Project Number: 6-CD109.55

Landslide Monitoring Report – Cargill Street, Dunedin Central

13 August 2021

CONFIDENTIAL

wsp

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Disclaimers and Limitations

This report ('Report') has been prepared by WSP exclusively for Dunedin City Council ('Client') in relation to the landslide monitoring at selected sites in Dunedin (Long-Term Landslide Monitoring 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 survey of the Cargill Street site was undertaken in June 2021 to assess the extent of movements compared with previous surveys. The main findings (where recorded across survey marks known to have shown deformation consistent with that expected of landslide movements) are presented in Table 1 below.

Table 1 Summary of recorded displacements.

	Horizontal	Vertical
Displacements from the May 2018 survey	0 – 6 mm upslope	0 – 8 mm
Displacements from the original survey	31 – 40 mm downslope	5 – 44 mm

The results suggest minor movement in the upslope direction since the May 2018 survey, however this barely exceeds the accuracy of the survey (± 5 mm Horizontal) and is not considered to reflect true movement. Vertical survey data across these same marks (accuracy of ± 2 – 4 mm) indicates settlement has continued at a rate approximately equal to the long-term average since 2018.

1 Introduction

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 Cargill Street site, as well as monitoring and/or treatment recommendations. A survey network diagram is provided in Appendix A.

2 Survey Monitoring

2.1 Monitoring History

Survey monitoring of the site has been undertaken since 2000. Due to marks having been destroyed, the monitoring baseline was re-established in 2006 and 2013. Recent monitors have referenced the original 2000 survey as the baseline data, however pre-2006 data is not available and has therefore not been presented.

Surveys since 2006 have been completed at approximate annual intervals, except for mid-2019 where the annual survey was missed. Approximate survey dates are shown in monitoring charts presented in Appendix B.

2.2 Methodology

The survey monitoring was undertaken by a WSP surveyor and assistant on 21 June 2021. The equipment used comprised a Leica DNA 03 digital level with fixed 3 m invar barcode staff and a Trimble S6 (3") DR300+ Total station with a fixed 0.1 m high mini prism. The manufacturers accuracy specifications are below:

Technical data

Height measurements
Standard deviation per km double run
(ISO 17123-2):

Electronic measurement	DNA03	DNA10
with invar staff	0.3mm	0.9mm
with standard staff	1.0mm	1.5mm
Optical measurement	2.0mm	2.0mm

TRIMBLE S6 DR300+

Angle measurement

Accuracy (Std deviation)	3" (1.0 mgon)
Angle Display (least count)	0.1" (0.01 mgon)

Distance measurement Accuracy (RMSE)

Standard Prism	2 mm + 2 ppm
Standard deviation:	1 mm + 2 ppm

2.2.1 Field Survey

The survey methodology for Cargill Street was previously established as relative measurements from a fixed baseline. The terminal points of the baseline are considered fixed (and outside the zone of movement), and a series of monitoring marks are installed on-line through the area of movement. All marks are located in the footpath; the 14 monitor nails are separated approximately 7 – 10 m on the south side of Cargill Street between house numbers 56 – 114.

The levels of each mark were determined by a double run (closed loop) between terminal baseline marks 14A and 15B. Each monitor mark was measured twice (once on each run). The use of invar was an important consideration and was used in preference of other staff materials that suffer from expansion and contraction with temperature changes. Depending on material of staff previously used, the effect of temperature on levels between summer and winter monitors could influence the level results more than the quoted accuracy.

Due to the method the previous installation of the survey marks and with asphalt re-sealing, marks 9 - 13 were below the level of seal and the foot of the level staff was not able to sit directly on these marks without contacting the seal.

Levels for marks 9 - 13 were therefore established by total station measurement using a 0.1 m mini-prism. This was done in conjunction with the horizontal offset measurement (i.e. with the total station set directly over mark 14A, the instrument height measured by steel tape). A second setup was carried out near mark 11A, and a resection to 14A and 15B with zero instrument height was carried out and level measurements to marks 9 - 13 were repeated as a level check.

All measurements for horizontal positioning were carried out from mark 14A using a 0.1 m mini-prism with the back-sight set to 15B. Each mark offset was derived from an average of left and right face measurements. An additional mark, a steel masonry anchor, was installed in the top of kerb fronting 123 Cargill Street for check purposes.

