BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

TOWN OF CANMORE

PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

FINAL

PROJECT NO.:	1261014	DATE:	September 27, 2016

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September 27, 2016
Project No.: 1261014

Mr. Andy Esarte, P.Eng.
Town of Canmore
Canmore Civic Centre
Canmore, AB T1W 3K1

Dear Mr. Esarte,

Re: Pigeon Creek Debris-Flood Risk Assessment – FINAL

Please find enclosed our above reference final report dated September 27, 2016.

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 this project.

Yours sincerely,

BGC ENGINEERING INC.
per:

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

EXECUTIVE SUMMARY

On June 19 and 20, 2013, extreme rainfall events in southeastern Alberta initiated flooding, debris floods and debris flows in the Bow River valley between Seebe and Banff National Park, 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 TetraTech EBA (EBA) to assess Pigeon Creek debris-flood hazards (EBA 2016). Subsequently, Canmore retained BGC Engineering Inc. (BGC) to complete a debris-flood risk assessment for Pigeon Creek.

This report presents methods and results of the 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 life loss risk and economic risk on Pigeon 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 risk to life (safety risk) due to impact by different debris-flood scenarios for persons located within buildings.
3. Compare estimated safety risk to international risk tolerance standards.

BGC assessed risk associated with 14 debris-flood scenarios representing a range in debris-flood return periods classes from 10 to 30 years to 1000 to 3000 years as presented in TetraTech EBA (EBA)'s Pigeon Creek Hazard Assessment (2016) and in accordance with the Draft Alberta Guidelines for Steep Creek Risk Assessments. 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 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.

[1] E.g., International standards for safety risk (Section 3.2) and/or standards set by Canmore.

Loss potential is based on EBA's numerical runout models and does not consider auxiliary hazards such as bank erosion or channel bed aggradation that may jeopardize existing and future mitigation works.

Estimated direct damage costs to buildings for individual scenarios ranged from $4.5 million (M) to $7.9 M depending on the scenario[2]. BGC's estimate of annualized building damage cost for all scenarios is about $440,000/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 interruption. As such, they should be considered a minimum loss potential cost. These factors, if considered, would increase annualized damage costs.

Annual business revenues in impacted areas range from $5.0 M to $6.8 M (75% to 100% of the total revenues of all business in the study area) depending on the scenario. Note that this should be considered a proxy for the level of business revenue in impacted areas, not an estimate of total economic loss, since revenue data was not available for all business, and the duration and severity of business loss is unknown and very challenging to quantify in detail. Furthermore, this value does not consider inventory (e.g., economic loss due to loss of product stockpiles at Thunderstone Quarry).

BGC identified one parcel 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 extends into the "As Low As Reasonably Practical (ALARP)" range when compared to international risk tolerance standards.

[2] Excludes Scenario 2B (see Section 4.2 for a discussion of this scenario).

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LIMITATIONS

BGC Engineering Inc. (BGC) prepared this document for the account of 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 TetraTech EBA (EBA) to assess Pigeon Creek debris-flood hazards (EBA 2016). Subsequently, Canmore retained BGC Engineering Inc. (BGC) to complete a debris-flood risk assessment for Pigeon Creek (Drawing 01). The work was based on BGC's proposal and work plan dated March 28, 2016 and completed under the Town of Canmore/BGC Master Consulting Agreement dated July 15, 2013 as per the award letter dated May 11, 2016.

Pigeon Creek fan is inter-jurisdictional (Drawing 01), with portions south of the TransCanada Highway being located within the Town of Canmore boundaries and lower portions within the Municipal District of Bighorn No. 8 (MD of Bighorn).

Previous work for Pigeon Creek includes a forensic assessment of the June 2013 debris flood (BGC 2013) and a hazard assessment (EBA 2016). EBA (2016) identified and characterized debris-flood scenarios across a wide range of frequencies and magnitudes following the same framework as completed for previous hazard assessments in the Canmore area. The reader should refer to the EBA (2016) report for background description of the physical and hydroclimatic setting of Pigeon Creek and the hazard assessment methodology and results. Two recent detailed studies (Liu et al., 2016, Pomeroy et al, 2016) summarize the hydroclimate and meteorology of the June 2013 events.

This report presents methods and results of the debris-flood risk assessment. The primary objective of this work is to support decisions and expenditures to reduce debris-flood risk on Pigeon Creek fan to levels considered tolerable by Canmore and its stakeholders.

Table 1-1 summarizes the scope of work.

Table 1-1. Work tasks.

Task	Work Component	Description and Method
1	Project management (budget tracking, communications, etc.)	• Project management, contract administration, client liaison, scope development.
2	Data Collection	• Compile debris-flood velocity and flow depth and peak flow, results from EBA's hazard assessment • Obtain proposed infrastructure data • Digitize Rivers Bend development plan (parcels, buildings, road and utilities) from CAD file to GIS shapefile • Organize buildings' infrastructure data into a format suitable for analyses (i.e., georeferenced shapefiles of elements at risk with attributes that can be joined to assessment data). • Update existing GIS linked database containing spatial and buildings infrastructure information with proposed infrastructure.
3	Data Processing	• Process EBA hazard analysis results for each hazard scenario into a format suitable for risk analysis • Discuss which scenarios (i.e., culvert capacity exceeded) will be included in risk analysis with Canmore • Complete spatial analysis assigning estimated debris-flood intensities to buildings or parcels in impact zones.
4	Risk Calculations (Loss of Life, Economic Risks)	• Characterize geohazard risk scenarios as debris-flood scenarios resulting in consequences • Estimate risk parameters including spatial and temporal probability of impact, and vulnerability of elements at risk, for different debris-flood scenarios and types of elements at risk • Combine risk parameters to estimate risk to life and levels of building damage, and associated direct building damage costs, for different debris-flood scenarios • Provide baseline levels of risk that can support future development planning (Phase 2).
5	Reporting (DRAFT/FINAL)	• Describe methodology and results • Compare estimates of risk to life to international risk tolerance thresholds • Present results in tabular and map format • Integrate Draft review comments into Final report • Meet in Canmore to present results (optional).

This assessment considers key debris-flood risks that can be systematically estimated, compared to risk tolerance standards adopted on an interim basis[3] in Canmore for steep creeks risk management, and then used to select and optimize mitigation strategies. This report does not include any assessment of risk associated with Bow River flooding. The results of this assessment should be considered as a snapshot in time, subject to periodic review in light of future changes (e.g., new development, debris flood mitigation, hydroclimatic and landslide events, and climate change-related changes in runoff and sediment movements).

The major steps in this assessment are to:

1. Identify debris-flood risk scenarios with potential to result in life- or economic losses.
2. Estimate risk to life due to debris-flood impact.
3. Estimate economic losses resulting from debris-flood impact.

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 Section 5.0.
- Appendix A shows debris-flood hazard intensity mapping based on modelling completed by EBA (2016).
- Appendix B describes hazard events occurring elsewhere, for comparison to Pigeon Creek.

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*

[3] Canmore does not currently have legislated geohazard risk tolerance standards. Those cited in this study reflect international risk tolerance standards used on an interim basis by Canmore for risk management planning.

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 Pigeon Creek fan (Drawing 01).

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 analysis (BGC 2013) and EBA's hazard assessments (EBA 2016) document the results of the first two phases of the risk management framework for Pigeon Creek. This report documents the third and fourth phase of the risk management framework for Pigeon Creek.

<table>
<tr><td rowspan="6"><u>Risk Communication and Consultation</u>
By way of maps, reports, signage, warning systems, public meetings, and educational materials</td><td>1. Project Initiation
a. Recognize the potential hazard
b. Define the consultation zone (study area) and level of effort
c. Define roles of the client, regulator, stakeholders, and QRP
d. Determine 'key' risks to be considered in the assessment</td><td rowspan="6"><u>Land Management Planning and Regulation</u>
Ongoing review of the risk management process for land use and development permitting</td></tr>
<tr><td>2. Hazard Assessment
a. Identify and characterize the hazard
b. Develop a hazard frequency-magnitude relationship
c. Identify hazard scenarios to be considered in risk estimation
d. Estimate hazard extent and intensity parameters for each scenario</td></tr>
<tr><td>3. Risk Assessment
a. Characterize elements at risk and determine vulnerability criteria
b. Estimate risk: the probability that hazard scenarios will occur, impact elements at risk, and cause particular consequences.</td></tr>
<tr><td>4. Risk Evaluation
a. Compare the estimated risk against tolerance criteria
b. Prioritize risks for risk control and monitoring</td></tr>
<tr><td>5. Risk Control
a. Identify options to reduce risks to levels considered tolerable.
b. Select option(s) providing the greatest risk reduction at least cost</td></tr>
<tr><td>6. Action
a. Implement chosen risk control options
b. Define ongoing monitoring and maintenance requirements</td></tr>
</table>

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

For this assessment, Canmore has 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. It also follows procedures outlined in the Draft Alberta Guidelines for Steep Creek Risk Assessments (AEP 2015).

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 EBA's Pigeon Creek hazard assessment (EBA 2016).

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.

2.0 DATA COMPILATION

Data required to assess the risk of debris floods in the Pigeon Creek study area 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 EBA's Pigeon Creek hazard assessment (2016). 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 reviewer[4]. 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 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 Pigeon Creek debris-flood risk assessment.

Element at Risk[1]	Description
Building Structures	Commercial, industrial, recreational, residential
Persons	Persons located within buildings
Roads	Local roads, Highway 1
Utilities	Sewerage, stormwater management, gas distribution, electrical power and telephone line distribution.
Critical facilities	Sewage treatment facility
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.

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

2.1.1. Buildings

Information on buildings within the study area was provided by the MD of Bighorn via Canmore within data compiled for each parcel (property boundary). The locations of existing buildings (building footprints) were digitized by Challenger Geomatics (Challenger) from orthophotos

[4] Dr. Norbert Morgenstern

obtained in the Spring of 2008 (Challenger 2014). The locations of parcels within the approved and partially constructed River's Bend Development were provided by MD of Bighorn via Canmore. Approximate building footprints within the River's Bend development were digitized by BGC at the center of each parcel. Locations of townhouses within lot 37 of the River's Bend Development were digitized from building outlines provided by Canmore. The location of the Thunderstone Quarry workshop was also digitized by BGC from Google Earth imagery. These data were used in the risk analysis to identify location(s) of buildings within parcels that could be impacted by debris-flood scenarios.

The hamlet of Dead Man's Flats occupies the northwest and central portion of Pigeon Creek fan. The area was initially developed as a commercial centre followed by residential development of an approximately 50-unit condominium constructed in 1992 and the recent approval and construction of the River's Bend Development. In 2013, an Area Structure Plan was completed and development is proceeding for a 78-unit residential and light industrial subdivision (MD of Bighorn 2016).

Building types on the fan include apartments (fewer than 5 stories), commercial, or industrial buildings. Single family-dwellings and townhouses are currently under construction in the River's Bend development. Risk to campers in tents, trailers or mobile homes at the Three Sisters Campground located on the northwest end of the Pigeon Creek fan was not included in the scope of work.

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, therefore this analysis does not consider building contents or differentiate building types.

For lots in the River's Bend Development without improvement values (i.e., under construction or vacant), BGC assumed that the improvement value of each lot had an appraised value similar to the average appraised improvement value in the River's Bend Development. Accordingly, PIDs PID's 2730829 to 2765110 without an improvement value were assigned a value of $426,000. Lot 37 in the Rivers Bend Development (PID 2765076) was assigned an improvement value of $6,412,000, which corresponds to an estimated building value of $229,000 for the 28 proposed townhomes on this lot.

In total, about $71 M of assessed buildings infrastructure is located within 146 parcels in the Pigeon Creek study area, including the fully constructed Rivers Bend Development (based on current development plans). The values listed above do not include building contents or inventory and do not necessarily correspond to replacement cost, which may be higher. As such, damage costs estimated from these values should be regarded as minimum.

Thunderstone Quarry occupies the southwest portion of the Pigeon Creek fan apex. The quarry includes a main workshop, outbuildings, and several product stockpiles.

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

Table 2-2. Building data uncertainties.

Type	Description
Building Value	Several buildings did not include improvement values. For these PIDs, the improvement value was estimated based on the following: 1) PIDs 2315939 and 2438860 are aggregations of multiple Land Identification Numeric Codes (LINC). The assessment values for these PIDs are a sum of all LINC codes on the parcel. 2) PIDs 419650 and 419651 land and improvement values from MD of Bighorn (pers. comm. Ulrika Gillespie, MD of Bighorn, May 17 2016). 3) PID 431946 is Thunderstone Quarry. The building assessment value for this PID was assumed to be 80% of the land value.
Parcel Lookup Code (Building Use)	Based on communication with MD of Bighorn and Canmore, the vast majority of the parcel lookup codes are correctly assigned, but some errors may exist. For Thunderstone Quarry, the building use code was manually adjusted from Vacant (VAC1) to Industrial/Outdoor Storage Yard (IND3). BGC has not reviewed the accuracy of remaining parcels data provided by MD of Bighorn and 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. Critical Facilities

Critical facilities are defined in guidelines developed for new facilities funded by Alberta Infrastructure (Alberta Infrastructure 2013) as those that:

- Provide vital services in saving and avoiding loss of human life
- Accommodate and support activities important to rescue and treatment operations
- Are required for the maintenance of public order
- House substantial populations
- Confine activities that, if disturbed or damaged, could be hazardous to the region (Alberta Infrastructure 2013)
- Contain hazardous products or irreplaceable artifacts and historical documents.

The only critical facility identified in the Pigeon Creek study area was a sewage treatment facility located on the lower north edge of the fan (Drawing 02).

Table 2-3 summarizes the types of critical facilities described in Alberta Infrastructure (2013). The table also shows the design flood levels cited by Alberta Infrastructure that should be protected against for such facilities. The only critical facility identified in the Pigeon Creek study area was a sewage treatment facility located on the lower north edge of the fan (Drawing 02).

Table 2-3. Critical Facilities (modified after Alberta Infrastructure 2013).

Class	Importance of Avoiding Major Damage During a Flood Emergency	Design Flood Level	Examples of Facilities
1	Critical to the ability to save and avoid loss of human life.	1:1000	Legislative buildings Communication centres
2	Critical to the ability to rescue and treat the injured and to prevent secondary hazards.	1:1000	Hospitals and medical facilities Extended care facilities
3	Critical urban linkages important to the maintenance and welfare of public order and welfare.	1:500	Courthouses Provincial Buildings
4	Critical to the ongoing housing of substantial populations.	1:500	Schools Post-secondary educational facilities Seniors Residences High-rise buildings Correctional facilities Rehabilitation treatment centres
5	Critical to the orderly return to long term social and economic welfare.	1:500	Airports
6	Important to the ability to avoid endangering human life and environment.	1:1000	Hazardous waste disposal and treatment facilities High risk research facilities
7	Important to retention of documented historical data and artifacts.	1:1000	Museums, archives, cultural centres

2.1.3. Persons

Population estimates used in this assessment are based on 2011 Census data (Statistics Canada 2011), dwelling counts from tax roll classification data (Municipal Affairs 2014), business data (Hoovers 2016), business websites (e.g., Copperstone Resort, 2016 and Bed Breakfast Home, 2011) and by BGC staff contacting businesses directly (pers. comm. May 17, 2016).

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. Estimated population results for the study area were then compared to census totals to ensure they fell within a reasonable range. Steps to complete this population estimate are described below.

First, BGC estimated the number of building units based on a combination of parcel land usage and property class codes. Second, BGC estimated the number of occupants per building unit.

Permanent residential occupancy rates were based on 2011 Census data. 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. Individual unit occupancy rates were calibrated so that the total population estimate for the Pigeon Creek study area corresponded approximately to 2011 Census totals for the same area. 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.

According to 2011 Census data, a population of 121 people occupy 75 dwellings in Dead Man's Flats[5]. For the purposes of risk assessment, it was assumed that two people occupy each dwelling in the River's Bend Development and in each of the 22 residences at Pigeon Creek Condos (PID 2438860). This assumption is consistent with the average number of persons in private households in Dead Man's Flats (Statistics Canada, 2011). Approximately 63 persons also work in private businesses on the fan.

Visitors staying in the campground were not considered in this assessment. Population estimates for hotels and motels on the fan were based on an occupancy rate of 1.5 people for guests on the main floor where debris flood impacts may occur for the following three accommodations:

- Copperstone Resort Hotel (PID 2315939) - 54 guest rooms, assumed 27 on the main floor
- Big Horn Motel (PID 419606) - 27 guest rooms, 11 rooms on the main floor
- Kiska Inn Bed and Breakfast (PID 419652) - 6 guest rooms, assumed 4 on the main floor.

Table 2-4 summarizes calculated populations used in the risk analysis and data sources for population estimates. Note that these values should not be summed because some population types overlap (e.g., students or workers might also live on the fan).

Table 2-4. Summary of calculated population estimates used in risk analysis.

Population Type	Population Total	Source
Residents	109	Calibrated to 2011 Census Data (121 people)
Residents (fully constructed Rivers Bend Development)	192	Based on occupancy rate of 2 people per dwelling
Employees (Pigeon Creek Fan)	38	Hoovers D&B (2016)
Employees (Thunderstone Quarry)	15	Thunderstone Quarry via Canmore
Total	**364**	

[5] Referred to as Pigeon Mountain in Statistics Canada data.

These calculated population estimates, while systematically compiled from the best available data, are subject to uncertainties listed in Table 2-5.

Implications of the uncertainties listed in Table 2-5 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 confirmed with building occupants.

Table 2-5. Uncertainties associated with estimating the number of occupants of a building.

Uncertainty	Implication
Average occupancy rates may not correspond to actual occupancy rates for a given dwelling unit.	Over- or underestimation of occupant numbers
Seasonal population fluctuations exist that were not accounted for.	
Errors in employee data sourced from Dunn and Bradstreet (D&B) (Hoovers 2016) may exist. These data were not verified by BGC.	
Errors in assignment of D&B employee data to specific parcels may exist, due to inconsistencies in building address data.	
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.	Uncertainty in estimation of human vulnerability to debris-flood impact
Seasonal visitors may occupy private residences, and additional temporary visitors occupy restaurants, shops, and professional services.	Underestimation of occupant numbers

2.1.4. Roads

Roads considered in the assessment include municipal roads on Pigeon Creek fan (1st Avenue, 2nd Avenue, 2nd Street, 3rd Street, George Biggy Sr. Road), Highway 1. The southeast and southwest ramps from Highway 1 to George Biggy Sr. Road and Three Sisters Campground access road were also considered in the assessment (Drawing 02).

2.1.5. Utility Systems

Utility systems located on Pigeon Creek fan are shown on Drawing 01 and include the following:

- Gas distribution infrastructure controlled by Alta Gas
- A buried pipeline operated by ATCO Gas
- MD of Bighorn sewage treatment facility
- Electrical transmission managed by Fortis Alberta and Altalink.[6]

[6] Assumed to also carry telephone cables.

2.1.6. Business Activity

Business activity considered in this assessment includes public and private employers with their primary address located on Pigeon Creek fan. Employer data are based on information compiled by the commercial information provider Dunn and Bradstreet (D&B) (Hoovers 2016), as well as communication with Canmore. Business data sourced from D&B (Hoovers 2016) was linked to parcel locations using Google Maps imagery.

In summary, nine employers are located on the fan of Pigeon Creek generating about $1.82 (CAD) M/year and employing approximately 48 people (Hoovers 2016). In addition, Thunderstone Quarry (located on the west bank of Pigeon Creek) employs 15 people on site from 8 am to 5 pm Monday to Friday. The annual business revenue of Thunderstone Quarry is $4-5 (CAD) M/year (pers. comm. Canmore, April 13, 2016).

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. For example, the Esso gas station and Thunderstone Quarry were not included in the business data sourced from D&B (Hoovers 2016), however were observed in the imagery (Google Street View). As such, business activity impacts listed in this report are likely underestimated and should be considered a minimum. Table 2-6 summarizes uncertainties associated with the data. In addition to the uncertainties listed in Table 2-6, 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.

Table 2-6. Business data uncertainties.

Type	Description
D&B data quality	BGC has not reviewed the accuracy of business data obtained for this assessment, where data was provided.
Worker location	Whether the employee primarily works at the office or some other location is 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).

2.2. Debris-Flood Scenarios

This section describes the different debris-flood scenarios that fed into the consequence and thus, risk assessment. The 2013 debris flood has been used as a basis to calibrate the risk model with observed damages and life loss.

2.2.1. June 2013 Debris Flood

BGC's forensic report (BGC 2013) described the storm and resulting debris flood that occurred on Pigeon Creek between June 19 and 21, 2013. Table 2-7 summarizes damages recorded, with costs summarized in Table 2-8 based on data provided August 28, 2014 by MD of Bighorn.

The costs summarized in Table 2-8 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), other workers (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 Pigeon Creek as a result of the June 2013 debris flood.

Table 2-7. Summary of damage to Pigeon Creek fan during the 2013 debris flood.

Area	Damage
Thunderstone Quarry	• Flooding and damage to the south side of the main workshop; a major volume of fine sediment had to be removed from its interior. • Blockage of culverts at two locations with large woody debris and sediment which redirected the creek through the quarry work area. • Erosion and downstream transport of product stockpiles. • Erosion and over steepening of the fill slope for George Biggy Sr. Road.
Upstream of Highway 1 and Highway 1	• Damage to the road shoulder • Damage to pipeline requiring repairs • Aggradation at the twin culverts under both the highway off-ramp and Highway 1 resulting in creek overflows flowing down the highway ditch to the west, pooling across from the business area along 1st Avenue and flow across the TransCanada highway. • The alignment of Pigeon Creek upstream of the highway crossing shifted east and now occupies the previous ditch line of George Biggy Sr. Road (EBA 2016).
Downstream of Highway 1	• Destruction of two 2.5 m corrugated steel pipe culverts under George Biggy Sr. Road that becomes 2nd Avenue leading failure of the crossing. • Damage to the bridge that provides access to the wastewater ponds. • Damage to the townhouse development at Block 5, 300-2nd Avenue (undercut foundations and loss of deck support). • Flooding and significant sediment deposition in the River's Bend development (EBA 2016).

Table 2-8. Reported cleanup costs for Pigeon Creek fan following the 2013 debris flood (MD of Bighorn, 2014).

Work	Description	Cost
Municipal Infrastructure		
Waste water system	Repairs to lift station	$20,000
Roads/sidewalks	Repair asphalt	$10,000
Recreational facilities	Relocate playground and repair trails	$25,000
Private Infrastructure		
Townhomes	Repair to decks/entrances at two townhomes	$20,000
Industrial Infrastructure		
Thunderstone Quarry[1]	Repairs and lost product	$3,000,000 to $4,000,000
Alberta Transportation	Repair highway, culvert replacement, crossing repairs	$1,000,000
TOTAL		**$4,075,000 to $5,075,000**

Notes:
1. Reported cleanup costs for Thunderstone Quarry provided by Canmore (pers. comm. Canmore April 13, 2016).

2.2.2. Debris-Flood Scenarios used in the Risk Assessment

The risk analysis described in Section 3.0 is based on select modeled debris-flood scenarios (EBA 2016), which are defined as debris-flood events with particular characteristics and likelihoods of occurrence. For debris floods in excess of the 30-year return period, Canmore anticipates that the culvert capacity will be exceeded and additional modelling of unblocked and blocked culvert scenarios was completed by EBA (2016). The culvert blockage scenarios were established after EBA's "Issued for Review" version of hazard report (2016) based on discussions with Canmore. According to Canmore (pers. comm. Julia Eisl, Canmore, March 15, 2016), the rationale for the culvert blockage scenarios was as follows:

1. Backwater effects at the upstream ramp culverts (George Biggy Senior Rd) will likely cause the culverts to fill up.
2. The very low grades (almost zero) between 2nd Avenue and River's Bend access will likely lead to reduced flow velocity and sediment aggrades in this section. Sediment will start to aggrade and fill up culverts of River's Bend access and may successively continue upwards.

Debris-flood scenarios considered the following culvert blockage scenarios (illustrated in Figure 2-1):

- No blockage (i.e., post-2013)
- Blockage of southeast ramp, southwest ramp and Highway 1 (Scenario 1)
- Blockage of 2nd Avenue and Rivers Bend access, Highway 1 and southeast ramp remain open (Scenario 2a)

- Blockage of 2nd Avenue and Rivers Bend access, partial blockage of Highway 1 and southeast ramp (Scenario 2b).

BGC reviewed the hazard modelling and, through discussion with Canmore, identified scenarios that were considered credible and should be considered in the risk analysis. The primary factors considered in the selection of scenarios were the return period (i.e., debris-flood magnitude) and the culvert capacity. Table 2-9 lists the scenarios selected for analysis and the reasons for removal of select scenarios. Canmore elected to proceed with this recommendation by accepting BGC's work plan in the award letter dated May 11, 2016.

Figure 2-1. Location of blocked culverts considered in the Pigeon Creek hazard modelling (provided by Canmore, March 17, 2016). The south-west and south-east ramp culverts are mislabelled in this figure received from Canmore. At the time of writing, Canmore has indicated this is not anticipated to change the modelling scenarios.

Drawings A2 to A15 (Appendix A) show estimated debris-flood intensities at each model grid cell location, for each scenario (i.e., raw model output from EBA 2016). 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 3.0), (Jakob et al., 2011).

Debris-flood scenarios modelled by EBA (2016) correspond to the 1:30 to 1:100, 1:100 to 1:300, 1:300 to 1:1000, and 1:1000 to 1:3000 year frequency intervals[7]. The bounds of a given range are exceedance probabilities. For example, the 1:100 to 1:300 year range should be interpreted as 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 being the middle of the range.

[7] 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.

Table 2-9. Summary of debris-flood scenarios considered in the risk assessment (EBA 2016).

BGC Scenario ID	Return Period Class (years)	Pigeon Creek input parameters (debris flood)[1]		Blockage Scenario (BGC letter ID)			
		Clear Water Peak Flow (m^3/s)	Debris Volume (m^3)	No blockage (A)	1 (B)	2a (C)	2b (D)
1	10 to 30	28 to 38	45,000 to 61,000	1A	Not assessed[2]	Not assessed[2]	Not assessed[2]
2	30 to 100	38 to 61	61,000 to 92,000	2A	2B	2C	2B
3	100 to 300	61 to 104	92,000 to 126,000	Not assessed[3]	3B	3C	3D
4	300 to 1000	104 to 154	126,000 to 258,000[4]	Not assessed[3]	4B	4C	4D
5	1000 to 3000	154 to 205	223,000 to 555,000[4]	Not assessed[3]	5B	5C	5D

Notes:
1. From Hazard Report Modelling (EBA 2016).
2. Culvert capacity not anticipated to be exceeded at this return period (e.g. is not considered credible).
3. Based on observations from the June 2013 event, blockage of Hwy. 1 culverts is anticipated at this return period (e.g., assuming no blockages is not considered credible).
4. According to Canmore (personal communication J. Eisl, June 2, 2016,) the lower bound of the range was used for modelling.

Elements at risk data were managed within Excel and a Microsoft SQL Server database[8], and linked to geospatial data (e.g., parcel boundaries) in ArcGIS. Debris-flood model grids produced as part of the hazard assessment (EBA 2016) 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 the study area without major changes to the data management structure.

The hazard scenarios considered in this study are entirely based on EBA's numerical runout models. BGC's assessment does not consider auxiliary hazards such as bank erosion or channel bed aggradation that, if occurring, could jeopardize existing and future mitigation works. In addition, BGC notes a potential avulsion point on a low section of stream bank upstream of the fan apex (Drawing 11). EBA's hazard modelling starts downstream of the fan apex, and thus does not consider avulsion at this location. By extension, flow avulsion scenarios at this location and implications for development are not considered in this risk analysis. Further analysis would be required to confirm avulsion potential or estimate the hazard and risk associated with such flows.

BGC is not responsible for any errors or omissions (if any), or assumptions that have been made as part of the EBA study.

[8] 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.

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 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-flow or debris-flood scenario i of n, where *n* is the total number of scenarios. It addresses the question, "how likely is the event"?

$P(S{:}H)_i$ is the spatial probability that the event would reach the element at risk. It addresses the question, "what is the chance that the event will reach an 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. It answers the question, "what is the chance of someone or something being in the area affected by the hazard when it occurs"?

$N = V_i E_i$ describes the consequences [2] where:

V_i is the vulnerability, which is the probability elements at risk will suffer consequences given hazard impact with a certain severity. For persons, vulnerability is defined as the likelihood of fatality given flood impact. For buildings, it is defined as the level of damage, measured as a proportion of the building replacement cost or as an absolute cost.

