BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

TOWN OF CANMORE

COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

FINAL
(REVISED)

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June 11, 2014
Project No.: 1261-001-10

Mr. Andy Esarte, P.Eng.
Town of Canmore
Canmore Civic Centre
Canmore, Alberta
T1Q 3K1

Dear Andy,

Re: Cougar Creek Debris Flood Risk Assessment – FINAL (REVISED)

Please find enclosed our revised final report for your review and comment.

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact the undersigned. We appreciate the opportunity to continue working on such an interesting and challenging project.

Yours sincerely,

BGC ENGINEERING INC.
per:

ISSUED AS DIGITAL DOCUMENT.
SIGNED HARDCOPY ON FILE WITH
BGC ENGINEERING INC.

Matthias Jakob, Ph.D., P.Geo.
Senior Geoscientist

EXECUTIVE SUMMARY

On June 19 and 20, 2013, extreme rainfall events in southeastern Alberta initiated flooding, debris floods and debris flows in the area encompassing the Town of Canmore (Canmore), resulting in extensive damage to houses, watercourses, roads, the Trans-Canada Highway, railways and other infrastructure in Canmore and surrounding areas.

In response to these events, Canmore retained BGC Engineering Inc. (BGC) to complete forensic studies for 9 creeks, a study describing the hydroclimate of the June 2013 event, and a detailed debris-flood hazard and risk assessment for Cougar Creek. This work was organized into three steps: 1) forensic assessment; 2) hazard assessment, and 3) risk assessment.

This report presents methods and results of the third phase, risk assessment which involves estimation of the likelihood that a debris flood will occur, impact elements at risk, and cause particular types and severities of consequences.

The principal objective of this work is to support decisions and expenditures to reduce debris-flood risk on Cougar Creek fan to levels considered tolerable by Canmore. This assessment does not consider all conceivable risks associated with debris floods. Rather, it considers a representative subset of risks that can be systematically estimated, compared to risk tolerance standards[1], and then used to optimize mitigation strategies. These mitigation strategies, once implemented, would also reduce relative levels of risk for a broader spectrum of elements at risk than those explicitly considered in this report.

The major steps in this assessment are to:

1. Assess direct consequences or potential consequences to buildings and infrastructure due to impact by different debris flood scenarios.
2. Assess vulnerability of critical facilities (school, police station) to loss of use due to impact by different debris flood scenarios.
3. Assess risk to life due to impact by different debris-flood scenarios for persons located within buildings.
4. Recommend steps required to optimize debris flood risk reduction measures.

BGC assessed risk associated with four debris flood scenarios representing a range in debris-flood return periods from 30-100 to 1000-3000 years. Elements impacted by these scenarios and considered in the risk assessment included buildings, roads, utilities, critical facilities, and persons within buildings. Of these, the risk analysis focused primarily on estimation of direct building damage and safety risk. These were selected as the key elements that can be systematically assessed and compared to risk tolerance standards. Risk mitigation decisions

[1] E.g. international standards for safety risk (Section 3.7) and/or standards set by Canmore

based on the elements assessed will also reduce relative levels of risk for a broader spectrum of elements than those explicitly considered.

Estimated direct damage costs to buildings for individual scenarios ranged from $8 M[2] to $129 M depending on the scenario. Average annualized building damage cost is $700 k.

It should be emphasized that the estimated building damage costs are based only on assessed building values. They do not include damage to contents or inventory, costs of cleanup and recovery, indirect costs of business interruption, loss of power transmission, or highway or rail transportation interruption. These factors, if considered, would likely increase annualized damage costs by a factor of 2 or more.

Annual business revenues in impacted areas range from $7 M for Scenario 2 to $123 M for Scenario 5. Note that this should be considered a proxy for the level of business activity in impacted areas, not an estimate of economic loss, since the duration and severity of business loss is unknown and very difficult to quantify in detail. For reference, revenues of all businesses on Cougar Creek Fan correspond to about $168 M/year.

BGC identified 190 parcels where estimated average safety risk for individuals exceeded 1:10,000 probability of death per annum. This risk tolerance threshold has been adopted internationally by several jurisdictions as well as by the District of North Vancouver, British Columbia, for existing developments. Estimated group safety risk also fell into the "Unacceptable" range when compared to international risk tolerance standards.

Critical facilities assessed included Elizabeth Rummel School, Mountain Munchkin Daycare, Alpine Helicopters, the RCMP office, and an industrial service yard containing equipment needed for emergency response. Alpine Helicopters was impacted by all debris flood magnitudes considered. Elizabeth Rummel School was impacted by the largest two debris-flood scenarios, corresponding to 300-1000 and 1000-3000 year return periods. The remaining facilities were also impacted by a 100-300 year scenario (Scenario 3b) that considered the potential for avulsion towards the eastern fan sector.

[2] M stands for million, k stands for thousands.

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LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of the Town of Canmore. The material in it reflects the judgment of BGC staff in light of the information available to BGC at the time of document preparation. Any use which a third party makes of this document or any reliance on decisions to be based on it is the responsibility of such third parties. BGC accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this document.

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1.0 INTRODUCTION

1.1. General

On June 19 and 20, 2013, extreme rainfall events in southeastern Alberta initiated flooding, debris floods and debris flows in the area encompassing the Town of Canmore (Canmore). This rainfall event resulted in extensive damage to houses, watercourses, roads, the Trans-Canada Highway, railways and other infrastructure in Canmore and surrounding areas.

In response to these events, Canmore retained BGC Engineering Inc. (BGC) to complete a number of forensic studies of creeks subject to geomorphic events during the extreme rainfall, a hydroclimate study, and a debris flood hazard and risk assessment for Cougar Creek (Drawing 1). This work for Cougar Creek has been organized into the following phases: 1) forensic assessment of the June 2013 debris flood; 2) hazard assessment; 3) risk assessment; and 4) risk-based evaluation of mitigation options.

The first two phases identified and characterized debris-flood scenarios across a wide range of frequencies and magnitudes. This work is described in BGC (2013a to 2013c). The reader should refer to these reports for background description of the physical and hydroclimatic setting of Cougar Creek and the hazard assessment methodology and results.

This report presents methods and results of the third phase, debris-flood risk assessment. The primary objective of this work is to support decisions and expenditures to reduce debris-flood risk on Cougar Creek fan to levels considered tolerable by Canmore and its stakeholders; a decision that has not been made at the time of this report. To complete this objective, the assessment considers key debris-flood risks that can be systematically estimated, compared to risk tolerance standards, and then used to select and optimize mitigation strategies.

The major steps in this assessment are to:

1. Assess direct or potential consequences to buildings and infrastructure from impact by debris floods expressed as debris-flood scenarios
2. Assess vulnerability of critical facilities (e.g. school, daycare, police station, helicopter base) due to impact by different debris floods
3. Assess risk to life due to impact for persons located within buildings
4. Recommend steps required to optimize debris flood risk reduction measures.

The report is organized as follows:

- Section 1.0 summarizes objectives and work scope
- Section 2.0 describes the data compiled for the assessment
- Section 3.0 summarizes the framework and steps of risk analysis, with results presented and discussed in Section 4.0. For estimated risk to life, the results are also compared to international criteria for life loss risk tolerance.
- Conclusions and recommendations are provided in Sections 0 and 5.2.

1.2. Risk Assessment Framework

Risk is a measure of the probability and severity of an adverse effect to health, property or the environment, and is estimated by the product of hazard probability (or likelihood) and consequences (Australian Geotechnical Society (AGS) 2007).

Debris-flood risk assessment involves estimation of the likelihood that a debris flood will occur, impact elements at risk, and cause particular types and severities of consequences.

Each of these components are estimated separately and then combined. The objective is to provide a systematic, repeatable assessment with an appropriate level of detail for the information available.

The geographic area considered for a geohazard risk assessment is known as the "consultation zone" (Hong Kong Geotechnical Engineering Office (GEO) 1998), defined in Porter et al. (2009) to include "*all proposed and existing development in a zone defined by the approving authority that contains the largest credible area affected by landslides, and where fatalities arising from one or more concurrent landslides would be viewed as a single catastrophic loss".* Definition of this zone is particularly important to assess group safety risk, which is proportional to the number of persons exposed to a hazard. The consultation zone in this assessment spans the entire fan and some adjacent areas and includes the elements at risk listed in Section 2.1 within the geomorphic extent of Cougar Creek fan (Drawing 1).

Geohazard risk assessment is part of the larger framework of geohazard risk management, which encompasses initial hazard identification through risk analysis and optimization of risk reduction and monitoring measures.

Figure 1-1 provides an overview of a risk management framework, after Canadian Standards Association (CSA 1997), AGS (2007), and ISO 31000:2009. BGC's forensic and hazard assessments (BGC 2013a to 2013c) document the results of the first two phases of the risk management framework for Cougar Creek, plus the hazard basis for the third phase, which is the subject of this report. Documentation of the results of the remaining phases will be forthcoming under separate cover.

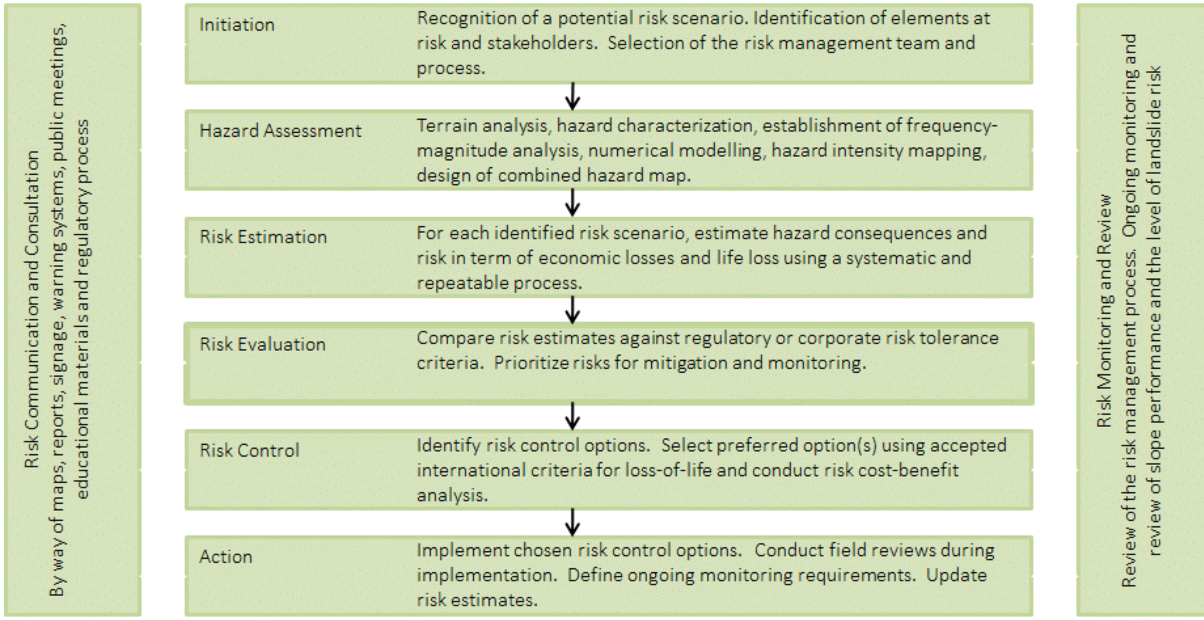

Figure 1-1. Risk management framework (adopted after CSA 1997, AGS 2007, and ISO 31000:2009).

For this assessment, BGC and Canmore have chosen a quantitative risk assessment (QRA) approach. This is compatible with Canadian and international guidelines for risk management as it provides a systematic method to assess risk based on estimated likelihoods of occurrence and consequences of an event. Using a QRA approach facilitates definition of thresholds for risk tolerance, evaluation of potential debris-flood mitigation alternatives, and transparent description of uncertainties. It also enables a more quantitative approach to characterize the high number of different elements at risk within the consultation zone. Other jurisdictions where risk assessment is a more established standard of practice, such as the District of North Vancouver, Hong Kong and Australia, use a similar approach.

While based on the best data available, it is important to note that each step in this risk assessment is subject to uncertainties. These uncertainties are noted where relevant in the report and should be considered when making risk management decisions. Additional description of risk assessment methodology is provided in Section 3.0.

1.3. Terminology

The appropriate use of this assessment requires some understanding of hazard and risk terminology. In particular, the following key terms are used in this assessment:

Hazard: Process with the potential to result in some type of undesirable outcome. For example, the hazard could include a debris-flood runout area intersecting the footprint of a building. The term hazard refers to the specific nature of the process (type, frequency, magnitude), but not the consequences. Hazards are described in terms of scenarios, which are specific debris-flood events of a particular frequency and magnitude. The debris flood hazard scenarios considered in this assessment are based on the results of BGC's Cougar Creek hazard assessment (BGC 2013c).

Element at Risk: Anything considered of value in the area potentially affected by hazards.

Consequence: The outcomes for elements at risk, given impact by a debris flood. In this report, consequences considered include potential loss of life, damage to buildings and infrastructure, loss of usage of critical facilities, and direct interruption of business activity.

Mortality: The number of potential fatalities divided by the number of persons exposed to a hazard, should the hazard occur.

Risk: Likelihood of a debris-flood hazard scenario occurring and resulting in a particular severity of consequence. In this report, risk is defined in terms of safety or damage level. For example, this could include the likelihood of debris-flood impact to a building resulting in destruction of the building.

1.4. Scope of Work

Table 1-1 describes the work required to meet the objectives described in Section 1.1. The work was approved in an award letter from Canmore dated October 23, 2013, based on BGC's initial (June 28, 2013) expression of interest and subsequent discussions with Canmore. The work scope was further refined in BGC's Mountain Creek Hazard Mitigation Detailed Hazard and Risk Assessment work plan dated December 10, 2013.

Table 1-1. Work tasks.

Task	Work Component	Description and Method
1	Project Management	• Project management, contract administration, client liaison • Budget tracking, communications, etc.
2	Data Collection	• Compile results from Phases 1 and 2 (forensic and hazard assessment) into a format suitable for risk analyses • Obtain and organize buildings infrastructure data into a format suitable for analyses • Create database linked to GIS containing spatial and buildings infrastructure information.
3	Data Processing	• Process hazard analysis results into GIS grid layers indicating debris-flood intensities (destructive power) for different debris-flood scenarios • Complete spatial analysis assigning estimated debris-flood intensities to buildings or parcels in impact zones
4	Risk Analysis	• Estimate risk based on estimated hazard probability, spatial and temporal probability of impact, and vulnerability of elements at risk, for different debris-flood scenarios and types of elements at risk
5	Reporting (DRAFT/REVISED DRAFT/FINAL)	• Description of methodology and results; • Comparison of estimates of risk to life to international risk tolerance thresholds • Presentation of results in tabular and map format • Framework for further evaluation of risk reduction options • Integration of draft review comments into Final report.

2.0 DATA COMPILATION

In this report, risk is a measure of the probability and severity of an adverse effect to defined elements at risk, estimated by the product of hazard probability (or likelihood) and its consequences. Data required to assess the risk of debris floods on Cougar Creek fan includes an inventory of elements at risk, modeled debris-flood scenarios (maximum water depth and velocity), and algorithms for the estimation of losses. Data showing elements at risk were provided by Canmore, and debris-flood scenarios were based on BGC's Cougar Creek hazard assessment (2013c). Methods to compile and manage these data are described in this section. Methods to develop the loss estimation algorithms are described in Section 3.0.

2.1. Elements at Risk

Table 2-1 lists the "elements at risk" considered in this assessment. These elements were defined through discussions with Canmore and the external review board. Table 2-1 does not include all elements that could suffer direct or indirect consequences due to a debris flood.

The elements at risk listed in Table 2-1 are limited to those that could be reasonably assessed, based on the information available. For example, indirect economic consequences due to highway interruption or CP Rail are not included. The assessment also focuses on risk associated with direct debris-flood impact. Additional risk associated with, for example, loss of access to the elements listed in Table 2-1, is not considered.

Risk mitigation decisions based on the elements assessed will also reduce risk for a broader spectrum of elements in protected areas than those explicitly considered.

Table 2-1. List of elements at risk considered in the Cougar Creek debris-flood risk assessment.

Element at Risk[1]	Description
Building Structures	Commercial, industrial, institutional, recreational, residential, transportation/utilities building types.
Persons	Persons located within buildings.
Roads	Local roads, Highway 1, Highway 1A.
Utilities	Sewerage, stormwater management, gas distribution, electrical power and telephone line distribution.
Critical facilities	Elementary school, Mountain Munchkin Daycare, RCMP, Alpine Helicopters
Business activity	Businesses located on the fan that have the potential to be directly impacted by debris floods, either due to building damage or interruption of business activity due to loss of access.

[1]The location and characteristics of buildings, roads, and utilities were provided by Canmore.

A description of each of these elements is provided below.

2.1.1. Buildings

Information on buildings within the study area was provided by Canmore within data compiled for each parcel (property boundary).

Building types on the fan include single family, wood construction dwellings and multi-family, commercial, or industrial buildings, also wood construction. Single family dwellings are typically constructed from wood rafters or joists on wood stud walls, and are typically not engineered (Canmore assessor, pers. com. October 9, 2013). The multifamily, commercial or industrial buildings are typically larger and framed from beams or major horizontal members spanning between columns supporting lighter floor joists or rafters. BGC understands that most buildings have 2.8 m high, sub-grade concrete basements.

Each land parcel contains a unique identification number ("PID") and unique lookup code identifying the primary use and type of building within the parcel. In the case of single buildings (e.g. residential houses), each parcel contains only one assessed land and building value. Parcels with multiple units (e.g. condominiums or mixed residential/commercial) contain multiple assessed values, all with the same PID but with different tax roll numbers. In these cases, the total assessed value of units(s) within a parcel was calculated by summing the assessed values for all roll numbers with the same PID. Data on building structure type or contents were not available. In the case of some multiple residential units, building and land values were not separated in the data[3]. Based on discussion with Canmore, BGC understands that building values in these cases can be estimated as 80% of the total land and building value.

Figure 2-1 summarizes assessed values of buildings located in parcels on Cougar Creek fan. In total, about $376 million (M) of assessed buildings infrastructure is located within 1,276 parcels on the fan, with assessed land values totaling about $790 M[4]. This corresponds to about 14% of the assessed building value and 21% of the assessed land value within Canmore. All buildings are less than 20 years old and, with the exception of mobile homes, are wood frame and less than 4 stories high. Most have full 2.8 m high basements. The values shown on Figure 2-1 do not include building contents or inventory and do not necessarily correspond to replacement cost, which may be higher. As such, they should be regarded as minimum costs.

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[3] Cases where the "Linc Number" (tax code) = 12, 12A, 20, 21, or 21A and no building value was assigned.

[4] Note that impacts on land values were not considered in this assessment.

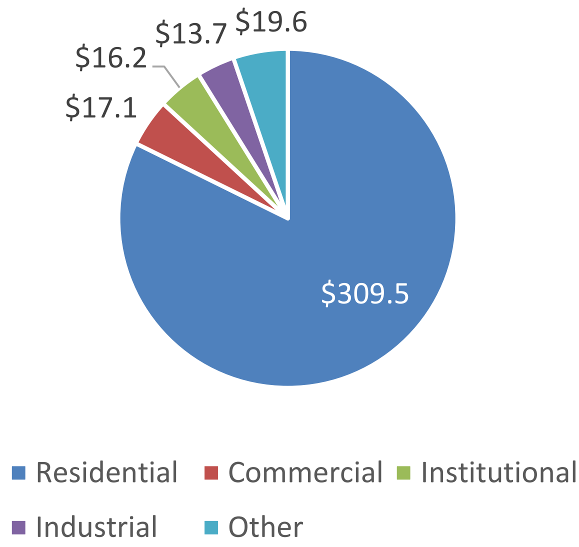

Figure 2-1. Summary of assessed building values on Cougar Creek Fan (total $ 376 M).

The locations of buildings (building footprints) were also provided by Canmore. These data were used in the risk analysis to identify location(s) of buildings within parcels that could be impacted by debris-flood scenarios.

Table 2-2 summarizes the main uncertainties associated with the buildings attributes data provided.

Table 2-2. Building data uncertainties.

Type	Description
Building Value	Assessed parcel land and building value was not separated for apartments, mixed residential and hotel, and mixed residential and service/retail (COM1, COM3, COM4). Based on communication with Canmore, building values were assigned as 80% of total assessed parcel value for these lookup types.
Building Structure	No information describing building structure (e.g. wood frame or concrete construction) were available. Building use (lookup code) was applied as a proxy for building type, and for building structure type for the purpose of vulnerability assessment (see Section 3.6.1).
Parcel Lookup Code (Building Use)	Based on communication with Canmore, the vast majority of the parcel lookup codes are correctly assigned, but some errors may exist. BGC has not reviewed the accuracy of parcels data provided by Canmore and they were assumed to be correct for the purpose of this assessment.
Building Location	Information on exact building types within parcels was not directly available, and ambiguities exist where multiple buildings exist within parcels and where building footprints overlap parcel boundaries.

2.1.2. Persons

Population estimates used in this assessment are based on 2011 Census summaries (Canmore 2011), dwelling counts from tax roll classification data (Canmore 2013), business data (Hoovers 2013), and direct communication with key facilities as noted below.

According to 2011 Census data, the Cougar Creek fan approximately intersects Municipal Census District nos. 12A, 13A, 13B, 20, 21 and 22, plus about 16 residential houses in District 16b. These areas are home to a permanent population of approximately 3700 people, plus about 400 non-permanent residents, excluding tourists staying in hotels (Canmore 2011). Approximately 2.7 persons occupy an average residential dwelling unit. Approximately 1600 persons also work in private businesses on the fan, plus workers in government, school, policing, and those working from a home office (approximately 10% of Canmore workers). Seasonal visitors occupy commercial hotels on about 34 parcels, not including private residences (e.g. bed-and-breakfasts), and additional temporary visitors occupy restaurants, shops, and professional services.

Assessment of risk at a parcel level of detail requires estimation of the number of persons in each parcel on the fan. These data are not directly available and were estimated based on the number of building units of a given type, in each parcel, and the estimated number of persons in a given unit type. Steps to complete this estimate are described below.

First, BGC estimated the number of building units based on a combination of parcel land usage and tax roll codes. For detached residential homes, there is only one roll number per parcel. For multiple units, unique tax roll numbers exist for each taxable entity (e.g. apartment, business, stratified hotel room), each with a tax code number and category description. Descriptions for ambiguous tax codes (which do not distinguish commercial use types) were clarified by referencing parcel land use codes (e.g. to distinguish a hotel room from an office[5]).

