NIWA
Taihoro Nukurangi

Tidal and flood influence on water level in Grey Lagoon

Environlink 965 - WCRC86

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Authors/Contributors:
David Plew

For any information regarding this report please contact:

David Plew
Scientist
Hydrodynamics
+64-3-343 7801
d.plew@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
10 Kyle Street
Riccarton
Christchurch 8011
PO Box 8602, Riccarton
Christchurch 8440
New Zealand

Phone +64-3-348 8987
Fax +64-3-348 5548

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Reviewed by

Graeme Smart

Approved for release by

Graham Fenwick

Executive summary

The West Coast Regional Council has asked if tide affects water level in the Grey River during floods. NIWA have analysed water level data recorded in the Grey Lagoon, and compared with flows recorded at the Dobson flow recorder site (10 km) upstream.

In the analysis, the effect of tide was removed from the water level data, and the water levels also adjusted to account for the effect of atmospheric pressure on sea levels. The pressure-adjusted and de-tided water levels were compared with river flow to establish the relationship between flow and change in water depth. This comparison was also made at different tidal water depths to determine the effect of river flow on water level at low, mid and high tides.

Am empirical, predictive model was derived that allows estimates of water depth in the Grey Lagoon during floods. The model is used to compare the likely water depths from a 4000 m^3/s flood at spring and neap high tides.

The analysis and model show that the tide does affect water levels during floods, but the tidal change in water level is considerably reduced during floods.

1 Background

West Coast Regional Council has asked NIWA for guidance on whether tide has an influence on river height during floods in the Grey River. This report describes an analysis of data from a water level recorder in the Grey Lagoon, comparing the influence of tides, flows in the Grey River (using data from a flow recorder at Dobson) and atmospheric pressure recorded at either Greymouth or Hokitika.

2 Data

The river flow recorder at Dobson is considered the most appropriate estimate of the river flow as it is close (10 km upstream), likely to record most of the flow reaching Greymouth, and there are few tributaries downstream. Flow data are recorded at 15 min intervals.

A water level recorder has been operating in the Grey Lagoon since 1 Jul 1993. However there are numerous gaps in the data, some of the data are recorded at 5 min intervals while others at 15 min intervals and the gauge may have been moved at some point. There also appear to be unexplained jumps in the mean sea level throughout the record. These offsets mean that it is not possible to analyse the entire dataset. An email from Stefan Beaumont (WCRC) to Kathy Walter (NIWA, 28 Oct 2011) suggests that water level data from the 1990's appear clipped (the instrument range was exceeded), and that it appears the gauge datum was different to more recent data. At some point post 2004, the staff gauge and bench mark were removed and a new point established. The current staff gauge may not be referenced to benchmarks.

Atmospheric pressure data are used to adjust for storm surge, and are taken from Greymouth Aero EWS station if available, otherwise from Hokitika AWS. Pressure data are recorded hourly.

A summary of the data used are given in Table 1.

Table 1 Data sources

Data	Site	Start Date	Frequency
Water level	91400 Grey at Lagoon	1 Jul 1993	5 min or 15 min
Flow	91401 Grey at Dobson	24 Jul 1968	15 min
Atmospheric Pressure	23934 Greymouth Aero EWS 3910 Hokitika AWS	27 Jan 2008 22 Oct 1986	Hourly

Due to the intermittent offsets in the water level data and because the focus of this study is flood flows, 3 time periods were selected which contain large flow events, and for which water level, flow and atmospheric pressure data are available. These time periods were

- 1 Nov – 31 Dec 1994
- 1 Jun – 11 Jul 2006
- 15 Dec 2010 – 16 Feb 2011

River flows for these time periods are plotted in **Figure 1**.The first period contains a number of high flow events in November 1994, including a flood of 4500 m^3/s on the 22 Nov 1994.

The second period has a large flood of 4700 m^3/s on 12 Jun 2006, and a second smaller peak flow of 1500 m^3/s on the 16 Jun 2006. The third time period is the most recent and includes the large flood events of 4200 m^3/s on 28 Dec 2010 and 4150 m^3/s on 19 Jan 2011, as well as a number of smaller flow peaks.

