Project Number: 6-CD109.55

Landslide Monitoring Report – Church Hill Road Site

7 December 2022

CONFIDENTIAL

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Document Details:

Date: 7/12/2022
Reference: 6-CD109.55
Status: Final

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Document History and Status

Revision	Date	Author	Reviewed by	Approved by	Status
A	7/12/2022	Chris Hall/ Scott Kvick	Nima Taghipouran	Abdul Obaid	Final

Revision Details

Revision	Details
A	Final

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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 Church Hill Road site has been undertaken in August 2022 to assess the extent of movements compared with previous surveys. Deformations found to exceed the accuracy of the survey (±15 mm horizontal, ±25 mm vertical) are presented in Table 1.

Table 1: Summary of recorded displacements.

	Horizontal	Vertical
Displacements from the previous survey	< 0 – 30 mm	< 0 – 25 mm
Displacements from the original survey	< 15 – 590 mm	< 25 – 230 mm

The results indicate a continuation of the previously recorded rate of movement for all markers.

We recommend the next survey to be undertaken in mid-2023.

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 Church Hill Road, Green Island site, as well as monitoring 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 at various intervals ranging from 9 months to 2.5 years since the original survey network was established in 1997. Approximate survey dates are shown in monitoring charts presented in Appendix B.

2.2 Methodology

This year's round of survey monitoring was undertaken by two WSP Surveyors on 19 August 2022. The equipment utilised included two Trimble R8-3 GNSS receivers and one Trimble R8-2 GNSS receiver.

2.2.1 *Field Survey*

The survey was undertaken using Real Time Kinematic (RTK) GNSS, with two 90'' occupations as per previous methodology. A local base station set on Iron Spike 1 (IS 1) logged static data at 1 Hz while simultaneously transmitting RTK corrections to the two rovers. Between measurements, the receiver was rotated 180° and a two-minute wait was observed to allow for a change of satellite geometry. The following methodology changes from the previous (2021) survey were made to ensure reported accuracies were met:

- Where possible, marks were measured with a tripod and optical plummet for increased accuracy on mark centring. Mark 5 was measured with a 2.0m long pole due to its proximity to a fence. Antenna heights were measured by steel tape three times and averaged. The previous survey method utilised a 2.0m pole measurement on all marks.
- Two new monitor marks, one spike and one nail, were installed on Kirkland St to increase coverage within the modelled slip zone. Their coordinates are provided in Appendix C.
- Any mark outside radio coverage (Trig A2 – intermittent radio connection on this survey) has been measured with 20 minutes of Static Data (2 x 10' observation at 1 Hz). This static observation also meets job accuracy requirements.

2.2.2 *Office Processing*

Survey data is processed using Trimble Business Centre post-processing software. Static data from permanent base stations OUSD and DUND are combined with the local base station static data from IS 1.

In 2021 (the first monitoring survey following contract handover), ambiguities around how the network was initially set-up were investigated. Findings are recorded below for clarity and to ensure future surveyors maintain the survey geodesy, which is of key importance on monitoring surveys.

1. The coordinates in this survey are not in terms of the Geodetic Survey Marks the geodesy settings (datums) suggest. This applies to both position and level. Therefore, this survey was previously carried out in a 'False' datum.

2. Ellipsoid levels are reported to the GRS80 Ellipsoid, not the International Hayford 1924 Ellipsoid as used within the NZGD1949 Datum.

A network adjustment was carried out holding existing IS 2, installed in 2021, fixed in terms of NZGD49 horizontal grid coordinate and GRS80 vertical ellipsoid height. Bench Mark Green Island (BM GI) landfill, an iron tube, is in an unsuitable location for use as a primary control mark. Now with the completion of this 2nd WSP survey, there are sufficient additional marks to no longer require measurement to BM GI Landfill.

2.2.3 *Geodetic Parameters*

For continuity of future surveys, ensure the following geodetic parameters presented in Figure 1 to Figure 5 are maintained.