E_i is a measure of the element at risk, quantifying the value of the elements that could potentially suffer damage or loss (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. 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 1A to 5D listed in Table 2-9.

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 3-2. 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:

$$f_i = \sum_{i=1}^{n} P(H)_i P(S:H)_i P(T:S)_i \quad [3]$$

and N_i is represented by equation [2] above.

Direct building damages were calculated as total annualized damage considering all scenarios, as well as direct damage costs for individual scenarios. Assessment of 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 areas 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 3.4 to 3.7.

3.3. Risk Tolerance Criteria

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, British Columbia in 2009, following guidelines developed in Hong Kong (Hong Kong Geotechnical Engineering Office (GEO) 1998). The District of North Vancouver 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 illustration purposes, these tolerance criteria are shown on Figure 3-1 compared with Canadian mortality rates for the year 2008 (Statistics Canada 2013). Figure 3-1 shows that the District of North Vancouver risk tolerance threshold of 10^{-4} (1/10,000) for existing development is comparable to the lowest background risks that Canadians face throughout their lives. This tolerance threshold is also similar to the average Canadian's annual risk of death due to motor vehicle accidents, 1/12,500, for the year 2008 (Statistics Canada 2013).

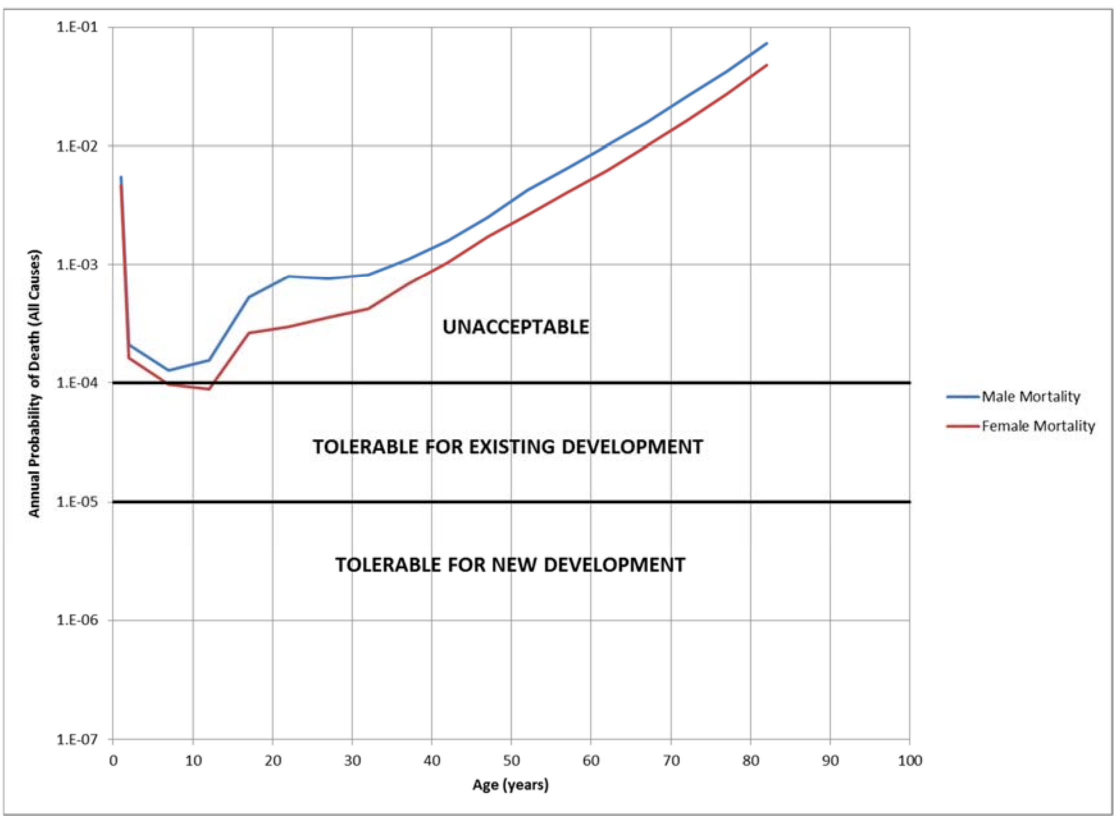

Figure 3-1. District of North Vancouver individual risk tolerance criteria for landslides compared with Canadian mortality rates in 2008.

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 District of North Vancouver. 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 3-2. 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.

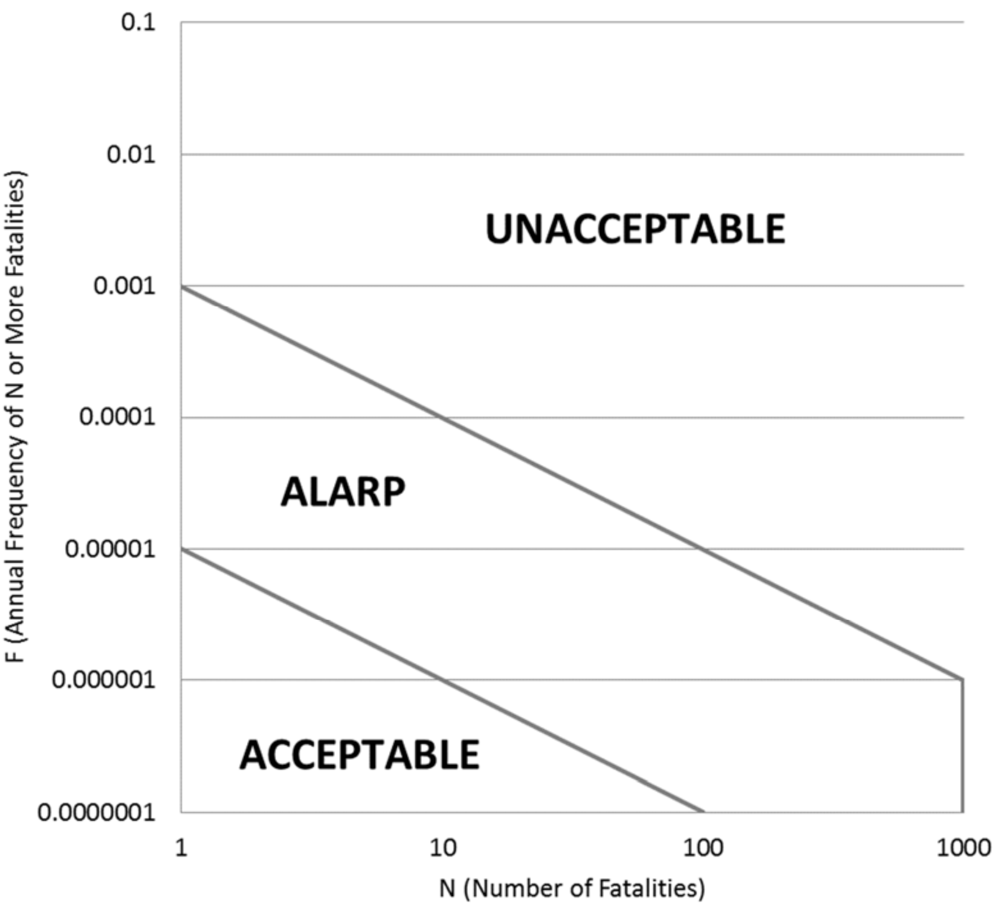

Figure 3-2. Group risk tolerance criteria as defined by GEO (1998).

3.4. Hazard Probability, $P(H)$

Hazard probability, $P(H)_i$, corresponds to the annual probability of occurrence of each hazard scenario, which are defined as annual frequency ranges in range.

Table 2-9. The bounds of a given range are "exceedance" probabilities, corresponding to the probability that an event of *at least* a certain magnitude will occur. As such, for a scenario with the annual probability range P_{min} to P_{max}, the probability of events within this range corresponds to:

$$P(H)_i = P_{max} - P_{min} \quad [4]$$

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

$$P(H)_i = \frac{1}{30} - \frac{1}{100} = \frac{1}{43} \quad [5]$$

In the example above, there is a 1 in 43 year chance that an event greater than the 1:30 year event, but not larger than the 1:100 year event, will occur.

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.

3.5. 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 >140 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.

3.6. 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).

3.7. 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 buildings and persons within buildings, based on estimated levels of destructive power and resistance to impact. Vulnerability levels were not quantified for roads and utility systems.

This section refers to debris flood "intensity", I_{DF} as a measure of destructive power, calculated as follows:

$$I_{DF} = (d)(v^2) \quad [6]$$

where:

I_{DF}	is the intensity index.
d	is the modelled flow depth.
v	is the modelled flow velocity.

3.7.1. Low intensity flows (I_{DF} < 1)

Lower intensity flows are defined as flows where intensity index (I_{DF}) was less than one. Damages associated with these low intensity flows are typically limited to flood damage. While the possibility of fatalities cannot be entirely ruled out, it is considered to be too low to be measurable given that high flood depths (e.g., > 2 m) were not estimated for any hazard scenario.

BGC used depth-damage functions to estimate flood damages as a proportion of building assessment value. These functions are based on flood depth at a particular building location and are expressed as a proportion of building cost for different building types (e.g., Figure 3-3). They do not consider flow velocity and apply where flood inundation is the primary factor for damage (e.g., areas downstream of the highway).

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.

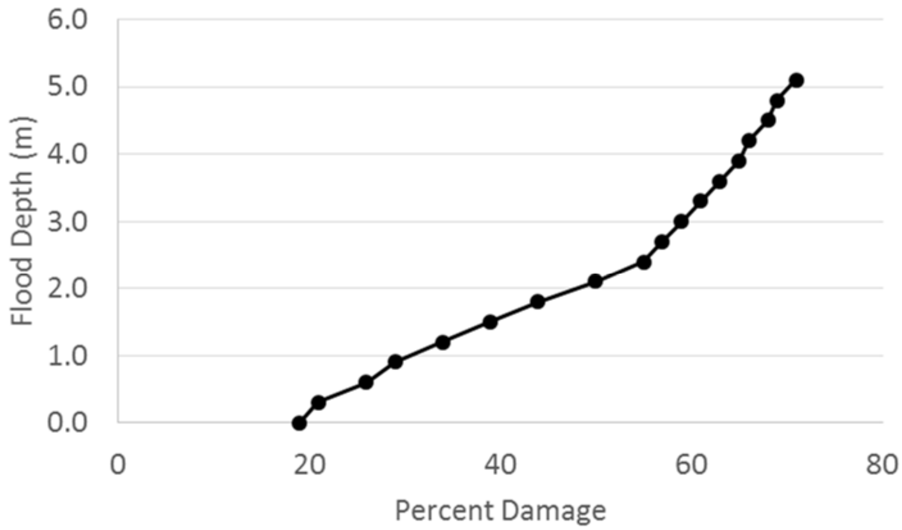

Figure 3-3. Example of a flood depth-damage function (residential homes).

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).

Note that on a depth-damage curve, "zero" flood depth corresponds to the first floor elevation. In the absence of site-specific data, these were assigned based on default Hazus criteria. For residential homes assumed to have full basements (Land Use Code = Res1), the first floor elevation is assumed to be 1.2 m. Flood depths shallower than 1.2 m were assumed to result in basement damage only. For simplicity, BGC assumed that all other buildings contained a concrete slab foundation with first floors 30 cm higher than the surrounding ground surface. The depth-damage curves applied to non-residential buildings did not consider basement damage and will underestimate such damage if existing.

3.7.2. High intensity flows (IDF >1)

Higher intensity flows are defined as modelled flows where I_{DF} was greater than 1. These flows have potential to result in structural building damage due to dynamic and static impact pressure, and are considered to have credible potential to cause loss of life. Vulnerability ratings for these flows consider the likelihood of fatalities as an indirect consequence of building damage or collapse.

Table 3-1 shows the vulnerability ratings used for flows where I_{DF} >1. These values are based on judgement with reference to Jakob et al. (2011). They contain uncertainty due to factors that cannot be captured at the scale of assessment, such as variations in the structure and contents of a given building and the location of persons within the building at the time of impact.

Table 3-1. Summary of estimated vulnerabilities as a function of hazard intensity.

Hazard Intensity Index (Range)	Building Damage Description		Building Vulnerability[1]	Human Vulnerability[2]	
	Category	Description	Best Estimate	Estimated Safety Vulnerability, Individual Risk (V)	Estimated Safety Vulnerability, Group Risk (V)
<1	Moderate	Low likelihood of building structure damage due to impact pressure. High likelihood of flood damage.	n/a[4]	~0[3]	~0[3]
1-10	Major	High likelihood of moderate to major building structure damage due to impact pressure. Certain severe sediment and water damage. Building repairs required, possibly including some structural elements.	>25% - 75% (50%)	0.01	0.005
10-100	Severe	High likelihood of major to severe building structure damage due to impact pressure. Certain severe sediment and water damage. Major building repairs required including to structural elements.	>75% - 90% (83%)	0.1	0.05
100-400	Destruction	Very high likelihood of severe building structure damage or collapse. Complete building replacement required.	>90% (95%)	0.5	0.5

Notes:

1. Proportion of building assessment value.
2. Probability of loss of life given impact.
3. Approximated in the risk analysis as 0.000001.
4. Depth-damage curves were used to assess low intensity flood damage.

3.7.3. Business Activity

As described in Section 2.1.6, BGC mapped the distribution of business activity in Pigeon Creek study area 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.

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

Assessment of roads and utilities was limited to identification of the location of infrastructure in relation to the extent and intensity of modelled debris-flood scenarios. Drawings A-01 to A-14 (Appendix A) show modelled debris-flood intensity in relation to surface and subsurface infrastructure, including roads and utilities, for the various debris-flood scenarios considered in the risk assessment.

For additional information regarding impacts to surface and subsurface infrastructure for each return period class, the reader should refer to Table 9.3 in EBA (2016).

4.2. Buildings and Business Activity

Drawing 06 shows estimated building damage proportions for individual parcels (i.e., Table 3-1), while Drawing 07 shows estimated building damage costs. Table 4-1 summarizes parcel consequence estimates for each scenario, including total building damage costs and annual business revenues affected.

For comparison, estimated direct damage costs to buildings for individual scenarios ranged from $8 M to $129 M at Cougar Creek depending on the scenario.

Table 4-1. Summary of consequence estimates.

BGC Scenario ID	Frequency (1:years)	Culvert Blockage Scenario	Number of Parcels Affected	Building Damage Cost ($M)	Average Cost/Parcel ($)	Annual Business Revenue of Impacted Parcels ($M) [1]
1A	1:10 to 1:30	None	17	$4.5	$260,000	$5.06
2A	1:30 to 1:100	None	17	$4.5	$260,000	$5.06
2B		1	12	$0.4	$30,000	$5.00
2C		2a	20	$4.7	$240,000	$5.06
2D		2b	15	$4.6	$310,000	$5.06
3B	1:100 to 1:300	1	26	$4.7	$180,000	$6.77
3C		2a	22	$4.8	$220,000	$5.06
3D		2b	25	$4.9	$200,000	$6.77
4B	1:300 to 1:1000	1	26	$4.9	$190,000	$6.77
4C		2a	31	$5.0	$160,000	$6.77
4D		2b	25	$4.9	$200,000	$6.77

BGC Scenario ID	Frequency (1:years)	Culvert Blockage Scenario	Number of Parcels Affected	Building Damage Cost ($M)	Average Cost/Parcel ($)	Annual Business Revenue of Impacted Parcels ($M) [1]
5B	1:1000 to 1:3000	1	28	$5.7	$200,000	$6.77
5C		2a	31	$6.8	$220,000	$6.77
5D		2b	27	$7.9	$290,000	$6.77

Notes:
1. D&B revenue data provided in USD and was converted at 1 USD = 1.28 CAD.
2. See footnote below for a discussion of Scenario 2B results.

With the exception of Scenario 2B[9], the estimated direct building damage costs range from $4.5 M for the 10 to 30 year return period scenario (2A) to about $7.9 M for the 10003000 year scenario (2D). For comparison, total assessed building value for the entire fan corresponds to about $72 M. Considering all scenarios together, the annualized unmitigated building damage cost is $440,000. Average annualized building damage cost at Stoneworks Creek is about $790,000 (BGC 2016).

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 (e.g., the Thunderstone Quarry product stockpile). In addition, costs of cleanup and recovery, such as those listed in Table 2-8 for the June 2013 event, are not included. If these were considered, actual damage costs would increase.

4.3. Critical Facilities

As described in Section 2.1.2, the only critical facility located in the Pigeon Creek study area is the sewage treatment facility. All debris-flood scenarios show flows extending to the boundary of the sewage treatment pond impoundment (Appendix A). However, the estimated flow intensities are very low (<0.1). This is consistent with the June 2013 event.

4.4. Safety Risk

As described in Section 3.2, 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.

[9] Building damage and business activity costs for Scenario 2B are lower than costs for other scenarios. This scenario considers the 100 to 300 year return period event with blockage of the southeast and southwest ramps, and Highway 1. As a result, flows avulsed along the southwestern edge of the fan along the Trans-Canada Highway and away from elements at risk located on the Pigeon Creek fan. In total 11 properties were impacted by Scenario 2B. For comparison, Scenario 2A impacted 16 properties. Furthermore, Scenario 2B is the only scenario modelled which did not impact the Copperstone Resort. These factors resulted in a much lower damage cost estimate for Scenario 2B than for the other scenarios considered.

4.4.1. Individual Risk

BGC identified one parcel that exceeds the individual risk tolerance standard for existing buildings of 1:10,000 ($1x10^{-4}$) risk of fatality per year. This parcel is located at 300 2nd Avenue to the south of Pigeon Creek (Drawing 13). Given the parcel scale of study, the area shaded on Drawing 13 encompasses the entire parcel, which includes 10 buildings. However, note that this rating conservatively reflects the risk result for the building impacted by the highest intensity flows in the parcel. Buildings further from the creek were subject to impact by relatively lower intensity modelled flows, and would be subject to a lower level of individual risk than is shown on Drawing 13.

4.4.2. Group Risk

Figure 4-1 presents the results of group risk analysis on an F-N curve, and Table 4-2 lists the estimated numbers of fatalities (N) for each debris-flood scenario.

Estimated overall group debris-flood risk for Pigeon Creek study area extends in to the "ALARP" range when compared to the international risk tolerance standards described in Section 3.3.

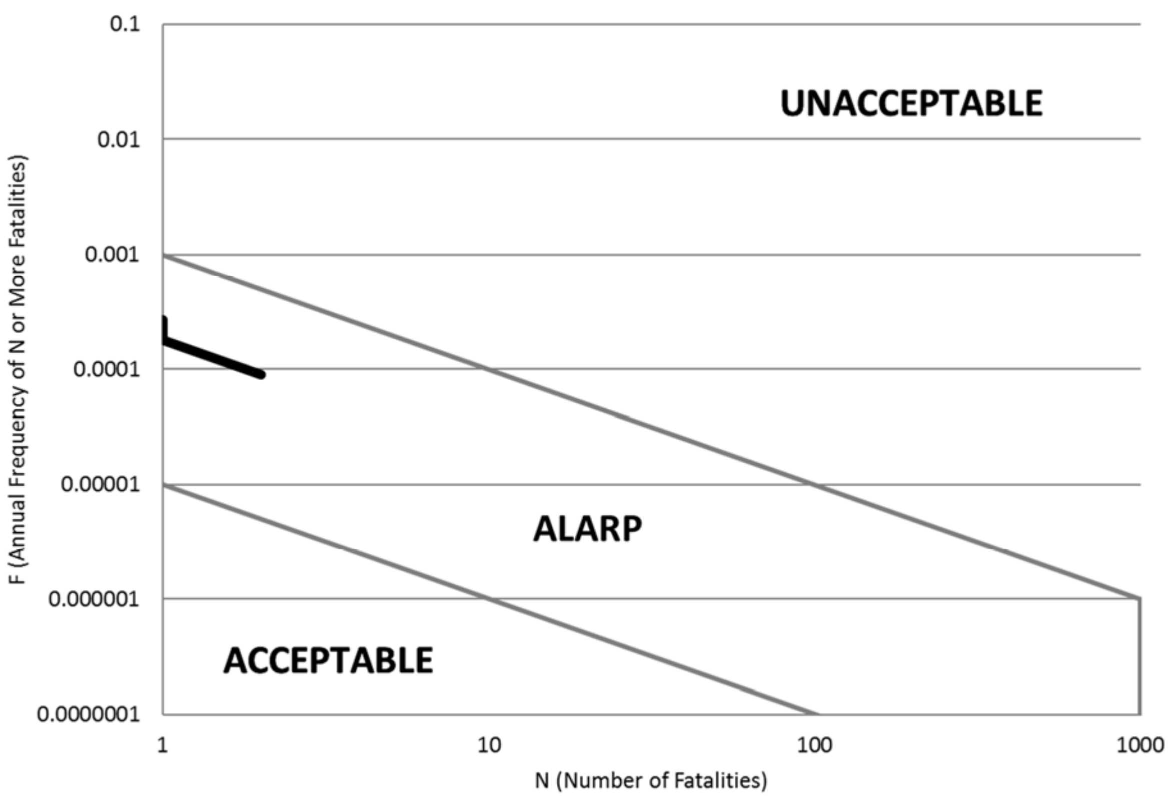

Figure 4-1. F-N curve showing the results of the Pigeon Creek risk analysis for groups (bold black line).

Table 4-2. Estimated number of fatalities (N) for each debris-flood scenario and with the assumptions made in this report.

Scenario ID	Frequency (1:years)	Estimated Number of Fatalities (N)[1]
1A	1:10 to 1:30	0
2A	1:30 to 1:100	0
2B		0
2C		0
2D		0
3B	1:100 to 1:300	0
3C		0
3D		0
4B	1:300 to 1:1000	0
4C		0
4D		0
5B	1:1000 to 1:3000	1
5C		1
5D		2

Note:
1. N values in the table are rounded to the nearest 1 fatality.

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[10].

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 Pigeon 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.

[10] Previous Debris-Flood Risk Assessments completed by BGC for the Town of Canmore (e.g., BGC 2015, BGC 2016) compared safety risk estimates to published mortality functions for large river floods (i.e., Jonkman et al. 2008). This comparison was not completed for Pigeon Creek because of the slightly higher vulnerability estimates at shallow flood depths inherent in the Dutch Mortality Model which isn't comparable to the low flood depths observed at Pigeon Creek.

4.5.1. Comparison to Case Studies

Appendix B describes hazard events occurring elsewhere, for comparison purposes. The events described in Appendix B 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 are relevant for comparison to Pigeon Creek. The examples chosen include cases where evacuation was either not possible due to the event's suddenness, or evacuations were resisted or not executed to their fullest extent.

The case studies have yielded mortalities ranging over one order of magnitude from about 0.01 (1%) to 0.12 (12%). BGC's estimated mortality rate for Pigeon Creek is at the low end of this range, at 0% to 4%. This is considered reasonable given that much of the impact is limited to Pigeon Creek channel and low velocity flood inundation downstream of Highway 1.

4.5.2. Comparison to 2013 Event

It is difficult to exactly simulate the consequences of the June 2013 event because of modelling limitations (e.g., sediment deposition, bank erosion or scour cannot be explicitly accounted for in the model). The $4 to 5 M costs recorded for the June 2013 event (Table 2-8) are also not the same as those quantified in this assessment (direct building damage costs), challenging direct comparisons between the 2013 event and the risk modelling results presented in this report.

The 100 to 300 year return period debris flood is of similar magnitude to the June 2013 event. Damage estimates for the 100 to 300 return period year event are within the range of costs recorded for the June 2013 event (Table 4-3).

Table 4-3. Comparison of June 2013 damage costs to estimated damage costs for the 100 to 300 year return period.

Scenario	Return Period Class (years)	Damage costs ($M)
June 2013	200 (EBA 2016)	$4.1 to $5.1
3B	100 to 300	$4.7
3C	100 to 300	$4.8
3D	100 to 300	$4.9

In terms of life loss, estimated life loss for the 100 to 300 year return period event (Table 4-3, Scenarios 3B to 3D) corresponds to no fatalities which is consistent with the June 2013 event.

4.6. Future Development

Canmore is considering future development south of the Highway between the highway ramp and the current location of Thunderstone Quarry.

To assist with development planning efforts, BGC prepared a map showing estimated levels of individual risk across the study area (Drawing 13). This map was prepared as follows:

1. For each model hazard scenario, BGC calculated individual risk (PDI) for every grid cell. The PDI values at each grid cell are based on debris-flood intensity at that cell and were calculated using the risk analysis methodology described in Sections 3.2 to 3.7.
2. Grid cell PDI values for each hazard scenario were summed in GIS to generate a composite map with grid cell values showing the total individual risk across all scenarios.
3. The results of Step 2 were interpreted to produce a generalized map of individual risk across the study area.

The resulting individual risk map shows zones where estimated annual risk of fatality for persons within buildings would be estimated as < 1:100,000, >1:100,000, or > 1:10,000, should a building be located in that zone.

Note that a key assumption of this map, for the purpose of baseline risk estimation, is uniform levels of building vulnerability to debris-flood impact. Similar vulnerability criteria were used to generate the map as were used to estimate individual risk for existing buildings.

4.6.1. Safety Risk Mapping Results

Drawing 13 displays zones where estimated individual risk exceeds 1:10,000 ($1x10^{-4}$) or 1:100,000 ($1x10^{-4}$) annual risk to life. Zones where estimated annual risk of fatality per year exceed 1:10,000 are concentrated along the Pigeon Creek channel, the southwest ramp and along Highway 1 (west). Downstream of Highway 1, the highest risk zone is concentrated along the Pigeon Creek channel from the Highway to the Three Sister's Campground.

Zones where estimated annual risk of fatality per year exceeds 1:100,000 include:

- George Biggy Sr. Road along the southwest ramp and across Highway 1
- A wider area (up to 50 m) on either side of Pigeon Creek channel upstream of the Highway
- Vicinity of Highway 1 travel further west and are wider when compared to the <1:10,000 PDI flows
- Downstream of the Highway, flows impact a wider area (up to approximately 200 m) at the bend in Pigeon Creek downstream of 2nd Avenue.
- Flows extend beyond the Three Sisters Campground towards the Bow River.

The above results are based on the current topography and are considered a snapshot in time. Safety risk zones may change in the future due to factors such as: implementation of mitigation measures, changes in topography, future hydrogeomorophic events and climate change. As such, review of the safety risk zones prior to development is recommended.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

This assessment estimated debris-flood risk for Pigeon Creek fan based on the results of EBA's hazard assessment (EBA 2016). The primary objective of the assessment was to estimate risk to life and economic losses resulting from debris-flood impact to establish an understanding of baseline risk to support development planning efforts.

BGC assessed risk associated with four debris-flood scenarios representing a range in debris-flood return periods from 10-30 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 $4.5 M for the 10-30 year scenario to $8 M for the 1000-3000 year scenario[11]. Estimated annualized building damage cost is $440,000/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.

Annual business revenues in impacted areas range from $60,000 for the 10 to 30 and 30 to 100 year return period scenarios to $1.7 M for the 100 to 300 and higher return period scenarios. For reference, revenues of all businesses in the Pigeon Creek study area correspond to about $7 M/year. As noted previously, 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 (e.g., product stockpiles at Thunderstone Quarry damaged in the June 2013).

BGC identified one parcel where estimated average safety risk for individuals exceeded 1:10,000 probability of death per year. Zones where PDI exceeded the 1:10,000 probability of death per annum are illustrated on Drawing 13. Estimated group safety risk fell into the "ALARP" range when compared to international risk tolerance standards.

5.2. Recommendations

Following this risk assessment, a number of steps will lead to optimization of the risk reduction strategy:

[11] Estimated building damage costs for Scenario 2B were $0.4M, however, this value is not considered representative.

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 define 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. BGC understands that Canmore has already developed a preliminary risk reduction plan for Pigeon Creek, including conceptual design of risk reduction measures. These were developed prior to the completion of the EBA hazard report (2016) and this assessment. As such, these measures should be reviewed in light of the results of this assessment.
4. Risk evaluation should be completed for each risk reduction option, to support selection of preferred options that reduce debris-flood risk to levels considered tolerable by Canmore.
5. The avulsion potential on the west bank of Pigeon Creek upstream of the fan apex should be confirmed. If it is determined that there is potential for avulsion at this location, additional hazard scenario modelling should be completed to estimate the extent and intensity of impact and associated risk.

Lastly, BGC notes that Pigeon Creek fan was ranked as the second highest priority fan (after Stoneworks Creek fan) in a study conducted for Alberta Transportation (BGC, 2016). The high ranking is attributed to the fact that Pigeon Creek is a large supply unlimited watershed, Highway 1 crosses the central portion of Pigeon Creek fan, and that a debris flood could block culverts and avulsion upstream of culverts is also possible. Debris flood risk reduction will need to consider both the highway and development as part of risk reduction design.