2.2.2 Office Processing

Survey data was processed using on-board Leica software and total station data brought through 12d survey software for QA. Level data measurements are kept on file in an excel spreadsheet and checks were carried out between the multiple measurements. In summary:

Level run misclose: 0.0002 m

Differences	$\bar{X}$ (m)	σ (m)	Min. (m)	Max (m)
Dual DNA03 measurements	0.0007	0.0002	0.0003	0.0009
DNA03 v Total Station	-0.0012	0.0009	-0.0027	0.0010

Total station measurement differences compared to the level were consistent, except one outlier, and slightly higher. A -0.0012 m correction was therefore applied to the total station measurements to bring marks 9 - 13 into terms with the level measurements.

2.2.3 Geodetic Parameters

This site is measured and processed as a flat plane with no scale factor or pre-existing geodesy settings.

The historically established Origin of Levels is mark 14A at 145.887. It is not known how this level was established or why it was chosen but is considered an arbitrary false datum for the purposes of this survey.

2.3 Accuracy

Historically, this survey is considered to meet the following accuracies:

Horizontal position	+/- 5 mm (@ 95% CI)
Vertical position	+/- 2 mm (@ 95% CI)

Considering this survey incorporates total station for some of the monitor levels, marks 9 – 13 are a lesser accuracy, estimated at +/- 4 mm.

A pattern of increasing vertical differences can be seen across the monitor marks as distance from the origin increases, in the present to previous (June 2020) comparison. This pattern does not exist when compared to the May 2018 survey, suggesting a small systematic error or correction was accumulating with each setup on the previous survey.

2.4 Future Monitoring

The above accuracies assume the terminal points are static. This assumption could be proven with measurement to additional marks adjacent to the terminal points. To set this up would take approximately 2.5 hours and add approximately 1.5 hours to each subsequent monitor.

The re-establishment of baseline marks on multiple occasions has increased the complexity of processing survey data. We recommend the DCC consider discussing options to improve redundancy and reliability of the survey with WSP.

3 Monitoring Results

The comparative results spreadsheet is presented in Appendix C of this report.

In the summary of monitoring results presented in Table 2 below, only data from markers which have displayed an historic trend consistent with landslide deformation (settlement and downslope deformation) has been assessed. Markers which exhibit uplift and/or movement in the upslope (northwest) direction have not been assessed as they are not considered relevant to the purpose of this report. Nevertheless, all data will be reviewed equally during each monitoring round to ensure that newly emerging trends of landslide deformation are not missed.

Due to an inferred systematic survey error discussed in Section 2.3, Table 2 below compares the most recent survey with that from May 2018, rather than the previous survey undertaken in June 2020. While this inferred error relates only to vertical deformations, both horizontal and vertical deformations have been compared with that from 2018 to maintain consistency. Two versions of graphed data have been presented in Appendix B, the first excluding June 2020 survey data, and the second including it.

Table 2 Summary of deformation monitoring results since the May 2018 and base surveys.

	Deformation since May 2018 survey		Deformation since base survey	
	Horizontal	Vertical	Horizontal	Vertical
Average	<5 mm	-4 mm	-36 mm	-30 mm
Maximum	+6 mm	-8 mm	-40 mm	-44 mm

While survey data suggests that up to 6 mm of horizontal movement has occurred in the upslope direction since the 2018 survey, this is not considered to reflect true movement as it only marginally exceeds the accuracy of the survey and is in the wrong direction for landslide deformations. This may have been caused by several factors, such as a change in survey personnel, or fluctuations within survey accuracy where little or no true movement has occurred.

4 Rainfall Data

A summary of the rainfall data since the previous survey is presented in Figure 1 below. 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 between 1981 and 2010 (source: https://niwa.co.nz/education-and-training/schools/resources/climate/meanrain).