Summary

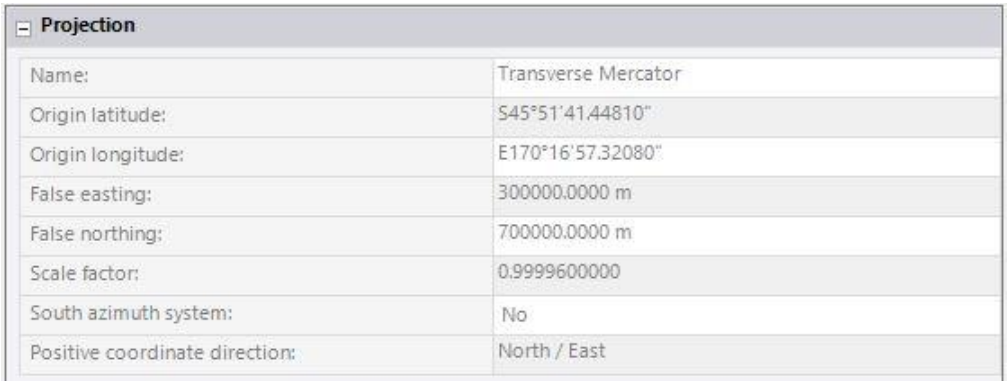
Coordinate system group:	New Zealand/NZGD1949 (LC)
Zone:	North Taieri
Datum transformation:	New Zealand Geodetic 1949 (LC) (Seven Parameter)
Global reference datum:	NZGD2000
Global reference epoch:	2000
Geoid model:	None
RTX datum:	No

Figure 1: Coordinate System to be maintained

Datum Transformation

Method:	Seven Parameter
Translation X:	-59.4700 m
Translation Y:	5.0400 m
Translation Z:	-187.4400 m
Rotation X:	0°00'00.47000"
Rotation Y:	-0°00'00.10000"
Rotation Z:	0°00'01.02400"
Scale factor:	6.333ppm
Local ellipsoid used:	International (NZLC)
Local ellipsoid semi-major axis:	6378399.0589 m
Local ellipsoid inverse flattening:	297.000000000

Figure 2: Transformation Parameters to be maintained

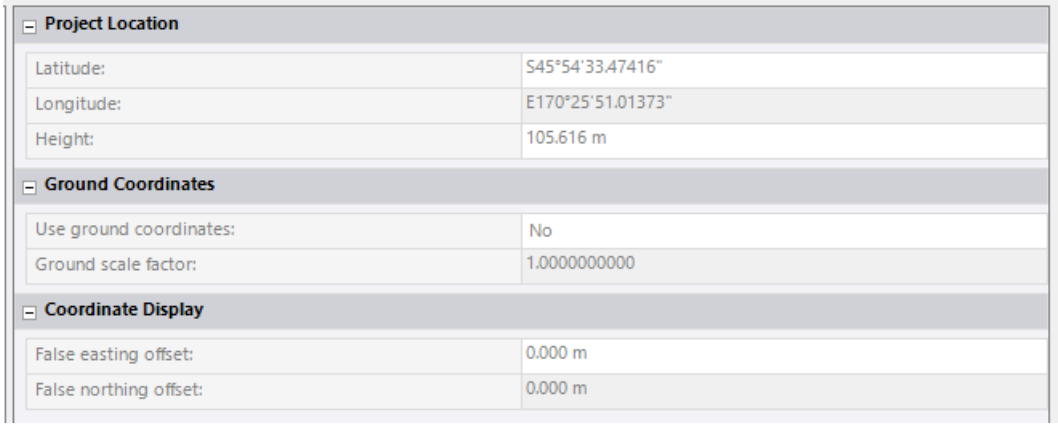


Projection	
Name:	Transverse Mercator
Origin latitude:	S45°51'41.44810"
Origin longitude:	E170°16'57.32080"
False easting:	300000.0000 m
False northing:	700000.0000 m
Scale factor:	0.9999600000
South azimuth system:	No
Positive coordinate direction:	North / East

Figure 3: Projection Settings 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



