02 September 2021 Reference No. 21490001_7407-001-LR-RevA_DRAFT

Luke Place
Queenstown Lakes District Council
Level 1
74 Shotover Street
Queenstown 9348

REVIEW OF NATURAL HAZARD ASSESSMENTS FOR PROPOSED CONEBURN INDUSTRIAL AREA PLAN CHANGE

Dear Luke

Introduction

Queenstown Lakes District Council (QLDC) has engaged WSP New Zealand Limited (WSP) to undertake a review of existing hazard assessments by others that support an application for a district plan amendment associated with the proposed Coneburn Industrial Area, Kingston Road (State Highway 1), Queenstown south of Frankton (see Figure 1). The development is proposed to be a dedicated industrial and service zone with a mix of compatible activities that excludes residential, standalone offices and most retail. In 2021 WSP acquired Golder Associates (NZ) Limited (Golder) and Golder has completed this review under the existing WSP contract for QLDC (WSP file/ref 6-XQ090.11)[1].

[1] This letter report is provided subject to the attached Report Limitations.

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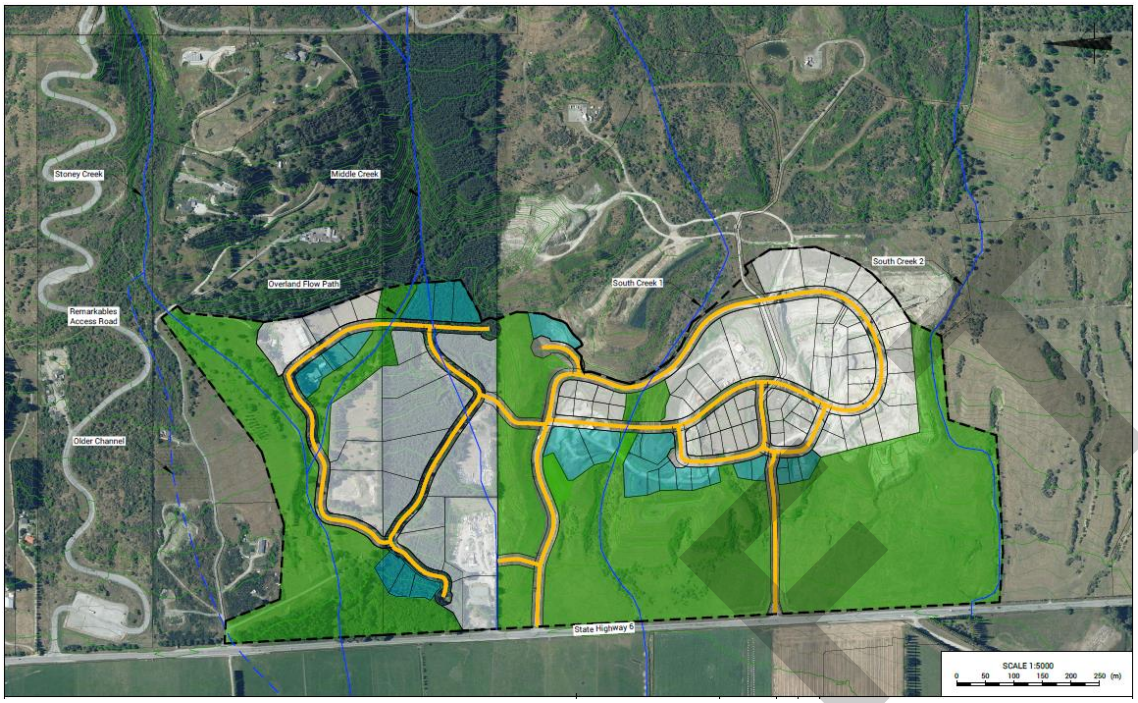

Figure 1: Proposed Coneburn Industrial Zone site plan (Figure 1a in Geosolve report July 2021).