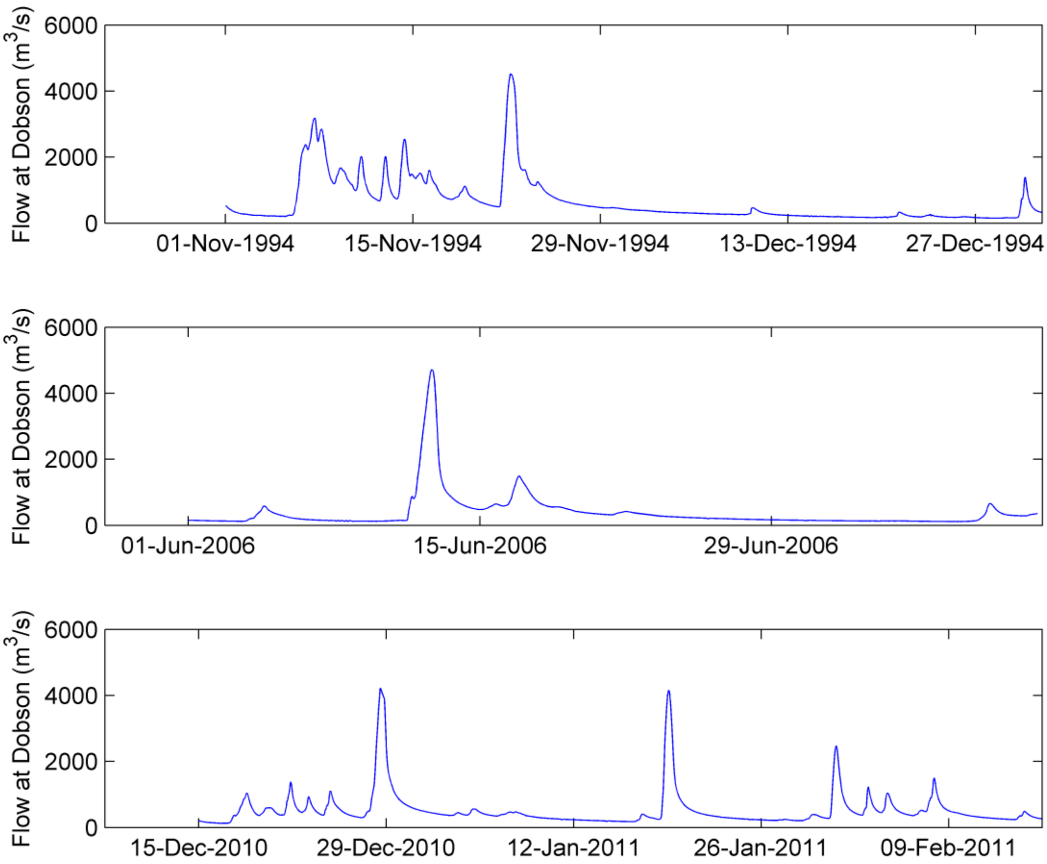

Figure 1 Flow data from Grey River at Dobson for the three time-periods analysed.

To conduct the analysis described in the flowing sections, the water level, flow and pressure data must be obtained at the same sample frequency. Water level data were resampled at 15 min intervals and hourly pressure data interpolated to 15 min intervals to be consistent with the flow data.

Data were also checked for gaps, and the water level data inspected for obvious off-scale measurements (for example the W.L recorder hit full scale on 28 Dec 2010). Bad data were removed.

3 Analysis and results

3.1 De-tiding

The water level at the Grey Lagoon is affected by tides. For each data period, the amplitude and phase of the tidal constituents were calculated using a least-squares fitting method described by Foreman (1977). Using these fitted tidal constituents, the tidal water elevation was predicted and subtracted from the measured water elevation (Figure 2(a)) to give a residual water level time-series (Figure 2(b)).

3.2 Storm surge/atmospheric pressure

Sea levels are also affected by large scale meteorological forcing. The sea level rises when atmospheric pressure is low, and drops when the pressure is high. Pressure and sea level data recorded at the sea-level monitoring station at Charleston were used to establish how sea-level changes with pressure near Greymouth. The Charleston sea-level data were de-tided then plotted against measured atmospheric pressure. The resulting regression indicates that a 1 hPa decrease in air pressure produces a 0.0093 m increase in sea level. The influence of atmospheric pressure on sea level is known as the Inverse Barometer effect (IB). Strong winds can also cause an increase or decrease in water level as they push water on-shore or offshore. Because strong winds are associated with pressure, and to simplify analysis, it is assumed here that the Inverse Barometer effect captures the majority of the storm-surge impact.