Project Location	
Latitude:	S45°54'33.47416"
Longitude:	E170°25'51.01373"
Height:	105.616 m
Ground Coordinates	
Use ground coordinates:	No
Ground scale factor:	1.0000000000
Coordinate Display	
False easting offset:	0.000 m
False northing offset:	0.000 m

Figure 5: Local Site Settings to be maintained

2.3 Accuracy

Historical surveys have been reported to horizontal accuracy of 20mm and vertical accuracy of 30mm. Changes to the measurement methodology include replacing pole measurements (low accuracy centring) with tripod optical plummet (high accuracy plate bubble), the addition of static measurements (greater accuracy than RTK) to Trig A2, and via site base station (introduced 2021) set-up on IS 1 (RTK and logging static) also strengthens network geometry. The survey network now has higher redundancy, improved repeatability and tighter precisions resulting in overall greater confidence of meeting the historic accuracy:

Horizontal position +/- 15 mm (@ 95% CI)
Vertical position +/- 25 mm (@ 95% CI)

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

2.4 Future Monitoring

It is recommended that future survey monitors follow the methodology and geodetic parameters detailed above, with changes to hold IS 2 (outside 47 Brighton Road) fixed horizontally and vertically with checks on IS 1, SS Weir St and Trig A2. In the 2021 survey it was recommended that IT BM GI Landfill be removed from checks should it meet accuracy tolerances due to poor overhead visibility. This has been achieved and the mark will no longer be recorded in future surveys. The new monitor marks installed will be tested on the subsequent survey to see if there is any movement compared to the 2022 baseline.

Should greater accuracy be required, an improved methodology suited to this site could include the addition of a second local base station on IS 2 and measurements to monitor marks using post-processed kinematic. Monitor marks would then be 'double tied' with perpendicular baseline geometry to tighten error ellipses.

3 Monitoring Results

The cumulative results spreadsheet is presented in Appendix C. The monitoring results are discussed below.

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

	Deformation since previous survey (June 2021)		Deformation since base survey (June 1997)	
	Horizontal	Vertical	Horizontal	Vertical
Average*	19 mm	< 25 mm	300 mm	85 mm
Maximum	30 mm	< 25 mm	590 mm	230 mm

* Deformations less than the accuracy of the survey (±15 mm horizontal, ±25 mm vertical) were excluded when calculating averages.

4 Rainfall Data

A summary of the rainfall data since the previous survey is presented in Figure 6. 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).