As part of the review we have been provided with the following technical documents:

1) May 2008 Tonkin + Taylor Natural Hazard Assessment Report for The Oasis Development, Stoney Creek, Frankton. Ref: 880077.100.

2) Sept 2019 Geosolve Geotechnical Report for Resource Consent (for water tanks). Ref: 190413.

3) 5 Nov 2019 Geosolve Geotechnical Slope Stability Assessment Coneburn Water Reservoir. Ref: 190413.

4) 2 June 2021 WSP memorandum Coneburn Industrial Area Proposed District Plan Change. Ref: 6-XQ090.11.

5) July 2021 Geosolve Request for Information – Natural Hazard Assessment. Ref: 190413.01, which includes as an appendix:
   Oct 2015 Lowe Environmental Impact Coneburn Industrial Park – Water Infrastructure Option Viability Report.

The Geosolve primary author (Simon Reeves) was contacted by Golder reviewer Matt Howard on 17 August 2021 for clarification of some aspects of the assessment. Geosolve presented photographs of exposed materials in water courses to support their debris flow assessment, which are attached to this letter for reference.

To support our understanding of the site and the regulatory requirements we have also viewed the following:

1) Publicly available historical aerial photographs (Retrolens - Historical Imagery Resource).

2) January 2021 Dunedin City Council Second Generation District Plan (2GP).

3) June 2021 Otago Regional Council Proposed Otago Regional Policy Statement (RPS).

This review considers whether the risks posed by the natural hazards have been adequately identified and assessed by Geosolve and whether they can be mitigated at the detailed design stage of the project (i.e., at the Resource Consent application stage). This review is related to natural hazards only. Information relating to other engineering aspects of the proposed development have not been considered.

Proposed Development

From Geosolve (2021):

The site is located on the gently to moderately sloping western aspect (lower slopes of the Remarkables Range), approximately 1100-1200 metres from the toe of the steeply sloping Remarkables mountain range. The subject site is generally sited on discontinuous terraced slopes formed by alluvial depositions of material adjacent to the glacial margins. These slopes have since been modified (post-glacial) by erosion, deposition and incision of various creeks. The various creeks drain from the steep Remarkables range and more moderately sloping intermediate slopes, upslope of the proposed development. Four main creeks appear to enter the upslope site boundary. Stoney Creek, the combined Middle Creek Channel and South Creek 1 & 2.

Natural Hazards Assessed by Geosolve

WSP (2021), on behalf of QLDC, concluded that existing reports (i.e., pre-2021) were inadequate to support the proposed District Plan change and listed the expected components that a natural hazard assessment should contain. These included an evaluation of the following:

- Rockfall hazard
- Alluvial fan hazard
- Cut and fill slope stability
- Debris flow hazard
- Flooding hazard
- Liquefaction hazard
- Hazard to the development posed by the proposed upstream water reservoir tanks

The Golder review refers exclusively to Geosolve (2021) and its appended report (Lowe, 2015). Previous reports offer beneficial background information for various iterations of the proposed development; however, they are generally less detailed or specific with respect to the assessment outlined in WSP (2021).

Risk Assessment Methodology

Two methods of semi-quantitative risk assessment have been used by Geosolve for each of the natural hazards. Both methods assume the hazard is not mitigated. The Dunedin City Council 2GP has five likelihood categories and three consequence categories that calculate a risk that is very low, low, moderate or high. The Otago Regional Council's RPS has the same number of likelihood categories, but five consequence categories with different descriptions. The risk categories are listed as acceptable, tolerable and significant. The two risk descriptions approximately overlap, with the 2GP's very low to low and moderate/high corresponding respectively with the RPS's acceptable and significant. It should be noted that the consequence descriptions in the RPS describe numerous applications to buildings as well as health and safety and the 2GP requires two of a list of hazard outcomes.

