[8] GEOTECHNICAL ASSESSMENT

QUEENSTOWN CABLE CAR

GEOSOLVE

GEOTECHNICAL

WATER RESOURCES

PAVEMENTS

Geotechnical Assessment

Queenstown Cable Car

Report prepared for:

Southern Infrastructure Limited

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Distribution:

Southern infrastructure Limited

GeoSolve Limited (File)

October 2025

GeoSolve Ref: 250134

Revision	Issue Date	Purpose	Author	Reviewed
0	13/10/2025	Client issue	PGF	CEM
1	31/10/2025	Reissue following review	PGF	CEM

GEOTECHNICAL WATER RESOURCES PAVEMENTS

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1 Introduction

1.1 General

A geotechnical assessment has been undertaken by GeoSolve to assess the proposed routes of the Queenstown Cable Car. This report has been completed to support a referral application under the Fast-track Approvals Act 2024 (FTAA) . Further geotechnical assessment inputs will be required at the substantive application stage, if the project is referred into the Act's process.

The assessment has been completed in accordance with the GeoSolve Ltd proposal reference 250125, dated 25 February 2025, and includes the following scope of works:

- Site inspections of key areas.
- Reviewing the proposed route with respect to geology and natural hazards using available reports, mapping and site observations.
- A preliminary geotechnical engineering review of the key locations, and provide a summary of future engineering requirements

1.2 Cable Car Proposal

Drawings (Patersons P240854) provided to Geosolve show the proposed routes and station locations. A general summary of the routes is provided in Section 2.1 below, and is shown in Figures 1a and 1d, Appendix A.

The development comprises a cable car connecting Queenstown Centre , Frankton and Ladies Mile. In addition, a separate connecting section, approximately 1.05 km in length, will branch off into Frankton to the Bus hub and airport area.

Options A and B are presented in this report which provide 2 options for the Frankton and Ladies Mile sections in the eastern part of the Cable Car route. The western part of the route remains the same for both options.

Figure 1.1 below shows the proposed Cable Car Route, including Options A and B.

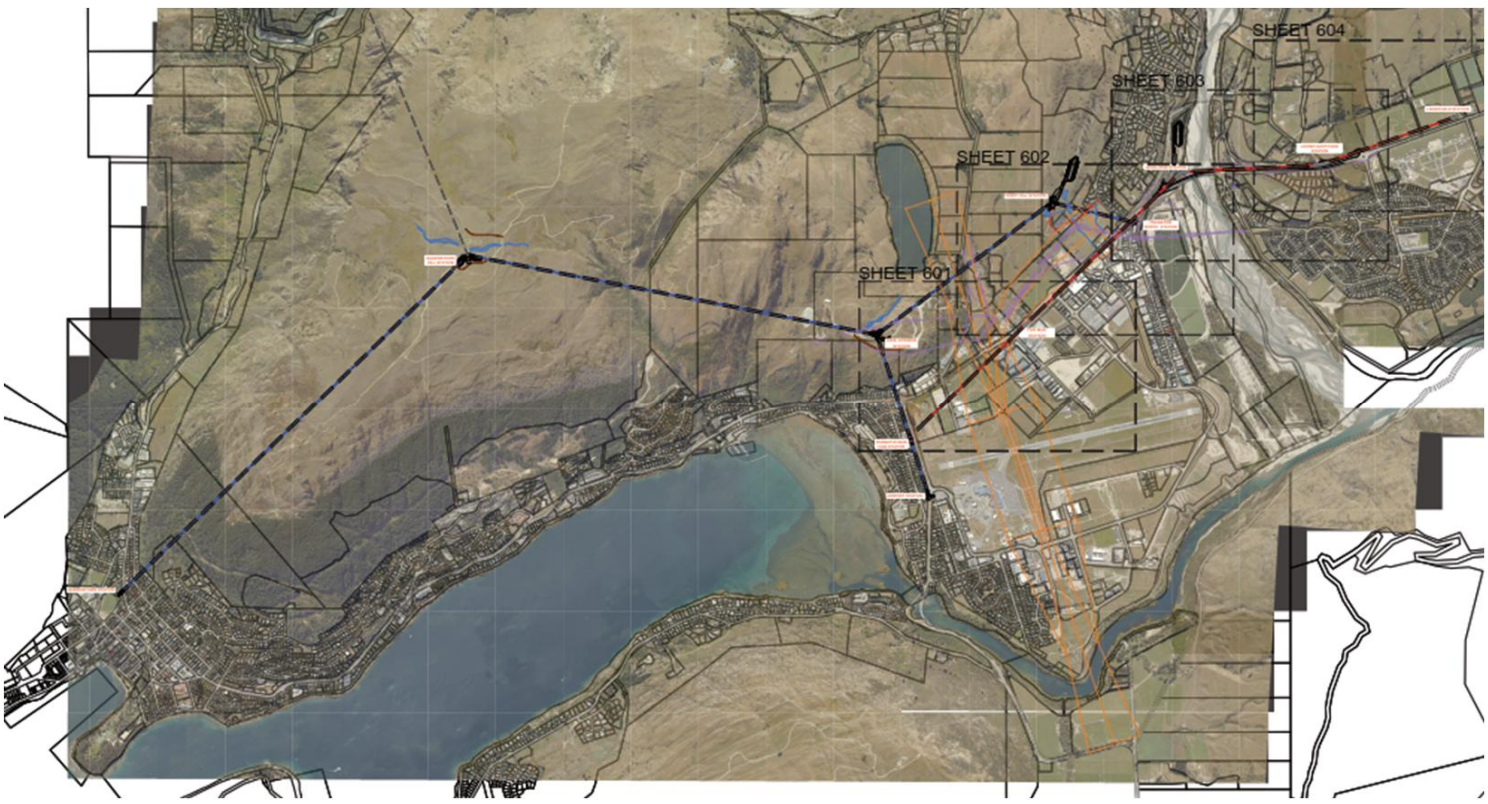


Figure 1.1: Proposed Cable Car Route, with Options A and B.

11 station locations are proposed, which includes all for Option A and B. The final number of stations will reduce depending on the final option taken. Geosolve understands a station will comprise a structure sufficient to transfer the cable car onto a different cable and allow a change in direction. Access and egress from the cable car can also occur at a station. A station is therefore proposed at each angle change and each end point.

Cables between each station will be supported by towers. Preliminary tower locations are shown on the drawings for most of the route, however, Geosolve expects final tower locations will be determined by multiple factors, not just geotechnical, e.g. site-specific environmental considerations, access constraints, ease of construction, and maintenance.

The project is at the referral application stage and therefore engineering details are not yet available. Geosolve expects the following general design philosophy for structure foundations:

Stations

The stations will comprise larger structures/buildings. Foundations are likely to comprise shallow strip and pad footings founded at shallow depths where ground conditions allow. Where Stations are present on or close to sloping ground deepening foundations e.g. piles or deep embedment of strip and pad foundations may be required. Constructing foundations on 'improved' ground i.e. reinforced engineered ground may also be appropriate.

Towers

The majority of tower foundations are expected to comprise shallow pad foundations. The pad foundations will be designed to suit the local bearing capacity conditions. Some towers will be required on steep ground and adjustment of foundations to account for the slope profile will need consideration. Options such as deepening foundations to achieve competent ground, or anchoring foundations, are expected to be required in some cases.

Similarly, if towers are required in close proximity to existing structures or services, foundation options such as pilling can be considered.

Earthworks

Temporary and permanent earthworks will be required in most structures' locations. Earthwork extents are expected to be relatively minor and localised to the structure.

2 Site Description

The drawings provided in Appendix A show the proposed cable car routes and key features associated with this assessment.

In general terms, described from west to east, the proposed route heads north east from Queenstown centre, climbs up over Queenstown hill and follows an elevated route eastwards. The route drops to Frankton at the eastern end. The route continues east from Frankton crossing the Shotover River to reach the Ladies Mile area north of the Shotover Country and Lake Hayes estate residential areas.

2.1 Option A

A brief description of each station location and section for the Option A route is provided below:

Queenstown Station

The proposed Queenstown Station location is at the existing Queenstown Lakes District Council (QLDC) car park on the downslope side of Gorge Road, 5 Boundary Street. The site is low lying and just above Horne Creek which is present a few metres to the west. The site currently has a gently sloping sealed car park surface. The eastern boundary of the site (bordering Gorge Road) comprises a vegetated slope (approx. 30° and 2 m in height) which climbs up to footpath on Gorge Road.

Cable Route to Queenstown Hill Station

This section of the proposed route climbs up from Queenstown Station to the summit of Queenstown Hill. The lower section will be in the developed lower slopes around Weaver Lane and Hallenstein Street. The middle section passes up through the forested area of Queenstown Hill. Rock bluffs are present in this area. The upper section crosses the western part of the Queenstown Hill summit plateau, which has localised rock exposures, and undulating ground.

Queenstown Hill Station

Located on the summit plateau of Queenstown Hill. A shallow drainage path (approx. 5 to 6 m lower than the station location) is present to the north. The site generally undulating.

Cable Route to Lake Johnson Station

This section to of the proposed route traverses across the moderately sloping eastern summit plateau of Queenstown Hill to the low hill present above Frankton and Lake Johnson (RL 781). The route will span across the deeply incised creek that drains to Queenstown Marina. East of this creek slope gradients vary from gently to steeply sloping with numerous rock outcrops and local drainage/gully features. The route will end on a low rounded hill spur with many low rock outcrops at Lake Johnson Station.

Lake Johnson Station

Lake Johnson Station is located on a low hill/spur above Frankton. The hill is gently to moderately sloping, with several nearby rock outcrops.

Cable Route to Ferry Hill Station

This section of the proposed route heads east from Lake Johnson Station, across gently to moderately sloping ground to reach the south facing slopes of Ferry Hill. This area has numerous shallow drainage features and undulations, and many gently sloping areas.

Cable Route to Frankton Bus Hub and Airport Station

This Section of the proposed route heads down the steep hillside on the south side of Lake Johnson Station to the Terrace Junction area. The route then continues south, roughly parallel to the highway to the bus hub and Airport Station. The route is flat/gently sloping and in the developed area of Frankton.