Using the correction obtained from Charleston and using atmospheric pressure measured at either Hokitika or Greymouth (depending on availability), the Inverse Barometer effect on water level at the Greymouth Lagoon could be estimated Figure 2(c). This pressure change in water level was then subtracted from the de-tided water level data.

Note floods and low pressures (or positive Inverse Barometer) often occur together – as indicated in Figure 2(c) and (d). However their effects have been separated for this analysis.

Because the pressure affects the sea level and pressure generally changes slowly, the response within the harbour is likely to be independent of the stage of the tide.

3.3 River flow

River flow data were first offset by 90 min to allow for the travel time between Dobson and the Grey Lagoon. The distance between these sites is approximately 10 km. The 90 min lag was estimated by comparing the time between peak flow at Dobson and peak de-tided water level at the lagoon. Note that the true travel time will depend on flow. However, for the purpose of this analysis a constant offset is considered adequate.

The river flow data were plotted against the de-tided and pressure-adjusted water levels. By fitting a regression to these data, an equation can be obtained that can be used to predict the effect of river flow on water level in the lagoon (Figure 3).

Three important factors can be identified in Figure 3. The first is that most of the data points are at low flows, with only a few points during floods. The second is that there is hysteresis in the relationship between water level and flow. It is commonly observed that for a given flow, water levels are higher on the receding flood than on the rising limb. Finally, there is scatter in the data, particularly at higher flows due to the flood hysteresis. The fitted regression curve gives a reasonably good prediction of water level, but there will be uncertainty if used for prediction.