The use of the two risk assessment approaches is considered by Golder/WSP to be appropriate as they are similar and comply with district and regional guidance. For the RPS a more detailed quantitative approach is appropriate where the initial risk is 'significant'.

The completed assessment did not, however, identify any "significant" risks for any of the natural hazards considered. The results from both methods are reproduced in Figure 2 and Figure 3 below.

Area	Debris Flood	Flooding	Rockfall	Landslide	Liquefaction
Proposed Development Area	-	-	Very Low to Low Risk	Very Low to Low Risk	Low Risk
Stoney Creek	Low to Moderate Risk	Low to Moderate Risk	-	-	-
Stoney Creek Overbank Area	Low Risk	Low Risk	-	-	-
Middle Creek Combined Channel	Very Low to Low Risk	Low to Moderate Risk	-	-	-
Middle Creek Combined Channel Overbank Area	-	Low Risk	-	-	-
South Creek 1	Low Risk	Low to Moderate Risk	-	-	-
South Creek 1 Overbank Area	-	Low Risk	-	-	-
South Creek 2	Low Risk	Low to Moderate Risk	-	-	-
South Creek 2 Overbank Area	-	Low Risk	-	-	-

Figure 2: Risk assessment results using methodology of Dunedin City Council's 2GP (colour added by Geosolve).

Area	Debris Flood	Flooding	Rockfall	Landslide	Liquefaction
Proposed Development Area	-	-	Acceptable Risk	Acceptable Risk	Acceptable Risk
Stoney Creek channel corridor	Acceptable to Tolerable Risk	Acceptable to Tolerable Risk	-	-	-
Stoney Creek Overbank Area	Acceptable Risk	Acceptable Risk	-	-	-
Middle Creek Combined Channel	Acceptable Risk	Acceptable to Tolerable Risk	-	-	-
Middle Creek Combined Channel Overbank Area	-	Acceptable Risk	-	-	-
South Creek 1	Acceptable Risk	Acceptable to Tolerable Risk	-	-	-
South Creek 1 Overbank Area	-	Acceptable Risk	-	-	-
South Creek 2	Acceptable Risk	Acceptable to Tolerable Risk	-	-	-
South Creek 2 Overbank Area	-	Acceptable Risk	-	-	-

Figure 3: Risk assessment results using methodology of Otago Regional Council's RPS (APP6 criteria).

Review of Geohazard Assessment

The following headings match those in the risk table above, which approximate the geohazards to be addressed as suggested by WSP (2021), listed above.

Debris Flow

- Geosolve has conducted a debris flow assessment for the four creeks that pass through the proposed development. They have correctly stated that there is no single, accepted criteria to definitively quantify debris flow hazard. The adopted approach is to observe the topography and geomorphology of the catchment, consider the likely sediment/debris input and apply empirical relationships. This is supported by RAMMS debris flow modelling.
- The site is located on an alluvial fan and is estimated to be potentially subject to debris floods due to the relatively low surface slope angle on and above the proposed development and the limited potential for sediment generation within the catchment. Compared to debris flows, debris floods typically contain finer sediment and do not have sufficient energy to entrain larger, more damaging boulders. Geosolve has inferred that debris flood flows increase the bulk of clearwater flows by a factor of 2.5.
- A debris flood environment is supported by empirical studies of landslide runout, which suggest that the catchment height and the low angle of fan slope at the proposed development are indicative of a relatively low stormwater energy environment. This is supported by site photographs of exposed material attached to this letter[2] that show generally small-sized material in creek banks (in Photograph 5 in South Creek 2, large boulders are interpreted to be glacially deposited and not carried by modern storms).
- The creeks on the area approximately 1 km upstream of the proposed development are currently located in relatively shallow, wide creeks when compared to the incised channels further upstream. Avulsion has

[2] Attachment provided as a supplement from Geosolve on 19/08/21 following phone conversation between S. Reeves and M. Howard.

the potential to occur from the shallower channels and mitigative earthworks would be required to protect the proposed development.

