Revised landslide database for the coastal sector of the Dunedin City district.

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GNS Science Consultancy Report 2017/41
July 2017

BIBLIOGRAPHIC REFERENCE

Barrell DJA, Smith Lyttle B, Glassey PJ. 2017. Revised landslide database for the coastal sector of the Dunedin City district. Lower Hutt (NZ): GNS Science. 29 p. (GNS Science consultancy report; 2017/41).

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EXECUTIVE SUMMARY

The Otago Regional Council (ORC) operates a natural hazards database. Landslides are a significant hazard in the Otago Region and an inventory of landslide information is an important dataset in the natural hazard database. The ORC landslide dataset documents the interpreted locations of past landslide movements based on landform characteristics, but does not provide forecasts of future landslides. Information in the ORC landslide dataset has been compiled from a variety of sources and at a variety of scales. As a result, there is considerable variation in the precision and quality of information on individual landslides. Of particular significance to communities is the exact geographic location of landslides, especially in regard to where the positions of landslide boundaries have been mapped. This is because there are potential implications for hazards associated with future landslide movement.

The ORC landslide dataset was first compiled in a comprehensive way in 2006 for all of Otago. A major revision for the Dunedin City district sector of the ORC landslide dataset was carried out in 2012. Further work was commissioned in 2014 and 2015 to refine the Dunedin sector of the dataset, with emphasis on areas of existing and future urban development, during of the formulation of the Dunedin 2nd Generation District Plan (2GP). However, it became apparent during consultation for the 2GP that the existing landslide mapping in the Dunedin area was too imprecise to be useful at the scale of individual property boundaries.

ORC and GNS Science then undertook a collaborative project to make an improved map of landslides for the near-coastal sector of the Dunedin district, with the revised map footprint encompassing all land that is proposed in the 2GP to be zoned as residential, rural residential, commercial and mixed use, major facilities and industrial. The intent was to produce a map of landslide locations that has sufficient precision to be used at the scale of individual property parcels, with clearly expressed accuracy information.

The work made use of high-quality aerial and satellite imagery, as well as topographic models derived from airborne laser scanning (lidar), as well as the more traditional archival resources of aerial photographs dating back to the 1940s. This work has produced a landslide dataset (Dunedin landslide dataset) that is much improved upon previous versions. One of the outcomes of using all of these high-quality resources is that a number of previously-unreported landslides have been detected. The total area of mapped landslides in the revised dataset is greater than in the previous dataset. The revised mapping covers a land area of 668 square kilometres and contains 146 square kilometres that are mapped as landslide terrain. In comparison, within that same footprint, the original dataset contained only 124 square kilometres that were mapped as landslide terrain. This represents a 18% increase in the area that is interpreted to have been affected by past landslide movement.

This report documents the revisions that have been undertaken to the database structure of the Dunedin landslide dataset, provides some examples of the changes that have been made in the mapping of landslide extents, and provides explanatory comments on some of the revisions that have been made in key areas.

1.0 INTRODUCTION

1.1 BACKGROUND

The Otago Regional Council (ORC) operates a natural hazards database. Landslides are a significant hazard in the Otago region and landslide information is one of the key data sets in the ORC natural hazard database.

In 2012, ORC commissioned GNS Science (GNS) to review, rationalise and update the ORC's landslide dataset for the Dunedin City district (Glassey & Smith Lyttle 2012). As a result of that work, about 1200 additional landslide areas ('polygons') were added, duplicated landslide information was removed, and source(s) of information for each landslide were identified, including any specific report(s) documenting the landslides. Several new categories of information ('fields') were added to the database structure to allow the entry of descriptors ('attributes') that characterise a particular landslide. Point locations of landslide information held by GNS were also incorporated into the dataset. A limitation of the 2012 landslide dataset was that it contained little, if any, information on the significance of the hazard posed by each identified landslide. ORC subsequently contracted GNS to provide more information on that aspect of the mapped landslides in six areas in the Dunedin City district (Glassey et al. 2014).

The Dunedin City Council (DCC) has, since 2012, been in the process of formulating a revised District Plan (2nd Generation District Plan – 2GP), for which ORC has been providing advice on the management of natural hazards. In early 2015, ORC contracted GNS to provide further information on the landslide hazard in Dunedin. That work involved an analysis of landslide locations in the existing Dunedin landslide dataset in relation to factors such as rock type, soil type and slope angle (Barrell & Smith Lyttle 2015). The aim was to highlight not just the locations where landslide movements have previously been identified, but also areas where geological and/or topographical conditions may be unfavourable for slope stability, and thus may possibly be susceptible to future landslide movement. Those areas were identified as 'awareness areas' and comprised the locations of landslides identified in the Dunedin landslide dataset (landslide awareness areas), places where the ground slope is relatively steep (slope awareness areas) and places that are underlain by geological formations that are commonly associated with slope instability (geological awareness areas).

An attempt was made to highlight the uncertainties associated with each of these awareness categories, by generating a band of set width ('buffer') around each defined area using computer technologies. The primary intent of the buffer was to account for inherent imprecision in the mapping of the extent of each landslide. There was considerable variability in the precision of mapping in the Dunedin landslide dataset. The dataset had been compiled from existing information, consisting mostly of maps from published or unpublished reports, and from unpublished files. Those maps had been made for various different purposes and at different scales. The buffers went some way towards highlighting the inaccuracies in the locations of many of the landslides in the dataset.

In the draft 2GP that the DCC issued for consultation in September 2015, the landslides and their buffers were identified as hazard zones. Landowners with a property parcel coinciding with one or more of those hazard zones were notified to that effect in writing, and the hazard zone maps and other information were made available for inspection and interrogation via the internet. A large number of submissions were received in relation to the landslide hazard zonation. Many submissions questioned the accuracy of the landslide mapping, and the validity of the hazard zonation, especially when viewed at the detailed scale of individual property parcels.

GNS Science administers and maintains a landslide database of national extent (The New Zealand Landslide Database; Rosser et al. 2017). Although the database is still under development, access to selected parts of its content is available via the GNS Science Databases page (https://www.gns.cri.nz/Home/Products/Databases) and the 'New Zealand Landslide Database' link. In the Dunedin district, the online webmap currently only offers point data on historic reported occurrences of landslide events that have occurred since the mid-1990s (the 'Landslide Catalogue' component of the database described by Rosser et al. 2017). Many of those landslide points are not accurately located, and most are identified as 'small', and probably would be sufficiently extensive to include in the Dunedin landslide dataset. The Dunedin landslide dataset described in this report provides more detailed and more complete information than currently exists in the New Zealand Landslide Database.

1.2 Scope and Purpose

ORC and GNS formulated an approach to address the general concerns about landslides in the 2GP submissions, involving the preparation of a more detailed map of landslide information for the coastal Otago area (Figure 1.1). This initiative took advantage of an in-progress government-funded GNS project to compile an updated geological map for the greater urban area of Dunedin, for which a more detailed map of landslides was desirable. The government funding was used to produce an improved map of landslide extents. ORC contracted GNS to integrate the new landslide extents into the Dunedin landslide dataset, review and refine the database structure, assign descriptive database attributes to the mapped landslides, and document the work in a report. This report provides that documentation.

The revised dataset described in this report builds upon and refines the Dunedin landslide dataset that was compiled by Glassey & Smith Lyttle (2012) and was amended in localised areas by Glassey et al. (2014). The 2016-2017 revisions, identified in the revised dataset and in this report as Barrell (2017), are only in respect of the landslides that are mapped as areas (polygons). No revisions have been made in regard to landslides that have previously been mapped as points. A partial exception is landslides associated with the June 2015 rainstorm, which were all represented by points (Martin & Smith Lyttle 2016). Some of the larger ones are extensive enough to map as polygons, and those are included in the revised polygon dataset. The revised landslide mapping supersedes the landslide polygon map and landslide awareness areas documented by Barrell & Smith Lyttle (2015). The scope of the present project did not extend to redoing the analyses described in the 2015 report.

The new mapping includes all areas of the near-coastal sector of the Dunedin City district that is proposed, in the 2GP, to be zoned as residential, rural residential, commercial and mixed use, major facilities and industrial. The intent was to produce, for the area defined in this report, a map of landslide locations with sufficient precision to be used at the scale of individual property parcels, with clearly specified accuracy information.

1.3 REPORT LAYOUT

Section 2 of the report describes the approach and methods used in the 2016-2017 review and revision of the Dunedin landslide dataset, with two illustrative examples. Section 3 provides an overview of some of the key revisions to the database structure, while Section 4 discusses some of the results of the work. Two appendices accompany the report. Appendix 1 provides descriptive notes on the refinements made to some of the landslide features. This focuses predominantly on revisions to the mapping of active or recently active landslides within, or close to, residential areas. Appendix 2 contains tables that set out the new database structure of the Dunedin landslide dataset along with definitions of important terms used in describing the characteristics of the landslides. In the interests of practicality, there is no comprehensive set of maps supplied for the area of the landslide review and revision, as that would require an exhaustive number of pages to cover the full extent of the revision area in appropriate detail. It is anticipated that people will be able to examine, in detail, areas of interest in interactive digital form via the ORC Natural Hazards Database on the ORC website.

