



Tahunanui Slump

Monitoring report November 2022 - April 2024

Prepared for

Nelson City Council

Prepared by

Tonkin & Taylor Ltd

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Client summary

As part of an ongoing Nelson City Council (NCC) project to better understand and manage risks associated with deep-seated instability of the Tahunanui Slump (TS) telemetered and manually measured data from ground movement and groundwater monitoring points installed by the Earthquake Commission¹ (EQC) within the deep-seated Tahunanui Slump (TS) and now monitored by Nelson City Council (NCC) have been assessed. This report presents data and findings for the period immediately following the August 2022 Nelson storm event until 19 April 2024.

The depth of deep-seated displacement of the TS has been recorded at four different locations (BH1A, BH06, BH09, and BH11). The greatest depth is in BH1A, where inclinometer readings prior to 2022 recorded displacement at 24.5 m below ground level (bgl). This inclinometer was sheared off in the August 2022 rainfall event.

A ShapeAccelArray (SAA) ground movement instrument installed after the August 2022 storm event in BH06, located in the Grenville Terrace (east of No 10 Grenville), has recorded 10 distinct movement episodes since its installation in December 2022. Downslope surface displacements as small as 0.1 mm and up to 3.7 mm are inferred during these events based on data from the SAA.

Surface movement data from the SAA in BH06 and other inclinometer readings have been compared with groundwater level data from eleven piezometers installed in six monitoring wells, and rainfall data at Princes Drive weather station to assess potential relationships between ground movement, groundwater level, and rainfall.

The data to date indicates that displacements measured in the SAA show a correlation with groundwater levels in BH03 (shallow) and the 15-day antecedent rainfall totals at Princes Drive weather station.

However, further collection and assessment of this data under a wider range of meteorological and groundwater conditions is required to strengthen our understanding of this and other correlations that may provide the basis on which the viability and effectiveness of risk reduction options such as groundwater drainage may be assessed.

Recommendations are provided with respect to optimization of the monitoring programme, identification of data gaps, and the setting of trigger levels for rainfall, groundwater, and ground movement.

¹ The Earthquake Commission is now referred to as the *Natural Hazards Commission* or *NHC*

1 Introduction

Following the high intensity rainfall event of 17–20 August 2022 landslide ground displacement occurred within the Tahunanui Slump (TS) causing damage to public and private land and property.

Following the August 2022 event (which led to a Civil Defence emergency, and local evacuation of residents in the northern part of the TS) a surface and subsurface investigation and installation of instrumentation was undertaken in the northern part of the TS (the main area of damage resulting from the event) on behalf of the Earthquake Commission² (EQC – now known as NHC).

As part of that investigation, ground movement (inclinometers) and groundwater monitoring instruments (piezometers) were installed in boreholes. This included (near) real-time telemetered ground movement and groundwater monitoring instruments.

In mid-2023 NCC agreed with NHC to take over monitoring of the NHC installed ground movement and groundwater level instruments. The collection of factual data from these monitoring instruments within the TS allows an interpretation of that data with respect to relationships between groundwater levels and ground displacement within the TS.

This report presents and assesses data from the date of installation of the instrumentation installed on behalf of NHC in December 2022 through until 19 April 2024.

This work was carried out as an extension to our existing agreement with Nelson City Council (NCC) for provision of professional services. Approval to proceed with the work was received from Alec Louverdis of NCC on 14 September 2023.

1.1 Purpose of report

The main purposes of this report are as follows:

- Present factual monitoring data including telemetered and manual groundwater readings, inclinometer readings, telemetered ShapeAccelArray (SAA) records, and rainfall through to 19 April 2024.
- To review of the significance of factual data and advise on the reliability of the information, and any data gaps.
- To provide advice on options and cost/benefits for continuing/deleting/refining future monitoring with the TS.
- Discuss options for trigger and alarm points for use in a potential natural disaster preparation plan.

1.2 Site description

The TS is a large complex landslide covering an area of 27 hectares³ (ha) in the Port Hills above Tahunanui Beach, located within Nelson City. Residential development (totalling ~120 houses) is present across the majority of the TS.

² The Earthquake Commission is now referred to as the *Natural Hazards Commission* or *NHC*

³ This is the area of the *Tahunanui Slump Core* and *Fringe* slope stability overlays in NCC's regional management plan



Figure 1.1: Tahunanui Slump Core Overlay and Fringe Overlay (NRMP)²

The Nelson Resource Management Plan (NRMP) has defined the TS as an area of slope risk where specific building or development rules control development⁴. The Tahunanui Slump Risk Area (TSRA) is defined on planning maps and consists of a core area where the landslide has been considered to be active, surrounded by a fringe area which includes the headscarp and side-scarps of the landslide along with an area of variable width marginal to the scarps. The TSRA comprises the Tahunanui Slump Core Overlay (TSCO) and Fringe Overlay (TSFO) as shown in Figure 1.1 above.

For a more detailed description of the surface and inferred subsurface conditions within the TS, including the results of recent investigations undertaken on behalf of NHC following the August 2022 storm event refer to Tonkin & Taylor Ltd (T+T) report⁵ prepared for NHC dated June 2023.

2 Scope of work

This monitoring report has been prepared to provide NCC with a factual record of groundwater level and ground displacement data up to 19 April 2024, that NCC collects in relation to ongoing assessment of stability issues within the TS and to provide interpretation of that data. We have summarised the following data within this report:

- Inclinometer results from the five (5) inclinometers installed in the northern part of the TS.
- Groundwater level monitoring carried out by NCC staff.
- Rainfall from the Princes Drive weather station via the HIRDS V4 (high intensity rainfall design systems) website, situated adjacent to the southern corner of the TS.

⁴ NCC, 2012. Nelson Resource Management Plan: Volume 2 Zones. Chapter 7 – Residential.

⁵ T+T report 'Tahunanui Slump – August 2022 Nelson storm event Geotechnical Assessment' dated June 2023 (T+T ref: 1089612).

3 Monitoring

3.1 Monitoring network

The locations of monitoring points are shown on T+T Figure 871193.2100-F1 attached in Appendix A. Monitoring results are presented in Appendix B and are discussed in Sections 3.3 and 4.1.

The following is a summary of groundwater and ground movement instruments and piezometers monitored on behalf of NCC within the TS:

- Five (5) inclinometers installed in the northern part of the TS (installed in boreholes BH2A, BH07, BH08, BH09, and BH11).
- A telemetered SAA providing near real-time landslide depth and movement instrument (installed in borehole BH06).
- Telemetered vibrating wire piezometers in BH03 (x2), BH06 (x2), BH07, BH08, BH09 (x2), and BH11 (x2).
- Groundwater levels recorded with (non-telemetered) downhole pressure transducers in BH1A, and BH2A.
- Historic and current manual groundwater level monitoring in BH1A, BH2B, and BH3A.

3.2 Groundwater monitoring

Groundwater monitoring carried out by and on behalf of NCC comprises both manual groundwater bore monitoring, and telemetered bores instrumented with either vibrating wire⁶ piezometers or down-hole pressure transducers⁷.

Historic manual groundwater monitoring of non-instrumented piezometers carried out prior to the monitoring period are shown on Figure B.6 titled *Manual Groundwater readings – Tahunanui Slump* attached in Appendix B. The monitoring was carried out periodically by T+T on behalf of EQC (2012-2015) and by NCC staff (2019-2023).

Vibrating wire piezometers installed in boreholes BH03, BH06 to BH09, and BH11 have been recording real-time groundwater levels in the northern part of the TS since 1 December 2022. We note that BH03 – which used to be monitored manually (as shown in Appendix B) is now also monitored via a telemetered vibrating wire piezometer. Telemetered VW groundwater levels are shown in Figure B.1 *All VW piezometers groundwater levels*, attached in Appendix B.

Following the August 2022 event, downhole pressure transducers were installed in BH1A and BH2A. Data recorded in these instruments are provided as Figures B.2 to B.4 in Appendix B.

Response zones (i.e. the depth zone where measurements are taken) for the various instruments and the inferred geology of the response zones are shown in Table 3.1 below.

⁶ **Vibrating wire piezometers** contain a magnetic, high-tensile strength, stretched wire, and work on the principle that varying groundwater levels will affect the pitch or frequency of wire vibration.

⁷ **Down-hole pressure transducers** contain a pressure sensor set at a certain depth below ground level that can measure metres of pressure head above the sensor.

Table 3.1: Response zones and inferred geology

Piezometer	Response zone* (m bgl)	Inferred geology in screened interval
BH1A (deep)	19.5 – 24	Within base of TS landslide deposits
BH1B (shallow)	3 – 8	TS displaced PHG landslide deposits
BH2A	12 – 18	Re-worked TS landslide derived deposits
BH03 (shallow)	2.5 – 9	TS displaced PHG landslide deposits
BH03 (deep)	40 – 44.5	Straddling inferred base of TS
BH06 (shallow)	23.55	Within base of TS landslide deposits
BH06 (deep)	28.75	PHG mudstone beneath base of TS
BH07	17.6	TS displaced PHG landslide deposits
BH08	8.1	At the base of the inferred earthflow-slide in the northern gully
BH09 (shallow)	16.5	At TS deep-seated failure plane
BH09 (deep)	34.0	In PHG conglomerate bedrock beneath inferred base of TS
BH11 (shallow)	4.9	TS displaced PHG landslide deposits
BH11 (deep)	12.3	PHG siltstone bedrock beneath inferred base of TS

* Depth ranges indicate screen depths and individual depths indicate device (i.e. pressure transducer or VW) depth

3.3 Landslide displacement monitoring

3.3.1 Manual inclinometer results

Inclinometers were installed in five boreholes drilled on behalf of EQC in 2012 and 2022 (following the December 2011 and August 2022 storm events). Inclinometer traces for the five monitored boreholes (note that BH1 could not be read following the August 2022 event) are attached in Appendix B.

These inclinometers were most recently monitored 30 November 2023. Monitoring results, including recorded responses to the August 2022 storm event are summarized below:

August 2022 event

- BH1A located in central Grenville Terrace was previously monitored on 15 August 2022, the day prior to the August 2022 storm. However, the instrument could not be read past 23 m depth below ground level (bgl) during the next inclinometer round on 26 August 2022 indicating that further movement had occurred. At the time of failure of the instrument in August 2022, it had recorded a total of approximately 100 mm of displacement at a bearing of 305° between 23 and 24.5 m bgl since it was first installed in January 2012. Over this 10-year period, this equates to an average movement rate of approximately 9.5 mm/yr.
- BH2A located midway between Grenville Terrace and Rocks Road showed a displacement of approximately 7 mm at a bearing of 345° at 10.5 - 11 m bgl as a result of the August 2022 event (as measured from 15 August – 26 August 2022). The total amount of displacement recorded from installation on 10 March 2012 and the last monitoring round carried out on 30 November 2023 is approximately 20 mm.

2023 movement

- No displacement has been recorded in BH07, located downslope of Moncrieff Avenue during any of the five (5) monitoring rounds since its installation on 26 October 2022.
- In BH08, located at the northern end of Grenville Terrace, within the Northern Gully, approximately 14 mm displacement at approximately 3.5-4.0 m bgl towards a bearing of 345° was recorded between the 12 April 2023 and 12 August 2023 monitoring rounds.
- In BH09, at the southern end of Grenville Terrace approximately 5 mm of displacement at approximately 16.3 m bgl towards a bearing of 305° was recorded between the 12 April 2023 and 12 August 2023 monitoring rounds.
- In BH11, downslope of the southern end of Grenville Terrace approximately 5 mm displacement towards a bearing of 310° was recorded at approximately 3.3 m depth bgl between the 12 April 2022 and 12 August 2023 monitoring rounds.
- BH2A has not shown movement since the 26 August 2022 monitoring round.

3.3.2 ShapeAccelArray (SAA)

A SAA ground deformation instrument has been installed in borehole BH06 in the central part of Grenville Terrace. This telemetered instrument provides high precision near real-time ground deformation and displacement data.

Figure B.8 - *BH06 ShapeAccelArray displacement (Y-axis - 308 degrees)* attached in Appendix B shows the displacement time series at the ground surface, 10 m, 20 m, 25 m, and 30 m below ground level (bgl) up till 17 April 2024.

Recorded displacements from the ground surface to the base of the instrument at 30 m below ground level are shown on Figure B.9 *BH06A ShapeArray Cumulative Displacement to 1 December 2022 to 17 April 2024* also attached in Appendix B.

The data indicates that since the instrument was installed on 8 December 2022 to 17 April 2024, approximately 6.4 mm total displacement of the ground surface at a bearing of 308° has been recorded in BH06. The instrument indicates that the majority of this movement is occurring at approximately 22.0 - 22.5 m depth bgl.

Assessment of the displacement data has identified ten distinct displacement episodes, as shown in Table 3.2 below, with inferred movement episodes as small as 0.1 mm⁸. Additional movement episodes smaller than 0.1 mm are also likely to be occurring outside of those identified in Table 3.2 below, however displacements of this magnitude are difficult to clearly identify.

⁸ The stated accuracy of each measurement of the SAA is '± 1.5 mm over 32 m' however movement episodes as small as 0.1 mm have been inferred from the continuous data as shown in Table 2 below.

Table 3.2: SAA displacement episodes in BH06

Date	Duration (days)	Approximate total downslope displacement (mm)*
8 December 2022 – 20 February 2023	74	0.8
18 – 26 April 2023	8	0.2
6 - 21 May 2023	15	3.6
26 June – 25 July 2023	29	0.9
19 - 29 August 2023	10	0.2
11 – 20 September 2023	9	0.3
5 – 15 November 2023	10	0.1
29 December 2023 – 3 January 2024	5	0.1
6 – 12 March 2024	6	0.1
12 – 17 April 2024	5	0.1

* Assessed displacements have been rounded to nearest 0.1 mm

4 Discussion

Recommendations and opinions expressed in this report are based on monitoring data from the locations discussed above in Section 3.1 above. The nature and continuity of subsurface conditions and ground displacements away from the test and monitoring locations are inferred and it must be appreciated that the actual conditions may vary from the assumed model.

