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Landslide Monitoring Report – Puketeraki

8 September 2022

CONFIDENTIAL

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Contents

List of Figures

List of Tables

List of Appendices

Disclaimers and Limitations

This report **('Report')** has been prepared by WSP New Zealand Limited exclusively for Dunedin City Council **('Client')** in relation to the landslide monitoring at selected sites in Dunedin (Landslide Monitoring Long-Term SoW DCC Reference 9662). The scope of this report is to present the survey monitoring results and recommendations for future surveys for the site **('Purpose')**. The findings in this Report are based on and subject to the assumptions specified in the Report. WSP accepts no liability whatsoever for any reliance on or use of this Report, in whole or in part, for any use or purpose other than the Purpose or any use or reliance on the Report by any third party.

Executive Summary

A recent survey of the Puketeraki site has been undertaken in July 2022 to assess the extent of movements compared with previous surveys. Deformations found to exceed the accuracy of the survey (±20 mm Horizontal, ±30 mm vertical) are presented in Table 1.

Table 1: Summary of recorded displacements.

	Horizontal	Vertical
Displacements from the previous survey	20 – 70 mm	0 mm
Displacements from the original survey	90 – 3,870 mm	50 - 980mm

The results indicate that deformation is continuing. We recommend the next survey to be undertaken in mid-2023 and a review of the viability of remote monitoring be completed in conjunction with WSP.

1 Introduction

WSP New Zealand Limited (WSP) have been commissioned by Dunedin City Council (DCC) to undertake monitoring of 12 landslide sites around Dunedin. The purpose of monitoring is to identify the trend and magnitude of movements and provide recommendations for future monitoring.

This report presents a summary of the factual survey monitoring results for the Puketeraki site, as well as monitoring recommendations. A mark displacement diagram is provided in Appendix A.

2 Survey Monitoring

2.1 Monitoring History

Survey monitoring of the site has been undertaken at various intervals ranging from 2 weeks to 2.5 years since the original survey network was established in 1992. Since 2003 surveys have been completed annually with the exception of 2019.

Pre-2003 surveys have been condensed into annual data points in the monitoring charts presented in Appendix B.

2.2 Methodology

This year's round of survey monitoring was undertaken by a WSP Surveyor on 29th July 2022, following a period of very high rainfall (refer Section 4 for further information). The equipment utilised were two Trimble R8-3 GNSS receivers.

2.2.1 Field Survey

The survey was undertaken using RTK GNSS, with two 30" occupations on a fixed 2.0 m pole as per the previous contractor's survey. The following notes and changes to the methodology are recorded for future reference;

- The 'free control point' IS 211 placed in 2021 within the Puketeraki lookout carpark for occupation of the local base-station was found bent over due to carpark grading. This mark was removed and replaced with new (IS 211a), in a similar location buried deeper.
- An additional control point, bronze plaque EW5H was observed with 2 x 5' static occupations using the 2.0 m pole. This mark was also in Karitane township on Kerr Street, is a LINZ 5th order Control Point and is Order 3 in vertical.
- There had been very high rainfall in the weeks leading up to the survey that saw many slips occurring around Dunedin. An on-site resident confirmed it was the wettest he had seen the farm in a long time and there were numerous springs and water flowing over-land that normally do not occur. He also mentioned slips occurring on the steep, north facing slopes near the lookout carpark. These were photographed for record purposes.
- Survey marks not shown on the mark displacement diagram in Appendix A can be located using the coordinates provided in Appendix C.

2.2.2 Office Processing

All survey data is processed using Trimble Business Centre post-processing software. Static data from permanent base station DUND has been combined with the local base station setup on IS 211a.

This year repeats the processing methodology of a single fixed Control point 103 with check on 105 as used in 2021, with the new control point, IS 201 placed in 2021 on the corner of Eris and Stornoway Streets as an additional check. We note this mark was on the upper limit of

acceptability in the vertical which prompted an additional control point to be incorporated in the survey at EW5H.

