# Notes about the Wellington Annual Mean Sea Level Data

Last updated 21 November 2022

The Wellington data, up to 1990, has been obtained from a number of sources, all of which are outlined in Hannah (1988) and Hannah (1990), and summarised in the general Mean Sea Level (MSL) dataset history annexed to these notes. Since those papers were written, the following data changes have occurred..

1. Data since 1988 has been added.

2. Mean Tide Levels (MTLs) for 1891 – 1893 were found in the Wellington Regional Council archives and added into the data set of annual means. Because these are very weak data points they have been given standard deviations of 0.05 m. The MTLs following 1901 are considered to have been derived from better raw data and have thus been allocated standard deviations of 0.04 m.

3. The original data has been completely reprocessed using the Sea Level Data Processing software from the University of Hawaii. Details about this package can be found in Caldwell (1998). During this reprocessing, a few obvious digitising errors in the original data were corrected. Any errors in the data that related to timing (generally the gauge clock being one hour in error) were typically left unchanged on the premise that they would have a negligible effect on monthly and annual MSL averages.

4. A new gauge was installed in Wellington in 1944, beginning operation in November of that year. For years there had been concern as to whether or not continuity of datum was retained at that time. Correspondence on Lands & Survey files note a sudden apparent change in MSL between 1944 and 1945 of about 0.2 feet. This issue was finally resolved by Hannah and Bell (2020) who, after a forensic analysis of the data, determined that a datum change of 0.04 m occurred at that time. As a result, all the MSL data prior to and including 1944 has had 0.040 m added so as to eliminate this datum shift.

5. File notes from the Department of Lands & Survey (Lands & Survey) indicate that the gauge zero was shifted by 1.0 feet on 1 May 1973. This shift is clearly evidenced in the raw data. All data prior to that date has been corrected such that it refers to the post-1973 datum, being 3.565 metres below B.M. K80/2 (LINZ code ABPC).

6. Digital recording of data commenced in 1998.

7. Leveling by the Institute of Geological and Nuclear Sciences (Beavan, 2002), when combined with a re-analysis of earlier leveling supports the view that the gauge structure has been subsiding at a rate of 0.2 mm/yr from 1945 until 2001 (inclusive). The annual MSL data from 1946 until the end of 2001 have been corrected for this effect.

8. The annual MSL values for the years prior to 2001 have been corrected by the nett effect of the 1973 datum shift and the subsidence described in the previous paragraph (applied retrospectively) so that all annual MSL values refer to the datum that was adopted in 1973, being 3.565 metres below B.M. K80/2 (LINZ code ABPC). Note that the offset for 1973 (+0.128) is (i) less than the 0.305 m datum change as this was implemented part-way through the year and (ii) includes the subsidence for that year.

9. Daily continuous GPS (cGPS) solutions since 2000 indicate a regional tectonic subsidence of about 1.8 mm/yr, presumed to have started at the time of a slow slip event in 1998. The most recent analysis of cGPS data indicates a very complex pattern of vertical deformation in the Wellington region.

10. The daily raw data (as recorded by the tide gauge) has been corrected for the regional tectonic movement caused by the 2016 Kaikōura earthquake. From 00:00 hours on 14 November 2016, 27 mm has been deducted from the recorded data with +41 mm being added in November 2018. The cumulative effect results in a present day +14 mm addition to the data. The daily data files are thus corrected for this datum inconsistency, as are the monthly and annual means.

11. All investigations have indicated that the Wellington tide gauges have been well maintained throughout their history. With the exception of the datum issue that occurred in 1944, the data is of high quality and there have been few data outages.

12. Each annual MSL value has been assigned a standard deviation as described in the accompanying notes regarding current international data standards.