4.1 Observations

4.1.1 Displacement observations

The displacement data shows the following:

- Although there is a degree of fluctuation evident from the data received so far it appears that it is possible to discern individual displacement episodes following rainfall as small as 0.1 mm using the continuous data from the SAA.
- Approximately 6.4 mm of downslope movement of the deep-seated TS at a bearing of approximately 305° has been recorded by the SAA since the instrument was installed in December 2022.
- The average annual movement recorded in the SAA since December 2022 is approximately 4.5 mm/yr. This is approximately half of the average displacement rate recorded in the inclinometer in BH1A over the previous decade (2012-2022).
- Recorded inclinometer and SAA displacements of the deep-seated TS landslide indicate displacements of a similar magnitude towards the same general bearing (305-310°).
- Movement at the base of the deep-seated TS has been recorded in BH06 (22.0-22.5 m bgl), BH09, and BH011 for the first time. The total number of individual monitoring points where displacement has been recorded at the inferred base of the deep-seated TS is now four⁹.
- Approximately 5 mm of movement at a bearing of approximately 345° at between 3 and 4 m bgl in the Northern Gully was measured in the September 2023 monitoring round in

⁹ BH06 is located near BH1A – where movement at depth within the TS was first recorded, hence movement has now been recorded at three distinct locations in the Grenville Terrace area.

inclinometer BH08. This movement is inferred to be a shallow earthflow-slide and is the first time the depth of this feature has been recorded to date.

4.1.2 Groundwater observations

The groundwater data shows the following:

- Groundwater in BH03 (shallow) shows a significantly more rapid rise following rainfall than all other monitored piezometers. This may indicate that this piezometer is connected to one of the steep tension cracks that have been mapped in this location, are thought to separate different blocks of movement within the TS, and which potentially transmit rainfall infiltration to the slide plane at the surface of sliding of the TS.
- BH03 (shallow) also shows the highest degree of fluctuation of groundwater level of the monitoring period – approximately 2.6 m.
- Groundwater recorded in BH03 (deep) shows a slower and more suppressed response to rainfall events than all other wells containing vibrating wire piezometers. Groundwater recorded in BH09 (deep) installed within bedrock below the base of the deep-seated TS at 34 m bgl shows a significantly lower degree of fluctuation than piezometers installed above the failure surface within the TS – in the order of 0.6 m over the monitoring period.
- Occasional erroneous readings occurring in BH07, BH06 (deep), and BH08 are visible on Figure B.1 attached in Appendix B as very sharp peaks or troughs not in keeping with the background rate of groundwater fall or rise of data either side of the erroneous data. These erroneous readings have been ignored in our assessment.
- Missing data in BH08 in December 2023 relates to damage to the telemetry electronics caused by contractors carrying out repairs to an accessway.

4.1.3 Rainfall observations

The rainfall data recorded during the monitoring period is shown on Figure B.10 Princes Dr daily rainfall with 15- and 30-day antecedent totals in Appendix B and shows the following:

- Rainfall daily totals during the monitoring period ranged up to 64 mm.
- The maximum 15-day cumulative rainfall total reached during the period covered by this report was 190 mm in May 2023.
- The maximum 30-day cumulative rainfall total reached during the period covered by this report was 250 mm in May 2023.
- The annual rainfall total for 2023 recorded at Princes Drive was 913.6 mm. This is slightly lower than Nelson City's average annual rainfall (959 mm/yr) reported by NIWA¹⁰.

4.1.4 Displacement correlations

Displacement episodes recorded in the SAA show a good correlation with elevated groundwater levels recorded in BH03 (shallow). Figure B.7 showing real-time ground displacement data from the BH06 SAA plotted against groundwater level data from BH03 (shallow) and 15-day rainfall at Princes Drive weather station is attached in Appendix B.

We note the following with respect to correlations between rainfall, groundwater levels and displacement recorded within the TS:

- When the groundwater level in BH03 (shallow) rises above -4.1 m bgl displacement in the SAA commences.

¹⁰ 'The Climate and Weather of the Nelson and Tasman District – 2nd Edition' – Macara G. R. 2015 (NIWA publication)

- Movement in excess of 1 mm occurs when the groundwater level in BH03 (shallow) rises above -2.75 m bgl and movement continues until groundwater falls below -4.1 m bgl.
- Groundwater in BH03 (shallow) will rise above -4.1 m bgl if there is more than 40 mm of rainfall in the preceding 15 days.
- Groundwater in BH03 (shallow) will rise above -4.1 m bgl when the accumulated rainfall over 15 days exceeds 40 mm.
- Displacement of more than 1 mm will occur when the accumulated rainfall over 15 days exceeds 128 mm.
- Displacement episodes recorded in the SAA show a better correlation with 15-day antecedent rainfall totals recorded at Princes Drive than with 10-day and 30-day antecedent rainfall totals.

Based on our assessment of the limited data available to date, the rate of ground displacement recorded in the SAA in BH06 shows some correlation with the groundwater level in BH03 and the displacement rate can be linked to the 15-day antecedent rainfall totals at Princes as is shown below in Table 4.1 and Table 4.2 below.

Table 4.1: Approximate TS displacement rates versus groundwater level in BH03 (shallow)

BH03 (shallow) GW level (m bgl)	Approximate displacement rates (mm/day)
>4.2 m	Not detectible with SAA
4.1 - 3.9m	0.01 - 0.02 mm/day
3.9 - 3.5 m	0.02 - 0.15 mm/day
3.5 - 3.0 m	0.15 - 0.35 mm/day
3.0 - 2.5 m	0.35 - 0.8 mm/day
<2.5 m	>0.8 mm/day

Table 4.2: Approximate TS displacement rates versus Princes Drive 15-day antecedent rainfall

15-day antecedent rainfall at Princes	Approximate displacement rates (mm/day)
<35 mm	Not detectible in SAA*
35 - 50 mm	0.01 – 0.02 mm/day
50 – 65 mm	0.02 – 0.1 mm/day
65 – 150 mm	0.1 - 0.3 mm/day
150 - 180 mm	0.3 - 0.8 mm/day
180 mm	>0.8 mm/day

* Some movement in the SAA is detectible at 15-day antecedent rainfall totals down to 25 mm when immediately following displacement episodes with a magnitude >1mm.

4.2 Trigger / alarm points

The following is a discussion with respect to the setting of trigger points for groundwater levels and ground displacement for potential future use in natural disaster response plans in relation to the deep-seated TS landslide.

Preliminary groundwater-displacement and rainfall-groundwater, correlations provide a link to predict displacements of the deep-seated TS based on rainfall.

The cumulative rainfall over a 15-day period, as measured at the Princes Drive rainfall gauge shows a general correlation with the onset of movement and the rate of movement as summarised above in Table 4.2.

However, further collection of groundwater, ground movement, and rainfall data is required to assess what amount and rate of movement may be associated land and/or infrastructure damage. For example, there is currently no data on movement rates for 15-day antecedent rainfall at Princes greater than 190 mm. It is also not clear whether small incremental deep-seated displacements may be a precursor to a significant land and property damaging event.

The correlation of SAA ground displacement with the cumulative total of rainfall that occurs over several days (the antecedent rainfall) is promising and suggests that a rainfall correlation is potentially a more useful tool than the groundwater correlation as the predictions of a ground displacement event can be made on the basis of a forecast rainfall in much the same way as rainfall forecast can be used to predict flooding.

We have noted that there is some variability in groundwater response and resultant displacement, and the seasonal groundwater level at the time of onset of a high rainfall period does affect the potential for and extent of groundwater rise.

4.3 Monitoring optimization / data gaps

Although groundwater levels in BH03 (shallow) and 15-day antecedent rainfall data collected to date show a reasonable correlation with episodes of ground movement within the TS, this data covered in this report has only been collected for a little over 17 months. Collection of data over a longer period with different seasonal rainfall patterns and presumably different groundwater levels will allow refinement of the correlation between the BH03 (shallow) groundwater and Princes Drive rainfall.

The SAA shows deep-seated displacement of the TS to a significantly higher degree of accuracy than inclinometer readings and is therefore more useful than inclinometer data when correlating ground displacements with rainfall or groundwater level data. However, inclinometers provide a cost effective method of tracking cumulative displacements at multiple locations throughout the TS that occur between monitoring rounds. In order to optimise expenditure with respect to inclinometer monitoring, we recommend that future monitoring rounds only occur following displacement recorded in the SAA over a certain trigger level (i.e. 3 mm) and up to a maximum of two (2) times per year.

Real-time groundwater monitoring utilizing down-hole data loggers provides more useful data with respect to correlation of ground displacement with groundwater levels than manual groundwater measurements. It also lowers health and safety risk by reducing the frequency of personnel accessing the road corridor. We recommend that consideration be given to telemetry of the existing pressure transducers currently installed in boreholes BH1A and BH2A.

Uploading of real-time rainfall data from the Princes Drive weather station would allow consideration of the effects of forecast storms on the 15-day antecedent rainfall totals and prediction of potential displacement rates and displacement magnitude.

4.4 Further work

4.4.1 Northern part of TS

4.4.1.1 General

Further collection of data over more seasonal cycles and review of data that initiates higher movement rates than have been observed in this monitoring period is required to further develop a reliable rainfall monitoring predictor.

Further collection and analysis of data is required to provide a basis on which the viability and potential effectiveness of options such as groundwater drainage on the stability of the TS may be assessed. We recommend that NCC continue to monitor the existing network. We note that the majority of data collected is located within a smaller area within the northern part of the TS upslope and downslope of Grenville Terrace.

The relative effectiveness of potential groundwater drainage will depend on the permeability characteristics of the soil and rock and makes up the TS, and its underlying bedrock geology. Pump-tests in existing boreholes, as well as the drilling of additional boreholes would be required to allow such an assessment.

As part of that assessment, slope stability modelling to predict the effects of groundwater drainage on stability should be carried out to assess the benefit of groundwater drainage under a variety of rainfall and seismic natural disaster scenarios.

Should data indicate that groundwater drainage is likely to significantly reduce deep-seated displacements of the northern part of the TS, further assessment will be required at that stage to assess the practicalities, risks and benefits of such a project for NCC and other stakeholders.

4.4.1.2 Days Track area

During and following the August 2022 storm event, the section of Days Track downslope of BH03 and adjacent private land, experienced higher rates of downslope displacement than adjacent areas of the TS, causing fresh movement on tension cracks where historical displacements have also been recorded as a result of the 1962 and 2011 natural disaster events.

Given the strong emerging relationship between groundwater levels in BH03 and deep-seated displacement of the TS recorded in the SAA, as well as the higher rates of deep-seated displacement experienced in this area relative to other adjacent areas of the TS it may be prudent for NCC to consider:

- Carrying out further assessment to confirm that all underground piped services crossing - or in the vicinity of these tension cracks - are suitably designed to accommodate likely future differential displacement across these cracks, and that defunct private services are not feeding water into this zone.
- Potential earthworks (or other) solutions to reduce direct infiltration of stormwater into this zone of tension cracks.

The mechanisms that control the relationship between groundwater levels in the area of BH03 and deep-seated displacements of the TS measured downslope in the TS are still not sufficiently clear to enable future options for risk mitigation to be confirmed. Any historic underground private services (i.e. old earthenware pipes that we have previously observed in the area) that straddle the tension crack upslope of this area may be contributing to the observed groundwater rises during rainfall events – particularly as springs have also been observed upslope of this area and may be flowing preferentially along such services. As such we recommend that a review of potential leakage pathways from unmapped private underground services be carried out in this area.

We also recommend that a pumping test be carried out in BH03 – located adjacent to the tension crack upslope of this area. This is likely to provide insight into the viability of lowering of groundwater levels in this area through pumping or gravity drainage of groundwater.

4.5 Southern part of TS

The spatial distribution of instruments in the northern part of the TS, where the main focus of deep-seated displacement has occurred in the recent past, is showing potential for prediction of the potential effects of groundwater drainage on the stability of that portion of the TS.

Should the monitoring network be extended into the southern part of the TS, it appears (based on data to date) that the SAA installed in that area can provide accurate data to allow displacement rates in that part of the TS to also be correlated with rainfall and groundwater level data.

5 Applicability

This report has been prepared for the exclusive use of our client Nelson City Council, with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose, or by any person other than our client, without our prior written agreement.

Recommendations and opinions in this report are based on data from discrete investigation locations. The nature and continuity of subsoil conditions away from these locations are inferred but it must be appreciated that actual conditions could vary from the assumed model.

Tonkin & Taylor Ltd

Environmental and Engineering Consultants

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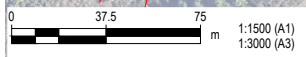
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MJL

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Appendix A T+T figures

- Figure 871193.2100-F1 - Monitoring Location Plan



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TITLE MONITORING LOCATION PLAN