Office processing is based on the assumption previous surveyed levels are derived from the Geodetic Reference System 1980 (GRS80) ellipsoid, no geoid has been applied. As there is no historical Origin of Coordinates or Level, it is not possible to confirm connection of measurements to the specified datums without undertaking additional survey work. With the inclusion of a second geodetic control point in this years' monitoring programme, we note that both DUND and EW5H are in terms of the North Taieri 2000 horizontal datum, being within 0.02 m, however both marks are 0.09 m and 0.11 m above the known GRS80 ellipsoid levels of these marks when holding the historic Puketeraki control points fixed.

2.2.3 Geodetic Parameters

Earlier monitoring survey programmes do not specify the vertical datum or geodesy used for monitoring at this site.

For continuity of future surveys, it is critical the following geodetic parameters presented in Figure 2 to Figure 5 are maintained.

Summary

Coordinate system group:	New Zealand/NZGD2000
Zone:	North Taieri 2000
Datum transformation:	New Zealand Geodetic 2000 (Molodensky)
Global reference datum:	NZGD2000
Global reference epoch:	2000
Geoid model:	None
RTX datum:	No

Figure 1: Coordinate System to be maintained.

Datum Transformation

Method:	Molodensky
Translation X:	0.0000 m
Translation Y:	0.0000 m
Translation Z:	0.0000 m
Local ellipsoid used:	Geodetic Ref System 1980
Local ellipsoid semi-major axis:	6378137.0000 m
Local ellipsoid inverse flattening:	298.257222101

Figure 2: Transformation Parameters to be maintained.

Projection	
Name:	Transverse Mercator
Origin latitude:	S45°51'41.00000"
Origin longitude:	E170°16'57.00000"
False easting:	400000.0000 m
False northing:	800000.0000 m
Scale factor:	0.9999600000
South azimuth system:	No
Positive coordinate direction:	North / East

Figure 3: Projection Settlings to be maintained.

Geoid Model	
Geoid model:	None
Geoid model file name:	
Geoid model quality:	Unknown quality
Vertical Datum	
Vertical datum:	

Figure 4:Vertical Datum to be maintained.

2.3 Accuracy

The survey has been undertaken to the following accuracy:

- Horizontal position +/- 20 mm (@ 95% CI)
- Vertical position +/- 30 mm (@ 95% CI)

Ground movement has occurred when any measurement exceeds the above error tolerances.

2.4 Future Monitoring

An additional control marker is recommended to be included in the Karitane Township for the following reasons;

- Control point redundancy.
- Distance from the site; the only remaining historic control points are at their closest are 240 m from a monitor mark; whereas the Karitane Township marks are 1.7 km from the same mark.
- To check if there is localised deep-seated movement affecting the historic control points nearer the site.
- Point 103 is likely to be unsuitable in future due to it being in the middle of Coast Road.

A change to the historic methodology is recommended to increase accuracy of measurements to control marks. This will improve overall reliability and consistency of the monitor data. It will also allow the surveyor to make informed decisions on control mark reliability. The following changes are recommended;

- Use of tripod and optical plumet to reduce centring errors associated with a 2.0 m pole.
- Static measurements to control marks in Karitane for 20 minutes (additional 1 hour of field work required).

3 Monitoring Results

The cumulative results spreadsheet is presented in Appendix C. A summary of the monitoring results are presented in Table 2 below.

Table 2: Summary of deformation monitoring results since the previous and base surveys.

	Deformation since previous survey		Deformation since base survey	
	Horizontal	Vertical	Horizontal	Vertical
Average*	60 mm	<30 mm	2,090mm	-330 mm
Maximum	75 mm	<30 mm	3,870 mm	-980 mm

* Deformations less than the accuracy of the survey (± 20mm horizontal, ± 30mm vertical) were excluded when calculating averages.

4 Rainfall Data

A summary of the rainfall data since the previous survey is presented in Figure 5. The rainfall data was retrieved from the NIWA (National Institute of Water and Atmospheric Research) National Climate Database website (CliFlo.niwa.co.nz) using the Musselburgh Station (Agent ID #15752).