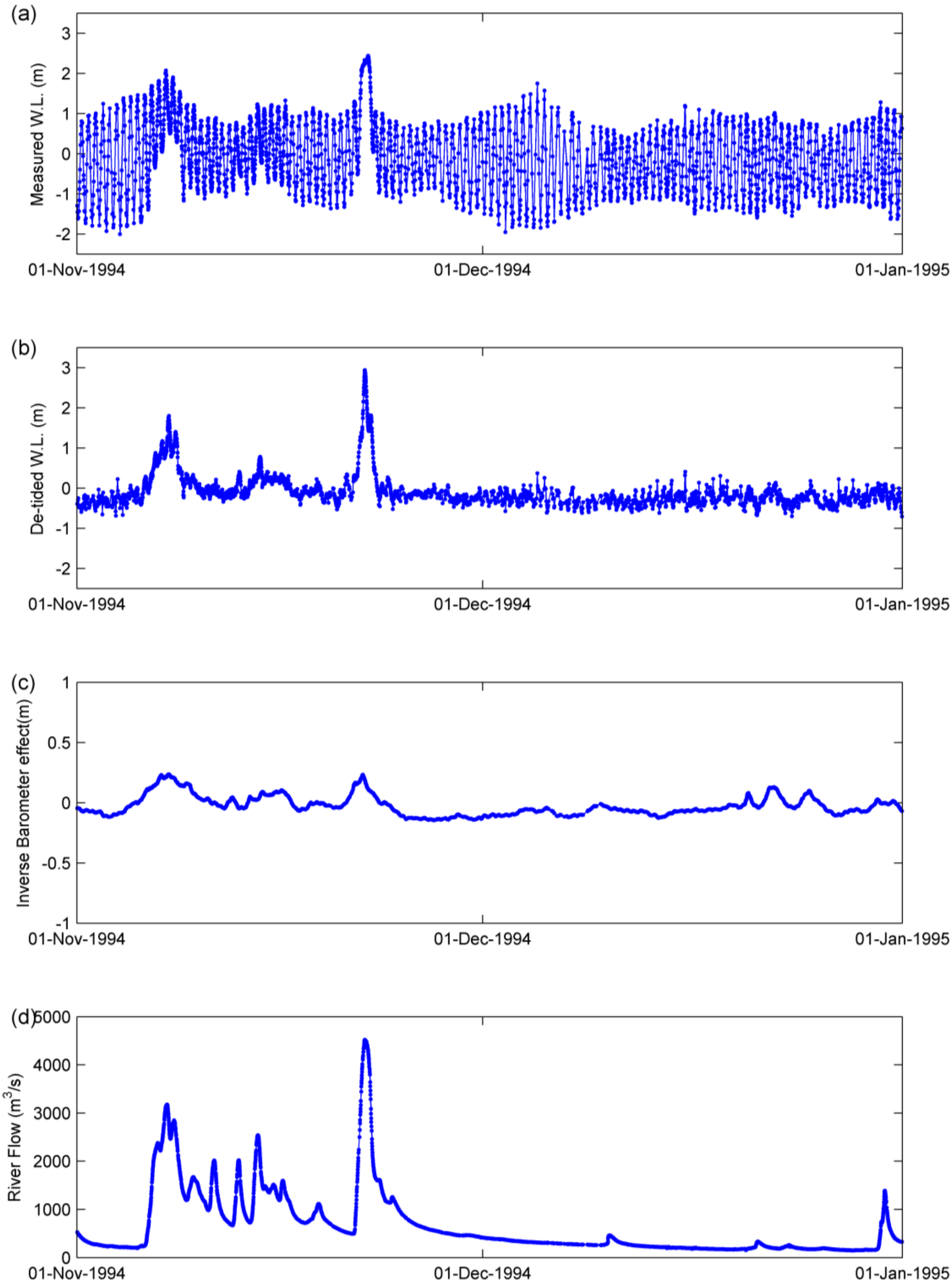

Figure 2 (a) Water level at Grey Lagoon, (b) de-tided water level, (c) predicted pressure effect on water level, (d) river flow recorded at Dobson.

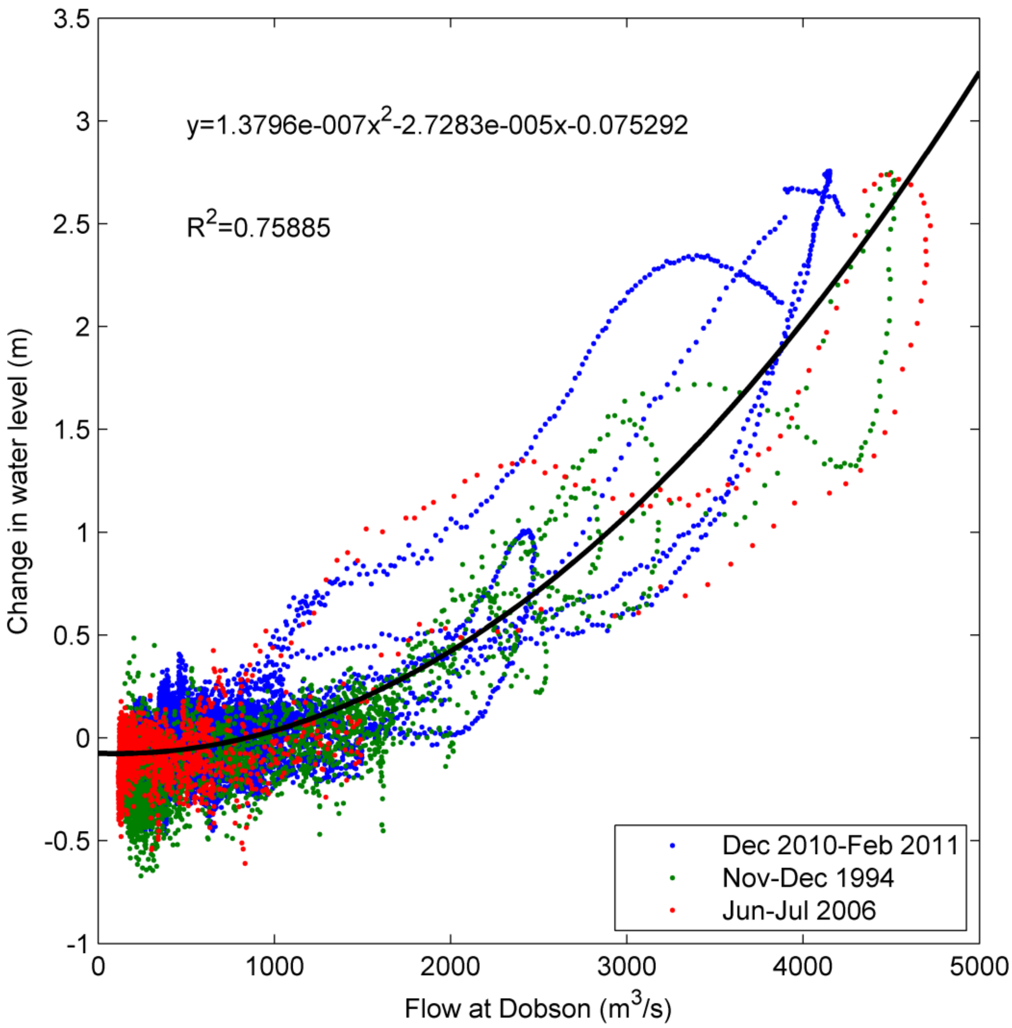

Figure 3 Change in water level at the Grey Lagoon site (after the effect of tide and atmospheric pressure are removed) with flow in the Grey River measured at the Dobson site. The different colours show data from different time periods. The black curve is a best-fit regression.