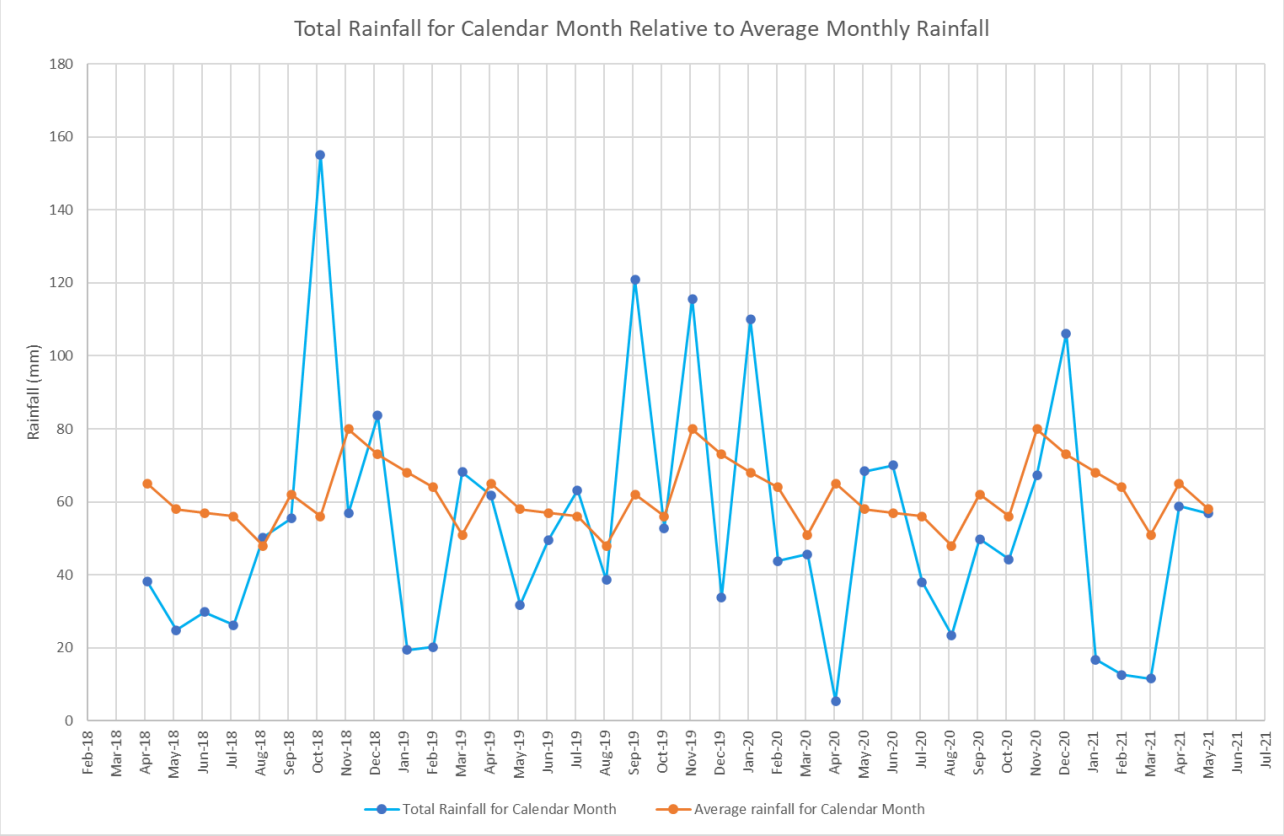

Figure 1 Measured monthly rainfall compared with average monthly rainfall (CliFlo.niwa.co.nz).

5 Conclusions and Recommendations

Within this report, characteristic landslide deformation has been defined as downslope movement in conjunction with vertical settlement. Either of these movements in isolation is likely related to a different mechanism such as consolidation, root jacking, retaining wall deflections etc. Only 4 marks (4b, 5a, 6a, and 7c) in this survey have exhibited movements consistent with landslide deformation.

The maximum displacements since the 2000 base survey are as follows:

- 40 mm in plan; and,
- 44 mm vertically.

Survey results indicate no negative horizontal deformation (downslope direction) exceeding the accuracy of the survey since 2018. Positive horizontal movements (in the upslope direction) of up to 18 mm have been recorded when compared with 2018, however these are considered unrelated to landslide deformation. The cause of these movements is currently unknown.

Of all marks considered related to landslide movement, an average settlement of 4 mm has been recorded when compared against 2018 data. The long-term average rate of settlement of these same marks since 2000 is equal to 1.4 mm/year, or 4.2 mm over 3 years since 2018.