- The larger, steeper catchment of Stoney Creek is estimated to pose the greatest debris flood hazard, with RAMMS modelling showing flows up to approximately 0.5 m deep tens of metres either side of the channel in its present condition. South Creeks 1 and 2 has debris flood potential, but is estimated to carry less debris at the proposed development. Middle Creek is estimated to be dominated by muddy stormwater.

Reviewer Comment:

- For clarity it would be beneficial to have graphical cross sections cut along modelled creek channels to show the proposed development boundary, the elevation that is referred to in the text, geology and downslope extent/depth of modelled debris flow.
- It is difficult to represent the many uncertain variables in a debris flow/flood event scenario (water flow, debris volume, type, speed debris enters the water flow, percentage of debris etc). Geosolve's conclusions regarding the potential for debris flood (not debris flow) are consistent with empirical studies, including a separate source shown in Figure 4.
- RAMMS is a useful visualisation tool for potential flood behaviour but does not quantify hazard without substantial analysis supported by historical studies. Geosolve infers a credible hazard from the modelling, particularly for Stoney Creek and South Creeks 1 and 2.
- We concur with the assessed risk by Geosolve. However, the debris flood model is considered preliminary as stormwater and conveyance structures will be developed during detailed design, requiring additional assessment. We agree that debris flood is possible and mitigation will be necessary for the proposed development. It is good engineering practice to mitigate the effects of natural hazards to as low as reasonably practicable, especially due to the inherently uncertain nature of debris-related hazards. Detailed design will occur at the Resource Consent stage and may take the form of training or containment structures (engineered earth and/or concrete) along the margins of susceptible creeks, and possibly on the upslope boundary of the proposed development.

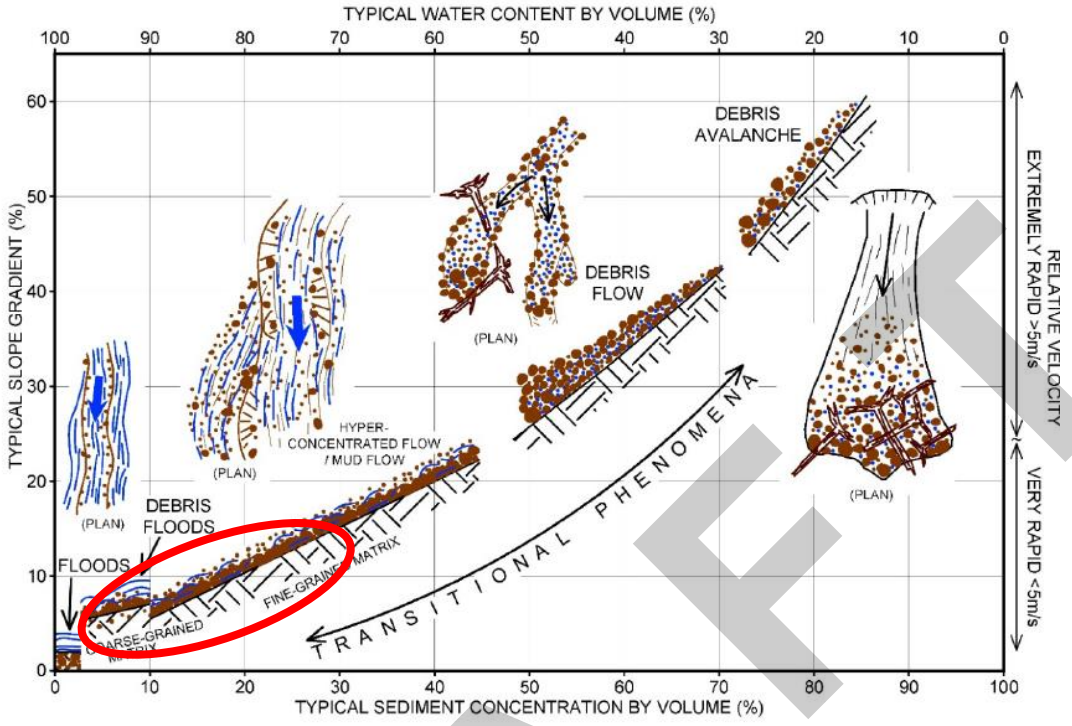

Figure 4: Debris flow/flood diagram indicating effect of slope on flow type. Red zone is likely to be consistent with Coneburn development conditions. After BGC (2020)[3].