Frankton Bus Hub and Airport Station

The Frankton Bus Hub and Airport Station are located in the flat to gently developed area of Frankton adjacent to the highway.

Ferry Hill Station

Ferry Hill station is located on the southern slope of Ferry Hill. This area is a moderately sloping 'spur' like feature, however earthworks have been undertaken that provide level cut/fill benches in the station location.

Cable to Frankton North Station

This section of the route falls eastwards from Ferry Hill Station over the steep lower slope of Ferry hill and the Arrow Irrigation water race. The line then crosses gently sloping ground to the east of the Quail Rise residential area before spanning over the state highway to reach Frankton North Station. The highway is in cut in this location.

Frankton North Station

Frankton North Station is located on a 'ridge like' feature formed by the state highway road cut to the north west, and the Shotover River terrace slope to the south west. The industrial area at Margaret Place is present immediately to the south and the site itself is a yard/storage area. The surrounding slopes are approximately 30-35° and 15 to 45 m in height.

Cable Route From Frankton North to Ladies Mile Station

This section of the route heads east from Frankton North Station and down the 30-35° terrace slope of the Shotover Delta. The route will pass over the wastewater treatment site and gravel yards, and then across the active Shotover River channel. The route climbs up the east bank of the Shotover River through a residential area and a series of terrace slope to the flat areas along the Ladies Mile Highway.

Ladies Mile Station

Ladies Mile Station is located on the flat are adjacent to Ladies Mile highway (SH6), which currently comprises undeveloped farmland.

2.2 Option B

Option B provides an alternative route through Frankton, crosses the Shotover River further north from Option A before heading east the Ladies Mile. A brief description of each station location and section for the Option B route is provided below.

Frankton Bus Hub

Under Option B a Station east of highway is proposed xlose to the Frankton Bus Hub area. The area is flat to gently sloping and on the margin of the Frankton Golf Centre.

Cable from Frankton Bus Hub to Quail Rise Station

This Section of the route heads north east across the northern part of the Frankton Flats commercial area. Topography is flat to gently sloping. Localised man made earthworks (landscaping, drainage and accessways) are present along eastern and central areas of the route. At the eastern end the route follows the cut formed to accommodate the state highway. The cut varies in depth up to approximately 25 m, and has been constructed with a batter of 1.5H:1.0V (33°). The route is expected to run along the base of the cut.

Five Mile Station

Five Mile Station is located on the flat to gently sloping topography immediately to the north of the Queenstown Central shopping area. This area is essentially undeveloped however has been landscaped with access paths and planting.

Quail Rise Station

Quail Rise Station is present on the true right (western bank) of the Shotover River just north of the State Highway bridge. This area has been locally modified to provide parking, access to the river and the local roading network. This area is located just above the active river channel and is gently sloping with level areas.

Cable from Quail Rise Station to Lower Shotover Station

This Section of the cable will cross the active channel of the Shotover River and head east and upslope though the cutting formed to accommodate the State highway. The cable will climb up the cutting slope at an angle to end Lower Shotover Station. The cutting slope varies in height up to approximately 20 m and has a batter of approximately 1.5H:1.0V (33°).

Lower Shotover Station

Lower Shotover Station is located on a flat/gently sloping area close to the junction between Spence Road and Lower Shotover Road. Low landscaping bunds, and the upper part of the State Highway cutting are present in close proximity. The cutting is low in height in this are (< 3 m).

Cable to Lower Shotover Station to Ladies Mile Station

This section of the cable route crosses flat, gently sloping in ground. Local drainage features, roading and landscaping are present in the general area.

Ladies Mile Station

See above for Route 1.

3 Geology

3.1 Geological Setting

The site is located in the Wakatipu basin, a feature formed predominantly by glacial advances. Published references indicate the last glacial event occurred in the region between 10,000 and 20,000 years ago. Glaciations have left deposits of glacial till, glacial outwash and lake sediment over ice–scoured bedrock. Post glacial times have been dominated by the erosion of the bedrock and glacial sediment, with deposition of alluvial gravel by local watercourses and lacustrine sediment during periods of high lake levels.

3.2 Seismicity

Active fault traces were not observed at the site or in the immediate vicinity. The closest major active fault is the Nevis-Cardrona Fault system located approximately 20 km east of the proposed development. A significant seismic risk exists in the Lakes District region from strong ground shaking associated with a rupture of the Alpine Fault, located approximately 80 km northwest from Queenstown. Recent research suggests there is a 75% probability of an Alpine Fault earthquake occurring within the next 50 years and an 82% probability that the next earthquake on the Alpine Fault will be of magnitude 8 or greater.

3.3 Location Specific Ground Conditions

Based on geological mapping, available investigation data and site inspection, the ground conditions for the key elements of the route have been reviewed and are summarised in Table 3.1 below. The location numbers are shown on Figure 1a and 1c, and the Geology is also summarised on Figures 1b and 1e, Appendix A.

Table 3.1 – Summary of the Ground Conditions along the Cable Car Route .

Location	Summary of Geology	Groundwater
Queenstown Station (1)	Up to 5 m of Alluvial/deltaic gravels overlying lake sediments. Rock head estimated to be at depths of 35 m+. Uncontrolled fill along the Gorge Road/car park boundary, and locally under the Carpark.	High groundwater, artesian conditions noted for drillholes that extend into the Lakes sediments (depths of 5 m+). Perched groundwater at shallow depth.
Cable to Queenstown Hill Station (2)	The line transitions from sediments in the lower section comprising silt, sand and gravel on the valley floor and glacial soils on the lower area of Queenstown hill. Geology in the middle and upper areas of the route will be predominantly glacial soils over rock at shallow depths.	Very shallow water table in lower areas (see 1 above). Above the valley floor, the regional water table will be at depth with shallow perched groundwater likely to be encountered in sloping areas.

Location	Summary of Geology	Groundwater
Queenstown Hill Station (3)	Surface topsoil and colluvium overlying Glacial till and schist rock.	Regional water table at depth, local perched water may be present at shallow depths (< 5 m)
Cable to Lake Johnson Station (4)	Surface topsoil and slope colluvium overlying Glacial till and schist rock	
Lake Johnson Station (5)	Surface topsoil and colluvium overlying schist rock	
Cable to Bus and Airport Station (6)	Schist bedrock and Schist landslide deposits in upper sloping areas. From the Terrace Junction area south, deltaic and lake deposits of silt, sand and gravel. Surface beach deposits may be present.	Regional water table at depth. Perched seepages in upper sloping areas.
Frankton Bus Hub Routes A and B (7)	Deltaic and lake deposits of silt, sand and gravel. Surface beach deposits may be present.	Regional water table at depth
Airport Station (8)	Deltaic and lake deposits of silt, sand and gravel. Surface beach deposits may be present.	Regional water table at depth
Cable to Ferry Hill Station (9)	Surface topsoil and colluvium overlying, local alluvium, glacial soils and schist rock	Regional water table at depth, local perched water expected to be present.
Ferry Hill Station (10)	Topsoil, colluvium and loess overlying glacial soils and schist rock. Localised fill.	Regional water table at depth, local perched water expected to be present.
Cable to Frankton North Station (11)	Topsoil, colluvium and loess overlying glacial soils and bedrock in upper areas, transitioning to deltaic sand and gravel adjacent to the highway.	Perched seepages in upper sloping areas, at depth adjacent to the highway.
Frankton North Station (12)	Deltaic Sand and Gravel.	Regional water table at depth.
Cable to Ladies Mile (13)	Recent alluvial deposits immediately adjacent to the Shotover River, deltaic silt, sand and gravel east of the Shotover River.	Very shallow immediately adjacent to the Shotover River, at depth in other areas.
Ladies Mile Station Routes A and B (14)	Deltaic deposits of silt, sand and gravel.	Regional water table at depth.

Location	Summary of Geology	Groundwater
Route B Cable from Frankton Bus Hub to Quail Rise Station (15).	Deltaic deposits of silt, sand and gravel	Regional water table at depth for most of the route, becoming shallower on the approach to Quail Rise Station where shallow groundwater is expected.
Route B Five Mile Station (16)	Deltaic deposits of silt, sand and gravel	Regional water table at depth.
Route B Quail Rise Station (17)	Recent alluvial deposits immediately adjacent to the Shotover River.	Very shallow immediately adjacent to the Shotover River.
Route B Cable from Quail Rise Station to Lower Shotover Station (18)	Recent alluvial deposits immediately adjacent to the Shotover River, deltaic silt, sand and gravel east of the Shotover River.	Very shallow immediately adjacent to the Shotover River, at depth in other areas.
Route B Lower Shotover Station (19)	Deltaic deposits of silt, sand and gravel	Regional water table at depth.
Route B Cable to Lower Ladies Mile Station (20)	Deltaic deposits of silt, sand and gravel	Regional water table at depth.

4 Mapped Natural Hazards

Natural Hazards are present along the Cable car route and in adjacent areas.

A regional seismic risk, which is not specific to the Cable car, is present, as discussed in Section 3.2 above. Localised natural hazards along the Cable car route are summarised below, and are shown on Figure 1c and 1f, Appendix A.

4.1 Queenstown Station

Flooding

A flooding hazard is indicated immediately to the south west of the proposed development, associated with Horne Creek (2012 and 2021 Otago Regional Council). Flow in the creek is largely controlled by upstream stormwater services with overflow in a flood event preferentially towards the recreation ground immediately to the south west.

Alluvial Fan

An alluvial fan hazard is indicated around the margins of Horne Creek. The hazard is based on regional mapping by Otago Regional Council (2008) and GNS (2007). More recent assessments by the Otago Regional Council (2011) do not show an alluvial fan hazard in this area. Horne Creek is primarily controlled by upstream stormwater drainage infrastructure in the developed area of Gorge Road, and given this restriction, and the relatively gentle gradient in this area, debris flows or other fan like activity are considered to have a very low likelihood of occurrence in the Queenstown Station location.

Liquefaction:

A liquefaction risk is shown on the hazard mapping and is summarised as follows:

- Opus 2005, regional analysis, 'Possibly Susceptible.'
- Tonkin & Taylor 2012, Liquefaction investigation category (LIC) 2 P, a 'possible moderate risk of liquefaction.'
- GNS 2019 Regional Analysis, Category B1, 'geotechnical data suggests the localised presence of liquifiable materials. Damaging Liquefaction is considered a possibility and is probably of minor to moderate severity.