3.4 Influence of tide on change in water level from river flow

To determine whether there is a larger or smaller increase in water level during a flood at different stages of the tide (e.g. high tide versus mid tide), the tide and pressure-adjusted water levels were again plotted against flow, but the data were separated based on the tidal prediction of water level. The data were grouped in 0.5 m bands from -1.5 m to +1.5 m above mean sea level. For example, all data where the tidal water level would be between 0.5 and 1.0 m above mean sea level in the absence of river flow or pressure effects were used to derive a relationship between the river flow and the flow-induced change in water level at the lagoon. These regressions are shown in Figure 4. The fit to the data are reasonable although the lower right plot indicates that few instances of high flow occurred during high tides (water levels >1.0 m above mean sea level) and caution should be taken extrapolating the curve to higher flows.

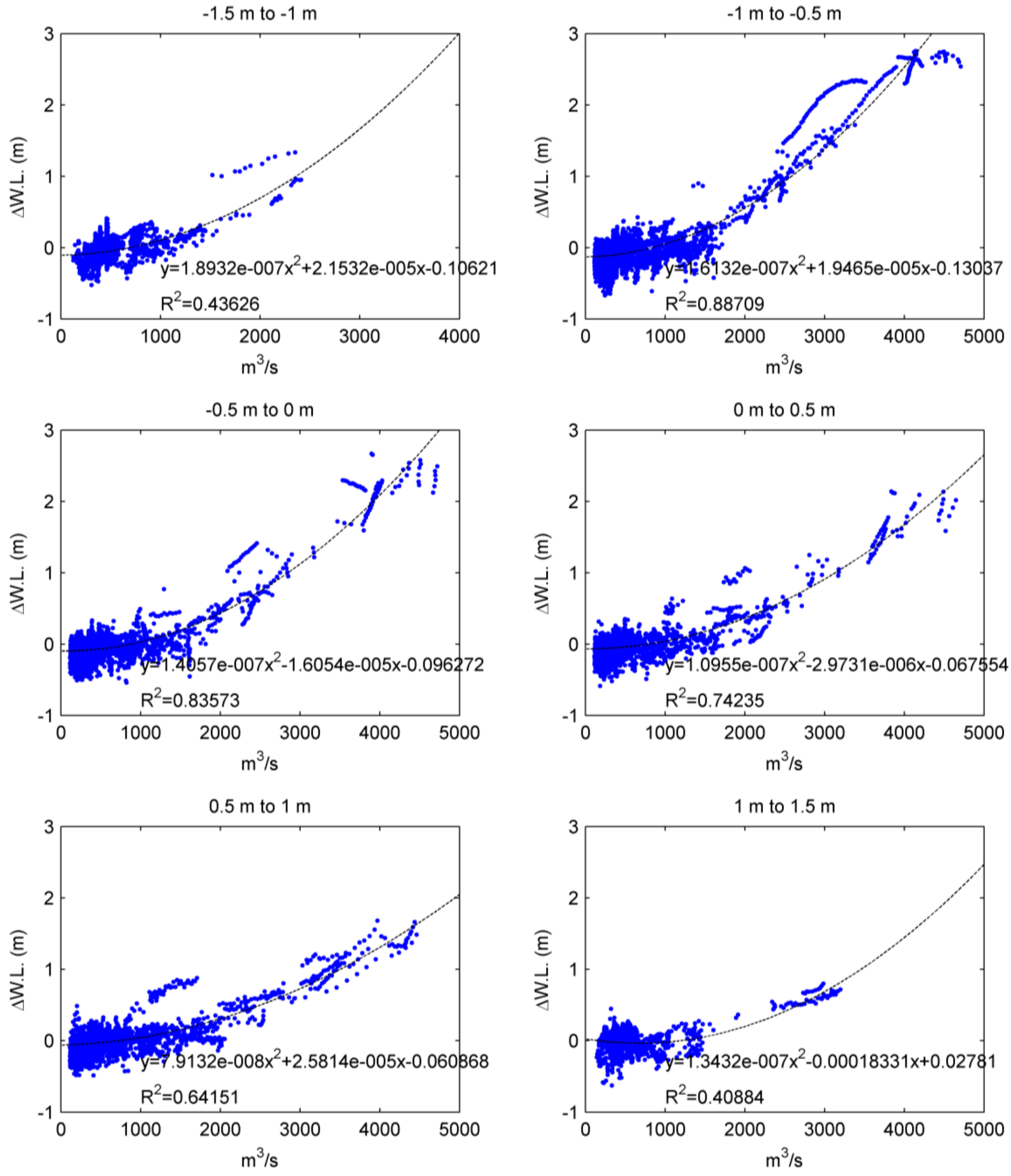