SCALE (A1) 1:1500

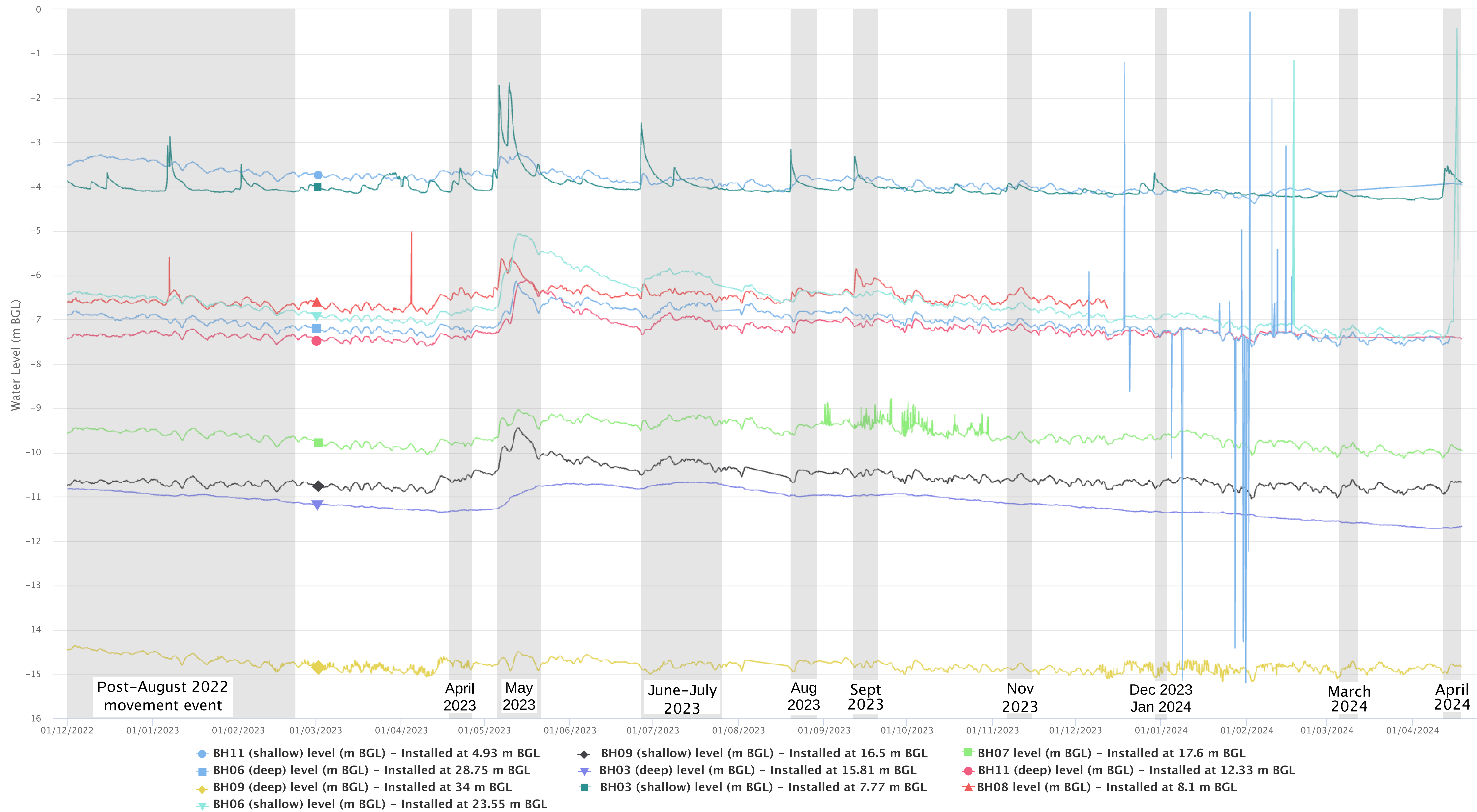
FIG No. 871193.2100-F1

REV 0

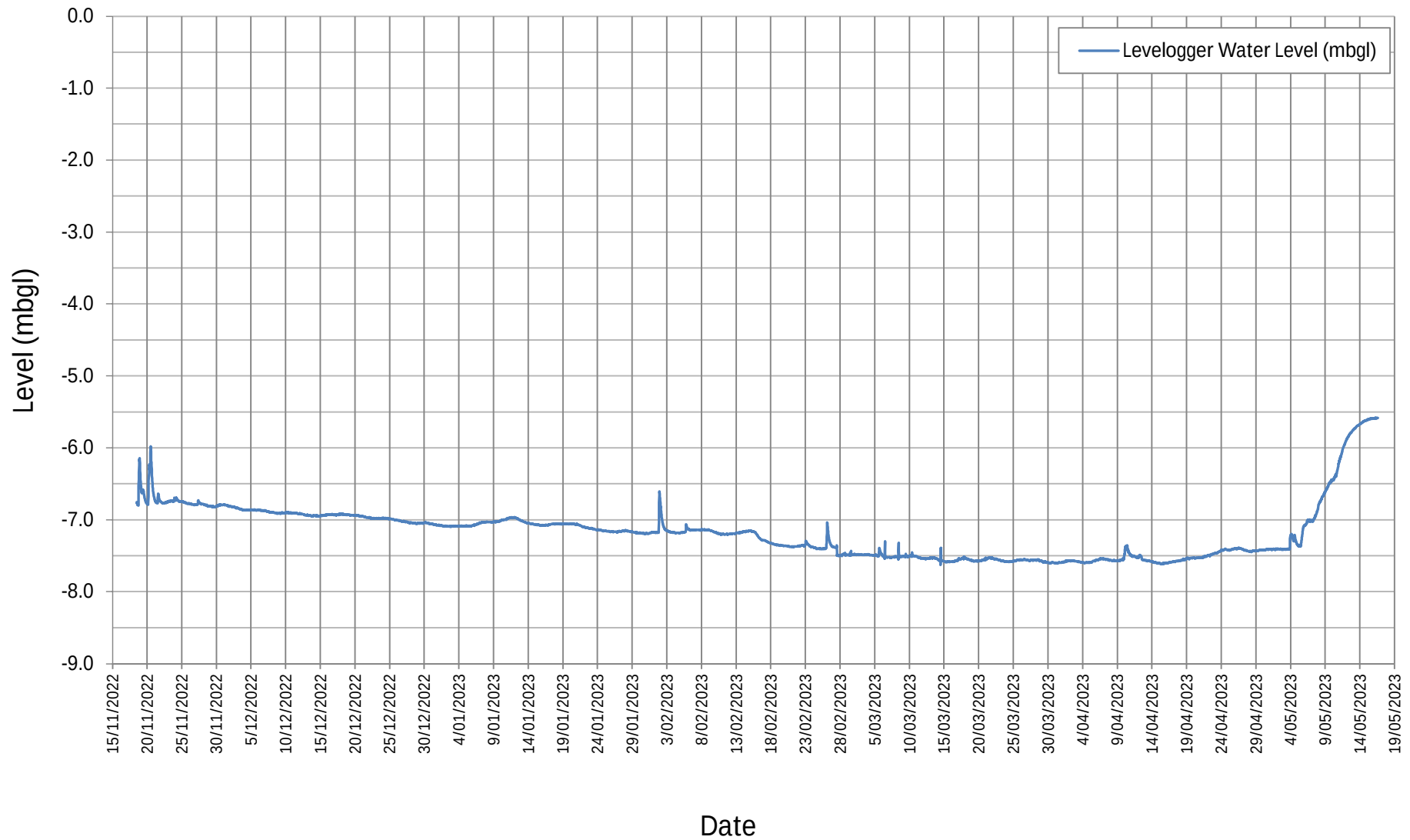
Appendix B Monitoring results

- **B.1 – All VW piezometers groundwater levels**
- **B.2 - BH1A (deep) groundwater pressure transducer**
- **B.3 - BH1B (shallow) groundwater pressure transducer**
- **B.4 - BH2B groundwater pressure transducer (Nov 2022 – Nov 2023)**
- **B.5 - Inclinator results (BH1A, BH2, BH7-BH9, and BH11)**
- **B.6 - Historic Manual groundwater monitoring graph (2012-2023)**
- **B.7 - ShapeAccelArray Y-Axis cumulative surface displacement (308 degrees) vs. daily/15-day cumulative rainfall and BH03 (shallow) groundwater level**
- **B.8 - ShapeAccelArray displacement (Y-axis - 308 degrees)**
- **B.9 - SAA Cumulative Displacement**
- **B.10 - B.10 - Princes Dr daily rainfall with 15 and 30 antecedent totals**

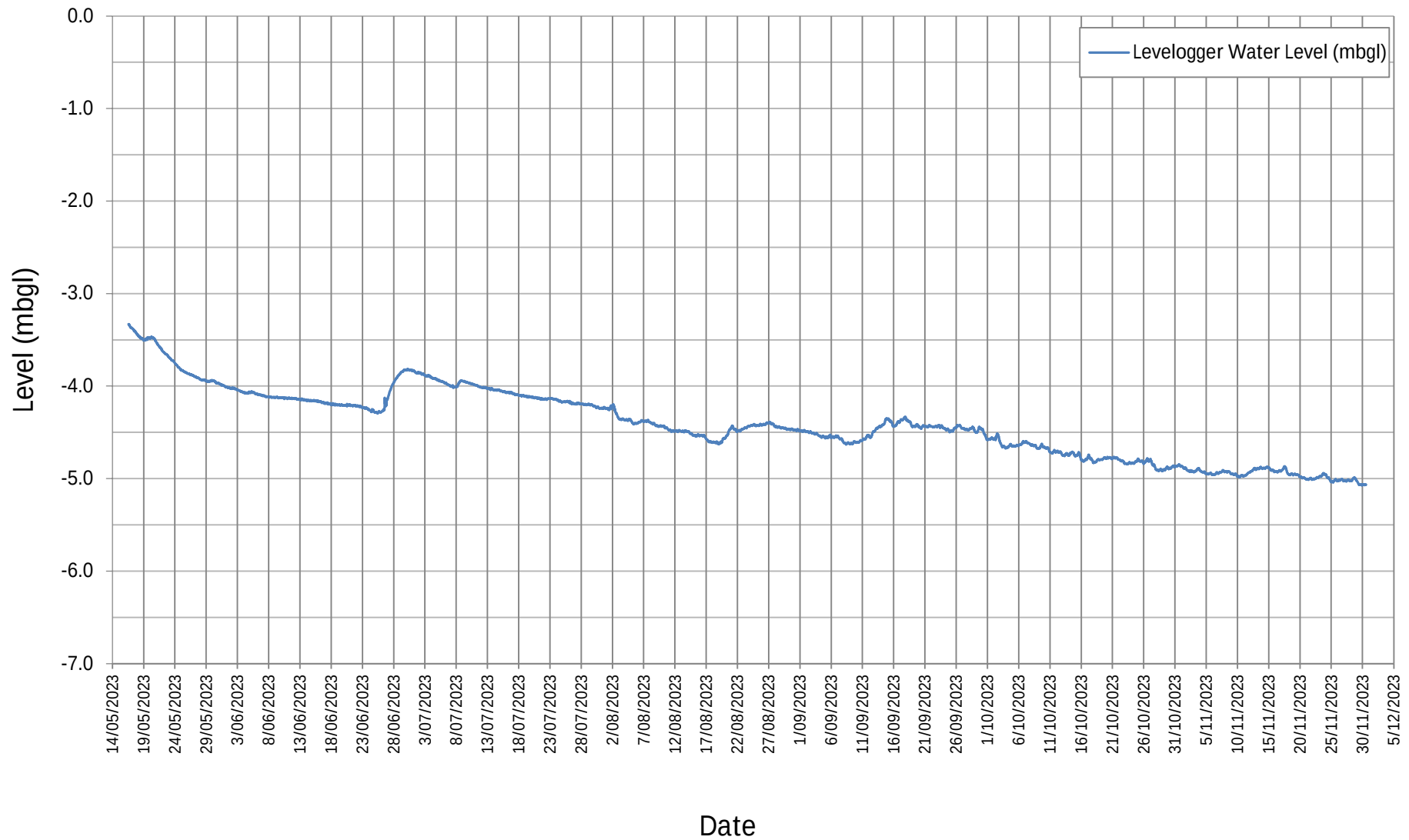
B.1 – All VW piezometers groundwater levels (m bgl)



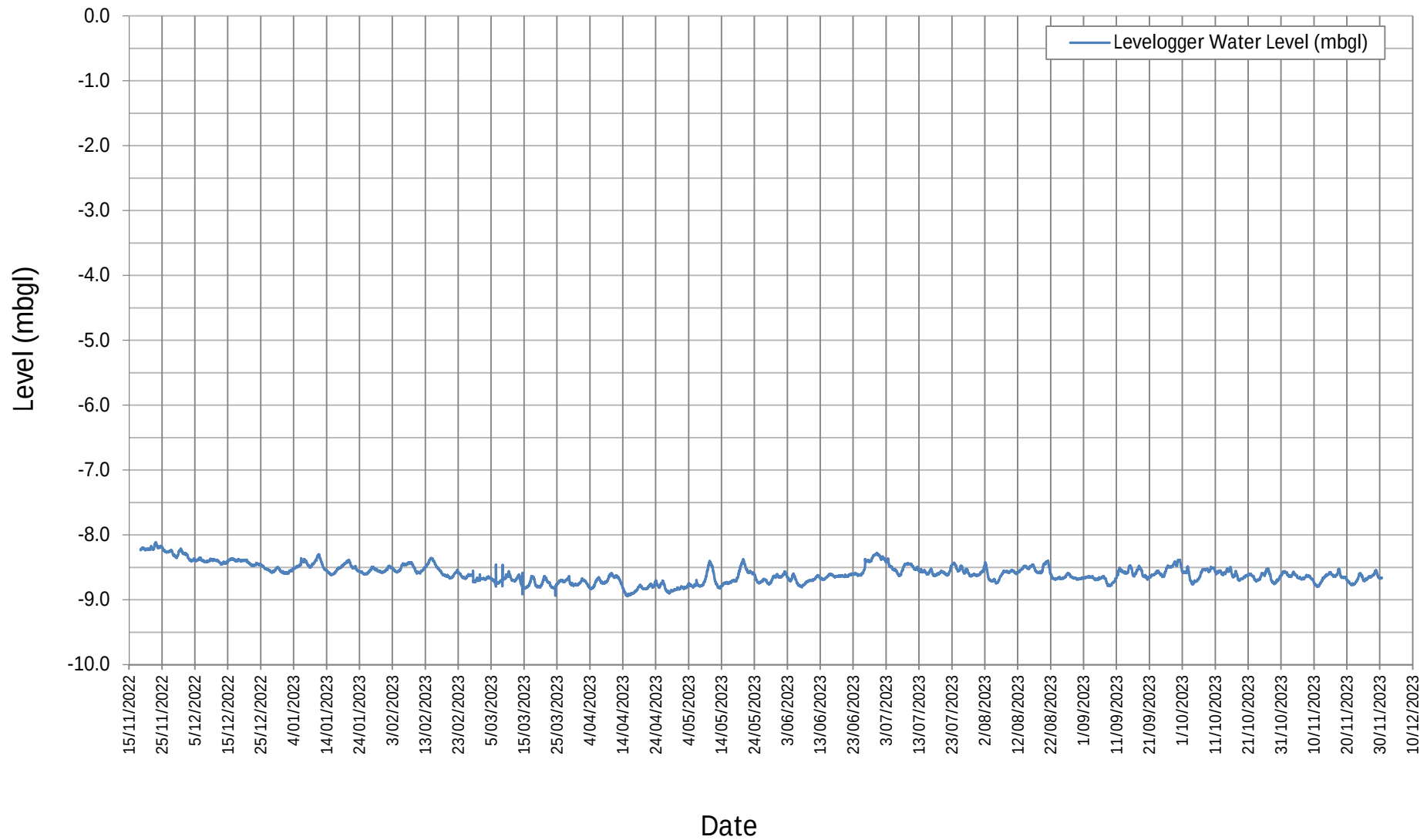
B.2 - BH1A (deep) groundwater pressure transducer (19.5 - 24 m depth bgl)



B.3 - BH1B (shallow) groundwater pressure transducer (3 - 8 m bgl)