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:

PROFESSIONAL GEOSCIENTIST
K. W. HOLM
ALBERTA

Sept 27, 2016.

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SK/MJ/jwc/cm

APEGA Permit to Practise: P5366

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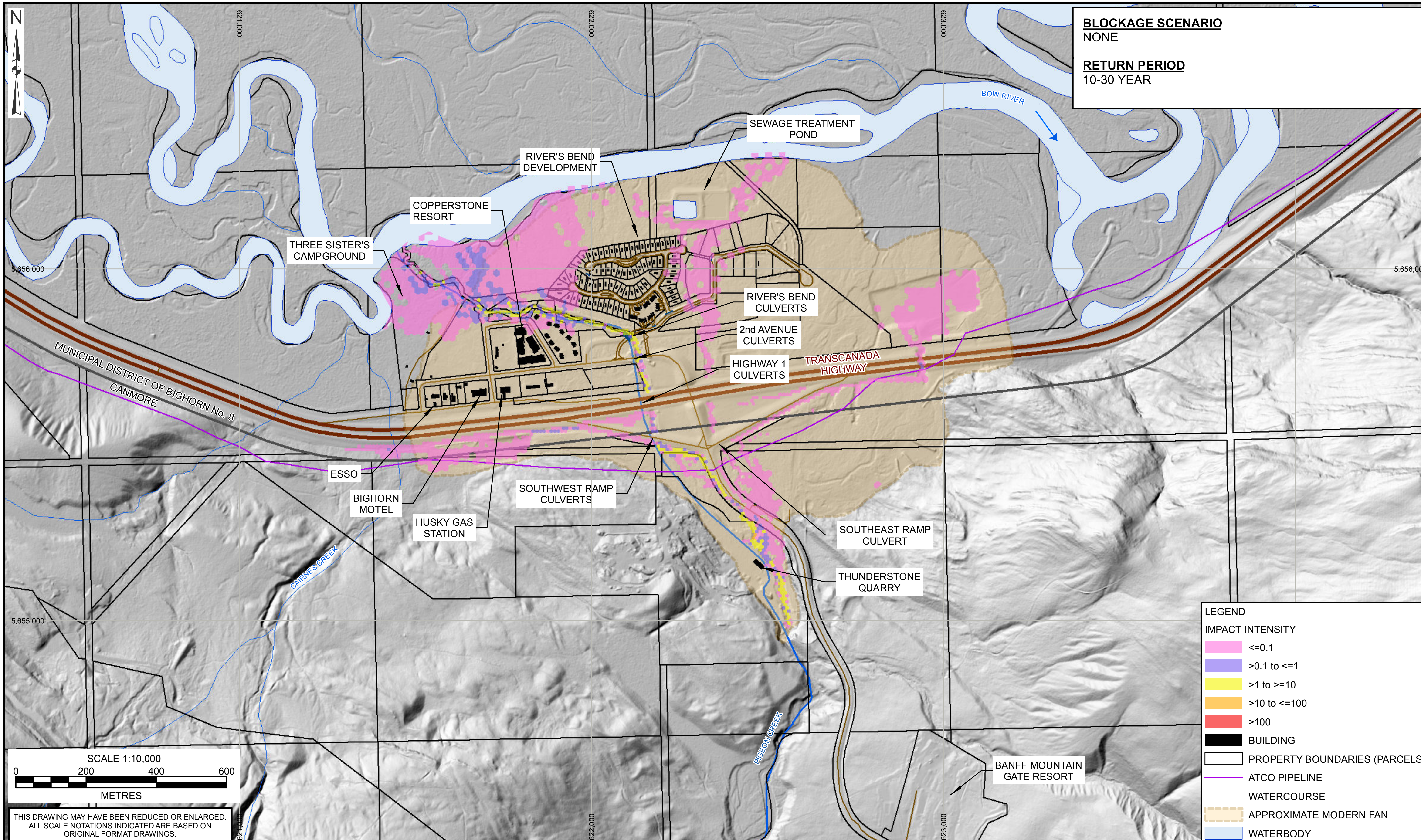
APPENDIX A
DEBRIS-FLOOD HAZARD INTENSITY MAPPING



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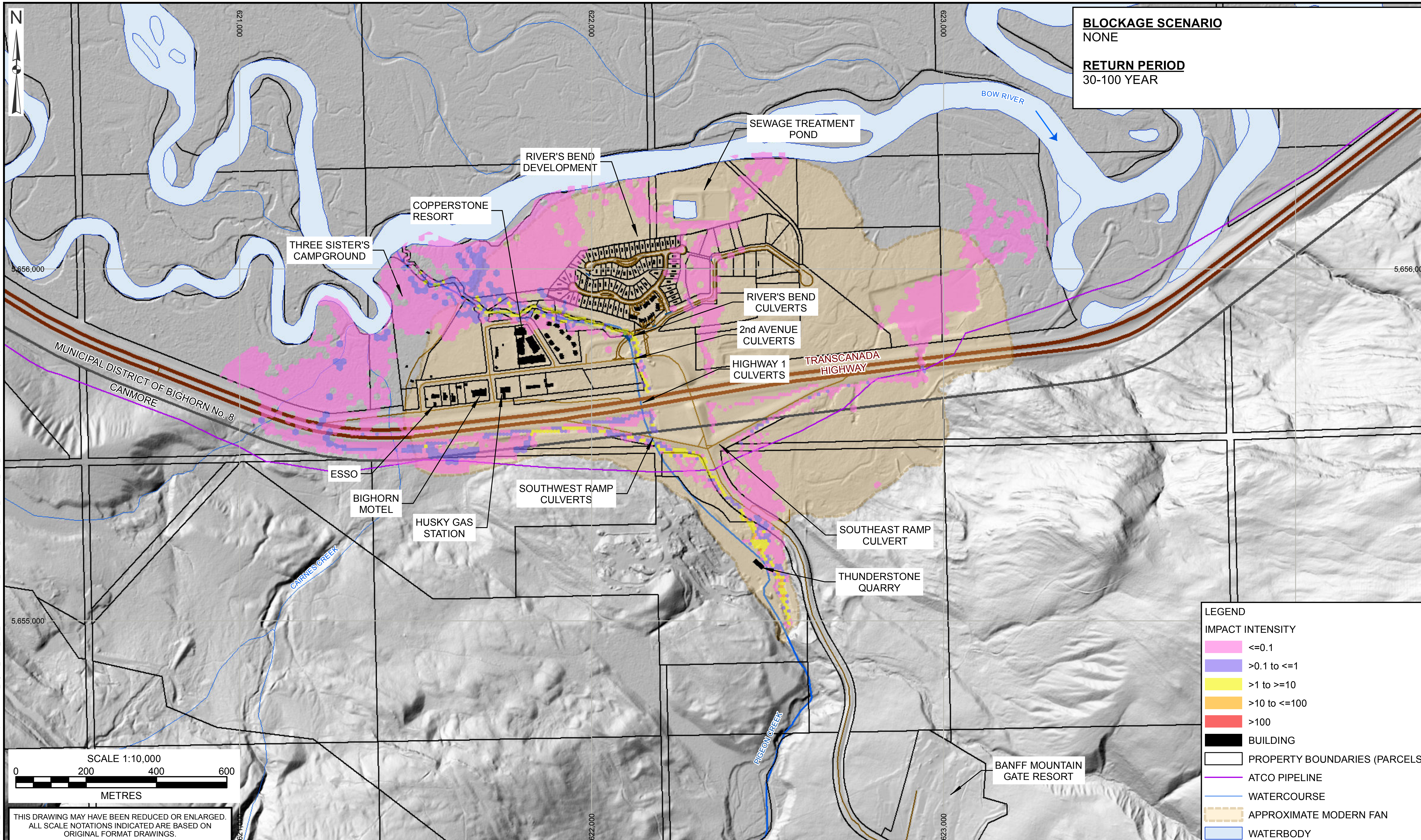

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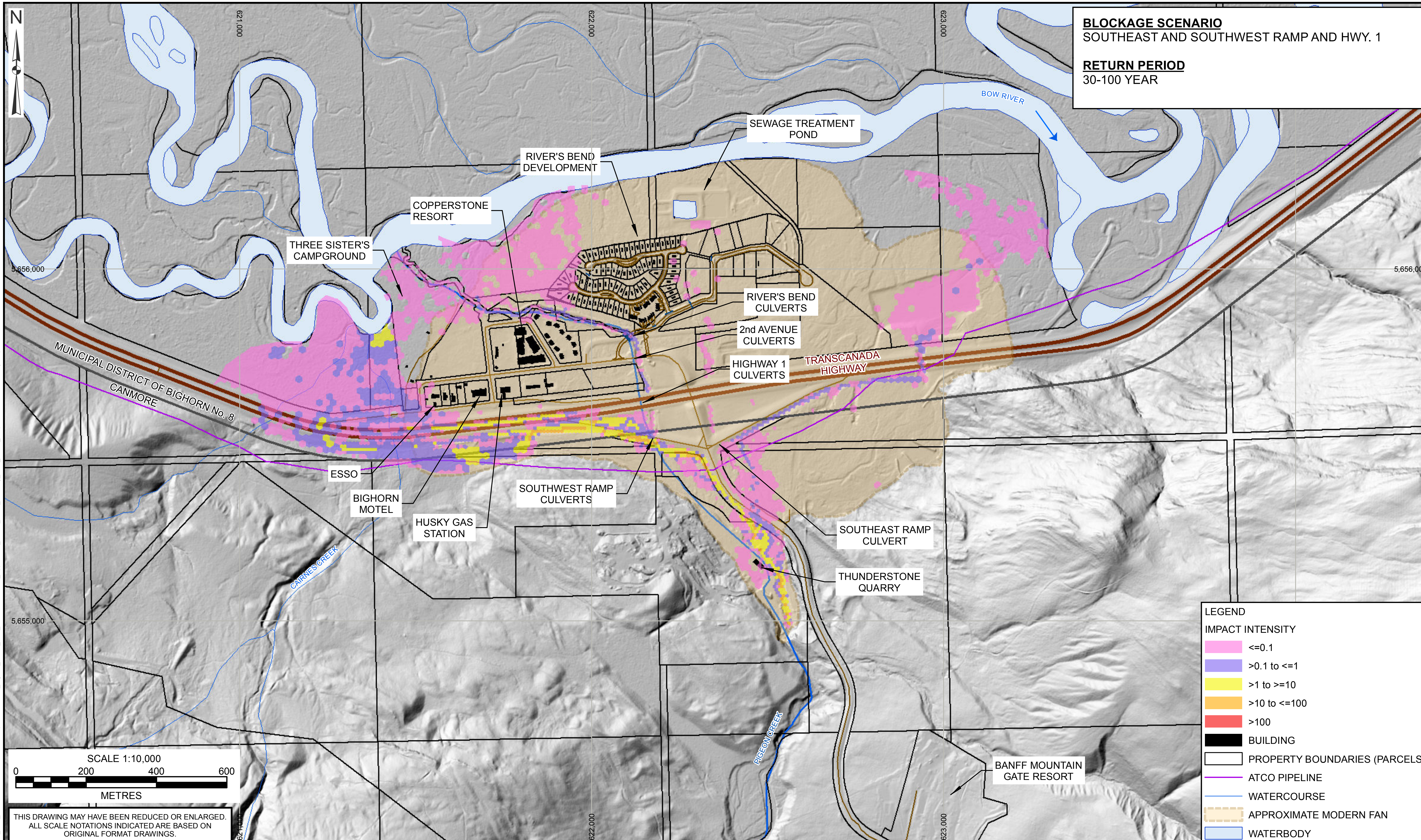

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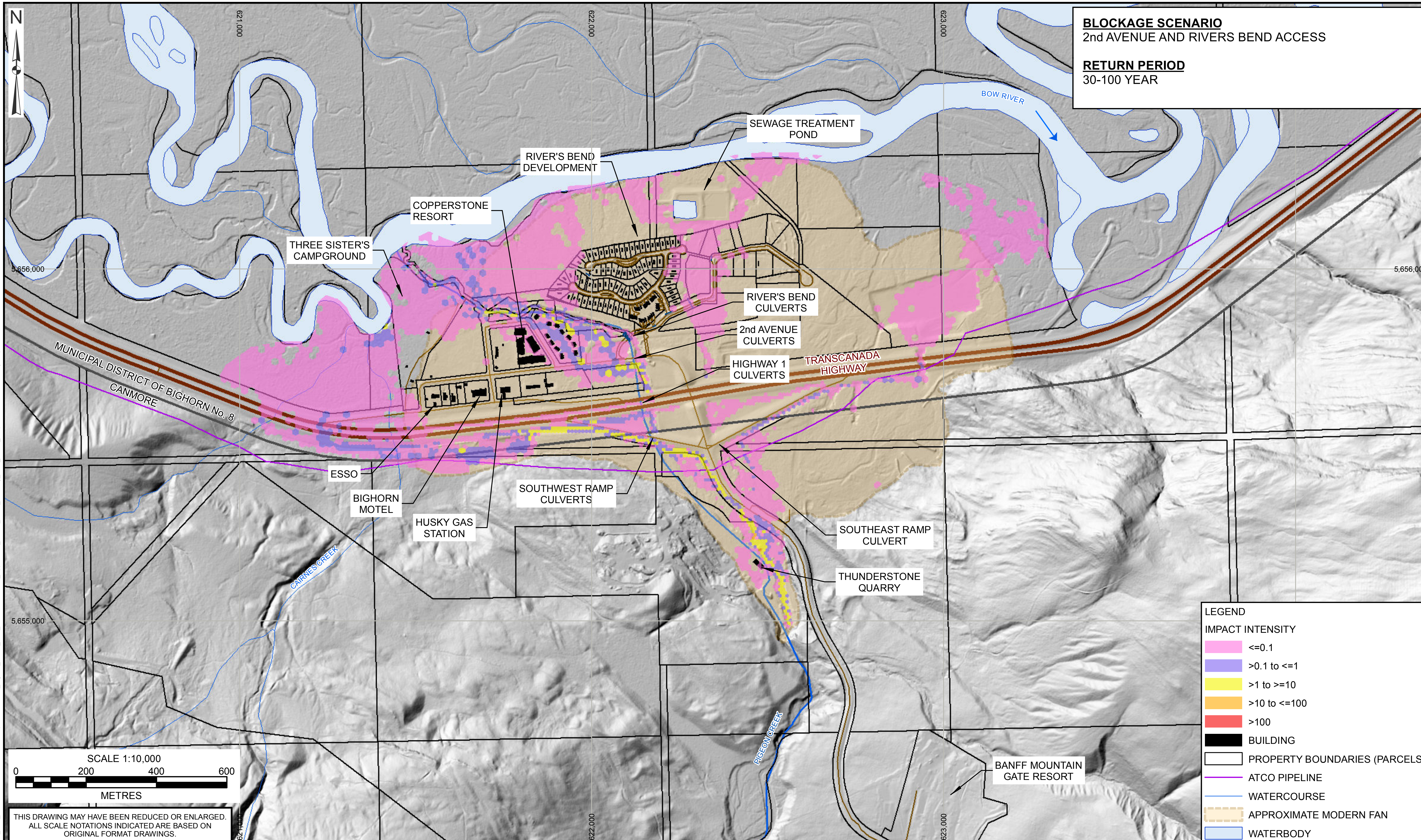

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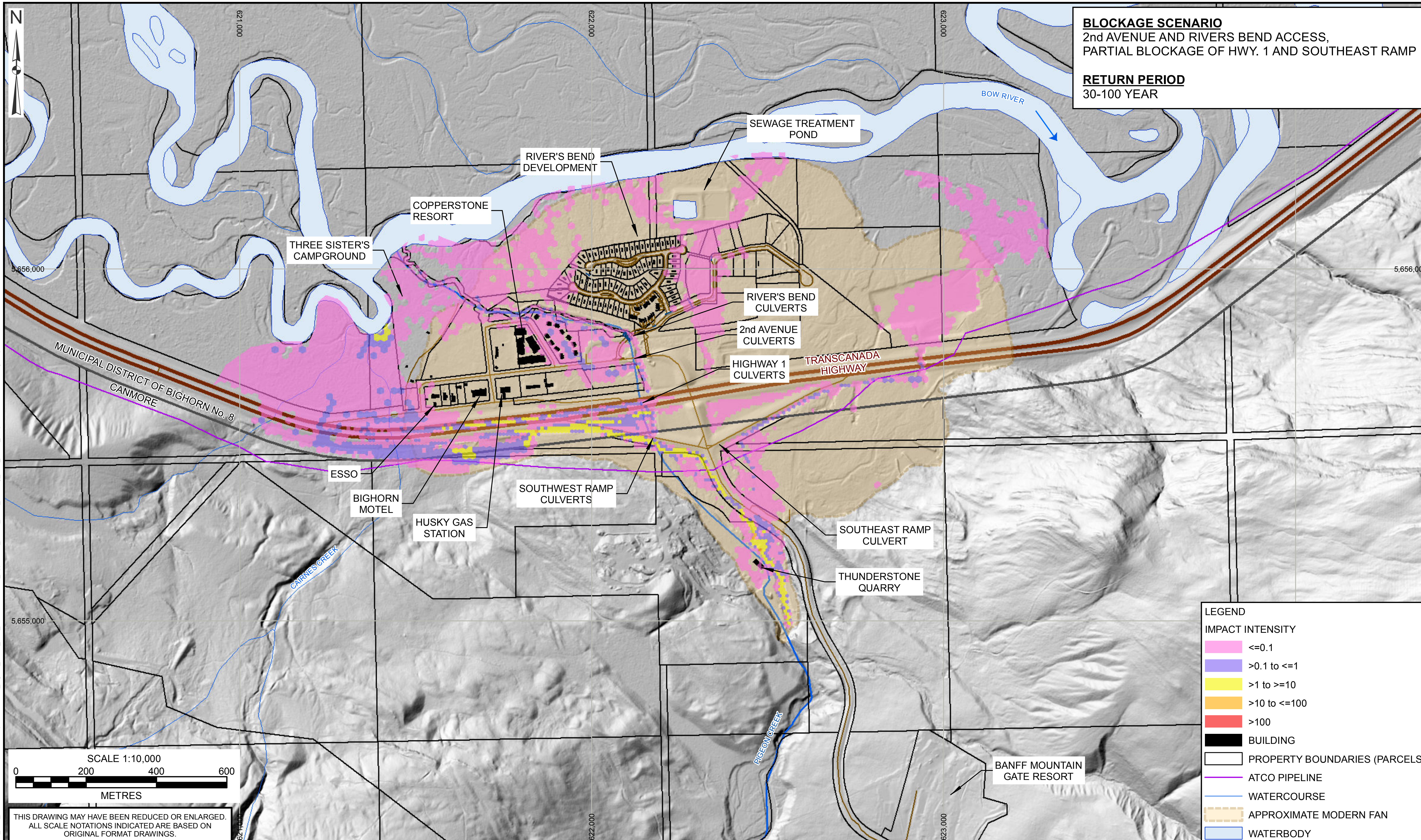

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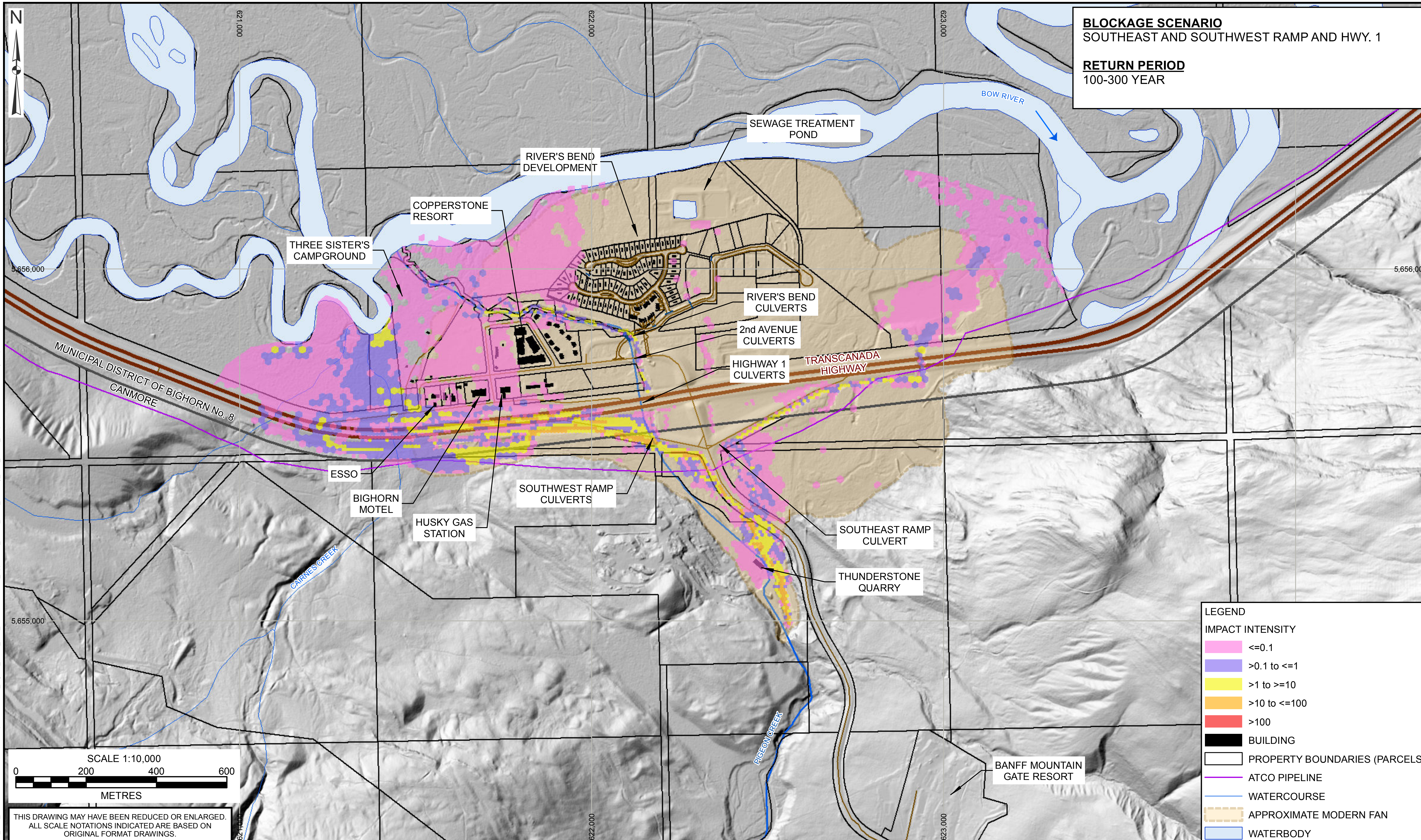

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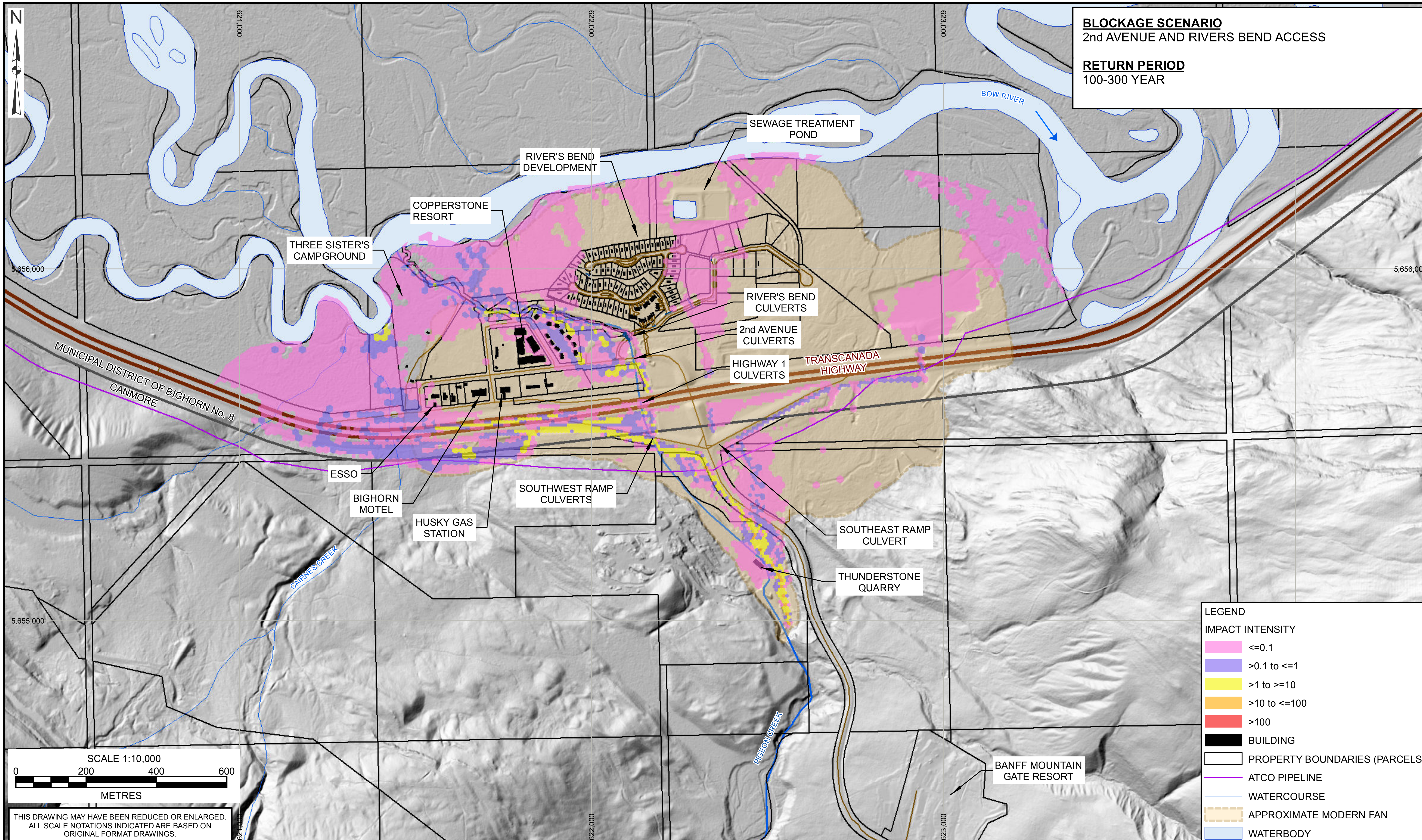

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APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

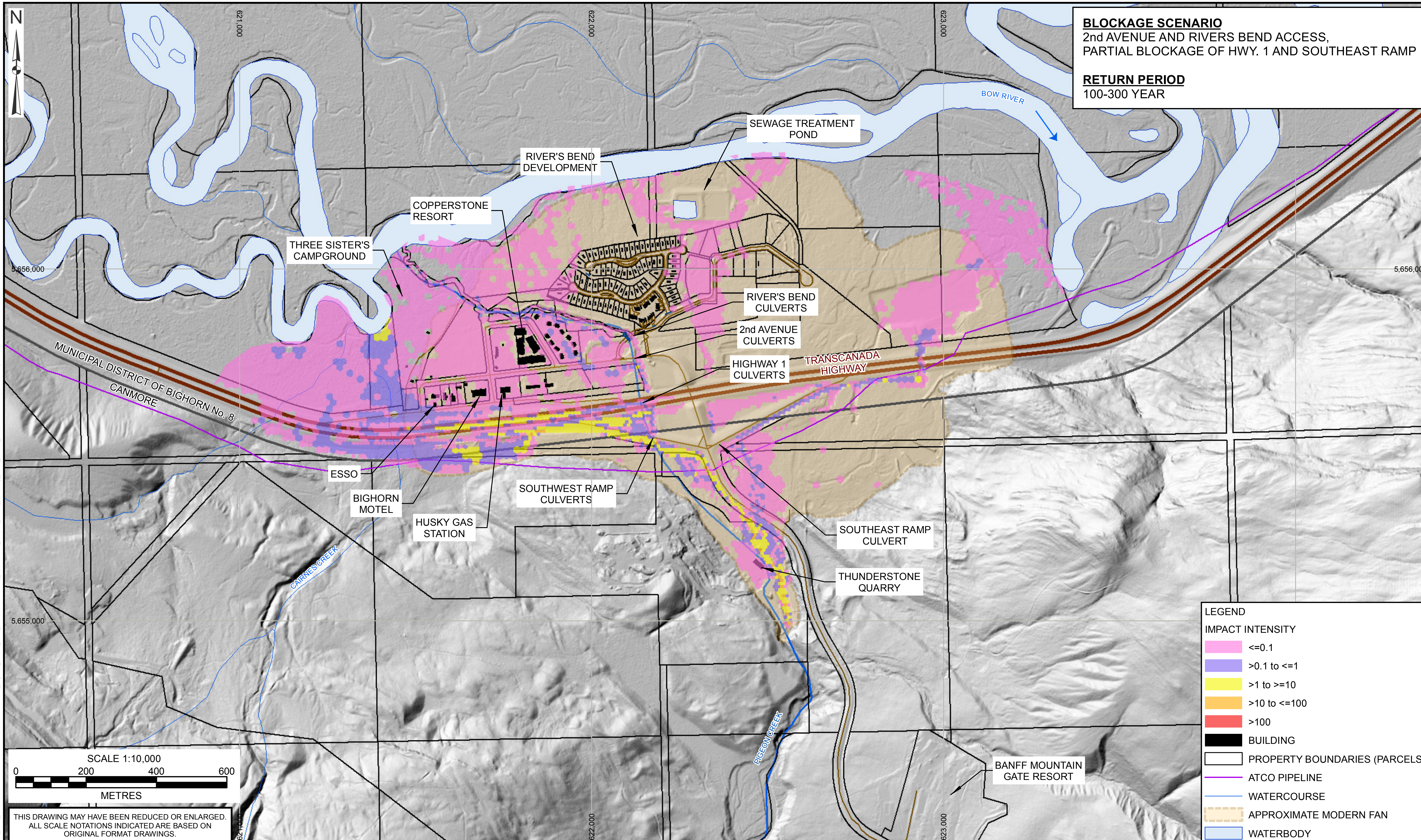
CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: DEBRIS-FLOOD RAW MODEL OUTPUT SCENARIO 3C