The recorded displacements are generally aligned with the long-term average, suggesting that the acceleration of vertical movement highlighted in the 2020 report is most likely related to the survey error discussed in Section 2.3.

We recommend the continuation of survey monitoring at an annual interval with the next survey scheduled for June 2022. We also recommend consideration be given to installing additional baseline markers in consultation with WSP to improve reliability of the monitoring network in future.

Appendix A
Network Diagram

NOTE:

1. Survey carried out on a false datum, no scale factor.
2. Measurements are relative to a fixed base-line 14A - 15B
3. Origin of Levels; 14A = 145.887m (False Datum)
4. Original Survey established Dec 2000, baseline destroyed and re-established in 2006 and 2013
5. Horizontal accuracy: +/- 5mm
   Vertical accuracy: +/- 2-4mm (see report for details)
6. Horizontal Vector arrows are exaggerated by 1000 of the distance moved

LEGEND

LANDSLIDE - OTAGO REGION (CERTAINTY)

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

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

OTHER

+/- Xmm = CUMULATIVE VERTICAL DISPLACEMENT

CUMULATIVE HORIZONTAL DISPLACEMENT

SURVEY MARKER

1:100 @ A1
1:200 @ A3
0 1 2 3 4 5 6 7 8 9 10 m

WORK IN PROGRESS

PRINTED 11/08/2021 10:32:13 AM

REVISION	AMENDMENT	APPROVED	DATE

DUNEDIN CITY COUNCIL | kaunihera a-rohe o Ōtepoti

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New Zealand

CIVIL

SCALES 1:

ORIGINAL SIZE A1

DRAWN | DESIGNED | APPROVED

DRAWING VERIFIED | DESIGN VERIFIED | APPROVED DATE

FOR INFORMATION

PROJECT
MONITORING
LONG TERM LANDSLIDE
MONITORING

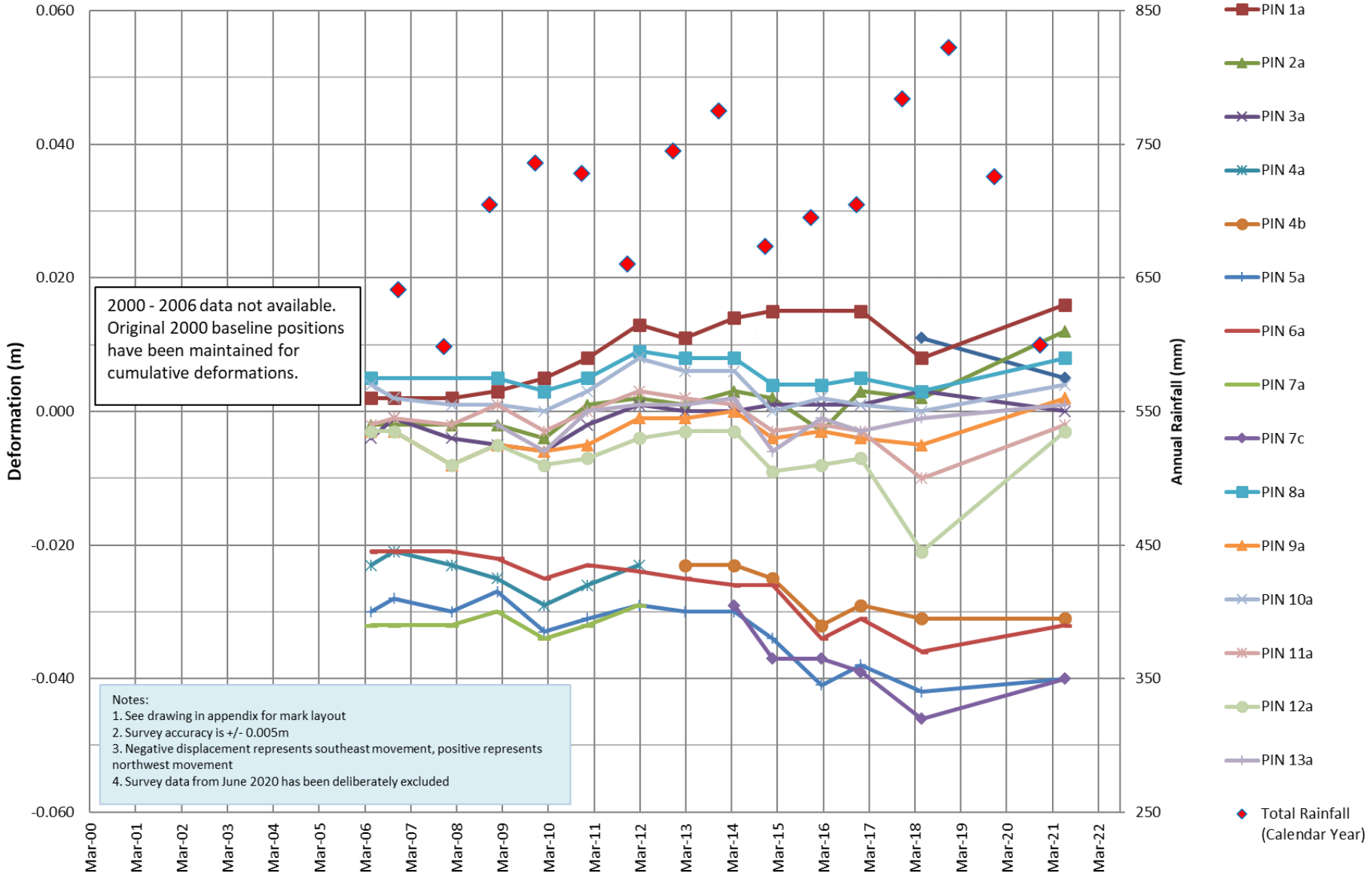
TITLE
CARGILL STREET
MONITORING NETWORK

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

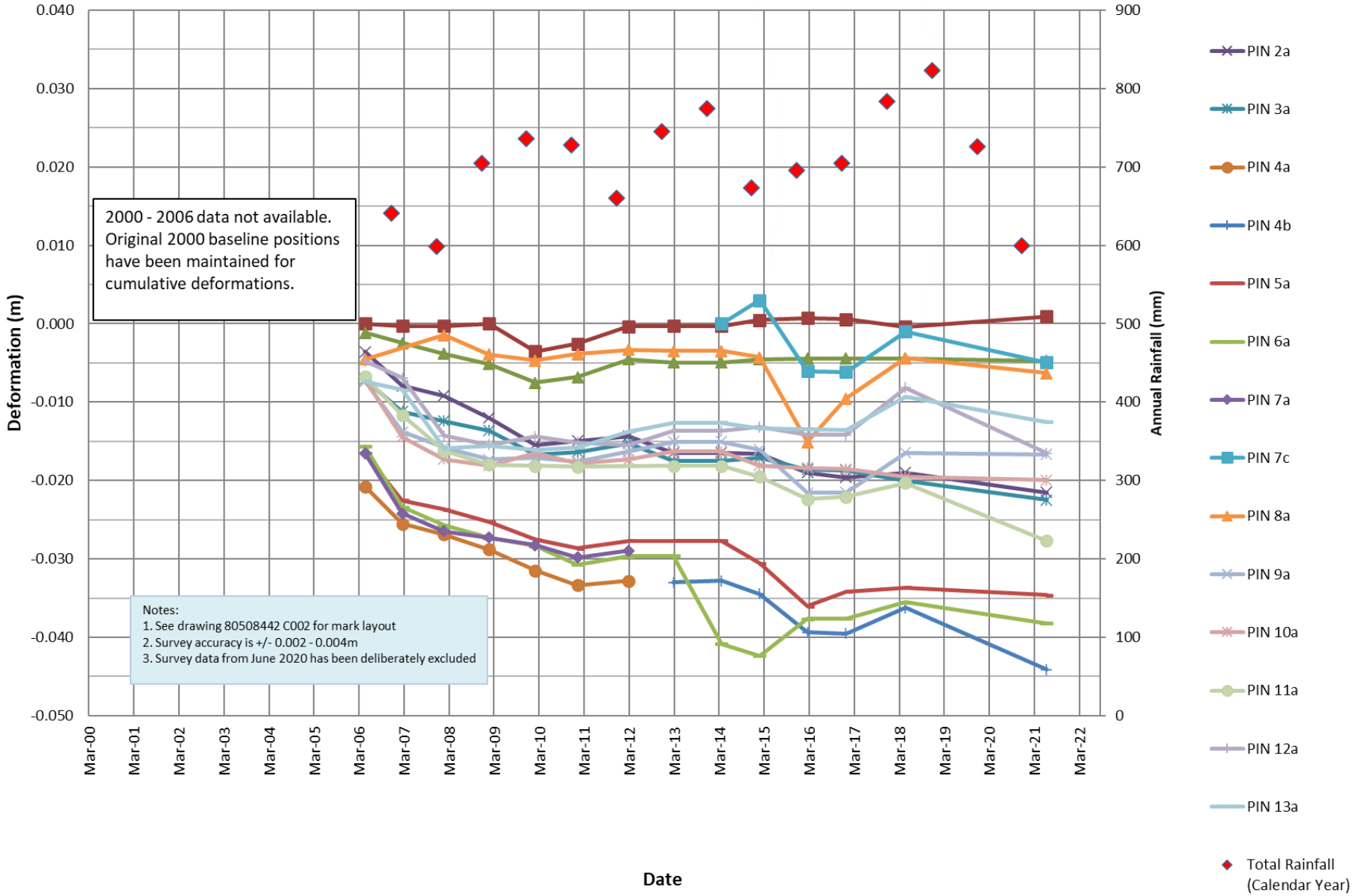
Original sheet size A1 (841x594) Plot Date 2021-08-11 at 10:32:13 AM \\corp.pbwan.net\ANZ\ProjectsNZ\6c\6-CD109.PP DCC LTES Project Bids\Home\LTES SoW Landslide Monitoring Long-Term\Folder Structure\001. Info from Stantec\dwg files\80509491 C002 Cargill Street.dwg Layout2