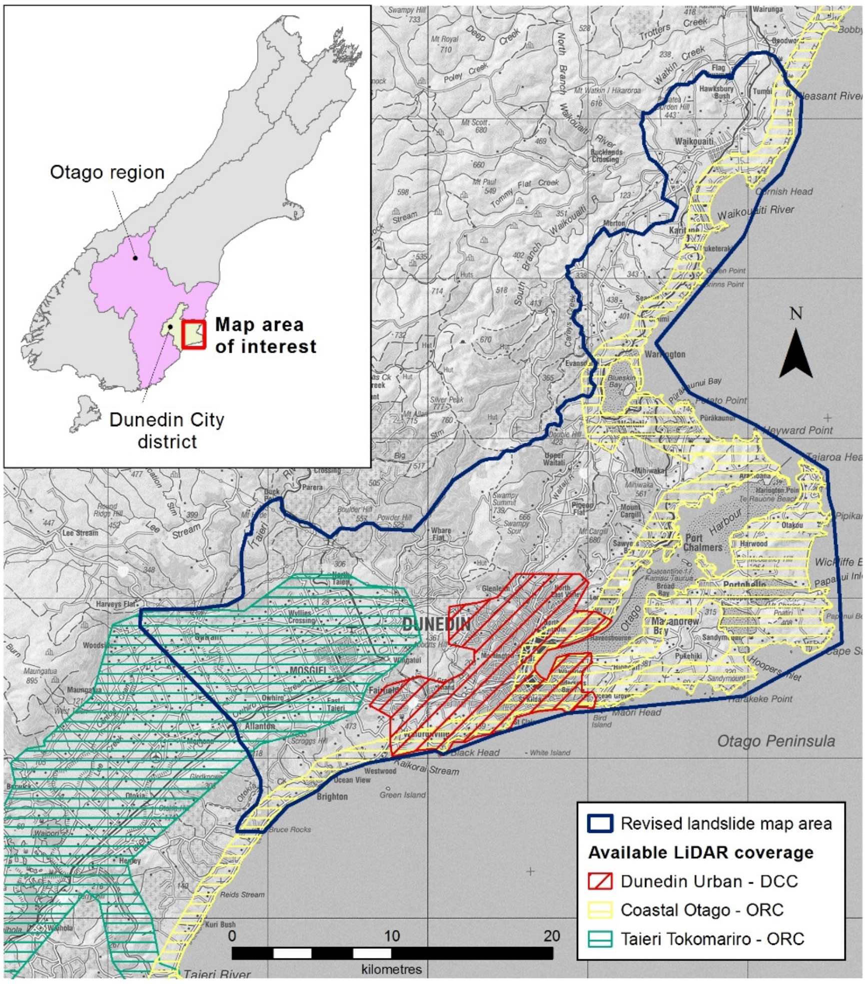

Figure 1.1 The area of revision of landslide mapping described in this report, along with the extent of lidar coverage that was used to assist the mapping.

2.0 APPROACH USED FOR REVIEW AND REVISION

Landslide terrain has distinctive and usually diagnostic topographic characteristics that, except in areas where the ground is obscured by vegetation, can readily be identified and interpreted in aerial photography or when viewed afar from good vantage points on the ground. Of particular and long-standing value are sequences of overlapping aerial photos, taken looking down vertically at the ground from a plane flying a pre-determined straight-line path. The overlap allows the photos to be examined 'stereoscopically', in a 3D perspective. There are archival sets of stereoscopic photos covering almost all of coastal Otago, dating back to the 1940s and 1950s. At that time, land use was almost exclusively pastoral farming, and the ground surface in most places is clearly visible, much more so than in recent decades, when many areas of steep or unstable terrain have been retired from farming and reverted to scrub, or converted to plantation forestry.

Ever-improving capabilities, such as easy access to high-quality aerial and satellite imagery that is registered in an accurate geographic location ('georeferenced') along with the very detailed topographic information from lidar provide a means for the efficient and accurate mapping of landform features related to landsliding. These technological capabilities allow accurate outlines of landslides to be drawn directly on-screen using a Geographic Information System (GIS). This affords far greater precision than was possible using the previously standard method, which involved identifying landslides in stereoscopic aerial photos, transcribing their location and outline as best as possible onto a printed topographic base map, and then digitising them from the base map into a GIS.

In the current review of the Dunedin landslide dataset in the area defined in Figure 1.1, a complete re-examination was made of the terrain, using the archival stereoscopic aerial photo sets held by GNS, the 2013 colour aerial georeferenced 'orthophoto' mosaic available from the DCC, which covers the entire assessment area, the digital 1:50,000 scale topographic map (Topo 50), and lidar datasets where available (Figure 1.1). At the few locations where detailed geotechnical information is available, and in particular where there are detailed technical maps of landslide features, use was made of those resources in compiling the improved map of landslide extents. The landslide locations (especially their perimeters) in the existing dataset were examined in relation to these various information resources. It quickly became apparent that the imprecisions and inconsistencies in the existing landslide dataset were such that a complete overhaul was needed (Figure 2.1). Aerial photograph runs in the collection of the GNS Dunedin Research Centre were examined stereoscopically. On the photos showing the best detail of the ground surface (typically the 1940s to 1950s photos), the outlines of the identifiable landslides were drawn on the photos with an erasable pencil. The annotated photos were then scanned and georeferenced in the GIS.

The annotated photographic interpretations were then examined in the context of detailed topography from 2013 orthophotos, Topo 50 maps, lidar and satellite imagery. Everything in the GIS was scrutinised with the scale typically set at 1:5,000 scale (1 cm on screen equals to 50 m on the ground), and in areas of lidar coverage, at 1:2,500 scale (1 cm on screen equals to 25 m on the ground). This was done to ensure consistency of mapping detail. Where existing landslide features in the dataset were approximately consistent with the new information, their positions and boundaries were adjusted to accord with the new information. In some cases, existing landslides were subdivided into several separate, new, entities, and many new landslides were identified and drawn into the dataset, directly on-screen via the GIS.