The following detailed geotechnical assessment reports have been undertaken for the QLDC Boundary Street Carpark, and have been reviewed as part of this assessment:

- Tonkin & Taylor Ltd (T&T), reference 880075, dated April 2009.
- T&T, Boundary Street Carpark Development, Preliminary Geotechnical Interpretative Report, reference 1007588.v1, August 2018.
- WSP, Boundary St Carpark Building, Geotechnical Assessment Report, reference 4-11562.00, August 2019.

Liquefaction and lateral spreading assessments were completed for the T&T 2018 and WSP reports. The results are summarised below.

T&T 2018

- A liquefaction assessment is provided assuming an Importance Level 2 structure.

- For a Serviceability Limited State (SLS), 1 in 25 year seismic event, liquefaction is not predicted;
- For an Ultimate Limit State (ULS), 1 in 500 year seismic event, liquefaction is predicted in liquefaction prone layers (silt and sand) at depths of 2.5 to 10 m.
- For a ULS event free field settlements of 100-150 mm are calculated, and a liquefaction Severity (LSN) of 13-28 is given, which indicates minor to moderate surface expression of liquefaction.
- Lateral spreading towards Horne Creek is predicted with a range of 300 – 1500 mm.

WSP

- Liquefaction and cyclic softening are predicted.
- No liquefaction is predicted for an SLS event, however liquefaction is calculated to trigger at 0.12g (estimated to be a 1 in 60 year event).
- Liquefaction is predicted for a ULS event with calculated free field settlements of 40 to 150 mm.
- Cyclic softening of the lake sediments is predicted to trigger at 0.18g (1 in 140 year event).
- Lateral spreading towards Horne Creek is predicted to be in the range 5 to 55 mm.

Both reports note the requirement for additional investigations to refine the liquefaction assessment for detailed design requirements. Based on the available T&T and WSP reporting it is expected liquefaction and lateral spreading will need to be considered for the detailed design of the Queenstown Station.

4.2 Queenstown to Queenstown Hill Station Cable

Liquefaction and Alluvial fan hazards at the extreme western end of the cable section close to Queenstown Station are as outlined above in Section 4.1.

Landslide: ORC Regional analysis shows a ‘dormant pre-existing schist landslide’ present above Hallenstein Street, Duncan Place and to the west of Kerry Drive. The landslide is shown on Figure 1c, Appendix A. Residential development has occurred locally on this landslide feature. Geosolve are not aware of any recent movement or adverse impact on the existing buildings from the landslide.

Schist landslides are typically characterised by steep slopes, highly fractured rock and in some cases a slow downward creep movement. Schist landslides can be dormant for many years, with no discernible movement. If movement does occur, rates are typically a few mm/yr. Landslide movement rates can increase or decrease in response to natural events such heavy rainfall or seismic shaking.

Rock Fall: In mid slope areas of Queenstown Hill the route enters a zone where schist bluffs are present. Geosolve undertook a general rock fall review of the area in 2024, Figure 4.1 below provides an excerpt from this reporting. The proposed cable car route can be seen passing through an area with very little likelihood of rock fall for the lower and mid sections of this zone. The upper part of the zone passes through an area with an increased rock fall risk relative to lower areas.

The principle bluffs (15, 16 and 19) were reviewed for the purposes of this assessment. Block formation was identified for each bluff and failure was considered possible. Scaling

(removal of potentially unstable blocks) was considered a practical remediation solution if required.

Gaps between the bluffs and the modelled rockfall run-out trajectories are readily apparent on the ground and on Figure 4.1 below. Locating towers in locations with a very low likelihood of rock fall impact on the structure is therefore expected to be achievable and will be a suitable method to address the risk of rock fall. See also Section 4.14 below.

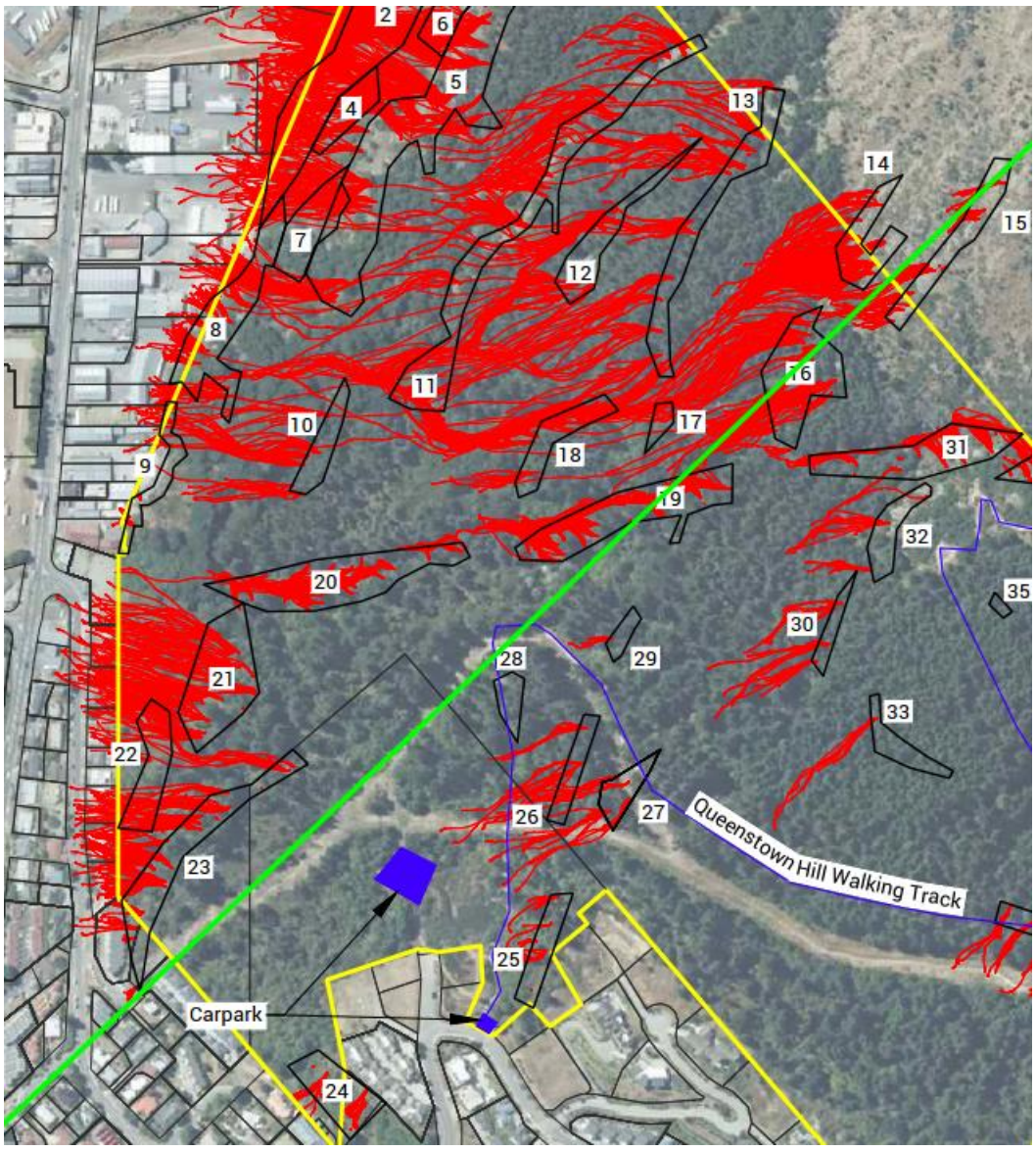


Figure 4.1. Mapped bluffs on Queenstown Hill and the proposed Cable car Route (green line).

Tree Removal

The lower slopes of Queenstown Hill pass through a forested area. To control the risk of tree fall and fire effecting the cable car cable, removal of trees along the cable car corridor may be required. Rock fall run-out distances can increase where tree removal has occurred, and, where tree removal is undertaken directly on bluffs, rock destabilisation can result. Geosolve have reviewed the bluffs present along the cable car corridor and, once tree removal extents are known, review of bluff impact can be completed. Generally, the risk from bluffs along the Cable car route is expected to be manageable with standard construction methods and assessment procedures.

As with recent similar projects, assessment and implementation of measures to control the risks associated with tree removal will be required. Such measures may include bluff treatment and engineering review of temporary works, e.g. access tracks and slope drainage. See also Section 5.2.6 below.