Second, BGC estimated the number of occupants per building unit. Permanent residential occupancy rates were based on 2011 Census data, and hotel rooms were assumed as double occupancy. These occupancy rates were multiplied by the number of units in a given parcel (based on number of rolls) to provide a total for the parcel.

The number of occupants at Elizabeth Rummel School (395 persons, PID#430396) and Mountain Munchkin Daycare (74 persons, PID#432668), Public Works Office (50 persons, PID#429764) were manually confirmed by calling the facility. Finally, the estimated number of workers (if any) within a given parcel (Section 2.1.6) was added to give the total estimate for the parcel.

[5] E.g. “COM1” (Commercial – Service/Retail/Office) versus “COM2” (Commercial – Hotel/Visitor Accommodation)

Table 2-3 summarizes calculated populations used in the risk analysis. Note that these values should not be summed without consideration that some population types overlap (e.g. students or workers might also live on the fan).

Table 2-3. Summary of calculated population estimates used in risk analysis.

Population Type	Population Total
Permanent Population	3780
Temporary Population	380
Hotel Rooms	1700
Employees	1550
Elizabeth Rummel School	322 students + 41 staff
Mountain Munchkin Daycare Children	74 children + 18 staff
RCMP	22

These calculated population estimates, while systematically compiled from the best available data, are subject to uncertainties. In the case of the permanent population, calculated values were calibrated to Census (2011) totals by reducing the average dwelling occupancy rate from 2.7 to 2.4 per dwelling unit. Additional uncertainties are listed in Table 2-4.

Implications of the uncertainties listed in Table 2-4 include possible over- or underestimation of group safety risk for particular parcels depending on whether the number of persons was over- or underestimated, respectively. BGC believes that the accuracy of population estimates is sufficient to allow risk management decisions. However, the estimates should not be used for detailed assessment of individual parcels (e.g. for building permit applications) without being manually checked.

Table 2-4. Uncertainties associated with estimating the number of occupants of a building.

<table>
<tr><th>Uncertainty</th><th>Implication</th></tr>
<tr><td>Average occupancy rates may not correspond to actual occupancy rates for a given dwelling unit.</td><td rowspan="4">Over- or underestimation of occupant numbers</td></tr>
<tr><td>Seasonal population fluctuations exist that were not accounted for.</td></tr>
<tr><td>Errors in employee data sourced from Dunn and Bradstreet (D&B) (Hoovers 2013) may exist. These data were not verified by BGC.</td></tr>
<tr><td>Errors in assignment of D&B employee data to specific parcels may exist, due to inconsistencies in building address data.</td></tr>
<tr><td>Distribution of persons within a building are unknown. As such, the number of persons most vulnerable to debris flood impact on the first floor or basement is unknown.</td><td>Uncertainty in estimation of human vulnerability to debris-flood impact</td></tr>
<tr><td>In a number of unspecified cases, hotels may not be “stratified”, which means that more than one hotel room exists for a given roll number. BGC understands from Canmore that these are rare, but cannot be identified from tax roll data.</td><td>Underestimation of occupant numbers</td></tr>
<tr><td>The number of ground floor occupants may be over- or under-estimated where unit numbers are not representative of the distribution of persons on different floors in a building.</td><td>Over- or underestimation of occupant numbers on the ground floor</td></tr>
</table>

2.1.3. Roads

Roads considered in the assessment include municipal roads on Cougar Creek fan, Highway 1 and Highway 1A (Drawing 2).

2.1.4. Utility Systems

Utility systems considered in this study are shown on Drawings 2 and 3 include the following:

- Gas distribution infrastructure controlled by Alta Gas
- Sanitary, water and storm systems managed by Canmore
- Electrical transmission managed by Altalink[6]
- Closed and remediated (covered) garbage dump.

2.1.5. Critical Facilities

Critical facilities are defined as buildings where continued function during a debris-flood event is considered of critical importance, or that contain a particularly vulnerable segment of the population (e.g. children or persons under medical care).

Buildings defined as “critical” on Cougar Creek fan are labeled on Drawing 2 and include Elizabeth Rummel School, Mountain Munchkin Daycare, Alpine Helicopters, the RCMP detachment, and the Industrial Storage Yard at 116 Boulder Crescent (which contains

[6] Assumed to also carry telephone cables

equipment required for emergency response). BGC understands that Elizabeth Rummel School, along with Canmore Collegiate High School and the Canmore Nordic Center (the latter two are not located on Cougar Creek fan) have been designated as emergency shelters.

2.1.6. Business Activity

Business activity considered in this assessment includes public and private employers with their primary address located on Cougar Creek fan. Employer data are based on information compiled by the commercial information provider Dunn and Bradstreet (D&B) (Hoovers 2013), as well as communication with Canmore (2013).

In summary, 330 employers are located on the fan of Cougar Creek, representing a wide range of economic sectors generating about $168 M/year[7] and employing approximately 1,600 people. Most places of work (80%) have less than 5 employees (Figure 2-2) and 70% have less than $500,000/year annual revenue (Figure 2-3). These figures represent approximately 24% of Canmore's workforce, generating 30% of Canmore's annual revenue.

Business locations were identified by linking business data sourced from D&B (Hoovers 2013) to individual roll numbers provided by Canmore.

The business data used in the assessment are subject to uncertainties associated with both the data itself and how it is assigned to particular parcels. Table 2-5 summarizes uncertainties associated with the data. In addition to the uncertainties listed in Table 2-5, business activity estimates do not include individuals working at home for businesses located elsewhere or businesses that are located elsewhere but that depend on transportation corridors. Inclusion of these figures would substantially increase the level of business activity that could be affected by a debris flood event, although this amount has not been quantified.

[7] D&B revenue data provided in USD and was converted at 1 USD = 1.05 CAD.

Table 2-5. Business data uncertainties.

Type	Description
Revenue data	Missing for 94 workplaces.
Number of workers	Missing for 4 workplaces.
D&B data quality	BGC has not reviewed the accuracy of business data obtained for this assessment, where data was provided. However, cases exist where parcel lookup codes indicate commercial activity (COM1, COM2) but where no D&B data was provided. These missing data likely mean that the total business activity within the study area is underestimated.
Worker location	Whether the employee primarily works at the office or some other location (e.g. an office administrator versus a tour guide or garbage collector) and whether a business' source of revenue is geographically tied to its physical location (e.g. a retail store with inventory, versus an office space with revenue generated elsewhere) are not known. The estimates also do not include individuals working at home for businesses located elsewhere.
Source of revenue	Whether a business' source of revenue is geographically tied to its physical location (e.g. a retail store with inventory, versus an office space with revenue generated elsewhere) is not known.
Geocoding	Some ambiguity existed in linking business data to parcels. Cases where more than one street address existed for a parcel were combined and summed. Cases where a single address corresponded to >1 adjacent parcels were arbitrarily assigned a single PID and may not be exactly correct, although they are most likely geographically close (e.g. within 1 parcel).

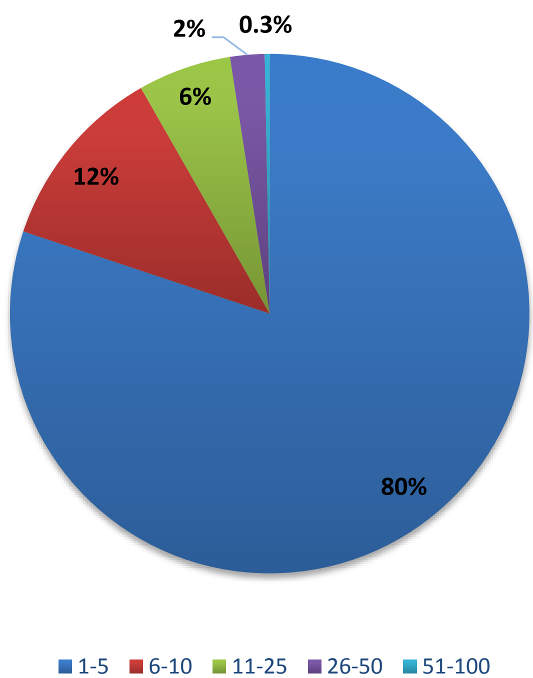

Figure 2-2. Breakdown of total number of employees for business on Cougar Creek fan.

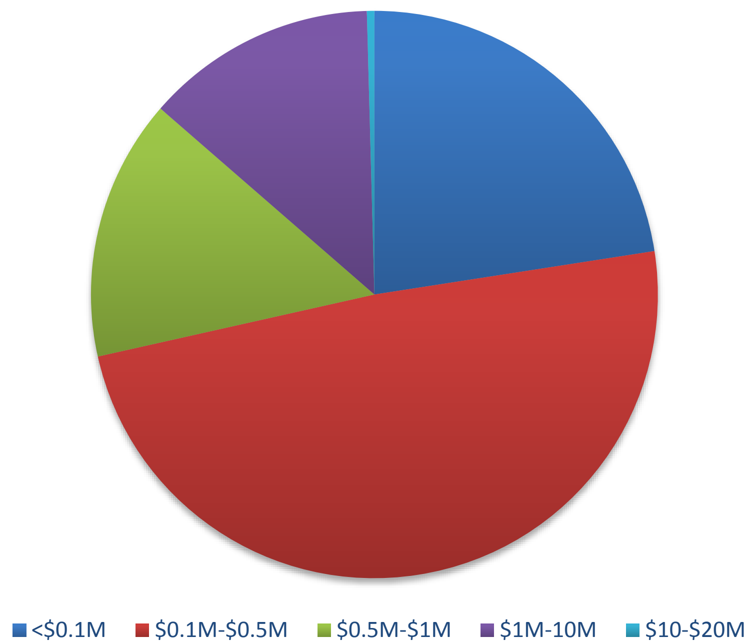

Figure 2-3. Breakdown of annual gross revenue for businesses on Cougar Creek fan.

2.2. Debris-flood Scenarios

This section describes the different debris flood scenarios that fed into the consequence and thus risk assessment. The 2013 event has been singled out as it provides a convenient basis to calibrate the risk model with observed damages and life loss.

2.2.1. June 2013 Debris Flood

BGC's forensic report (BGC 2013a) described the storm and resulting debris flood that occurred on Cougar Creek between June 19 and 21, 2013. Table 2-6 summarizes damages recorded, with costs summarized in Table 2-7 based on data provided December 30, 2013 by Canmore.

The costs summarized in Table 2-7 include work to complete emergency assessments and reconstruction. They do not include many additional costs, such as services provided by the fire department (e.g. time, food, or equipment), town staff (e.g. overtime, benefits, food, clothes, equipment, etc.), or any costs associated with flood relief accommodations. Importantly, they also do not include estimates of direct damage costs to impacted development and infrastructure (e.g. roads, buildings, property, water/sewer system, gas, or power transmission), costs of professional services to assess hazard and risk (e.g. this assessment), or costs of long-term risk reduction measures. As such, actual costs of the June 2013 event were higher than those summarized below.

No fatalities occurred on Cougar Creek as a result of the June 2013 debris flood. Notwithstanding the major bank erosion that took place, the confinement of the June 2013 event to the existing channel through the most densely developed portions of the fan likely lowered the potential for fatalities during this event.

Table 2-6. Summary of damage to Cougar Creek fan during the 2013 debris flood.

Area	Damage
Above Elk Run Blvd	• Bank erosion along section of Benchlands Trail resulting in property and utilities damage • Erosion of backyards along Canyon Road and Eagle Landing • Erosion up to the foundation of the Winter Residence above Canyon Road • Complete washout of outdoor hockey rink on left bank at Elk Run Blvd. • Major erosion behind both concrete wingwalls of Elk Run Blvd. culvert • Complete destruction of riprap on either side of the creek bank
Elk Run Blvd to Hwy 1	• Severe damage to homes due to creek widening (especially along the east bank) • Complete washout of walking path along both sides of the creek • Pedestrian bridge outflanked on either bank and structural damage to the east abutment • Complete destruction of riprap on either side of the creek bank
Hwy 1 to CPR	• Complete blockage of box culverts under Hwy. 1 resulting in flow over highway • Sediment deposition along highway surface and ditch • Erosion of median fill and partial road surface collapse on Hwy. 1 • Major damage to Alpine Helicopters and Ford dealership directly west of creek due to avulsion • Complete destruction of riprap on either side of the creek bank • Blockage of culverts at Hwy. 1A and CPR resulting in flow over the crossings • CP rail line shut down for three days for repairs

Table 2-7. Reported cleanup costs for Cougar Creek fan following the 2013 debris flood.

Work	Cost	Source
Cougar Creek emergency operations	$2,364,000	ISL Engineering and Land Services Ltd. (ISL)
Cougar Creek restoration	$7,943,000	ISL
Bow Valley Trail	$365,000	ISL
Alpine Helicopters (invoiced) services	$19,000	ISL
Alpine Helicopters (remaining estimate) services	$115,000	ISL
Miscellaneous flood cleanup in Cougar Creek area	$83,000	ISL
Culvert Cleanup[1]	$25,000	ISL
Professional Services	$583,000	ISL
Emergency work, traffic control, culvert clean out and repair of the Cougar Creek crossing at Hwy. 1	$2,000,000	Alberta Transportation
TOTAL[1]	**$13,498,000**	

[1]Excludes culvert repairs at Hwy. 1A and Elk Run Blvd., which did not have estimated costs.

2.2.2. Debris-flood Scenarios used in the Risk Assessment

The risk analysis described in Section 3.0 is based on modeled debris-flood scenarios, which are defined as debris-flood events with particular characteristics and likelihoods of occurrence. BGC (2013c) developed debris flood scenarios that are considered representative proxies of events across the range of return periods considered. These are listed in Table 2-8 and are the debris-flood scenarios considered in this report. For description of methods to develop these scenarios and further discussion of uncertainties and limitations, see BGC (2013c).

Drawings 4-6 show estimated debris-flood intensities at each model grid cell location, for each scenario. Debris-flood intensity is defined as the destructive power of a debris-flood, measured in this assessment as flow depth multiplied by the square of flow velocity (see Section 3.6.1), (Jakob et al., 2011).

Scenarios 2 to 5 correspond to 1:30 – 1:100, 1:100 – 1:300, 1:300 – 1:1000, and 1:1000 – 1:3000 year frequency intervals[8]. The bounds of a given range are exceedance probabilities. For example, the 1:100 – 1:300 year range should be interpreted as to the probability of events at least as large as a 1:100 year event, but not as large as a 1:300 year event, with the “best” estimate falling towards the middle of the range.

Although it is impossible to exactly replicate the conditions of the June 2013 event, a scenario (Scenario 6) representing the 2013 event was also developed for comparison and calibration purposes (see Section 4.5.3). Note that the larger event scenarios (> 1:300) involve increasing contributions of landslide dam outbreak floods (LDOF) to the process. This has implications

[8] Note that the inverse of return period is event frequency, and that the bounds of the interval are cumulative frequencies; e.g. the frequency of an event of at least a certain magnitude.

other than an increase in volume (e.g. less warning time). Uncertainties for model scenarios involving LDOF are also higher than for the smaller events.

Table 2-8. Summary of debris-flood scenarios (BGC 2013c).

ID	Frequency Interval (1:years)	Volume Estimate (m^3)	Sediment concentration (%)	Peak[1] Flow (m^3/s)	Hydro-Geomorphic Processes	Model Runs and Assumptions
2	1:30 to 1:100	40,000	20	50	Debris flood	ERBC performs to capacity
3a	1:100 to 1:300	60,000	20	60	Debris flood/LDOF	ERBC performs to capacity
3b						ERBC is blocked
4	1:300 to 1:1000	160,000	30	700	LDOF	ERBC is blocked
5	1:1000 to 1:3000	260,000	30	1000	LDOF	ERBC is blocked
6	(1:400)[2]	90,000	20	80	Debris flood	ERBC performs as it is kept open artificially

Notes:
1. Peak flow as reported here is the total discharge including the sediment in transport.
2. Scenario with peak discharge similar to that estimated for the June 2013 event
3. LDOF = landslide dam outbreak flood.
4. ERBC = Elk Run Boulevard culvert.

2.3. Data Management

Elements at risk data were managed within Excel and a Microsoft SQL Server database[9], and linked to geospatial data (e.g. parcel boundaries) in ArcGIS. Debris flood model grids produced as part of the hazard assessment (BGC 2013c) were also imported to ArcGIS. This approach allows updating of any data component (e.g. new development, new flood loss algorithms, or new flood scenarios) and expansion of the analysis to different fans or floodplains within Canmore without major changes to the data management structure.

[9] Relational database management system produced by Microsoft.

3.0 RISK ASSESSMENT

3.1. General

Risk assessment involves estimation of the likelihood that a debris-flood scenario will occur, impact elements at risk, and cause particular types and severities of consequences.

The primary objective of the risk assessment is to support risk management decision making. Importantly, the assessment does not consider all possible risks that could be associated with a debris flood. Rather, the risk assessment considers key risks that can be systematically estimated, compared to risk tolerance standards, and then used to optimize mitigation strategies. These mitigation strategies, once implemented, would also reduce relative levels risk for a broader spectrum of elements than those explicitly considered in this report. Debris-flood impact and resulting consequences are determined by relating the characteristics of debris-flood scenarios (flow velocity and depth) to impacted elements at risk at a given location.

This assessment considers direct impact to the elements at risk listed in Section 2.1, and focuses on direct structural building damage and risk to life. It excludes emergency response and reconstruction costs (e.g. the costs of the June 2013 event summarized in Section 2.2.1). This approach represents a practical way to achieve the assessment objectives given the data available. However, such auxiliary costs would have to be added to assess the total costs of a destructive debris flood, as these costs could exceed the direct damages that have been systematically considered in this assessment.

This risk assessment does not consider structural debris-flood mitigation or evacuation prior to or during an event. This approach provides a baseline estimation of risk to facilitate comparison of different debris-flood risk reduction options.

Following presentation of results, Section 4.5 compares BGC's estimates of safety risk to alternative analysis methodologies and previously recorded events, to calibrate estimates where possible and check that the results are within a reasonable range.

3.2. Quantitative Risk Assessment (QRA)

Risk (P_E) was estimated using the following equation:

$$P_E = \sum_{i=1}^{n} P(H)_i P(S:H)_i P(T:S)_i \, N \qquad [1]$$

where:

$P(H)_i$ is the annual hazard probability of debris-flood scenario i of n

$P(S:H)_i$ is the spatial probability that the event would reach the element at risk

$P(T:S)_i$ is the temporal probability that the element at risk would be in the impact zone at the time of impact

$N = \mathrm{V_i E_i}$ describes the consequences. [2]

where:

V_i is vulnerability, the probability elements at risk will suffer consequences given debris-flood impact with a certain severity of destructive power

E_i is a measure of the element at risk, quantifying the severity of potential consequences (e.g. number of persons, building value).

In the case of safety risk (risk to life), risk is estimated separately for individuals and groups (societal) risk (see Section 3.7). Estimated risk for combined debris-flood scenarios is calculated by summing the risk quantified for each individual debris-flood scenario. The analysis considers debris-flood Scenarios 2-5 (Table 2-8).

Direct building damages were calculated as total annualized damage considering all scenarios, as well as direct damage costs for individual scenarios. Assessment of loss of function for critical facilities and impact to business activity were completed for individual scenarios.

Assessment of roads and utilities included identification of the location of infrastructure in relation to the extent and intensity of modelled debris-flow scenarios, but did not include estimation of damage levels. An estimate of damage level would be very difficult in such cases, given uncertainties in any estimation of erosion severity for flows avulsing out of the channel and flowing over the fan surface, a significant portion of which is paved. In all cases, the assessment considers area directly impacted by modelled flows. It does not include assessment of consequences associated with, for example, areas rendered inaccessible due to impact elsewhere.

Methods used to estimate each variable in equation [1] are described in Sections 3.3 to 3.6.

3.3. Hazard Probability, $P(H)$

Hazard probability, $P(H)_i$, corresponds to the annual probability of occurrence of each hazard scenario, which are defined in Table 2-8 as annual frequency ranges. The bounds of a given range are exceedance probabilities. As such, for a scenario with the annual probability range P_{min} to P_{max}, the probability of events within this range corresponds to:

$$P(H)_i = P_{min} - P_{max} \quad [2]$$

For example, for the 1:30 – 1:100 year range, this would correspond to:

$$P(H)_i = \frac{1}{30} - \frac{1}{100} = \frac{1}{43} \quad [3]$$

The upper and lower bounds of each range were used in the risk analysis as approximate upper and lower uncertainty bounds for each frequency range.

Scenario 6 was modelled for comparison to the 2013 event. Since it overlaps the frequency ranges already considered in the other scenarios, it was not included in the estimation of overall safety risk for combined scenarios.

3.4. Spatial Probability, $P(S:H)$

Spatial probability, $P(S:H)$ of debris-flood impact considers modelled debris-flood extents in relation to the location of elements at risk. Cases where modeled debris-floods impacted (intersected) these elements were considered certain ($P(S:H)$=1) to be impacted. Those elements outside the modeled flow extent were not considered subject to impact by the scenario ($P(S:H)$=0).

In the case of buildings, ambiguities exist where there are multiple buildings within parcels or parcel boundaries overlap, because data on these buildings is only available at the parcels level of detail (the building footprints themselves do not have data associated with them). For example, in case of a parcel containing a detached home and an out-building, no data existed to automatically distinguish the home from the out-building. With >1200 parcels in the assessment, manually reviewing such cases was not possible.

To account for these uncertainties, buildings in a parcel were assumed as impacted if a debris-flood scenario impacted any building footprint within the given parcel. In cases where a building footprint intersects more than one modelled debris-flood intensity level, the maximum (most conservative) value was used.

3.5. Temporal Probability, $P(T:S)$

For assessment of risk to buildings, temporal probability, $P(T:S)$, was assigned as 1 (certain) based on the assumption that all buildings considered are permanent structures.

For assessment of safety risk, the value of $P(T:S)$ corresponds to the proportion of time spent by persons within a building.

For persons in residential buildings, an average value of 0.5 was assigned for analysis of risk to groups implying that about half of the residents will be in their homes during a debris flood. A more conservative value of 0.9 was used for estimation of individual risk, corresponding to a person spending the greatest proportion of time at home, such as a young child, stay-at-home person, or an elderly person.