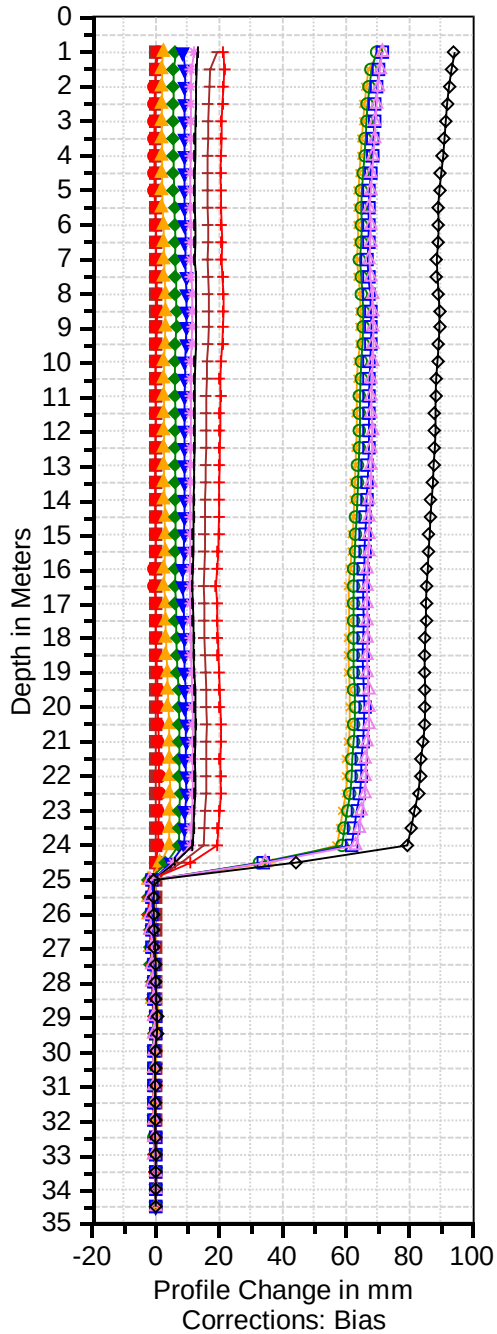
B.4 - BH2B groundwater pressure transducer (12 - 18 m bgl)



B.5 - Inclinator results

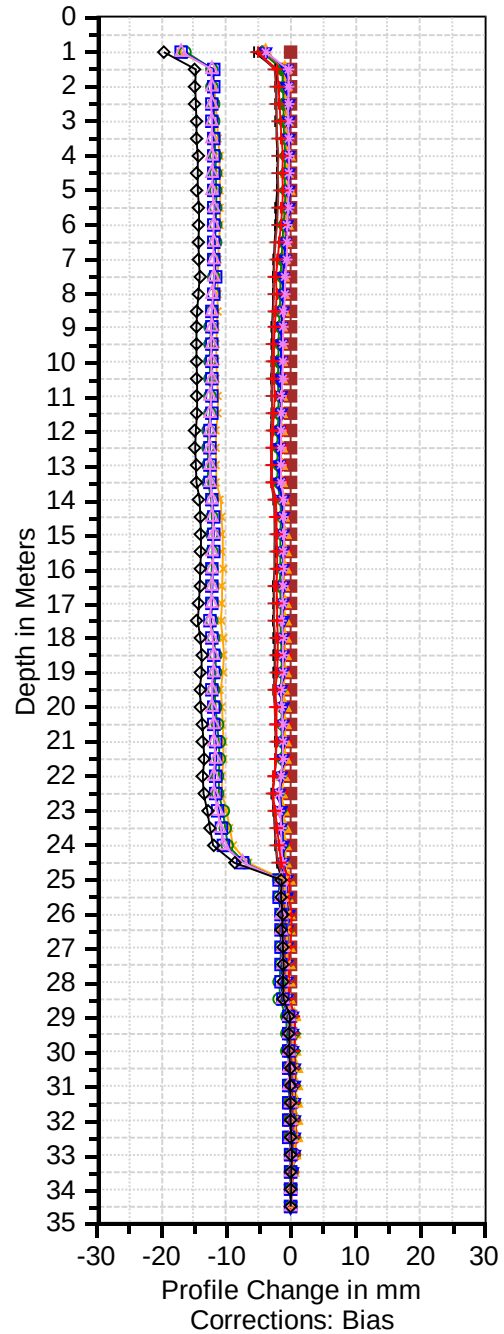
BH1A A0 = 310°

31/01/2012	14/06/2012	24/08/2012
20/09/2012	27/09/2012	17/12/2012
29/04/2013	29/07/2013	25/07/2014
13/03/2018	11/06/2019	23/06/2020
17/06/2021	15/08/2022	



BH1A B0 = 040°

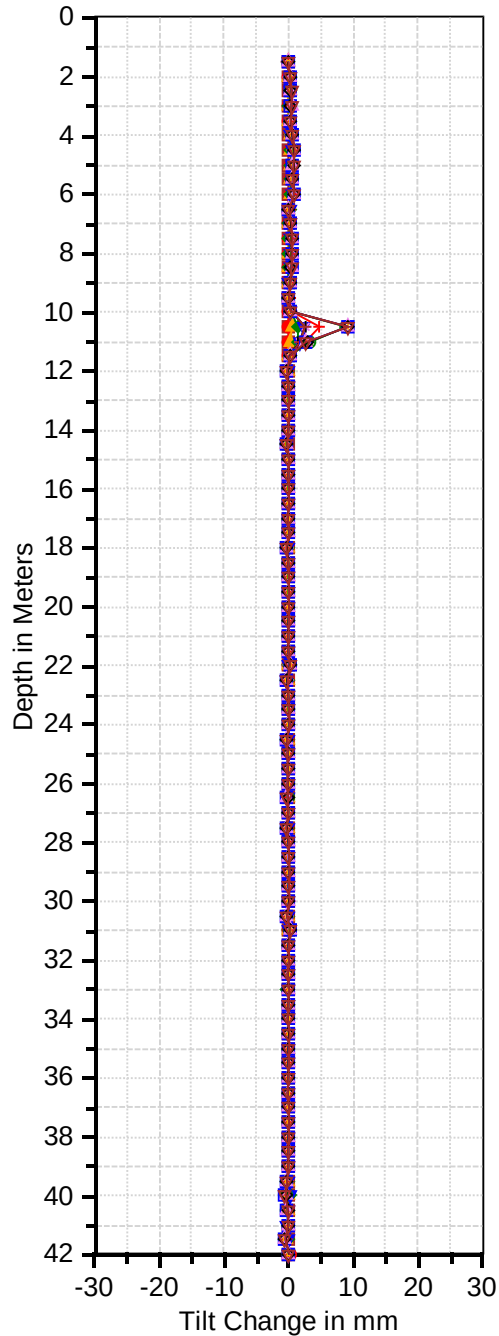
31/01/2012	14/06/2012	24/08/2012
20/09/2012	27/09/2012	17/12/2012
29/04/2013	29/07/2013	25/07/2014
13/03/2018	11/06/2019	23/06/2020
17/06/2021	15/08/2022	



Area: Grenville Terrace
 Ao Axis: Towards down slope direction.
 Baseline reading: 31/01/2012
 NB: Inclinometer summed/plotted from the bottom up.
 Job number: 1006192.1000.0.0

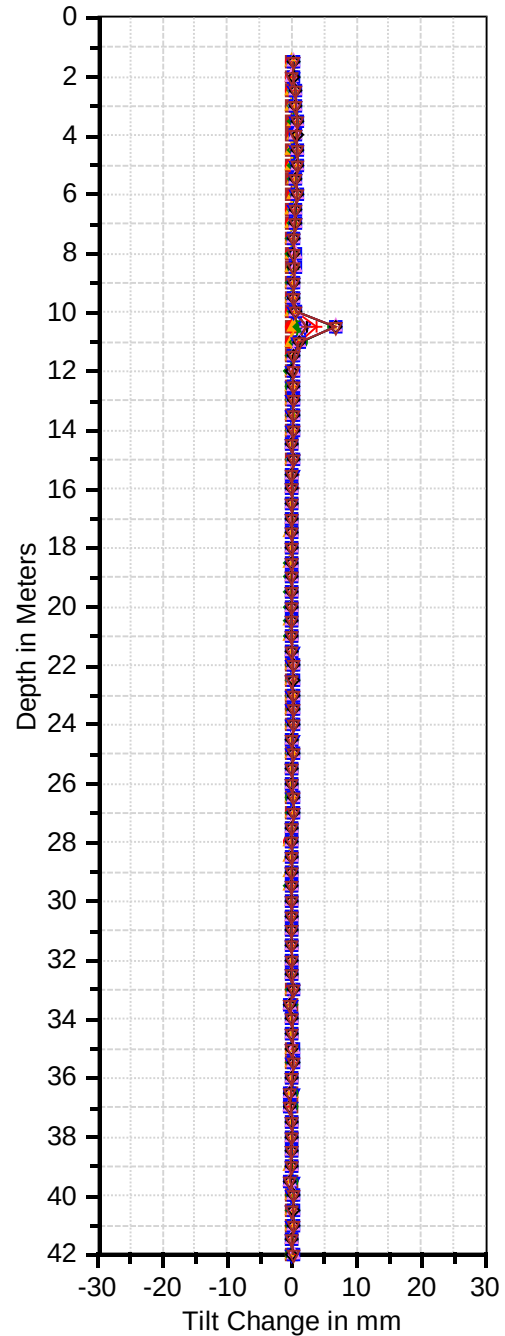
BH2A A0 = 300°

19/03/12	29/04/13	29/07/13
25/07/14	20/03/18	11/06/19
23/06/20	17/06/21	15/08/22
26/08/22	27/10/22	24/01/23
12/04/23	13/09/23	30/11/23



BH2A B0 = 30°

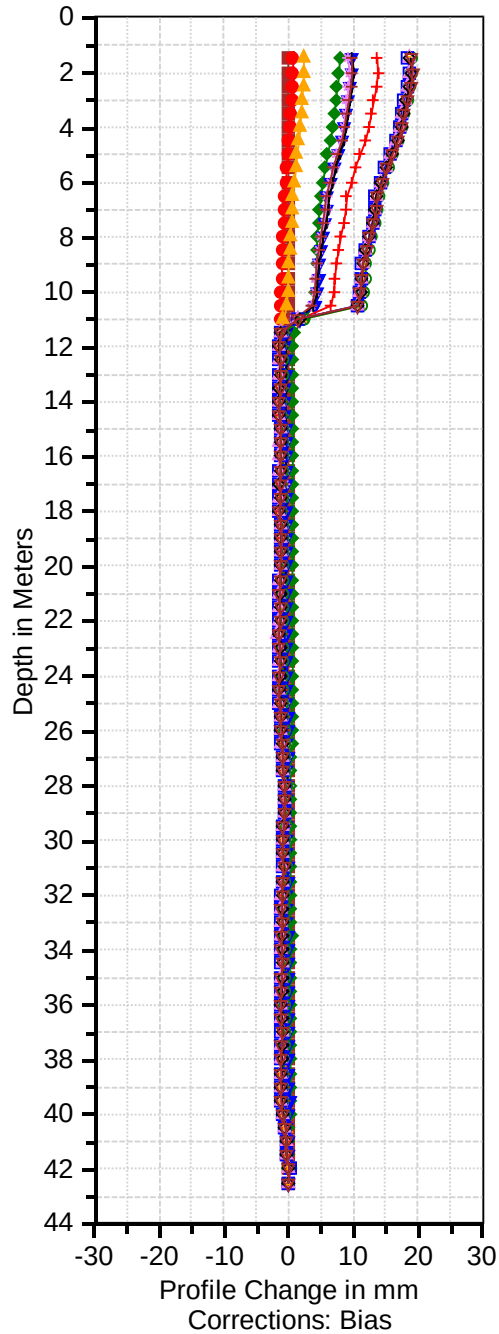
19/03/12	29/04/13	29/07/13
25/07/14	20/03/18	11/06/19
23/06/20	17/06/21	15/08/22
26/08/22	27/10/22	24/01/23
12/04/23	13/09/23	30/11/23



Tahunanui Slump Inclinerometers
 BH2A - Tilt Change Plots
 563 Rocks Road, Moana, Nelson (next to Days Track)
 Baseline reading: 19/03/2012
 Job number: 1006192.2000.0.0

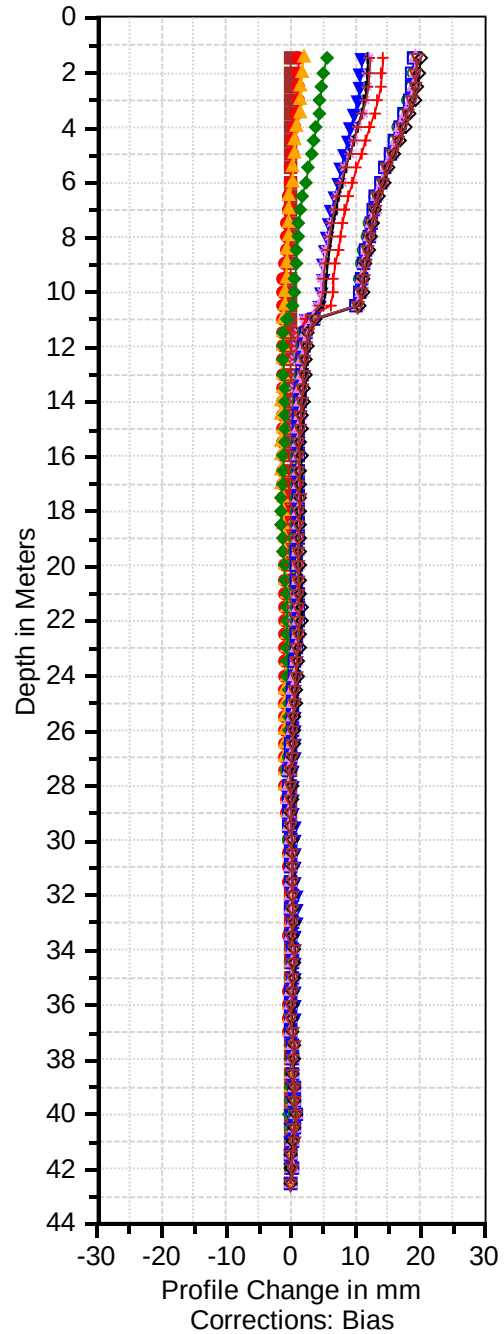
BH2A A0 = 300°

19/03/12	29/04/13	29/07/13
25/07/14	20/03/18	11/06/19
23/06/20	17/06/21	15/08/22
26/08/22	27/10/22	24/01/23
12/04/23	13/09/23	30/11/23