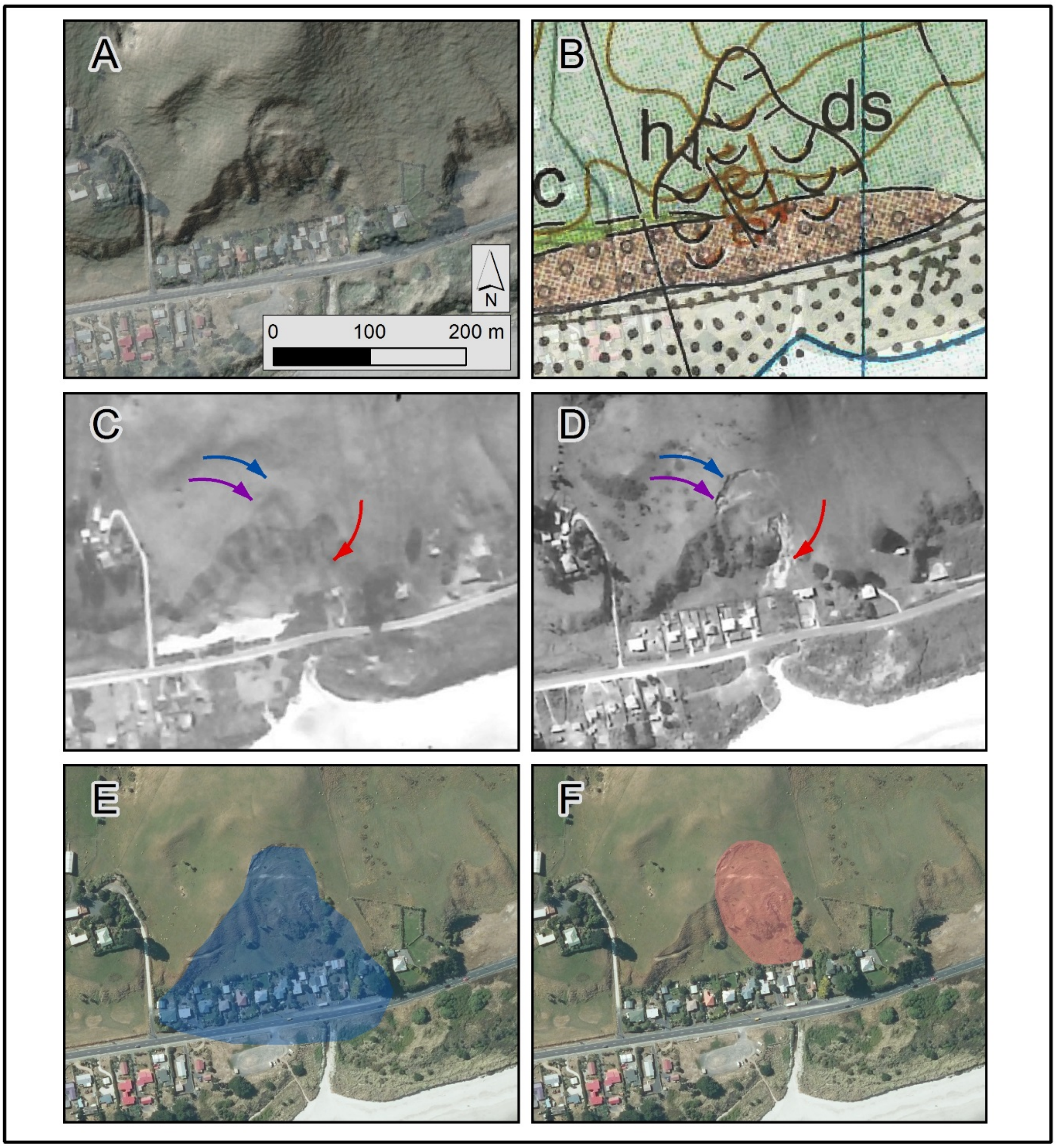

Figure 2.1 Example of landslide mapping revisions, as illustrated by the Brighton Road Slide, located close to Ocean View village, about 0.5 km east of the Brighton Road/Creamery Road intersection. Each panel of the diagram shows the same scene at the same scale, with different backgrounds displayed. **Panel A** shows the scene, with the 2013 aerial orthophotography draped transparently with the ORC lidar hillshade model. The hillshade model shows, in shade, a steep slope north of the road and houses with a crescentic embayment, which is a former sea cliff, cut by wave action before the present sand dunes built up. **Panel B** shows the geological map of McKellar (1990). The 'bell-shaped' line with tick marks enclosing half-crescent lines denotes the interpreted extent of a pre-existing landslide, with a red arrow and date indicating a movement occurred in 1980. **Panels C and D** have arrows at identical locations in each panel, to illustrate the presence/absence of key features at different times. Panel C shows aerial photo SN1004/56, taken 14th April 1946; landslide features evident in later photos (blue and red arrows) were not present at that time. The purple arrow indicates a small triangular shadow that may possibly be a small pre-existing landslide. Panel D shows aerial photo SN2556/19, taken 20th February 1958; a substantial landslide movement has occurred sometime between 1946 and 1958, with the prominent crack at its head indicated by the blue and purple arrows. At the lower right margin, an elongate light-coloured area (red arrow) is a debris slide that has run out to the back fence line of some of the Brighton Road residential properties. **Panel E** shows, in blue, the interpreted landslide extent shown by McKellar (1990) and refined slightly in its extent by Glassey and Smith Lyttle (2012). It is considered in the present report that McKellar (1990) misinterpreted the embayment in the old sea cliff as a landslide feature. **Panel F** shows the revised interpretation, which limits the landslide extent to the areas of definite movement recorded in imagery and other sources since the 1940s-50s (also see Mackey 2015). The background image in panels E and F is the 2013 orthophotography. Revisions to the mapping of the Brighton Road Slide are described in Appendix 1.

The comparison between the archival aerial photographs and more recent imagery available through Google Earth and the 2013 orthophotos enabled the identification of landslide movements or reactivations that have occurred in recent decades (see Figure 2.1). Google Earth imagery was also used to map, and via the time sequence of images, bracket the dates, of some recent landslides, including those from the June 2015 rainstorm. The lidar has proved to be a valuable resource in some locations where the topography makes it difficult to use other methods. For example, in Dunedin's Town Belt, much of which has been thickly forested since the early days of the city, it was known that northeast of Moana Pool, there were some areas of irregular terrain but the thick vegetation made accurate mapping from aerial photographs impossible. The lidar for that area now reveals rift-like depressions that are likely to have been caused by landslide movements (Figure 2.2).

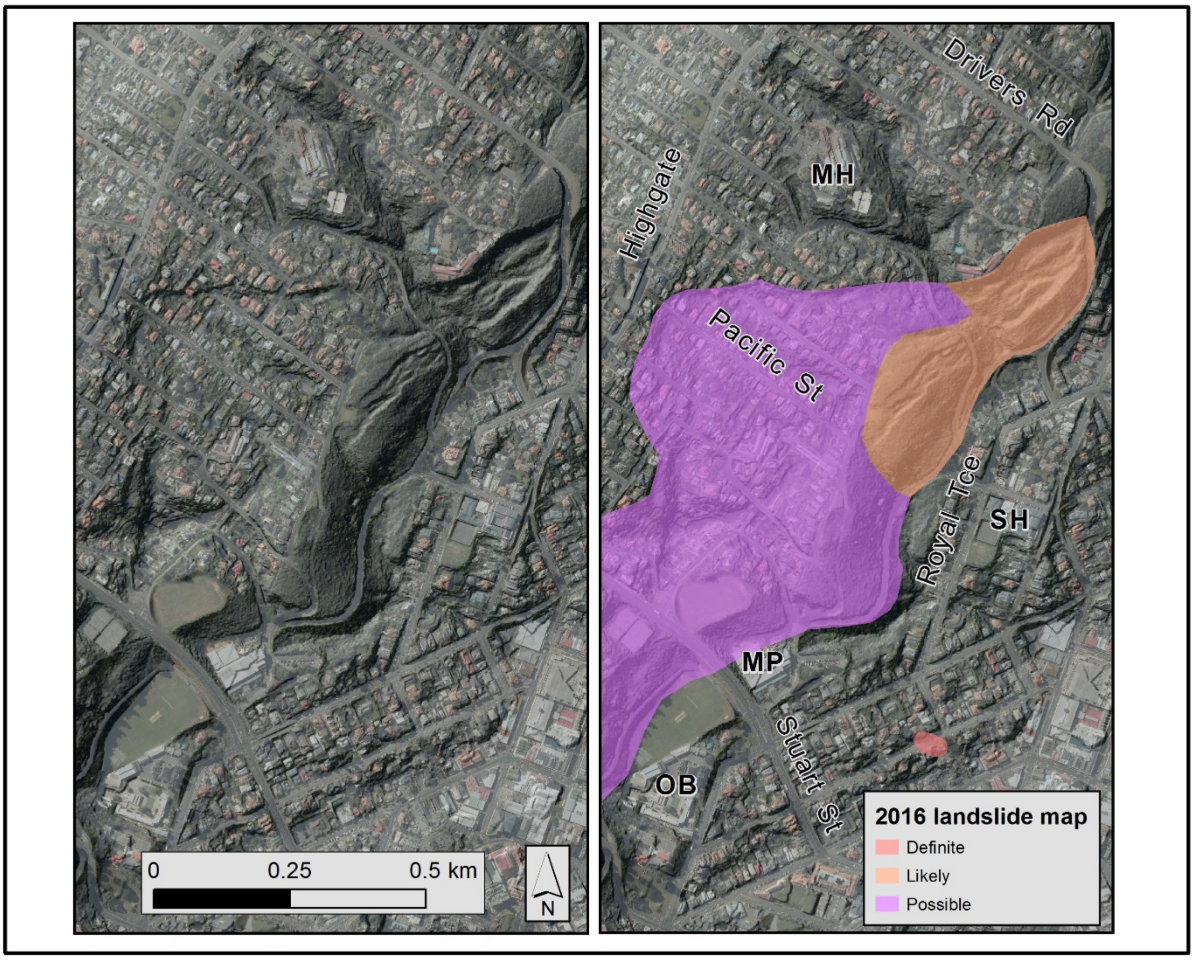

Figure 2.2 Illustration of the usefulness of high-resolution aerial photography (the 2013 orthophotos) when draped transparently over a high-resolution terrain model derived from lidar. These two panels show the same area but the right hand one includes an interpretation of landslide features, and annotation of some locations, including roads and major facilities. OB = Otago Boys High School, MP = Moana Pool, MH = Mercy Hospital, and SH = St Hilda's Collegiate School. The large area mapped in purple (possible landslide) is identified as such because it has a reasonably sharp topographic step around its upslope perimeter (upper left). Its possible existence was first recorded in an unpublished aerial photograph interpretation by P.J. Glassey (2001) and named the 'Town Belt Block Slide'. The area mapped in orange (likely landslide) was first delineated in the Barrell (2017) dataset. This interpretation is based on the presence of prominent rift-like depressions, revealed by the lidar. Together with the larger possible slide, they are referred to in the revised landslide dataset as the 'Town Belt Slide Complex'. The small pink area at the lower right (definite landslide) is the Cargill Street Slide which has been active in recent historical times. There are no known indications (e.g. historical reports of damaged streets, gutters or underground pipes) that the Town Belt Slide Complex has experienced any movement since Dunedin was established. See discussion in Appendix 1 of this report.