For workers in non-residential buildings, a value of 0.25 was assigned for analysis of risk to both groups and individual workers, corresponding to 8-9 hours per day, 5 days per week, 50 weeks per year. Hotel rooms were also assigned a value of 0.25, corresponding to 0.5 x 50% average annual occupancy (pers. comm, Canmore, Nov. 4, 2013).

3.6. Vulnerability

Vulnerability is defined in this report as the degree of loss of a given element at risk that results from debris-flood impact with a certain level of destructive power. For human life loss it addresses the question, “what is the chance of fatality for persons within buildings, should the building be impacted by a debris flood?” For buildings, it addresses the question, “what level of direct damage will occur if the building is impacted by a debris flood?” This section describes how vulnerability ratings were assigned to different elements at risk based on estimated levels of destructive power and resistance to impact. Section 3.6.1 first describes methods to estimate destructive power in terms of debris-flood "intensity" and flow depth. Sections 3.6.1 to 3.6.5 then describe criteria used to estimate vulnerability for different elements at risk.

3.6.1. Buildings

Vulnerability of buildings to damage was assessed in terms of four damage categories, as shown in Table 3-1. These categories were derived from an international review of the literature and reported in Jakob et al. (2011). These classes represent a spectrum of potential damages ranging from flooding and sedimentation to building collapse.

Table 3-1. Damage categories for buildings.

Damage Class	Damage Level	Percent Damage[1] (% Range, Average)	Description
1	Moderate	>0 - 25% (12.5%)	Moderate likelihood of building structure damage and high likelihood of major sediment and/or water damage. Building repairs required but primarily to non-structural elements.
2	Major	>25% - 75% (50%)	High likelihood of moderate to major building structure damage and severe sediment and water damage. Building repairs required, possibly including some structural elements.
3	Severe	>75% - 90% (83%)	High likelihood of major to severe building structure damage and sediment and water damage. Major building repairs required including to structural elements.
4	Destruction	>90% (95%)	Very high likelihood of severe building structure damage or collapse. Complete building replacement required.

Note: 1. Percent damage in terms of assessed building value.

Vulnerability estimates were based on the maximum modelled flow depth and velocity at a given building location. Two different criteria, depth-damage functions and a flow "intensity index", were used to consider two different factors for building vulnerability: low-velocity flood inundation (e.g. in areas of backwater flooding) and higher velocity debris-flood impact. Both criteria were applied to each parcel and the maximum estimated damage level was used. These criteria are described below.

<u>Depth-Damage Functions (Flood Vulnerability)</u>

Depth-damage functions are empirical relations between flood depth and average damage for particular building types. These functions are based on flood depth at a particular building location and are expressed as a proportion of building cost (e.g. Figure 3-1). They do not consider flow velocity and apply where flood inundation is the primary factor for damage (e.g. areas with backwater flooding).

Depth-damage functions used in this analysis were obtained from the U.S. Federal Emergency Management Agency (FEMA) software program Hazus-MH, which is a multi-hazard loss estimation tool developed by FEMA. The functions were compiled by FEMA from a variety of sources including the Federal Insurance and Mitigation Administration (FIMA), U.S. Army Corps of Engineers (USACE), and the USACE Institute for Water Resources (USACE IWR), and include damage functions for building structure, contents, and inventory for 457 different classified building types.

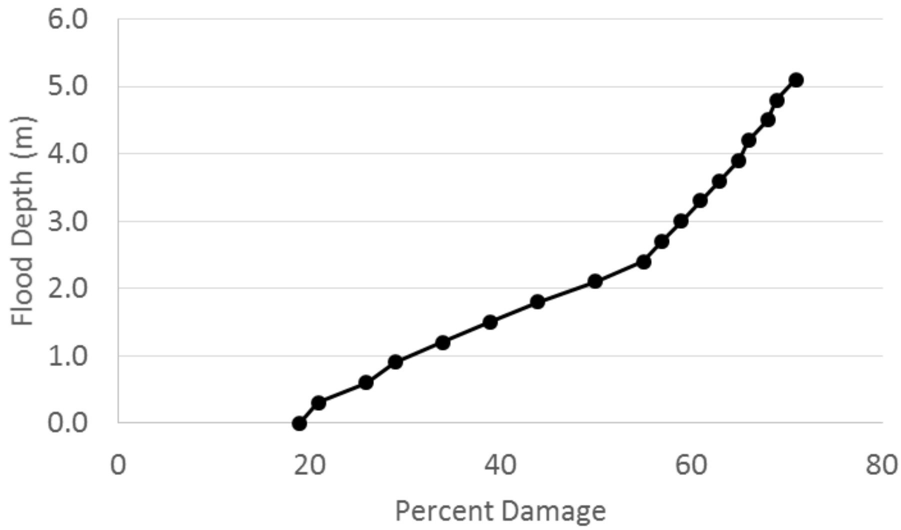

Figure 3-1. Example of a flood depth-damage function (residential homes).

Given the large number of depth damage curves and the requirement to associate these curves with Canmore's assessment building types, building type data were generalized. Depth-damage curves used as "default" in Hazus-MH are available for 44 average building types. These curves represent the mean of curves for 44 simplified building categories (e.g. the default depth-damage curve for retail stores is the average of curves for 144 retail store types).

Default Hazus-MH depth-damage functions were cross-tabulated with Canmore's building use codes. For simplicity, damage functions for building structure only were used, and parcel "improvement" assessment values were used as a proxy for building replacement costs. Applied to assessed building values, the damage costs estimated based on these functions should be regarded as a minimum.

Intensity Damage Function (I_{DF}) (Debris-flood Vulnerability)

The "intensity index" is based on Jakob et al. (2011), who documented sixty-six case studies where characteristics related to flow intensity, such as flow depth and velocity, were recorded or could be estimated and related to recorded building damage. These criteria were chosen for this study because it is based on the largest available case study survey relating damage to parameters that can be estimated by modelled debris-flood scenarios.

Debris flow intensity was represented by Jakob et al. (2011) as follows:

$$I_{DF} = d \times v^2 \qquad [3]$$

where: d is flow depth (m) and v is flow velocity (m/s).

Values of I_{DF} were plotted on a log scale against recorded building damage to estimate probabilities of a certain proportion of building damage, categorized similarly to Table 3-1. These criteria apply where debris-flood impact is the primary factor for damage and are less applicable for low velocity areas (e.g. v < 1 m/s), where I_{DF} will approach zero for any flow depth.

Figure 3-2 shows building damage cases reported by Jakob et al. (2011), plotted as a function of reported flow depth and velocity. Figure 3-2 displays a general trend towards higher building damage cases at higher flow intensities, as would be expected, but with some overlap between damage levels at a given flow velocity and depth. This overlap may be associated with uncertainties in estimating flow characteristics, differences in vulnerability between different buildings, or variations in how damage levels were estimated. Note that building damage cases from the June 2013 debris flood are not shown on Figure 3-2. Flow depth and velocities were not recorded during that event, and modelled velocities and depths could not be relied upon because building damage during this particular event mostly related to bank encroachment, not direct impact. Section 4.5.3 compares model results to the June 2013 event, including discussion of a similar figure (Figure 4-4) where the June 2013 cases are plotted.

Figure 3-2 also shows I_{DF} thresholds (I_{DF} = 1, 10, 100) that were used to estimate the building damage categories listed in Table 3-1. Buildings on the fan include non-engineered, wood construction dwellings (“Res1” land use category) and engineered multifamily, commercial, or industrial buildings, also wood construction. Although the larger engineered buildings likely have greater resistance to debris-flood impact than single family dwellings, for simplicity all buildings were considered together in a single set of criteria. This simplified approach reflects the level of detail of hazard and building structure information available.

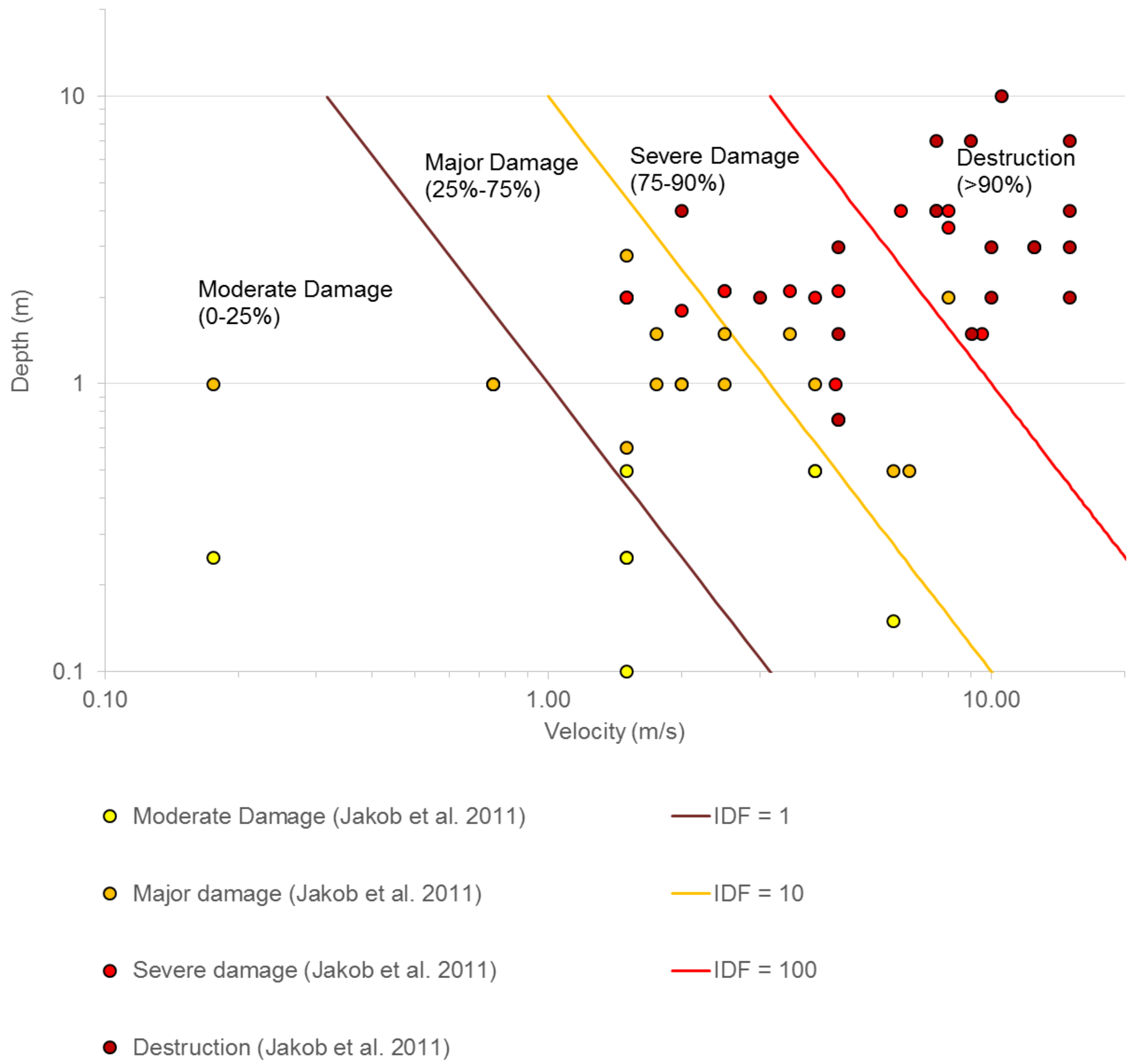

Figure 3-2. Building damage cases reported by Jakob et al. (2011), plotted as a function of flow depth and velocity. Damage thresholds are plotted according to Equation [3].

3.6.2. Critical Facilities

Assessment of critical facilities (Section 2.1.5) included identification of debris-flood scenarios that could directly impact the facility. Vulnerability levels associated with modelled debris-flood impact intensities for a given scenario were not assessed.

3.6.3. Roads and Utility Systems

Roads and utility systems were considered as potentially subject to damage if impacted by a modelled debris-flood scenario. Vulnerability levels associated with modelled debris-flood intensities at a given location were not assessed.

3.6.4. Persons

Within buildings, human vulnerability was estimated as an indirect outcome of building damage or collapse. Outside buildings, estimates of risk to life were not attempted because the position of persons in relation to debris flooding is unknown and unpredictable during a debris flood. Within buildings, human vulnerability criteria is also subject to uncertainties because of limited information on factors influencing vulnerability. These include the specific nature of damage, the position of persons within a building, and the ability of persons to escape impact.

Table 3-2 shows estimated average probability of life loss assigned for a certain level of building damage. Note that vulnerability to injury is not considered. The criteria shown in Table 3-2 were calibrated based on known events and comparison to results calculated from published mortality functions for large scale river floods (see Section 4.5). These criteria were also used to estimate approximately 1 fatality for Scenario 6 (Table 2-8), which corresponds in size to the June 2013 event. While it is difficult to compare a modelled to a real event, that no lives were actually lost in the June 2013 event suggests that the criteria shown in Table 3-2 are relatively conservative.

Two different vulnerability classes are shown. Estimates for individual risk correspond to an individual most at risk, who may be located on the building ground floor. Estimates used for group risk are 50% lower, with the exception of the highest damage category. This reflects an average estimate for the parcel, recognizing that persons on upper floors (e.g. multiple unit buildings) will have a relatively lower vulnerability to debris flood impact except in the case of building destruction.

Table 3-2. Vulnerability categories for persons within buildings.

Building Damage Level			Estimated Safety Vulnerability, Individual Risk (V)	Estimated Safety Vulnerability, Group Risk (V)
Class	Percent Damage[1] (% Range, Average)	Damage Level		
1	<0 to 25%	Moderate	1:1000	1:2000
2	>25% to 75%	Major	1:100	1:200
3	>75% to 90%	Severe	1:10	1:20
4	>90 to 100%	Destruction	1:2	1:2

Note: 1. Percent damage in terms of assessed building value.

3.6.5. Business Activity

As described in Section 2.1.6, BGC mapped the distribution of business activity on Cougar Creek fan by estimating the total annual revenue for each parcel identified as containing businesses.

Based on the data available, it is not possible to determine the vulnerability of businesses to complete loss of function, and associated economic cost, due to debris-flood impact. For example, a retail store could suffer loss of inventory and business function, whereas a business generating revenue elsewhere could suffer office-related damages without necessarily losing their source of revenue.

As a proxy for level of business impact, BGC summed the annual revenue estimated for parcels impacted by a debris-flood scenario. Additional factors such as indirect losses, damages to business equipment or inventory, interruption of transportation corridors, or effects of prolonged outage, were not estimated.

3.7. Safety Risk Assessment

In the case of safety risk (risk to life), risk is estimated separately for individuals and groups (societal) risk. Estimated risk for combined debris-flood scenarios is calculated by summing the risk quantified for each individual debris-flood scenario. The analysis considers Scenarios 2-5 (Table 2-8).

Individual risk considers the probability that a hazard scenario result in loss of life for a particular individual, referred to as Probability of Death of an Individual (PDI). Individual risk levels are independent of the number of persons exposed to risk.

In contrast, group risk considers the probability of a certain number of fatalities. Unlike individual risk, a greater number of persons exposed to the same hazard corresponds to increased risk. For this reason, it is possible to have a situation where individual risk is considered tolerable, but group risk is not tolerable due to the large number of people affected.

Group risk is typically represented graphically on an F-N curve, as shown in Figure 3-3. The Y-axis shows the annual cumulative frequency, f_i, of each hazard scenario, and the X-axis shows the estimated number of fatalities, N_i, where:

$$f_i = \sum_{i=1}^{n} P(H)_i P(S{:}H)_i P(T{:}S)_i \qquad [4]$$

and N_i is represented by equation [2] (see Section 3.2)

Currently, Canmore has not yet adopted criteria to assess whether safety risk for individuals or groups exceed tolerable levels. However, to help guide decisions regarding levels of risk tolerance, results of this assessment were compared to criteria adopted elsewhere.

Estimated safety risk to individuals was compared to tolerance criteria adopted by the District of North Vancouver (DNV), British Columbia in 2009, following guidelines developed in Hong Kong (Hong Kong Geotechnical Engineering Office (GEO) 1998). The DNV criteria for individual geohazard risk tolerance are as follows:

- Maximum 1:10,000 (1x10-4) risk of fatality per year for existing developments
- Maximum 1:100,000 (1x10-5) risk of fatality per year for new developments.

For risk to groups, estimated risks were compared to group risk tolerance criteria formally adopted in Hong Kong (GEO 1998) and informally applied in Australia (AGS 2007) and the DNV. Group risk tolerance criteria reflect society's general intolerance of incidents that cause higher numbers of fatalities. Group risk tolerance thresholds based on criteria adopted in Hong

Kong (GEO 1998) are shown on an F-N Curve in Figure 3-3. Three zones can be defined as follows:

- Unacceptable – where risks are generally considered unacceptable by society and require mitigation
- As Low as Reasonably Practicable (ALARP) – where risks are generally considered tolerable by society only if risk reduction is not feasible or if costs are grossly disproportionate to the improvement gained (this is referred to as the ALARP principle)
- Acceptable – where risks are broadly considered acceptable by society and do not require mitigation.

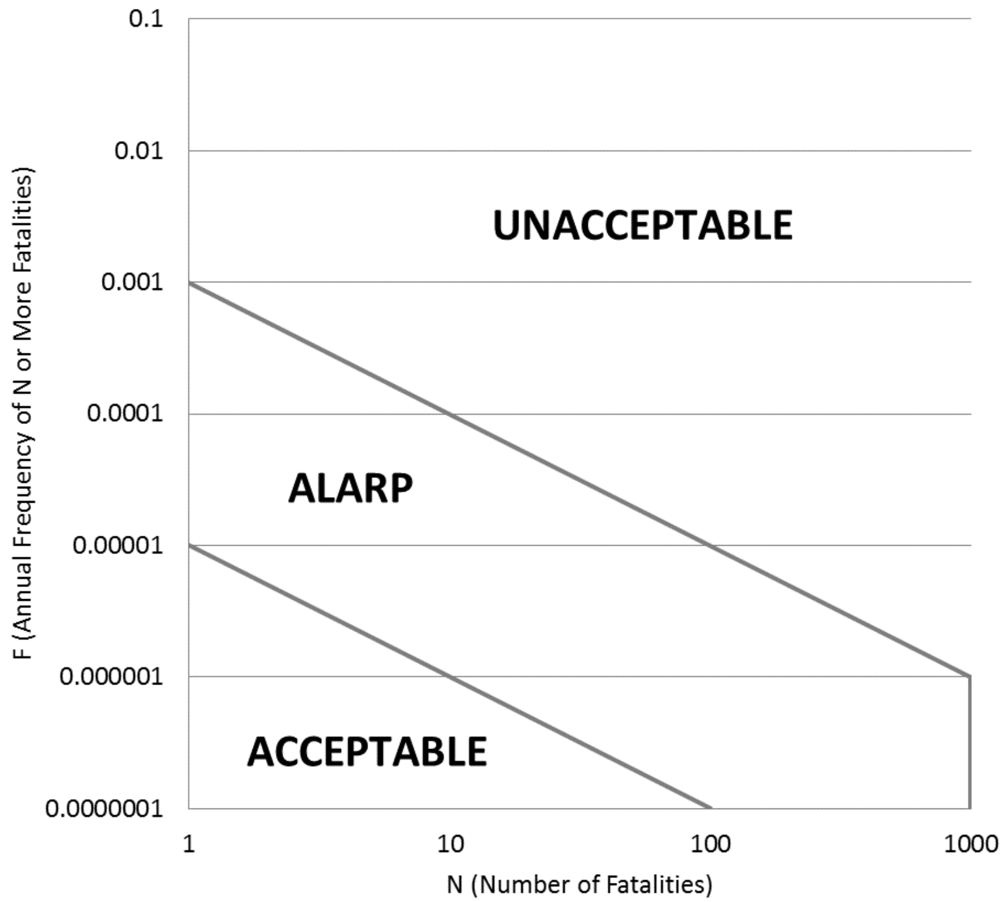

Figure 3-3. Group risk tolerance criteria as defined by GEO (1998).

4.0 RESULTS

This section summarizes results of the risk analysis based on the methods described in Section 3.0.

4.1. Surface and Subsurface Infrastructure

As noted in Section 1.4, assessment of roads and utilities was limited to identification of the location of infrastructure in relation to the extent and intensity of modelled debris-flow scenarios. Drawings 4 and 5 show modelled debris-flood intensity in relation to surface and subsurface infrastructure, including roads and utilities, for the various debris-flood scenarios. Table 4-1 provides an overview of potential impacts, which were previously described in BGC (2013c).

Table 4-1. Description of potential debris-flood scenario impacts.

Return Period (years)	Scenario	Sediment Volume (m^3)	Results
10-30	1	20,000	• The flow remains within the confines of the channel
30-100	2	40,000	• The flow stays largely within the confines of the channel to Hwy. 1 • Bank erosion upstream and downstream of Cougar Creek Boulevard to the Hwy. 1 crossing can be expected • Depending on the sequence of sediment deposition during the event, some avulsion could occur towards the western fan sector around the eastern portions of Grizzly Crescent • Inundation of sections of Hwy. 1 and 1A as well as the CPR line is considered very likely • Likely impact and significant introduction of fine-grained sediment of Police Creek
100-300 ERBC at capacity	3a	60,000	• Similar to Scenario 2 but with larger inundation areas and higher likelihood of avulsion near eastern portion of Grizzly Crescent • Backwater effect from Hwy. 1 and inundation/erosion of properties on east and west of Cougar Creek channel • Inundation of Hwy. 1, Alpine Helicopters, the industrial property south of Lincoln Park Ave, Hwy.1A, and the CPR line
100-300 ERBC blocked	3b	60,000	• Similar to 3a with less inundation of the area south of Hwy. 1 • Avulsion at the ERBC with flow due south into the Industrial area • More widespread inundation on the eastern fan sector in the area of Canyon Close and Lady MacDonald Drive • Possibly severe erosion along Lady MacDonald Crescent and Lady MacDonald Drive • Flow depths of up to ~ 3 m and significant deposition in the industrial area • Hwy. 1A is impacted south of the industrial area

Return Period (years)	Scenario	Sediment Volume (m^3)	Results
300-1000	4	160,000	• The outcome is similar to a combination of Scenario 3a, b. • Most of the eastern fan sector would be inundated with maximum flow depths of up to 1.6 m and localized flow depth exceeding 3 m • It is conceivable that 1.2 km of Hwy. 1 and 2.1 km of Hwy. 1A and the CPR line will be impacted. • At this peak flow, avulsion to the west is possible at Elk Run Blvd. with flows descending the Coyote Way area, crossing Kodiak Road and Cougar Creek Drive, heading towards the school and Hoodoo Crescent.
1000-3000	5	260,000	• Almost the entire eastern fan sector would be inundated with water and debris and over 50% of the western fan sector. • It is conceivable that 1.5 km of Hwy. 1 and 2.2 km of Hwy. 1A and the CPR line will be impacted. • Police Creek on the Bow River floodplain are impacted which is likely to lead to a back-water effect and upstream flooding in downtown Canmore • Police station, electrical substation and possibly the firehall would be impacted • Flood flows would extend down Elk Run Blvd to the south and north
2013 event	6	90,000	• No avulsion at ERBC, but backwater effect possible at Hwy. 1 with properties affected along the southwestern side of Grotto Road and southeastern portions of Grizzly Road • Avulsions possible into the industrial area on the eastern fan sector (parallel to Hwy. 1) • Inundation of Hwy. 1, Alpine Helicopters, the industrial area south of Lincoln Park Ave, Hwy.1A and CPR • Note that without continuous excavation at the ERBC, avulsion onto the eastern fan sector would have been very likely

4.2. Buildings and Business Activity

Drawing 6 shows estimated building damage proportions for individual parcels (i.e. Table 3-1), while Drawing 7 shows estimated building damage costs. Annual business revenues in impacted areas range from $12 M for Scenario 2 to $122 M for Scenario 5. Note that this should be considered a proxy for the level of business activity in impacted areas, not an estimate of economic loss. For reference, revenues of all businesses on Cougar Creek fan are about $168 M/year.