PROJECT No.: 1261-014

DWG No.: A-07



NOTES:
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2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT", AND DATED SEPTEMBER 2016.
3. FOOTPRINT OF EXISTING BUILDINGS OBTAINED FROM CANMORE. FOOTPRINT OF RIVER'S BEND DEVELOPMENT FROM MD BIGHORN VIA CANMORE.
4. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY McELHANNEY, DATED AUGUST AND OCTOBER 2013.
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CLIENT:
Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: DEBRIS-FLOOD RAW MODEL OUTPUT SCENARIO 3D

PROJECT No.:	DWG No.:
1261-014	A-08

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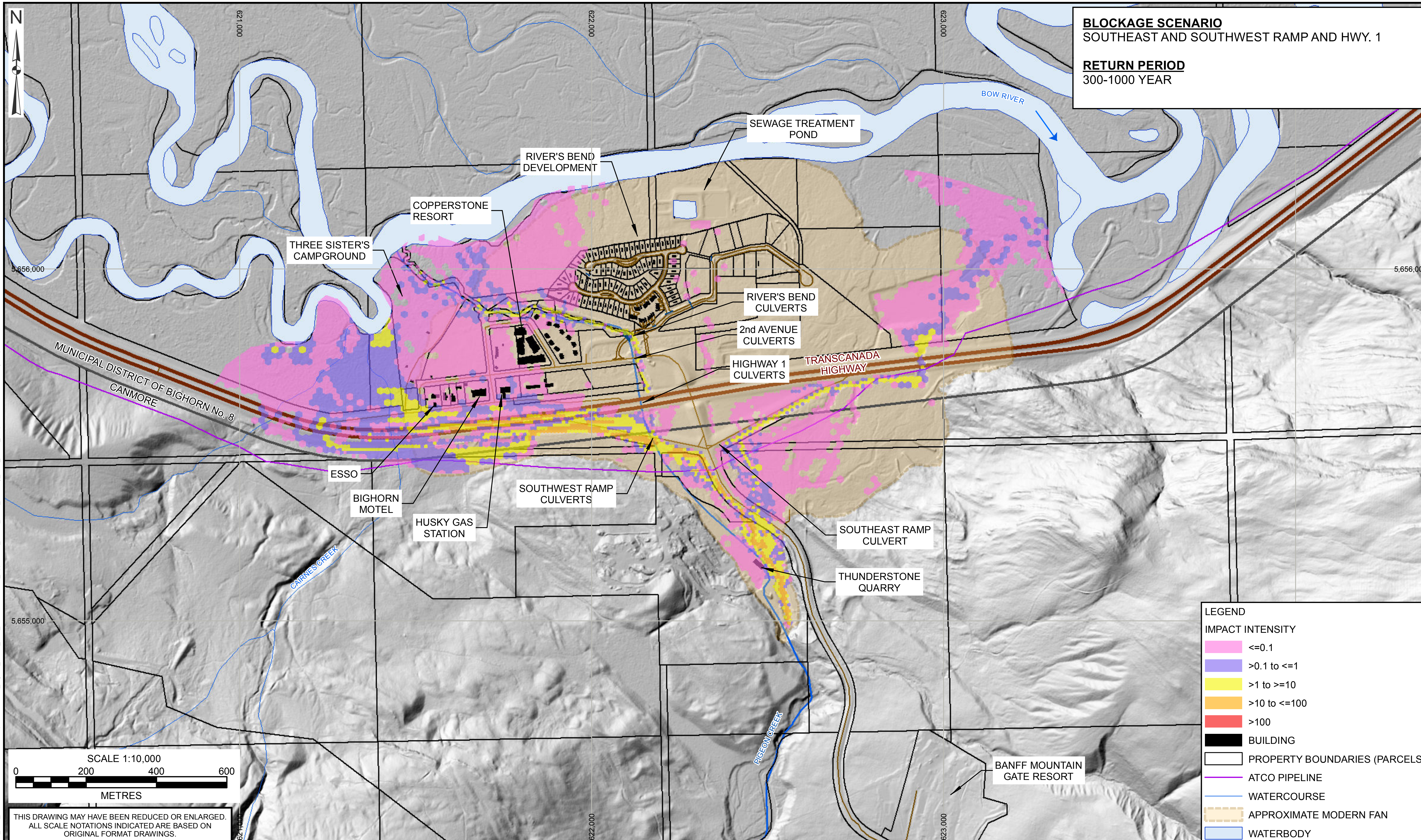
BLOCKAGE SCENARIO
SOUTHEAST AND SOUTHWEST RAMP AND HWY. 1

RETURN PERIOD
300-1000 YEAR



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CLIENT:
Town of CANMORE

PROJECT:
PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE:
DEBRIS-FLOOD RAW MODEL OUTPUT
SCENARIO 4B

PROJECT No.:	DWG No.:
1261-014	A-09

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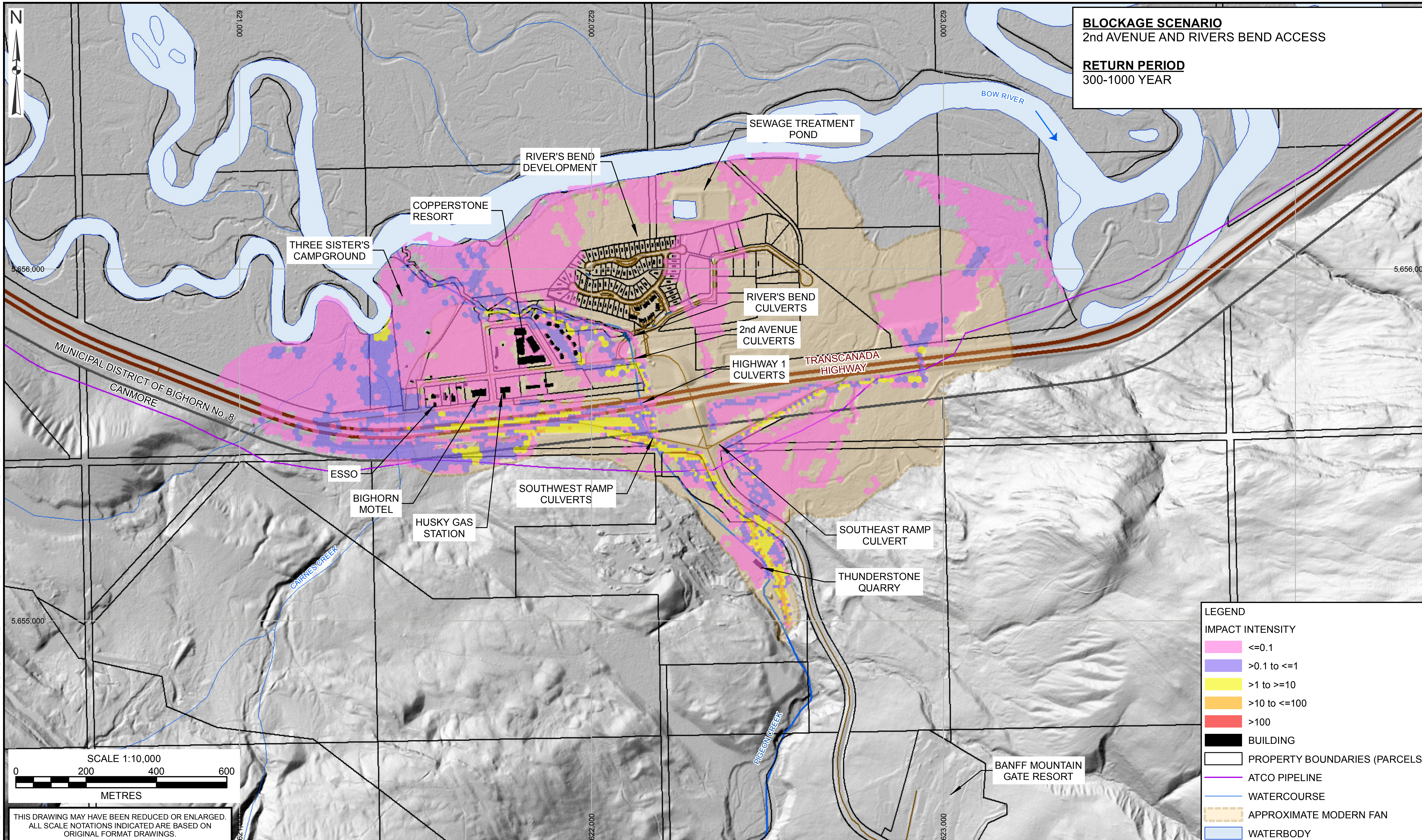

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CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: DEBRIS-FLOOD RAW MODEL OUTPUT SCENARIO 4C

PROJECT No.: 1261-014

DWG No.: A-10

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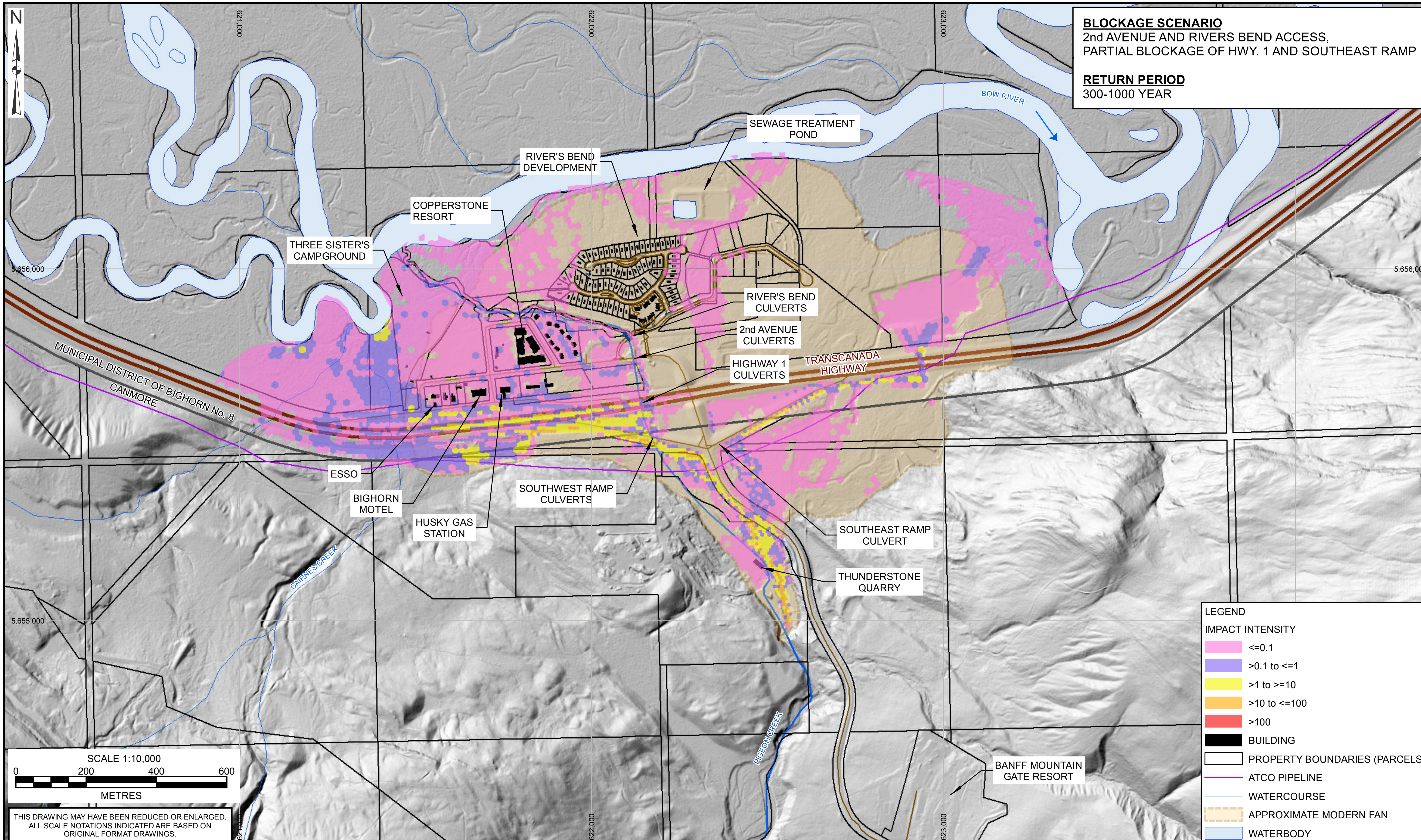

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Town of CANMORE

PROJECT:
PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE:
DEBRIS-FLOOD RAW MODEL OUTPUT
SCENARIO 4D

PROJECT No.:	DWG No.:
1261-014	A-11

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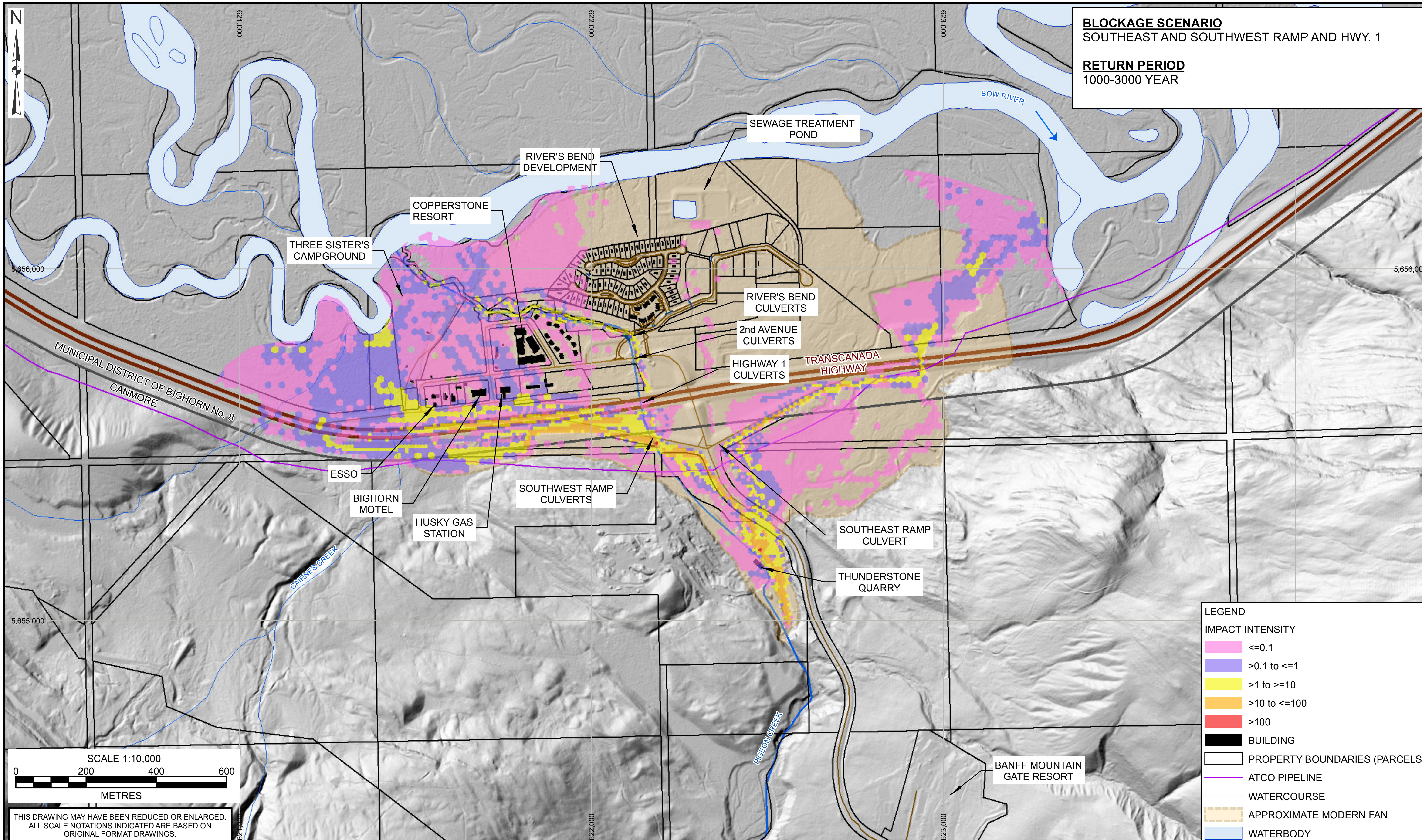

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CLIENT:
Town of CANMORE

PROJECT:
PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE:
DEBRIS-FLOOD RAW MODEL OUTPUT
SCENARIO 5B

PROJECT No.:	DWG No.:
1261-014	A-12

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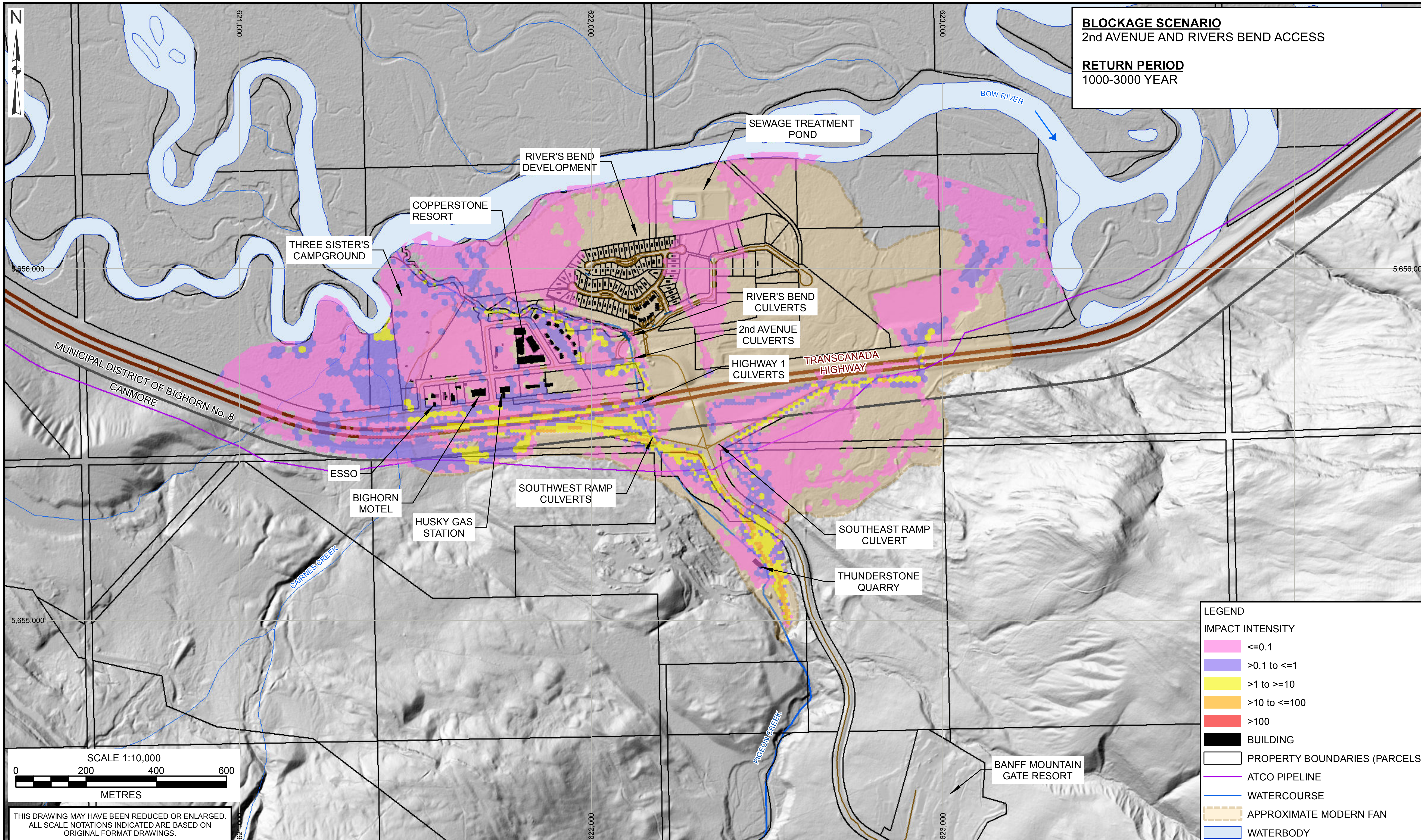

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BGC ENGINEERING INC.
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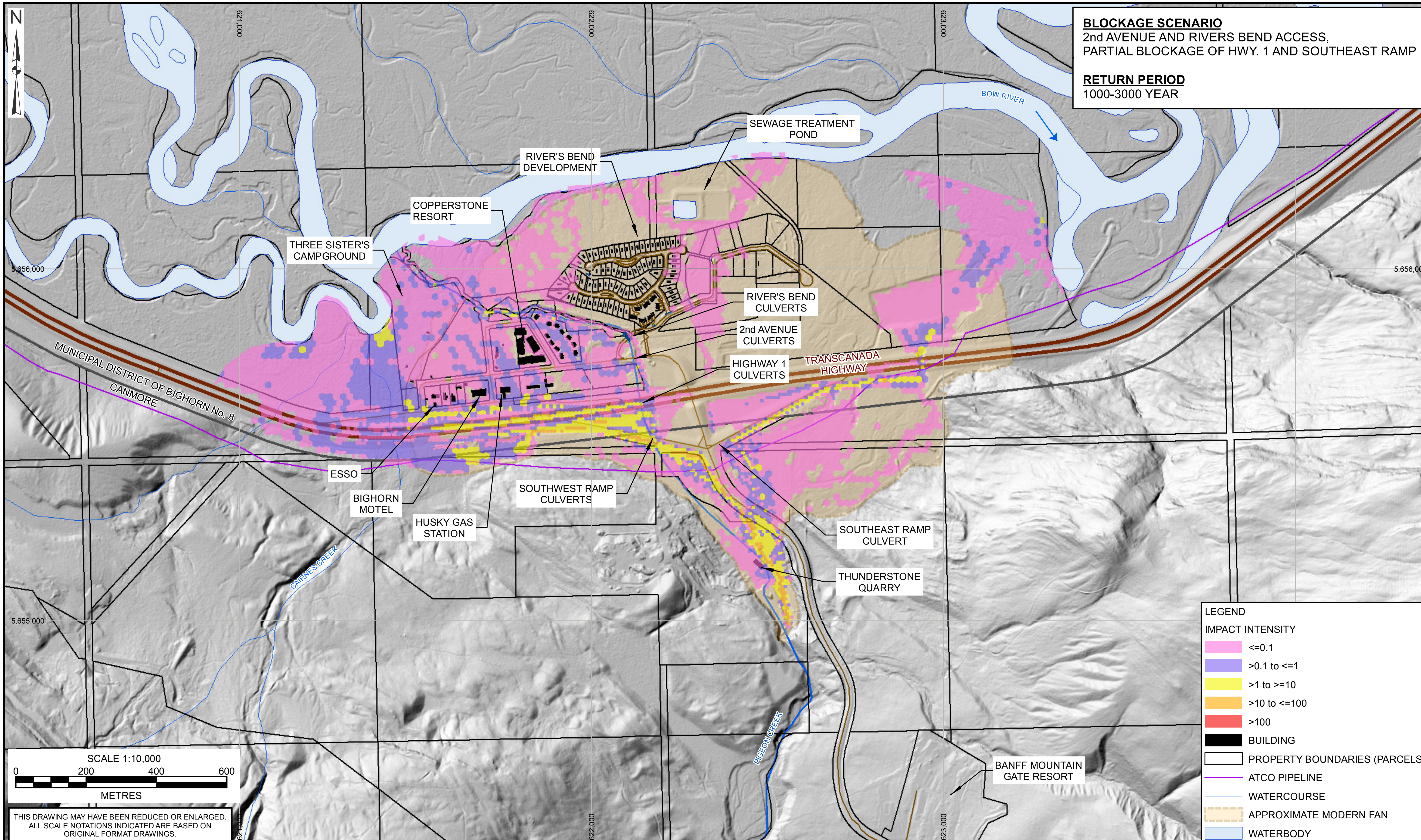
CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: DEBRIS-FLOOD RAW MODEL OUTPUT SCENARIO 5C

PROJECT No.: 1261-014

DWG No.: A-13



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Town of CANMORE

PROJECT:
PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE:
DEBRIS-FLOOD RAW MODEL OUTPUT
SCENARIO 5D

PROJECT No.:	DWG No.:
1261-014	A-14

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APPENDIX B
COMPARISON OF CASE STUDIES

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.

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[1]. The photographs suggest that an area alongside and south of the current creek was 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.

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.

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.

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

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.

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.

Although seven homes were destroyed or severely damaged, no deaths occurred. However, 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. Furthermore, it is reported that some residents heard the approaching debris flow and ran away from their homes.

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[2]. 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 %).

August 2005 Flooding, New Orleans, USA

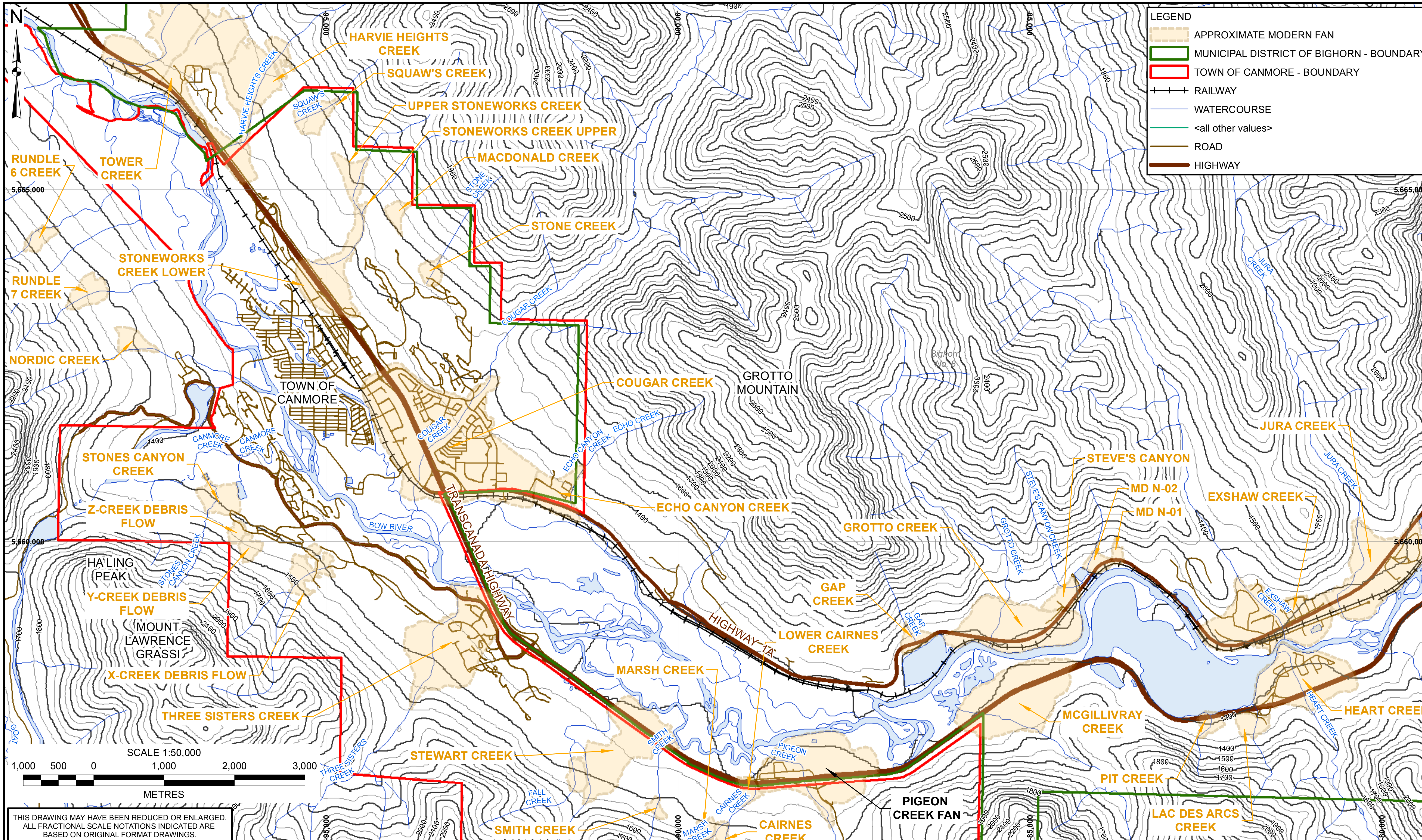
During landfall on August 29, 2005, Hurricane Katrina caused massive flooding and devastation along a 270 km stretch of the US Gulf Coast. The storm surge caused overtopping and breaching of levees around New Orleans. An area of 260 km^2 of the city flooded at some locations up to 4 m deep. It took over 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

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

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. 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%).