3.0 DATABASE STRUCTURE

As part of this project, the Dunedin landslide database structure was reviewed, and a number of revisions were made, primarily to make things simpler. The data field and attribute structure was revised, and the new version is set out in Appendix 2. In this report, the following format convention is used for terms in the Dunedin landslide dataset:

- **Bold** (e.g. **Landslide**) refers to a database table.
- *Italicised* (e.g. *Certainty*) refers to a field (column name) within a database table.
- Underline (e.g. definite) refers to an attribute or value that can populate a data field.

Notable refinements include the addition of fields to the **Landslide** table that enable the documentation of multiple methods used to identify and interpret an individual landslide (*Landslide recognition method*, *Landslide recognition method 2*, *Landslide recognition method 3*, and *Landslide recognition detail*). In addition, fields were added that identify multiple sources for the information (*Source latest*, *Source secondary* and *Source original*), along with a field explicitly stating the scale at which the landslide feature has been mapped in the current iteration of the dataset (*CaptureScale*), and the most detailed scale at which the feature is intended to be viewed (*ResolutionScale*). The *ResolutionScale* is always a larger number (i.e. a less detailed scale) than the *CaptureScale*.

Revisions have also been made to the *Activity* classification of Glassey & Smith Lyttle (2012) with the abandonment of the somewhat subjective terms potentially active and inactive. Instead, more age-descriptive terms have been utilised, comprising ongoing activity, recent historical activity, older historical activity, and prehistoric activity[1]. Building on the refinements introduced by Glassey et al. (2014), the classifications of *Certainty* and *Sensitivity* have been applied to all landslides in the revision area (see Appendix 2). A field called *Geological Context* has been added for the purpose of indicating whether a landslide is thought to have occurred within the underlying geological strata (bedrock) or within thin near-surface soil-related materials (surficial). Another refinement on the 2014 work has been to change the *Remediation* field to allow descriptive text of what stabilising measures are known to have been employed, rather than a shortlist of restricted subjective terms (e.g. major, minor) as applied previously.

Some minor refinements have also been made to the fields in the **Source** table. The addition of the *CaptureScale* and *ResolutionScale* fields to the **Landslide** table has enabled us to remove the *Scale* field within the **Source** table of the previous iterations of the dataset. That field was formerly the only way to infer the accuracy of the mapping of an individual landslide, with such information now being more explicit in the scale fields of the **Landslide** table. In Appendix 2, Section A2.2 sets out the relationship between scale and mapping precision in relation to the Dunedin landslide dataset described in this report.

1 'Historical' refers to the period since European settlement, i.e., since the mid-1800s.

4.0 DISCUSSION

The revised Dunedin landslide dataset, within the sector of coastal Otago addressed in this report (Figure 4.1), has for the most part been compiled at a *ResolutionScale* of 1:10,000 or better. It is intended that this degree of detail will be generally applicable at the scale of individual property parcels. Nevertheless, it is important to appreciate that the landslide mapping is still based mostly on the interpretation of aerial or satellite imagery, rather than on-the-ground inspection. Doubtless, many refinements could be made in the event of future detailed ground inspections. It is also relevant to note that there are bound to be future landslide movement events that may warrant incorporation in future iterations of the dataset.

In the course of making this methodical review and revision of landslides in the area defined in this report, it was perhaps inevitable that some considerable revisions would be necessary, and also that many previously unreported landslide features would be detected, given the excellent level of detail available in the imagery resources and lidar. By way of statistics, the total area of mapped landslides in the revised dataset is greater than in the previous dataset. The footprint of the mapping revision area (onland area only, of the blue perimeter shown in Figure 1.1) is 668 km², and contains 146 km² that are mapped as landslide terrain (22% by area). In comparison, within that same footprint, the original dataset contained 124 km² that were mapped as landslide terrain (19% by area).

The work undertaken for this project illustrates that many knowledge improvements can be achieved from a comprehensive and methodical review of landslide features. For the revision area, there is now a landslide map in which considerable confidence can be placed. There are several substantial advantages within the new data structure, perhaps the most useful of which will be the distinction that is made between landslides developed on the underlying bedrock (bedrock landslides), versus those associated with movement in the near-surface soils (surficial landslides). By this distinction, it should be possible to undertake more robust future analyses of the relationship between different types of bedrock and the occurrence of landslides. The analyses made by Barrell and Smith Lyttle (2015) in regard to association of landslides with bedrock type were clearly fraught because the previous landslide map was insufficiently complete, as illustrated by the addition of 22 km² of landslide terrain (an 18% increase) as a result of the work reported here.

Another strength of the new data structure is the replacement of subjective terms describing landslide activity with terms that relate to more explicit estimates of when the most recent movement of a particular landslide occurred. While this does not in itself provide any explicit guidance on the degree of hazard presented by particular landslide, it does provide a better knowledge base for evaluating hazard and risk in regard to landslide movement. The sensitivity criterion is intended to provide information related to hazard potential, by highlighting those landslides which may be more sensitive to reactivation on account of natural or human-induced processes.

It is hoped that the revised landslide dataset for this sector of coastal Otago will be a useful resource for future land-use planning and improvements to societal resilience in the greater Dunedin area, in relation to the long-standing significance of slope instability problems in this part of New Zealand.

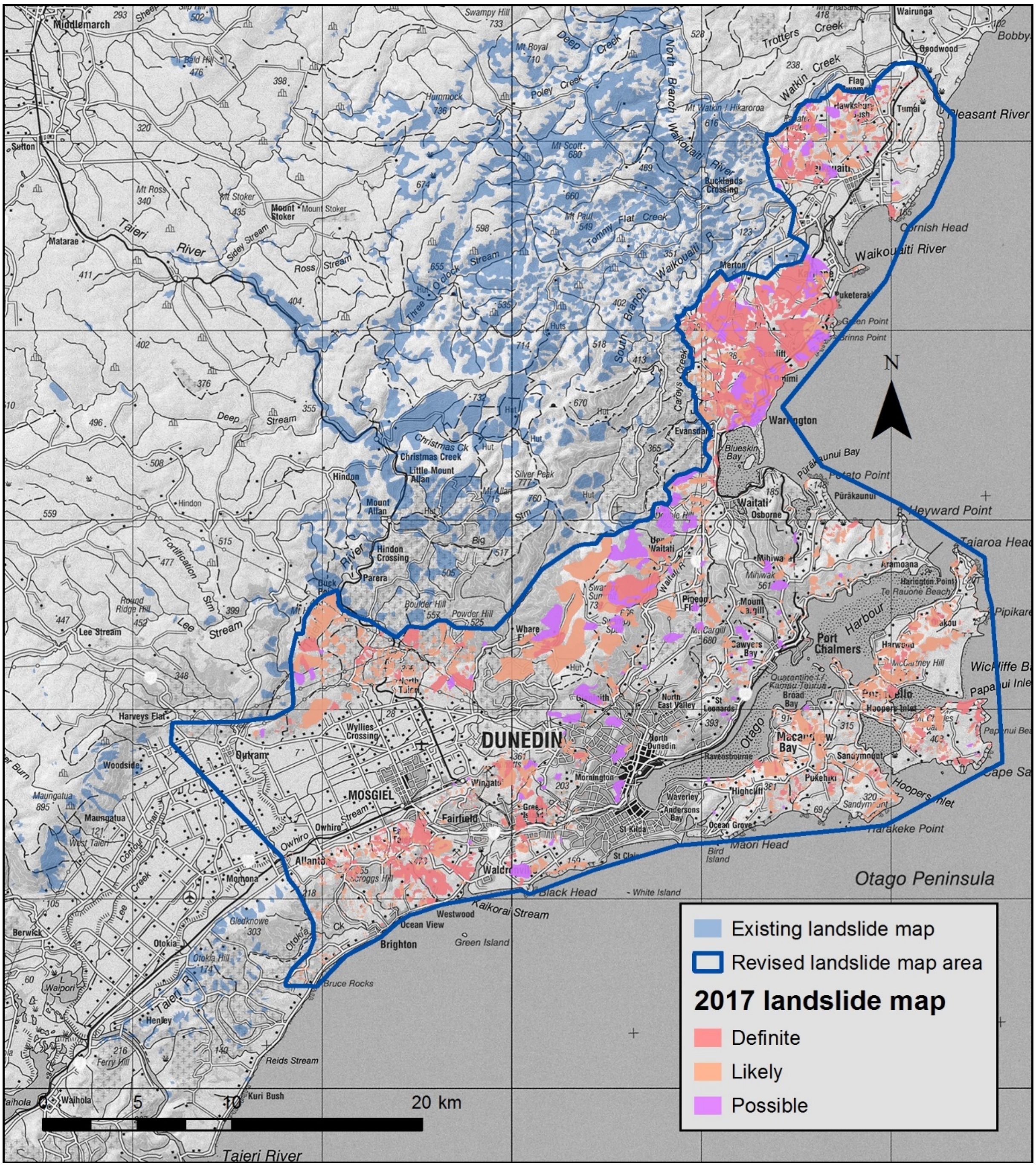

Figure 4.1 Illustration of the revised landslide map, coloured according the certainty that each mapped landform feature is actually a landslide. Outside the perimeter of the revision, the dataset comprises the previously-mapped landslides (existing landslide map).