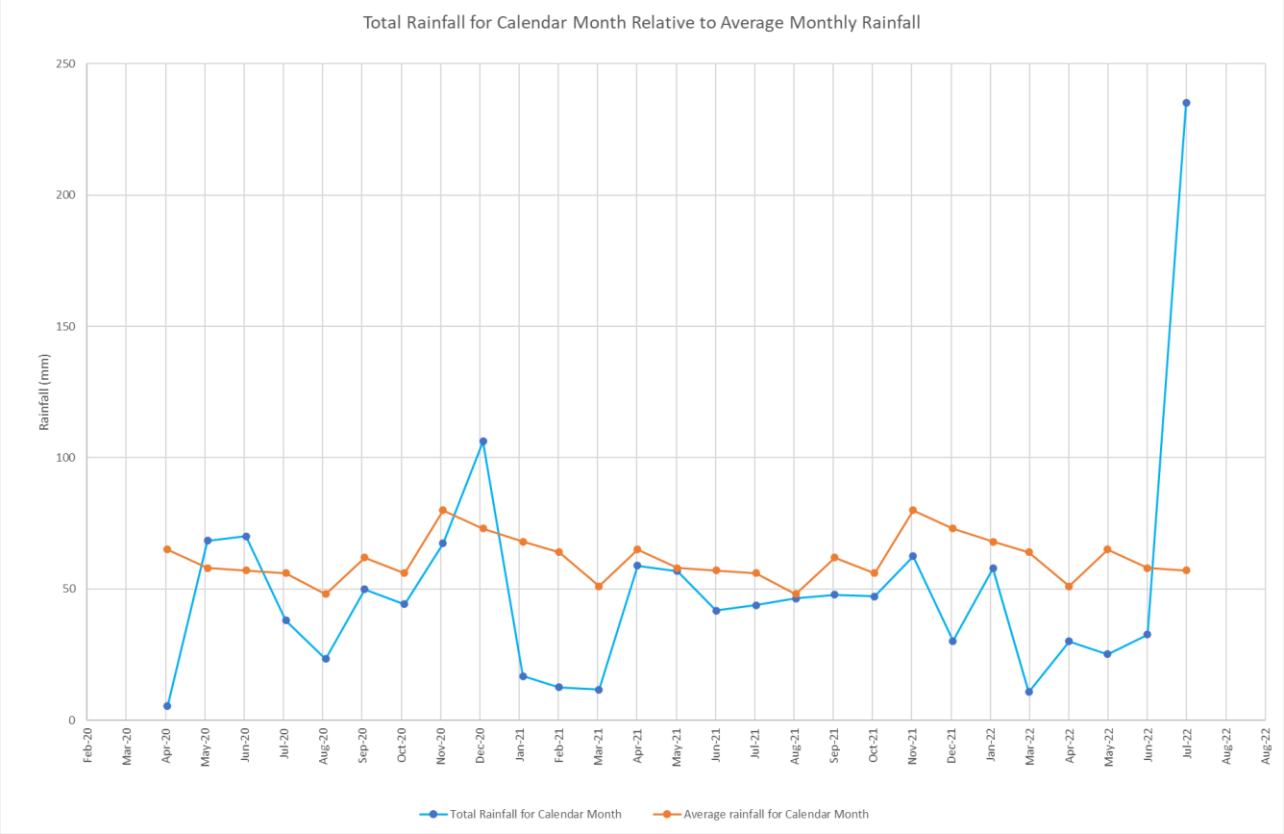


Figure 6 Measured monthly rainfall compared with average monthly rainfall (CliFlo.niwa.co.nz).

5 Conclusions and Recommendations

The maximum displacements recorded since the 1997 base survey was completed are as follows:

- 590mm in plan,
- 230mm vertically.

Survey results indicate the rate of horizontal and vertical movement since the previous survey is consistent with the long-term trend across all marks. The maximum horizontal deformation recorded since the base survey (mid-1997) indicates an average rate of horizontal movement of approximately 24mm/year at Marks 5, 6, and 7 at the northern and western ends of the mapped landslide extent (see Appendix A), which is broadly consistent with this year's records. In comparison, Marks 11, 12, and 13 at the eastern and southern ends of the mapped landslide exhibit relatively low total deformations since the base survey.

Going forward, tripods should be maintained for recording deformation marks where possible as it has shown a marked improvement in accuracy.

Despite Mark 3B being destroyed, its position is well outside of the slip area. This could be replaced and discarded at the DCC's discretion.

We recommend the monitoring to be continued on an annual basis, with the next monitoring scheduled for mid-2023.

Appendix A
Network Diagram

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 LITTLE, 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 SINCE THE BASE SURVEY

CUMULATIVE HORIZONTAL DISPLACEMENT SINCE THE BASE SURVEY (1:1000 SCALE)

SURVEY MARKER

1:1500 @ A1
1:3000 @ A3
0 20 40 60 80 100 120 140 m

REVISION	AMENDMENT	APPROVED	DATE
A	2021 DEFORMATION MONITORING DATA	SK	30/07/2022
B	2022 DEFORMATION MONITORING DATA	SK	25/10/2022

DUNEDIN CITY COUNCIL | kaunihera a-rohe o Ōtepoti

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

CIVIL

SCALES: 1:3000 @A1, 1:6000 @A3
ORIGINAL SIZE: A1
DRAWN: J.W.
APPROVED: C.H.
DRAWING VERIFIED: C.H.
APPROVED DATE: 25/10/2022