Appendix B
Selected Monitoring Charts

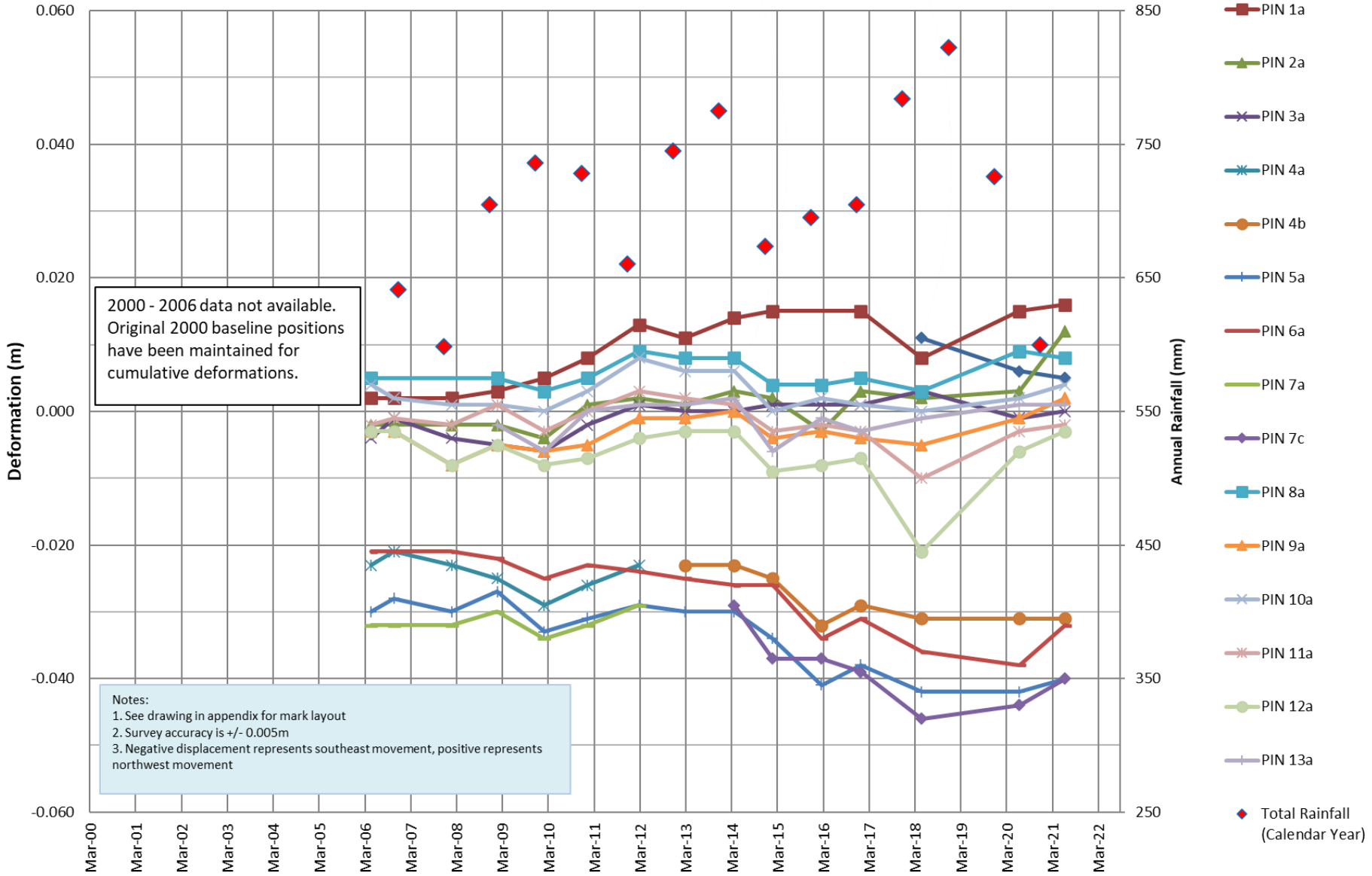
Cargill St Landslide Monitoring
Chart 1 : Horizontal Deformation - February 2000 to present