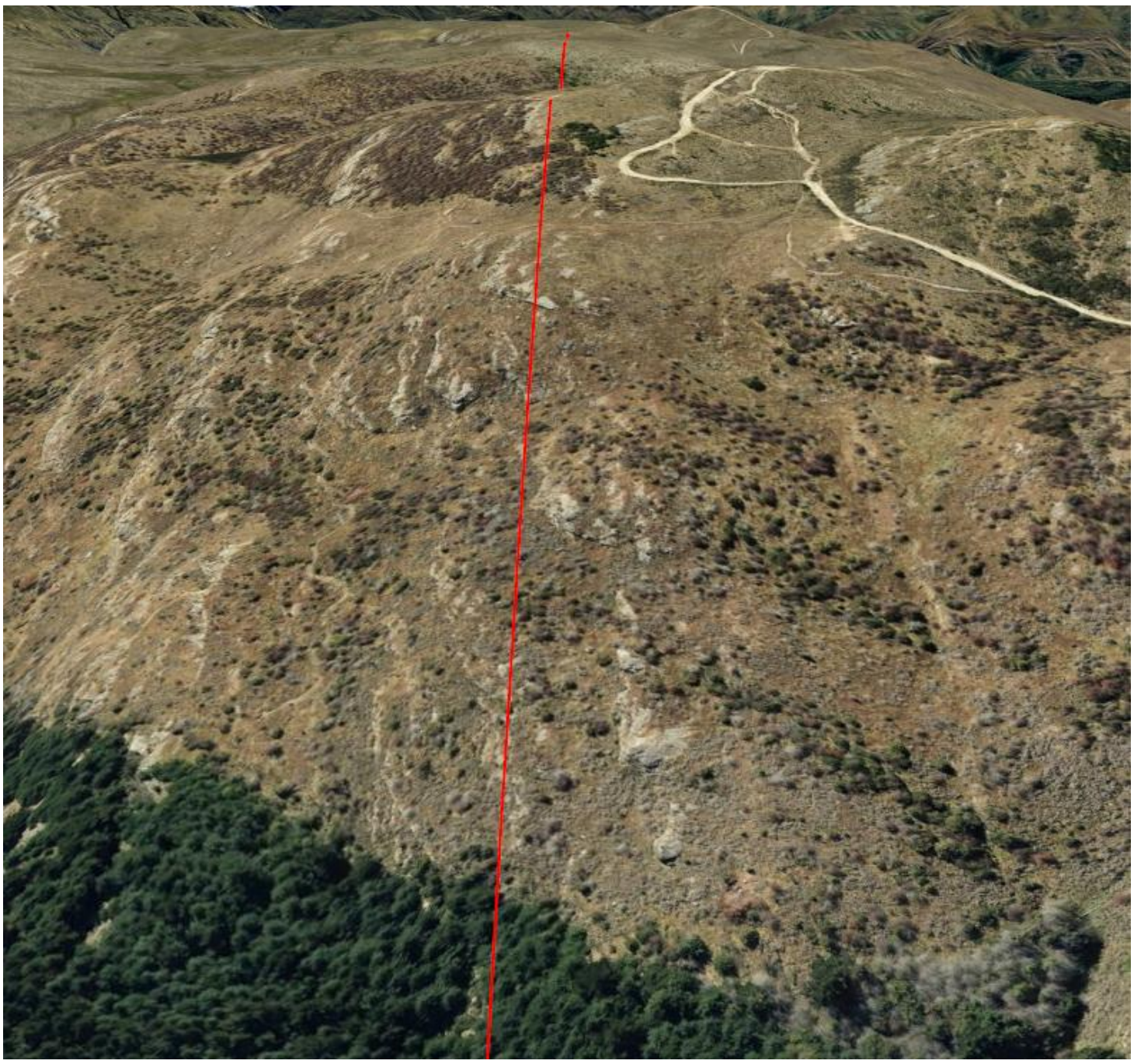


Figure 4.2 Proposed Cable Car Route and bluffs in the middle and upper area of Queenstown Hill (Google Earth).

4.3 Queenstown Hill Station

No mapped natural hazards are shown in the location of Queenstown Hill Station. The upslope extent of the Queenstown Hill Landslide is approximately 250-300 m to the south.

4.4 Queenstown Hill to Lake Johnson Station Cable

The upper part of the route is close to the summit of Queenstown Hill and is as described in Section 4.3 above. The route is upslope of the Queenstown hill landslide for the first section, before crossing the deeply incised creek that separates Queenstown Hill from the hill to the west (summit RL 781 m). There are no mapped hazards directly on the route. Deep seated schist landslides are present along the south facing slopes of the hillside above Frankton Road in several locations, however the route is upslope of these features.

The route crosses a series of shallow gullies and bluffs, see Figure 4.3 below. Rock fall, and shallow surface erosion and instability, should be expected in this area. Tower locations that target the elevated ridge like features are recommended to address the risk from localised shallow instability.

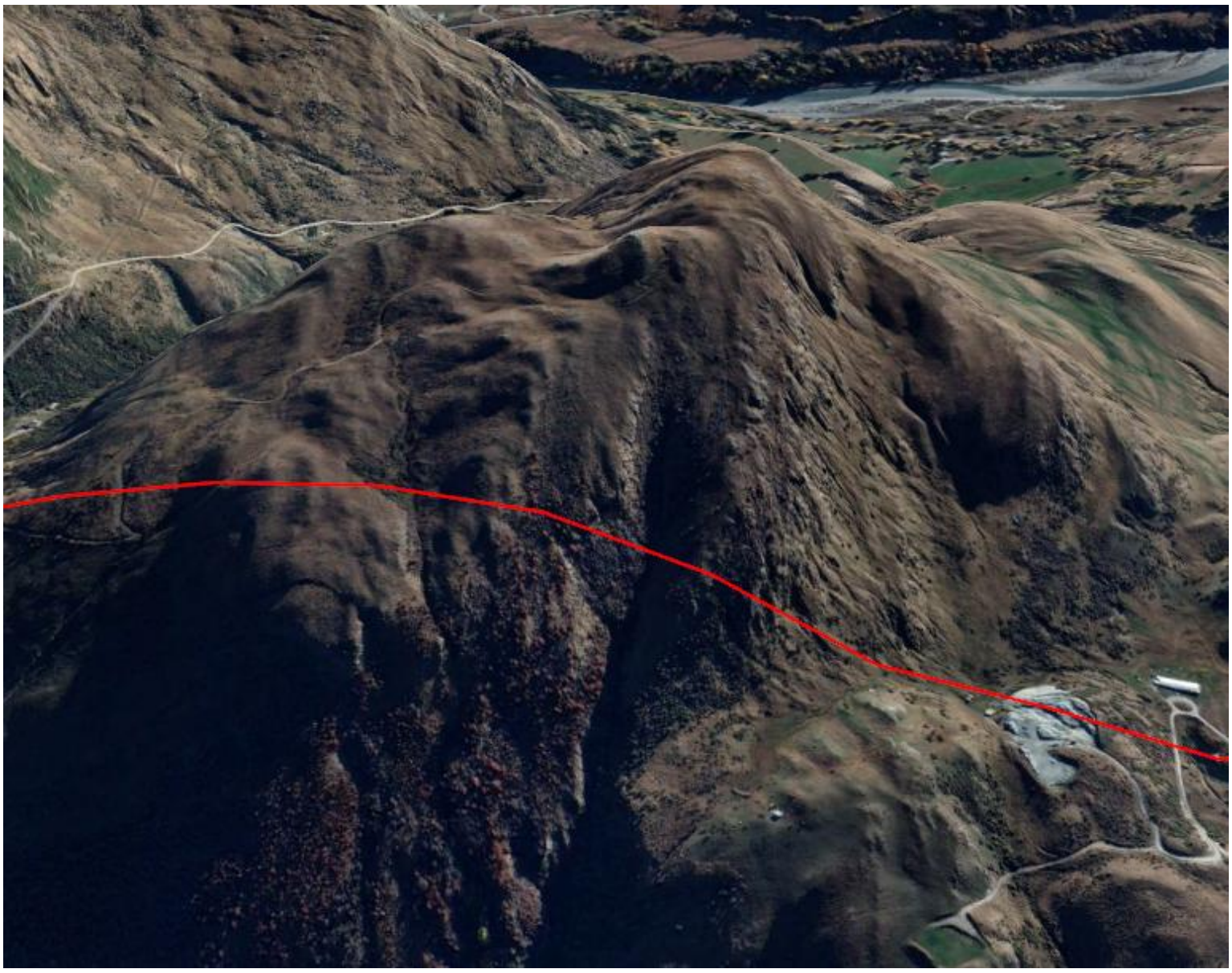


Figure 4.3. Proposed Cable car Route on the southern flank of Hill 781.

4.5 Lake Johnson Station

No mapped natural hazards are shown in the location of Lake Johnson Station. Hazard mapping shows the upper extent of a schist debris landslide is present approximately 60 m to the south, see Figure1c, Appendix A.

4.6 Lake Johnson to the Bus and Airport Station Cable

The proposed route passes down the hillside immediately to the north of the Terrace Junction development. This is a relatively low hill, approximately 165 m in height above Terrace Junction. The south face of the hill comprises a schist debris landslide also noted in Section 4.5. The general behaviour of schist landslides is described in Section 4.2. and is described on QLDC hazard mapping as ‘activity unknown.’

A timber pole retaining wall constructed for the Terrace Junction Development, and the Arrow Irrigation Water Race are present at the slope toe. Geosolve are not aware of any recent movement of the landslide.

4.7 Frankton Bus Hub and Airport Station

Hazard mapping for the proposed Airport Station indicates the following with respect to liquefaction:

- Opus 2005, regional analysis, 'Possibly Susceptible.'
- Tonkin & Taylor 2012, Liquefaction investigation category (LIC) 1 P, a 'probably low' risk of liquefaction.'
- GNS 2019 Regional Analysis, Category A 'the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.'

The groundwater table is known to be at or close to the level of Lake Wakatipu under the Frankton Flats area, which will be approximately 40 m below the development level. liquefaction is therefore not considered to be a risk at the site.

4.8 Lake Johnson to Ferry Hill Station Cable

Liquefaction mapping for this section (GNS 2019 Regional Analysis) of the route shows the site to be Category A: 'the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.' Geosolve agrees with this assessment and expects liquefaction will not need consideration for this section of the route.

The extreme eastern end of this section, where Ferry Hill Station is reached, will enter an area with an identified shallow landslide hazard, which is discussed in Section 4.9 below.

4.9 Ferry Hill Station

Liquefaction mapping for the proposed Ferry Hill Station site (GNS 2019) is shown as Category A 'the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.' Rock is present at shallow depths in this area, and the regional groundwater table will be at depth. Liquefaction is considered a very negligible risk in this location.

A regional landslide analysis (Otago Regional Council) shows a risk of 'shallow slips and debris flows in colluvium' for the eastern slopes of Ferry Hill. Geosolve expects this map category relates to observed shallow instability following the 1999 heavy rainfall event that affected the Lakes District. Numerous shallow slips occurred on Ferry Hill during this event. The slips were mostly in topsoil and colluvium and were influenced by local slope topography such as channels and undulations that concentrated surface run-off. The instability is a function of shallow soil saturation, overland flow/drainage rather than an underlying deep seated issue. The immediate area around the proposed Ferry Hill Station shows some evidence of this type of instability, however, being close to the crest of the ridge/spur the location is considered to be at a low risk of inundation from this type of process and management by standard engineering is expected to be achievable.

4.10 Ferry Hill to Frankton North Station Cable

Landslide

The initial section of the route heads south east from Ferry Hill Station. As discussed in Section 4.9, the eastern slopes of Ferry Hill have an identified risk of 'shallow slips and debris flows in colluvium' (Regional landslide analysis by Otago Regional Council).