Fluvial Flooding and Stormwater

- The Lowe (2015) stormwater assessment is the primary catchment study for the proposed development. It identifies the four existing water courses that enter the site. It is informed by appended geological characterisation of the area.
- Building lots are proposed outside of the natural water courses, with zones either side specified as 'Open Space – no buildings or structures' in Geosolve's Figure 1a.
- The stormwater assessment considers a 200-year return period event, which is more conservative than QLDC's requirement for a 100-year return period event. Flood estimation uses the "Flood Frequency In New Zealand" method by McKerchar and Pearson. In the assessed scenario overbank inundation from stream avulsion is expected in the unmitigated condition.
- The catchments that flow through the site (Catchment B – Middle Creeks, and Catchment C – South Creek 1) are estimated to have a Q_{200} of less than 10 m^3/s (cumecs), which corresponds to channel dimensions of 2-3 m wide at the base and 0.5-1 m deep, depending on channel slope. Doubling of flow due to avulsion from one channel to another would require a doubling of channel depth.
- Lowe (2015) notes that flood protection earthworks already exist upstream of the proposed development (e.g., Stoney Creek) and these should be re-assessed and upgraded as appropriate in the future.

[3] BGC Engineering Inc., 10 April 2020: Squamish-Lillooet Regional District – Geohazard Risk Prioritization - FINAL. Project No.: 1358007. Report prepared for Squamish-Lillooet Regional District.

Reviewer comment:

- The stormwater modelling appears to correctly assess the catchment size and relevant properties appropriately; however, we have not recalculated the expected flow values.
- It is our opinion that the flooding risks associated with the four creeks that pass through the site require detailed assessment with the potential inclusion of upstream and on-site mitigation to reduce the impacts of surface flooding. It is recommended that any stormwater management options be reviewed by an appropriate stormwater design engineer.

Rockfall

- The primary evidence for judging rockfall hazard is the observation of previous fallen boulders. Geosolve noted large boulders near the bottom of the steep Remarkables Range slopes (the rockfall source), but these were not observed further downslope in the approximately 1 km wide zone of flatter topography uphill of the proposed development.
- Three dimensional rockfall simulation modelling was undertaken using RAMMS software. The simulation modelled an elongated-to-tabular boulder of 5.1 m^3 to represent the 95th percentile boulder. This was selected by noting the size of the largest boulder at the toe of the steep slope below.
- The RAMMS modelling indicated fallen boulders would come to rest at the base of the steep Remarkables Range slopes and would not travel on the flatter, alluvial surface uphill of the proposed development.

Reviewer comment:

- Geosolve has correctly identified the likely rockfall source in the slopes above the proposed development and the selected boulder size of 5.1 m^3 is justified.
- The primary evidence for judging rockfall hazard is the observation of previously fallen boulders. The absence of large boulders having rolled onto the flatter alluvial surface uphill of the proposed development is a strong indicator that the rockfall hazard is negligible.
- Rockfall simulation is a supplement to the primary evidence. We have not undertaken a similar exercise, nor assessed the parameters used, however, the RAMMS simulation appear to be an appropriate proxy for a realistic rockfall scenario.
- The assessed negligible hazard is judged to be appropriate.