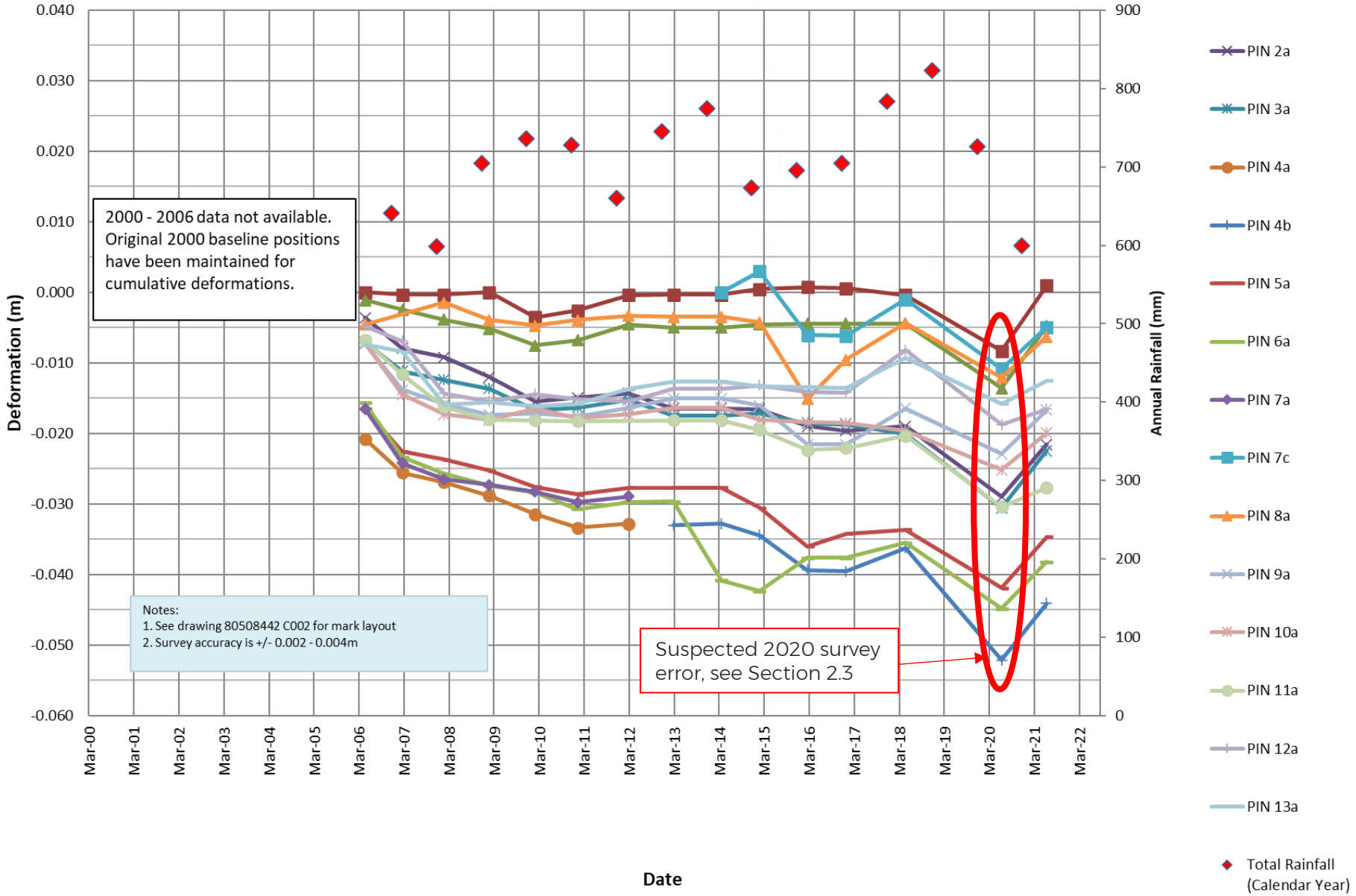
Cargill St Landslide Monitoring
Chart 2 : Vertical Deformation - February 2000 to present