DRAWINGS



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NOTES:
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3. BASE TOPOGRAPHIC DATA BASED ON GEOBASE PROVIDED BY GEOBASE.CA, DATED 2013. CONTOUR INTERVAL IS 50 m.
4. PROJECTION IS NAD 83 3TM 114.
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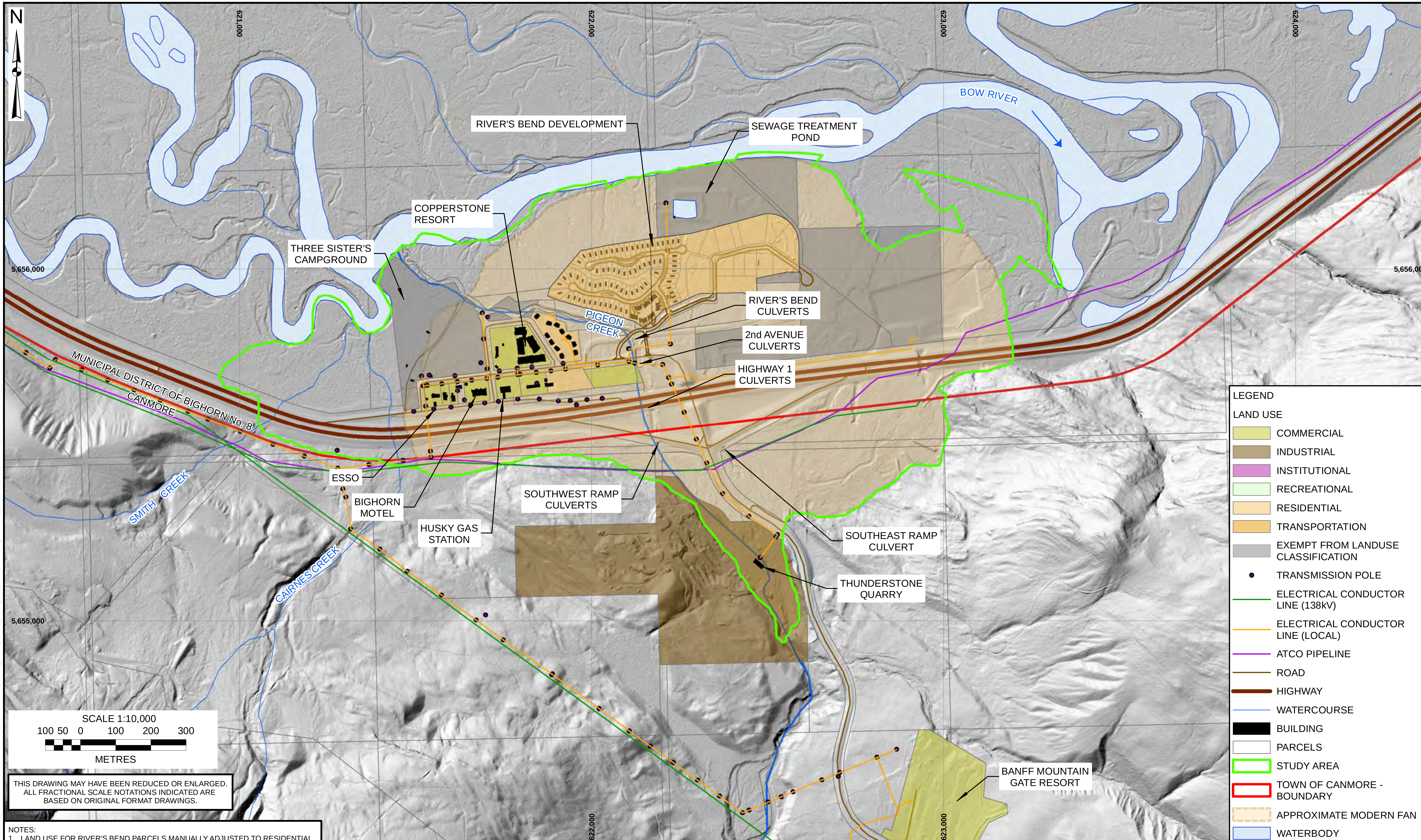
CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: LOCATION MAP

PROJECT No.: 1261014

DWG No.: 01



THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

NOTES:
1. LAND USE FOR RIVER'S BEND PARCELS MANUALLY ADJUSTED TO RESIDENTIAL.
2. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
3. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT," AND DATED SEPTEMBER 2016.
4. THE STUDY AREA BOUNDARY EXTENDS BEYOND THE GEOMORPHIC EXTENT OF THE FAN TO INCLUDE AREAS IMPACTED BY MODELLED DEBRIS-FLOODS.
5. PARCELS AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
6. TRANSMISSION POLE, ELECTRICAL POWER LINE PROVIDED BY TOWN OF CANMORE.
7. WATERCOURSE, WATER BODY AND RAILWAY WERE OBTAINED FROM CANVEC.
8. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY LIDAR SERVICES IN C. (LSI), DATED JUNE 28, 2013. CONTOUR INTERVAL IS 5 m.
9. PROJECTION IS NAD 83 UTM ZONE 11N.
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AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: BASEMAP: BUILDINGS AND SURFACE INFRASTRUCTURE

PROJECT No.:	DWG No.:
1261014	02

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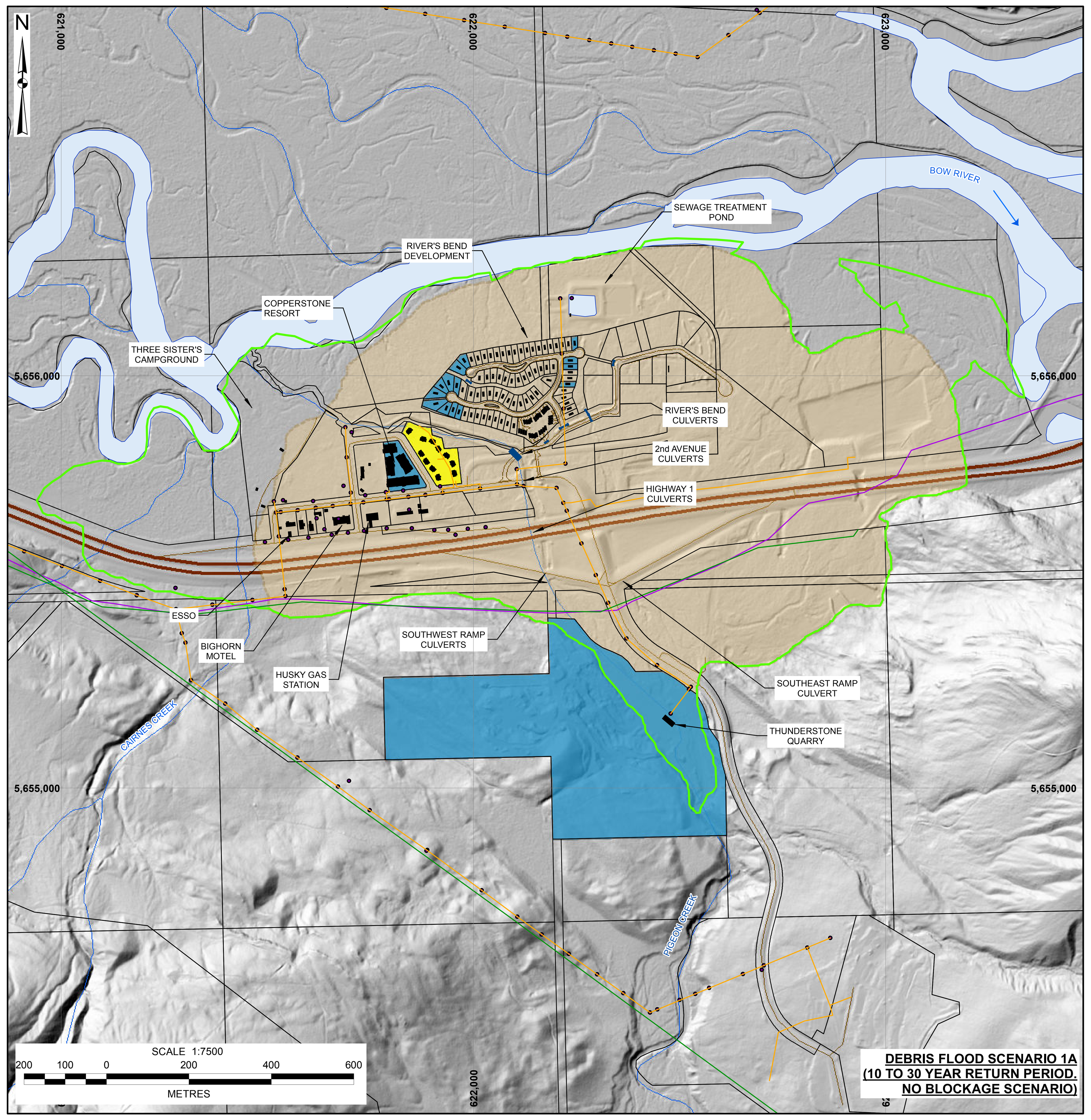

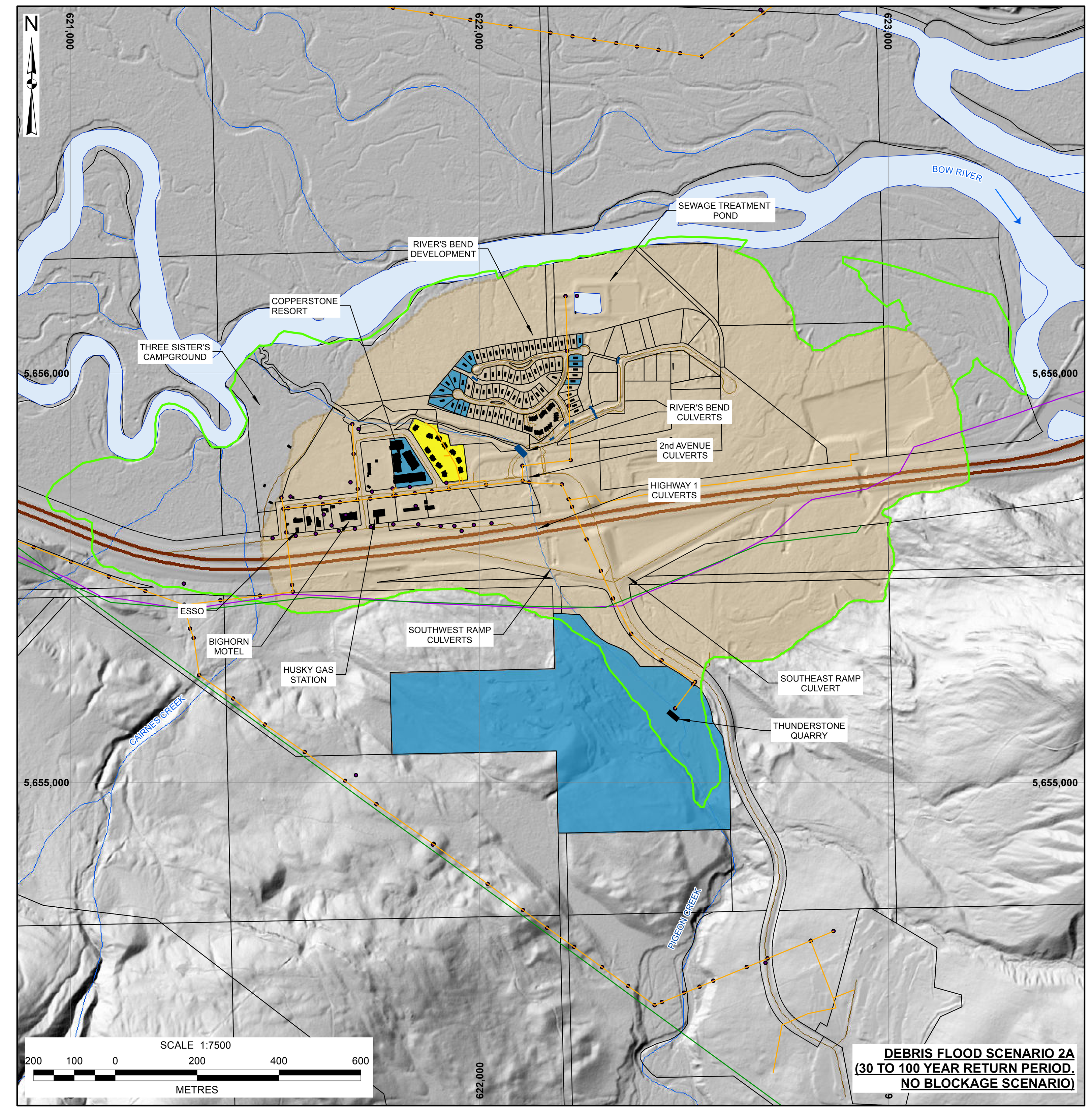

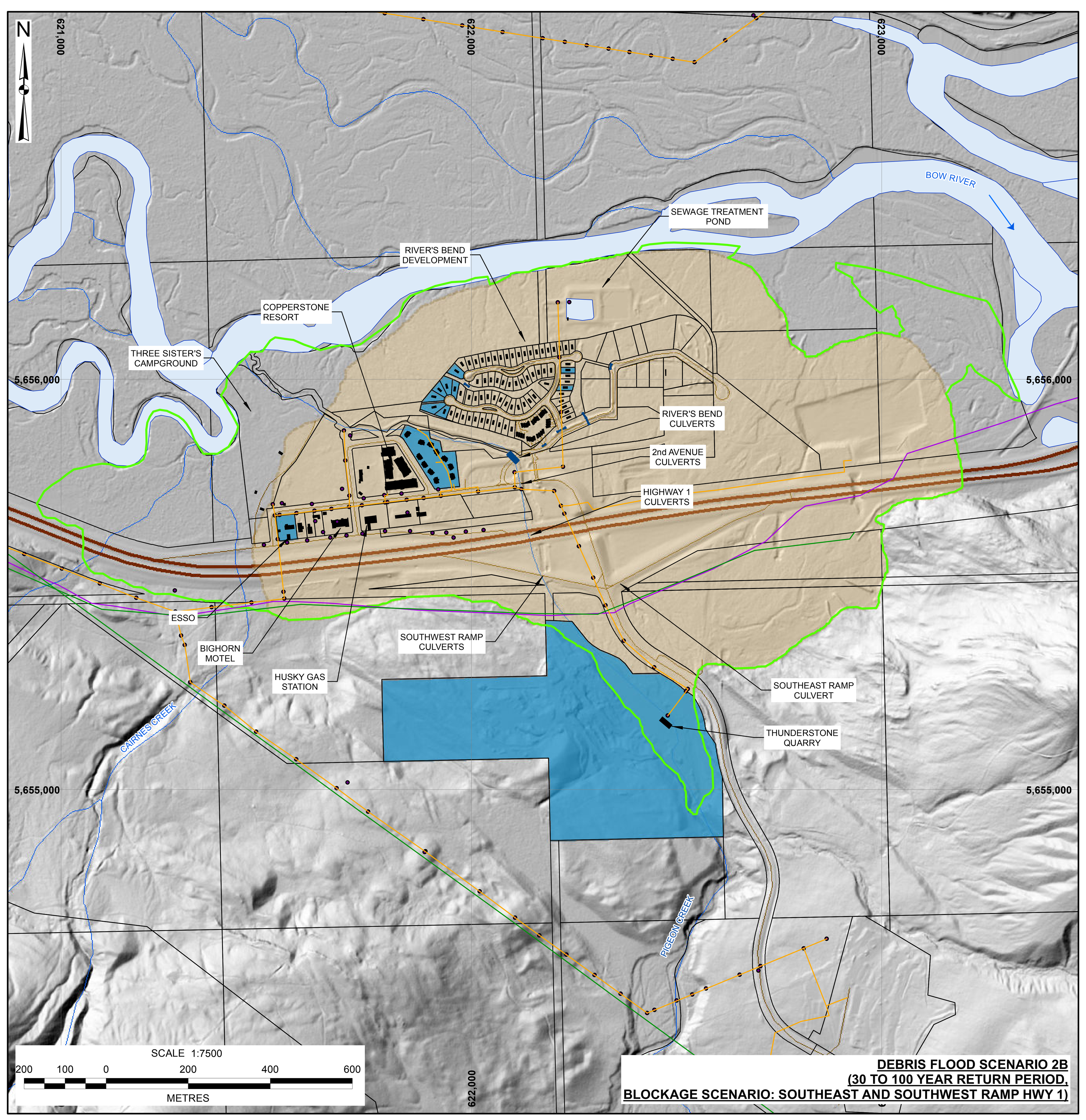

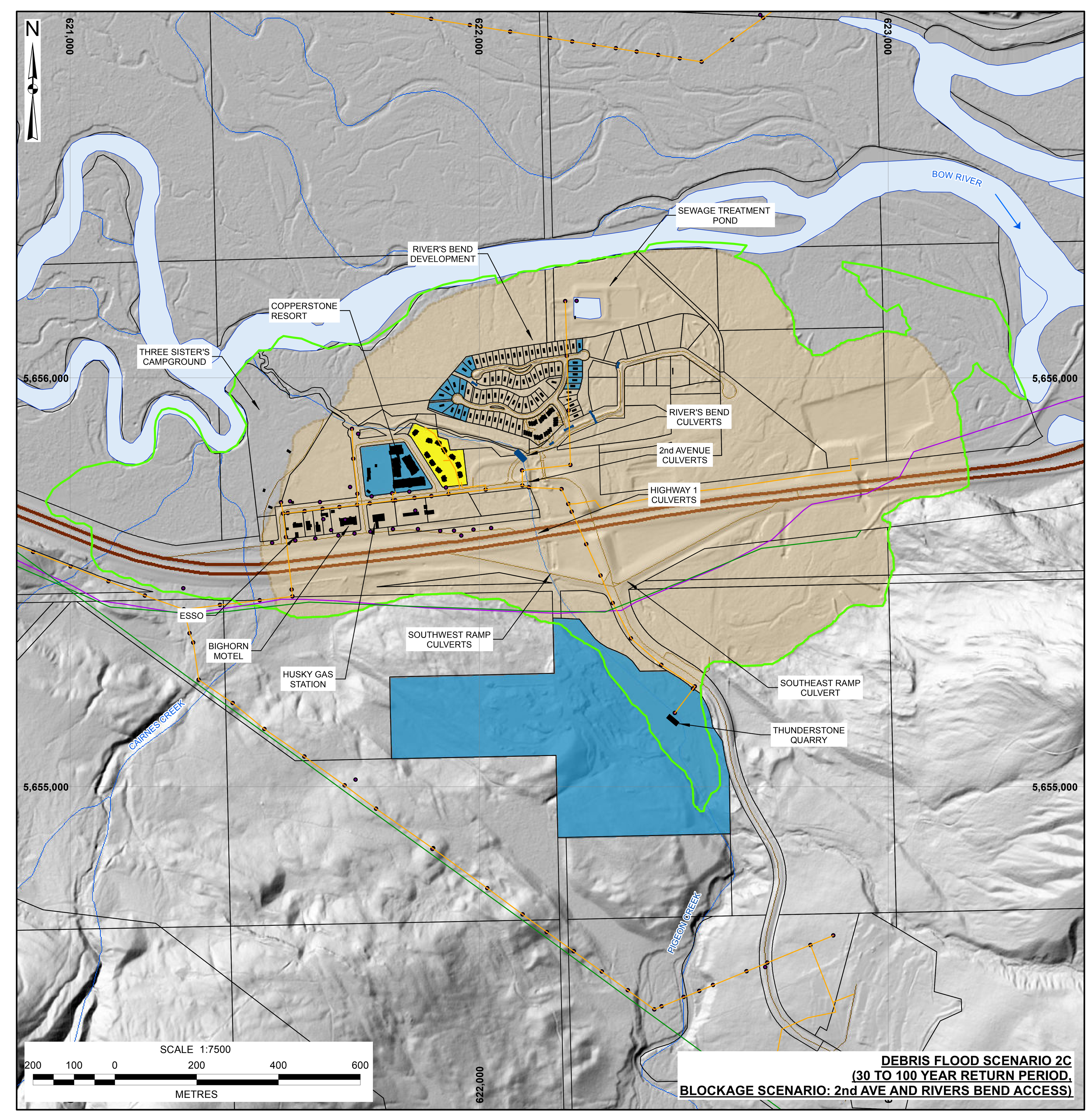

THIS BAR MEASURES 100 mm AT FULL SIZE. ALL SCALES REFERENCED TO FULL SIZE

THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

BUILDING DAMAGE
- MODERATE DAMAGE (>0-25%)
- MAJOR DAMAGE (>25%-75%)
- SEVERE DAMAGE (>75%-90%)
- DESTRUCTION (>90%)
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (138kV)
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- ATCO PIPELINE
- CULVERTS
- ROAD
- HIGHWAY
- WATERCOURSE
- BUILDING
- PROPERTY BOUNDARIES (PARCELS)
- STUDY AREA BOUNDARY
- APPROXIMATE MODERN FAN
- WATERBODY

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT" AND DATED SEPTEMBER 2016.
3. PROJECTION IS NAD 83 UTM ZONE 11N.
4. THE STUDY AREA BOUNDARY EXTENDS BEYOND THE GEOMORPHIC EXTENT OF THE FAN TO INCLUDE AREAS IMPACTED BY MODELLED DEBRIS-FLOODS.
5. BUILDINGS, PARCELS, AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
6. WATERCOURSES, WATERBODIES, ROADS AND RAILWAY WERE OBTAINED FROM CANVEC.
7. HILLSHADE WAS DERIVED FROM LIDAR PROVIDED BY LIDAR SERVICES IN C. (LSI), DATED JUNE 28, 2013.
8. MODEL RUNS (DEBRIS FLOOD SCENARIOS) ARE LABELLED IN THE LOWER RIGHT HAND CORNER OF EACH MAP INSET.
9. THIS MAP SHOULD NOT BE RELIED UPON AT A SCALE LARGER THAN (MORE DETAILED) THAN SHOWN ON THIS MAP.
10. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT THE RE-DRAWING OF CERTAIN AREAS.
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SCALE:	1:7,500
DATE:	SEP 2016
DRAWN:	JDC
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: DIRECT DAMAGE LEVELS, BUILDINGS: DEBRIS-FLOOD SCENARIOS 1A-2C

PROJECT No.: 1261014

DWG No.: 03

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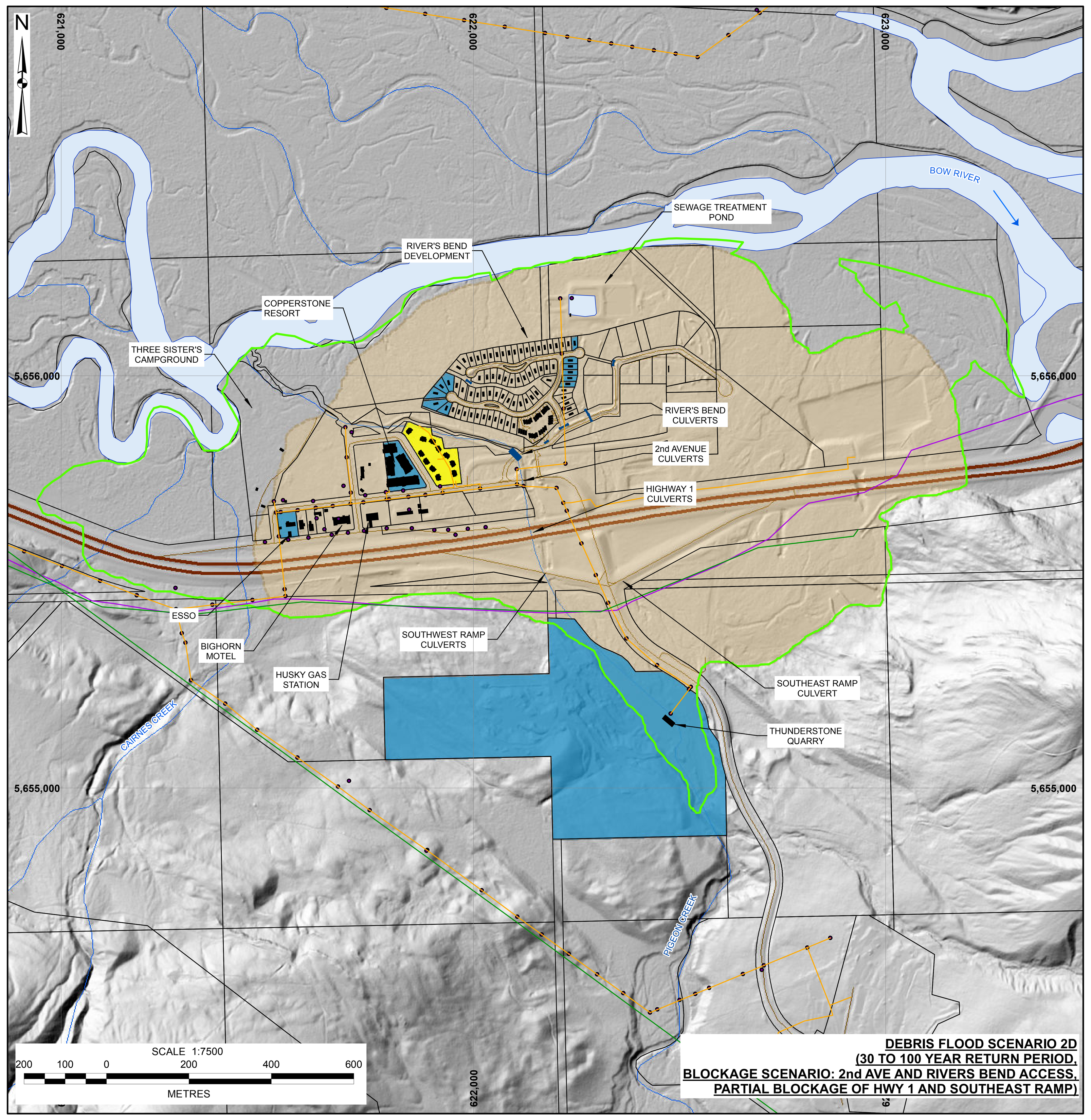