2022 SURVEY RESULTS

PROJECT
DUNEDIN CITY COUNCIL
CHURCH HILL ROAD
LONG-TERM LANDSLIDE MONITORING

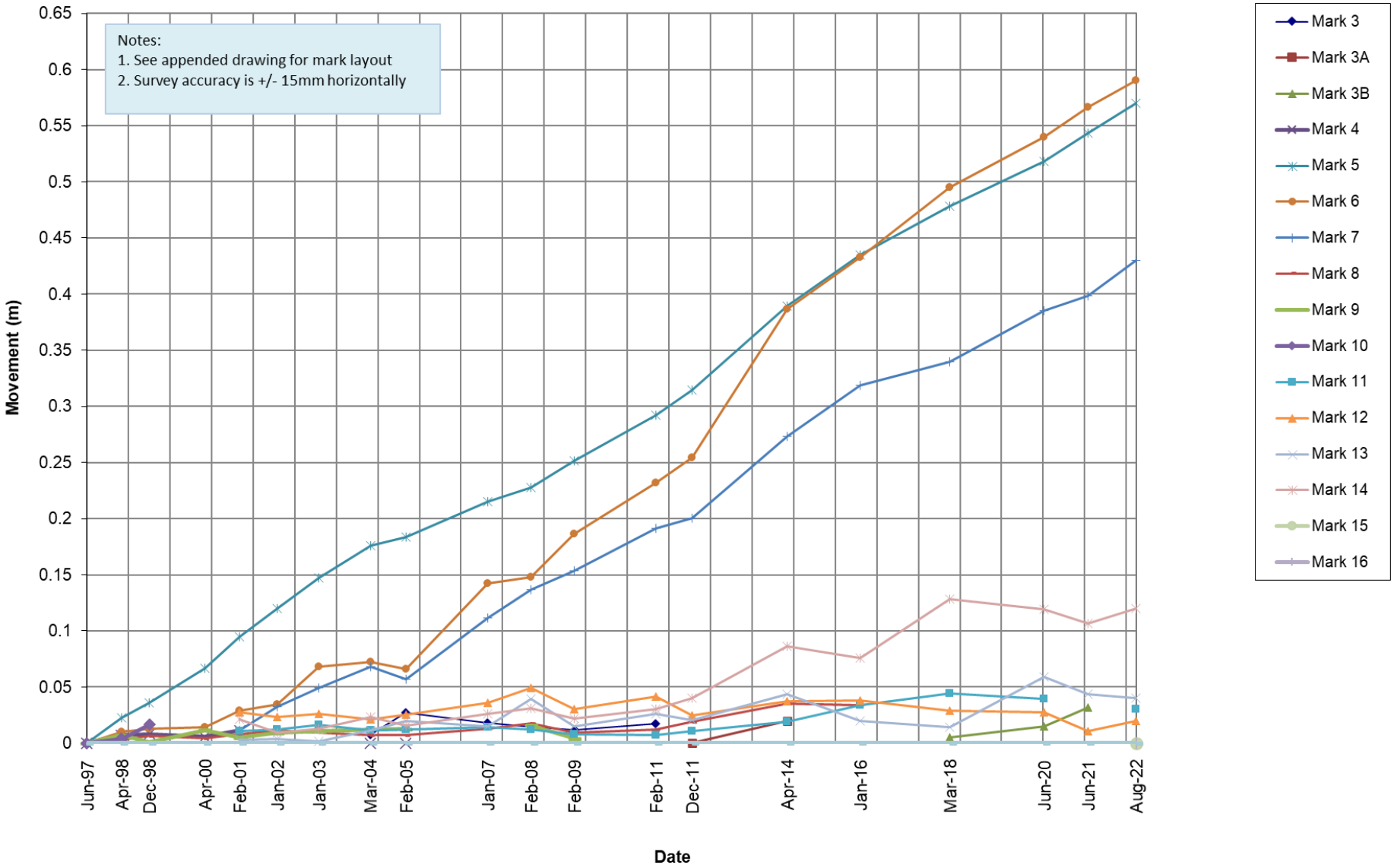
TITLE
CUMULATIVE LANDSLIDE DISPLACEMENTS
CHURCH HILL ROAD

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