Cargill St Landslide Monitoring
Chart 1 : Horizontal Deformation - February 2000 to present



Cargill St Landslide Monitoring
Chart 2 : Vertical Deformation - February 2000 to present



Appendix C
Cumulative Monitoring Results Spreadsheet

DCC LANDSLIDE MONITORING
CARGILL STREET BASELINE

Original Baseline established December 2000
Baseline re-established in May 2006 due to pins being destroyed
Levels measured by spirit levelling
Baseline offsets measured using robotic total station
Estimated accuracy: +/-5mm horizontal
+/-2mm vertical
Pin 14 is held fixed for levels at RL: 145.887
A negative offset indicates movement in a southerly direction (towards York Place).

NOTE: Data is flagged where movement is in excess of:
5mm (Hz)
2mm (Vt)

SURVEY 15			Present to Previous		Present to Original			Present to	
Survey Date:	21/06/2021		18/06/2020		(Dec 2000)			11/05/2018	
Pin #	Height	Offset	dRL	dOffset	dRL	dOffset		dRL	dOffset
PIN 0a	131.020	0.013	**0.009**	-0.001	0.001	0.005	PIN 0a	0.001	0.002
PIN 1a	132.569	0.014	**0.009**	0.001	**-0.005**	**0.016**	PIN 1a	0.000	**0.008**
PIN 2a	132.996	0.003	**0.007**	-0.002	**-0.022**	0.001	PIN 2a	**-0.003**	-0.001
PIN 3a	133.387	0.004	**0.008**	0.001	**-0.022**	0.000	PIN 3a	**-0.002**	-0.003
PIN 4b	133.880	-0.096	**0.008**	0.000	**-0.044**	**-0.031**	PIN 4b	**-0.008**	0.000
PIN 5a	134.544	-0.010	**0.007**	0.002	**-0.035**	**-0.040**	PIN 5a	-0.001	0.002
PIN 6a	135.420	-0.011	**0.007**	**0.006**	**-0.038**	**-0.032**	PIN 6a	**-0.003**	0.004
PIN 7c	136.505	0.001	**0.006**	0.004	**-0.005**	**-0.040**	PIN 7c	**-0.004**	**0.006**
PIN 8a	137.495	0.003	**0.006**	-0.001	**-0.006**	**0.008**	PIN 8a	-0.002	0.005
PIN 9a	138.476	0.005	**0.005**	0.003	**-0.018**	0.002	PIN 9a	-0.002	**0.007**
PIN 10a	139.210	0.003	**0.003**	0.002	**-0.022**	0.004	PIN 10a	**-0.002**	0.004
PIN 11a	140.084	0.000	0.002	0.001	**-0.028**	-0.002	PIN 11a	**-0.008**	**0.008**
PIN 12a	141.030	0.000	0.003	0.003	**-0.015**	-0.003	PIN 12a	**-0.007**	**0.018**
PIN 13a	141.905	0.006	0.003	0.000	**-0.013**	0.001	PIN 13a	**-0.004**	0.002

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