0.035) m	+0.009(0.035) m

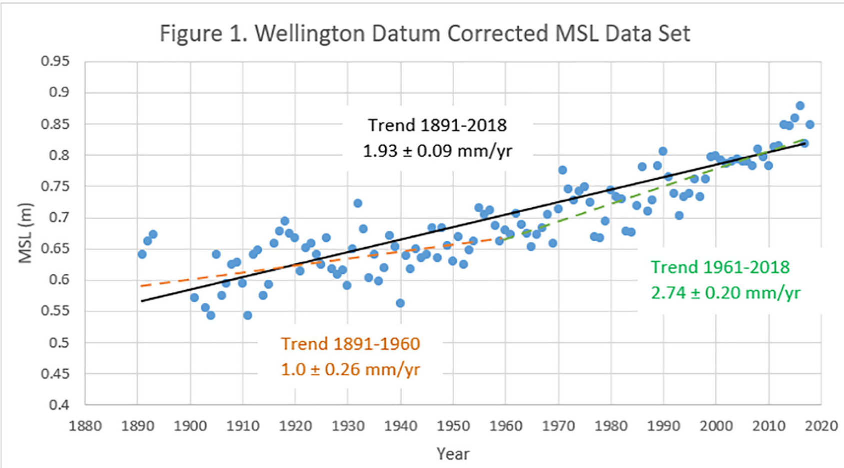
Datum Change = 0.045 m – 0.010 m (mean for other 2 ports)
= 0.035 (0.053) m

To gain at least some idea of the accuracy of the process, the data histories at all three ports were examined and a sample of eleven years of consecutive annual MSL data were extracted. The data had to be for the same years, as close as possible in time to 1944, and had to be of high quality i.e., had to have standard deviations for the annual mean of 0.03 m or better. The period 1959-1970 was selected and the above calculations performed at each port for each consecutive data pair. The average difference between Wellington and Auckland proved to be 0.003 m whilst the average difference between Wellington and Lyttelton was -0.007 m. On two out of 20 occasions, outliers of 0.040 m and 0.042 m occurred. It needs to be understood that this method, while indicative, certainly lacks the statistical strength of the other two.

Discussion

While each of the three approaches have their strengths and weaknesses, they are all consistent in their conclusion, namely that a significant datum offset occurred when the TG was moved to Queens Wharf in November 1944. Depending upon the approach adopted, this movement is calculated as being between 0.035 m and 0.044 m. A simple rounded number of 0.04 m has been adopted. This is consistent with a setting and reading accuracy of the new 1944 gauge of ± 0.01 m as noted on the old Department of Lands & Survey files. In order to derive a single data set referenced to the same TG zero, 0.04 m has been added to all the annual MSL values prior to and including 1944.

With this parameter now given a fixed value (rather than being estimated each time a new trend analysis is undertaken), new MSL trends at Wellington trends have been calculated using the same model as described under Approach 1 and for the same time periods used in Hannah (2019). The trend using the full MSL data set (1891-2018) now becomes 1.93 (± 0.09) mm/yr whilst the trend from 1891-1960 becomes 1.00 (± 0.26) mm/yr. The trend from 1961-2018 is unaffected, remaining at 2.74 (± 0.20) mm/yr. The new Wellington MSL data set, known as the Datum Corrected data set, together with the above trend lines is shown in Figure 1.



Notes

[1] Note: Mean Tide Level (MTL) is a simple average of high and low tides, and would have included weather influences such as storm surge and set-down during anticyclones.

[2] Equivalent to ~0.06 m.

[3] Including annual MSL data on MfE/StatsNZ web site: https://www.stats.govt.nz/indicators/coastal-sea-level-rise.

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