Liquefaction

South eastwards from the toe of Ferry Hill hazard mapping indicates the follow with respect to liquefaction:

- Opus 2005, regional analysis, 'Possibly Susceptible.'
- Tonkin & Taylor 2012, Liquefaction investigation category (LIC) 1, a 'nil to low' risk of liquefaction.'
- GNS 2019 Regional Analysis, Category A 'the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.'

Liquefaction is not expected to be a risk for this section of the route due to the depth to the groundwater table and composition of underlying geology.

4.11 Frankton North Station

Hazard mapping for the location of the proposed Airport Station indicates the follow with respect to liquefaction:

- Opus 2005, regional analysis, 'Possibly Susceptible.'
- Tonkin & Taylor 2012, Liquefaction investigation category (LIC) 1 P, a 'probably low' risk of liquefaction.'
- Opus 2005, regional analysis, 'Possibly Susceptible.'
- GNS 2019 Regional Analysis, Category A 'the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.'

The groundwater table is known to be at or close to the level of the Shotover under this area of Frankton Flats, which will be approximately 45 m below the development level, liquefaction is therefore not considered to be a risk at the site.

No existing slope instability features are present in the Station location, however, slope stability with respect to the building code will require consideration and is discussed further in Section 5.2.1 below.

4.12 Frankton North to Ladies Mile Station Cable

The initial part of the route will be as per Frankton North Station described above. The route drops down to the immediate delta area of the Shotover River delta. Mapped hazards in this area include:

Liquefaction:

A liquefaction risk is shown on the hazard mapping and is summarised as follows:

- Opus 2002, regional analysis, 'Susceptible.'

- Opus 2005, regional analysis, 'Possibly Susceptible.'
- Tonkin & Taylor 2012, Liquefaction investigation category (LIC) 1 P, a 'probably low' risk of liquefaction.'
- GNS 2019 Regional Analysis, Category B, 'low to moderate likelihood of liquefaction susceptible materials being present' and 'damaging liquefaction is considered to be a possibility.'

The subsurface conditions in the Shotover Delta are expected to comprise normally consolidated gravel, sand and silt materials to depths of 60 m+. Shallow groundwater is also expected. The potential for liquefaction is therefore present and will need to be assessed for any structure present in the immediate Shotover River and adjacent delta area.

Geosolve have completed liquefaction assessments[1] on the eastern (true left) side of the Shotover Delta in similar geological terrain and ground water conditions for a residential development (importance level 2). The results show deformation is not expected for an SLS event. For a ULS event ground deformation may occur with free field settlements of < 50 mm expected. Similar results are expected for cable car structures present in this area.

Flooding:

Hazard mapping (Otago Regional Council 2012 and 2021, shows a flood hazard immediately around the margins of the Shotover River. Depending on the final tower locations flooding may need to be considered.

4.13 Ladies Mile Station

Hazard mapping for the location of the proposed Ladies Mile Station indicates the follow with respect to liquefaction:

- Opus 2005, regional analysis, 'Possibly Susceptible.'
- GNS 2019 Regional Analysis, Category A 'the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.'

The regional groundwater table is known to be at or close to the level of the Shotover River under the Ladies Mile area, which will be approximately 45 m below the development level, liquefaction is therefore not considered to be a risk at the site.

4.14 Five Mile Station and Cable to Quail Rise Station

Hazard mapping for the location of the proposed Ladies Mile Station indicates the follow with respect to liquefaction:

- Opus 2005, regional analysis, 'Possibly Susceptible.'
- Tonkin & Taylor 2012, Liquefaction Investigation Category (LIC) 1, nil to low risk of liquefaction.
- GNS 2019 Regional Analysis, Category A 'the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.'

[1] Geotechnical Report, Shotover Country SHA, Shotover County Queenstown, Reference 160554, October 2016.

The regional groundwater table is known to be at or close to the level of the Shotover River in this area, which will be approximately 40 m+ below the development level, liquefaction is therefore not generally considered to be a risk for these areas. The risk of liquefaction is expected to increase on the western approach to Quail Rise Station, see Section 4.15 below.

4.15 Quail Rise Station

Liquefaction

A liquefaction risk is shown on the hazard mapping and is summarised as follows:

- Opus 2002, regional analysis, 'Susceptible.'
- Opus 2005, regional analysis, 'Possibly Susceptible.'
- Tonkin & Taylor 2012, Liquefaction investigation category (LIC) 1 P, a 'probably low' risk of liquefaction.'
- GNS 2019 Regional Analysis, Category B, 'low to moderate likelihood of liquefaction susceptible materials being present' and 'damaging liquefaction is considered to be a possibility.'

The subsurface conditions in the Shotover Delta are expected to comprise normally consolidated gravel, sand and silt materials to depths of 60 m+. Shallow groundwater is also expected. The potential for liquefaction is therefore present and will need to be assessed for any structure present in the immediate Shotover River and adjacent delta area.

Geosolve have completed liquefaction assessments[2] on the eastern (true left) side of the Shotover Delta in similar geological terrain and ground water conditions for a residential development (importance level 2). The results show deformation is not expected for an SLS event. For a ULS event ground deformation may occur with free field settlements of < 50 mm expected. Similar results are expected for cable car structures present in this area.

Flooding:

Hazard mapping (Otago Regional Council 2012 and 2021), shows a flood hazard immediately around the margins of the Shotover River and is expected to be present at or very close to the proposed location of Qual Rise Station, and, depending on the final structure locations, flooding may need consideration.

4.16 Quail Rise Station to Lower Shotover Station Cable

The initial part of the route will be as per Quail Rise Station described above with respect to liquefaction and flooding. Once east of the Shotover River a risk of liquefaction continues to be shown on regional hazard mapping.

- Opus 2002, regional analysis, 'Possibly Susceptible'
- Opus 2005, regional analysis, 'Possibly Susceptible.'

[2] Geotechnical Report, Shotover Country SHA, Shotover County Queenstown, Reference 160554, October 2016.

- GNS 2019 Regional Analysis, Category A, ‘the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.’

Geosolve expect the risk of liquefaction will reduce significantly a short distance east of the Shotover River as the depth to groundwater increases.

4.17 Lower Shotover Station

Hazard mapping for the location of the proposed Ladies Mile Station indicates the follow with respect to liquefaction:

- Opus 2005, regional analysis, ‘Possibly Susceptible.’
- GNS 2019 Regional Analysis, Category A ‘the ground is predominantly underlain by rock or firm sediments. It is unlikely that damaging liquefaction will occur.’

The regional groundwater table is known to be at or close to the level of the Shotover River under the Ladies Mile area, which will be approximately 45 m below the development level, liquefaction is therefore not considered to be a risk at the site.

4.18 Risk to life and Natural Hazards

Stations

Annual Individual Fatality Rates (AIFR) for the person most at risk will be governed by staff working at the station locations. The only stations that have an identified natural hazard risk are Queenstown, which has a liquefaction hazard, and Frankton North, which has a slope stability consideration for detailed design (not an existing active hazard). Some risk may be present at the Quail Rise Station depending on the final layout and location. For These stations, detailed engineering design of the structures will need to meet performance criteria as required by the Building Code, in particular for the Ultimate Limit State Design Case which governs collapse and loss of life. The natural hazard risk will therefore be mitigated by the detailed design process.

Towers

Separate to the Stations there are 2 sections of cable that pass through areas with a rockfall hazard. The cable from Queenstown Station to Queenstown Hill Station passes through an area of bluffs, See Figures 4.1 and 4.2 above. For this section of the route rock fall modelling shows significant space is available between the bluffs. Options to avoid areas of possible rock fall are therefore present for tower locations. Additionally, if required, localised bluff remediation can be completed to address areas of instability.

The eastern end of the Queenstown Hill to Lake Johnson section of cable passes over a series of low ridgelines and bluffs. The ridgelines are elevated above the bluffs and provide logical positions for towers.

Risk Summary

Based on the above, and provided the risk is considered during the detailed design phase of the project, an Acceptable risk from natural hazards is expected to be achievable measured against the APP6 methodology and the Regional Policy Statement.

5 Engineering Considerations

5.1 General

Preliminary engineering recommendations are provided below. The recommendations and opinions are based upon ground investigation data obtained at discrete locations and historical information. The nature and continuity of subsoil conditions away from the investigation locations is inferred and cannot be guaranteed.

The ground conditions and associated geotechnical engineering issues will vary in each structure location. Specific engineering assessment will be required at the detailed design stage of the proposed Cable car development to confirm site specific detailed design elements.

5.2 Site Specific Engineering Considerations

5.2.1 Slope Stability

Frankton North Station

Frankton North Station is located on a 'ridge' like feature with a slope to the north west, the SH6 Road cut, and to the south west, the Shotover River terrace. The width of the ridge varies, as can be seen on Figure 5.1 below.

Figure 5.1. Frankton North Station location showing the surrounding slopes.

Geosolve has undertaken a preliminary slope stability assessment for both slopes. The following assumptions have been made for the assessment:

- The structure will be importance level 2 (in accordance with NZS1170).
- The geological model at the site comprises deltaic sand and gravel to depth, with the following geotechnical design parameters:
    - Bulk Density (g) 18 kN/m^3
    - Effective Friction (f´) 34°
    - Effective Cohesion (c´) 0 kPa

Table 5.1 below presents the preliminary slope stability results

Table 5.1. Slope stability results assuming standard shallow foundation construction.

Loading Case	Minimum Factor of safety (FoS) Requirements	Preliminary Results
State Highway Slope		
Static	1.5	1.5 achieved at approximately 10-12 m from the crest.
Seismic Serviceability Limit State (SLS), 0.1g	1.2	1.2 achieved at approximately 10-12 m from the crest
Seismic Ultimate Limit State (ULS)	No target FoS - estimated lateral stretch to be restricted to less than 20 mm at the building location	(Lateral stretch exceeds 20 mm until approximately 13 m from the crest).
Shotover River Terrace Slope		
Static	1.5	(1.5 achieved at 30-35 m from the crest)
Seismic Serviceability Limit State (SLS), 0.1g	1.2	(1.2 achieved at 30-35 m from the crest)
Seismic Ultimate Limit State (ULS)	No target FoS - estimated lateral stretch to be restricted to less than 20 mm at the building location	(Lateral stretch exceeds 35 mm at 13 m from the crest).