BH2A B0 = 30°

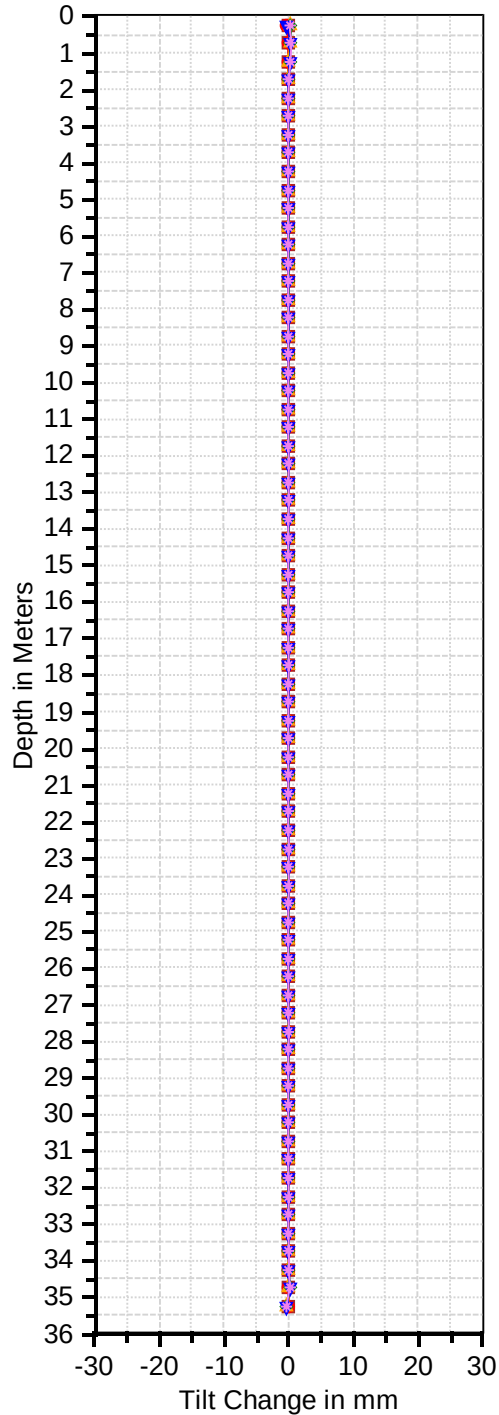
19/03/12	29/04/13	29/07/13
25/07/14	20/03/18	11/06/19
23/06/20	17/06/21	15/08/22
26/08/22	27/10/22	24/01/23
12/04/23	13/09/23	30/11/23



Tahunanui Slump Inclinometers
 BH2A - Profile Change Plots
 563 Rocks Road, Moana, Nelson (next to Days Track)
 Baseline reading: 19/03/2021
 Job number: 1006192.2000.0.0

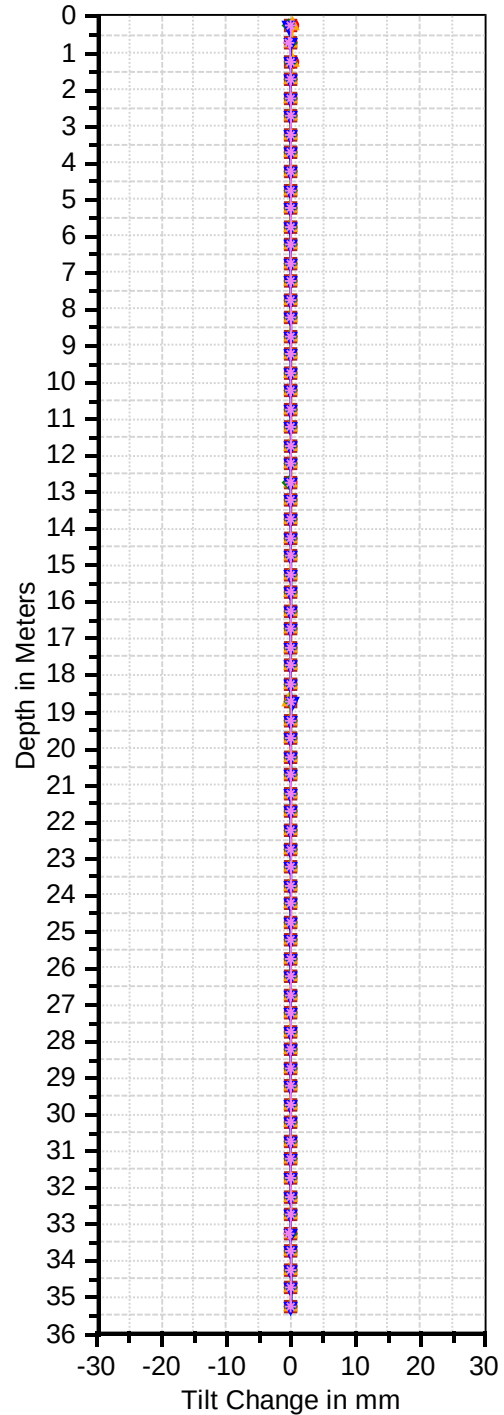
BH07 A0 = 300°

26/10/22 21/11/22 23/01/23
12/04/23 13/09/23 30/11/23



BH07 B0 = 030°

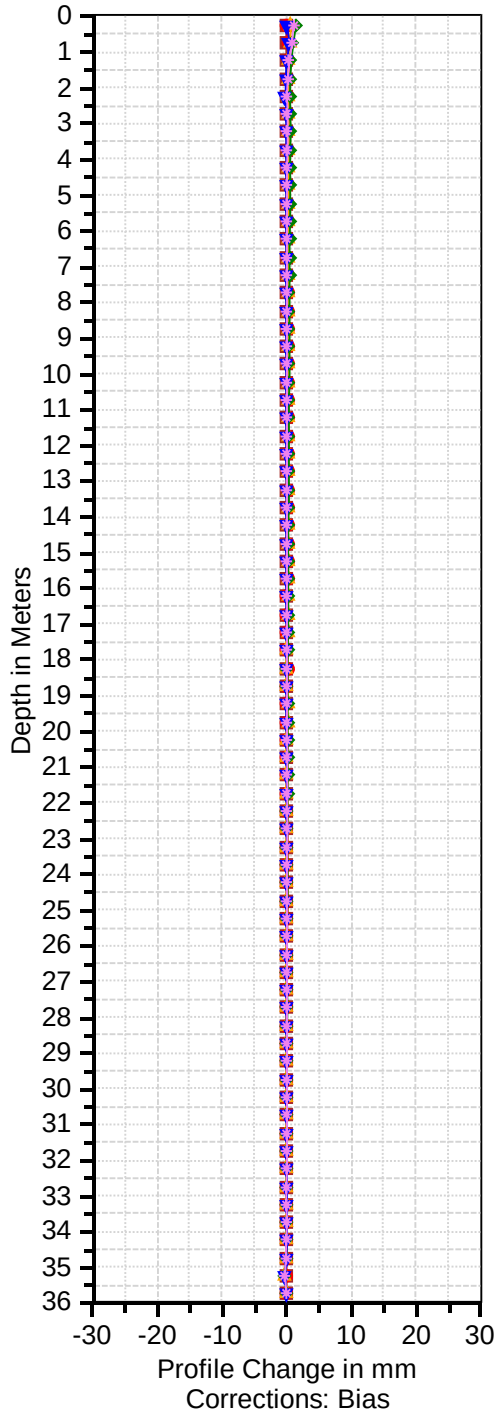
26/10/22 21/11/22 23/01/23
12/04/23 13/09/23 30/11/23



Tahunanui Slump Inclinometers
BH07 - Tilt Change Plots
15A Moncrieff Avenue, Britannia Heights, Nelson
Baseline Reading: 26/10/2022
Job Number: 1006192.2000.0.0

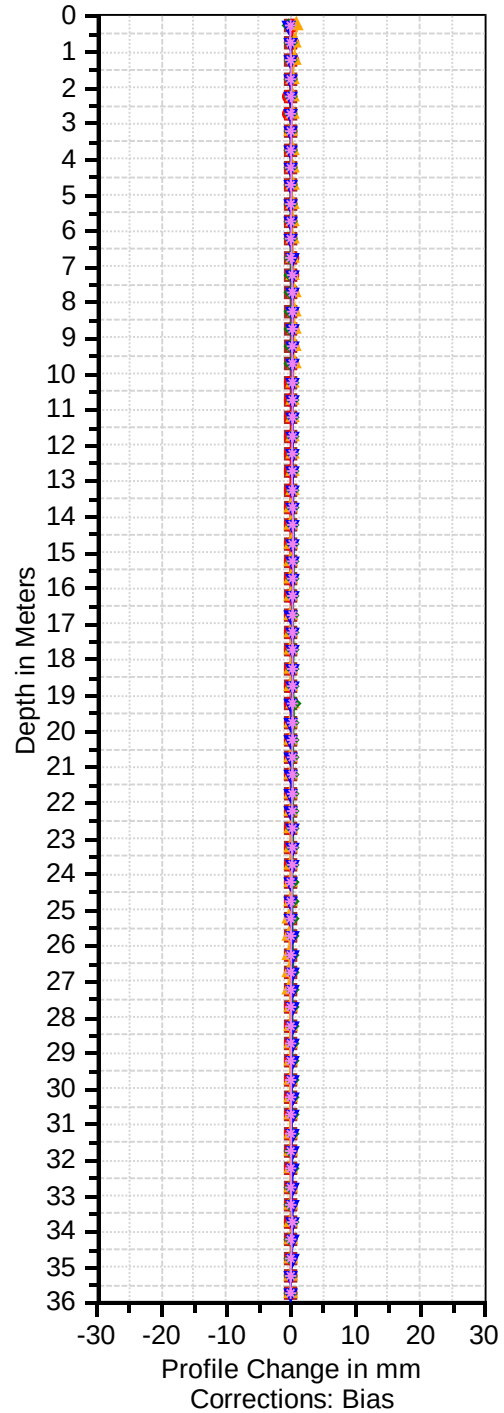
BH07 A0 = 300°

■ 26/10/22
 ● 21/11/22
 ▲ 23/01/23
◆ 12/04/23
 ▼ 13/09/23
 ✦ 30/11/23



BH07 B0 = 030°

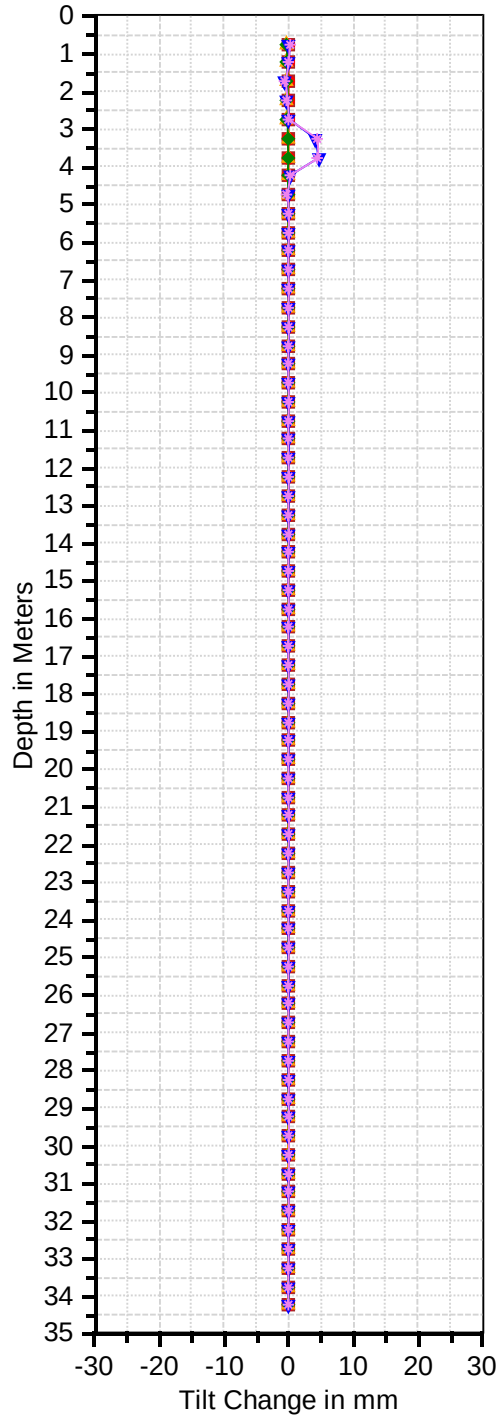
■ 26/10/22
 ● 21/11/22
 ▲ 23/01/23
◆ 12/04/23
 ▼ 13/09/23
 ✦ 30/11/23



Tahunanui Slump Inclinometers
 BH07 - Profile Change Plots
 15A Moncriess Avenue, Britannia Heights; Nelson
 Baseline Reading: 26/10/2022
 Job Number: 1006192.2000.0.0