13. Corrections applied to original data (refer also to the following diagram):

1891 – 1950	+0.316 metres
1951 – 1955	+0.315
1956 – 1960	+0.314
1961 – 1965	+0.313
1966 – 1970	+0.312
1971 – 1972	+0.311
1973	+0.128
1974 – 1975	+0.006
1976 – 1980	+0.005
1981 – 1985	+0.004
1986 – 1990	+0.003
1991 – 1995	+0.002
1996 – 2000	+0.001
2001 –	0.000
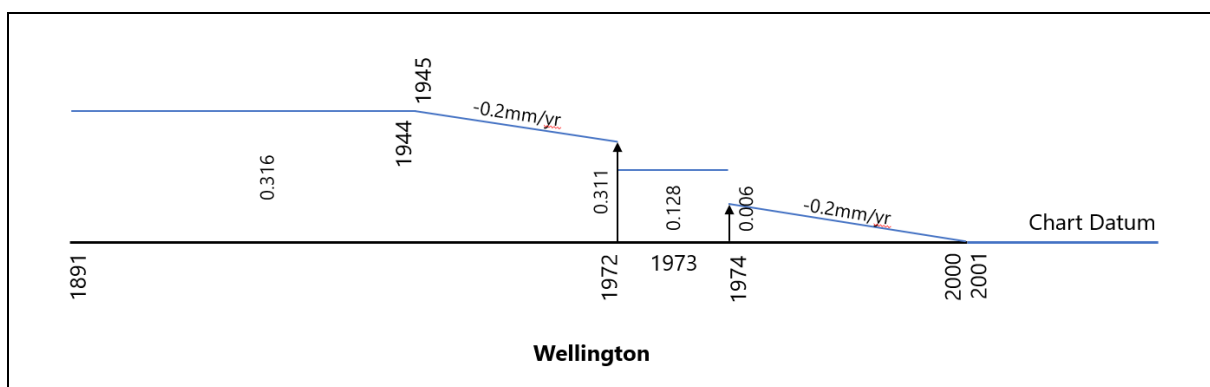
Offsets (decimal values in metres) between gauge zero (blue lines) and chart datum as defined since 1973

References

Beavan, R.J., (2001). Long-term Stability of Wellington tide gauge, 1911 – 2001, incorporating May 2001 leveling survey to Wellington fundamental BM K80. IGNS Report 2001/9.

Caldwell, P., (1998). Sea level data processing on IBM-PC compatible computers, Version 3.0. JMAR Contribution No. 98-319, University of Hawaii at Monoa, School of Ocean and Earth Science Technology, Honolulu, Hawaii. (2014: Updated to v4.0 – SLP64, available from http://ilikai.soest.hawaii.edu/UHSLC/jasl/slp64/slp64.html).

Hannah, J., (1988). Analysis of Mean Sea Level Trends in New Zealand from Historical Tidal Data. Report No. 2, Department of Survey and Land Information, Wellington.

Hannah, J., (1990).   The Analysis of Mean Sea Level Data from New Zealand for the Period 1899-1988, The Journal of Geophysical Research, 95, No. 88.

Hannah, J., Bell R.G., (2020). Forensic analysis of the 1944 datum shift at the Wellington tide gauge. NZ Surveyor No. 306.

History and Composition of the New Zealand MSL Dataset

J. Hannah, April 2022

These notes detail the history of the New Zealand Mean Sea Level (MSL) dataset.

Historically, and within New Zealand, tide gauges (TGs) were owned and maintained by the local harbour boards associated with the major cities (Auckland, Wellington, Lyttelton and Dunedin). While many of the earlier TGs at these locations were temporary, more permanent installations began to be established about 1900. The harbour boards collected and stored the resulting hard-copy tidal records.

In 1908, the then Surveyor General of the Department of Lands & Survey (Lands & Survey), Mr Theo Humphries, observed that New Zealand was a tectonically active country and that good TG documentation and maintenance was necessary. He therefore requested that the existing gauges be documented and that they have their zero points linked to permanent reference marks in secure positions on the adjacent shoreline (Lands & Survey, 1908).

Some years later, (in the 1920s and 1930s), New Zealand began to establish a nation-wide geodetic control datum (Lee, 1978). Height control was to be based upon MSL datums established via the operational TGs located at important locations around the country. To assist with this process, the hardcopy records from the early gauges at Auckland, Wellington, Lyttelton and Dunedin were obtained and their hourly sea levels hand-measured. This was done for a number of years of data (typically 6 – 10). These were then used to form annual MSLs that in turn were combined to form individual MSL height datums. These datums were eventually linked via precise levelling undertaken by Lands & Survey and then, subsequently, by the Department of Survey & Land Information (DoSLI).

By the mid-1980s, the prospect of human induced climate change had become a topic of interest in the scientific literature. It was expected that any such climate change might have its fingerprints seen in rising sea levels. As a consequence, a decision was made to have all the existing old hard copy tide gauge records from Auckland, Wellington, Lyttelton and Dunedin hand digitised (hourly point values) and analysed to identify any long-term sea level trends that might exist. At this time a preliminary investigation was undertaken for each of these TGs in an attempt to identify any long-term datum problems that might exist. Clearly, it was important to try to ensure that the MSL records all related to the same TG zero-mark and that this zero-mark, in turn, had been stable with respect to shoreline reference marks. This work was undertaken by DoSLI personnel and is fully described in Hannah (1988) and Hannah (1990).