Mean monthly rainfall is calculated for the "Dunedin" area using data between 1981 and 2010 (source: https://niwa.co.nz/education-and-training/schools/resources/climate/meanrain).

The significant rainfall during July 2022 is evident in Figure 1, whereby 235 mm was recorded in the calendar month, including 97.6 mm on 12 – 13 July and 94.6mm on 26 – 28 July 2022.

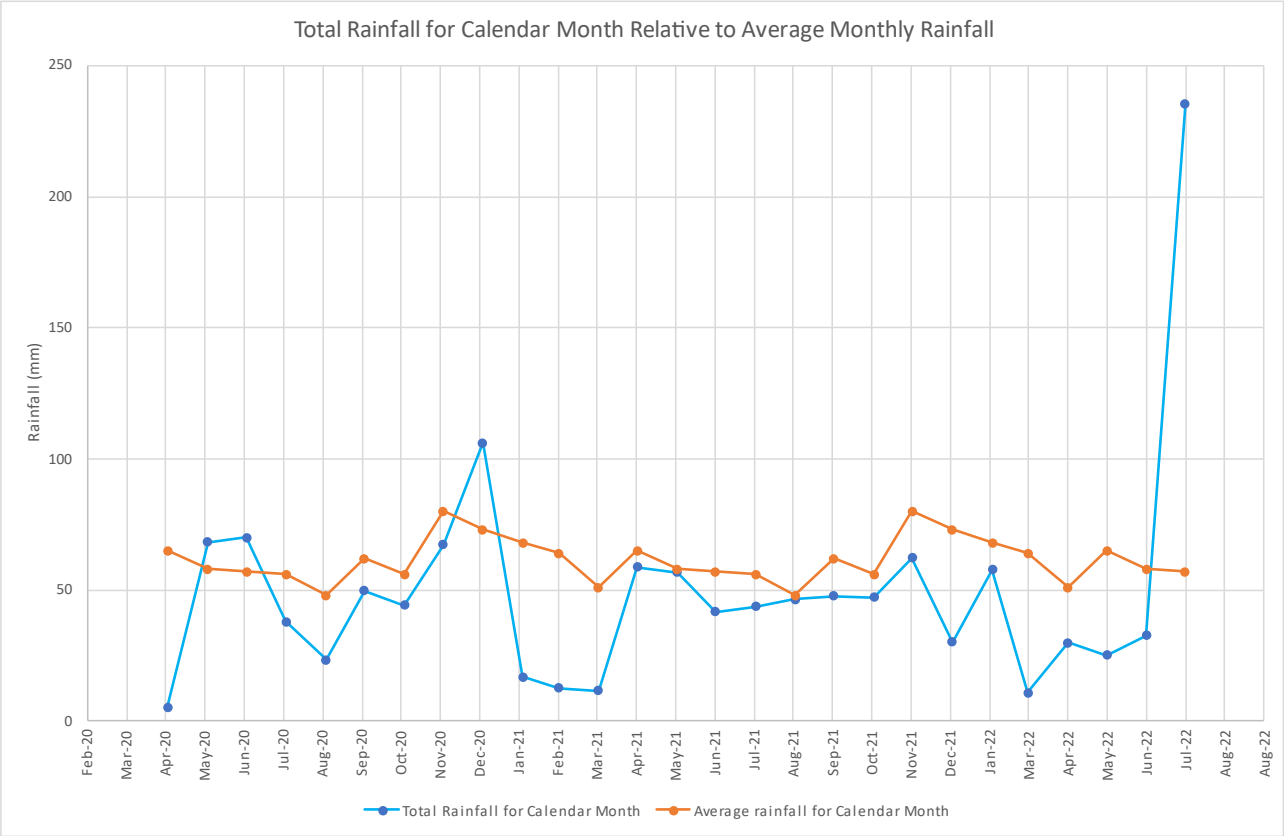


Figure 5: Measured monthly rainfall compared with average monthly rainfall (CliFlo.niwa.co.nz).