Figure 4 Effect of Grey River flows (measured at the Dobson site) on water level in the Grey Lagoon at different predicted tidal levels after removing the effect of tides and atmospheric pressure from the measured water level (ΔW.L. = change in water level from the predicted water level caused by tide and atmospheric pressure).

The regression curves are overlaid in Figure 5. This figure shows that the change in water level due to river flow decreases at high tide compared to mid or low tide: i.e., the higher the tide, the smaller the increase in water level that occurs during a flood. This is likely to be due to the shape of the river and lagoon cross-sections which widen with height. Higher water levels cover greater area, so the change in depth required to accommodate an increase in river flow is smaller.

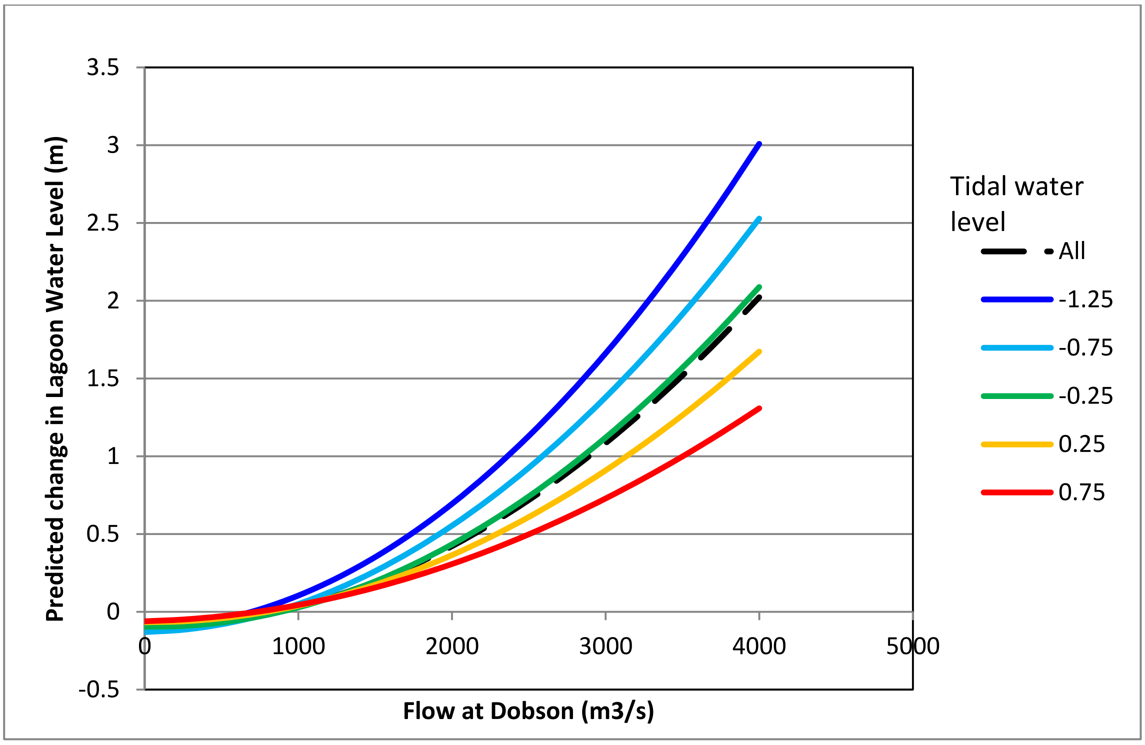

Figure 5 Predicted change in water level in lagoon due to river flow at different tidal water depths. The dashed black line shows the predicted water level change if tidal height is not included. The changes in water level shown in this graph should be added to the predicted tidal water depth and adjusted for atmospheric pressure.