Table 4-2 summarizes parcel consequence estimates for each scenario, including total building damage costs and annual business revenues affected.

Table 4-2. Summary of consequence estimates.

Debris-flood Scenario	Frequency (1:years) (average)	Number of Parcels Affected	Building Damage Cost ($M)	Average Cost/Parcel ($k)	Annual Business Revenue of Impacted Parcels ($M)
2	1:30 to 1:100	37	$8	$220	$12
3a	1:100 to 1:300	39	$10	$260	$12
3b		487	$40	$80	$95
4	1:300 to 1:1000	707	$106	$150	$114
5	1:1000 to 1:3000	875	$129	$150	$122
6	(1:400) June 2013 “simulation”	55[1]	$12	$220	$12

Note: See Section 4.5.3

The estimated direct building damage costs range from $8 M for the 30-100 year scenario to about $129 M for the 1000-3000 year unmitigated scenario. For comparison, total assessed building value for the entire fan corresponds to about $376 M. Estimated average annualized building damage cost is $700 k, considering the scenarios and building damage costs listed in Table 4-2.

It should be emphasized that the estimated building damage costs are based only on a portion of assessed building values and do not include damage to contents or inventory. In addition, costs of cleanup and recovery, such as those listed in Table 2-7 for the June 2013 event, are not included. If these were considered, actual damage costs could increase by a factor of 2 or more.

Annual business revenues in impacted areas range from $12 M for Scenario 2 to $122 M for Scenario 5. Note that this should be considered a proxy for the level of business activity in impacted areas, not an estimate of economic loss. For reference, revenues of all businesses on Cougar Creek fan are about $168 M/year.

4.3. Critical Facilities

Table 4-3 lists critical facilities impacted by different scenarios. Alpine Helicopters was impacted by all magnitudes considered, although technically Scenario 3b did not impact the building footprint[10]. Elizabeth Rummel School was impacted by the largest two debris-flood scenarios, corresponding to 300-1000 and 1000-3000 year events. The remaining facilities were also impacted by Scenario 3b, corresponding to a 100-300 year event with avulsion towards the eastern fan sector.

Table 4-3. Scenarios impacting critical facilities (shown by check marks).

Debris-flood Scenario	Frequency (1:years) (average)	Elizabeth Rummel School	Mountain Munchkin Daycare	RCMP Detachment	Alpine Helicopters	Industrial Storage Yard
2	1:30 to 1:100 (1/65)	-	-	-	✓	-
3a	1:100 to 1:300 (1/200)	-	-	-	✓	-
3b		-	✓	✓	Near-miss[11]	✓
4	1:300 to 1:1000 (1:650)	✓	✓	✓	✓	✓
		✓	✓	✓	✓	✓
5	1:1000 to 1:3000 (1:2000)	✓	✓	✓	✓	✓
6	(1:400) Represents June 2013 Event	-	-	-	✓	-

4.4. Safety Risk

As described in Section 3.7, safety risk is estimated separately for individuals and groups (societal risk). The results presented are the combined annual risk from all debris-flood scenarios, given that some parcels may be impacted by more than one scenario.

To account for uncertainty, the results are reported as a range. The lower and upper risk estimate bounds are based on the lower and upper bounds of debris-flood hazard probability, respectively, for each scenario. BGC's "best estimate" is based on the average hazard probability estimate for a given scenario.

[10] Although Scenario 3b technically did not impact the Alpine Helicopters building footprint itself, a slightly different model flow permutation for a similar sized event could impact the facility, as was the case for Scenario 3a.

4.4.1. Individual Risk

BGC's best-estimate of individual risk exceeded the tolerance standard of 1:10,000 ($1x10^{-4}$) risk of fatality per year for 190 parcels. A complete list of parcel IDs is available upon request.

Drawing 8 shows zones where BGC's best-estimate of individual risk (PDI) exceeds 1:10,000 ($1x10^{-4}$) and 1:100,000 ($1x10^{-5}$) risk of fatality per year. Drawing 8 is based on the spatial distribution of individual parcels exceeding the above two thresholds, but the results have been aggregated into zones to reflect uncertainties in the assessment. Parcels exceeding the 1:10,000 ($1x10^{-4}$) threshold are concentrated along the west side of Cougar Creek main channel or along an avulsion path paralleling Lady MacDonald Drive.

4.4.2. Group Risk

Figure 4-1 presents the results of group risk analysis on an F-N curve, and Table 4-4 lists the estimated numbers of fatalities (N) for each debris-flood scenario. The solid line on Figure 4-1 is BGC's "best estimate", and the dashed lines are based on the upper and lower hazard probability range for each scenario. Estimated overall group debris-flood risk for Cougar Creek fan plots well into the unacceptable range when compared to the international risk tolerance standards described in Section 3.7.

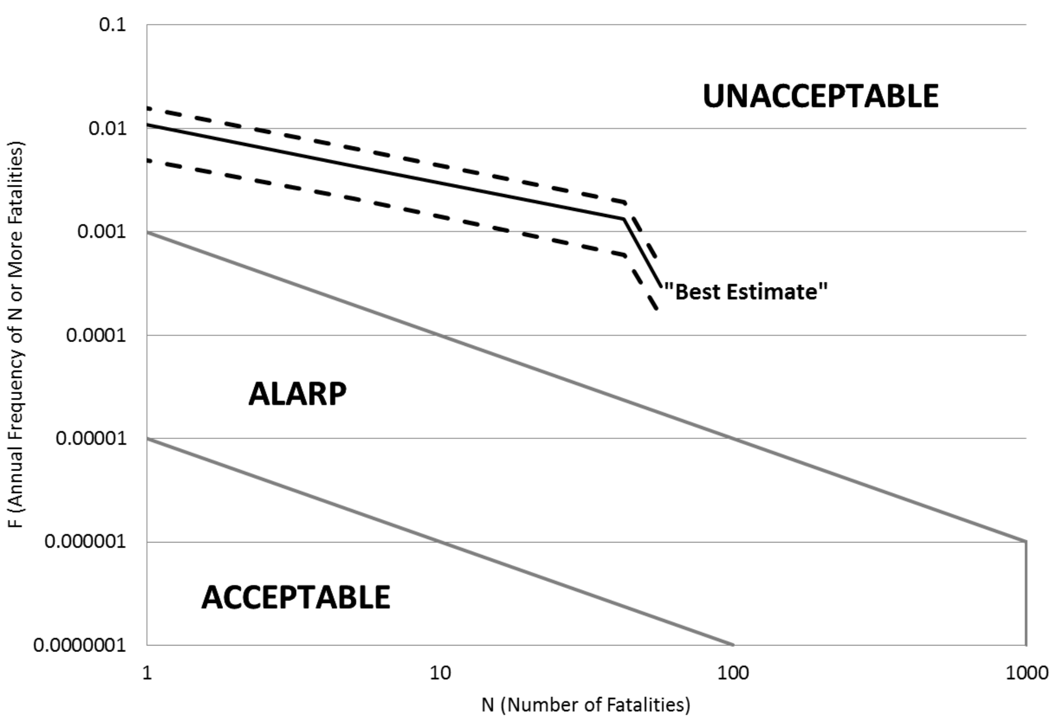

Figure 4-1. F-N curve showing the results of the Cougar Creek risk analysis for groups.

Table 4-4. Estimated number of fatalities (N) for each debris-flood scenario and with the assumptions made in this report.

ID	Frequency (1:years)	Estimated Number of Fatalities (N)
2	1:30 to 1:100	< 1[1]
3[2]	1:100 to 1:300	5
4	1:300 to 1:1000	42
5	1:1000 to 1:3000	57
6	(1:400) Represents June 2013 Event	1

[1]a value of < 1 denotes that there is a non-zero statistical chance of a fatality, but that the estimate is less than one. As an analogy, the probable number of children per family in a country might be between one and two even though this is not physically possible.

[2]based on equal probability of occurrence of either avulsion scenario 3a or 3b.

4.5. Discussion

This section compares BGC's estimates of safety risk to recorded events The objective is to verify that vulnerability criteria and results of the safety risk estimation are reasonable when compared to documented events and to results based on published mortality functions for large river floods (where there is more recorded data than mountain creeks).

This section uses the term *mortality*, defined as the number of potential fatalities divided by the number of persons exposed to hazard. For example, a mortality rate of 1 indicates that the entire exposed population will likely perish or that there is a 100% chance of death of the entire population at risk. A mortality rate of 0.01 indicates that 1% of the affected population will likely perish.

For Cougar Creek, the number of persons exposed to debris-flood hazard was calculated for each debris-flood scenario as the total number of persons within the area impacted by a scenario multiplied by their temporal probability of being in the hazard zone (Table 4-5). Table 4-5 also shows mortality rates based on the results presented in Section 4.4.

Table 4-5. Number of exposed persons used for mortality estimates for Cougar Creek, rounded to the nearest 10 persons[11].

Debris Flood Scenario	Frequency (1:years) (average)	Number of Exposed Persons	Mortality Rate (%)
2	1:30 to1:100	50	1%
3	1:100 to1:300	490	1%
4	1:300 to1:1000	1300	3.3%
5	1:1000 to1:3000	1600	3.6%
6	Represents June 2013 Event	90	1%

4.5.1. Comparison to Case Studies

The events described in this section include some cases where loss of life and the population that was exposed to hazard are both known, and other cases where loss of life did not occur but that are relevant for comparison to Cougar Creek. The examples chosen include cases where evacuation was largely not possible prior to the event, as would be comparable to the scenarios considered at Cougar Creek.

4.5.1.1. October 1921 Debris Flood at Britannia Beach, BC

On October 28, 1921, after a full day of torrential rain, a massive flood destroyed much of the community and mine operations on the lower beach area. Fifty of 110 homes were destroyed and thirty-seven people lost their lives. Construction activities had led to a landslide that dammed a portion of the creek, and when this dam collapsed the town below was flooded.

This event has some similarities with a debris flood triggered by a potential landslide-dam break at Cougar Creek. In both cases, the channel gradient does not lend itself to debris flows but rather debris floods and significant amounts of organic and mineral debris would be entrained. Finally, there was little to no warning on October 28, 1921 and little warning may occur for a dam outbreak flood on Cougar Creek unless a warning system were to be installed that would recognize sudden drops in streamflow.

BGC reviewed historical documents to estimate the flow velocities and flow depths associated with the Britannia Creek debris flood. Eye witness accounts talking about a “20 m high wave of water” are likely misinterpreted from “20 feet of water”, since the imperial system prevailed in those days. Even 20 feet (~7 m) appears unlikely given the photographic evidence from the flood[12]. The photographs suggest that an area alongside and south of the current creek was

[11] Note that these estimates are not the total number of persons in affected areas, which would be higher, because they consider the temporal probability that persons will be in the building at the time of impact.

[12] http://www.seatoskycommunity.org/archived/britanniabeach/disaster/1921flood.html

overwhelmed by debris and water with flow depth to perhaps 3 m near the fan apex and 1 m near the fan fringe. Because the loss of confinement on the fan decreased flow velocities, it is expected that velocities ranged between 4 m/s just downstream of the fan apex to perhaps 2 m/s at the fan margins.

In summary:

- Of 300 people living in the community on the Britannia Creek fan, 37 were killed, resulting in a mortality of 0.12 (12%). For a single person, the chance of death was 37/300 = 0.124
- Of the 300 people living on the fan, 15 suffered severe injuries (5% injury rate)
- Per home destroyed, there was on average one (0.74) fatality
- 45% of all buildings on the fan were destroyed.

4.5.1.2. December 1981 Debris Flow at Charles Creek, BC

On December 4, 1981, a 30,000 to 40,000 m^3 debris flow travelled down Charles Creek, approximately 4 km north of Horseshoe Bay, following a period of heavy rain and snowmelt. Initial surges blocked a bridge under a residential road, resulting in further deposition upstream, blockage of the highway bridge and deposits of up to 6 m high on the surface of the highway.

Two houses were inundated by water and gravel, although no structural damage occurred. Of the 40 residents who attempted to evacuate from the houses below Charles Creek, 1 woman was swept away by flood water. This corresponds to a 0.025 (2.5%) mortality rate for this event.

4.5.1.3. Hummingbird Creek near Salmon Arm, British Columbia

On July 11, 1997 a large debris flow occurred at Hummingbird Creek on Mara Lake. A 25,000 m^3 debris avalanche was initiated downstream of a forest road culvert that drained a small catchment. The debris avalanche evolved into a debris flow that reached between 600 and 1000 m^3/s and deposited 92,000 m^3 of sediment on the fan (Jakob et al. 1997). There were no impact-related fatalities recorded, but one heart attack related to the trauma of seeing the debris flow.

Deposition depths ranged between 3.5 and 1 m upstream of Highway 97A and between 0.1 and 0.5 m downstream of the highway. Flow velocities upstream of the Highway ranged between 6 m/s and perhaps 12 m/s. Downstream of Highway 97A flow velocities ranged between an estimated 1 and 3 m/s. Of the five cabins upstream of the highway, 2 were destroyed. There were no people present in these cabins at the time of impact. Lower Hummingbird Creek fan is largely settled with private residences, mostly for weekend use. The total number of cabins on the fan that were affected by the event is approximately 20.

Assuming a potential occupancy of two people per cabin, mortality for the upper fan could have ranged from 0.1 to 3. For the lower fan, mortality could have ranged between 0.2 and 0.8.

The fact that no one died through impact is clearly associated with the absence of many property owners at the time of impact, which underlines the necessity to include temporal probabilities in risk calculations.

4.5.1.4. Testalinden Creek near Oliver, British Columbia

On June 13, 2010, a debris flow was triggered by the overtopping and subsequent incision of an earth fill dam at Testalinden Lake. The debris flow destroyed five houses, severely damaged two, obliterated several orchards and vineyards, and deposited debris on a major highway. This event was highly publicized and photographed, allowing estimation of flow depths that appeared to have ranged between 1 and 2 m at impact with homes. Eye-witness accounts of 20 feet high[13] (7 m) flowing debris are believed to be exaggerated given the photographic evidence.

Although 7 homes were destroyed or severely damaged, no deaths occurred. However, the the event occurred in the afternoon on a Sunday during summer, and it is not known how many homes were occupied (if any) at the time of impact.

4.5.1.5. February 2010 Debris Floods in Funchal, Madeira

On February 26, 2010, 108 mm of rain were recorded within a 5 hour period (average intensity of 22 mm/hr) at Funchal (pop. approx. 100,000), the capital of the Portuguese Island of Madeira in the North Atlantic. This event triggered landslides and debris floods that caused the loss of 50 lives[14]. Based on Google Earth imagery showing houses along the flooded corridors, an estimated 1000 to 5000 people were exposed to the debris-flood hazards, corresponding to a mortality rate of 0.01 to 0.05 (1 to 5 %).

4.5.1.6. August 2005 Flooding, New Orleans, USA

During landfall on August 29, 2005, Hurricane Katrina caused massive flooding and devastation along a 270 km stretch of the US Gulf Coast. The storm surge caused overtopping and breaching of levees around New Orleans. An area of 260 km^2 of the city flooded at some locations up to 4 m deep. It took over 40 days to dewater the city. Flow depths reached up to 3 m. The rate of water level rise over the first 1.5 m reached up to 50 m/hr or roughly one cm/min. The total death toll associated with hurricane Katrina amounted to 1464. Of the 746 fatalities that were recovered in their location of death, 54% died in their residence, 20% in medical facilities and 10% in nursing homes and 7% perished in the open. The typical causes of death were drowning or physical trauma due to debris impacts and collapsing buildings.

Mortalities were calculated for various neighborhoods in New Orleans that could reasonably be homogenized. Mortalities range between 0 and 0.15 (15%). For the whole of New Orleans (including Orleans, St. Bernard and New Orleans East), a mortality of 1.2% was calculated.

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[13] Estimated by Roop Smagh (resident) to CBC news (Monday, June 15).

[14] See the Youtube video of debris floods: (http://www.youtube.com/watch?v=nXjb5QBb9TA).

For the Lower 9th Ward, which was one of the worst affected areas and suffered the direct impact of a wave due to dike breach, mortalities ranged between 0.03 (3%) and 0.07 (7%).

4.5.1.7. Summary of Case Studies

The above case studies have yielded mortalities ranging over one order of magnitude from about 0.01 (1%) to 0.12 (12%). Figure 4-2 shows BGC's estimate of group risk ("Best Estimate") plotted in comparison to estimates based on 1% and 12% mortality rates, respectively. These rates were applied uniformly to the population impacted by debris-flood scenarios (e.g. irrespective of flood depth or velocity at a particular location). BGC's estimate lies in the middle of the range, close to the lower bound for lower magnitude scenarios and towards the middle of the bounds for larger scenarios. This variation is expected given that BGC's estimate considered flow intensity in assigning vulnerability ratings, with larger events having higher flow intensities and thus higher consequences.

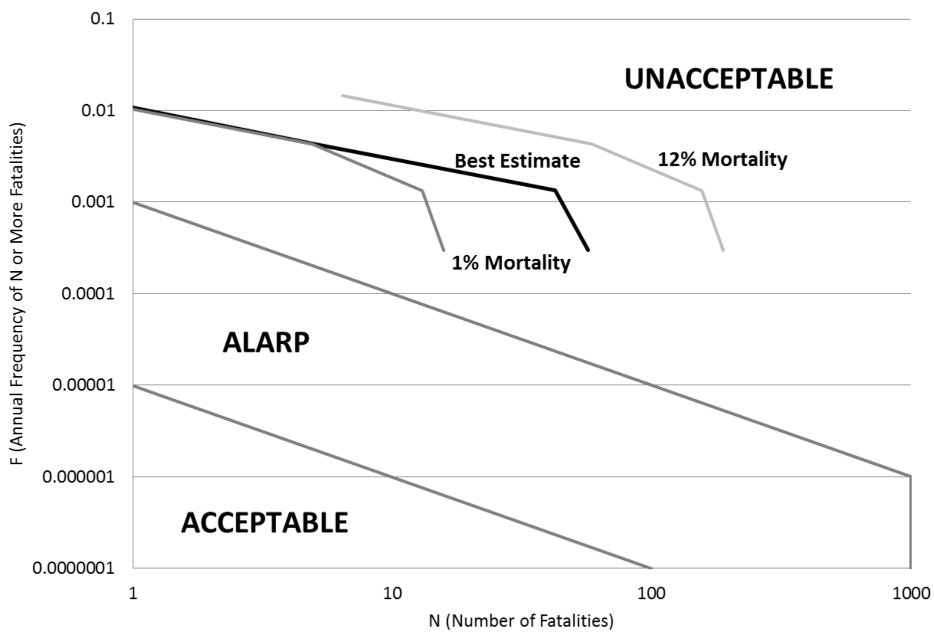

Figure 4-2. F-N curve showing assessment results ("Best Estimate") and curves plotted based on 1% and 12% mortality rates.

4.5.2. Comparison to Flood Mortality Models

Unlike debris floods on mountain creeks, much more research has been focused on estimating mortalities from flooding in lowland areas (Di Mauro 2012). These include complex models focusing on the behavior of single individuals, such as the Life Safety Model (Johnstone et al. 2006) and the US LifeSim Model (Aboelata and Bowles 2005), and relatively simpler "mortality functions" based on statistical relations between measurable flood variables and fatalities (De Bruijn and Klijn 2009). Of the latter, one of the most commonly applied models is that of Jonkman *et al.* (2008), which is currently included in the Standard Dutch Damage and Casualty

Model (De Bruijn and Klijn 2009). Mortality functions of this model were applied to Cougar Creek debris flood scenarios for comparison purposes.

The mortality functions of Jonkman *et al.* (2008) are based on investigation of about 165 historic flood locations in the Japan, Netherlands, UK, USA, and South Africa. The functions were calibrated for large scale flooding of low-lying areas following a dike breach and do not account for the higher sediment concentrations and sustained higher flow velocities typical of debris floods. However, they are still useful for comparison purposes because they are based on much more data than is available for debris flood events.

Jonkman *et al*. (2008) propose mortality functions for 3 zones:

1. *Breach Zone.* This zone was defined for the vicinity of a dike breach, where high flow velocities lead to collapse of buildings and instability of people standing in the flow. Due to lack of data to develop a mortality function for this zone, mortality is arbitrarily assumed as 1 (certain) where flow intensity exceeds a threshold defined as velocity exceeding 2 m/s, flow depth rising by more than 0.5 m/hr, and where velocity multiplied by depth exceeds 7.
2. *Rapidly Rising Water Zone*: This zone corresponds to areas where water depths exceed 2 m and rise at more than 0.5 m/hr. The mortality function relates mortality to flood depth using a best-fit trendline for a lognormal distribution:

$$F_D(h) = \emptyset_N\left(\frac{\ln(h)-\mu_N}{\sigma_N}\right) \qquad [5]$$

$$\mu_N = 1.46 \qquad \sigma_N = 0.28$$

   where F_D is flood depth (m), $\emptyset_N$ is the cumulative normal distribution; σ_N is the average of the normal distribution; and μ_N is the standard deviation of the normal distribution.