It is important to reinforce some of the issues documented in Hannah (1990). Firstly, some hard copy tide charts were not available for digitisation. They had been lost over time. In such cases it was sometimes possible to use the corresponding annual MSLs that had been derived when establishing the MSL datums used for various levelling datums. This information, when available, was recorded in archived Lands & Survey correspondence files. Secondly, none of the pre-1944 Wellington tide charts could not be found and thus MSLs had to be derived either from recorded MSLs or from recorded Mean Tide Levels. Table 1, updated from Hannah (1990), outlines the extent of these issues.

Table 1 (Reproduced and Updated from Hannah, 1990)

Data Source	Auckland Gauge	Wellington Gauge	Lyttelton Gauge	Dunedin Gauge
Digitised tide charts (hourly point values)	1904-1988	1945-1988	1903,1904,1906, 1913, 1924-1988	1899-1903, 1905-1915 1918,1919,1921, 1923-1925, 1936, 1938-1942,1944-1952, 1954-1980, 1983-1988
Archived data (annual MSLs only)		1901,1909,1915, 1919, 1921-1924, 1927,1930,1933, 1936,1937,1939,1942	1901,1907,1908, 1914,1918,1919, 1923	1926, 1927,1929, 1932,1935,1937
Derived data (from Mean Tide Levels)	1899-1901	1891-1893,1903-1908,1910-1914, 1916-1918,1920, 1925,1926,1928, 1929,1931,1932, 1934,1935,1938, 1940,1941,1943,1944		

In 2000 the University of Hawaii tidal analysis software (Caldwell, 1998) was used to undertake a far more rigorous assessment of the raw digital data. The data sets were corrected (where necessary) and reformed into both daily and monthly means. Any month where at least half the data existed was used to help form the requisite annual MSL.

Contemporaneously with this work, a complete review of all the old Lands & Survey correspondence files was undertaken to confirm all the datum changes that had been introduced to the various port tide gauges over their many decades of operation. This work is described in Hannah (2004). The only port where a continuous record could not be obtained was at Wellington where it appeared that a small (but undocumented) datum change had occurred with the installation of a new TG in 1944.

It was also about 2000 that the School of Surveying at the University of Otago, in conjunction with Institute of Geological and Nuclear Sciences (IGNS) began a research programme in which GPS receivers were co-located with the tide gauges at the four main ports (Auckland, Wellington, Lyttelton, and Dunedin). This enabled the real-time monitoring of any physical motion that might be occurring to the tide gauges - whether from tectonic or other sources. These GPS receivers have proven invaluable in enabling the MSL recorded to be corrected for subsequent tectonic and seismic changes e.g., those associated with the Canterbury (2010 and 2011) and Kaikoura (2016) earthquake sequences.

In 2008, the University of Otago, again in conjunction with GNS Science (formerly IGNS), undertook a programme to digitise the hard copy tide gauge records from New Plymouth (Port Taranaki). This data, whilst in the public domain, is problematic due to non-recorded datum shifts that have clearly affected some of the old tide charts used in the 1960s and 1970s. A reasonable body of work still needs to be done to identify these datum errors and bring this MSL record up to international standards.

In recent years, other historical data has also become available. For example, the National Institute of Water and Atmospheric Research (NIWA) has collected hourly digital data since 1971 for a TG at Moturiki, near Tauranga.

In 2019 a project was undertaken to determine and remove the datum inconsistency that had long been part of the Wellington tide gauge record (Hannah and Bell, 2020). Wellington now joins the other ports (New Plymouth excepted) in having a single continuous datum to which all historical tide gauge data refers.

Current International Data Standards

The current international standards for data sets associated with climate change/sea level studies are not fully consistent – particularly in their completeness of data criteria. The WMO standard for surface meteorological observations (WMO, 2017) assume that daily mean values for sea level pressure are calculated from either eight evenly spaced 3-hourly observations or six evenly spaced 4-hourly observation. It is accepted that the calculation of daily mean temperatures may differ, dependent upon country. However, they do recommend that where a monthly value is the mean of that month's daily values, it should not be calculated if either of the following criteria are satisfied:

- observations are missing for 11 or more days during the month;
- observations are missing for a period of 5 or more consecutive days during the month.