As can be seen in Table 5.1 the proximity of the structure to the existing slope crests and specific foundation design will need consideration. If the structure is close to either slope crest shallow footings are not expected to be appropriate. Specific Engineering design such as enhanced foundation systems, piles, and/or ground improvement, may be required to achieve the required long term performance for the structures design life.

The preliminary slope stability assessment presented above is considered conservative and for guidance only. Refining the assessment by undertaking a borehole investigation should be undertaken at the detailed design stage of the project.

Other Station Locations

The other stations are present in areas with relatively level or gentle sloping topography, or with favourable ground conditions with respect to deep seated instability e.g. shallow rock. Any slope stability issues will be very localised around the immediate area of the structure. Engineering solutions such as increasing foundation embedment depths or retaining are expected be appropriate to provide suitable long term performance with respect to slope stability in other station locations.

Tower Locations

Towers will be located on a variety of slopes and ground conditions. Tower foundations are typically of concrete pad construction and adjusting embedment depths and pad dimensions are expected to be sufficient in most cases to provide long term stability. Where towers are required on very steep ground ,anchoring the foundation back into the slope can be undertaken, and/or pile foundations may be appropriate in some cases.

The cable route between Lake Johnson Station and the bus terminal in Frankton will pass over an existing schist landslide present above the Terrace Junction development. Avoidance of placing towers in this area may be feasible, however, if towers are required on this feature, the potential for creep movement should be considered in the detailed design.

5.2.2 Liquefaction

Queenstown Station is assessed to have a liquefaction risk.

Detailed existing assessments for Queenstown Station have been reviewed for the purposes of this report and are summarised in Section 4.1 above. The foundation and structural engineering design will need to consider the effects of liquefaction induced settlement and lateral spreading. To date, assessments have concluded ground deformation does not occur for an SLS event. Ground deformation is predicted for a ULS event, and liquefaction is also shown to trigger at relatively low peak ground accelerations. Collaboration between the structural and the geotechnical engineer will be required to optimise the building performance and meet design requirements. Further geotechnical investigation may be required, pending detailed engineering review.

Preliminary review indicates appropriate foundation options for Queenstown Station are likely to comprise:

- Pile Foundations targeting an appropriate soil layer at depth.
- Shallow foundations e.g. raft, bearing on improved ground.’ Improved ground may take the form of stone columns, a gravel raft or soil mixing.

Quail Rise Station is also preliminarily assessed to have the potential for liquefaction. Geosolve are not aware of any specific liquefaction assessments completed directly in this location and specific assessment will therefore be required. As noted in Sections 4.12 and 4.15, liquefaction assessments in similar ground conditions have been completed nearby,

and the presence of infrastructure in close proximity, particularly the water treatment buildings to the south, indicate development will be achievable.

5.2.3 Foundation Bearing

A range of soil and rock materials will be present at typical foundation depths and the bearing capacity will vary from location to location. Geotechnical assessment will be required to determine an appropriate bearing capacity for each structure location. Foundation dimensions can then be determined by a structural engineer.

With respect to liquefaction, reduced bearing and accommodating seismic effects are anticipated for Queenstown and Quail Rise Stations.

5.2.4 Earthworks

Detailed earthworks plans have not been provided at this stage, however, cut and fill earthworks are expected to be required to construct foundations and provide level areas for the towers and station buildings. Ground conditions across the route will vary and excavations will be in both soil and rock.

Many tower foundations will be in sloping hillside areas and, to establish competent ground, excavations of up to approximately 2 m depth are expected in some cases. Given the remote location of many of the tower structures, and the relatively small foundation excavations expected, adverse effects from temporary or permanent works cut slopes are expected to be readily controllable by construction observation and appropriate geotechnical guidance on permanent and temporary batter stability.

Where towers are required in urban areas, particularly in close proximity to adjacent buildings or other infrastructure, more detailed geotechnical guidance will be required. Temporary and/or permanent retaining may be required to ensure no adverse impacts on neighbouring developments.

Station buildings will require detailed engineering assessment to determine specific design requirements. The following preliminary comments are provided:

Queenstown Station

Any excavations into the slope adjacent to Gorge Road will require retaining (permanent and temporary) to maintain the integrity of the road above.

Any excavations at the carpark level will require consideration of weak soil conditions and high ground water levels.

Queenstown Hill and Lake Johnson Stations

The station location is present in very open area with gentle/moderate slopes and no surrounding development. Earthworks are expected to be relatively straight forward with standard engineering solutions available to achieve long term stability e.g. slope re-grades and retaining. Earthworks are expected to be required to form level helicopter pads in these locations.

Ferry Hill Station

Earthworks platforms area already available in this location and are expected to be fit for purpose. Geotechnical review of suitability can be completed at the detailed design stage. Modification of the existing platforms may be appropriate however, if required, can be assessed at the detailed design stage.

Frankton North Station

No adverse effects are anticipated provided there is geotechnical input at the detailed design stage.

5.2.5 Overland Flow and Drainage

Tower structures are not expected to be sufficient in size to capture and divert stormwater flows, however, they should be located away from obvious overland flow paths.

Station locations will be in a variety of locations however none are located in an established flow path. Run-off from the buildings will be generated by rainfall and suitable options to control run off include:

- Connection to existing reticulated infrastructure.
- Disposal to ground.
- Capture and discharge into established adjacent flow path(s).
- Detention e.g. tanks, and a throttled outlet into an engineer approved location, existing flow path.

5.2.6 Access Tracks

Construction of access tracks and lay down areas in remote locations, particularly on Queenstown Hill and Hill 781 to the east, are expected to be required. The tracks will facilitate tower construction, and possibly long term maintenance and emergency evacuation. The tracks may therefore be temporary or permanent i.e. required to function for the lifetime of the cable car.

Tracks constructed in hillside areas typically traverse steep ground and existing established natural flow paths. Modification of surface run-off can occur which can result in adverse downstream effects. In extreme cases increased flow, sediment transport and slope instability can occur and impact downslope areas, which in this case are the residential areas on the lower slopes of Queenstown Hill and Hill 781.

Tracks of this type are typically infrequently used however are required to remain functional and fit for purpose.

Engineering assessment commended to ensure no adverse effects on downslope areas from track construction. Typically this is achieved by ensuring the works do not modify the natural drainage behaviour of the areas traversed.

6 Further Work for Detailed Design

For the detailed design of the individual structures, further geotechnical inputs will be required and should be undertaken once structure locations and station extents are available.

All locations:

Assessment to confirm bearing capacity and, if appropriate more detailed foundation requirements, e.g. pile or anchoring to address local slope profiles, ground conditions and infrastructure. Inspection, test pitting and/or penetrometer testing will be appropriate in most cases.

Queenstown Station

Collaboration between the geotechnical engineer and the structural engineer will be required to ensure the station performance during a seismic event is appropriate with respect to liquefaction effects. A combination of structural design and ground improvement is expected to be required. Significant investigation information is already available for this area however further intrusive investigation e.g. Cone Penetrometer Testing may be required to refine the analysis in key locations.

Frankton North Station

Collaboration between the geotechnical engineer and the structural engineer will be required to ensure the station performance during a seismic event is appropriate with respect to slope stability. A preliminary slope stability assessment indicates specific foundation and structural design will be required. Completing a borehole investigation is recommended to refine the geotechnical design parameters and slope stability modelling.

Queenstown Hill and Hill 781

Confirmation of final tower locations will be required relative to bluffs and rock fall. Significant areas are available for safe tower placement, however some local adjustment may be needed to optimise the tower positions.

If tree removal is undertaken, the impact on rock fall and slope run-off will require engineering assessment.

Quail Rise Station

A liquefaction assessment will be required to determine ground deformation and impact on a structure in this location. Collaboration between the geotechnical engineer and the structural engineer will be required to ensure the station performance during a seismic event is appropriate with respect to liquefaction effects. A combination of structural design and ground improvement may be required.

If final building location encroaches into the flood hazard zone, assessment will be required to determine appropriate design and confirm there are no negative effects on adjacent areas.

7 Summary and Conclusions

Geosolve has undertaken a review of the expected ground conditions and geotechnical considerations for the proposed cable car route, and main station locations. The development is considered feasible from a geotechnical perspective.

The geological terrain, and associated geotechnical issues across the proposed route vary, however, are geotechnically well understood. A wide range of developments have been completed in the same terrain across the Lakes District region using available geotechnical engineering design and construction methods.

Detailed assessment and geotechnical design inputs for the individual station and tower sites will be required. Intrusive investigations, including deep testing (Cone Penetrometer Testing and Borehole) for structure locations with a liquefaction or seismic slope stability design requirement, are expected to be required. Detailed engineering design for the stations and tower structures will be required and will ensure natural hazards risks are addressed, including seismic design aspects, liquefaction and sloping ground considerations.

Final tower locations are not confirmed at this stage, however, over the elevated areas of the route flexibility in tower location is available to suit the local terrain. In urban areas tower locations are expected to be less flexible, however, geotechnical aspects will be subject to detailed assessment and design.

Further Geotechnical work will be required at the detailed design stage of the project as per Section 6.