5.0 ACKNOWLEDGEMENTS

Co-funding for the revised mapping of landslides was provided by GNS Science with Direct Crown Funding through the Minerals, Urban and Regional Geology research programme. This report has benefited from technical reviews by Sally Dellow and Simon Cox of GNS Science and Ben Mackey of Otago Regional Council.

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APPENDICES

A1.0 COMMENTARY ON LANDSLIDE MAP REVISIONS

A1.1 WEST OF BRIGHTON

In two locations, one ~400 m NW of the Big Stone Road/Brighton Road intersection (*Landslide ID* 2902) and one immediately SW of Scroggs Hill Road, ~1 km NW of the Brighton Road intersection (*Landslide ID* 2895), the previous dataset showed a landslide feature. These have been deleted from the new dataset because both these features are old quarries. Their mapping as landslides arose from a misinterpretation of the symbol used to show quarries on the McKellar (1990) geological map.

A1.2 NORTH OF THE TAIERI PLAIN/WEST OF SILVER STREAM

Most areas here were clear of forest in the historic (1940s-60s) black and white aerial photos, but in recent aerial/satellite imagery (2013 orthophotos; Google Earth), there is extensive forest cover in many parts of the area, both exotic plantations and native regrowth. In areas where the ground is obscured in modern high-resolution georeferenced imagery, there is less certainty about delineating the location of landslides seen in the old imagery. In areas of contemporary forest cover, *CaptureScale* of 1:6,000 and *ResolutionScale* of 1:12,000 are assigned. Elsewhere, the equivalent scales are *CaptureScale* 1:5,000 and *ResolutionScale* of 1:10,000. Along the fringe of the Taieri Plain, there is lidar coverage, and in that area, the typical *CaptureScale* and *ResolutionScale* values assigned are 1:2,500 and 1:5,000 respectively.

A1.3 BRIGHTON – OCEAN VIEW AREA

At a location ~300 m NW of the Creamery Road /Brighton Road intersection (*Landslide ID* 2894), the previous dataset showed a landslide feature. This has been deleted from the new dataset because it is an old quarry shown on the McKellar (1990) geological map, but the quarry symbolisation had been misinterpreted as that of a landslide.

Note that for the purposes of assessing relative ages of slope movements near the coast, the database *Comments* field include reference to the 'mid-late Holocene sea cliff', comprising a relatively young coastal cliff that is no longer affected by wave action, generally because a sand dune barrier has built up seaward of the now-abandoned cliff. The abandoned sea cliff is assumed to have an age in the range of ~6,500 to ~1,000 years.

The 'Brighton Road slide' (Stevens et al. 2003) or 'Brighton Slide' (Mackey 2015) lies northwest of several properties, 702 to 712 Brighton Road, at the eastern end of the Ocean View township. In this report, the name 'Brighton Road Slide' is adopted, to avoid any confusion arising from the slide not being within Brighton township. In the revised dataset, this slide has been much reduced in extent from its original depiction by McKellar (1990). The McKellar (1990) map shows what is considered, in this report, to be a substantial over-interpretation of the extent of the slide. Comparison between what is shown on that map, and aerial photography and lidar, indicates that part of the mid-late Holocene coastal cliff (seen in the background of Figure 5 of Mackey 2015) was misinterpreted as a landslide scarp. As a result, the landslide was interpreted as being much wider, and extending farther seaward, than can be justified from the landform evidence. The revised extent shown in the dataset accords well with the obvious landslide headscarp and margin features, and also with movements recorded in the DCC monitoring programme for this slide, as described by Stevens et al. (2003) and Mackey (2015). See Figure 2.1 of the main report.

The McKellar map shows a ‘year of last movement’ of 1980 on the Brighton Road Slide. A further small slip/earthflow occurred from part of the slide area during the 17-19 March 1994 rainstorm (Stewart 1996; feature 111); A further movement event occurred in 2008. Mackey (2015) presented monitoring survey data that show continuing creep in the head area.

Between about 200 and 500 m north of the Brighton Road/Rockview Road intersection, McKellar (1990) showed an elongate landslide to which a ‘year of last movement’ date of 1980 was assigned (*Landslide ID* 100111). Mackey (2015) briefly discussed this landslide and applied the name ‘Rockview Slide’. Examination of aerial photos revealed that this landslide existed in much its present form in 1942 photos. Whether the 1980 movement involved localised or entire reactivation is unknown.

Between about 80 and 130 m east of the Brighton Road/Rockview Road intersection, there is evidence of an active landslide, with bowed road-marginal fences on Rockview Road indicated in Google Earth imagery. Signs of recent ground disruption were noted by Barrell in 2015 during landslide reconnaissance following the June 2015 rainstorm. This appears to be the main locus of recent landslide movement in the Rockview Road area. It is mapped as a triangular slide (*Landslide ID* 100340), interpreted to be a surficial movement that is remobilising earlier-formed landslide debris. In the present iteration of the dataset, the name Rockview Road Slide is not used.

A1.4 WESTWOOD AREA

The 1870, 1910, 1925 and 1936 slides shown by Benson (1946) are differentiated in the new map. As it is not clear how accurate was the surveying (if any) done by Benson, an accord has been struck in relation to what can be seen in airphotos, and the modern basemaps (ORC 2013 airphotos and lidar). The margins of these slides in the digital dataset should be regarded as approximate.

A1.5 SADDLE HILL

The feature shown by Coote (1995) as ‘Saddle Hill Earthflow’ has been added, in greatly modified location, aided by aerial photography. In order to avoid confusion with numerous other flows in the vicinity of Saddle Hill, this name is not used in the dataset.

At 44 McMaster Road, it has not been possible to accurately rectify the map of Glassey (2001a) at the scale of the buildings on the property, indicating that buildings and other features on that map were at sketched locations rather than more accurately surveyed. Only a generalised depiction of the limits of the large landslide complex is included in this landslide dataset, rather than the detail of interpreted blocks within the complex shown in the Glassey (2001a) report. The feature in the dataset at this location is a relocated and expanded version of the landslide indicated by McKellar (1990), guided by the descriptions in the Glassey (2001a) report.

A1.6 ABBOTSFORD-GREEN ISLAND AREA

A1.6.1 Miller Street Landslide

The 'Miller Street Landslide' was first depicted on a map by Barrell & Glassey (1993), based on the interpretation of landform features in aerial photos, and examined on the ground. This interpreted feature was examined in more detail by Glassey (2005) and Golder Associates (2009). An impediment to understanding is that a prominent topographic step (scarp) marking the uphill extent of the interpreted landslide west of Reeves Street was removed during mining for clay in the 1970s. This scarp is well expressed in vertical aerial photo runs collected in 1942, 1962 and 1970, all of which can be viewed stereoscopically which allows the ground to be seen in 3D.

The original scarp extended to the southeast, where it is still present today, as a ~5 m high and ~40 m broad topographic step evident on the ground and viewable in Google Earth Street View. However, the form of the scarp has been greatly subdued by residential development in Reeves Street, Miller Street and Will Street, and that development had occurred prior to 1942, when the earliest aerial photos were taken. As a result, there is no visual record of the original form of the scarp in the Miller Street area. Golder Associates (2009) undertook a geotechnical investigation in the area where the scarp had been removed, and concluded that there was no offset of the near-surface deposits and thus the topographic step was not of landslide origin. As part of the present assessment, detailed rectification of the historical aerial photos was undertaken, and showed that the base of the now-removed scarp was incorrectly positioned on previous maps, both of Glassey (2005) and Golder Associates (2009). The actual position was between 8 and 15 m northeast of the position shown on maps in those reports. As a result, we consider it highly probable that the test pits G3 and G4 that were crucial to the Golder Associates (2009) interpretation were sited on the landslide block, and not to the northeast of it, as they assumed. In that case, a landslide origin is not disproved. In the present dataset, the interpreted landslide feature is retained, and its location adjusted to accord with the detailed rectified aerial photo evidence. The evidence from aerial photos, and what can be still seen today in the Miller Street area, is judged sufficient to classify the *Certaint*y of the feature as <u>likely</u>. The particularly evident landslide terrain farther west, also judged by Golder Associates (2009) to be of landslide origin and to which they confined the name 'Miller Street Landslide', is classified here as <u>definite</u>. There is no evidence for recent activity of the wider slide area, such as might be indicated by cracking or disruption of the Miller Street carriageway where it crosses the scarp. Both components of the Miller Street Landslide are assigned a *Sensitivity* value of <u>low</u>.

A1.6.2 West Abbotsford Slide

The generalised extent given on the McKellar (1990) map has been replaced by the more detailed information from the original source report and map by Brickell Moss Ltd (1981), refined and repositioned aided by the 2013 orthophotos and DCC lidar. The early 20th century 'Railway Slip' and the 1967 'Motorway Slip' are separated as components within the slide complex. The west margin of the Motorway Slip was defined by a stepped array of shears. Connecting lines have been drawn between each of the south-facing mapped shears from the Brickell Moss report, giving a saw-tooth appearance that approximates the western boundary of moved ground in the 1967 event.