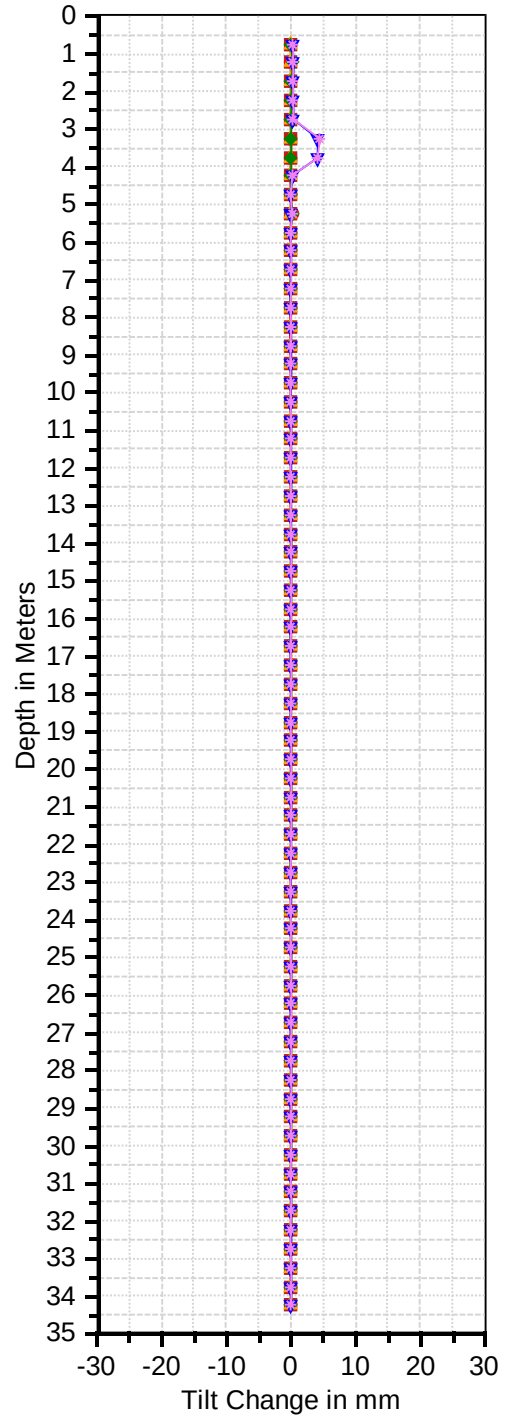
BH08 A0 = 300°

■ 27/10/22 ● 21/11/22 ▲ 23/01/23
◆ 12/04/23 ▼ 12/09/23 ✦ 30/11/23



BH08 B0 = 030°

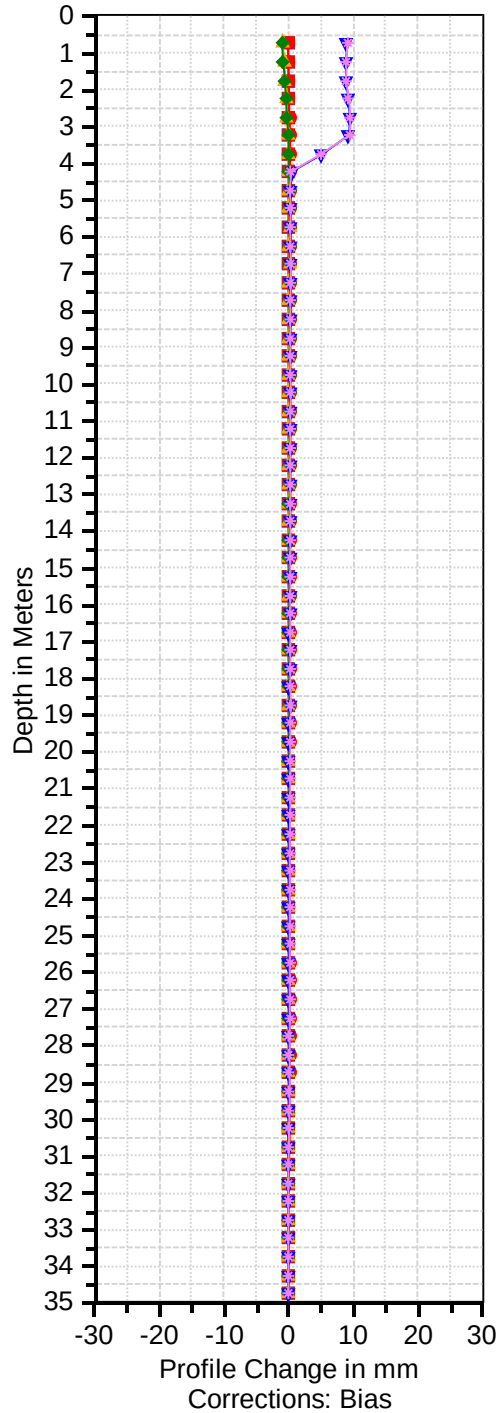
■ 27/10/22 ● 21/11/22 ▲ 23/01/23
◆ 12/04/23 ▼ 12/09/23 ✦ 30/11/23



Tahunanui Slump Inclinometers
 BH08 - Tilt Change Plots
 33 Grenville Terrace, Moana, Nelson (on driveway)
 Baseline Read: 27/10/2022
 Job Number: 1006192.2000.0.0

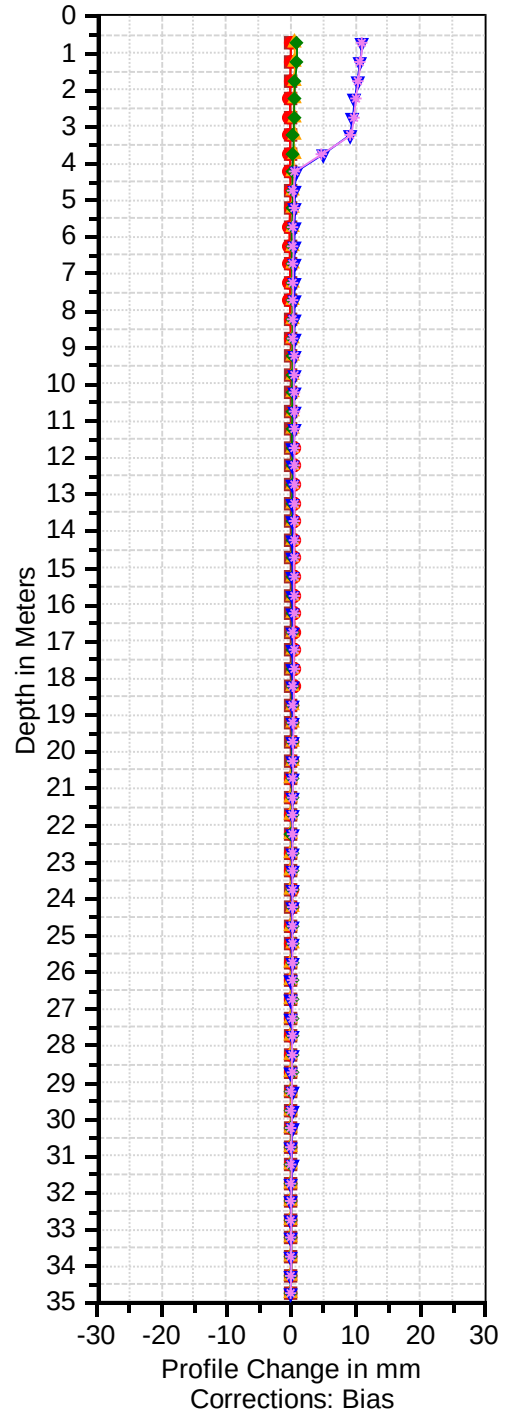
BH08 A0 = 300°

27/10/22 21/11/22 23/01/23
12/04/23 12/09/23 30/11/23



BH08 B0 = 030°

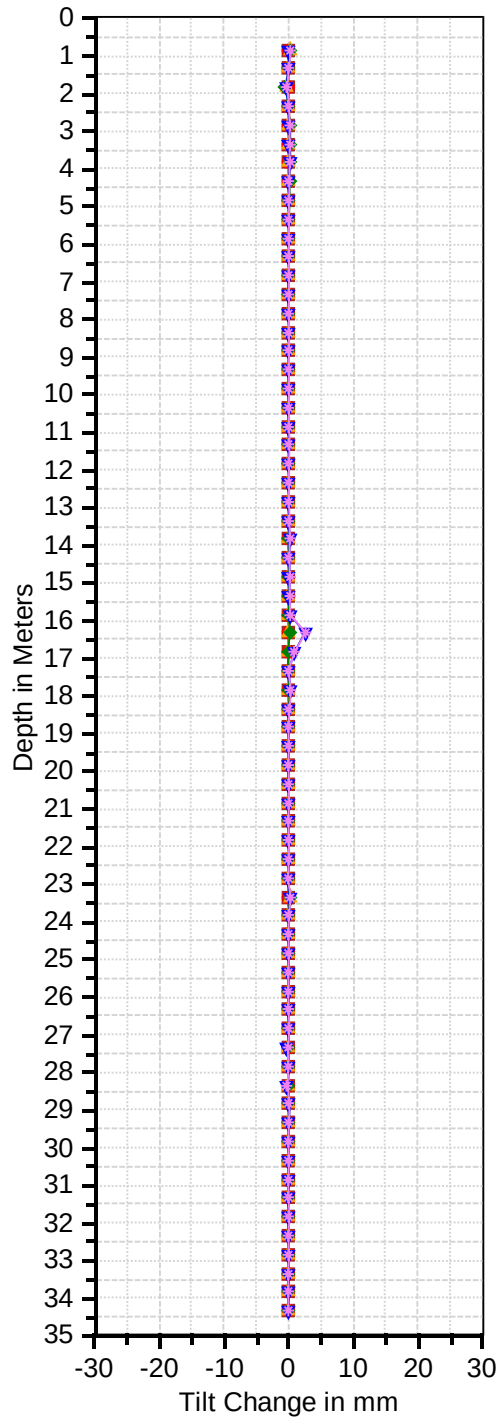
27/10/22 21/11/22 23/01/23
12/04/23 12/09/23 30/11/23



Tahunanui Slump Inclinometers
BH08 - Profile Change Plots
33 Grenville Terrace, Moana, Nelson (on driveway)
Baseline Read: 27/10/2022
Job Number: 1006192.2000.0.0

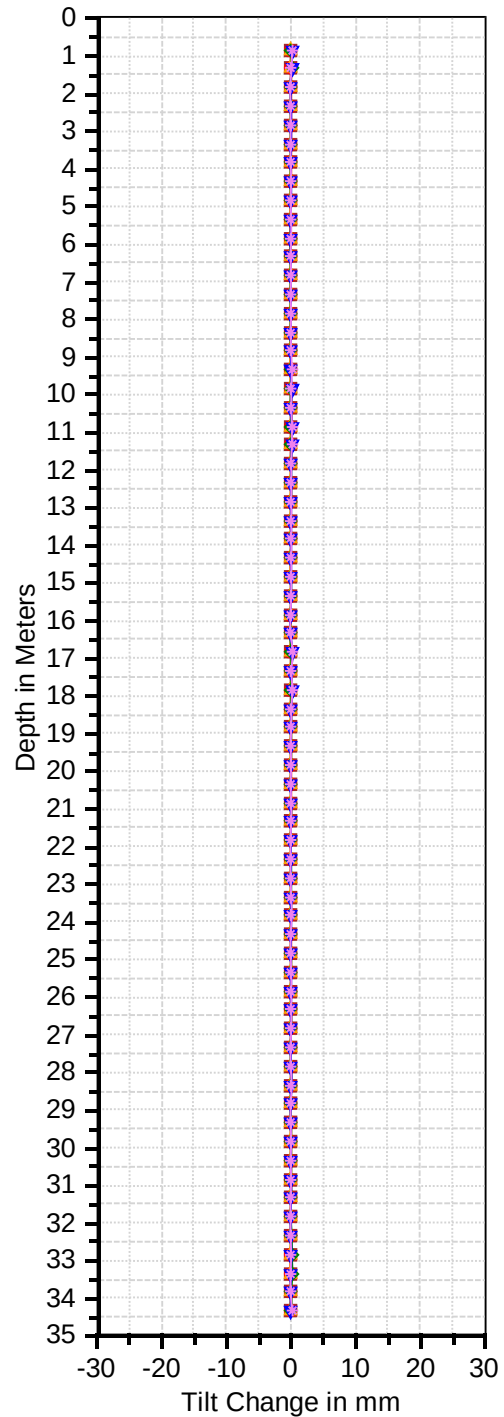
BH09 A0 = 300°

27/10/22 21/11/22 24/01/23
 12/04/23 12/09/23 6/12/23



BH09 B0 = 030°

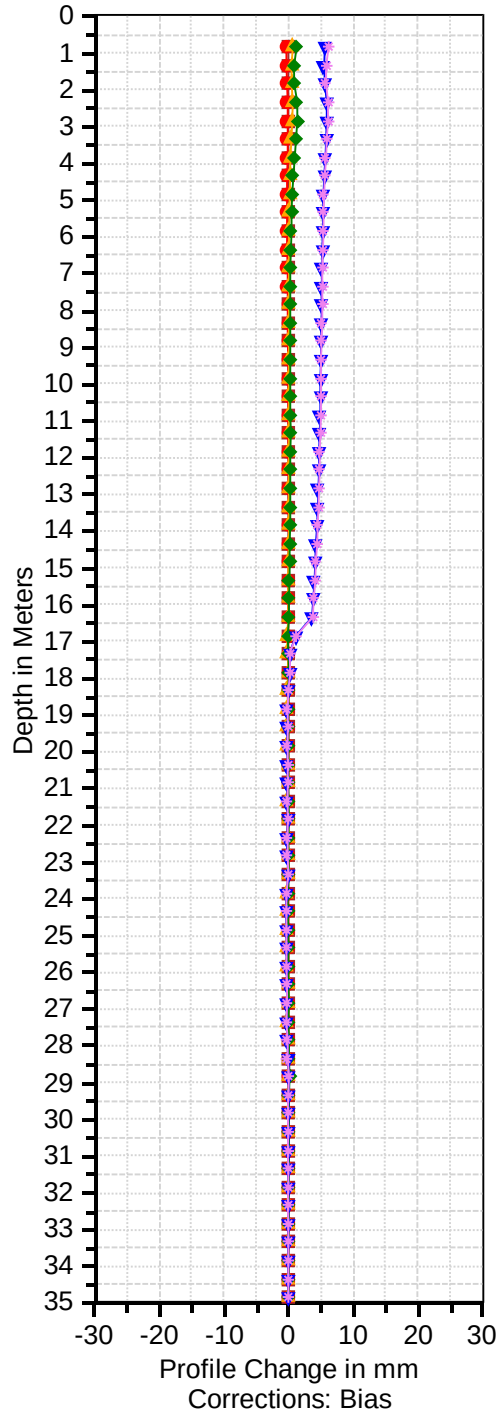
27/10/22 21/11/22 24/01/23
 12/04/23 12/09/23 6/12/23



Tahunanui Slump Inclinometers
 BH09 - Tilt Change Plots
 7 Grenville Terrace, Moana, Nelson (on the road)
 Base Read: 27/10/2022
 Job Number: 1006192.2000.0.0