5 Conclusions and Recommendations

The maximum displacements recorded since the base survey was completed are as follows:

- 3,870 mm horizontally,
- 980 mm vertically.

The long-term average horizontal deformation from 2000 to 2020 ranges from 85 mm/year to 115 mm/year; however, an average rate of 30 – 60 mm/year from 2020 to present shows this has decreased notably in recent times. This reduced rate appears to be continuing as exhibited by the deformations since previous survey reported above. Similarly, the rate of vertical movement after 2020 is less than the long-term average.

The rate of deformation appears to fluctuate over a period of several years, likely accelerating in response to periods of particularly high rainfall. A brief assessment of deformation rate versus annual rainfall has shown that stages of increased rates of deformation (approaching 300 mm/year, IS 13) coincides roughly with an annual rainfall in excess of 700 mm.

Given the possible link between annual rainfall and the rate of deformation, the infrastructure likely to be affected by movement (water pipes, Coast Road, KiwiRail Main South Line) and the potential implications for public safety, we recommend further investigation into the viability and cost benefits of installing remote monitoring at this site.

Remote monitoring would allow for immediate notification in the event of significant movement, both for the DCC and KiwiRail, and enable a better understanding of the factors which affect deformation characteristics and provide a more proactive management of risk. WSP would be happy to discuss this further.

It is recommended that:

1. A follow-up manual survey is completed in 12 months' time (July 2023), and;
2. Undertake a review of the viability of remote monitoring at this site in conjunction with WSP.

We trust this meets your requirements. If you have any questions or concerns, please do not hesitate to contact WSP.

Appendix A
Mark Displacement Diagram

LEGEND

LANDSLIDE - OTAGO REGION (CERTAINTY)

- DEFINITE
- LIKELY
- POSSIBLE
- NOT ASSESSED
- NO INFORMATION

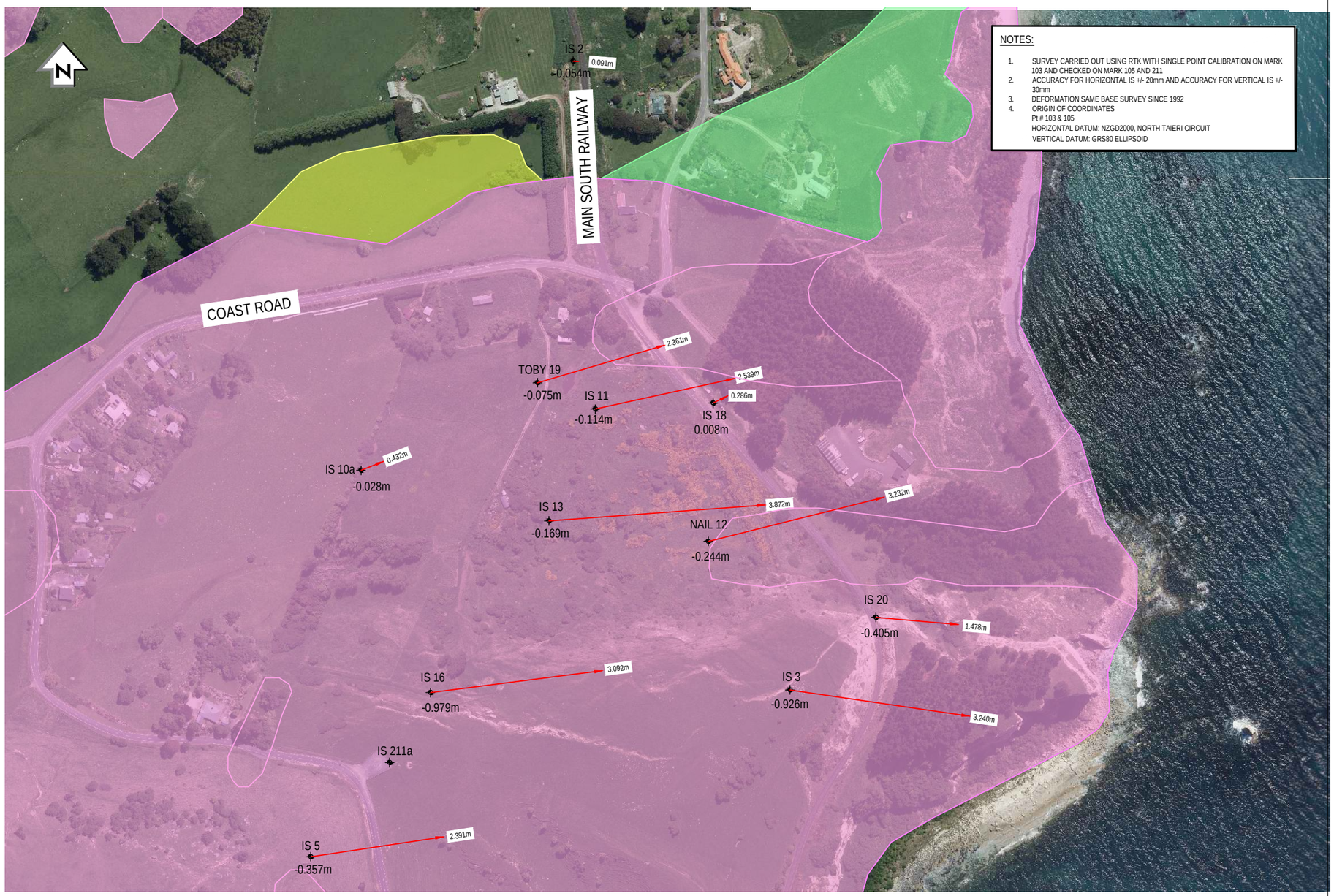
INDICTIVE LANDSLIDE EXTENTS ARE BASED ON "REVISED LANDSLIDE DATABASE FOR THE COASTAL SECTOR OF THE DUNEDIN CITY DISTRICT" BY BARRELL, D.J.A., SMITH LITTLE, B., GLASSEY, P.J. FNS SCIENCE CONSULTANCY REPORT 2017/41, JULY 2017, SOURCED FROM THE OTAGO REGIONAL COUNCIL (ORC) NATIONAL HAZARDS PORTAL.