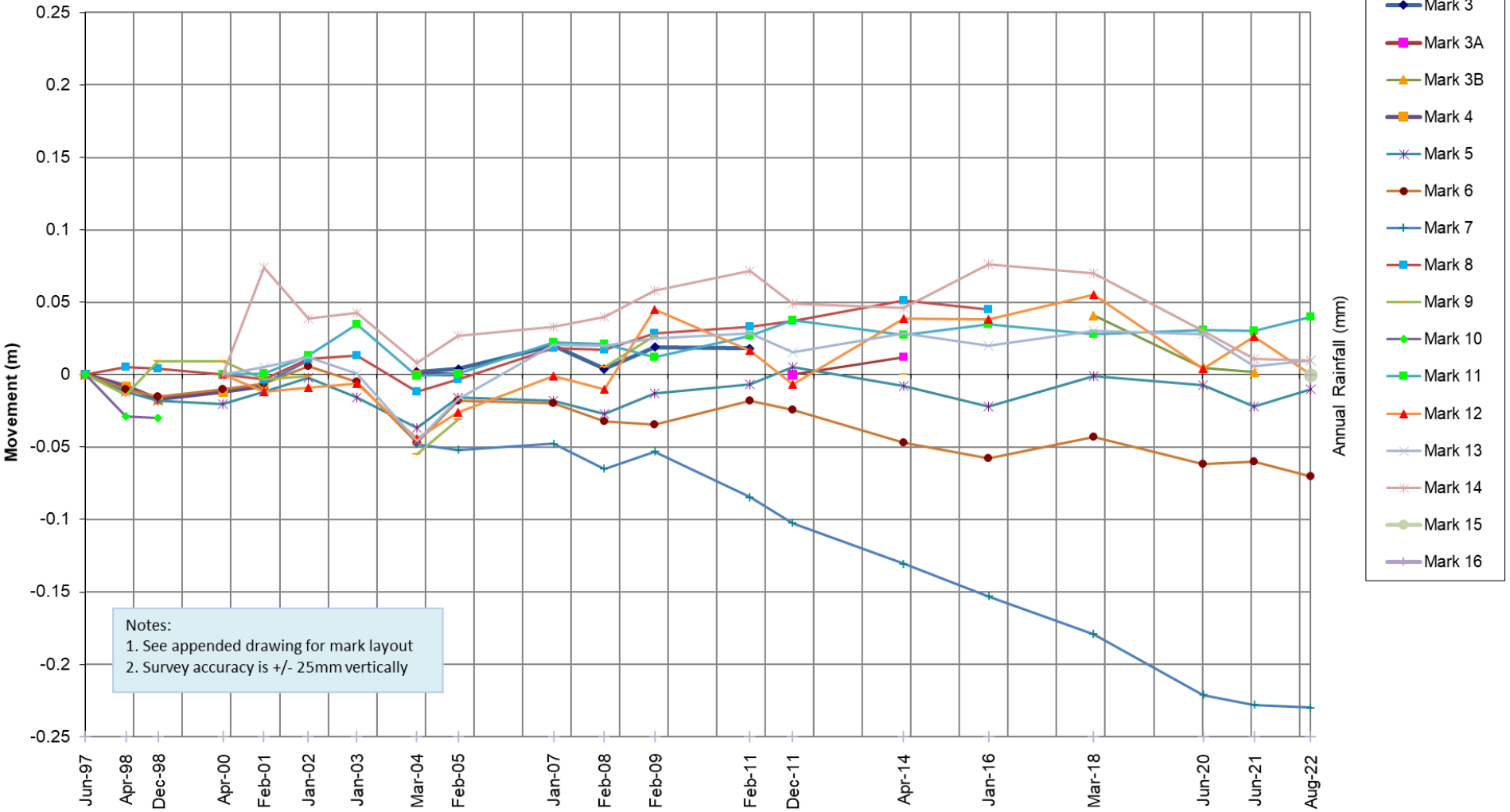
Original sheet size A1 (841x594) Plot Date 2022-10-27 at 3:08:15 PM U:\ProjectsNZ\6c\6-CD109.55 LTES Long-term Landslide Monitoring\Home\03_Delivery\Site Plans - DWG\805010203-C006 church hill.dwg Layout1