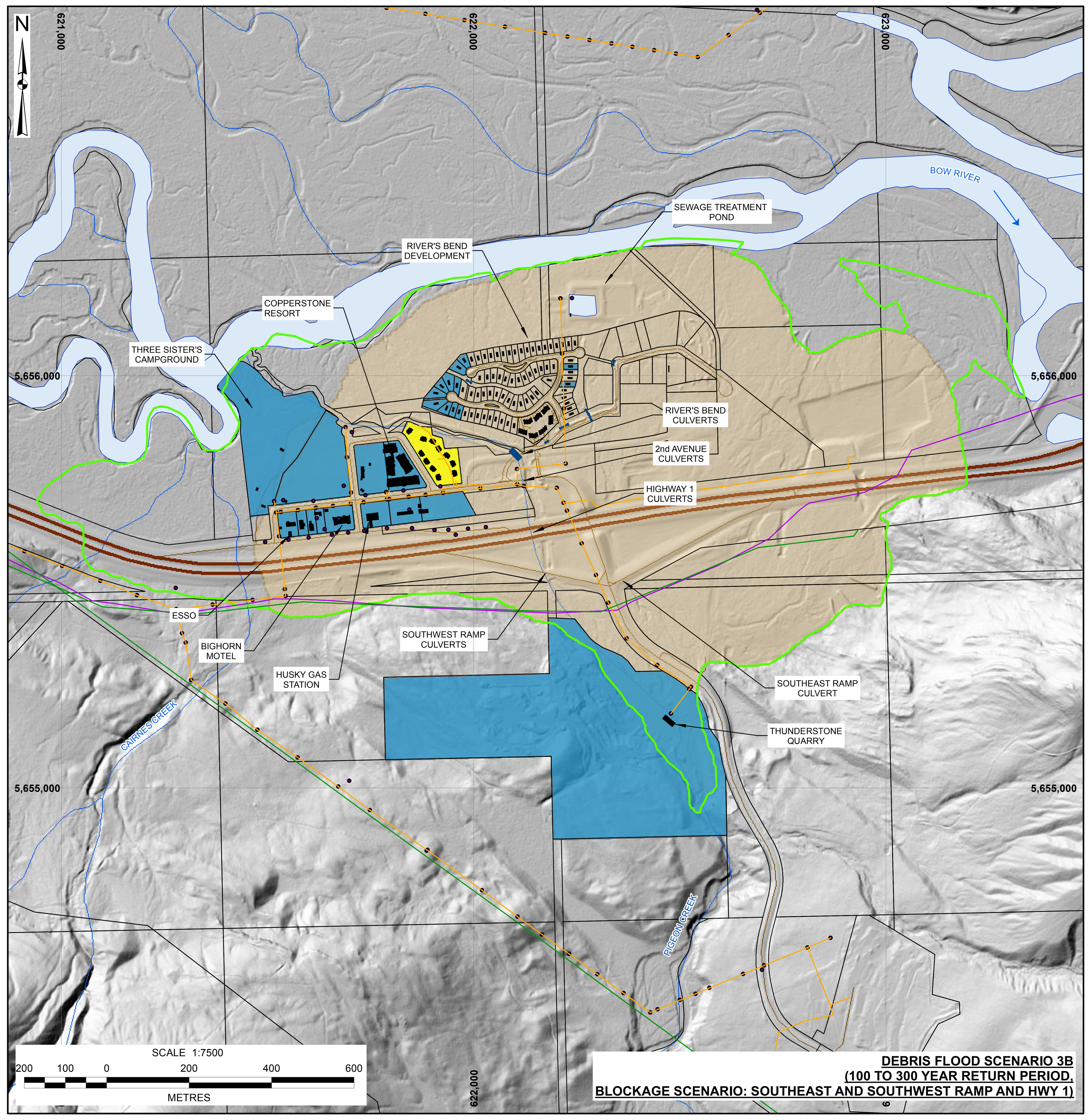

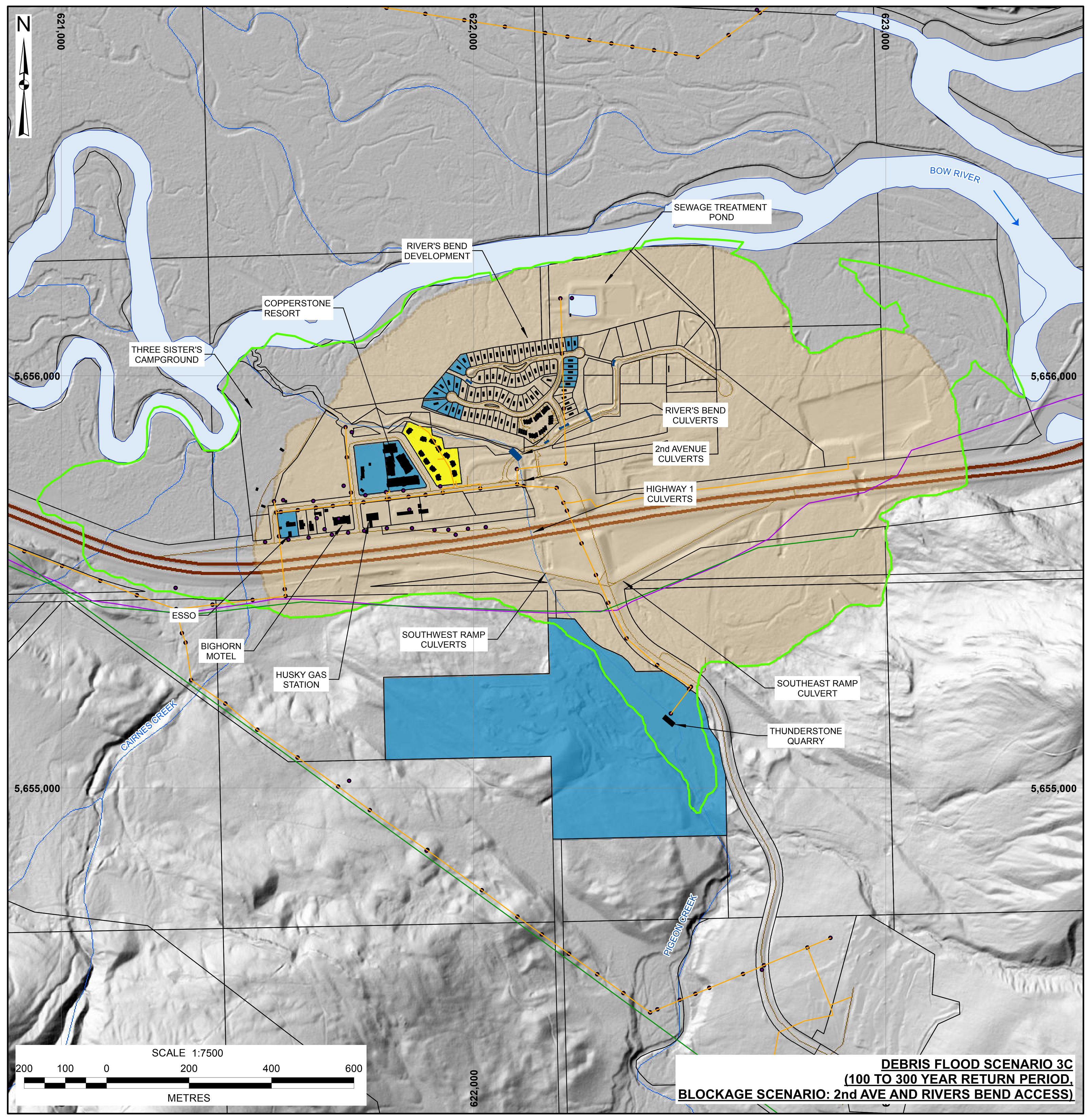

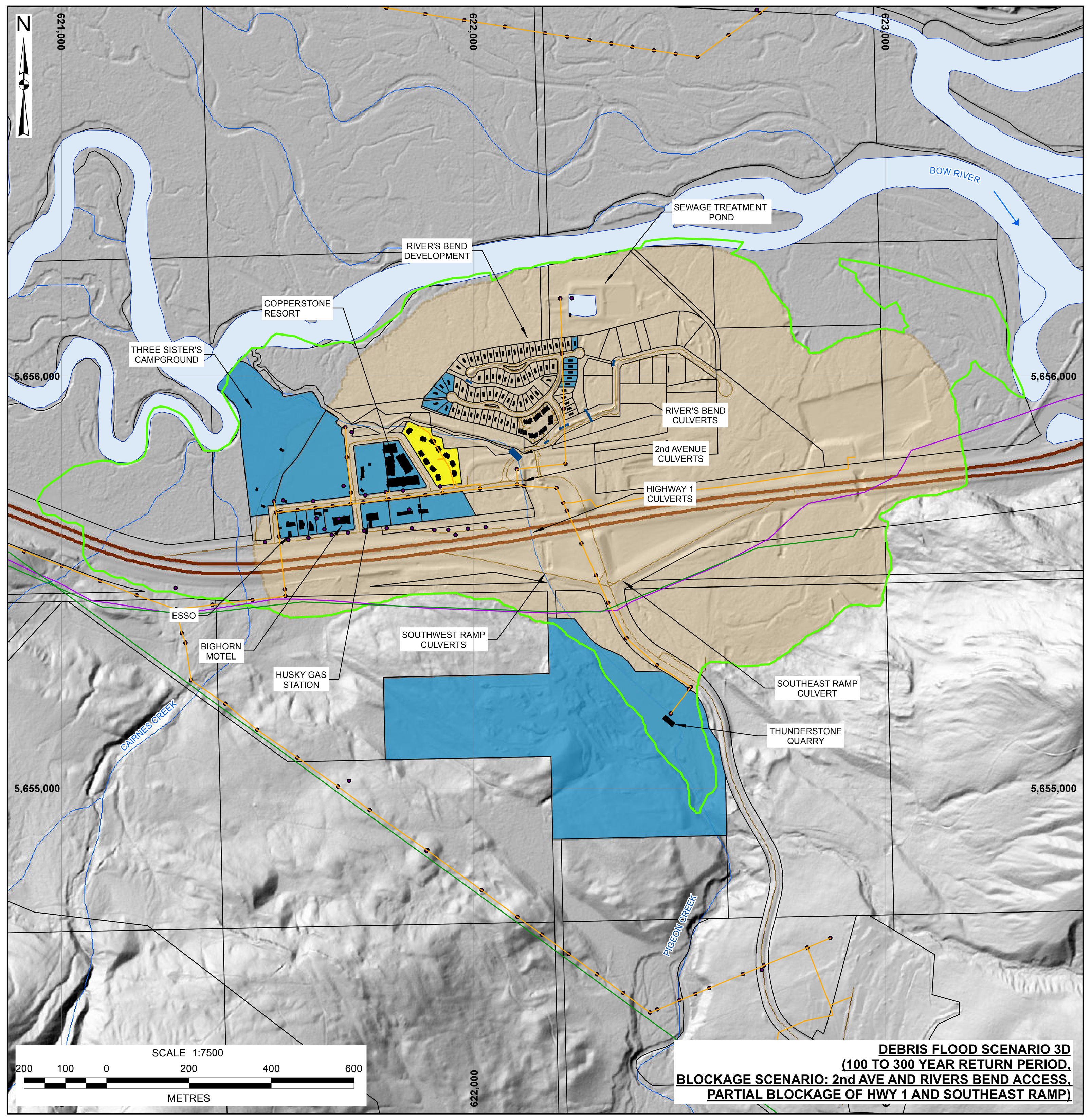

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LEGEND

BUILDING DAMAGE
- MODERATE DAMAGE (>0-25%)
- MAJOR DAMAGE (>25%-75%)
- SEVERE DAMAGE (>75%-90%)
- DESTRUCTION (>90%)
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (138kV)
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- ATCO PIPELINE
- CULVERTS
- ROAD
- HIGHWAY
- WATERCOURSE
- BUILDING
- PROPERTY BOUNDARIES (PARCELS)
- STUDY AREA BOUNDARY
- APPROXIMATE MODERN FAN
- WATERBODY

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT" AND DATED SEPTEMBER 2016.
3. PROJECTION IS NAD 83 UTM ZONE 11N.
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SCALE:	1:7,500
DATE:	SEP 2016
DRAWN:	JDC
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

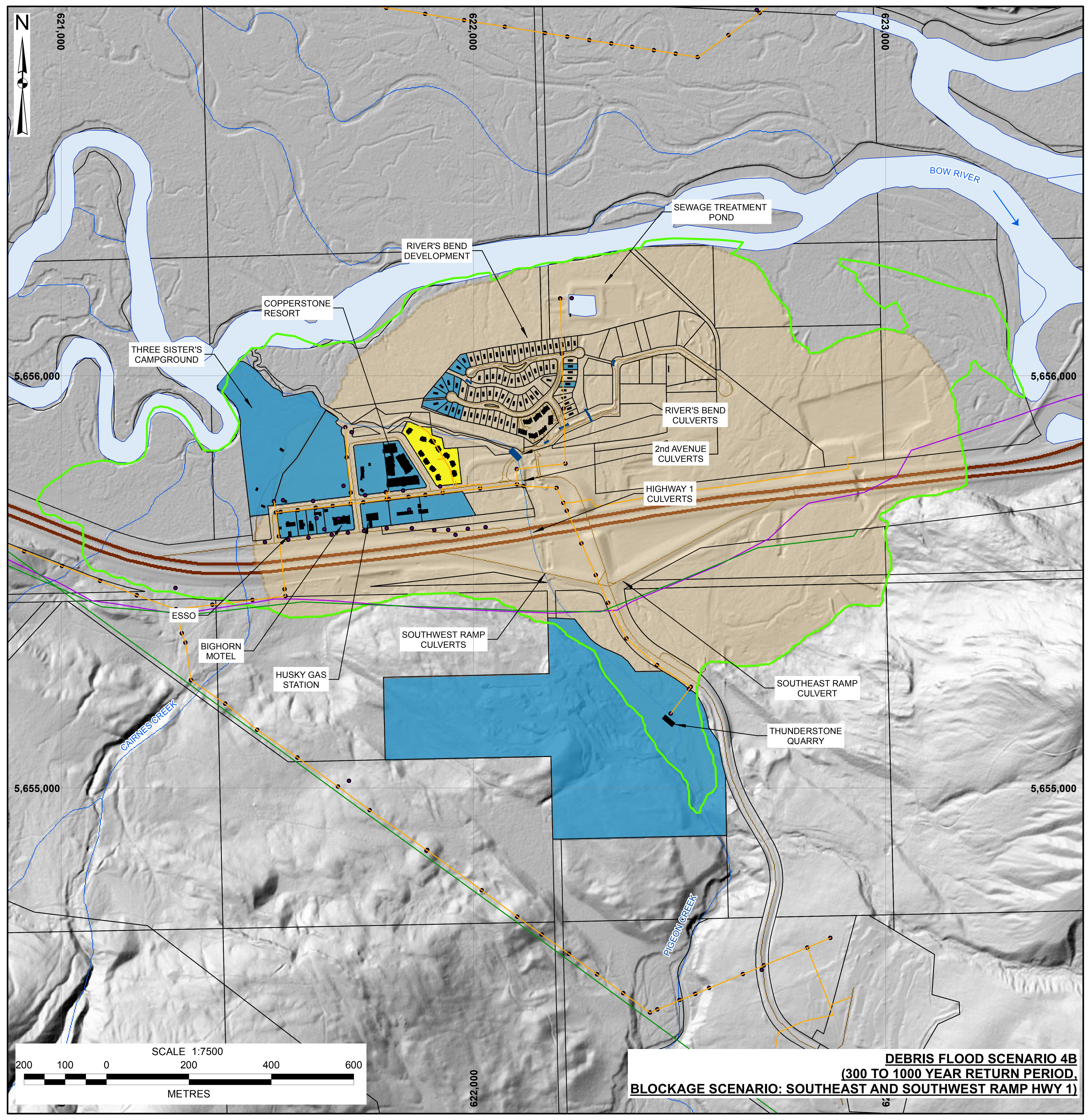
CLIENT: Town of CANMORE

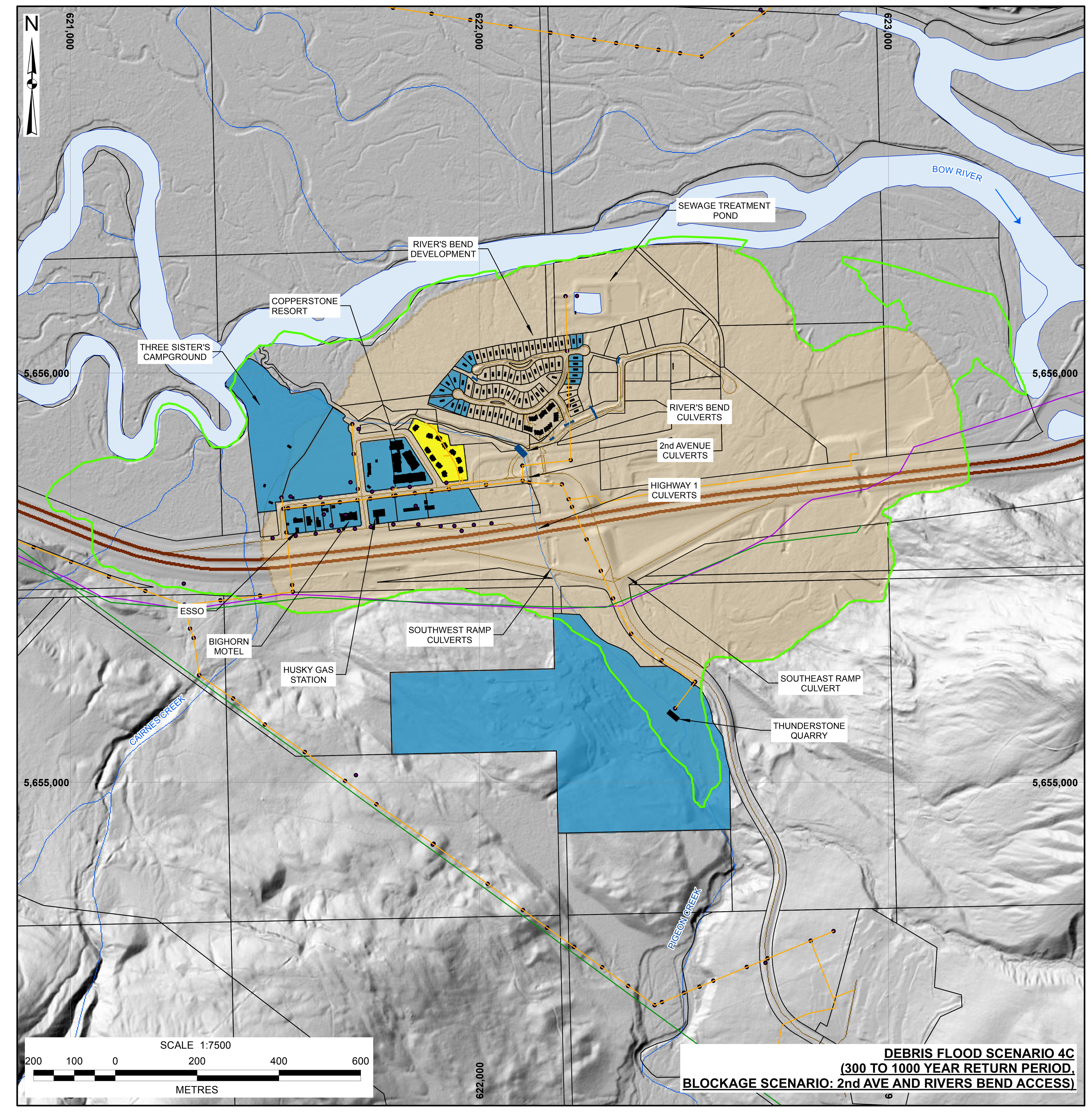
PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

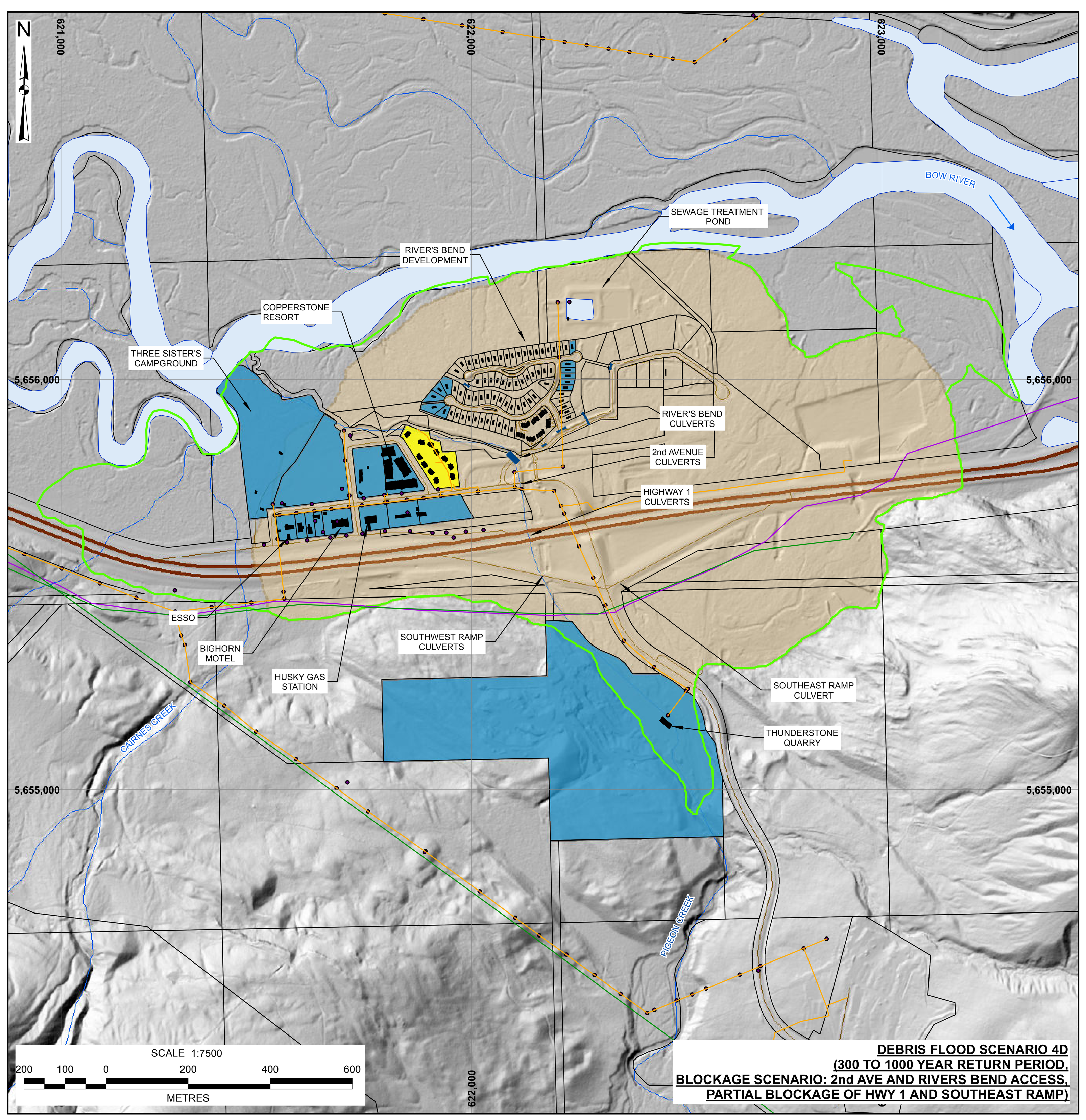
TITLE: DIRECT DAMAGE LEVELS, BUILDINGS: DEBRIS-FLOOD SCENARIOS 2D-3D

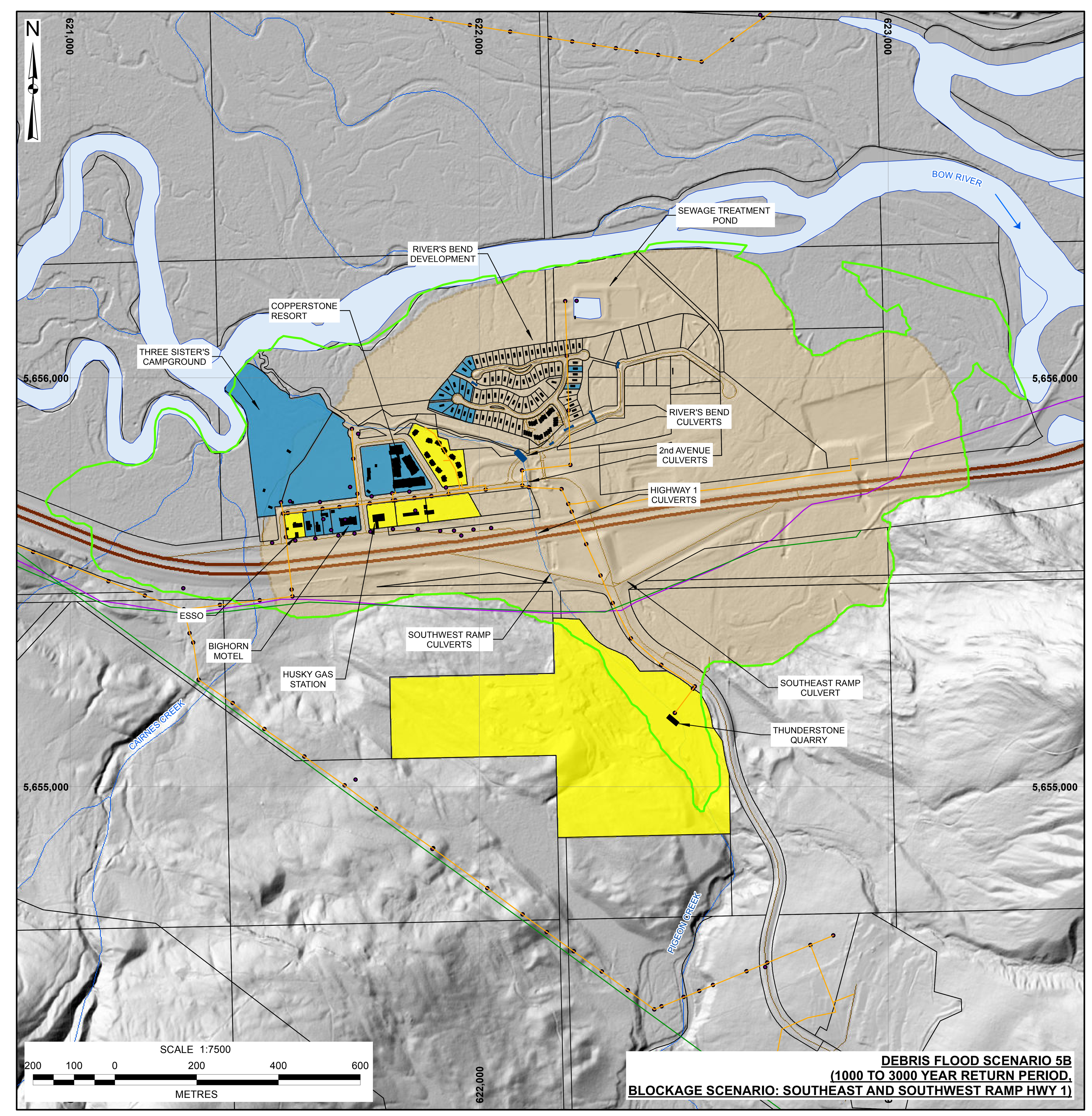
PROJECT No.: 1261014

DWG No.: 04









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LEGEND

BUILDING DAMAGE
- MODERATE DAMAGE (>0-25%)
- MAJOR DAMAGE (>25%-75%)
- SEVERE DAMAGE (>75%-90%)
- DESTRUCTION (>90%)
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (138kV)
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- ATCO PIPELINE
- CULVERTS
- ROAD
- HIGHWAY
- WATERCOURSE
- BUILDING
- PROPERTY BOUNDARIES (PARCELS)
- STUDY AREA BOUNDARY
- APPROXIMATE MODERN FAN
- WATERBODY