McKellar (1976) described a radiocarbon dating result from basal slide debris overlying Kaikorai Stream alluvium, obtained from samples collected by J.G. Cookson of the Ministry of Works. A median age of 9,000 years BP (uncalibrated radiocarbon years), which equates to about 10,000 calendar years BP, was given by McKellar. Its location was 'just west' of the Dall Street footbridge over the stream, which is at about the same location as the modern foot overbridge that spans both the motorway and the stream. This means that the sample was collected from the toe of the main lobe of the slide, rather than the frontal slides, which lie a little farther west of that location. The date provides a maximum age for a movement event involving at least part of the main slide body.

A1.7 CENTRAL CITY AREA

A1.7.1 City Rise – Town Belt

The existence of several very large ancient block landslides on the southeast-facing slopes of the City Rise – Roslyn – Maori Hill areas has been suspected since the late 1990s, based on topographic evidence. The particularly distinctive feature is the presence of steep, though subdued, steps, of curved or stepped geometry when viewed from above.

The suspected landslide towards the southwest is named the 'City Rise Slide Complex' in this dataset. The step forming the upslope margin of this suspected landslide can be seen, for example, as the steep wooded slope about 70 m southwest of the Maitland Street-Carroll Street intersection, and on Melville Street within about 50 m downhill of the High Street intersection (its form there is more subdued due to urban development landscaping). We are not aware of any historical reports of damage to streets, gutters or underground pipes in that area that would suggest any historic activity of this suspected landslide, and it is classified as a <u>possible</u> landslide with <u>low</u> *Sensitivity*.

The suspected landslide farther north is identified as the 'Town Belt Slide Complex', and several sectors are identified, with two classified with *Certainty* of <u>likely</u>, because although this terrain is heavily wooded, the lidar reveals a number of rift-like basins. The subdued step at the suspected upslope margin of the overall slide complex can be seen, for example, at about the intersection of Tweed and Selkirk streets, and the Melrose Street/Garfield Avenue intersection. The step is clearest at the southwestern edge of the suspected slide complex, near the Town Belt, for example where it is crossed by Sligo Terrace a few tens of metres east of City Road. We are not aware of any historical reports of damage to streets, gutters or underground pipes in that area that would suggest any historic activity of this suspected landslide complex, and it is assigned a <u>low</u> *Sensitivity*.

A1.7.2 Evans Street Slide

Differing interpretations have been presented for this landslide area in the Opoho suburb. It was examined in detail and documented in technical reports by Johnson (1987a, 1988), and the status of the slide's stability was reviewed by Glassey (1993). Subsequent re-interpretation by Glassey (2001b) delineated a broader, hypothesised, extent of prehistoric movement, encompassing and expanding upon the movement areas mapped by Johnson (1987a, 1988). The 2016-17 landslide review and revision has adjusted the extent of the Evans St Slide back to that as documented by Johnson (1988), comprising two small landslide features, and the wider interpretation was removed. Of the two mapped landslide areas, the larger one close to the dwelling at 193 Evans Street, had documented movement in the 1980s, determined from surface ground cracking and survey monitoring, and is classed as <u>definite</u>. Recognition of the smaller landslide area, some 40 m or so to the northeast, was based on Johnson's (1987a) field observation of a suspected bulge in the ground at the slide toe, and the presence of small, bent, pine trees. No ground cracking was reported. To highlight that its recognition is less definitive, it is classed as <u>likely</u>, with *Last known movement* of <u>probably historic</u>.

A1.8 OTAGO PENINSULA

A1.8.1 Howard Street Slide

The slide extents have been amended to accord with the most recent work, as set out in Halliday (2013), Paterson (2013) and Glassey (2014). A 'primary slide' and a 'secondary slide' are recognised. The slide boundaries have been refined using lidar, high-resolution aerial imagery and Google Earth Street View. The area of the 'secondary slide' includes the zones involved in the 1968, 1993-94 and 2013 reactivations. Detailed review of the historical files (Wood 1968; Leslie 1968) in May-June 2017 commissioned by ORC after the hearing of public submissions on the 2GP showed that the extent of the 1968 movement was about the same as occurred in 2013, and that the 1993-94 movement likely extended farther downslope in the subsurface (Barrell 2017). Accordingly, the 'secondary slide' area has been divided into two portions, the upslope sector that was involved in both 1968 and 2013 movement, designated as 'Howard St Slide (secondary slide - 1968, 2013 movement)', and the remainder, identified as the 'Howard St Slide (secondary slide)'.

It should be noted that the survey monitoring data (MWH 2016) indicate that the 2013 movement event also affected survey mark IS 9, located on the 'primary slide' area, and this mark was also involved in movement between 1978-1995 (Glassey 1995). Halliday (2013) also reported a fresh crack at the foot of the slope below the block on which IS 9 is situated. However, no survey marks farther downslope show significant movement. For that reason, a separate block is identified in the dataset as the 'primary slide – IS 9 block'.

Also differentiated explicitly in the 'primary slide' area is the evacuated trough in which the northwestern part of Howard Street lies. Morphologically, this appears to a younger part of the 'primary slide' area, because it has 'eaten back' into the debris of the primary slide. This trough is identified as the 'central lobe' following the term used by Halliday (2013). Notably, an area of high ground within this lobe, at 3 Howard Street, is interpreted to be a displaced block within the lobe, but this is not differentiated separately within the dataset.

That sector of the 'primary slide' area downslope of historically-active 'secondary slide' is identified as the 'primary slide – northern lobe'.

For the purposes of this dataset, both sectors of the 'secondary slide', as well as the 'primary slide – IS 9 block' are identified as having undergone historical activity.

A point worth highlighting is that considerable material has been evacuated from the overall basin of the Howard St Slide, and that material is no longer present at the slide toe. Most likely, erosion by the sea is how it was removed, and serves to highlight that this landslide has been evolving over a considerable amount of prehistoric time. The slide is a long-standing natural feature of the environment, and this helps to give context to the apparent absence of historical activity over much of the slide area. It is likely that the slide in general is quasi-stable, and equilibrated to its present geometry and conditions.

A1.8.2 Dickson Street Slide

The wider area referred to as the East Macandrew Bay Mass Movement Area (Barrell 1994) is considered to lack sufficient evidence in support of a landslide origin, and has been removed from the dataset. Instead, localised areas with more definitive landslide characteristics are retained as identified landslide features.

Two-yearly survey monitoring indicates that the Dickson Street Slide continues to move slowly (MWH 2015).

A1.9 WAITATI VALLEY

The southwestern headwaters of the Waitati River, on the eastern flank of Swampy Summit, and including Burns Creek, lie in a broad topographic basin, named ‘Burns Creek Slide Complex’ in the dataset associated with this report. Benson (1940, 1946) interpreted it to be an ancient landslide, with sufficient differential movement of displaced blocks to enable their mapping as fault-bounded blocks on his geological map (Benson 1968). The land surface texture includes areas of arcuate topographic steps and, where in areas where bush has been cleared to farmland, extensive tracts of irregular hummocky ground. The larger blocks have been mapped as <u>possible</u> landslide, and areas of hummocky terrain as <u>definite</u> landslide. Benson’s landslide papers (1940, 1946) both contain an account of his involvement in a 1927 investigation of a proposed DCC water reservoir site in the Burns Creek headwaters. Trench excavations there showed offset Quaternary-age sediments, locally capped by un-deformed alluvium. About ‘200 yards’ to the southeast, Benson described and mapped ‘low scarps’ that had bare soil exposed in their faces, indicating recent movement. This is within a large area of landslide terrain, and because the extent of the recent movement is not known, an *Activity* of <u>unknown</u> has been applied.

Benson also describes offset of the DCC pipeline corridor that collects water from Burns Creek, and the Waitati River headwater (called ‘Williams Creek’ on his maps), and conveys it to Sullivans Dam, via a tunnel under Leith Saddle. Benson’s 1946 paper describes it as follows:

> *“A line of pipes, diverting the drainage water from Swampy Hill into a reservoir beyond the area illustrated, follows the lower margin of the volcanic rocks and is continuously moving. Here the volcanic rocks rest on Caversham Sandstone, which, as its calcareous cement is removed by percolating waters, is reduced to a mass of readily rolling grains. A displacement of the pipes, 26 feet laterally and 16 feet downwards within 20 years, marks the latest phase of the long continued movements”.*

The pipeline follows an excavated bench, and even today two zones of past slope movement are clearly evident, one for ~150 m NE of the Waitati River (‘Williams Creek’ on Benson’s maps) crossing, and a ~120 m long section south of the Burns Creek intake. The latter one is almost certainly the one described by Benson, as there is a considerable depression in the otherwise evenly graded excavated bench. The pipe is buried beneath the bench everywhere except in the zones of slippage, where it is above ground and in places on trestles. In the revised landslide dataset, it is inferred that each historically active area extends into a prominent landslide basin upslope of the pipeline corridor.