Appendix B
Selected Monitoring Charts

Church Hill Road Landslide Monitoring
Chart 1: Horizontal Deformation - June 1997 to present



Church Hill Road Landslide Monitoring
Chart 2: Vertical Deformation - June 1997 to present



Appendix C
Cumulative Monitoring Results Spreadsheet

DCC LANDSLIDE MONITORING
CHURCH HILL

Monitoring network established June 1997
Survey carried out by RTK and Static GNSS observations
False Horizontal & Vertical Datums

Horizontal Geodesy: New Zealand Geodetic Datum 1949
Projection: North Taieri Circuit
Vertical Geodesy: GRS80 Ellipsoid

NOTE: Ground movement is considered any measurement greater than:
20mm (Hz)
30mm (Vt)

Estimated accuracy: +/-20mm horizontal
+/-30mm vertical

SURVEY20

Survey Date: 19/08/2022

				Present to Previous (21/06/2021)					Present to Original (June 1997)					
Pin #	Northing	Easting	Height	dN	dE	Bearing	Dist	dRL	dN	dE	Bearing	Dist	dRL	
Trig A2	694110.915	311761.555	189.276	0.005	0.003	31	0.006	-0.011	0.026	0.014	28	0.030	0.023	
BM GI Landfill	694882.971	310710.799	9.812	0.009	0.006	34	0.011	-0.012	0.009	0.006	34	0.011	**0.035**	
SS WEIR ST (BD5U)	694507.273	310627.831	21.325	0.006	0.005	40	0.008	0.013	0.027	0.006	13	0.028	0.013	
IS 1	695294.196	311497.219	20.627	0.006	0.004	34	0.007	0.014						
IS 2 (IS WSP)	694566.570	310599.975	15.821											**Fixed**
Mark 03B														**Destroyed**
Mark 05	694943.883	311300.300	47.519	0.025	-0.010	338	0.027	0.009	0.537	-0.192	340	**0.570**	-0.013	
Mark 06	694803.844	311350.077	64.532	0.021	-0.012	330	0.024	-0.007	0.562	-0.181	342	**0.590**	**-0.067**	
Mark 07	694861.498	311393.706	60.890	0.026	-0.014	332	0.030	0.000	0.390	-0.176	336	**0.428**	**-0.228**	
Mark 11	694900.044	311520.726	56.437	-0.010	0.005	153	0.011	0.009	0.029	0.010	19	**0.031**	**0.040**	**Compd. to Srvy18**
Mark 12	694606.306	311682.495	125.673	0.003	-0.006	297	0.007	-0.024	0.014	-0.005	340	0.015	0.002	
Mark 13	694510.851	311716.834	144.897	-0.003	-0.004	233	0.005	0.001	0.037	0.014	21	**0.040**	0.007	
Mark 14	694678.094	311502.631	105.622	0.014	0.003	12	0.014	-0.003	0.119	-0.016	352	**0.120**	0.008	
Mark 15	695013.384	311491.014	40.904											**New**
Mark 16	694986.963	311417.029	38.790											**New**

Notes:
1. Survey holds IS2 fixed H&V
2. Marks 15 (IS) and 16 (Nail) are installed to increase coverage in slip area
3. Mark 03B is destroyed - roadworks

Appendix D
Network Adjustment Report

Project File Data		Coordinate System	
Name:	U:\ProjectsNZ\6c\6-CD109.55 LTES Long-term Landslide Monitoring\Home\03_Delivery\Church Hill Rd\Survey\2022\03 TBC\220819ChurchHill.vce	Name:	New Zealand/NZGD1949 (LC)
Size:	111 KB	Zone:	North Taieri
Modified:	19/09/2022 2:38:41 PM (UTC:12)	Datum:	New Zealand Geodetic 1949 (LC)
Time zone:	New Zealand Standard Time	Global reference datum:	NZGD2000
Reference number:		Global reference epoch:	2000
Description:		Geoid:	
Comment 1:		Vertical datum:	
Comment 2:		Calibrated site:	
Comment 3:			