NOTES:
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2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT" AND DATED SEPTEMBER 2016.
3. PROJECTION IS NAD 83 UTM ZONE 11N.
4. THE STUDY AREA BOUNDARY EXTENDS BEYOND THE GEOMORPHIC EXTENT OF THE FAN TO INCLUDE AREAS IMPACTED BY MODELLED DEBRIS-FLOODS.
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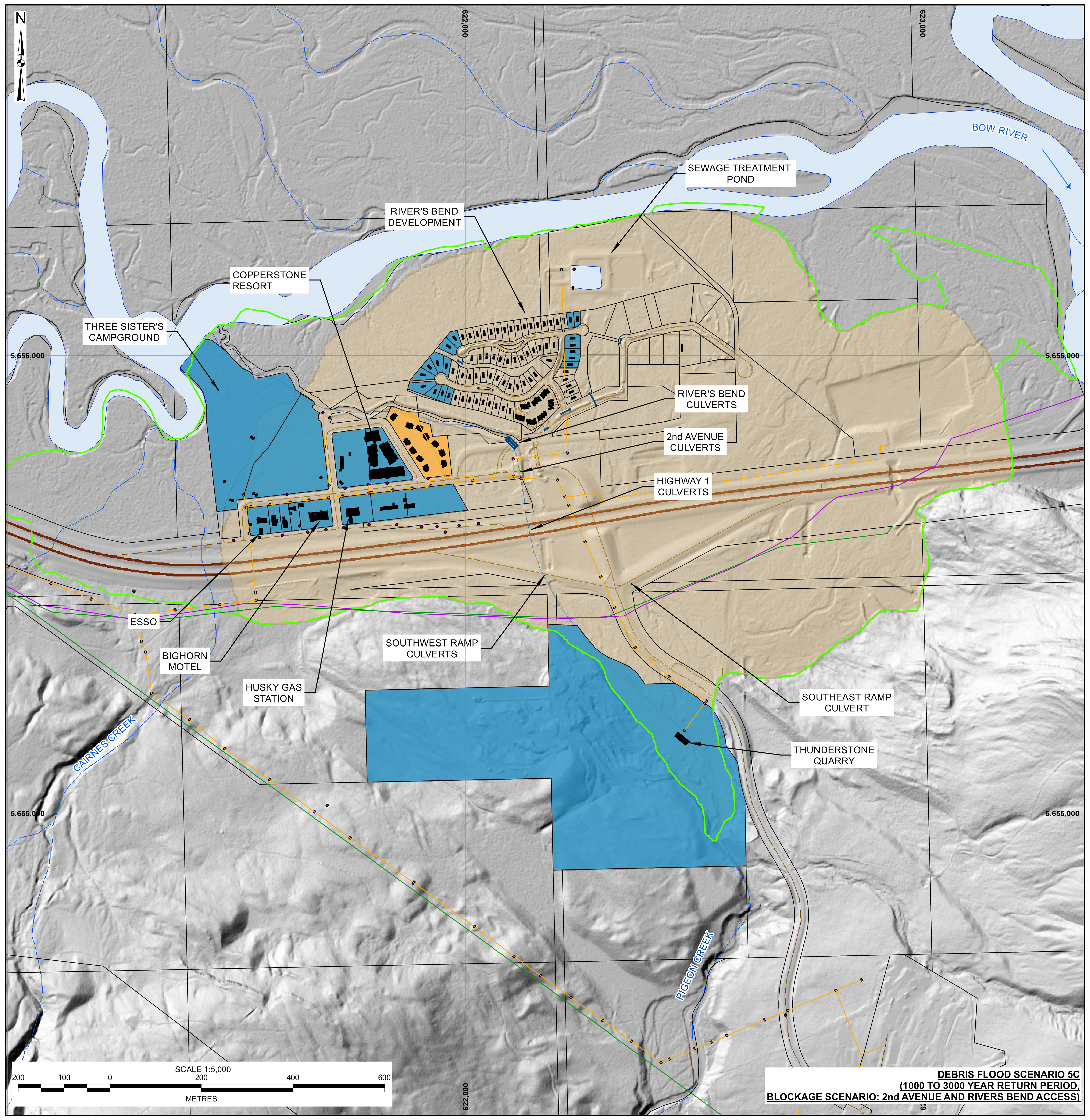
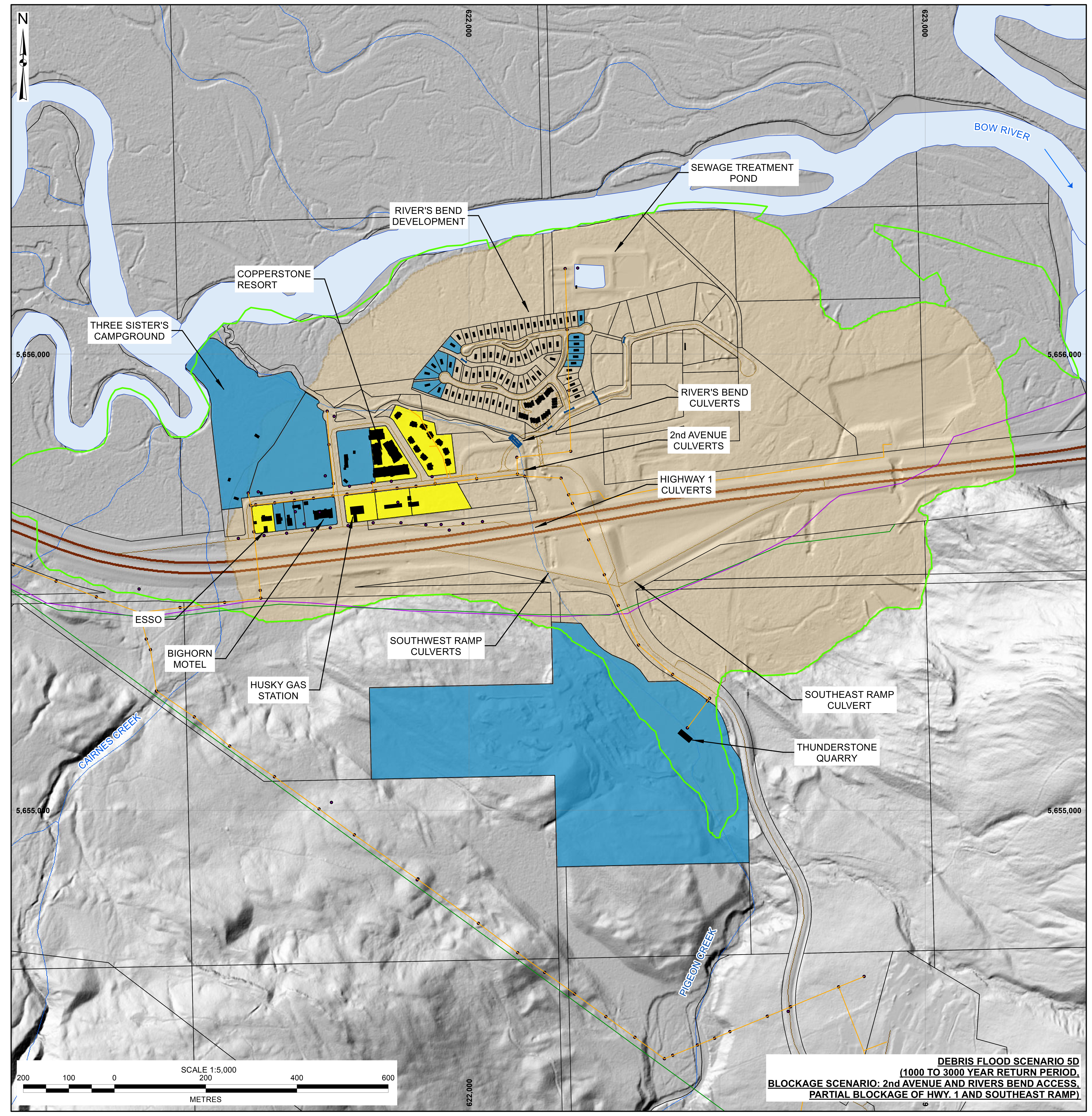
SCALE: 1:7,500	BGC ENGINEERING INC. AN APPLIED EARTH SCIENCES COMPANY	PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT	
DATE: SEP 2016		TITLE: DIRECT DAMAGE LEVELS, BUILDINGS: DEBRIS-FLOOD SCENARIOS 4B-5B	
DRAWN: JDC	CLIENT: Town of CANMORE		
CHECKED: SK		PROJECT No.: 1261014	DWG No.: 05
APPROVED: KH			

THIS BAR MEASURES 100 mm AT FULL SIZE. ALL SCALES REFERENCED TO FULL SIZE





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LEGEND

BUILDING DAMAGE
- MODERATE DAMAGE (>0-25%)
- MAJOR DAMAGE (>25%-75%)
- SEVERE DAMAGE (>75%-90%)
- DESTRUCTION (>90%)
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (138kV)
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- ATCO PIPELINE
- CULVERTS
- ROAD
- HIGHWAY
- WATERCOURSE
- BUILDING
- PROPERTY BOUNDARIES (PARCELS)
- STUDY AREA BOUNDARY
- APPROXIMATE MODERN FAN
- WATERBODY

NOTES:
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3. PROJECTION IS NAD 83 UTM ZONE 11N.
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SCALE:	1:5,000
DATE:	SEP 2016
DRAWN:	JDC
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

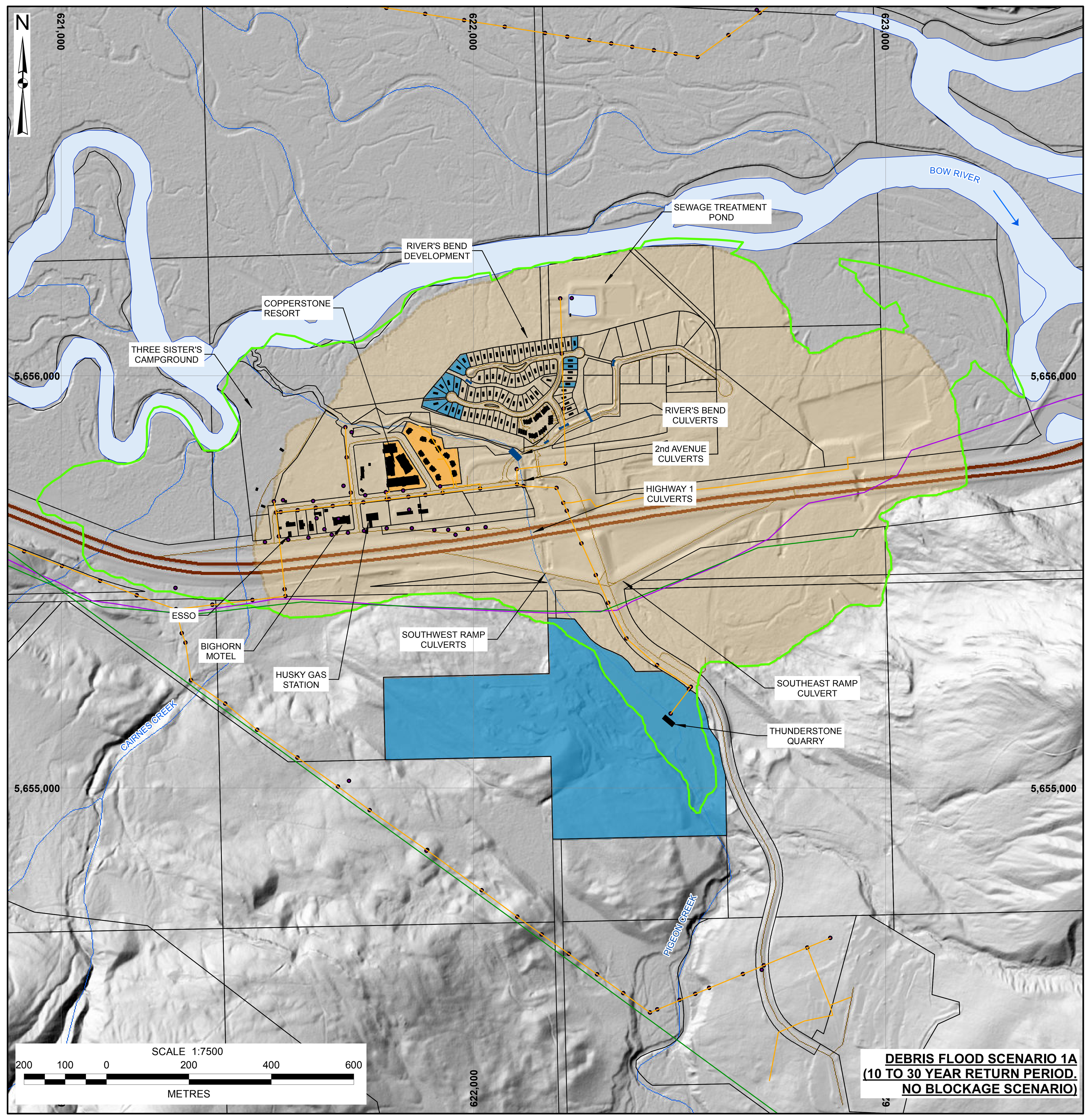
CLIENT: Town of CANMORE

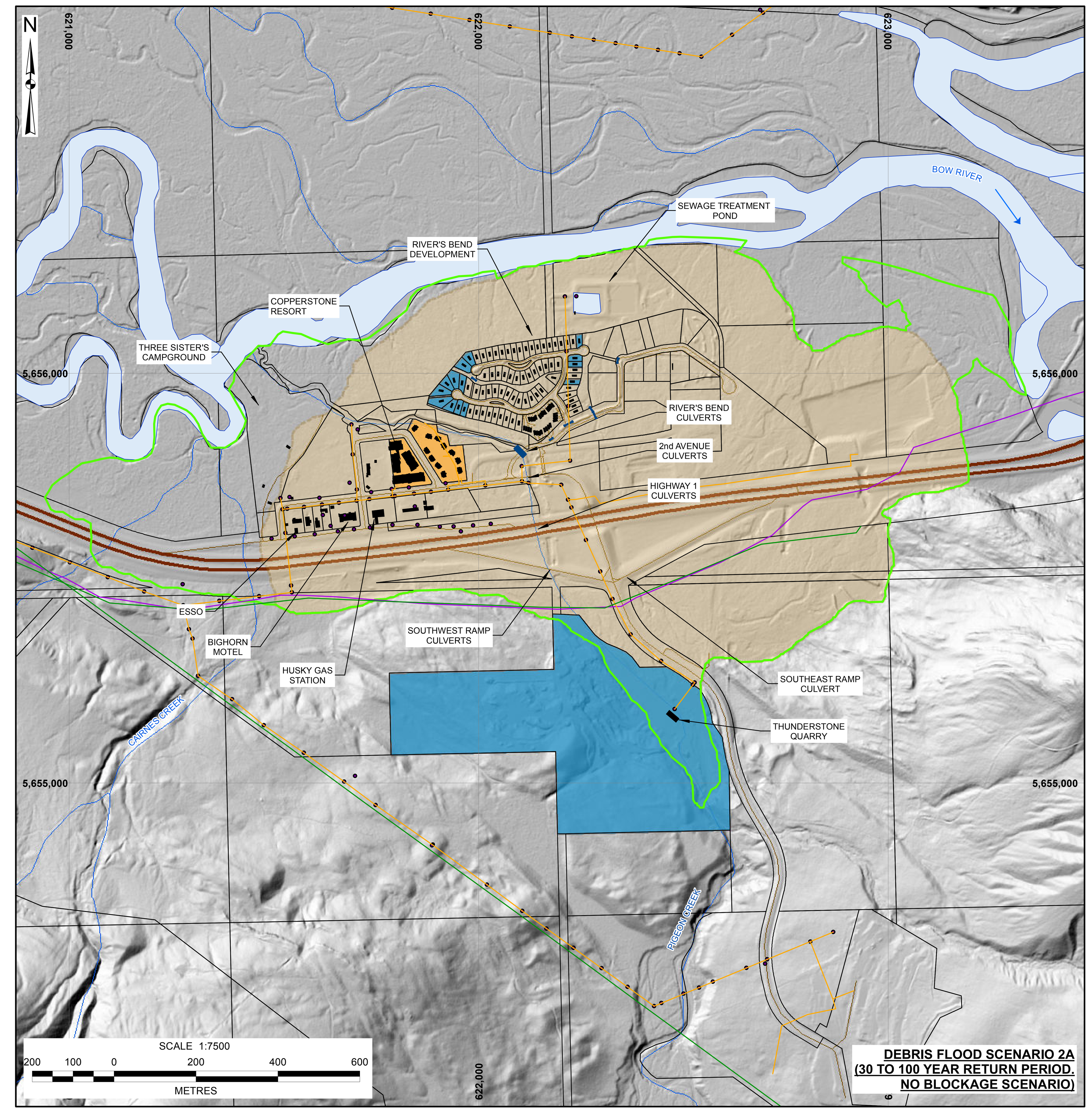
PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

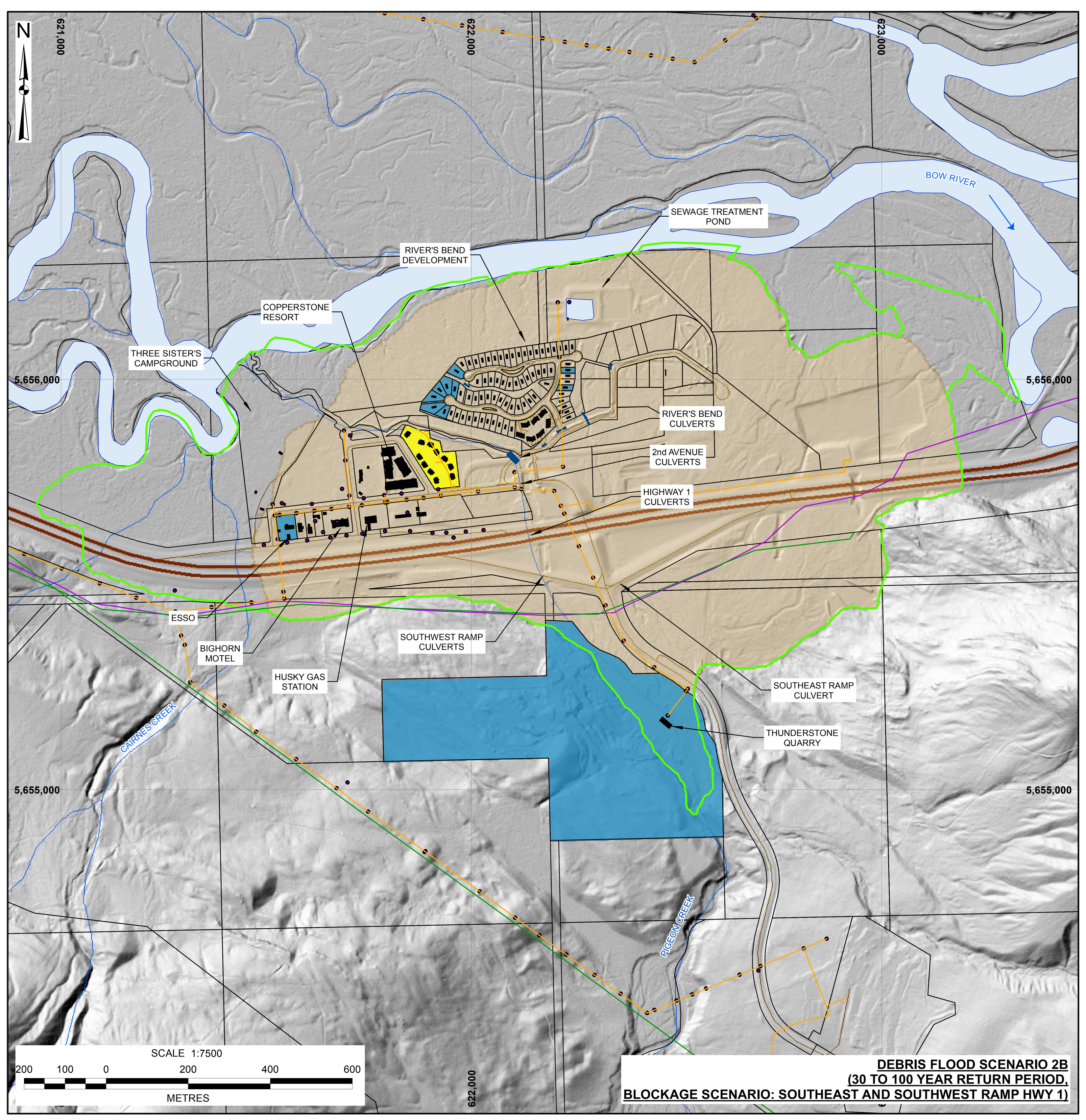
TITLE: DIRECT DAMAGE LEVELS, BUILDINGS: DEBRIS-FLOOD SCENARIOS 5C-5D

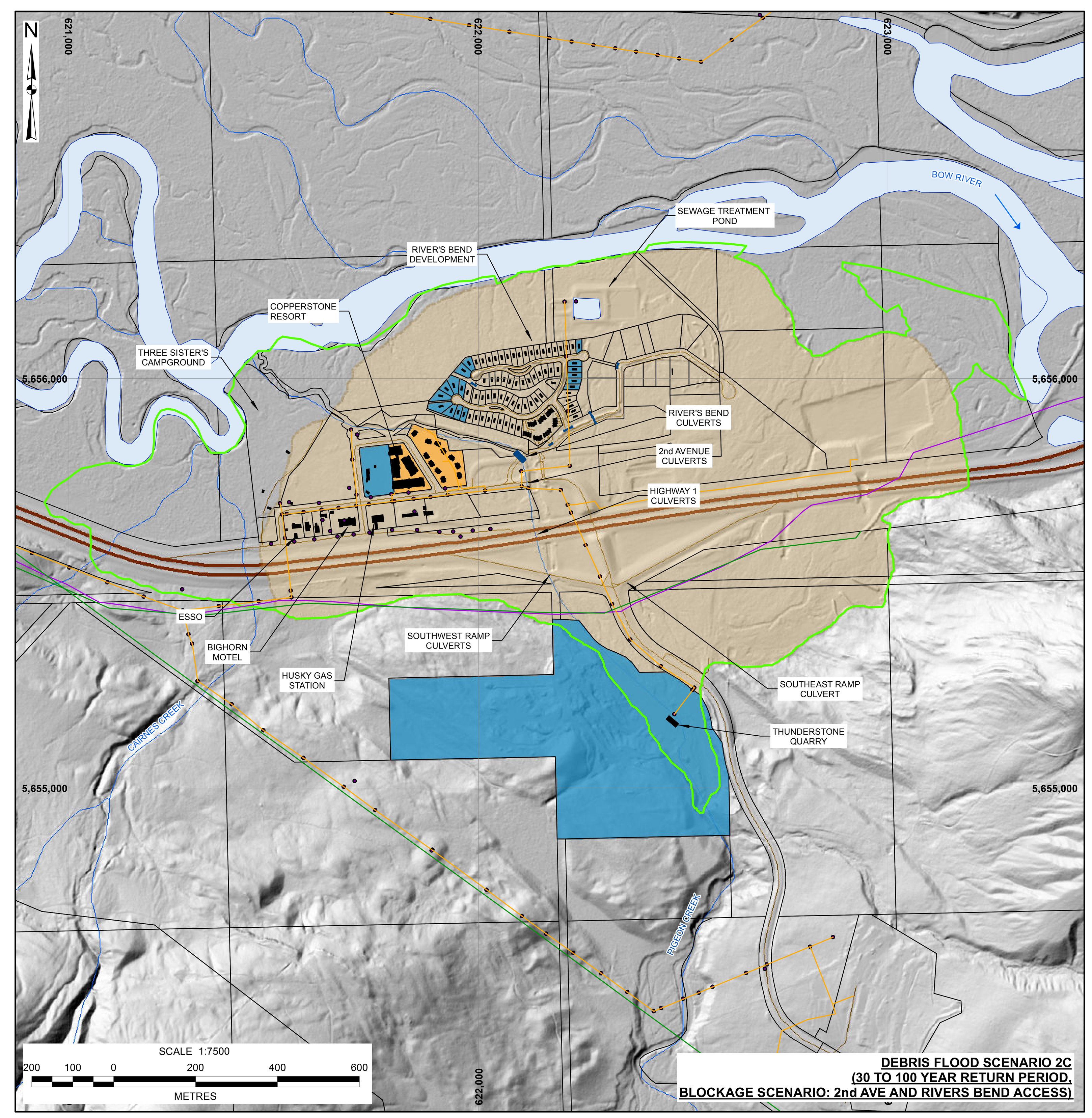
PROJECT No.: 1261014

DWG No.: 06









THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

BUILDING DAMAGE COST
- ≤\$0.1M DAMAGE
- >\$0.1M TO \$1M DAMAGE
- >\$1M TO \$10M DAMAGE
- >\$10M DAMAGE
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (138kV)
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- ATCO PIPELINE
- CULVERTS
- ROAD
- HIGHWAY
- WATERCOURSE
- BUILDING
- PROPERTY BOUNDARIES (PARCELS)
- STUDY AREA BOUNDARY
- APPROXIMATE MODERN FAN
- WATERBODY

NOTES:
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3. PROJECTION IS NAD 83 UTM ZONE 11N.
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SCALE:	1:7,500
DATE:	SEP 2016
DRAWN:	JDC
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: DIRECT DAMAGE COSTS, BUILDINGS: DEBRIS-FLOOD SCENARIOS 1A-2C

PROJECT No.: 1261014

DWG No.: 07

THIS BAR MEASURES 100 mm AT FULL SIZE. ALL SCALES REFERENCED TO FULL SIZE

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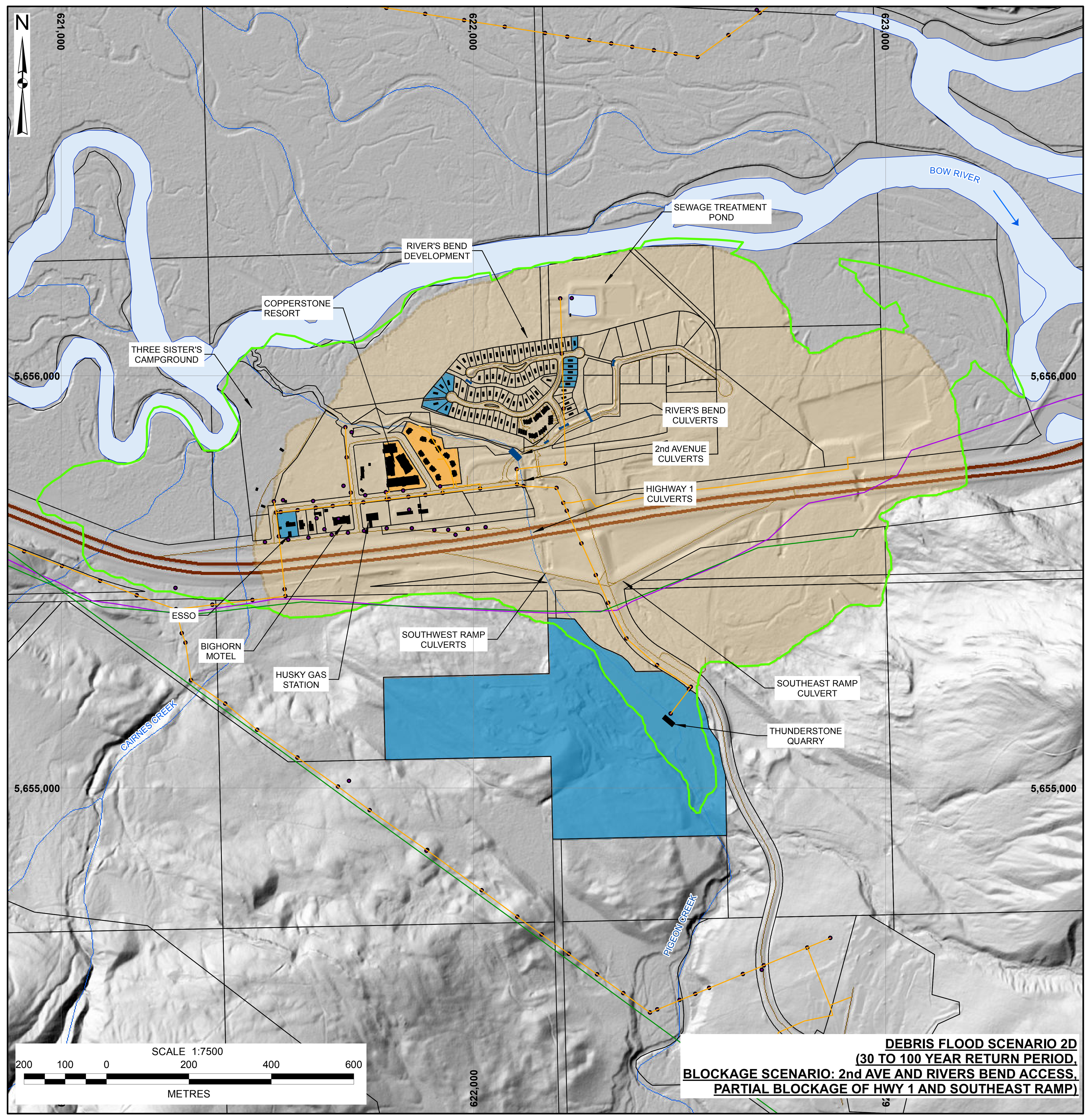