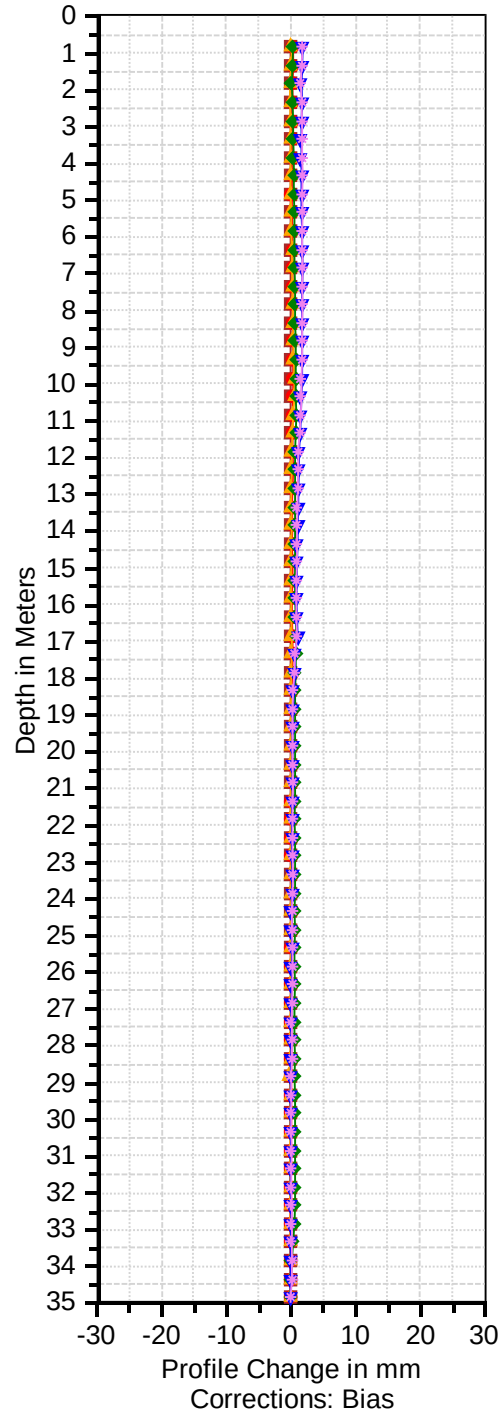
BH09 A0 = 300°

■ 27/10/22 ● 21/11/22 ▲ 24/01/23
◆ 12/04/23 ▼ 12/09/23 ✦ 6/12/23



BH09 B0 = 030°

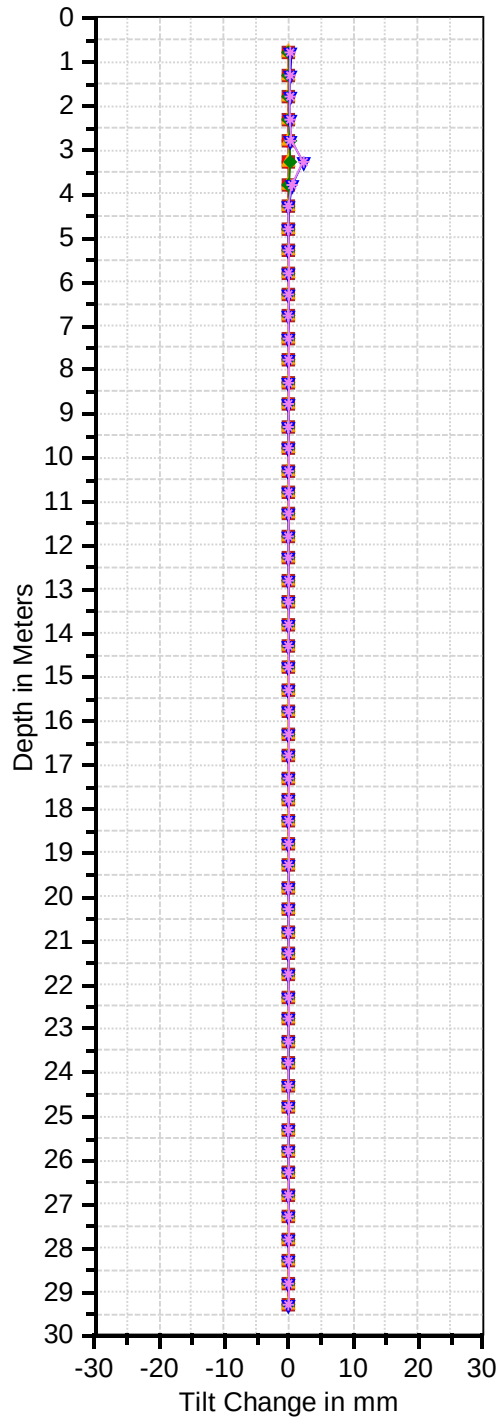
■ 27/10/22 ● 21/11/22 ▲ 24/01/23
◆ 12/04/23 ▼ 12/09/23 ✦ 6/12/23



Tahunanui Slump Inclinometers
 BH09 - Profile Change Plots
 7 Grenville Terrace, Moana, Nelson (on the road)
 Base Read: 27/10/2022
 Job Number: 1006192.2000.0.0

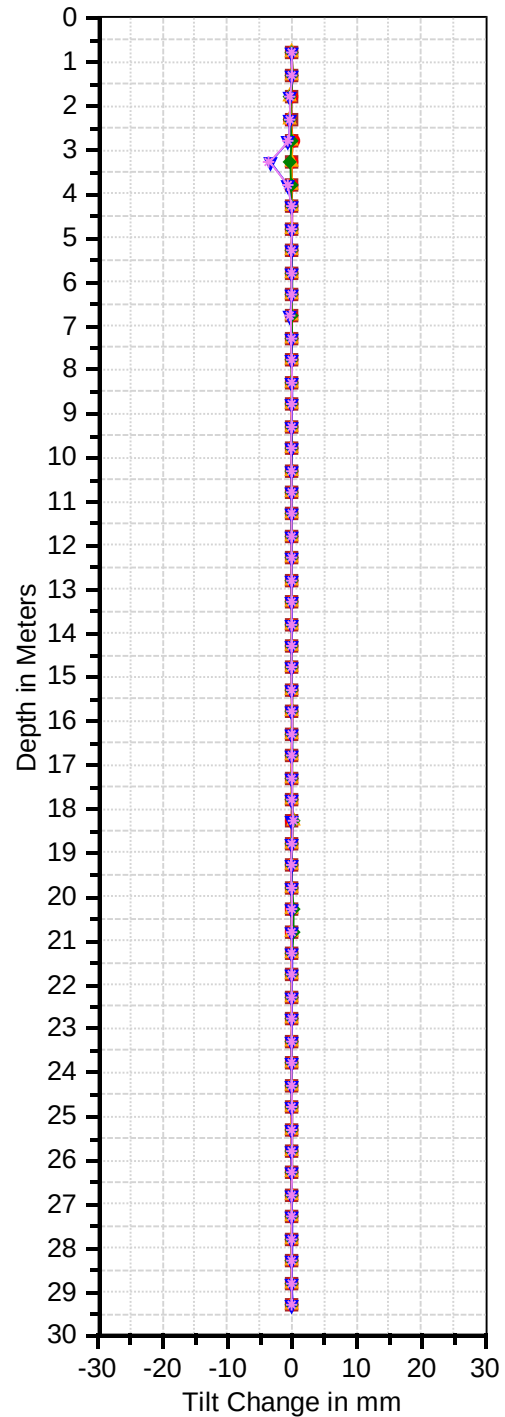
BH11 A0 = 020°

■ 26/10/22 ● 21/11/22 ▲ 24/01/23
◆ 12/04/23 ▼ 12/09/23 ✦ 30/11/23



BH11 B0 = 110°

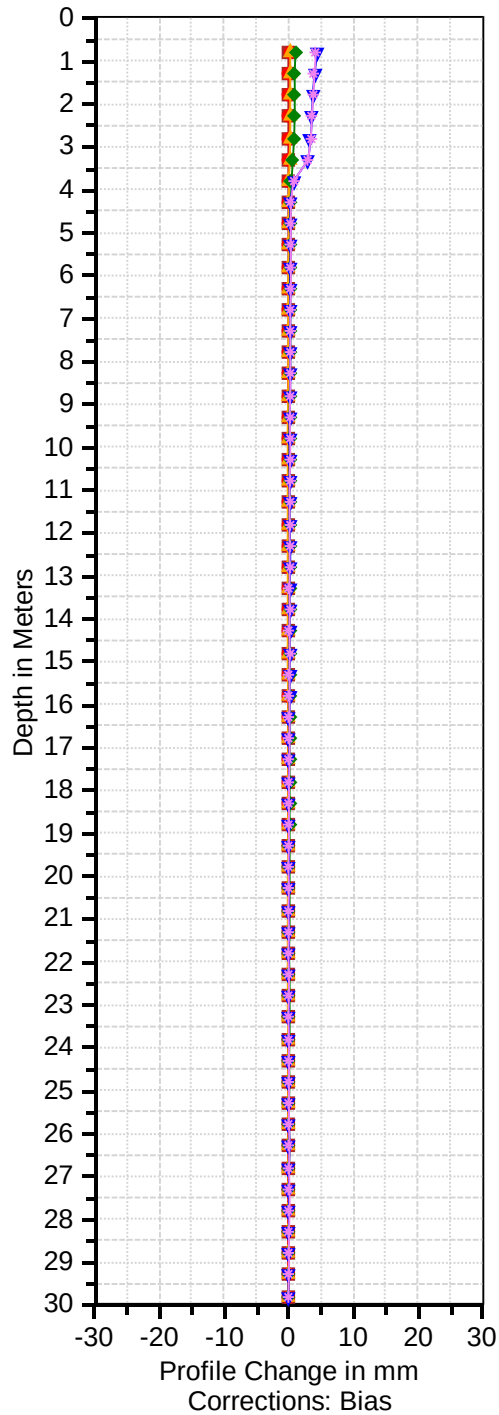
■ 26/10/22 ● 21/11/22 ▲ 24/01/23
◆ 12/04/23 ▼ 12/09/23 ✦ 30/11/23



Tahunanui Slump Inclinerometers
 BH11 - Tilt Change Plots
 3 Grenville Terrace, Moana, Nelson (on lawn in backyard)
 Base Read: 26/10/2022
 Job Number: 1006192.0000.0.0