3. *Remaining Zone*. This zone corresponds to areas with shallower water depths and/or slower rates of water rise, where it is easier to escape and find shelter. The mortality function is defined for areas not included in the Breach or Rapidly Rising Water zones. It is defined similarly to equation [5], but where $\mu_N = 7.6 \quad \sigma_N = 2.75$.

Figure 4-3 shows BGC's estimate of group risk plotted in comparison to group risk estimated using Jonkman et al. (2008)'s functions to define human vulnerability. Rather than pre-defining geographic zones, the appropriate mortality function was selected for each parcel based on modelled flow velocities and depths at that location.

As shown on Figure 4-3, estimated group risk based on the mortality functions of Jonkman et al. (2008) is slightly higher than BGC's best-estimate, exceeding BGC's upper bound estimate for the largest scenarios. This is primarily due to Jonkman (2008)'s assumption of 100% mortalities within the above-defined "breach zone". In BGC's opinion this assumption is overly conservative and cannot be supported by recorded observations. Estimation of group risk based only on Jonkman (2008)'s "Rapidly Rising" and "Remaining" mortality functions that rely on observed mortalities would have placed the estimate near BGC's lower bound.

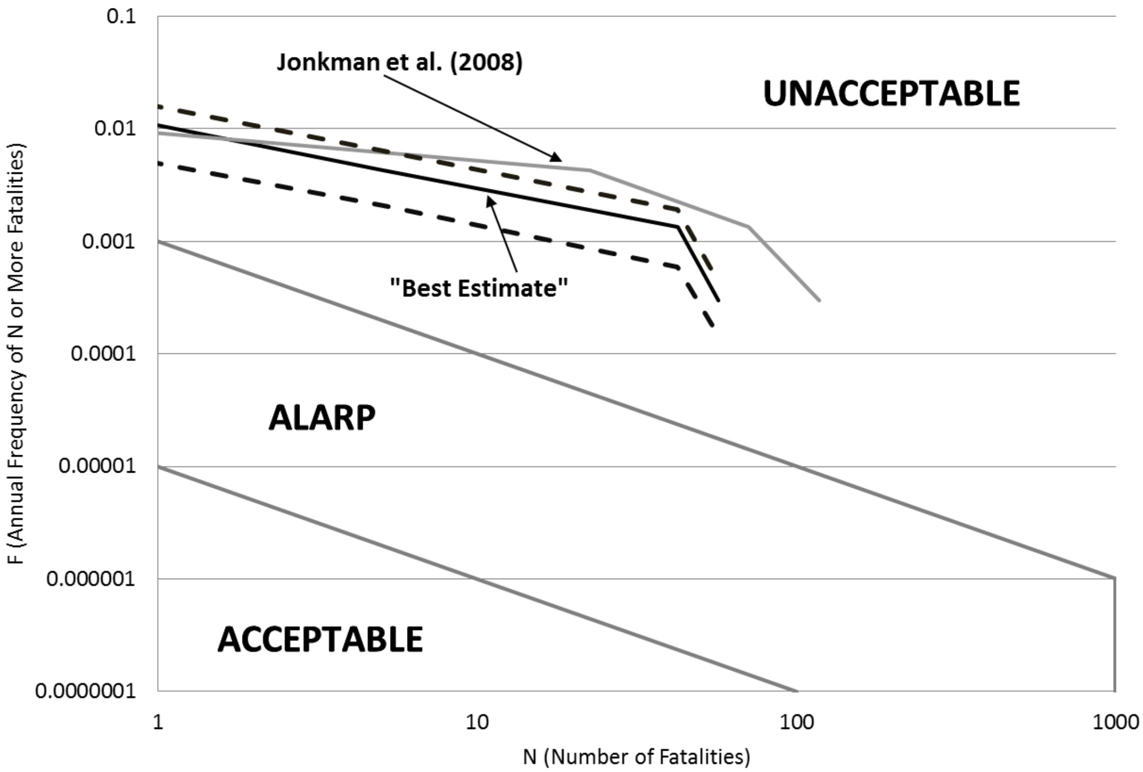

Figure 4-3. F-N curve showing results based on mortality functions of Jonkman et al. (2008) (grey line) in comparison to BGC's estimate (dark line, bounded by dashed upper and lower bounds).

4.5.3. Comparison to 2013 Event

As described in Section 2.2, it is difficult to exactly simulate the consequences of the June 2013 event because of factors that could not be modelled satisfactorily (e.g. bank erosion). Furthermore, the event itself could have had alternate outcomes, depending, for example, on whether avulsion had occurred at Elk Run Boulevard culvert, which was likely only avoided by continuous excavation of debris that threatened to block the culvert. The $17 M costs recorded for the June 2013 event (Section 2.2.1) are also not the same as those quantified in this assessment (direct building damage costs), making direct comparison difficult.

However, BGC did model one scenario (Table 2-8, Scenario 6) representing a similar magnitude debris flood to the one that occurred in June 2013. This section compares the spatial extent of impact and level of damage (where possible) for this model scenario to the June 2013 event. The comparison focuses on the 41 cases where Canmore recorded structural damage to buildings.

Drawing 4 (lower right map tile) shows modelled debris-flood intensities of Scenario 6. Drawing 9 shows parcels impacted by the June 2013 event and mapped by Canmore according to the damage levels listed in Table 4-6. For comparison, Drawing 9 also shows damage levels estimated based on the debris flood modelling (i.e. Scenario 6).

Visual inspection of Scenario 6 on Drawing 4 suggests that the runout extent is broadly similar to the June 2013 event (see BGC 2013a). However, some differences exist. Table 4-7 summarizes the number of parcels with different levels of recorded structural building damage (e.g. "red" category) compared to those predicted by Scenario 6. A total of 9 parcels had recorded building damage that were not impacted by Scenario 6. Note that this includes Alpine Helicopters and Bow Valley Ford (labelled on Drawing 9), which did suffer damage in June 2013 that was not recorded in Canmore's damage inventory.

Table 4-6. Canmore damage levels and equivalent BGC damage category.

Damage Category Assigned By Canmore	Description	Equivalent BGC Damage Category
Green	Land damaged but no safety issues, and no damage to buildings.	Not equivalent because this assessment does not consider land damage.
Yellow	Land damaged. Some buildings may have lost decks.	
Red (R3)	Structural instability (minor)	Moderate damage
Red (R2)	More significant structural damage (not at risk of collapsing)	Major damage
Red (R1)	Significant damage	Severe damage

Table 4-7. Comparison of actual and modelled damage estimates, June 2013 event.

BGC Damage Category	Equivalent Canmore Damage Category	Recorded Number of Parcels Affected by June 2013 Event[1]	Predicted Number of Parcels, Scenario 6[2]
Severe	R1	7	7
Major	R2	12	10
Moderate	R3	22	15
	Total	**41**	**32**

Notes: 1. Reported by Canmore
2. Based on debris-flood model scenario #6

Figure 4-4 shows recorded building damage for the June 2013 debris flood, plotted for parcels also impacted by Scenario 6. The flow velocities and depths plotted correspond to modelled values for Scenario 6. The I_{DF} thresholds (I_{DF} = 1, 10, 100) and damage categories shown on Figure 4-4 are the same as those used (along with Hazus depth-damage curves) to estimate building damages for Scenario 6 (see Section 3.6.1).

In summary, Figure 4-4 shows some agreement between recorded damage levels and those that might be predicted based on modelled flow velocities and depths, but also substantial differences. Given these differences, building damage cases from the June 2013 debris flood were not added to the building vulnerability criteria shown on Figure 3-2 (Section 3.6.1). Primary factors that could result in these differences include:

- Differences in channel configuration between those used in the model and those from the June 2013 event. BGC attempted to account for channel changes during the June 2013 debris flood by adjusting the channel planform to the state observed towards the latter part of the flood. However, transient channel elevations that are created by cycles of aggradation and degradation cannot be simulated with any accuracy.
- Differences in the actual versus assumed peak discharge of the event. Since discharge was not measured during the event it has to be back-calculated (BGC, 2014) which is uncertain because bed elevations during the event are unknown.
- Bank erosion was a primary factor for land and building damage during the June 2013 event, but there is no reliable model capable of simulating bank erosion and bank encroachment is not an input parameter for debris-flood modelling.

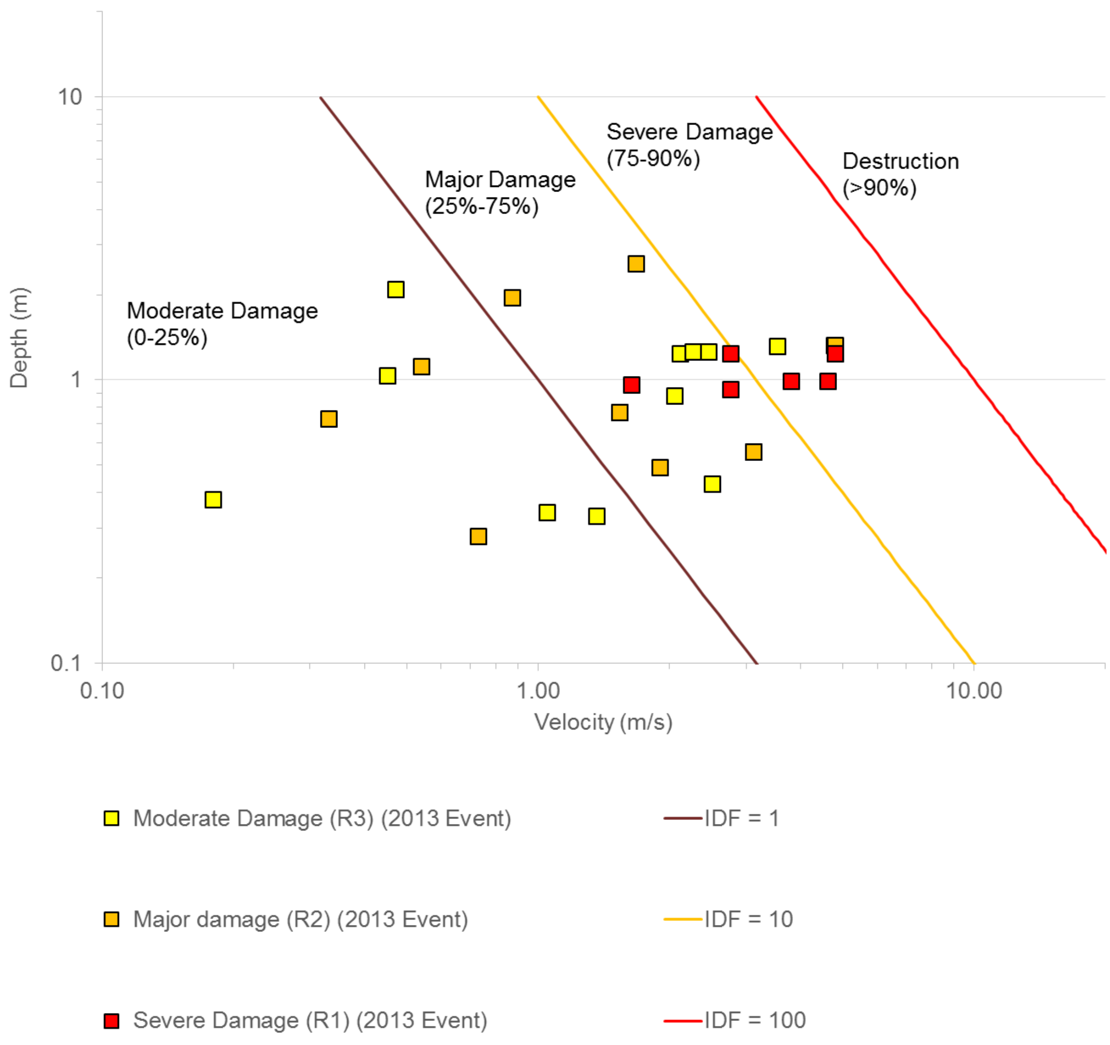

Figure 4-4. Building damage cases reported for the June 2013 debris flow, plotted using modelled flow depth and velocity from debris flood Scenario 6. Damage thresholds are plotted according to Equation [3].

However, it should be noted that the above discrepancies are not necessarily a failure of the model, but rather signify that flows even of similar magnitude may result in different outcomes. For example, Scenario 6 predicts slightly more extensive inundation adjacent to Highway 1 than actually occurred, but this potential outcome is still considered credible. BGC considers modelling uncertainties regarding bank encroachment as more significant for modelling main channel flows compared to avulsions onto relatively erosion-resistant portions of the fan (e.g. areas covered by asphalt, vegetation and houses) as well as a lack of a pre-existing channel. While some erosion cannot be discarded, for un-channelized fan sectors direct flow impact and inundation will be more important for damage assessment. Within the channel, the mitigation measures completed thus far include armoring of channel banks to control erosion, and bank erosion such as that occurring in June 2013 is significantly less likely in the future.

In terms of life loss, estimated life loss for Scenario 6 corresponds to 1 fatality, whereas no lives were lost in the June 2013 event. This suggests that the criteria for direct building damage and risk to life used in this assessment are relatively conservative. BGC considers this estimate to be credible; that no lives were lost during the June 2013 event is no guarantee that lives could not be lost by an unmitigated event of similar magnitude in the future.

4.5.4. Summary

As noted in Section 4.5.1, large variations exist in mortality rates for different recorded events, and a multitude of factors influence human vulnerability to life loss in each event. This was also the case in the June 2013 Cougar Creek debris flood where the concerted actions of emergency response workers and citizens were highly influential in preventing life loss. Moving forward, long-term management of debris-flood risk requires estimates of safety risk that can be considered reasonable: neither under-conservative nor so pessimistic as to result in unnecessary concern.

Comparison of scenario modelling to the June 2013 event suggests that differences will likely exist between specific model scenarios and actual events, but that modelled scenarios can be considered a credible proxy for debris flood risk estimation and evaluation. Comparisons of estimated group safety risk for Cougar Creek to other events based on mortality criteria suggest that while uncertainties exist, estimated risk levels for Cougar Creek are conservative but within a reasonable range.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This assessment estimated debris-flood risk for Cougar Creek fan based on the results of BGC's hazard assessment (BGC 2013c). The primary objective of the assessment was to support decision making and expenditures to reduce debris-flood risk to levels considered tolerable by Canmore.

BGC assessed risk associated with four debris-flood scenarios representing a range in debris-flood return periods from 30-100 to 1000-3000 years. Elements impacted by these scenarios and considered in the risk assessment included buildings, roads, utilities, critical facilities, and persons within buildings. Of these, the risk analysis focused primarily on estimation of direct building damage and safety risk (i.e. loss of life). These were selected as the key elements that can be systematically assessed and compared to risk tolerance standards. Risk mitigation decisions based on the elements assessed will also reduce relative levels risk for a broader spectrum of elements than those explicitly considered.

Estimated direct damage costs to buildings for individual scenarios ranged from $8 M for the 30 - 100 year scenario to $129 M for the 1000-3000 year scenario. Estimated annualized building damage cost ranged from $300 k to $1.4 M, based on the lower and higher hazard probability bounds for individual debris flood scenarios. BGC's "best estimate", based on average hazard probability, is $600 k/year. The estimated building damage costs are based only on assessed building values. They do not include damage to contents or inventory, costs of cleanup and recovery, indirect costs of business interruption, loss of power transmission, or highway or rail transportation interruption. These factors, if considered, would likely increase annualized damage costs by a factor of 2 or more.

Annual business revenues in impacted areas range from $12 M for the 30-100 year scenario to $122 M for the 1000-3000 year scenario. For reference, revenues of all businesses on Cougar Creek Fan correspond to about $168 M/year. As noted in Section Table 4-2, the impact to business revenue should be interpreted as a proxy for the level of business activity in impacted areas, not an estimate of economic loss.

BGC identified 181 parcels where estimated average safety risk for individuals exceeded 1:10,000 probability of death per annum. This risk tolerance threshold has been adopted internationally by several jurisdictions as well as by the District of North Vancouver, British Columbia, for existing developments. Estimated group safety risk also fell into the "Unacceptable" range when compared to international risk tolerance standards.

Critical facilities assessed included Elizabeth Rummel School, Mountain Munchkin Daycare, Alpine Helicopters, the RCMP Attachment, and an industrial yard containing essential equipment for emergency response. Alpine Helicopters was impacted by all return periods considered. Elizabeth Rummel School was impacted by the largest two debris-flood scenarios, corresponding to 300-1000 and 1000-3000 year events. The remaining facilities were also impacted by Scenario 3b, corresponding to a 100-300 year event with avulsion towards the eastern fan sector.

5.2. Recommendations

Following this risk assessment, a number of steps should be followed to optimize the risk reduction strategy:

1. Building damage cost estimates and vulnerability ratings should be reviewed for calibration purposes if detailed building damage cost information becomes available for the June 2013 debris flood.
2. Canmore will need to agree on risk tolerance levels primarily in terms of loss of life for individual and group risk, and annualized economic loss potential.
3. Debris-flood risk reduction options should be identified including both structural and non-structural measures. Structural measures, such as containment of debris through barriers upstream of the populated channel sections, channel armouring as well as concrete check dams, are some of the components of a comprehensive risk reduction strategy. Moreover, debris flood risk could also be lowered by reducing the following:
    - Probability of the debris flood occurring (e.g. watershed stability). This option is not considered feasible due to lack of watershed access, the fact that most of the watershed is within park lands, and because of the abundance of potential sediment sources.
    - Debris-flood magnitude (e.g. volume or peak discharge). Volume reduction can be achieved through debris containment and reduction of potential channel bank erosion through armoring (e.g. measures currently being completed).
    - Debris-flood intensity (e.g. runout extent, velocity, impact forces). This can be achieved through containment (reduction of flow velocities and runout extent) and thus, reduction of impact forces.
    - Spatial probability of impact (likelihood that the debris flood will reach or impact elements at risk). This can also be reduced by containing debris floods upstream of the developed area.
    - Number of persons exposed to hazard. This could be achieved through evacuations tied to an early warning system, or by property acquisitions.
4. Risk evaluation should be completed for each risk reduction option, once identified, to support selection of preferred options that reduce debris flood risk to levels considered tolerable by Canmore. Temporal aspects of changing flow intensities during the course of an event should be considered as part of this evaluation.

6.0 CLOSURE

We trust the above satisfies your requirements at this time. Should you have any questions or comments, please do not hesitate to contact us.

Yours sincerely,

BGC ENGINEERING INC.
per:

ISSUED AS DIGITAL DOCUMENT.
SIGNED HARDCOPY ON FILE WITH
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REFERENCES

Aboelata MA, Bowles DS, 2005. LIFESim: A model for estimating dam failure life loss. Institute for water resources, US Army Corps of Engineers and Australian National Committee on Large Dams.

Australian Geomechanics Society (AGS), 2007. A national landslide risk management framework for Australia. Vol. 42 No. 1, March 2007.

BGC Engineering Inc. (BGC), 2013a. Cougar Creek, Forensic Analysis and Short-Term Debris Flood Mitigation. Final Report prepared for the Town of Canmore dated December 11, 2013.

BGC Engineering Inc. (BGC), 2013b. Hydroclimate Analysis of the June 19-21, 2013 Rainstorm. Final Draft Report prepared for the Town of Canmore dated January 10, 2014.

BGC Engineering Inc. (BGC), 2013c. Cougar Hazard Debris Flood Hazard Assessment. Final Report prepared for the Town of Canmore dated March 7, 2014.

Canadian Standards Association (CSA), 1997. CAN/CSA – Q859-97 Risk Management: Guideline for Decision Makers. 55 p.

Canmore, 2011. 2011 Canmore Census Summary prepared for Town Of Canmore by Big Shoes Social Enterprise, dated June 11, 2011.

Canmore, 2013. List of registered Canmore Businesses. Data provided in spreadsheet format dated November 8, 2013.

De Bruijn KM, Klijn F, 2009. Risky places in the Netherlands: a first approximation for floods. Journal of Flood Risk Management, vol. 2, pp. 58–67.

Di Mauro, M., De Bruijn, K., and Meloni, M., 2012. Quantitative methods for estimating flood fatalities: towards the introduction of loss-of-life estimation in the assessment of flood risk. Natural Hazards, vol. 63, pp. 1083-1113.

Hong Kong Geotechnical Engineering Office (GEO), 1998. Landslides and Boulder Falls from Natural Terrain: Interim Risk Guidelines. Geo Report 175, Geotechnical Engineering Office, Civil Engineering Department, Hong Kong Special Administrative Region, 184 pp.

Hoovers, 2013. Company Lead List: Complete Gold. Obtained from Hoovers, a Dunn and Bradstreet (D&B) Company, on October 9, 2013.