An attempt to produce a prediction of the change in water depth during a flood at any stage of the tide has made by analysing how the coefficients of each regression between river flow and depth increase changes with the tidal water depth. The relationship between the terms and tidal water depth are approximately linear. Based on this observation, the following equation for the change in water depth in the lagoon during a flood is obtained:

$$\Delta z_Q = aQ^2 + bQ + c \tag{1}$$

where Δz_Q (m) is the change in water depth due to the flow, Q (m^3/s) is the river flow. The coefficients a, b and c are obtained from

$$a = \frac{2.248 - h}{18371600}, \quad b = \frac{3.194 - h}{360430}, \quad c = \frac{h - 2.755}{32.6} \tag{2}$$

where h is the predicted tidal water level above mean sea level.

4 Predictive model

Based on the analysis above, the following method can be used to estimate the water depth during a flood.

1. Obtain tidal prediction for water level (e.g. from LINZ) at desired time
2. Subtract mean sea level (M.S.L) to get h

3. Use equations (1) and (2) to estimate the change in water depth Δz_Q due to the flood flow Q (m^3/s)

4. Estimate the change in water depth due to atmospheric pressure using weather maps or measured data. The change can be estimated as Δz_P= -0.0093(P-1013.5) where P is the pressure in hPa.

5. Add $h + \Delta z_Q + \Delta z_P$ to get total change in water depth.

6. Add mean sea level (MSL) if desired to obtain depth relative to datum of tide prediction.

4.1 Example

In this example, the water level during a flood of 4000 m^3/s is compared at spring and neap high tides.

Mean sea level (MSL) at Greymouth is 2.0 m above datum. Mean High Tide Water Spring (MHWS) is 3.4 m, and Mean High Water Neap is 2.6 m above datum.

At MHWS, h =3.4-2.0 = 1.4 m. From equation (2), the coefficients are a = 4.6158×10^{-8}, b = 4.977×10^{-6}, and c =-0.042. Using equation (1), the water level increase due to the flood is 0.717 m.

At MHWN, h =2.6-2.0 = 0.6 m. From equation (2), the coefficients are a = 8.9704×10^{-8}, b = 7.197×10^{-6}, and c =-0.066 Using equation (1), the water level increase due to the flood is 1.398 m.

For illustrative purposes, assume that the atmospheric pressure during this flood is 995 hPa. The increase in water level due to atmospheric pressure will be -0.0093×(995-1013.5) = 0.175 m.

The total water depth at MHWS will be 1.4+0.717+0.175 = 2.292 m above MSL, or 4.292 m above datum.

At MHWN, the total water depth will be 0.6+1.398+0.175 = 2.173 m above MSL, or 4.173 m above datum.

Although the difference between MHWS and MHWN is 0.8 m, the difference in water level during a 4000 m^3/s flood is predicted to be only 0.12 m.

5 Summary and recommendations

The analysis of water level data from the Grey Lagoon show that water levels are influenced by tide, river flow, and atmospheric pressure. Water level increases during high flows and floods. During floods, the tidal response appears reduced, although is still present. For example, the empirical model presented here suggests that during a flood of 4000 m^3/s, the water depth during a spring high tide would be about 0.12 m higher than if the flood occurred at neap high tide, even though the difference between spring and neap high tide is 0.8 m.

The model presented here is purely empirical, based on a limited selection of data from the Grey Lagoon water level recorder and the flow gauge at Dobson. No validation has been made of the model against data from other time periods. The model also does not account for how the water level response would change if flood banks were over-topped.

Recommendations:

- The water level recorder at the Grey Lagoon should be referenced to a standard benchmark (and checked periodically) to ensure future data are reliable.
- Estimates of the uncertainty in the predictions of the empirical model could be made by analysing more of the available data.
- River inflow from below the Dobson gauging site was not considered. WCRC also asked about the timing of gate closure in the Cobden arm. This was not considered in this study. This could be investigated as part of a future envirolink project.
- More accurate predictions of water level during floods could be obtained using numerical modelling. NIWA have expertise in modelling both river floods and storm surge. Numerical modelling is a more expensive option.

6 References

Foreman, M.G.G. (1977). Manual for tidal heights analysis and prediction. *Pacific Marine Science Report 77-10*