Slope Stability (landslide)

- Geosolve has acknowledged the presence of landslides of several hundred metres in maximum length in the headwaters of Stoney Creek, as shown on QLDC hazard maps. They note the absence of features during field inspection that would indicate recent or highly active movement, such as vegetation disruption or recently exposed subsurface materials (e.g., opening of tension cracks). Additionally, the landslide is more than 1 km upstream of the proposed development.

Reviewer comment:

- The identified landslide appears to be a relict feature or is moving very slowly - such features are common in Otago schist. The assessed benign hazard is judged to be appropriate.

Liquefaction

- Geosolve has identified granular material underlying areas of the site and consider this can be assumed to underlie the proposed development. Groundwater is considered to be 20 m below ground level across the site.

Reviewer comment:

- Liquefaction of foundation soil is not feasible above the water table and therefore beyond the likely influence zone of large, heavy buildings (i.e., upper 20 m of ground). This should be confirmed at detailed design stage by intrusive geotechnical investigations, which will be required to support structure design and to support Building Consent.

Engineering Considerations

- Geosolve recommend that the stability of natural and cut slopes be subjected to slope stability analysis at the detailed design stage and they list some remedial options.
- The proposed reservoir will be designed to the performance criteria of the building code as part of Building Consent application.
- Overland stormwater conveyance will be engineered and the hazard mitigated by the appropriate application of design criteria at the time of Resource Consent.

Reviewer comment:

- This is an appropriate approach for slope stability given the dominant presence of granular materials and water table at a depth unlikely to influence slope stability.
- Structures and stormwater conveyance and mitigation can be adequately managed at detailed design. The present risk is acceptably low and engineering controls are unlikely to be prohibitively expensive.

Conclusion

We conclude that the Geosolve (2021) report adequately addresses the geohazards for the proposed Coneburn development to a level appropriate for District Plan land use change. The assessed risk uses the appropriate methods and are Moderate risk or lower (using Dunedin City Council's 2GP) or Tolerable or lower (using Otago Regional Council's RPS APP6 criteria). Good engineering practice requires the effects of natural hazards to be managed to as low as reasonably practicable; therefore, it is expected that mitigation works will be required to manage flood and debris flood hazard. Mitigation can be more accurately assessed and specified at the detailed design stage as part of the Resource Consent application for the final site layout. The risk assessment should be also be updated to reflect the 'as designed' development.

Yours sincerely
GOLDER ASSOCIATES (NZ) LIMITED

Matt Howard
Principal Engineering Geologist

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Principal Engineering Geologist
CMENGNZ (PENGGEOL) 176867

MEH/TJM/jsb

Attachments: Report Limitations
Geosolve channel exposure photos for debris flow assessment (19 August 2021)

https://golderassociates.sharepoint.com/sites/151445/project files/6 deliverables/001 lr-geohazard review/reva_draft/21490001_7407-001-lr-reva-coneburn_draft.docx

