Notes about the Lyttelton Annual Mean Sea Level Data

Last updated 16 November 2022

Lyttelton 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. 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 Mean Sea Level (MSL) averages.

3. In general terms, the gauge record is not particularly good. The data is rough and has many gaps. This was particularly true for the pre-1958 data. In the late 1980s a new, but largely untested Elwood tide gauge was installed. The data for the next few years (particularly in early 1990 and again from 1992-1994) were very poor and required considerable work to eliminate the obvious problems. This data was captured and supplied sometimes as monthly but also, on occasion, as annual MSLs by the Lyttelton Port Company. Digital recording began in 1995. From this time on the data, although quite noisy when viewed at 5 minute point data, give good annual MSL means.

4. A complete review of the gauge history was undertaken in 2008. This revealed the following:
   - (i) The tide pole was moved in 1934 with care being taken to ensure that continuity of datum was maintained. However, leveling in 1970 showed the tide pole as being 0.04 ft (0.012m) lower than in 1940. In the absence of information as to when this change occurred, the period has been equally divided with a correction being applied to the MSL data at 1956.
   - (ii) The available evidence points to tide pole stability from 1970-1980. A new metric tide pole was installed in 1980. Leveling in 1981 showed this pole as being 0.04 ft lower than that accepted during the period 1956-1980. In 1987, the pole was returned to its pre-1981 position.
   - (iii) In 2001, the tide pole was moved and a new pole installed. At the same time the datum was lowered by 0.96 ft (0.293 m).
   - (iv) All data prior to 2001 has been corrected such that it refers to the post-2001 datum, being 4.478 metres below B.M. UD40 (LINZ code B40V).
   - (v) There is no evidence of subsidence on or around the wharf structures. The official Toitū Te Whenua Land Information (LINZ) records relating to the local benchmarks are not strictly correct in their height origins.

   The daily raw data (as recorded by the tide gauge) has been corrected, in stages, between 4 September 2010 and 4 September 2020 to account for the regional tectonic movement caused by the various Christchurch and Kaikōura earthquakes. In greater detail:
   - (i) From 4 September 2010 @ 04:35 to 31 December 2010 @ 23:59, +0.006 m applied.
   - (ii) From 14 March, 2011 @ 00:00 to 13 June 2011 @13:00, +0.060 m applied.

(iii) From 13 June, 2011 @13:00 to 23 December 2011 @ 13:58, +0.108 m applied.

(iv) From 23 December 2011 @ 13:58 to 7 December 2012 @ 23:59 + 0.111 m applied.

(v) On 8 December 2012, the accumulated uplift of 111 mm was applied directly by the port company to the recorded dataand the adjustment made by LINZ was discontinued.

(vi) The November 2016 Kaikōura earthquake produced another required adjustment of 30 mm. From 00:00 hours on 14 November 2016, 30 mm has been deducted by LINZ from the recorded data.

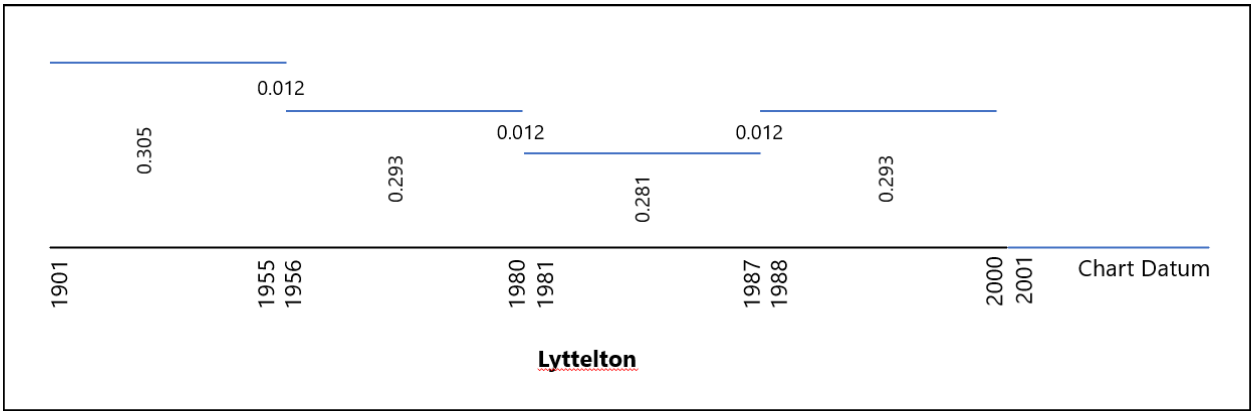
The daily data files during this 10-year period are thus already free of these datum inconsistencies, as are the monthly and annual means.

5. On 4 September 2020 the gauge at the tug berth was replaced by a new gauge located at No. 1 Breastwork. The zero of this new gauge being set to chart datum.

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

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

1901 – 1955	+0.305 metres
1956 – 1980	+0.293
1981 – 1987	+0.281
1988 – 2000	+0.293
2001 –	0.000



Offsets (decimal values in metres) between gauge zero (blue lines) and chart datum as defined since 2001

References

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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

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