Additional Coordinate System Details

Local Site Settings			
Project latitude:	S45°54'33.47416"	Ground scale factor:	1
Project longitude:	E170°25'51.01373"	False easting offset:	0.000 m
Project height:	105.616 m	False northing offset:	0.000 m

Network Adjustment Report

Adjustment Settings

Set-Up Errors

GNSS

Error in Height of Antenna: 0.003 m
Centering Error: 0.000 m

Covariance Display

Horizontal:
Propagated Linear Error [E]: U.S.
Constant Term [C]: 0.000 m
Scale on Linear Error [S]: 1.960
Three-Dimensional
Propagated Linear Error [E]: U.S.
Constant Term [C]: 0.000 m
Scale on Linear Error [S]: 1.960

Adjustment Statistics

Number of Iterations for Successful Adjustment: 2
Network Reference Factor: 1.00
Chi Square Test (95%): Passed
Precision Confidence Level: 95%
Degrees of Freedom: 72

Post Processed Vector Statistics

Reference Factor: 1.00
Redundancy Number: 18.00
A Priori Scalar: 1.30

RTK Vector Statistics

Reference Factor: 1.00
Redundancy Number: 54.00
A Priori Scalar: 0.89

Control Coordinate Comparisons

Values shown are control coordinates minus adjusted coordinates.

Point ID	ΔEasting (Meter)	ΔNorthing (Meter)	ΔElevation (Meter)	ΔHeight (Meter)
201	-0.003	-0.005	?	?
202	-0.006	-0.009	?	?
203	-0.005	-0.006	?	?
51	-0.004	-0.006	?	?

Control Point Constraints

Point ID	Type	East σ (Meter)	North σ (Meter)	Height σ (Meter)	Elevation σ (Meter)
152	Grid	Fixed	Fixed		
152	Global			Fixed	
Fixed = 0.000001(Meter)					

Adjusted Grid Coordinates

Point ID	Easting (Meter)	Easting Error (Meter)	Northing (Meter)	Northing Error (Meter)	Elevation (Meter)	Elevation Error (Meter)	Constraint
1002	311491.014	0.004	695013.384	0.006	?	?	
1003	311417.029	0.005	694986.963	0.006	?	?	
1010	310599.975	0.005	694566.569	0.007	?	?	
152	310599.975	?	694566.570	?	?	?	ENh
201	311761.555	0.004	694110.915	0.006	?	?	
202	310710.799	0.005	694882.971	0.007	?	?	
203	310627.831	0.005	694507.273	0.006	?	?	
205	311300.300	0.004	694943.883	0.006	?	?	
206	311350.077	0.006	694803.844	0.008	?	?	
207	311393.706	0.005	694861.498	0.007	?	?	
211	311520.726	0.005	694900.044	0.006	?	?	
212	311682.495	0.005	694606.306	0.007	?	?	
213	311716.834	0.007	694510.851	0.008	?	?	
214	311502.631	0.006	694678.094	0.009	?	?	
303	311682.352	0.004	695078.703	0.006	?	?	
51	311497.219	0.003	695294.196	0.004	?	?	
DUND	324412.325	0.004	697311.149	0.005	?	?	
OUSD	317721.861	0.004	698908.186	0.005	?	?	

Error Ellipse Components

Point ID	Semi-major axis (Meter)	Semi-minor axis (Meter)	Azimuth
1002	0.007	0.005	174°
1003	0.008	0.006	176°
1010	0.009	0.006	2°
201	0.007	0.006	175°
202	0.009	0.006	172°
203	0.008	0.006	180°
205	0.007	0.005	178°
206	0.010	0.007	5°
207	0.008	0.006	5°
211	0.008	0.006	179°
212	0.008	0.007	171°
213	0.010	0.008	174°
214	0.011	0.007	8°
303	0.007	0.006	176°
51	0.006	0.004	1°
DUND	0.007	0.005	179°
OUSD	0.006	0.005	180°

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