Standards governing sea level data are different. Daily MSLs are calculated from hourly means by passing them through a filter such as the 39-hour Doodson filter, a 71-hour Demerliac filter, or some other appropriate filter. This filter removes the tidal energy at diurnal and higher frequencies (UNESCO/IOC, 2020). The resulting data are then quality assured against a predicted tide.

A simple arithmetic monthly mean is calculated from the daily means. The Permanent Service for Mean Sea Level (PSMSL) recommends discarding the month if over 15 days are missing. Some software, however, such as the University of Hawaii software (Caldwell, 1998), will calculate a monthly mean automatically only if seven or fewer days of data are missing. The PSMSL calculates annual means as a weighted mean of the monthly values, with each month weighted by the number of days present. If over one month is missing, the annual mean is not calculated.

Much of the early work on the New Zealand data sets was undertaken prior to the development of the above international data standards. Fortuitously, the processes used largely meet the PSMSL standard. The fact that the hourly data has been filtered using the University of Hawaii software generally results in a monthly mean being calculated when only seven or fewer daily means are missing.

The one major point of difference in the existing datasets with respect to the PSMSL standards, relates to the annual MSLs. Wherever at least one month of data is available a MSL is recorded. However, it has been assigned a standard deviation derived as follows:

a) Where the data record is based upon very reliable and well-maintained tide gauges with few outages, the associated standard deviation is calculated from the equation:

$$\sigma_{MSL} = \frac{0.09 \ m}{\sqrt{n}} \qquad \text{where n = number of months of data.}$$

In other words, an annual mean with one month of good, consistent data will have a standard deviation of 0.09 metres, whilst an annual mean with 12 months of data will have a standard deviation of 0.025 m. The standard deviations have all been rounded down to the nearest 0.005 m. This weighting system was determined by a posteriori variance analysis and is documented in Hannah (2004).

b) Where the tide gauge has a poor maintenance history or over periods when the data record seems less reliable, the 0.09 m in the above equation is replaced by 0.11 m.   Conversely, when the digitised record has shown good consistency, even if the overall gauge maintenance has not been good, the 0.011 m has been replaced by 0.09 m.

c) Due to its derivation process, a MSL derived from a Mean Tide Level is considered even less reliable again.

This weighting procedure was chosen so that all the annual MSL data could be used in a weighted least squares estimation process from which the linear sea level trends could be calculated. Standard deviations for each annual MSL are shown in the data files.

References

Caldwell, P., (1998). Sea level data processing on IBM-PC compatible computers, Version 3.0. JMAR Contribution No. 98-319, University of Hawaii at Monoa, School of Ocean and Earth Science Technology, Honolulu, Hawaii. (2014: Updated to v4.0 – SLP64, available from http://ilikai.soest.hawaii.edu/UHSLC/jasl/slp64/slp64.html).

Hannah, J., (1988). Analysis of Mean Sea Level Trends in New Zealand from Historical Tidal Data. Report No. 2, Department of Survey and Land Information, Wellington.

Hannah, J., (1990).   The Analysis of Mean Sea Level Data from New Zealand for the Period 1899-1988, The Journal of Geophysical Research, 95, No. 88.

Hannah, J., (2004). An Updated Analysis of Long-Term Sea Level Change in New Zealand. Geophysical Research Letters, 31, L03307, 4 pp.

Hannah, J., and Bell, R.G., (2020). Forensic analysis of the 1944 datum shift at the Wellington tide gauge. NZ Surveyor, No. 306.

Lee, L.P., (1978). First-order geodetic triangulation of New Zealand 1909-49 and 1973-74, Technical Series No. 1, Department of Lands and Survey, Wellington.

Lands & Survey, (1908). Unpublished correspondence, archived Dept. of Lands & Survey correspondence files.

UNESCO/IOC, (2020). Quality Control of in-situ Sea Level Observations: A Review and Progress towards Automated Quality Control, Vol. 1. Paris. UNESCO. IOC Manuals and Guides No. 83. (IOC/2020/MG/83 Vol. 1).

WMO, (2017). WMO Guidelines for the Calculation of Climate Normals. WMO-No. 1203, available from https://library.wmo.int/doc_num.php?explnum_id=4166.