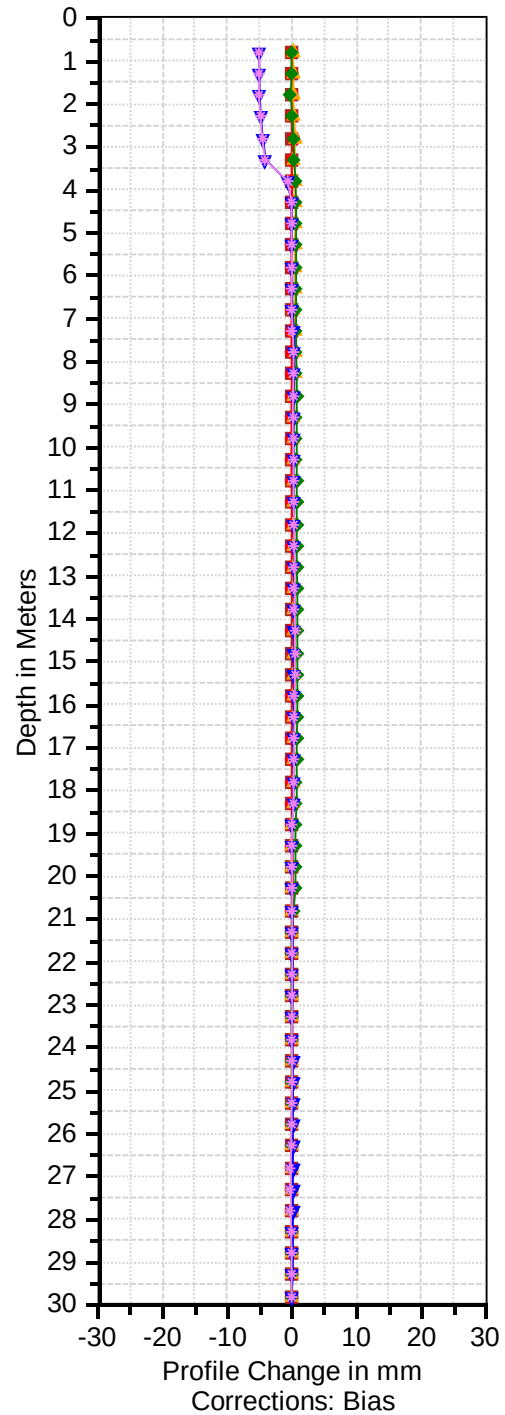
BH11 A0 = 020°

■ 26/10/22 ● 21/11/22 ▲ 24/01/23
◆ 12/04/23 ▼ 12/09/23 ✦ 30/11/23



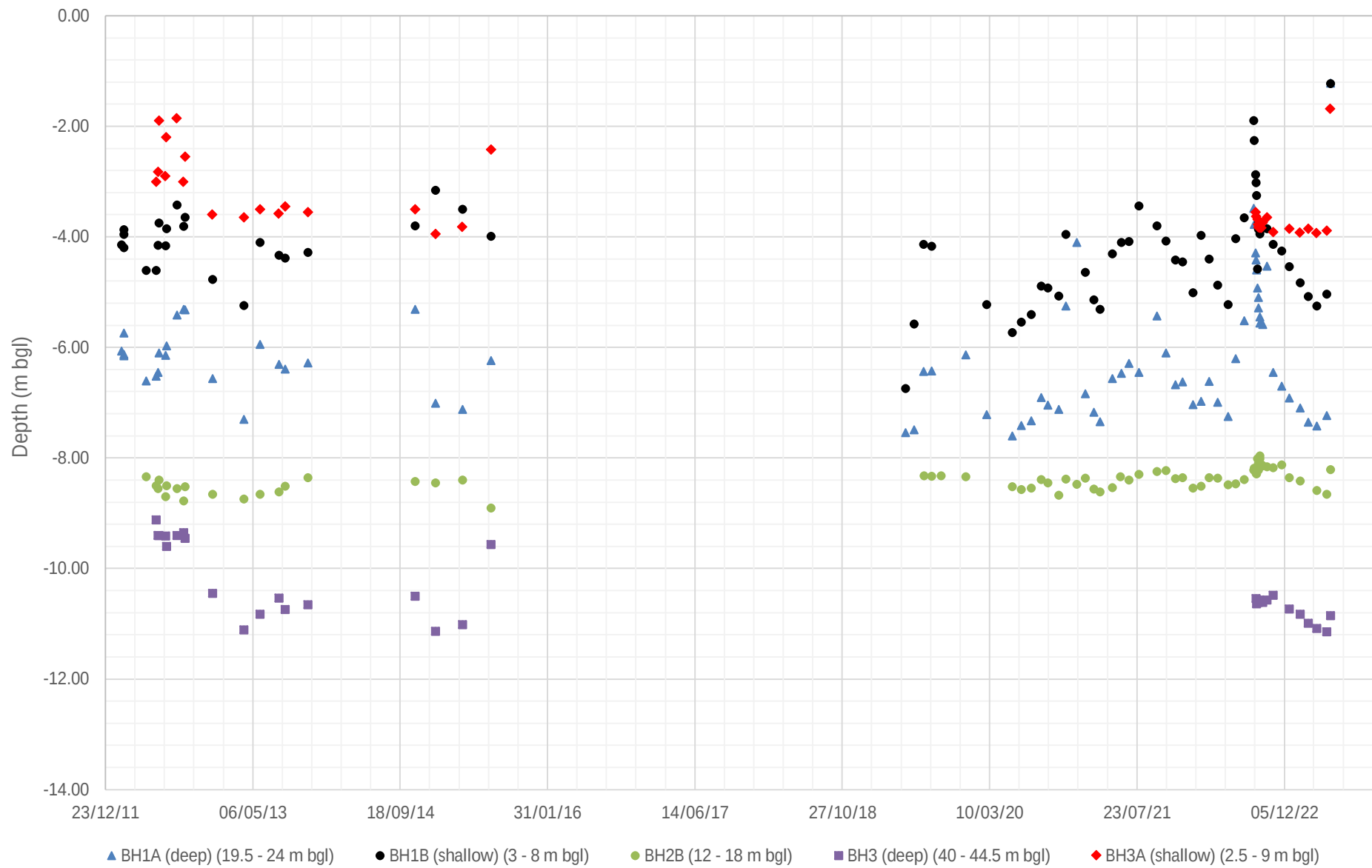
BH11 B0 = 110°

■ 26/10/22 ● 21/11/22 ▲ 24/01/23
◆ 12/04/23 ▼ 12/09/23 ✦ 30/11/23

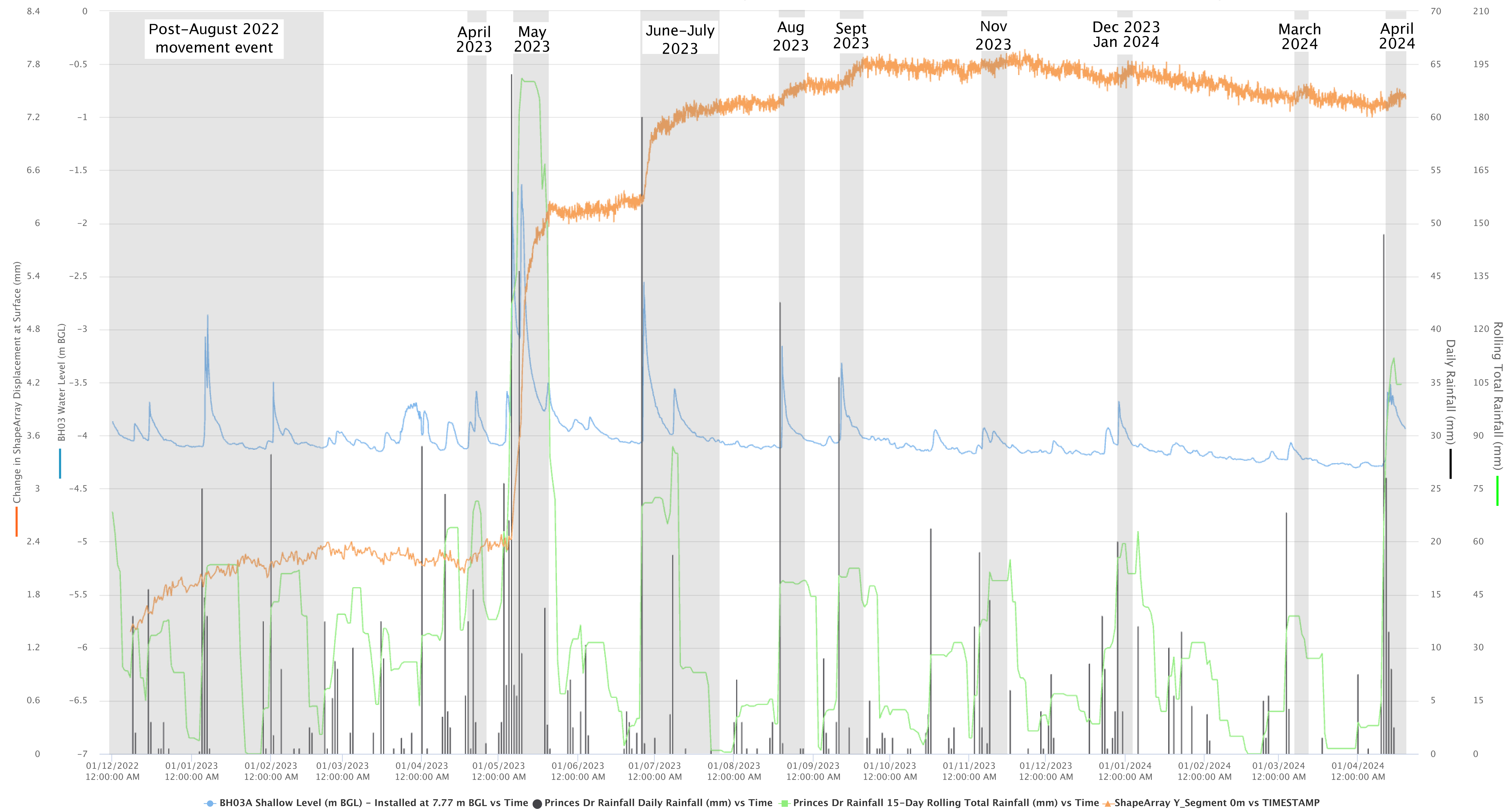


Tahunanui Slump Inclinometers
 BH11 - Profile Change Plots
 3 Grenville Terrace, Moana, Nelson (on lawn in backyard)
 Base Read: 26/10/2022
 Job Number: 1006192.0000.0.0

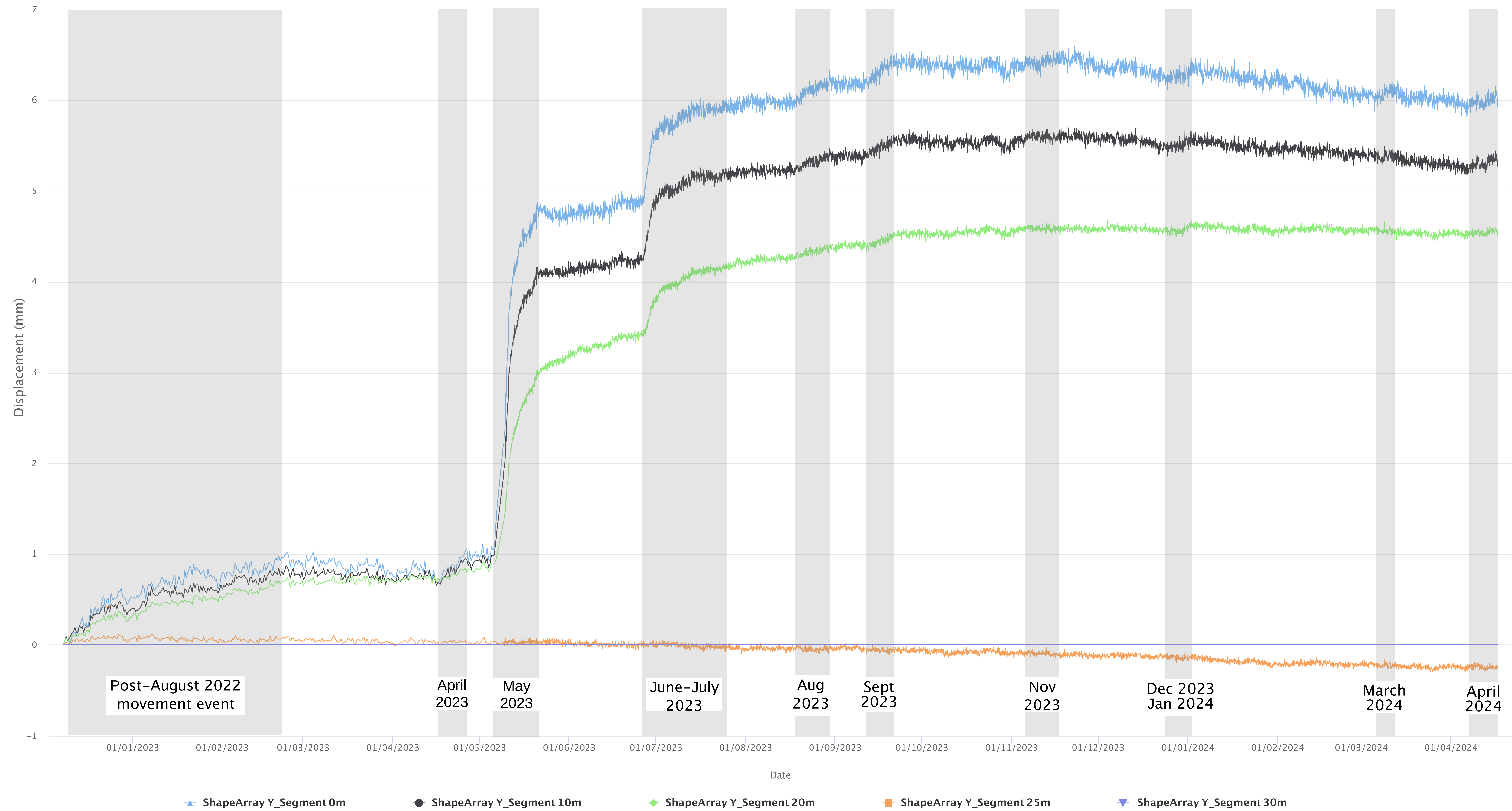
B.6 - Historic Manual Groundwater readings - Tahunanui Slump



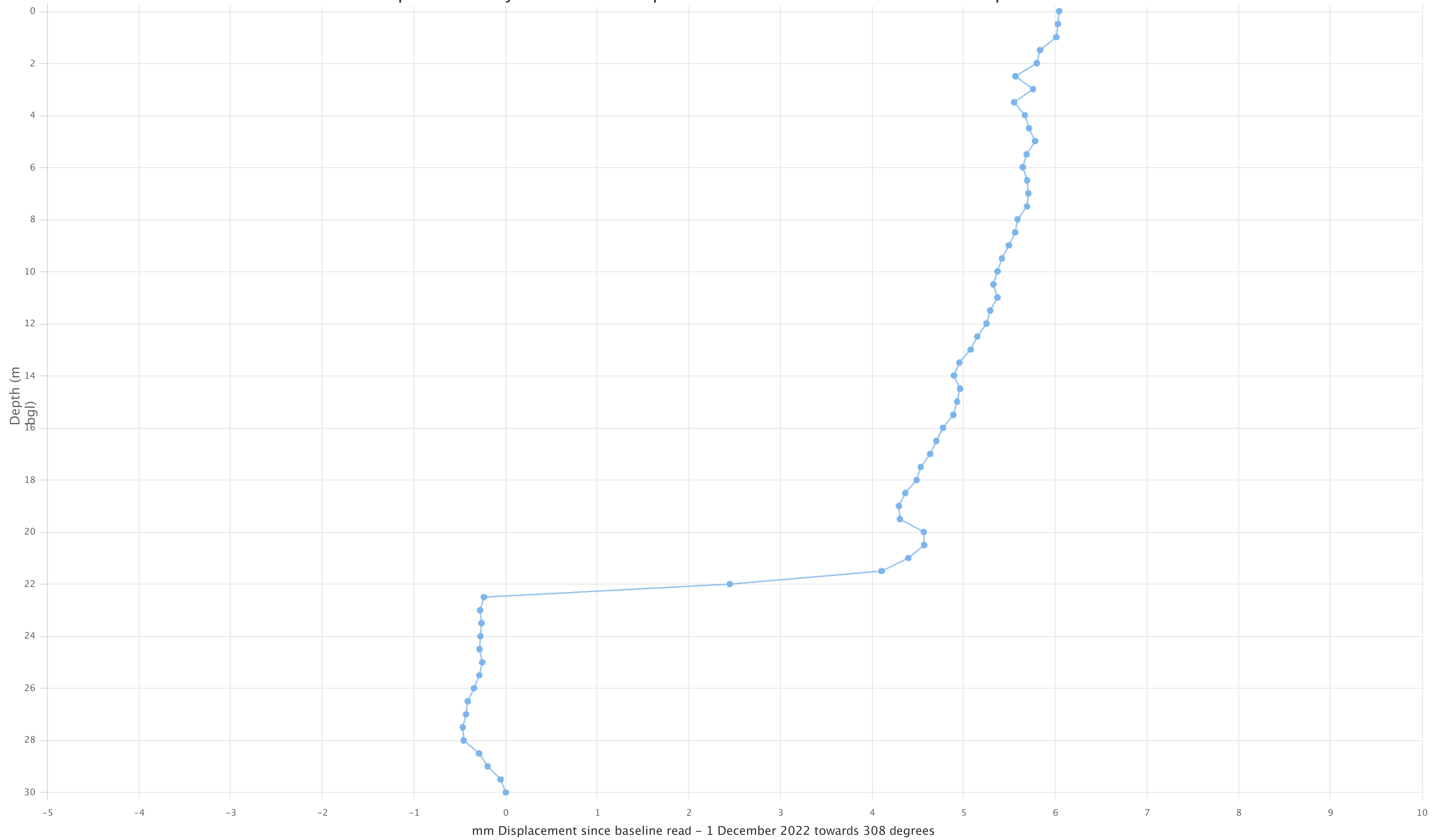
B.7 – ShapeAccelArray Y-Axis cumulative surface displacement (308 degrees) vs. daily/15-day cumulative rainfall and BH03 (shallow) groundwater level



B.8 - ShapeAccelArray displacement (Y-axis – 308 degrees)



B.9 - ShapeAccelArray Cumulative Displacement to 1 December 2022 to 17 April 2024



B.10 – Princes Dr daily rainfall with 15 and 30 day antecedent totals