International Organization for Standardization (ISO), 31000:2009. Risk Management – Principles and Guidelines. Source: www.iso.org

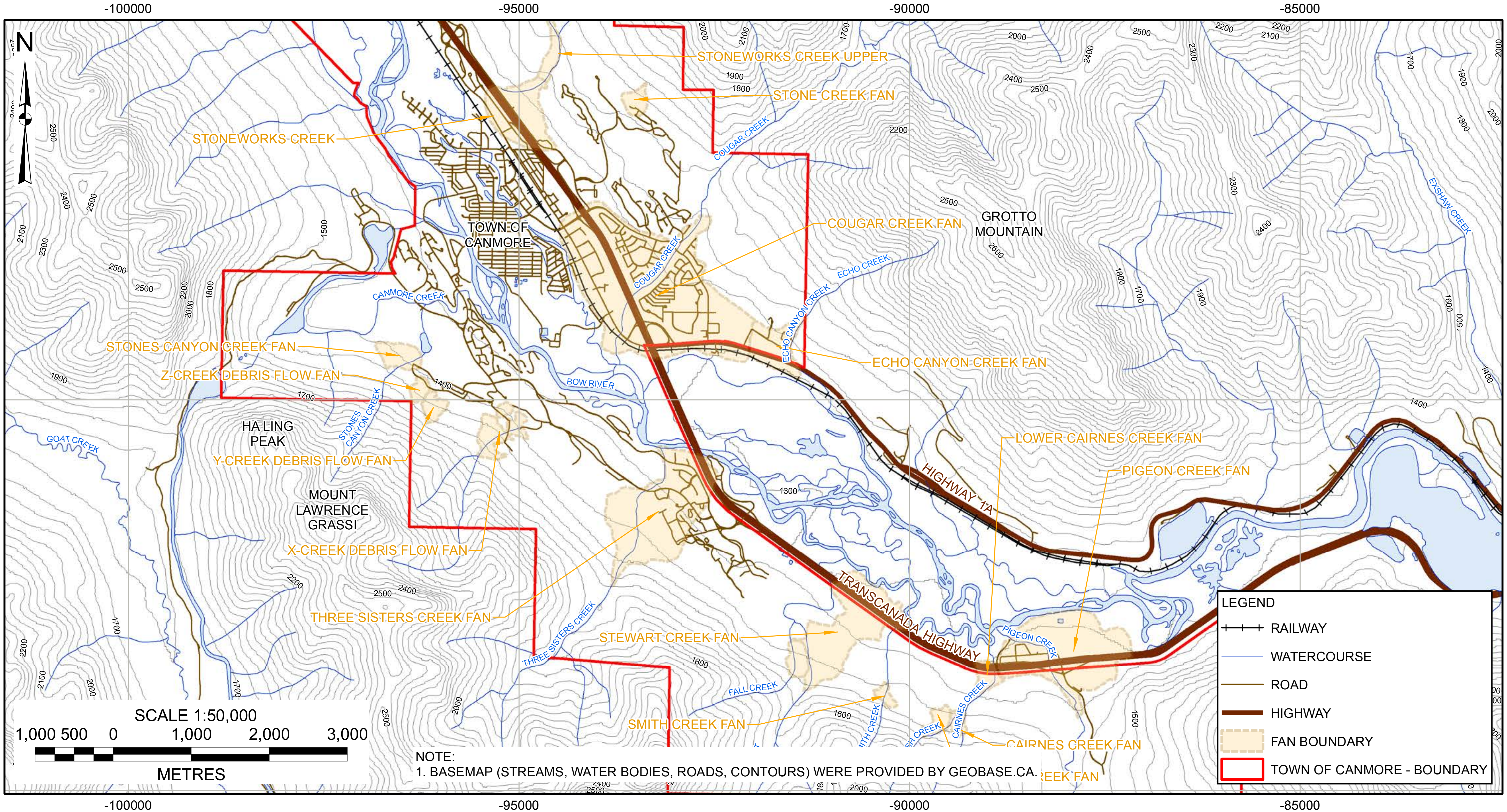
Porter, M., Jakob, M., and Holm, K. Proposed landslide risk tolerance criteria. GeoHalifax 2009, 9 pp.

Jakob, M., Stein, D., and Ulmi, M., 2011. Vulnerability of buildings to debris flow impact. Natural Hazards, Vol. 60, Issue 2, pp. 241-261.

Johnstone WM, Alexander D, Underwood D, Clark J, 2006. LSM system V1.0: guidelines, procedures and calibration manual. BC Hydro Engineering.

Jonkman, S., Vrijling, J., and Vrouwenvelder, A. (2008). Methods for the estimation of loss of life due to floods: a literature review and a proposal for a new method. Natural Hazards (2008), vol. 46, pp. 353-389.

DRAWINGS



NOTE:
1. BASEMAP (STREAMS, WATER BODIES, ROADS, CONTOURS) WERE PROVIDED BY GEOBASE.CA.

3TM

X:\Projects\1261001\Workspace\20131008_Report_Cougar_Creek_Debris_Flood_Risk_Assessment\01_Location_Map.mxd Date: Monday, June 09, 2014 Time: 5:20 PM

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:50,000
DATE:	JUN 2014
DRAWN:	GLT
DESIGNED:	KH, MJ
CHECKED:	KH, MJ, HW
APPROVED:	KH, MJ

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: CANMORE

PROJECT: COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

TITLE: LOCATION MAP

PROJECT No.:	DWG No.:	REV.:
1261001	01	

DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT" DATED JUNE 2014

5 m CONTOUR INTERVAL (LIDAR 2013)
3TM

SCALE 1:5,000

100 50 0 100 200 300

METRES

NOTES:
1. BUILDINGS, PARCELS, AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
2. WATERCOURSE, WATERBODY, AND RAILWAY WERE OBTAINED FROM CANVEC.
3. HILLSHADE WAS DERIVED FROM LIDAR RECEIVED FROM TOWN OF CANMORE, JULY 2013.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:5,000
DATE:	JUN 2014
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APPROVED:	KH, MJ

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Town of CANMORE

PROJECT: COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

TITLE: BASEMAP: BUILDINGS AND SURFACE INFRASTRUCTURE

PROJECT No.:	DWG No.:	REV.:
1261001	02	

DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT" DATED JUNE 2014

SCALE 1:5,000

100 50 0 100 200 300

METRES

NOTES:
1. PARCELS AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
2. WATERCOURSE, WATERBODY, AND RAILWAY WERE OBTAINED FROM CANVEC.
3. HILLSHADE WAS DERIVED FROM LIDAR RECEIVED FROM TOWN OF CANMORE, JULY 2013.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:5,000
DATE:	JUN 2014
DRAWN:	GLT
DESIGNED:	KH, MJ
CHECKED:	KH, MJ, HW
APPROVED:	KH, MJ

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

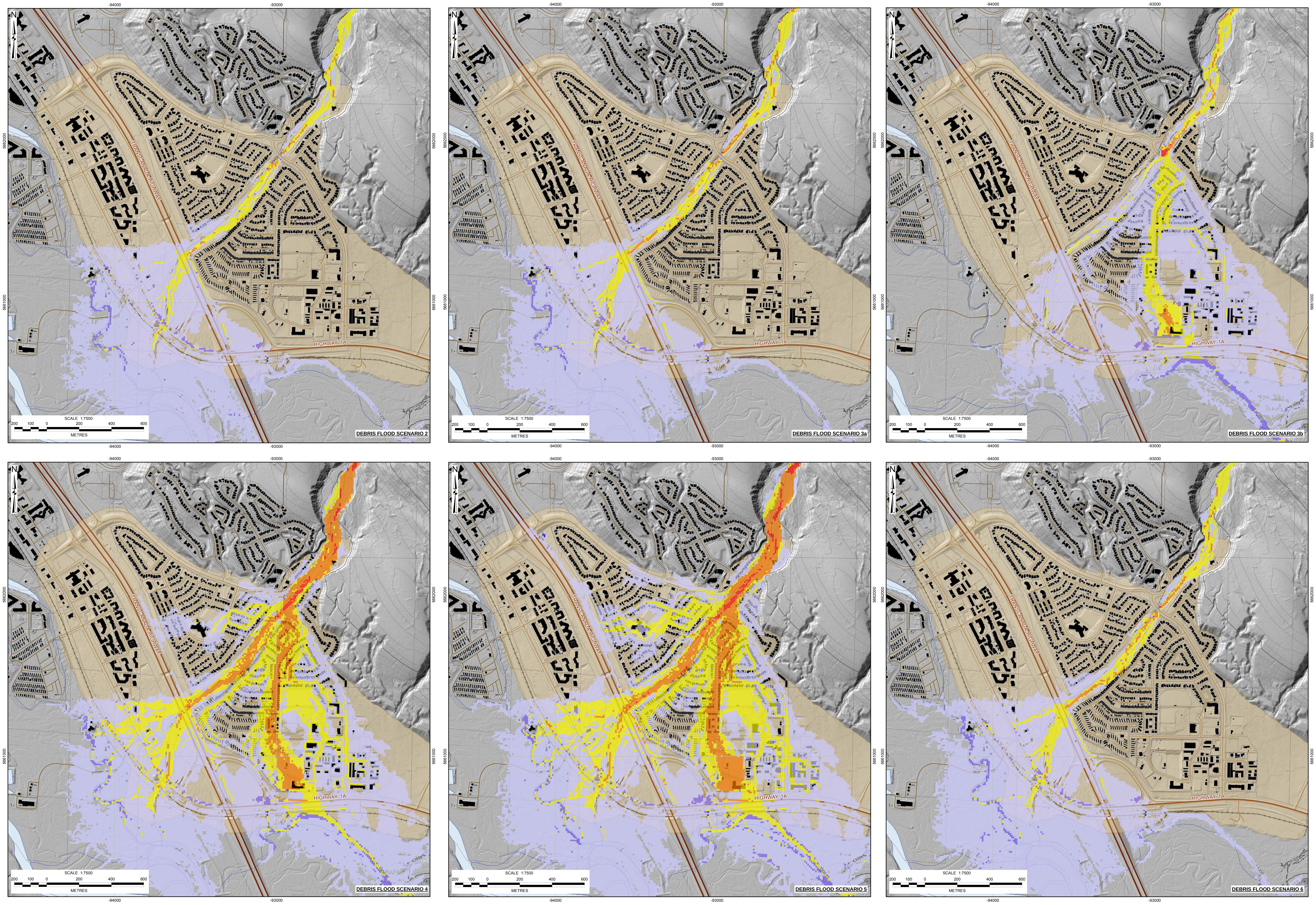
CLIENT: Town of CANMORE

PROJECT: COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

TITLE: BASEMAP: SUBSURFACE UTILITIES

PROJECT No.:	DWG No.:	REV.:
1261001	03	

DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT" DATED JUNE 2014



LEGEND

FLOW DEPTH (m) (v < 1 m/s)
- < 1
- 1 to 2.5
- > 2.5

IMPACT INTENSITY (m^3/s^2) (v > 1 m/s)
- < 10
- 10 to 100
- > 100

- PARCELS
- BUILDING
- FAN BOUNDARY
- ROAD
- HIGHWAY
- RAILWAY
- WATERCOURSE
- WATERBODY

NOTES:
1. MODEL RUNS (DEBRIS FLOOD SCENARIOS) ARE LABELLED IN THE LOWER RIGHT HAND CORNER OF EACH MAP INSET.
2. SEE BGC (2013C) FOR METHODS AND LIMITATIONS OF DEBRIS FLOOD MODEL RUNS.
3. BUILDINGS, PARCELS, AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
4. WATERCOURSE, WATERBODY, AND RAILWAY WERE OBTAINED FROM CANVEC.
5. HILLSHADE WAS DERIVED FROM LIDAR RECEIVED FROM TOWN OF CANMORE, JULY 2013.
6. THIS MAP SHOULD NOT BE RELIED UPON AT A SCALE LARGER THAN (MORE DETAILED) THAN SHOWN ON THIS MAP.
7. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT THE RE-DRAWING OF CERTAIN AREAS.

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:7,500
DATE:	JUN 2014
DRAWN:	GLT
DESIGNED:	MJ, KH
CHECKED:	MJ, HW, KH
APPROVED:	MJ, KH

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: TOWN OF CANMORE

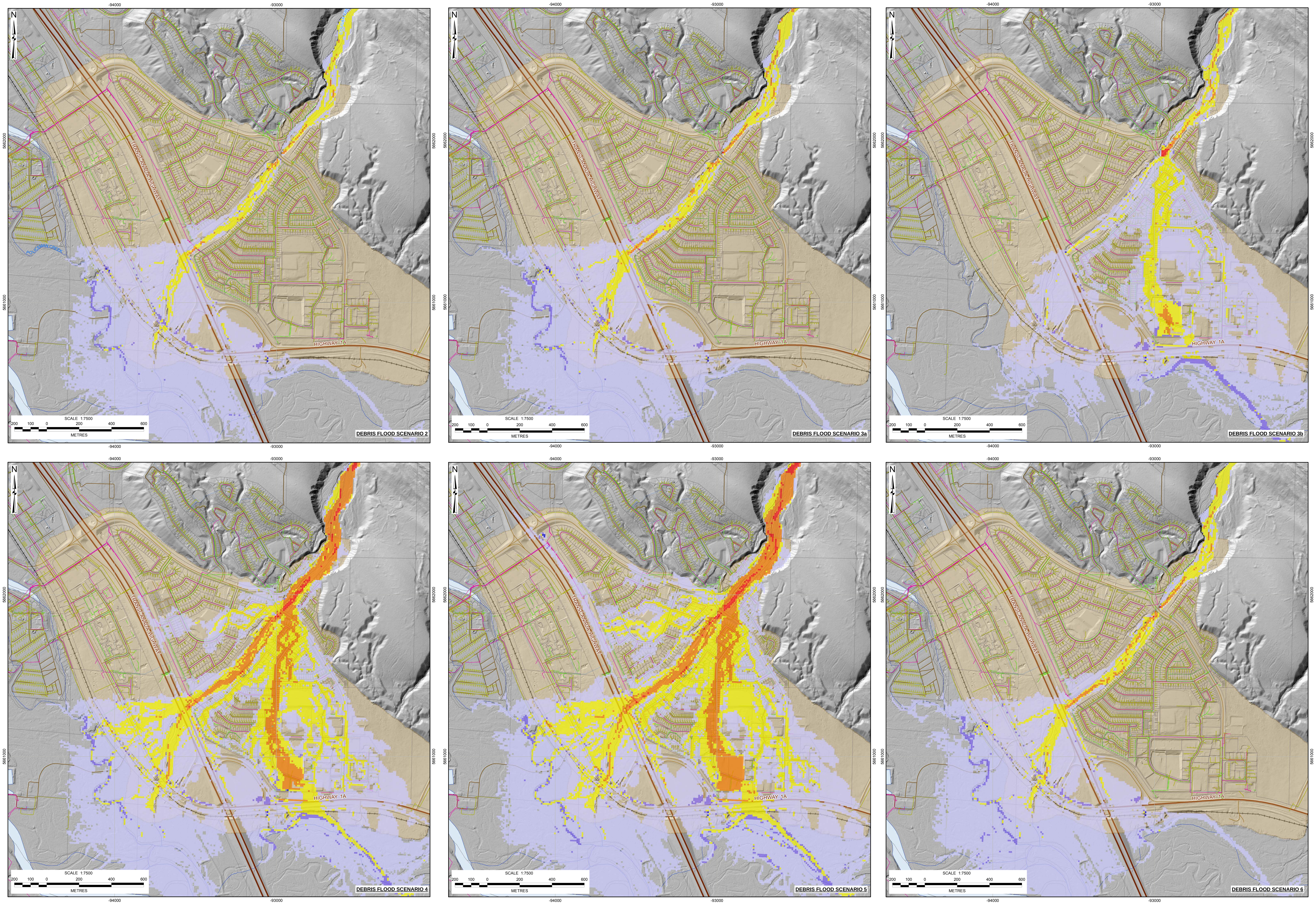
3TM

PROJECT: COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

TITLE: DEBRIS FLOOD INTENSITY, SURFACE INFRASTRUCTURE: DEBRIS FLOOD SCENARIOS 2-6

PROJECT No.:	DWG No.:	REV.:
1261001	04	

DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT" DATED JUNE 2014



LEGEND

FLOW DEPTH (m) (v < 1 m/s)
- < 1
- 1 to 2.5
- > 2.5

IMPACT INTENSITY (m^2/s^2) (v > 1 m/s)
- < 10
- 10 to 100
- > 100

- PARCELS
- GAS LINES
- SANITARY MAIN
- WATERMAIN
- STORM MAIN/CHANNEL/SERVICE
- FAN BOUNDARY
- ROAD
- HIGHWAY
- RAILWAY
- WATERCOURSE
- WATERBODY

NOTES:
1. MODEL RUNS (DEBRIS FLOOD SCENARIOS) ARE LABELLED IN THE LOWER RIGHT HAND CORNER OF EACH MAP INSET.
2. SEE BGC (2013C) FOR METHODS AND LIMITATIONS OF DEBRIS FLOOD MODEL RUNS.
3. PARCELS AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
4. WATERCOURSE, WATERBODY, AND RAILWAY WERE OBTAINED FROM CANVEC.
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NAD 1983 UTM Zone 11N

REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE:	1:7,500
DATE:	JUN 2014
DRAWN:	LL, GLT
DESIGNED:	MJ, HW, SL
CHECKED:	MJ, HW, KH
APPROVED:	MJ, HW

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

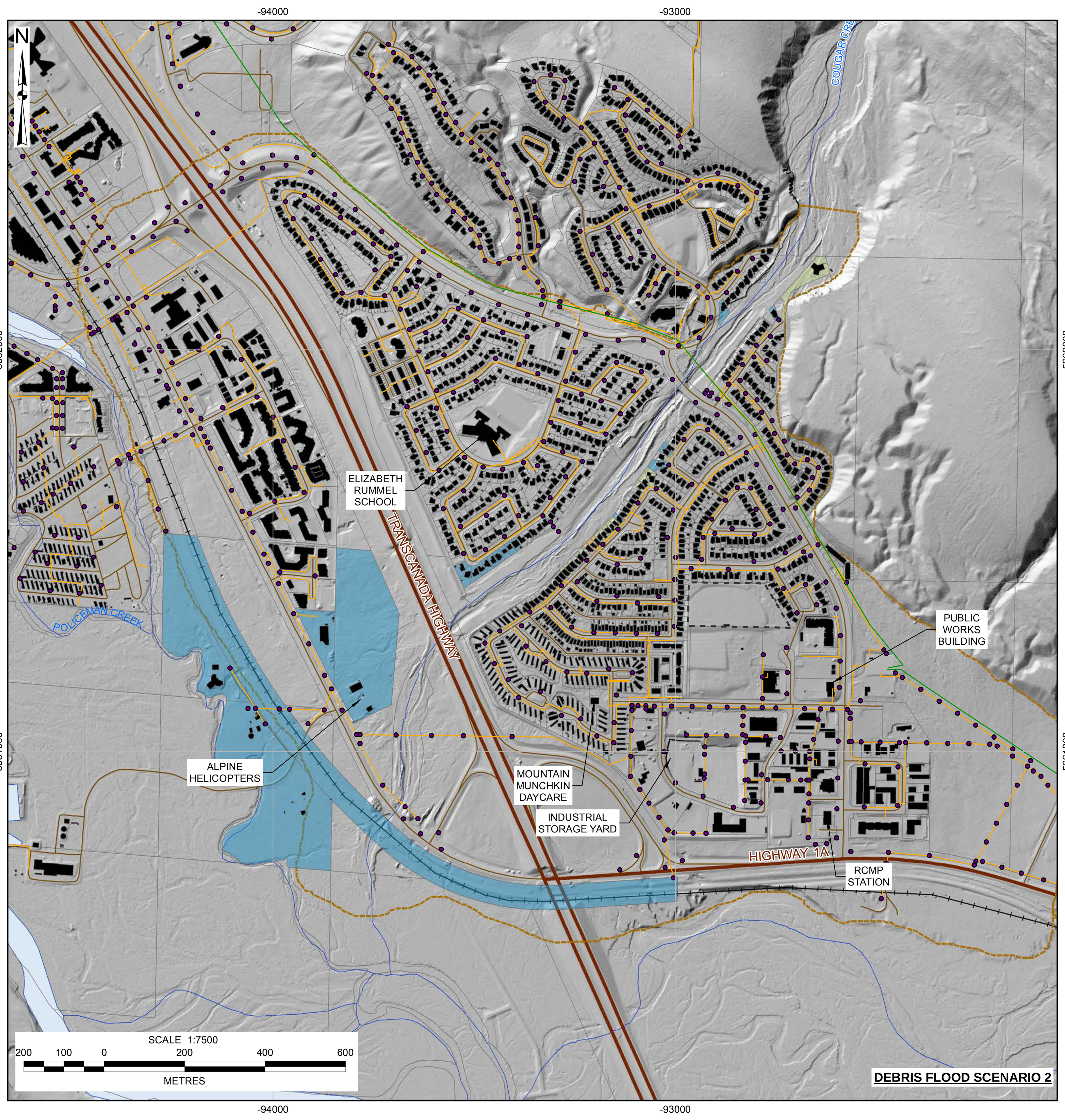
CLIENT: TOWN OF CANMORE

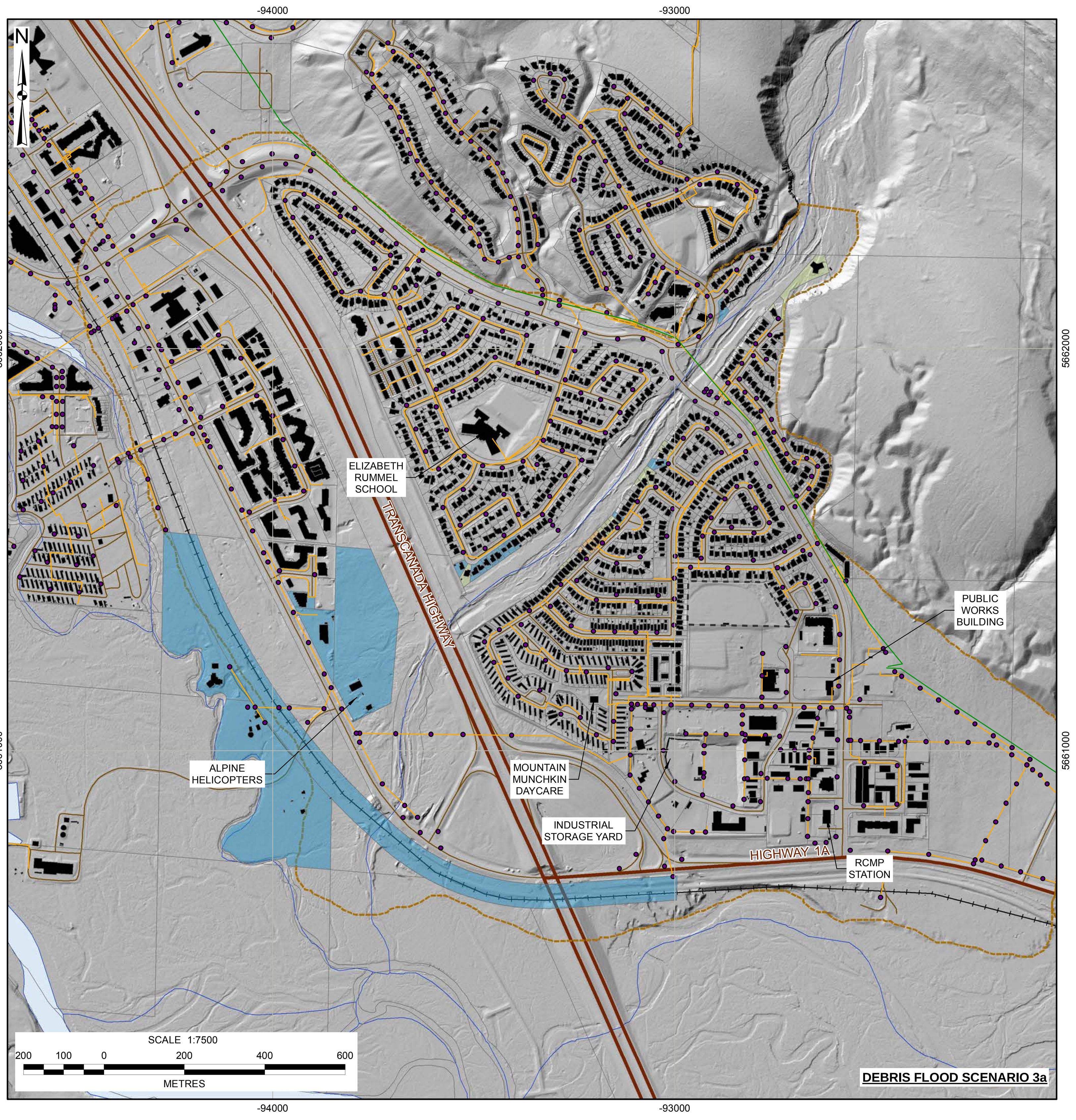
PROJECT: COUGAR CREEK DEBRIS FLOOD HAZARD ASSESSMENT