A1.10 WARRINGTON

The entire area of Warrington township is interpreted to be landslide terrain, much of it classified as <u>possible</u>, with the most recent movements suspected to be prehistoric. S.C. Cox (pers. comm., May 2016) has suggested that broad, elongate NE-trending ridges in Warrington, up to about 100 m wide, could be folds disrupting a late interglacial marine terrace, buckled up as a result of landslide movement, but this hypothesis is as-yet untested. The toe of the suspected slide is the ‘mid-late Holocene sea cliff’, which is no longer exposed to wave erosion due to the build-up of the Warrington sand-spit. Cessation of coastal erosion at the toe of the suspected slide, and accumulation of sand, will have tended to improve slope stability conditions. There is no evidence of any historical movement of this suspected slide area.

Some northwestern parts of Warrington township are on terrain that is identified as <u>definite</u> or <u>likely</u> landslide.

A1.11 KILMOG SECTOR OF STATE HIGHWAY 1

Jacobson (1985) documents historical areas of slope movement along the Kilmog section of SH1; information from that report was used to delineate slope movement areas in the landslide dataset. Recommendations from that report led to further studies, such as that of the Site Office Slide (Johnson 1987b). The dataset incorporates the slide names used by Jacobson (1985). We have consulted only the information held in GNS Science files, from 1987 and earlier. More recent information is likely to be held by the New Zealand Transport Agency, and its advisors such as Opus International Consultants Ltd.

The Jacobson (1985) report does not include maps, but rather illustrates the locations of the slides on annotated aerial photos. The slides were mapped from those photos, aided by the 2013 orthophotos and Google Earth imagery (including Street View). Remedial drainage works still evident today aided the locating of the slide areas, such as along the northward downhill sector of SH1 toward Waikouaiti from the Steep Hill Rd/Church Rd intersection. There, cut-off drains on the western side of SH1 across the heads of Terry’s Slide and Scott’s Slide discharge into surface flumes that carry water downhill away from the slide areas. Relative to the Whites Rd/SH1 junction, pipe-to-flume discharge points are located about 60 m uphill (Terry’s Slide) and 520 m downhill (Scott’s Slide) from the intersection. Stereoscopic examination of archival aerial photos revealed that both Terry’s Slide and Scott’s Slide have toes that have encroached into the floor of the small un-named stream valley along which SH1 runs. This indicates movement has occurred sufficiently recently that the stream has not yet trimmed the slide toes. In contrast, the slide areas mapped either side of these small slides have stream cliffs cut along their toes, indicating that their most recent movements are probably prehistoric.

A1.12 WAIKOUAITI AREA

A large landslide was mapped across much of the Waikouaiti township area during regional geological mapping in the 1990s (Forsyth 2001) on the basis of irregular topography. Glassey et al. (2014) considered it likely that this is not a landslide, and the topographic irregularities are more likely to be ancient, long-stabilised, sand dunes. They retained it in the dataset, but it has been removed from the revised dataset. The reasoning is that even if this terrain does have its origin in landslide movement, it must have formed at a time when the landscape was different from today, because there is no identifiable source area for such a landslide and there is no longer sufficient topographic relief for it to move again. In other words, even this terrain did form by landslide movement, there is no credible threat of further, large-scale, movement in today’s landscape.

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A2.0 DATABASE STRUCTURE AND SCALES

A2.1 DATABASE STRUCTURE

The structure and components of the **Landslide** database table are set out in Table A2.1. The structure comprises a set of attribute fields, which are named using database syntax, and each field is accompanied by an Alias, which provides a plain English descriptive name. For each field, Table A2.1 has a Description column stating the type of information that each field contains. Some of the fields have a 'Domain' component that provides a restricted list of attributes that can populate the field. These domains/restricted lists are set out in Table A2.2 (landslide *activity*), Table A2.3 (landslide *certainty*), Table A2.4 (landslide *movement type*), Table A2.5 (landslide *geological context*), Table A2.6 (landslide *sensitivity*), and Table A2.7 (*landslide recognition method*).

The **Landslide** attribute table has an additional restricted list (*landslide_sourceIdentifier*) which gives a reference to existing information sources (usually reports or maps). There is a total of just over 100 of these in the dataset, and it was not thought useful to include a tabulation in this report, as they are only of relevance to someone searching the dataset, who is seeking background information for a specific mapped landslide feature.

Reference to the information sources are compiled in the **Sources** attribute table, whose structure and components are given in Table A2.8. Fields in that table provide details of each information source. The *landslide_sourceIdentifier* restricted list of the **Landslide** layer is populated from the Sources layer attribute field Identifier, describing author(s) and date for each feature in that layer (e.g. Barrell 1994).

There is one domain/restricted list associated with the **Source** table, giving the Source status (Table A2.9). This offers a choice of just two attributes, identifying whether the source is publicly available, or whether enquiry should be made to the source's owner/archiver regarding availability.

Table A2.1 Structure of the **Landslide** database table. This contains descriptive information for each mapped landslide area in the Landslide polygon feature class of the geodatabase.

Field	Alias	Type	Size	Description	Restricted list
landslide_id	Landslide ID	Integer	4	Unique identifier assigned to each landslide feature	
name	Name	String	255	Free text identifying common name of the landslide feature, if any (e.g. West Abbotsford Slide, Evans Street Slide)	
initiation	Time of Initiation	String	50	Free text estimating when landslide movement began, or giving a date, if known, for historic landslides	
lastMovement	Last known movement	String	50	Free text estimating when landslide last moved, or giving a date, if known, for historic landslides	
activity	Activity	Integer	4	Restricted list giving a representative age of activity of the landslide feature (e.g. ongoing activity, older historical activity)	Landslide_activity
certainty	Certainty	Integer	4	Restricted list describing the level of certainty that the feature is a landslide (e.g. definite, possible)	Landslide_certainty
moveType	Movement type	Integer	4	Restricted list classifying the type of movement displayed by the landslide feature (e.g. translational slide, flow)	Landslide_movementType
geolContext	Geological context	Integer	4	Restricted list stating the nature of the geological layer within which the movement is thought to have occurred	Landslide_geologicalContext
sensitivity	Sensitivity	Integer	4	Restricted list giving an interpretation of how sensitive the landslide feature is to environmental and/or human-induced modifications	Landslide_sensitivity
remediation	Remediation	String	64	Free text describing what measures, if any or if known, may have been taken to try and improve stability of the landslide feature	
recogn	Landslide recognition method	String	50	Restricted list identifying the most important method used to determine the spatial extent of the landslide feature	Landslide_unitRecognition
recogn2	Landslide recognition method 2	String	50	Restricted list identifying a supporting method used to determine the spatial extent of the landslide feature	Landslide_unitRecognition
recogn3	Landslide recognition method 3	String	50	Restricted list identifying a supporting method used to determine the spatial extent of the landslide feature	Landslide_unitRecognition
recognDetail	Landslide recognition detail	String	150	Free text identifying the source materials used in the landslide recognition fields	
source1	Source latest	Integer	4	Restricted list identifying the report, map or dataset that provides the latest, most detailed, information on this landslide feature	Landslide_sourceIdentifier
source2	Source secondary	Integer	4	Restricted list identifying the report or map that provides additional depiction of this landslide feature, if any	Landslide_sourceIdentifier
source3	Source original	Integer	4	Restricted list identifying the report or map that provides the original depiction of this landslide feature, if any	Landslide_sourceIdentifier
resScale	ResolutionScale	Integer	4	Scale at which the mapped depiction of this landslide feature is intended to be used	
capScale	CaptureScale	Integer	4	Scale at which the landslide feature was digitised	
comments	Comments	String	255	Free text identifying any important features or additional information concerning the landslide feature that do not fit into existing attribute fields, or any other information deemed relevant	
SHAPE_Length	featurePerimeter	Double	8	Geometric descriptor, giving the length of the perimeter of the landslide polygon, in metres	
SHAPE_Area	featureArea	Double	8	Geometric descriptor, giving the area of the landslide polygon, in square metres	

Table A2.2 Restricted list of codes and definitions for landslide *activity*. The Geodatabase domain "Landslide_activity" contains this list of codes. These definitions are modified from Glassey et al (2014).

Code	Definition
not assessed	No assessment has been made of landslide activity
unknown	There is insufficient information to make a definitive statement on the activity of the landslide
ongoing activity	Movement has been detected in monitoring surveys, or by observed ground offset, within the past two years or so
recent historical activity	Movement was initiated, or has recurred at least once, since the mid-1960s (i.e. in the past 50 years or so)
older historical activity	Movement was initiated, or has recurred at least once, between European settlement (mid-1800s) and the mid-1960s (i.e. between about 165 and 50 years ago)
prehistoric activity	No landform indications of historical or ongoing activity, and landform features suggest the most recent movement occurred more than 165 years ago. Any additional information on the age(s) of landslide activity should be stated in the *Comments* field

Table A2.3 Restricted list of codes and definitions for landslide *certainty*. The Geodatabase domain "Landslide_certainty" contains this list of codes. These definitions are from Glassey et al. (2014) with the addition of an attribute of not assessed.