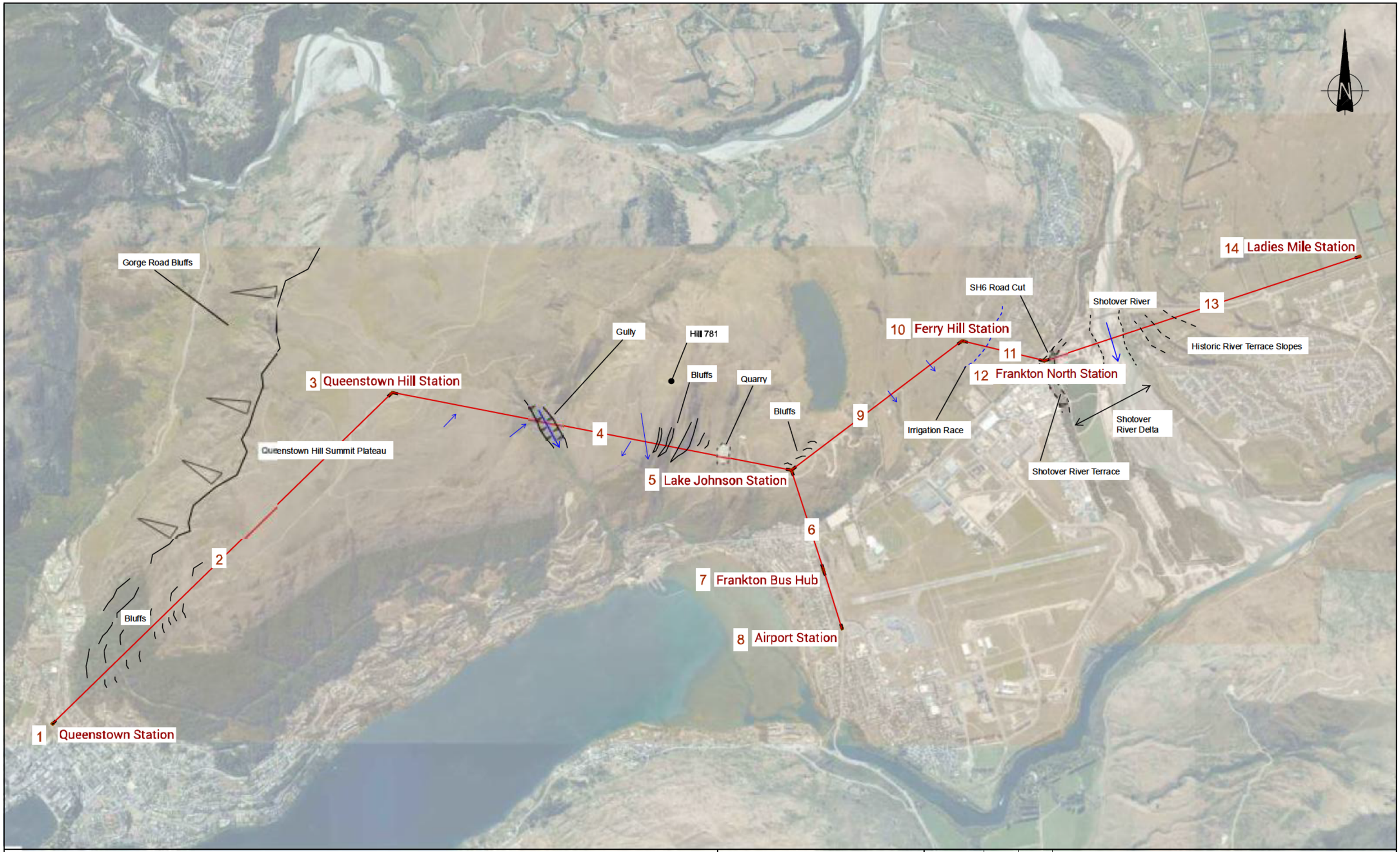
8 Applicability

This report has been prepared for the benefit of Southern Infrastructure Limited with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Report prepared by:	Reviewed By
.....	.....
Paul Faulkner Principal Engineering Geologist	Colin Macdiarmid Principal Geotechnical Engineer

Appendices: Appendix A – GeoSolve Drawings

Appendix A: Site Plans



Notes:
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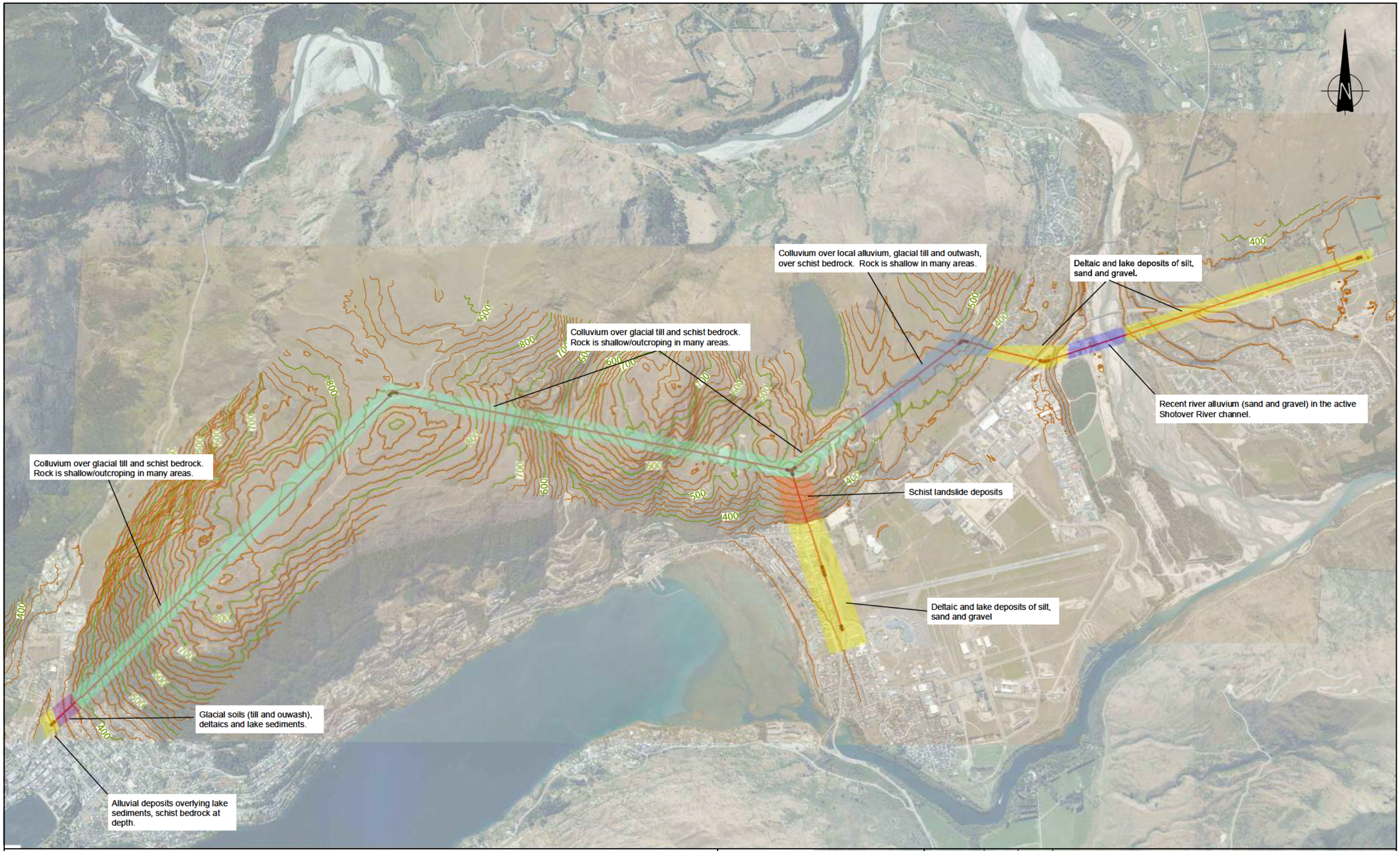
Project No.: 250134		

Southern Infrastructure Limited
Queenstown Hill Gondola
Geotechnical Review
Layout Plan

Figure No.: Appendix A, Figure 1a
Revision: 0



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Queenstown Hill Gondola

Geotechnical Review

Overview Geology Plan

Figure No.: Appendix A, Figure 1b

Revision: 0

Ladies Mile Station
Lower Shotover Station
Ferry Hill Station
Frankton North Station
Queenstown Hill Station
Lake Johnson Station
Frankton Hub Station
Airport Station
Queenstown Station

Legend:

Landslide Areas - ORC Regional Analysis
- Active Schist Debris Landslides
- Dormant Schist Debris Landslides
- Schist Debris Landslides (Activity Unknown)
- Area Susceptible to Slips or Sliding
- Landslide (Non Verified/Outside Priority Areas)

Liquefaction Hazards - 2012 Tonkin & Taylor Local Analysis
- LIC 1 - Nil to Low
- LIC 1 (P) - Probably Low
- LIC 2 (P) - Possibly Moderate
- LIC 3 (P|) - Possibly High
- 2021 ORC Flooding Areas

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Southern Infrastructure Limited