OTHER

+/- Xmm = CUMULATIVE VERTICAL DISPLACEMENT

CUMULATIVE HORIZONTAL DISPLACEMENT (1:50 SCALE)

SURVEY MARKER



NOTES:

1. SURVEY CARRIED OUT USING RTK WITH SINGLE POINT CALIBRATION ON MARK 103 AND CHECKED ON MARK 105 AND 211
2. ACCURACY FOR HORIZONTAL IS +/- 20mm AND ACCURACY FOR VERTICAL IS +/- 30mm
3. DEFORMATION SAME BASE SURVEY SINCE 1992
4. ORIGIN OF COORDINATES
   Pt # 103 & 105
   HORIZONTAL DATUM: NZGD2000, NORTH TAIERI CIRCUIT
   VERTICAL DATUM: GRS80 ELLIPSOID

0 10 mm 50 100 200 300 mm

1:2000 @ A1
1:4000 @ A3
0 20 40 60 80 100 120 140 160 180 200 m

REVISION	AMENDMENT	APPROVED	DATE

DUNEDIN CITY COUNCIL | kaunihera a-rohe o Ōtepoti

WSP
Dunedin Office
+64 3 471 5500
Private Bag 1913
Dunedin 9016
New Zealand

CIVIL

SCALES 1:2000
ORIGINAL SIZE A1
DRAWN J. W.
APPROVED S.K.
DRAWING VERIFIED C.H.
APPROVED DATE 31/08/2022

FOR INFORMANTION

PROJECT
DUNEDIN CITY COUNCIL
PUKETERAKI
LONG TERM LANDSLIDE MONITORING

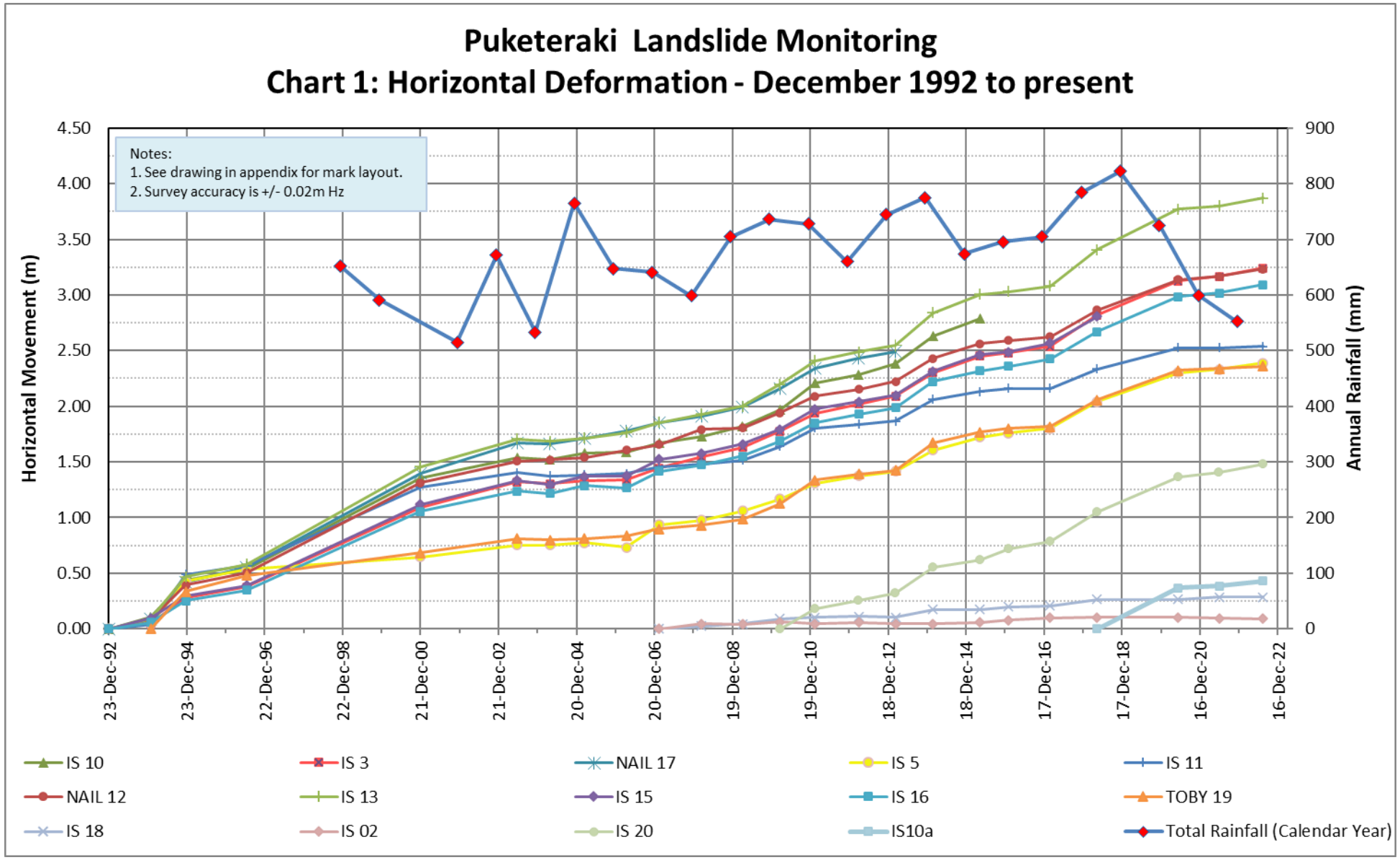
TITLE
CUMULATIVE MARK DISPLACEMENT DIAGRAM
PUKETERAKI - 2022

WSP PROJECT NO.	PROJ-ORIG-VOL-LOC-TYPE	SHEET NO.	REVISION
6-CD109.55	6-CD109.55	C01	A

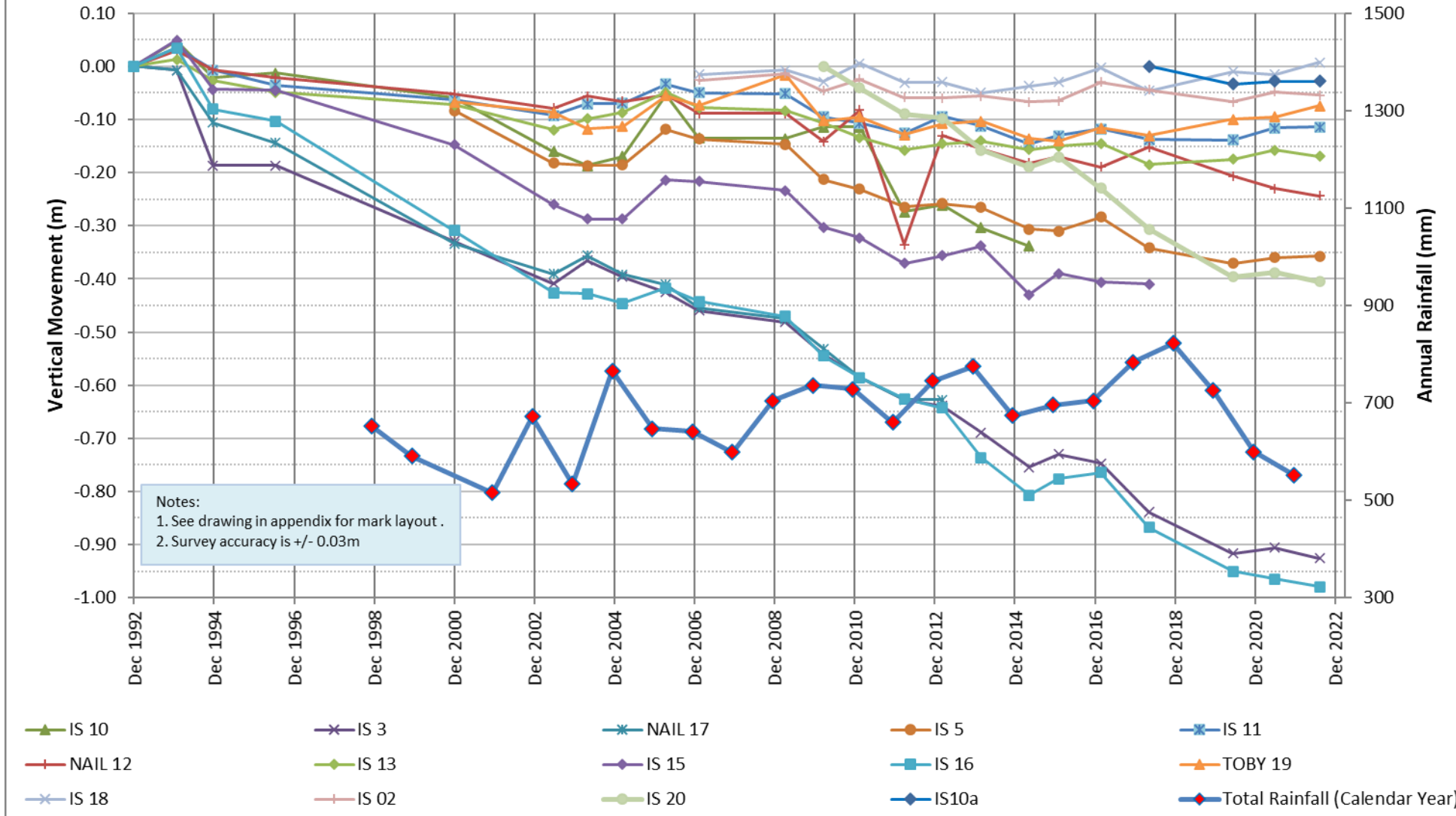
Original sheet size A1 (841x594) Plot Date 2022-09-05 at 4:36:34 PM \\corp\anz\ProjectsNZ\6c\6-CD109.55 LTES Long-term Landslide Monitoring\Home\03_Delivery\Puketeraki\Site Plan\autocad\dwg\80510203-C008 puketeraki.dwg Layout1