Code	Definition
definite	Landform features are present that can only be the result of landslide activity [and/or] the landslide has been observed historically to have moved
likely	Landform features are present that are most likely the result of landslide activity, and other explanations are less likely
possible	Landform features are present that may possibly be indicative of landslide movement having occurred, but other explanations are plausible
not assessed	No assessment has been made of landslide certainty

Table A2.4 Restricted list of codes and definitions for landslide *movement type*. The Geodatabase domain "Landslide_movementType" contains this list of codes. These definitions are modified from Glassey & Smith Lyttle (2012).

Code	Definition
not assessed	No assessment has been made of landslide movement type
unknown	There is insufficient information to make a definitive statement on the movement type of the landslide
fall	Detachment of soil or rock from a steep slope along a surface on which little or no shear displacement has taken place
rotational slide (slump)	Movement along a surface of rupture that is curved and concave-upwards
translational slide	Movement along a surface of rupture that is planar or undulating
topple	Forward rotation out of the slope of a mass of soil or rock about a point or axis below the centre of gravity of the displaced mass
complex	The landslide has involved 2 or more movement types
flow	Spatially contiguous movement in which surfaces of shear are short-lived, closely spaced, and usually not preserved
lateral spread	Extension of cohesive soil or rock mass combined with a general subsidence of the fractured mass into softer underlying material. Would include lateral spreading caused by earthquake liquefaction
other	Other type of movement as explained in the *Comments* field

Table A2.5 Restricted list of codes and definitions for landslide *geological context*. The Geodatabase domain "Landslide_geologicalContext" contains this list of codes.

Code	Definition
bedrock	The landslide is interpreted to be seated within bedrock strata. It is appropriate to assess the landslide in relation to geological map information
surficial	The landslide is interpreted to be seated within near-surface materials (e.g. loess, colluvium, topsoil) overlying the bedrock strata. It is appropriate to assess the landslide in relation to soil map information
composite	The landslide is interpreted to be seated within some combination of bedrock and surficial materials. This category includes landslides interpreted to be seated within a zone of highly weathered bedrock close to the ground surface, as well as landslides thought to have involved remobilisation of previously-formed bedrock landslide debris. It is appropriate to assess the landslide in relation to geological map information
uncertain	The geological context of the landslide is uncertain
not assessed	No assessment has been made of the geological context of the landslide

Table A2.6 Restricted list of codes and definitions for landslide *sensitivity*. The Geodatabase domain "Landslide_sensitivity" contains this list of codes. These definitions differ from, and supersede, those given by Glassey et al. (2014).

Code	Definition
not assessed	No assessment has been made of the sensitivity of the landslide
low	No geomorphic modifiers are currently active
medium	Potential geomorphic modifiers are present, such as one or more of: stream channel or valley along slide toe; indications of seepage or swampy ground on the slide or at the slide margins; streams or gullies draining onto the slide head; presence of steep or very steep slopes; human modifications including material added at slide head, material removed at slide toe, or water storage (open or enclosed) on or adjacent to slide area; any other relevant factors as explained in the *Comments* field.
high	Significant geomorphic modifiers are present, such as one or more of: sea or river erosion at the slide toe; documented historical activity without remediation; where there is little or no self-buttressing; where there is documented ongoing movement (constant or intermittent); any other relevant factors as explained in the *Comments* field.
uncertain	The sensitivity of this landslide is difficult to assess, for reasons explained in the *Comments* field

Table A2.7 Restricted list of codes and definitions for *landslide recognition method*. The Geodatabase domain “Landslide_unitRecognition” contains this list of codes.

Code	Definition
aerial observation	Identified by an observer in an aircraft
aerial photography	Identified by the interpretation of photography taken from aircraft, including vertical or oblique photographs; the photographic source is identified in the *Landslide recognition detail* field
field observation	Identified by an observer on the ground, including close-up inspection or viewing from a distance (the latter is likely to be mentioned or quantified in the *Comments* field)
geological map	The interpreted presence of a landslide is recorded on a pre-existing geological map; the map document is identified in a *Source* field(s)
geomorphological map	The interpreted presence of a landslide is recorded on a pre-existing geomorphological map; the map document is identified in a *Source* field(s)
ground photography	Identified by interpretation of photography taken by an observer on the ground, including from close-up or distant positions; includes Google Earth Street View
historical records	Identified from information recorded in unpublished documents; may include anecdotal spoken reports
lidar data	Identified by the interpretation of processed lidar data
remote sensing	Identified by the interpretation of remotely-obtained measurements not otherwise classifiable by other descriptions (e.g. photography, lidar, etc.)
satellite imagery	Identified by the interpretation of imagery obtained from satellites; the imagery source (e.g. Google Earth) is identified in the *Landslide recognition detail* field
soil map	The interpreted presence of a landslide is recorded on a pre-existing soil map; the map document is identified in a *Source* field(s)
topographic map	The presence of a landslide is interpreted from information recorded on a pre-existing topographic map; the map is identified in the *Landslide recognition detail* field
stereoscopic aerial photography	Identified by the interpretation of vertical stereoscopic photography taken from aircraft; the primary photographs used are identified in the *Landslide recognition detail* field
technical report	Identified from information recorded in a published or unpublished technical report; the report is identified in a *Source* field(s)
digital data	Identified using numerical data; including landslide movement monitoring data; identified in a *Source* field(s) or in the *Landslide recognition detail* field
survey	Identified as a result of cadastral surveying; the survey data are identified in a *Source* field(s) or in the *Landslide recognition detail* field
sketch map	Identified from a sketch map; the map is identified in a *Source* field(s)
detailed field mapping	Determined from detailed field mapping; the map is identified in a *Source* field(s)

Table A2.8 Structure of the **Source** database table. This contains reference information for each source identified in the **Landslide** table.

Field	Alias	Type	Size	Description	Restricted List
source_id	Source ID	SmallInteger	2	Unique identifier assigned to each source extent	
authors	Authors	String	255	Free text identifying all author(s) of source data (e.g. Barrell DJA, Turnbull IM)	
year	Year	SmallInteger	2	Free text identifying year of publication/creation of source data	
identifier	Identifier	String	100	Concatenation of author and year (e.g. Barrell & Turnbull 1997)	
title	Title	String	255	Free text identifying title of publication, report, map, digital data, etc. of source data	
organisation	Author Organisation	String	100	Free text identifying the organisation that created the source data	
reportNum	Report Number	String	50	Free text identifying report number, if any	
reportType	Report Type	String	50	Free text identifying type of document providing source data. (e.g. science report, unpublished technical record)	
mapEquiv	MapNumberEquivalentIdentifier	String	50	Free text describing the figure number, map name, number or other designation identifying the source data	
notes	Notes	String	255	Free text identifying any important features or additional information concerning the source data that do not fit into existing fields	
status	Status	Integer	4	Restricted list describing the availability of the source data	Source_status
capDate	captureDate	Date	8	Date when the feature was digitised	
modDate	modifiedDate	Date	8	Date when the feature was last modified	
SHAPE_Length	featurePerimeter	Double	8	Geometric descriptor, giving the length of the perimeter of the source map, in metres	
SHAPE_Area	featureArea	Double	8	Geometric descriptor, giving the area of the source map, in square metres	

Table A2.9 Restricted list of codes and definitions indicating the availability of each information source in the **Source** table. The Geodatabase domain "Source_status" contains this list of codes.

Code	Definition
available	The source is understood to be publicly available
refer to source organisation	The *author organisation* should be approached to request access to this information source

A2.2 UNCERTAINTY IMPLICATION OF SCALE VALUES

The *CaptureScale* field in the **Landslide** database table (Table A2.1) documents the scale (e.g. 1000 = 1:1000 scale) at which the polygon was digitised. The assigned *ResolutionScale* represents the scale at which the polygon is intended to be used/viewed. The *ResolutionScale* is intended to indicate the precision with which the polygon perimeter is located. The *ResolutionScale* parameter is a nominal value, generally equating to about twice the value of the *CaptureScale*. It is not assumed that there is a linear relationship with precision. Rather, the precision values given here are conservative estimates of how much plus or minus is an appropriate representation of the locational accuracy of the mapped landslide perimeters.

The values assigned to the *ResolutionScale* field should be regarded as equating to the following uncertainties in the location of the perimeter of the landslide polygon:

Scale	Precision
1000	+/- 5 m
2000	+/- 5 m
2500	+/- 10 m
5000	+/- 15 m
10000	+/- 25 m
12000	+/- 30 m
15000	+/- 40 m
20000	+/- 80 m
50000	+/- 120 m
100000	+/- 200 m

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