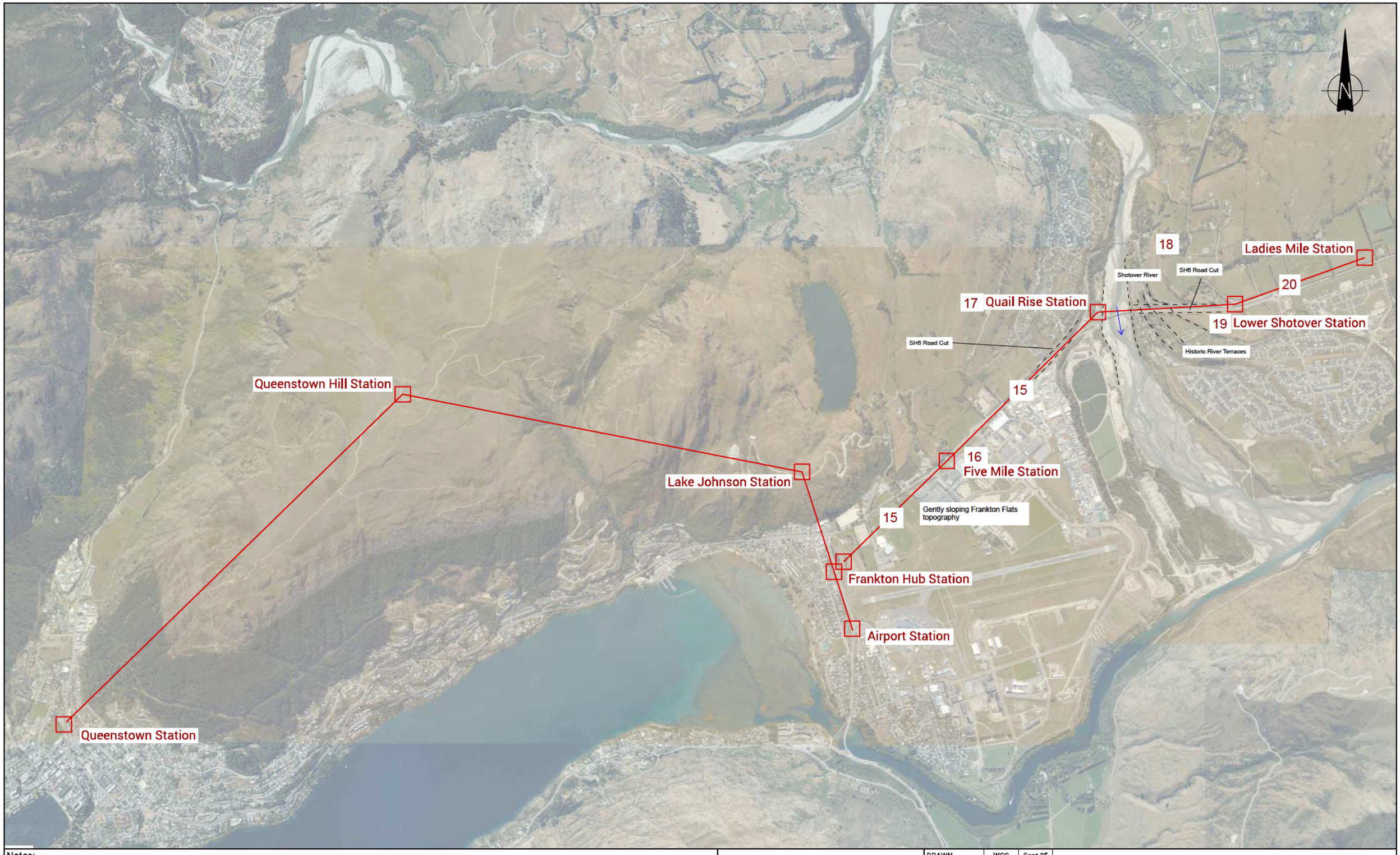
Queenstown Cable Car

Geotechnical Review

Natural Hazards Plan - Route A

Figure No. Appendix A, Figure 1c

Revision 0



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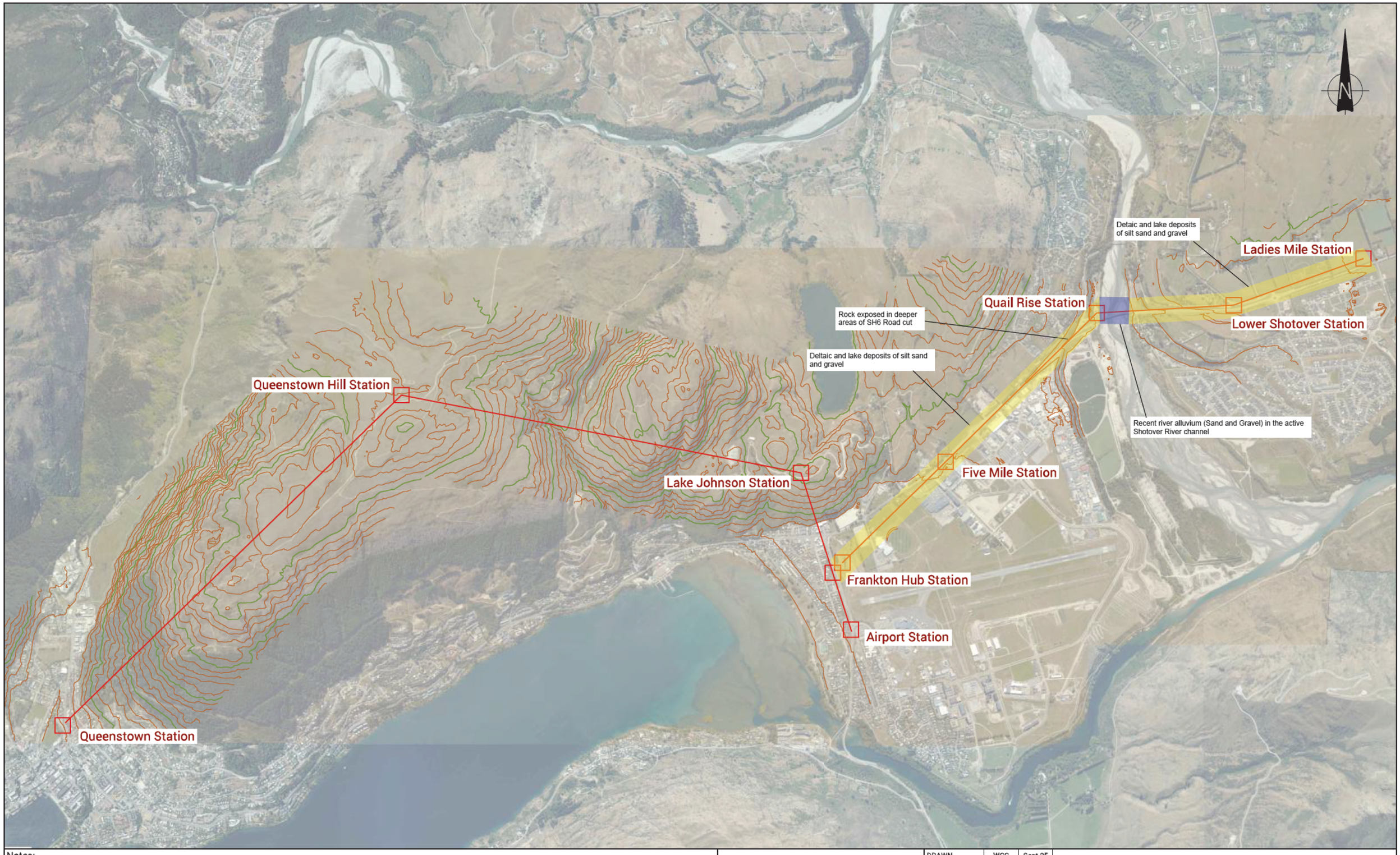
Queenstown Cable Car

Geotechnical Review

Layout Plan - Route B

Figure No.: Appendix A, Figure 1d

Revision: 0



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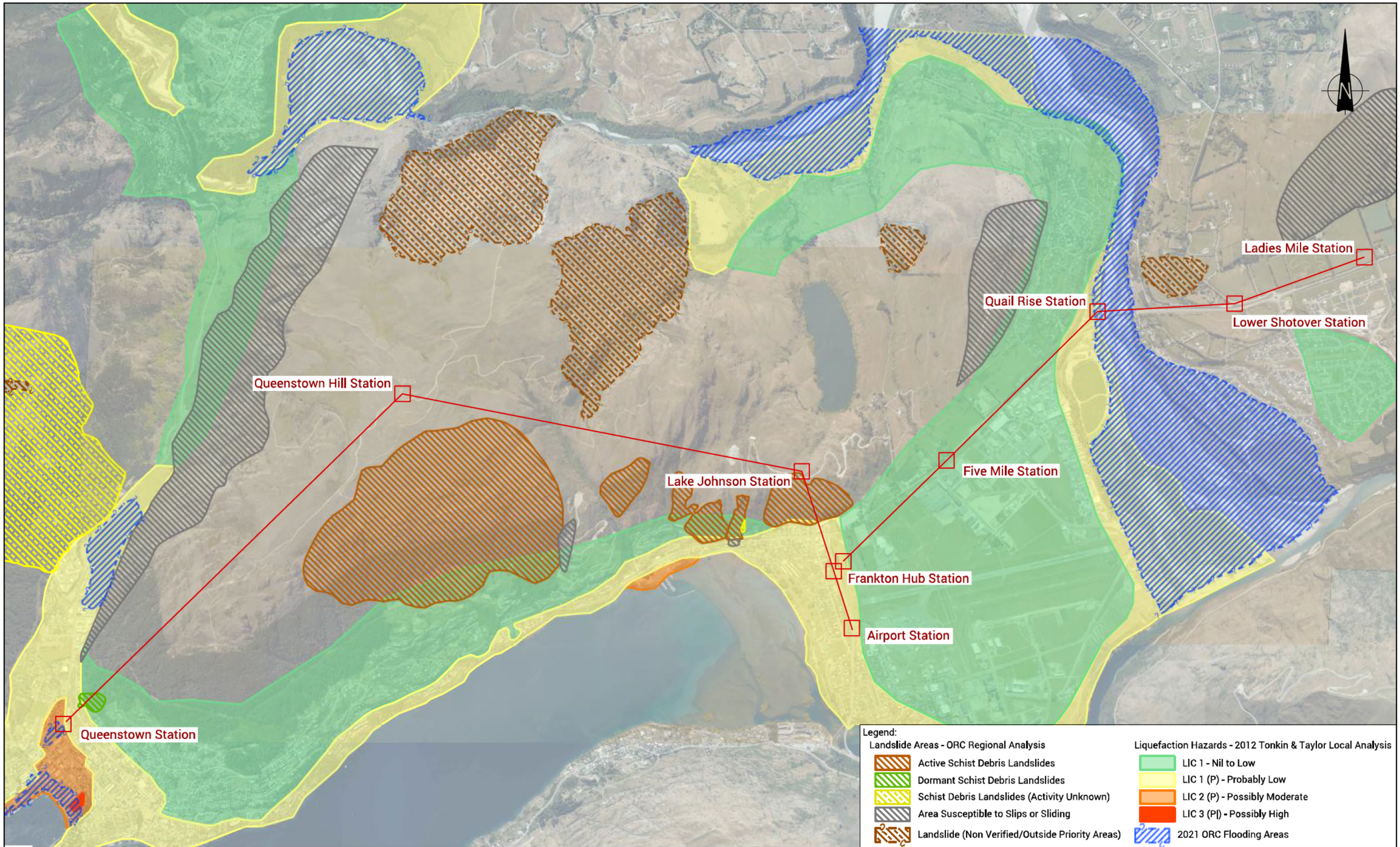
Southern Infrastructure Limited
Queenstown Cable Car
Geotechnical Review
Overview Geology Plan - Route B

Figure No.	Revision
Appendix A, Figure 1e	0



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Queenstown Cable Car
Geotechnical Review
Natural Hazards Plan - Route B

Figure No.: Appendix A, Figure 1f
Revision: 0

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