Appendix B
Selected Monitoring Charts

Puketeraki Landslide Monitoring
Chart 1: Horizontal Deformation - December 1992 to present



Puketeraki Landslide Monitoring
Chart 2: Vertical Deformation - December 1992 to present



Appendix C
Cumulative Monitoring Results Spreadsheet

DCC LANDSLIDE MONITORING
PUKETERAKI

Geodetic Parameters

Monitoring marks established December 1992
Initially surveyed by STATIC GPS, subsequently by RTK
Monitored yearly since 2004 and more frequently prior to 2004
Estimated accuracy: +/-20mm horizontal
+/-30mm vertical

Vertical: GRS80 Ellipsoid
Horizontal: NZ GD2000
Projection: North Taieri

NOTE: Data is flagged where movement is in excess of:
20mm (Hz)
30mm (Vt)

SURVEY34
Survey Date: 29/07/2022

				Present to Previous (16/06/2021)					Present to Original (08/03/2010)					
Pin #	Northing	Easting	Height	dN	dE	dH	Dist	dRL	dN	dE	Bearing	Dist	dRL	
103	823271.253	428653.839	35.139	0.000	0.000	0.000	0.000	0.000	0.000	0.000		0.000	0.000	FIXED
105	823234.581	428647.600	36.286	-0.001	-0.007	0.009	0.007	0.009	-0.002	0.012	97.125	0.012	0.026	CHECK
150	824788.53	428718.01	17.59	New Control Point Placed for future use										NEW CONTROL
201	824938.249	428913.020	10.248	-0.001	-0.006	-0.020	0.006	-0.020						CHECK
211a	822439.418	428317.776	156.486	New Free Spike Replaces damaged old										NEW BASE CNTRI
2	823064.948	428481.597	70.531	-0.006	-0.005	-0.006	0.008	-0.006	-0.007	0.091	94.399	**0.091**	**-0.054**	
3	822503.946	428676.708	112.554	-0.013	**0.072**	-0.020	**0.073**	-0.020	-0.471	3.206	98.361	**3.240**	**-0.926**	
5	822355.616	428248.897	184.328	0.011	**0.061**	0.003	**0.062**	0.003	0.355	2.364	81.460	**2.391**	**-0.357**	
10a	822700.04	428292.191	111.427	**0.020**	**0.042**	0.000	**0.047**	0.000	0.158	0.402	68.543	**0.432**	**-0.028**	
11	822754.862	428502.311	86.468	0.004	0.012	0.002	0.013	0.002	0.547	2.480	77.558	**2.539**	**-0.114**	
12	822637.040	428603.627	66.415	**0.020**	**0.062**	-0.014	**0.065**	-0.014	0.786	3.135	75.929	**3.232**	**-0.244**	
13	822655.070	428461.910	86.386	0.013	**0.070**	-0.011	**0.071**	-0.011	0.285	3.862	85.776	**3.872**	**-0.169**	
16	822501.873	428355.808	131.168	0.003	**0.073**	-0.014	**0.073**	-0.014	0.394	3.066	82.672	**3.092**	**-0.979**	
18	822760.063	428606.727	69.548	0.001	-0.001	0.023	0.001	0.023	0.127	0.256	63.614	**0.286**	0.008	
19	822778.584	428451.132	88.214	0.003	**0.022**	0.020	**0.022**	0.020	0.665	2.265	73.629	**2.361**	**-0.075**	
20	822568.740	428752.872	69.835	-0.005	**0.073**	-0.017	**0.073**	-0.017	-0.128	1.472	94.970	**1.478**	**-0.405**	

Notes: IS 211 found bent over due to carpark grading, replaced with new IS 211a
2 x 5' Static Observed to EW5H
New 'free-control' check point 211 placed in Puketeraki car-park for base station occupation
1 x additional control mark recommended in Karitane Town for future redundancy

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