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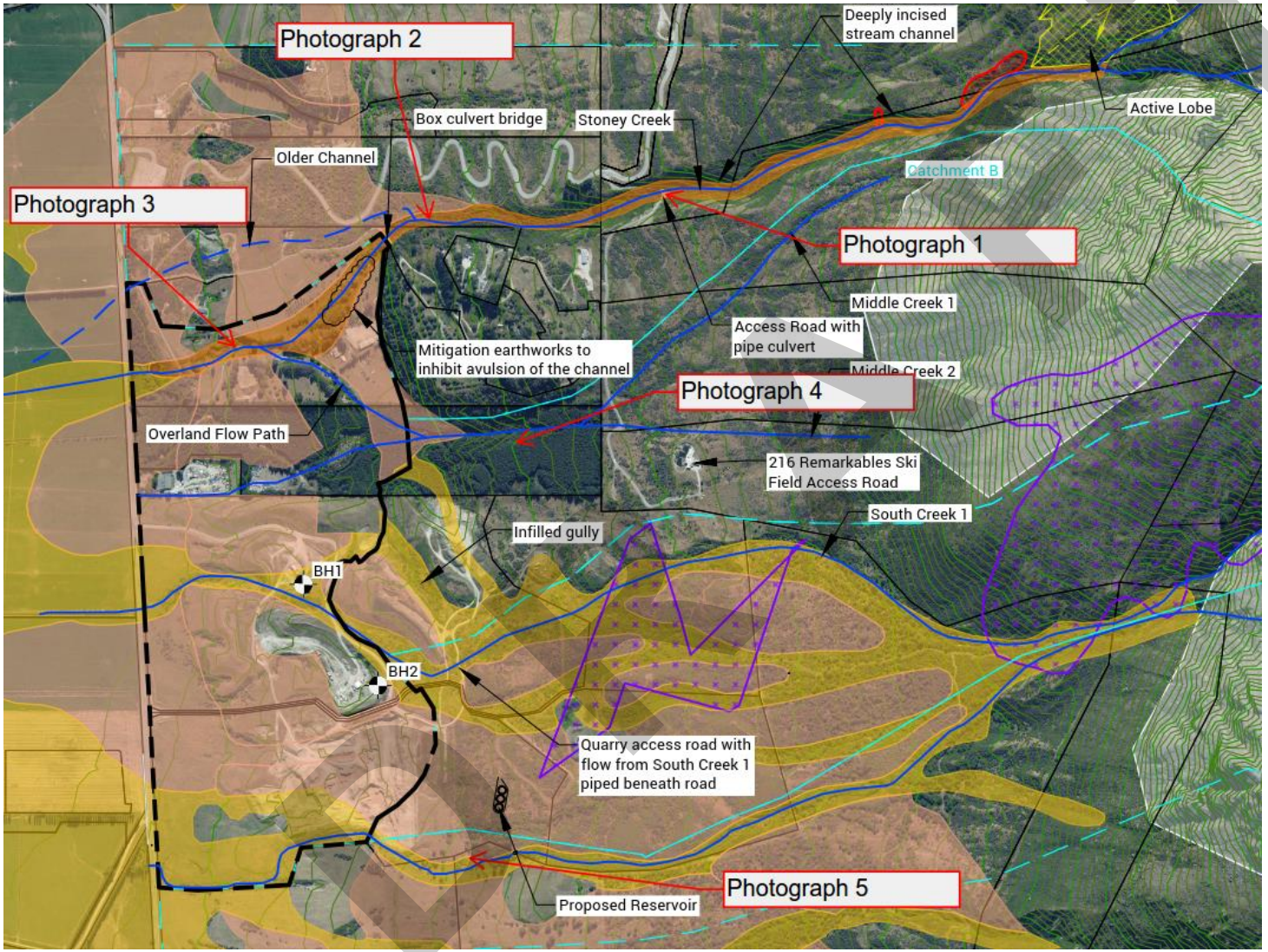
Channel Exposure Photograph Request:

Figure 1: Location of Photograph for Stoney Creek channel exposures



Stoney Creek:

Photograph 1: Road cut for access to 216 Remarkables Ski Field Access Road. RL ~520 above the site. Showing coarser material with cobbles & boulders inferred from debris flow/flood deposition in the higher elevation transfer zone.

Photograph 2: Incised Stoney Creek channel. RL ~440 above the site. Showing finer material with cobbles from material debris flow deposition in the lower elevation transfer zone

Photograph 3: Stoney Creek channel. RL ~340 within the site. Showing limited coarse material from debris flood deposition in the depositional zone.

Combined Middle Creek Channel:

Photograph 4: Middle Creek channel. RL ~430 above the site. Showing limited coarse material from debris flood deposition in the depositional zone.

South Creek 2:

Photograph 5: South Creek 2 channel. RL ~400 above the site. Showing limited coarse material from debris flood deposition in the depositional zone.

South Creek 1= No photographs- Generally vegetated similar in nature to South Creek 2.