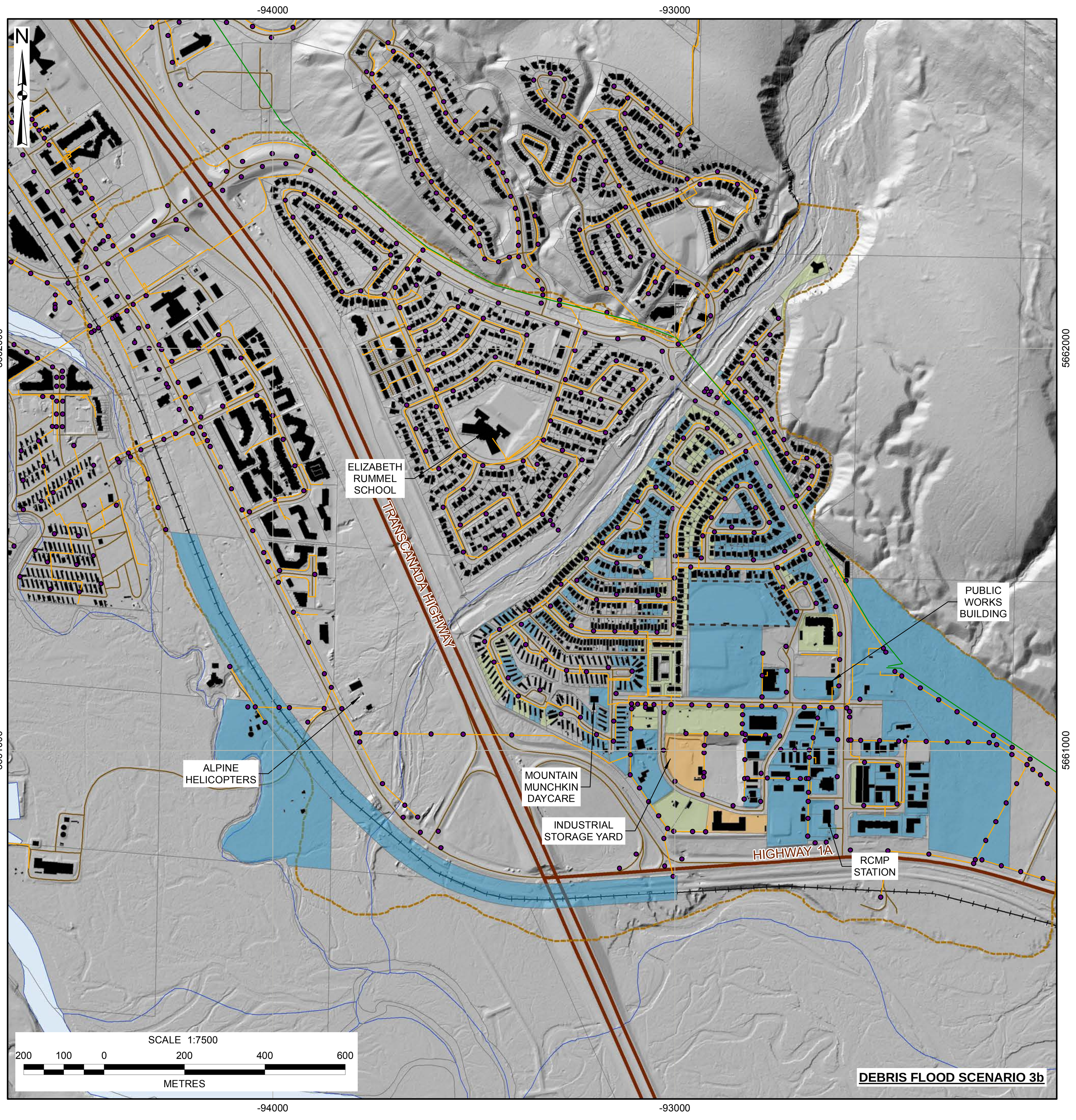
TITLE: DEBRIS FLOOD INTENSITY, SUBSURFACE UTILITIES: DEBRIS FLOOD SCENARIOS 2-6

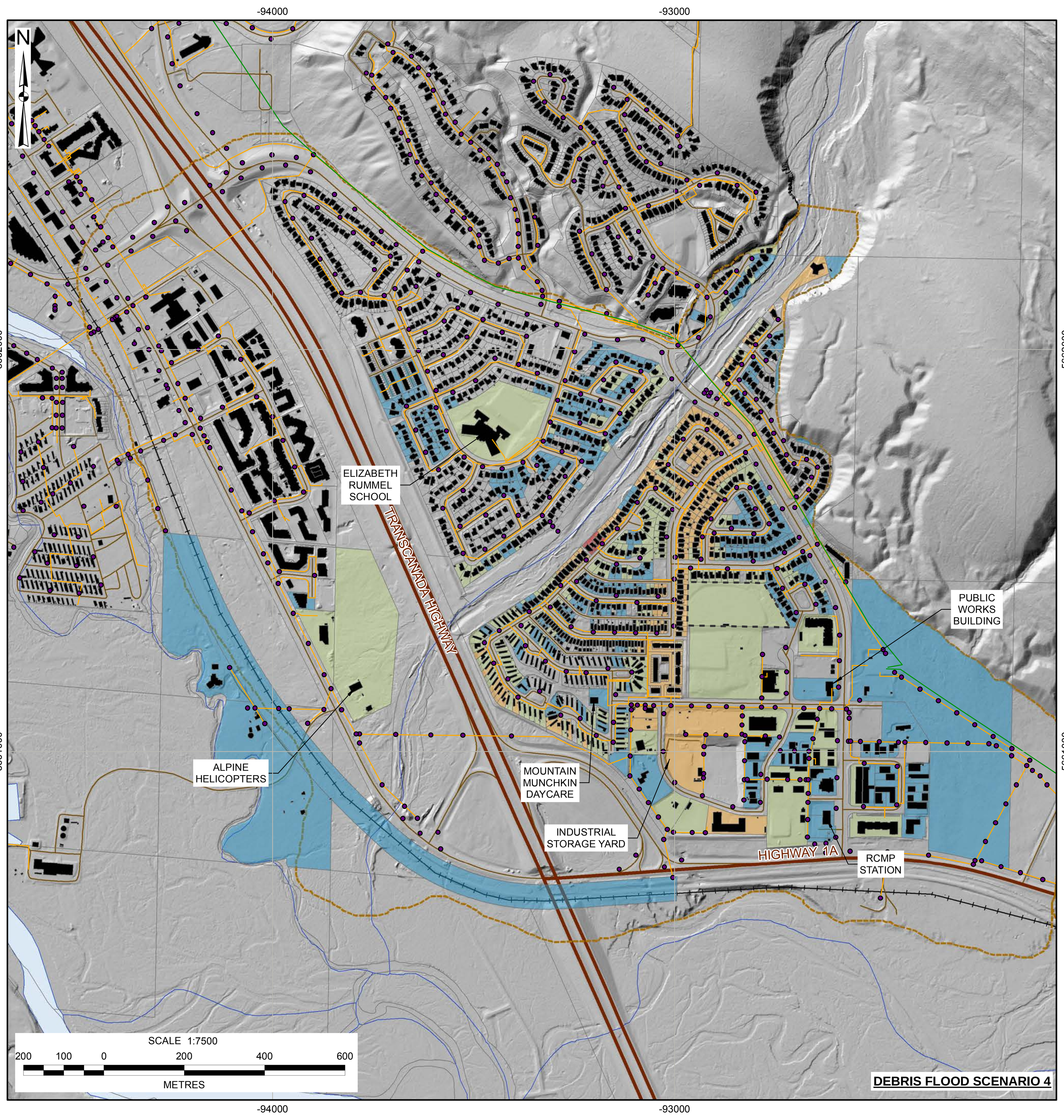
PROJECT No.:	DWG No.:	REV.:
1261001	05	

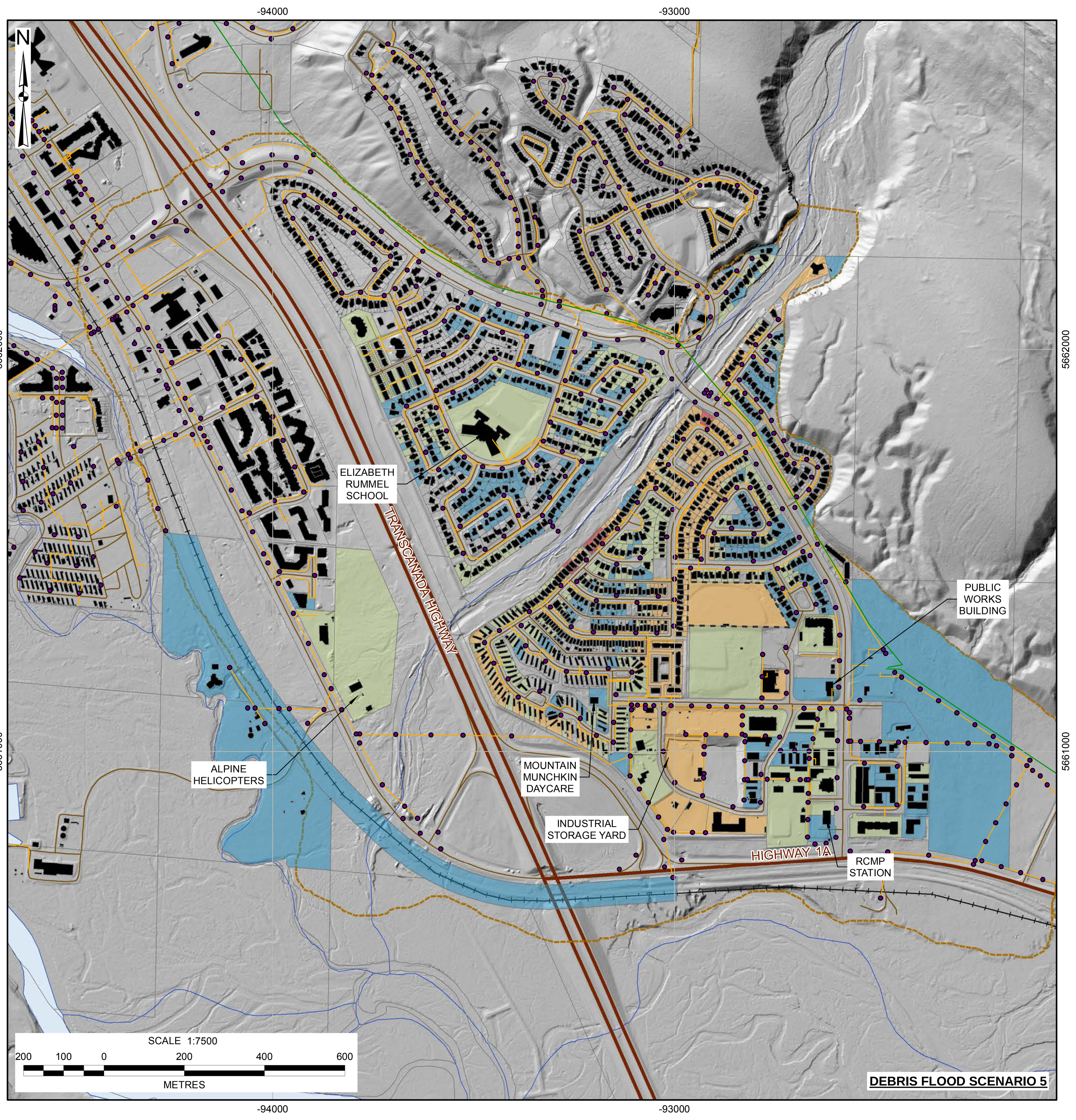
DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD HAZARD ASSESSMENT" DATED JUNE 2014

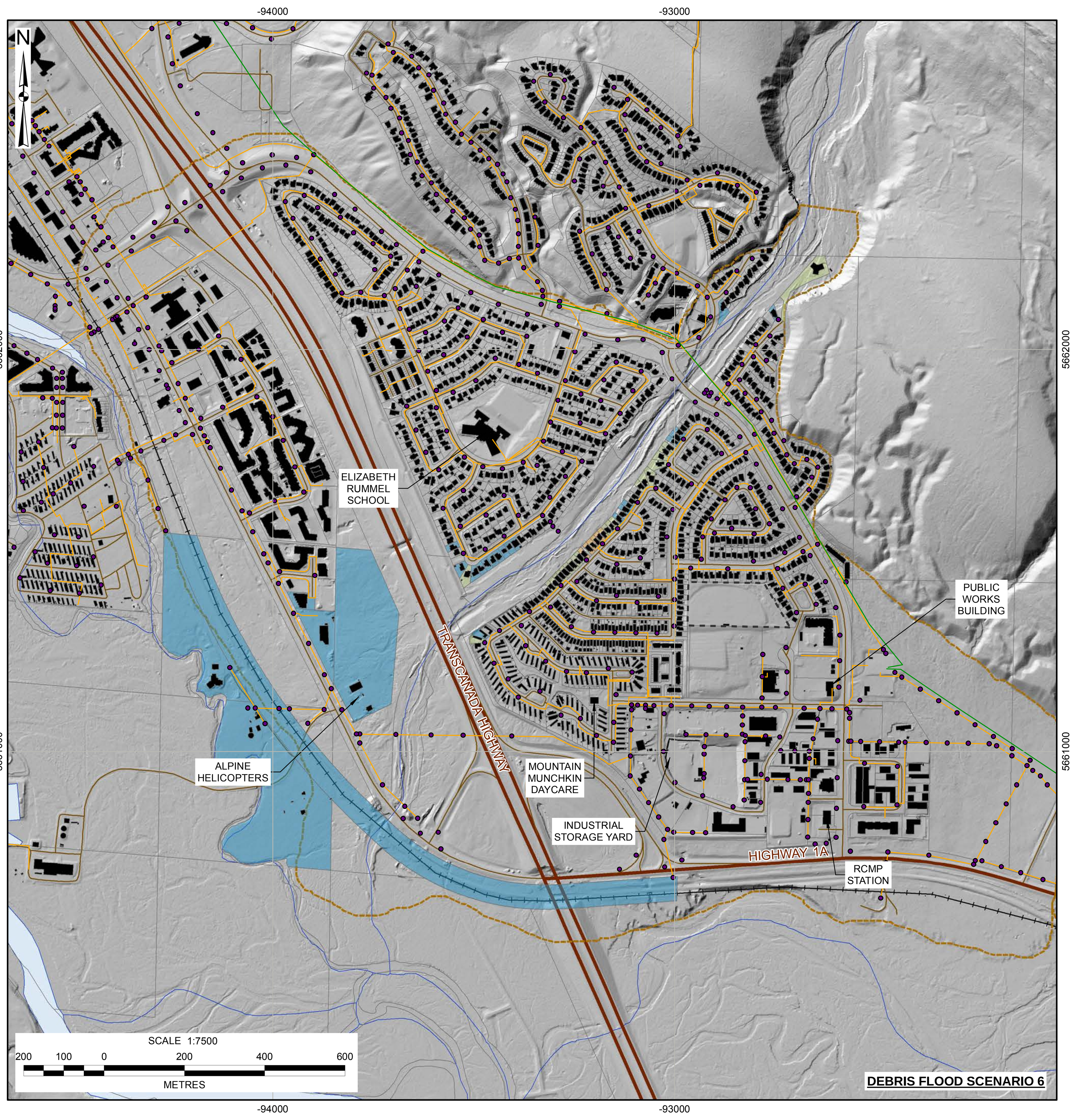












LEGEND

- ELECTRICAL CONDUCTOR LINE (138KV)
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- OLD GARBAGE DUMP
- BUILDING
- PARCELS

BUILDING DAMAGE

- MODERATE DAMAGE (>0-25%)
- MAJOR DAMAGE (>25%-75%)
- SEVERE DAMAGE (>75%-90%)
- DESTRUCTION (>90%)

- FAN BOUNDARY
- ROAD
- HIGHWAY
- RAILWAY
- WATERCOURSE
- WATERBODY

NOTES:
1. MODEL RUNS (DEBRIS FLOOD SCENARIOS) ARE LABELLED IN THE LOWER RIGHT HAND CORNER OF EACH MAP INSET.
2. RESULTS ARE SHOWN AT THE PARCEL LEVEL OF DETAIL.
3. SEE THE REPORT FOR METHODS AND LIMITATIONS OF BUILDING DAMAGE ESTIMATES.
4. PARCELS AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
5. WATERCOURSE, WATERBODY, AND RAILWAY WERE OBTAINED FROM CANVEC.
6. HILLSHADE WAS DERIVED FROM LIDAR RECEIVED FROM TOWN OF CANMORE, JULY 2013.
7. THIS MAP SHOULD NOT BE RELIED UPON AT A SCALE LARGER THAN (MORE DETAILED) THAN SHOWN ON THIS MAP.
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REV.	DATE	REVISION NOTES	DRAWN	CHECK	APPR.

SCALE: 1:7,500
DATE: JUN 2014
DRAWN: GLT
DESIGNED: KH, MJ
CHECKED: MJ, HW, KH
APPROVED: MJ, HW

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: TOWN OF CANMORE

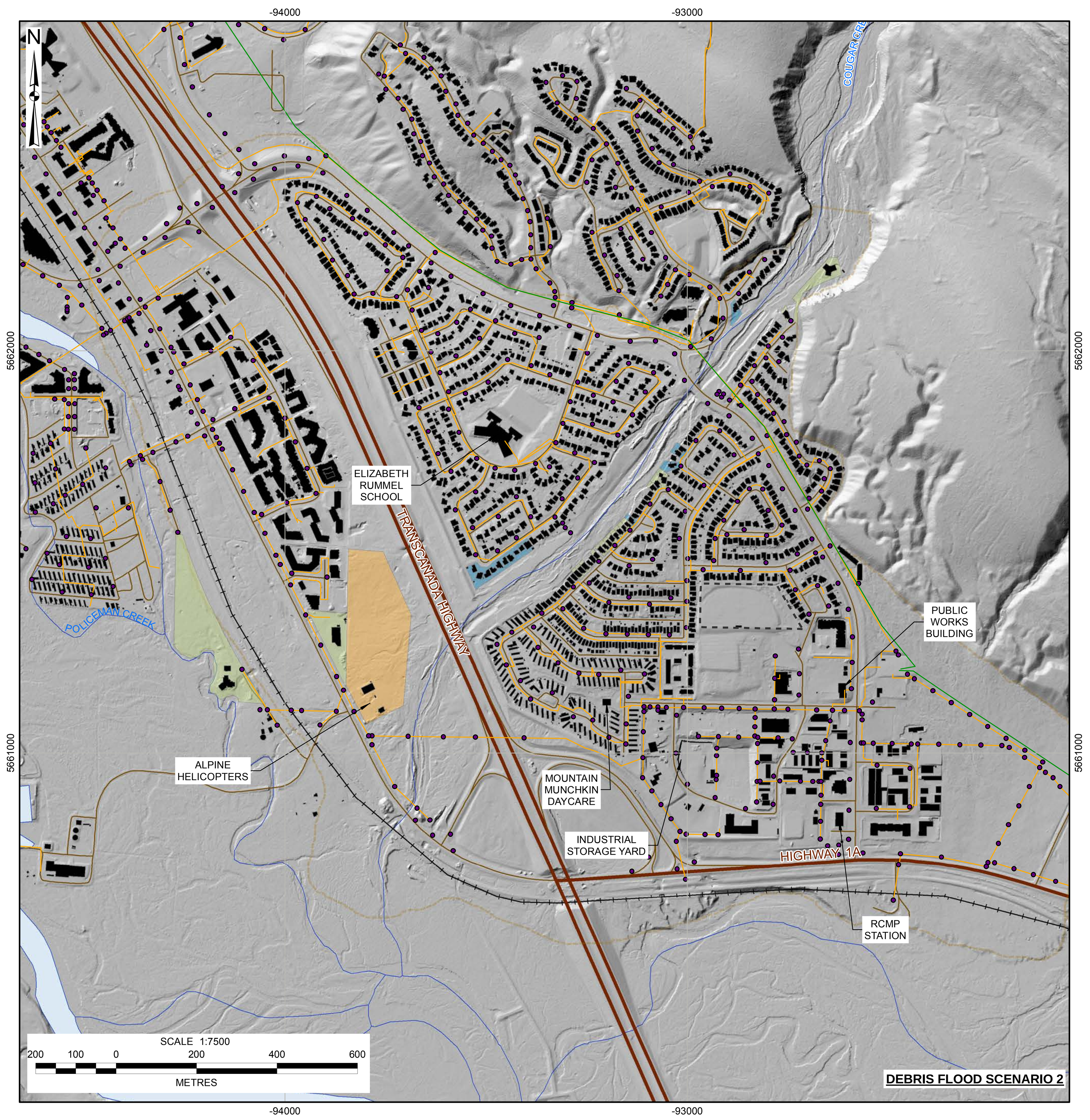
3TM

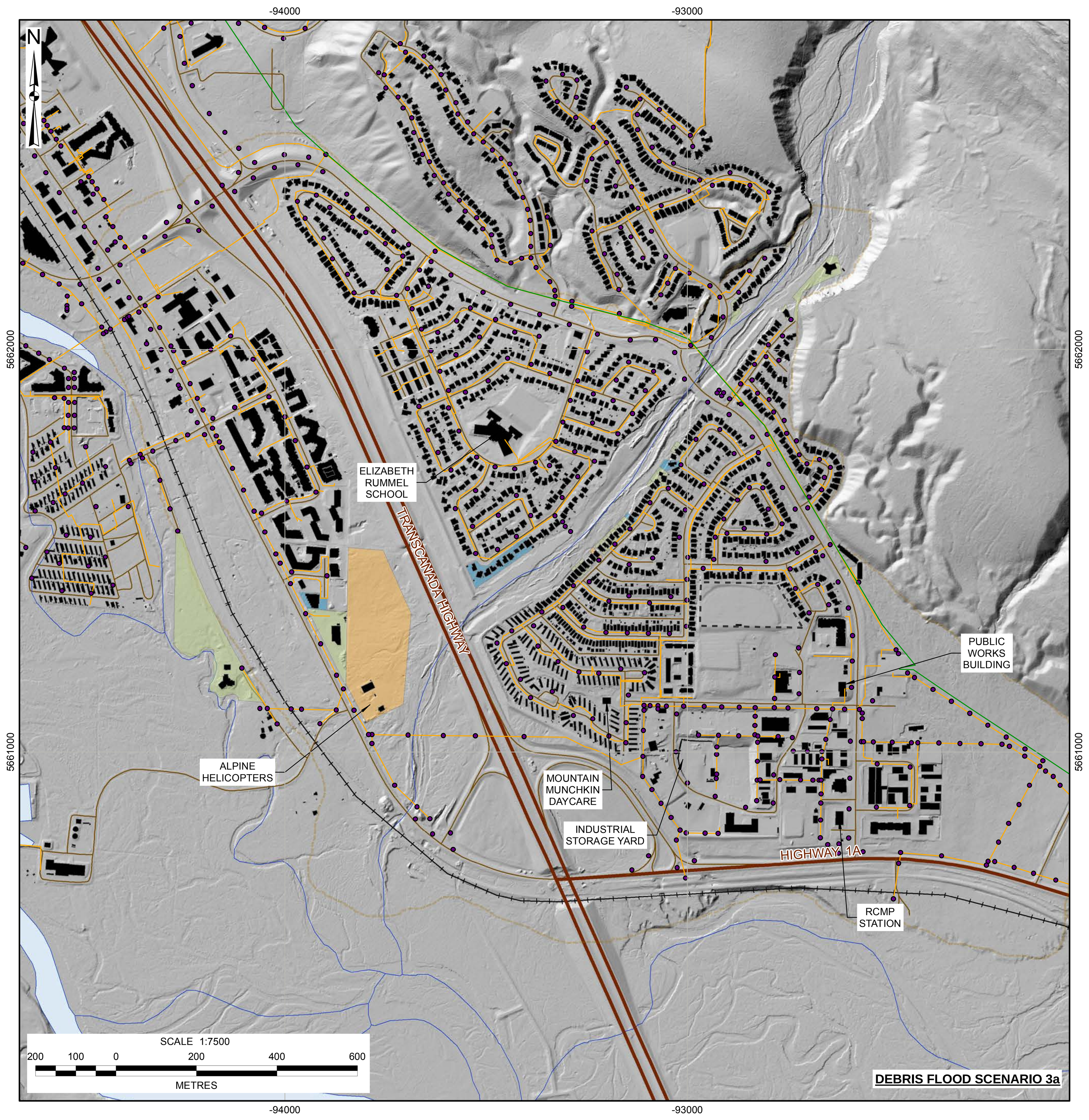
PROJECT: COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

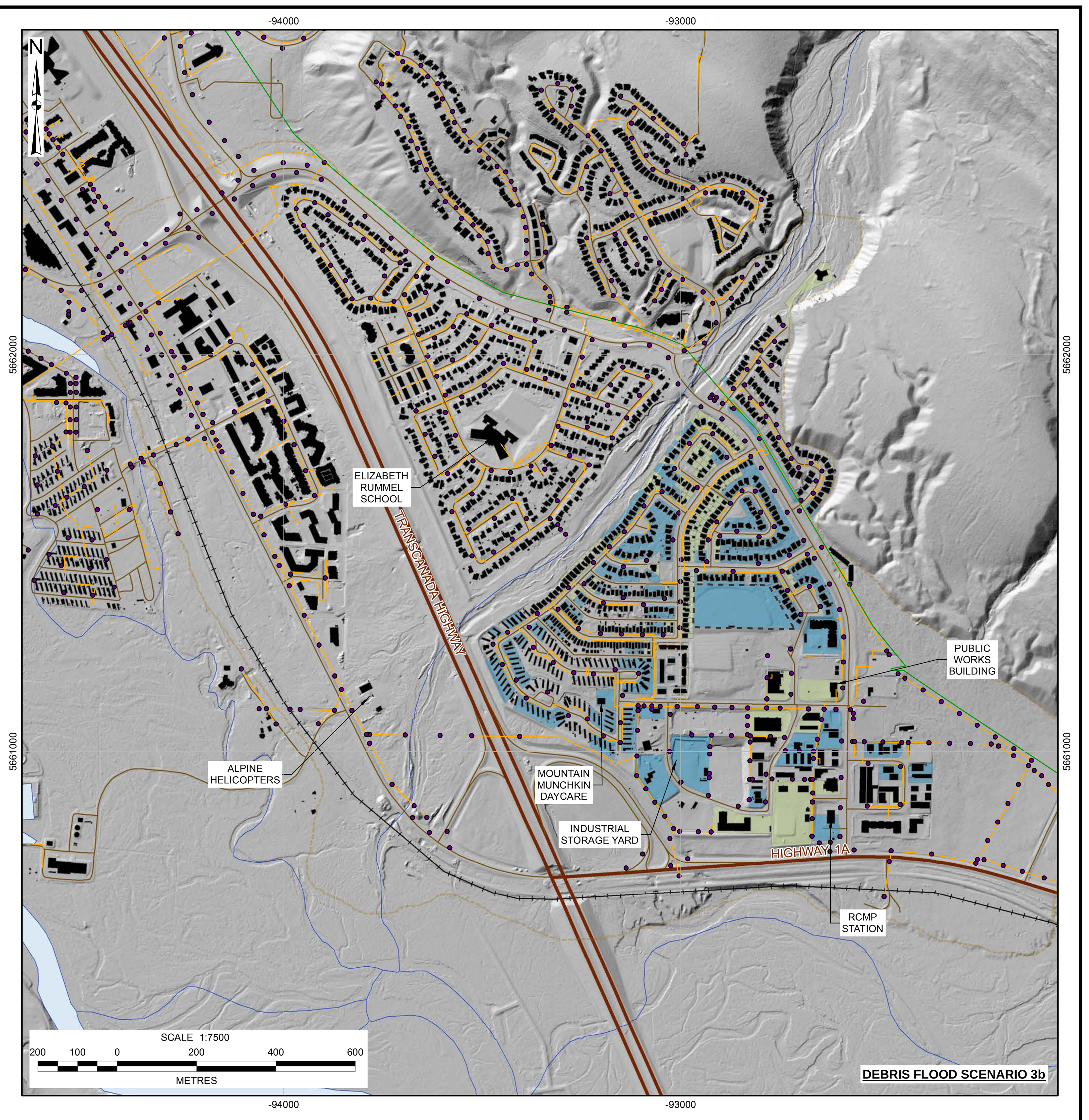
TITLE: DIRECT DAMAGE LEVELS, BUILDINGS: DEBRIS FLOOD SCENARIOS 2-6

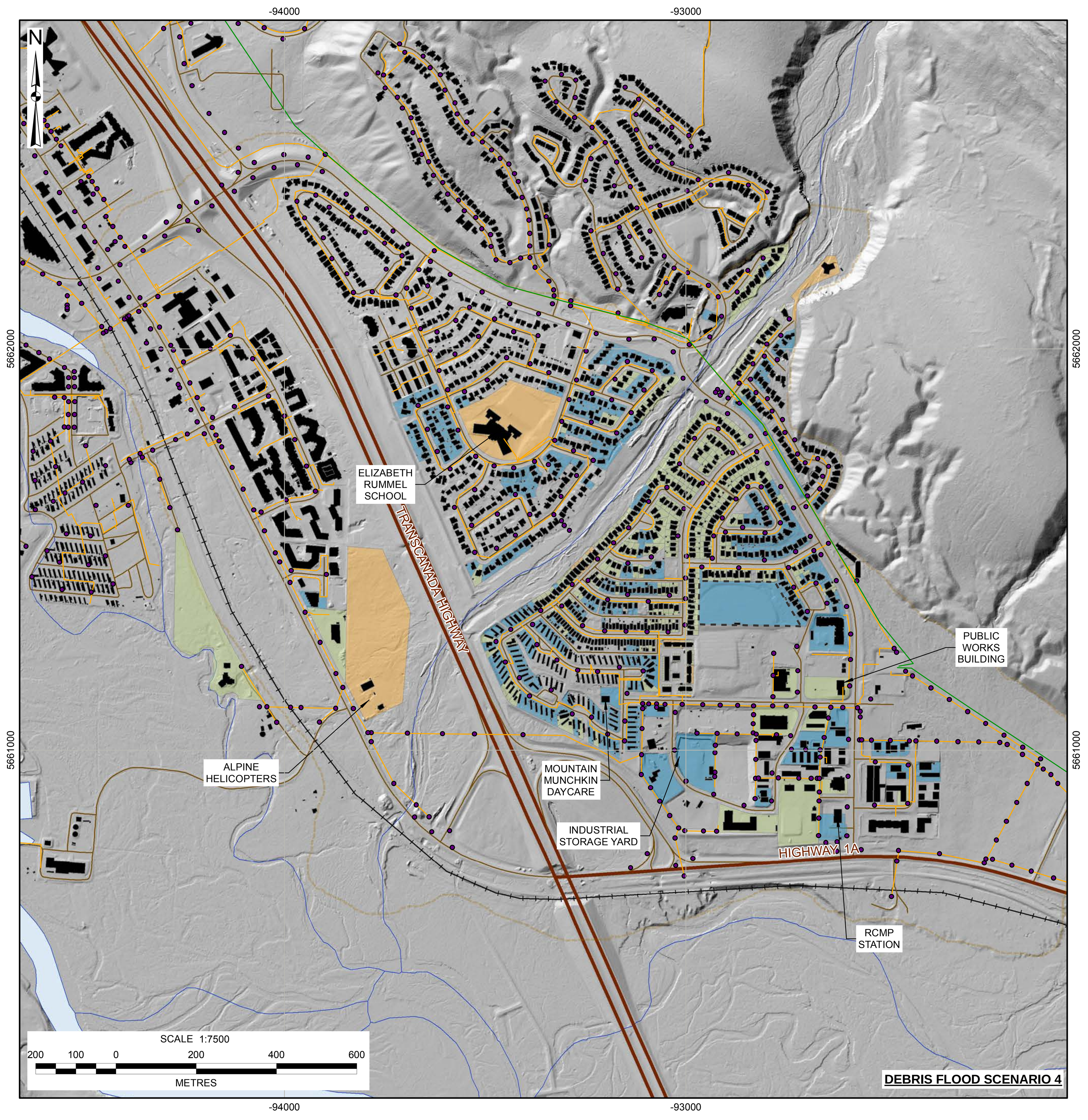
PROJECT No.: 1261001
DWG No.: 06
REV.:

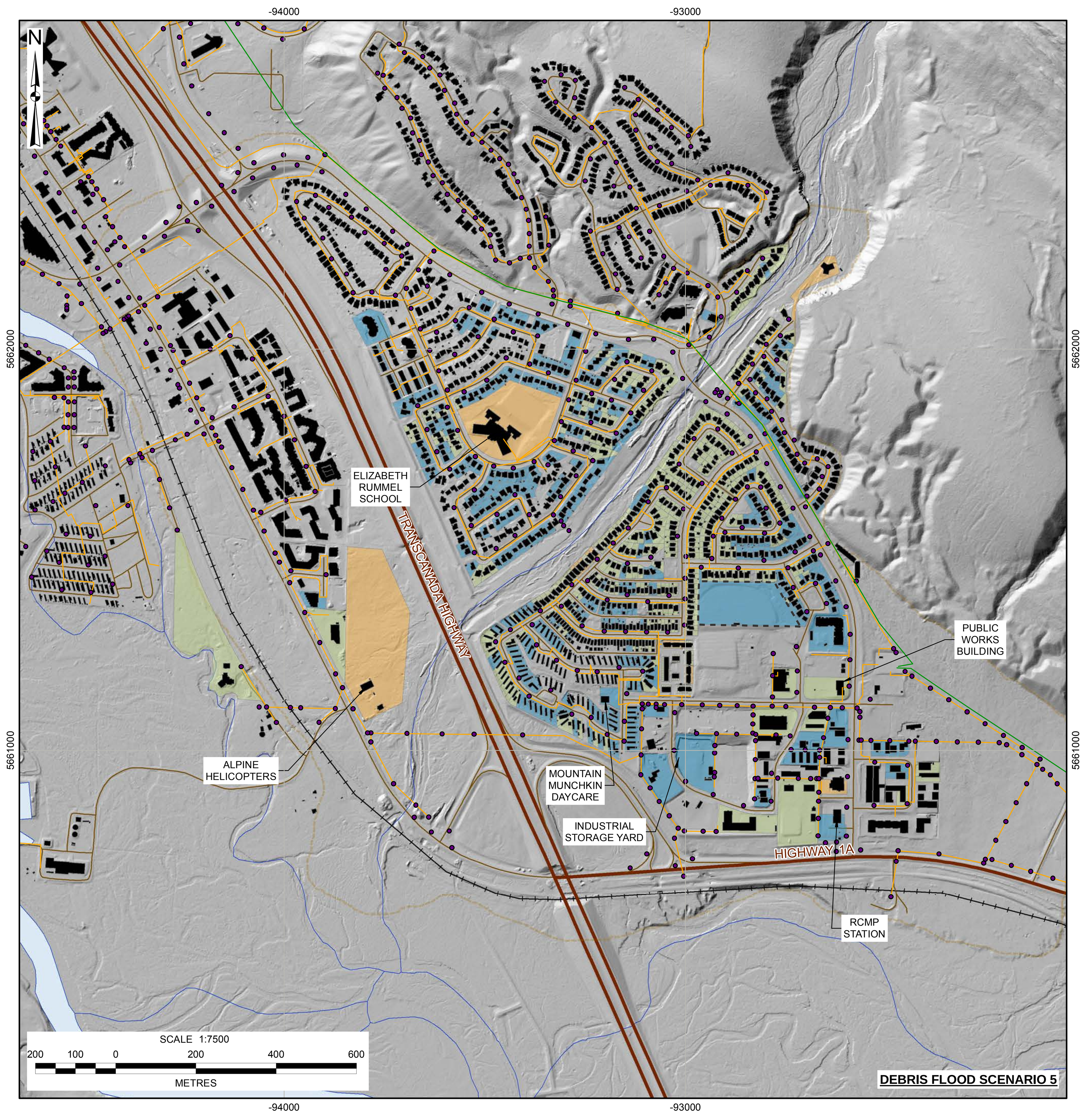
DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT" DATED JUNE 2014

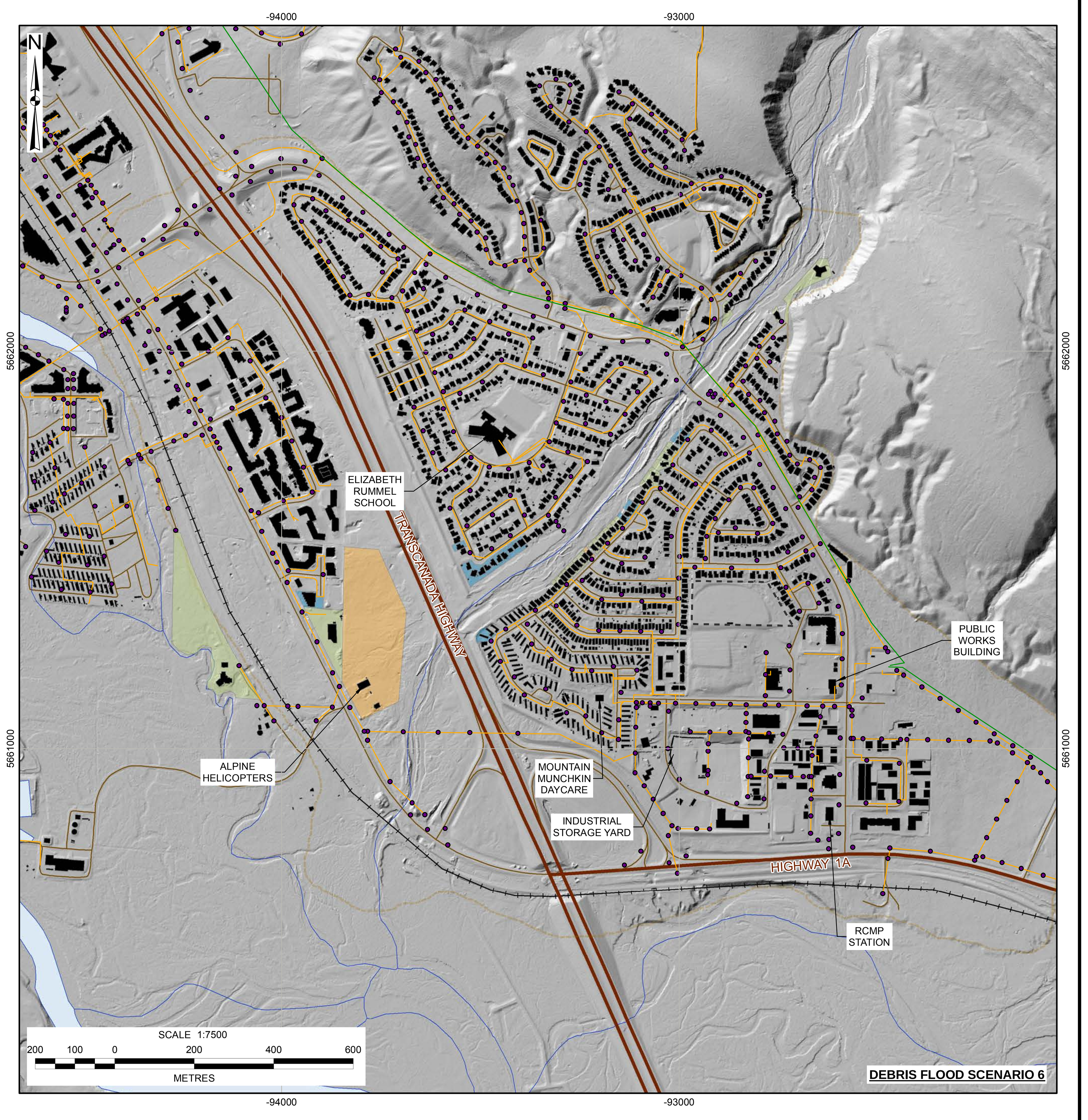












LEGEND

- ELECTRICAL CONDUCTOR LINE (138KV)
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- OLD GARBAGE DUMP
- BUILDING

BUILDING DAMAGE COST

- ≤$0.1M DAMAGE
- >$0.1M TO $1M DAMAGE
- >$1M TO $10M DAMAGE
- >$10M DAMAGE

- FAN BOUNDARY
- ROAD
- HIGHWAY
- RAILWAY
- WATERCOURSE
- WATERBODY

NOTES:
1. MODEL RUNS (DEBRIS FLOOD SCENARIOS) ARE LABELLED IN THE LOWER RIGHT HAND CORNER OF EACH MAP INSET.
2. RESULTS ARE SHOWN AT THE PARCEL LEVEL OF DETAIL.
3. SEE THE REPORT FOR METHODS AND LIMITATIONS OF BUILDING DAMAGE COST ESTIMATES.
4. PARCELS AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
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3TM

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SCALE:	1:7,500
DATE:	JUN 2014
DRAWN:	LL, GLT
DESIGNED:	MJ, KH
CHECKED:	MJ, HW, KH
APPROVED:	MJ, KH

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: TOWN OF CANMORE

PROJECT: COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

TITLE: DIRECT DAMAGE COSTS, BUILDINGS: DEBRIS FLOOD SCENARIOS 2-6

PROJECT No.:	DWG No.:	REV.:
1261001	07	

DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT" DATED JUNE 2014

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SCALE 1:5,000

100 50 0 100 200 300

METRES

NOTES:

1. SEE THE REPORT FOR METHODS AND LIMITATIONS OF INDIVIDUAL RISK ESTIMATES.
2. "PDI" CORRESPONDS TO "PROBABILITY OF DEATH OF AN INDIVIDUAL".
3. RESULTS ARE SHOWN AT A PARCEL LEVEL OF DETAIL AND CONSIDER ONLY PERSONS INSIDE BUILDINGS.
4. PARCELS AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
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3TM

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SCALE:	1:5,000
DATE:	JUN 2014
DRAWN:	GLT
DESIGNED:	KH, MJ
CHECKED:	KH, MJ, HW
APPROVED:	KH, MJ

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: CANMORE

PROJECT: COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

TITLE: RISK TO INDIVIDUALS: DEBRIS FLOOD SCENARIOS 2-5

PROJECT No.:	DWG No.:	REV.:
1261001	08	

DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT" DATED JUNE 2014

(LIDAR 2013)
3TM

SCALE 1:5,000
100 50 0 100 200 300
METRES

NOTES:
1. SEE THE REPORT FOR METHODS AND LIMITATIONS OF DAMAGE LEVEL ESTIMATES.
2. RESULTS ARE SHOWN AT A PARCEL LEVEL OF DETAIL.
3. PARCELS AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
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SCALE:	1:5,000
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CHECKED:	KH, MJ, HW
APPROVED:	KH, MJ

PROFESSIONAL SEAL:

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Town of CANMORE

PROJECT:
COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT

TITLE:
COMPARISON OF RECORDED BUILDING DAMAGE (JUNE 2013) TO PREDICTED DAMAGE, DEBRIS FLOOD SCENARIO 6

PROJECT No.:	DWG No.:	REV.:
1261001	09	

DWG TO BE READ WITH BGC REPORT TITLED "COUGAR CREEK DEBRIS FLOOD RISK ASSESSMENT" DATED JUNE 2014