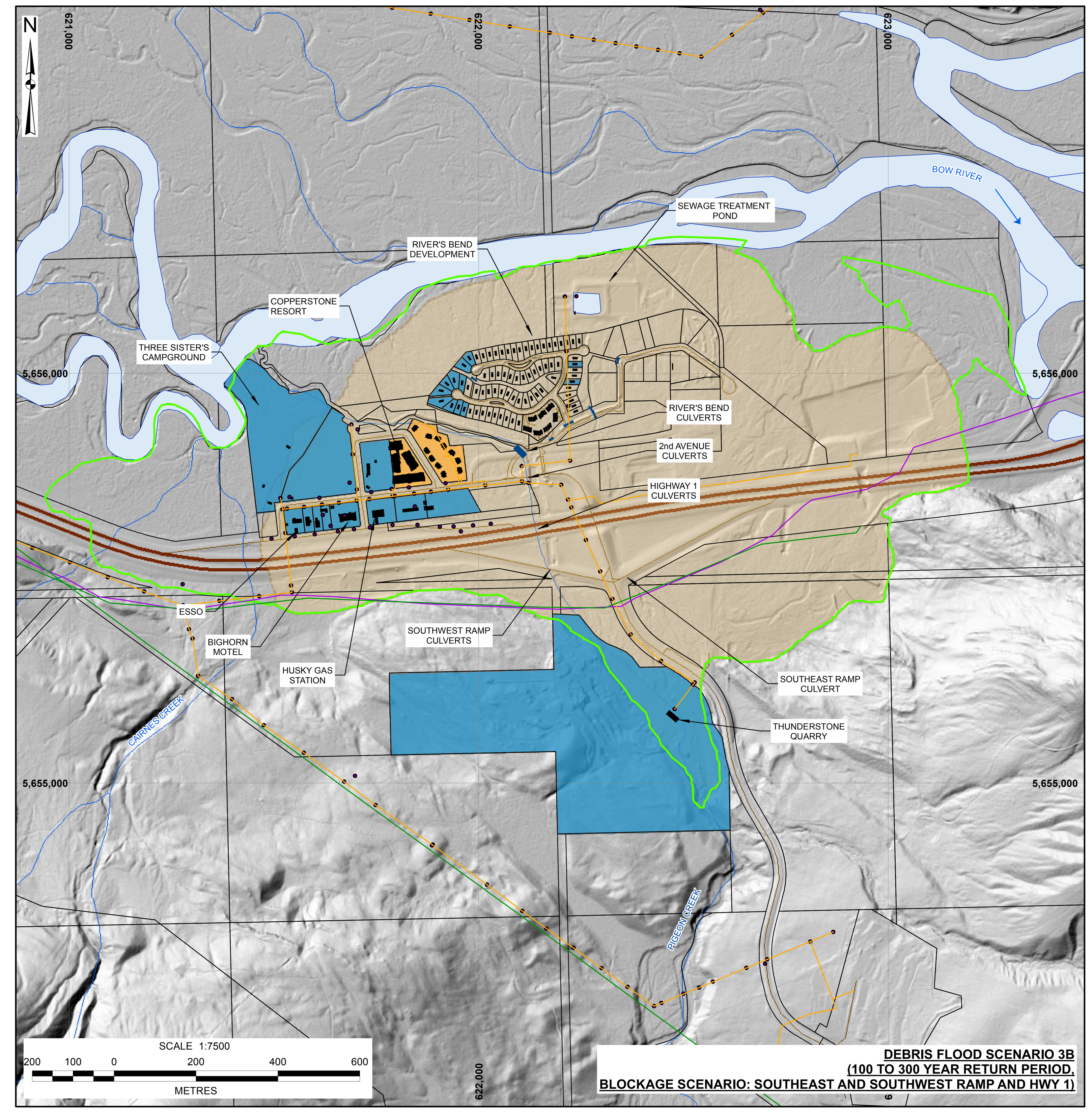

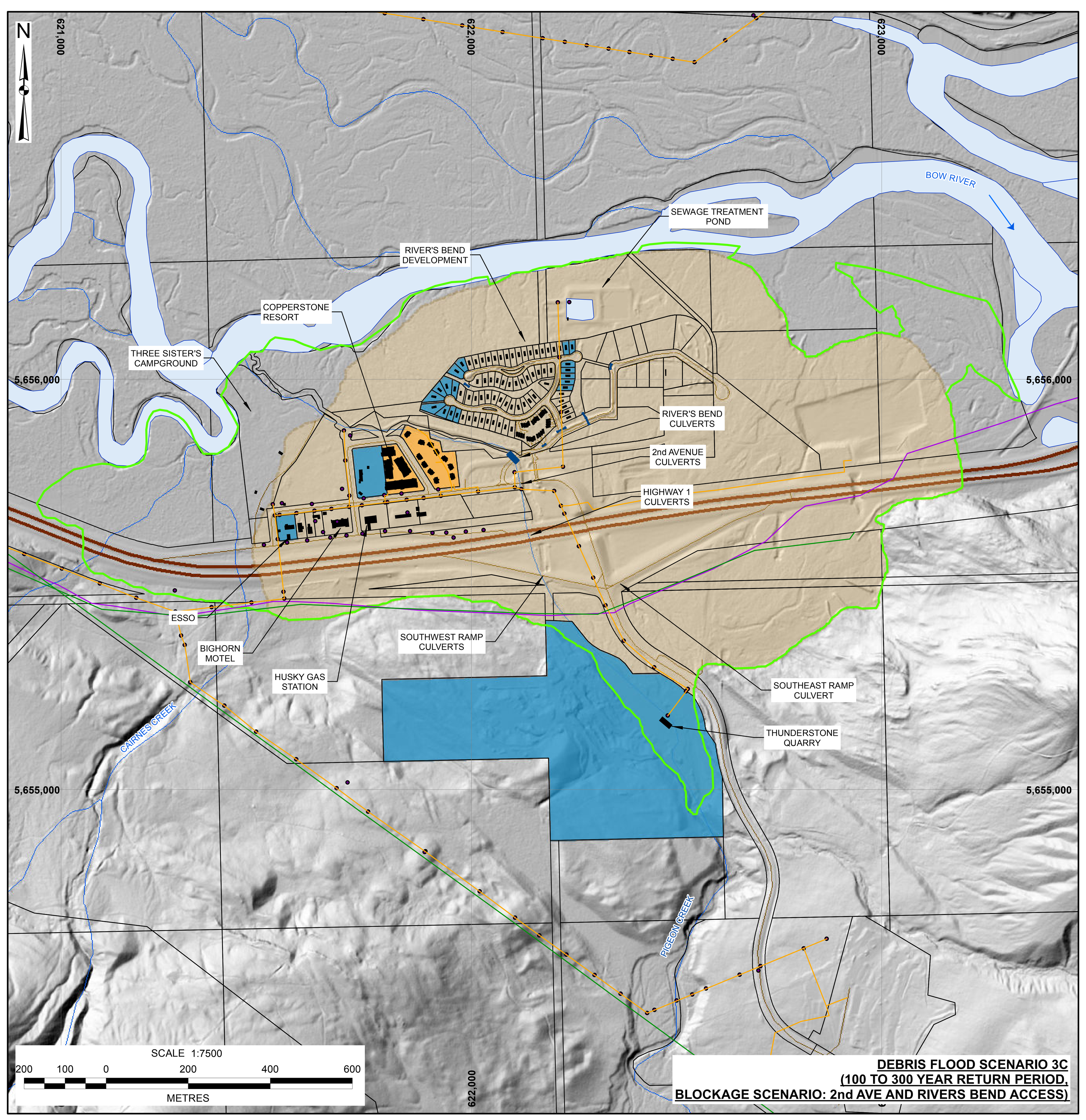

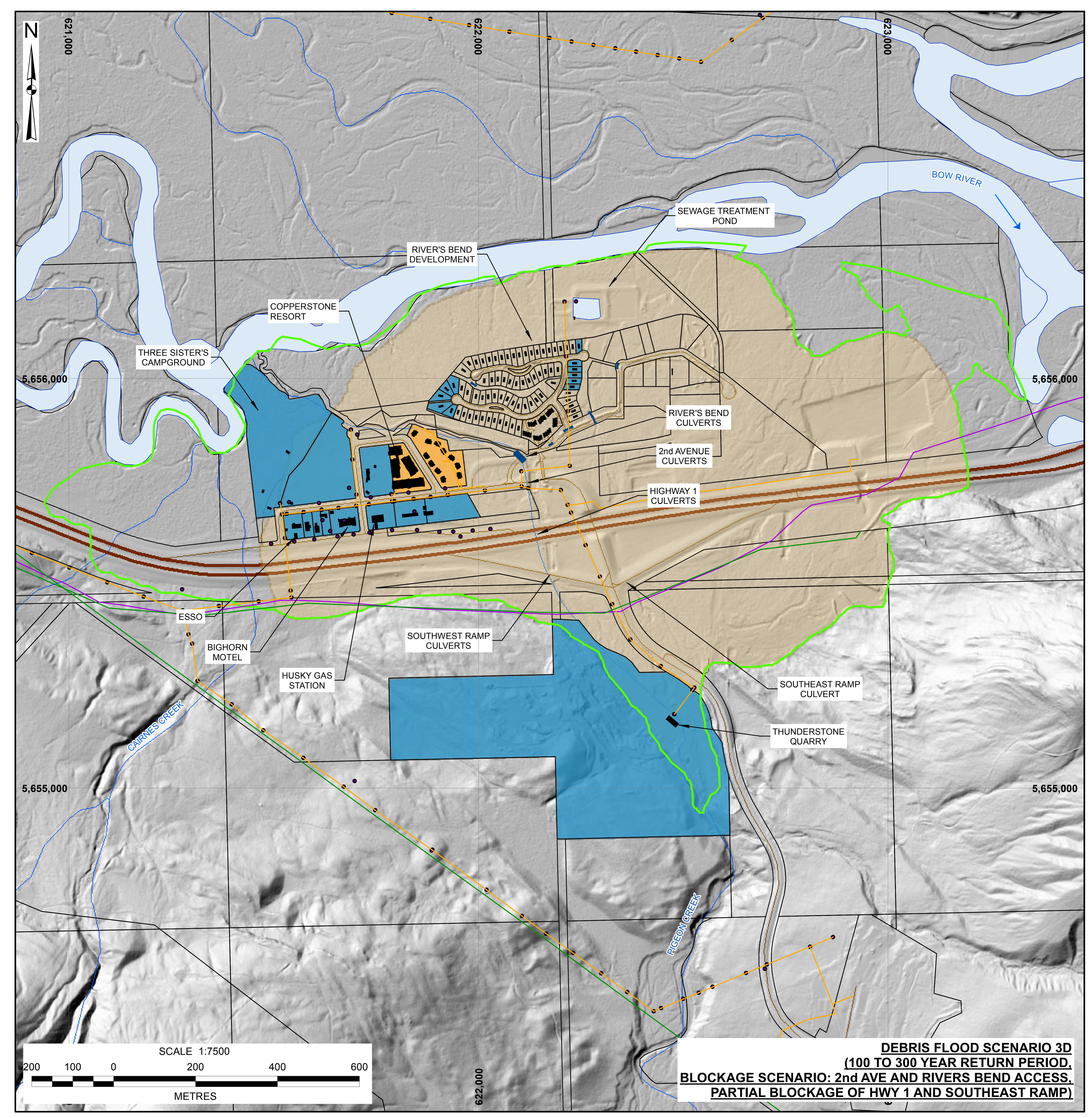

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LEGEND

BUILDING DAMAGE COST
- ≤$0.1M DAMAGE
- >$0.1M TO $1M DAMAGE
- >$1M TO $10M DAMAGE
- >$10M DAMAGE
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (138kV)
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- ATCO PIPELINE
- CULVERTS
- ROAD
- HIGHWAY
- WATERCOURSE
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SCALE:	1:7,500
DATE:	SEP 2016
DRAWN:	JDC
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

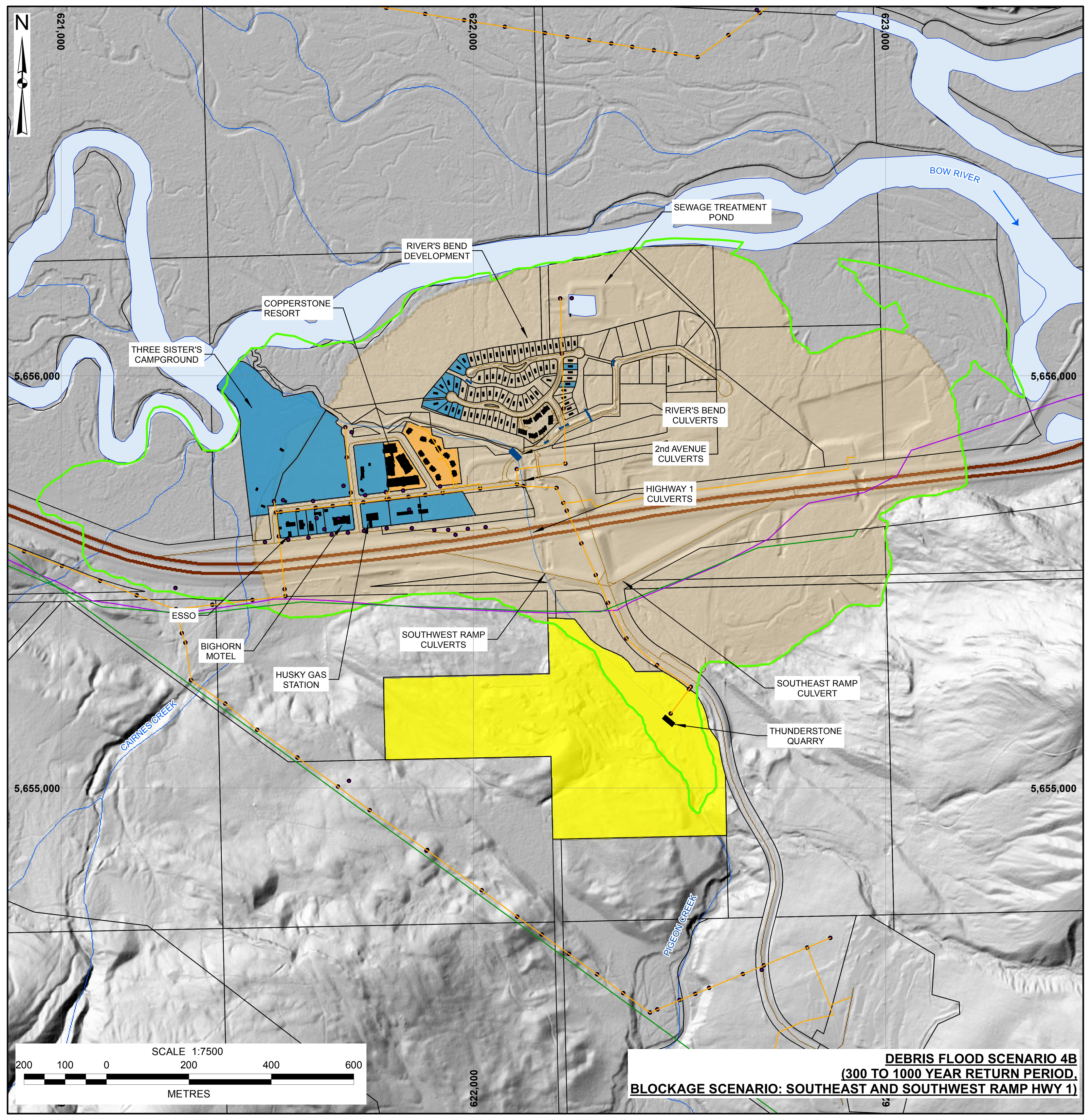
CLIENT: Town of CANMORE

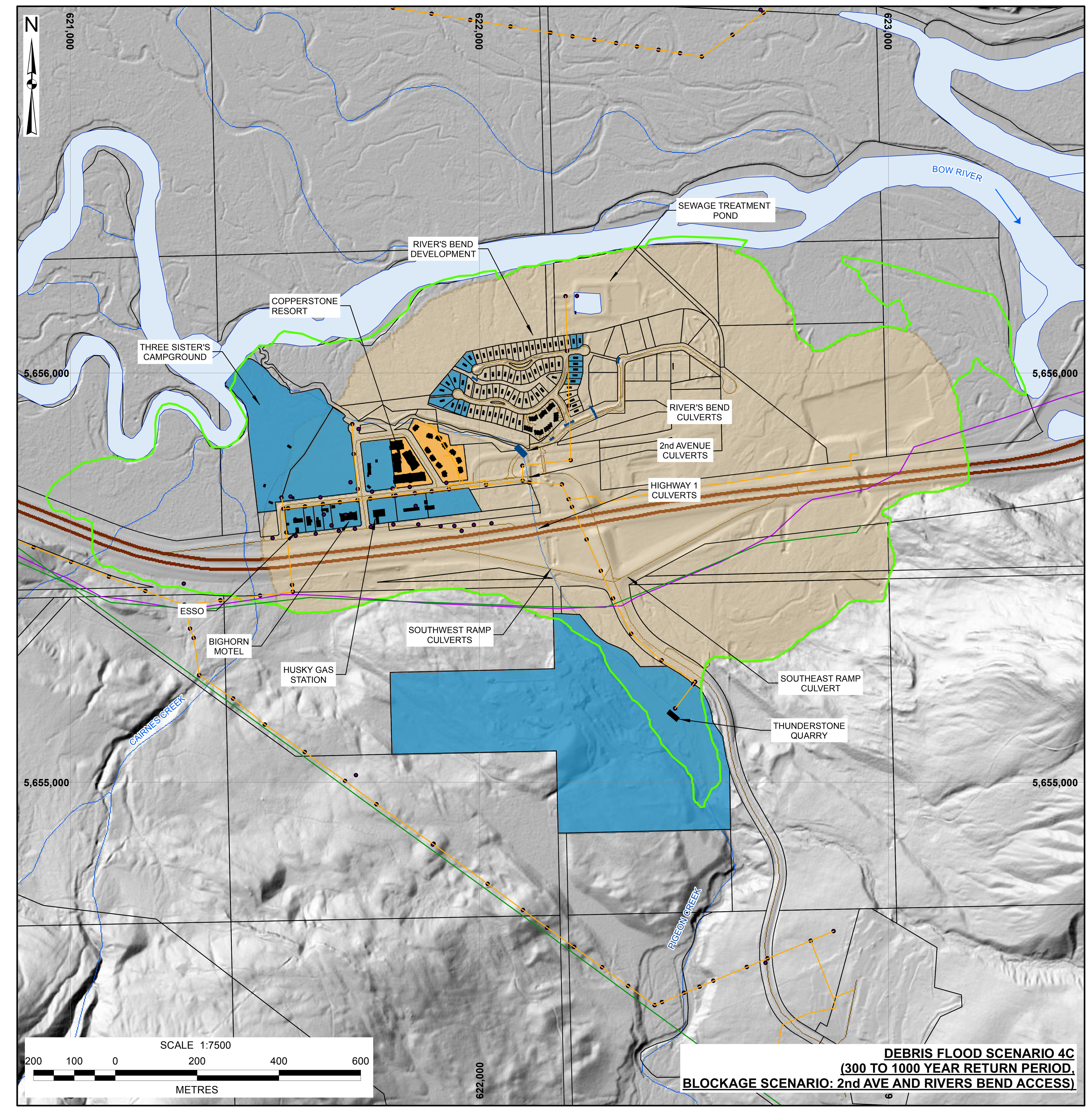
PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

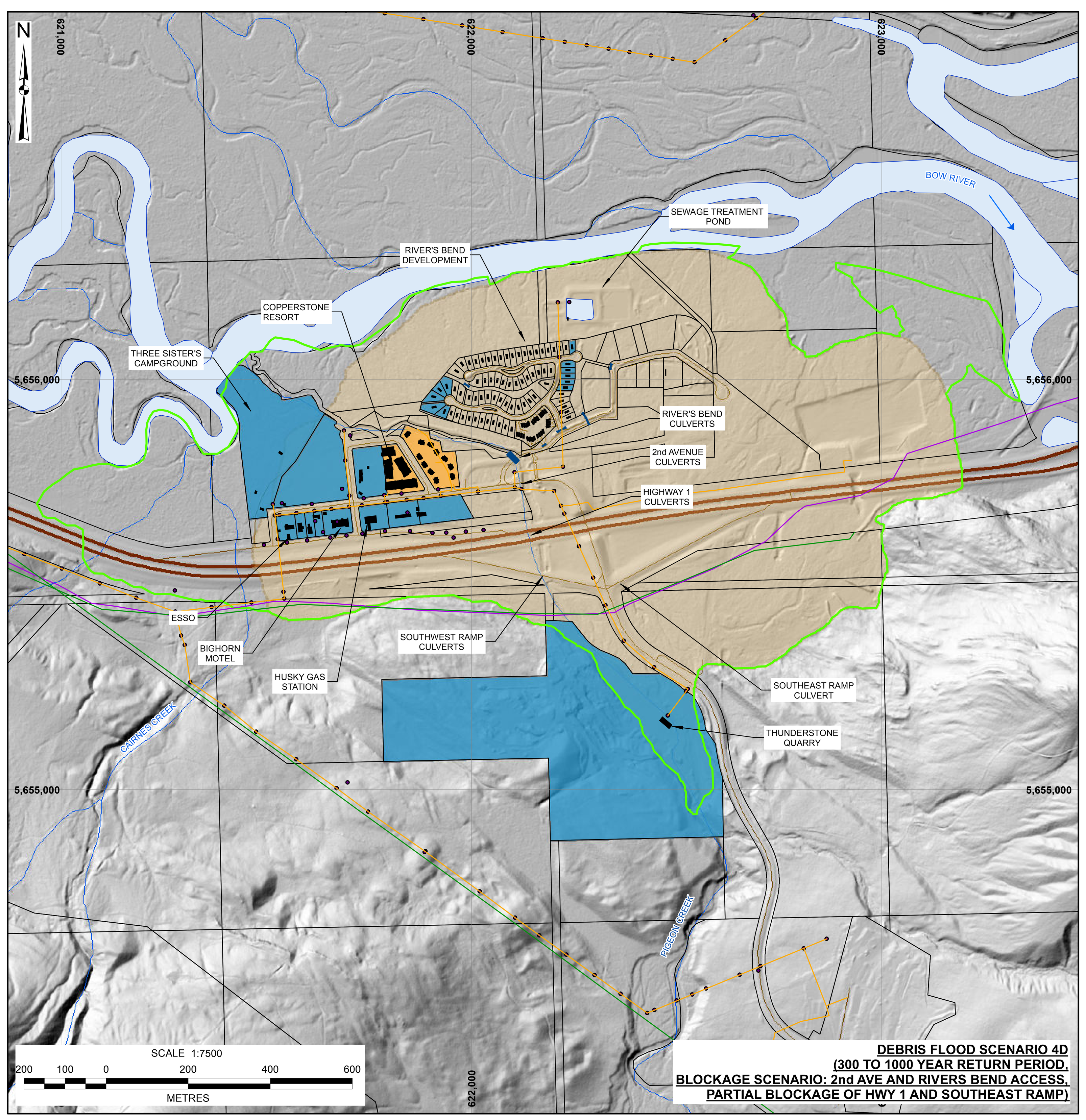
TITLE: DIRECT DAMAGE COSTS, BUILDINGS: DEBRIS-FLOOD SCENARIOS 2D-3D

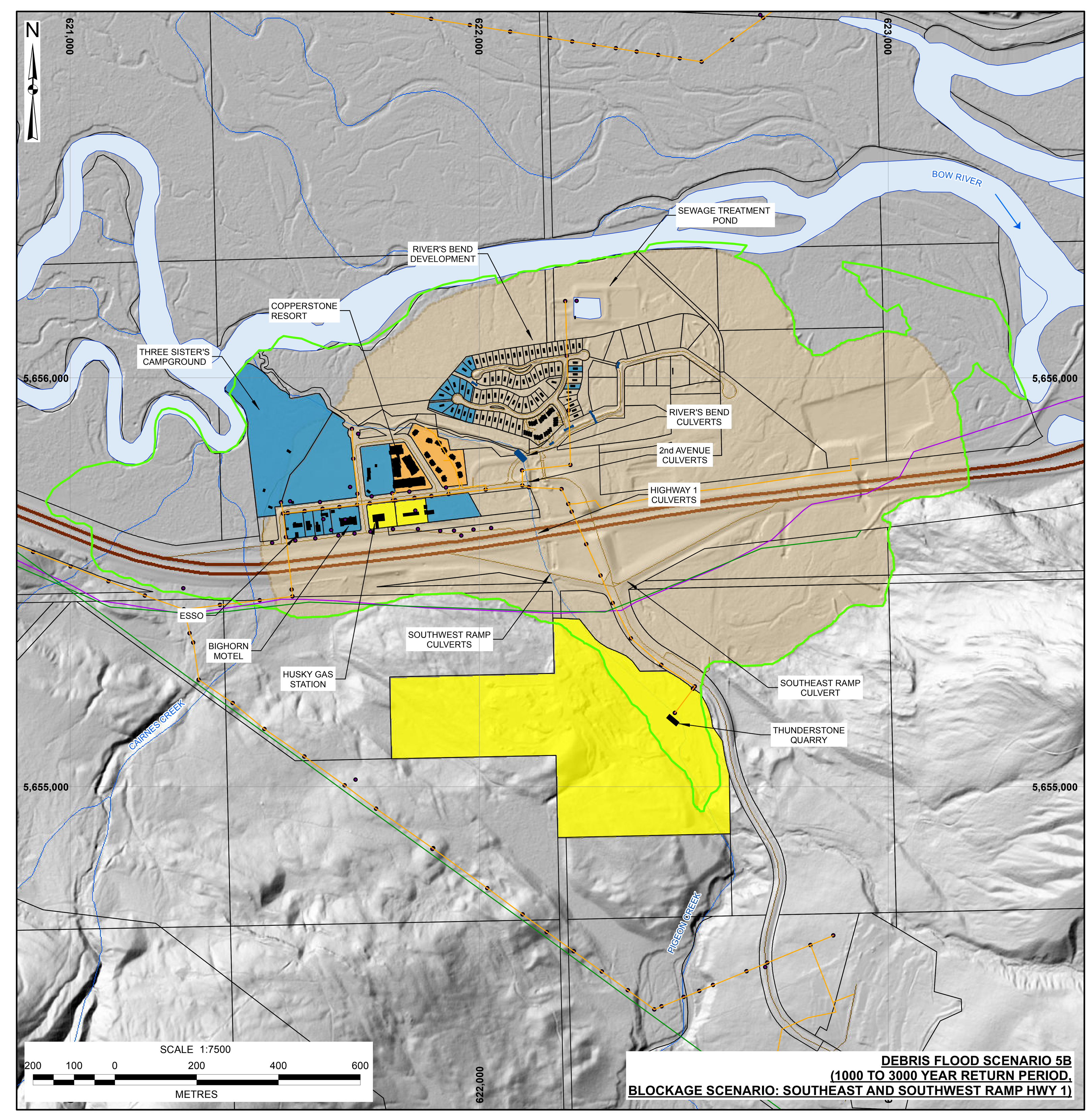
PROJECT No.: 1261014

DWG No.: 08









THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

BUILDING DAMAGE COST
- ≤$0.1M DAMAGE
- >$0.1M TO $1M DAMAGE
- >$1M TO $10M DAMAGE
- >$10M DAMAGE
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (138kV)
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- ATCO PIPELINE
- CULVERTS
- ROAD
- HIGHWAY
- WATERCOURSE
- BUILDING
- PROPERTY BOUNDARIES (PARCELS)
- STUDY AREA BOUNDARY
- APPROXIMATE MODERN FAN
- WATERBODY

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT" AND DATED SEPTEMBER 2016.
3. PROJECTION IS NAD 83 UTM ZONE 11N.
4. THE STUDY AREA BOUNDARY EXTENDS BEYOND THE GEOMORPHIC EXTENT OF THE FAN TO INCLUDE AREAS IMPACTED BY MODELLED DEBRIS-FLOODS.
5. BUILDINGS, PARCELS, AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
6. WATERCOURSES, WATERBODIES, ROADS AND RAILWAY WERE OBTAINED FROM CANVEC.
7. HILLSHADE WAS DERIVED FROM LIDAR PROVIDED BY LIDAR SERVICES IN C. (LSI), DATED JUNE 28, 2013.
8. MODEL RUNS (DEBRIS FLOOD SCENARIOS) ARE LABELLED IN THE LOWER RIGHT HAND CORNER OF EACH MAP INSET.
9. THIS MAP SHOULD NOT BE RELIED UPON AT A SCALE LARGER THAN (MORE DETAILED) THAN SHOWN ON THIS MAP.
10. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT THE RE-DRAWING OF CERTAIN AREAS.
11. THIS DRAWING SHOWS ESTIMATED BUILDING STRUCTURE DAMAGE PROPORTIONS FOR INDIVIDUAL PARCELS.
12. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:7,500
DATE:	SEP 2016
DRAWN:	JDC
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Town of CANMORE

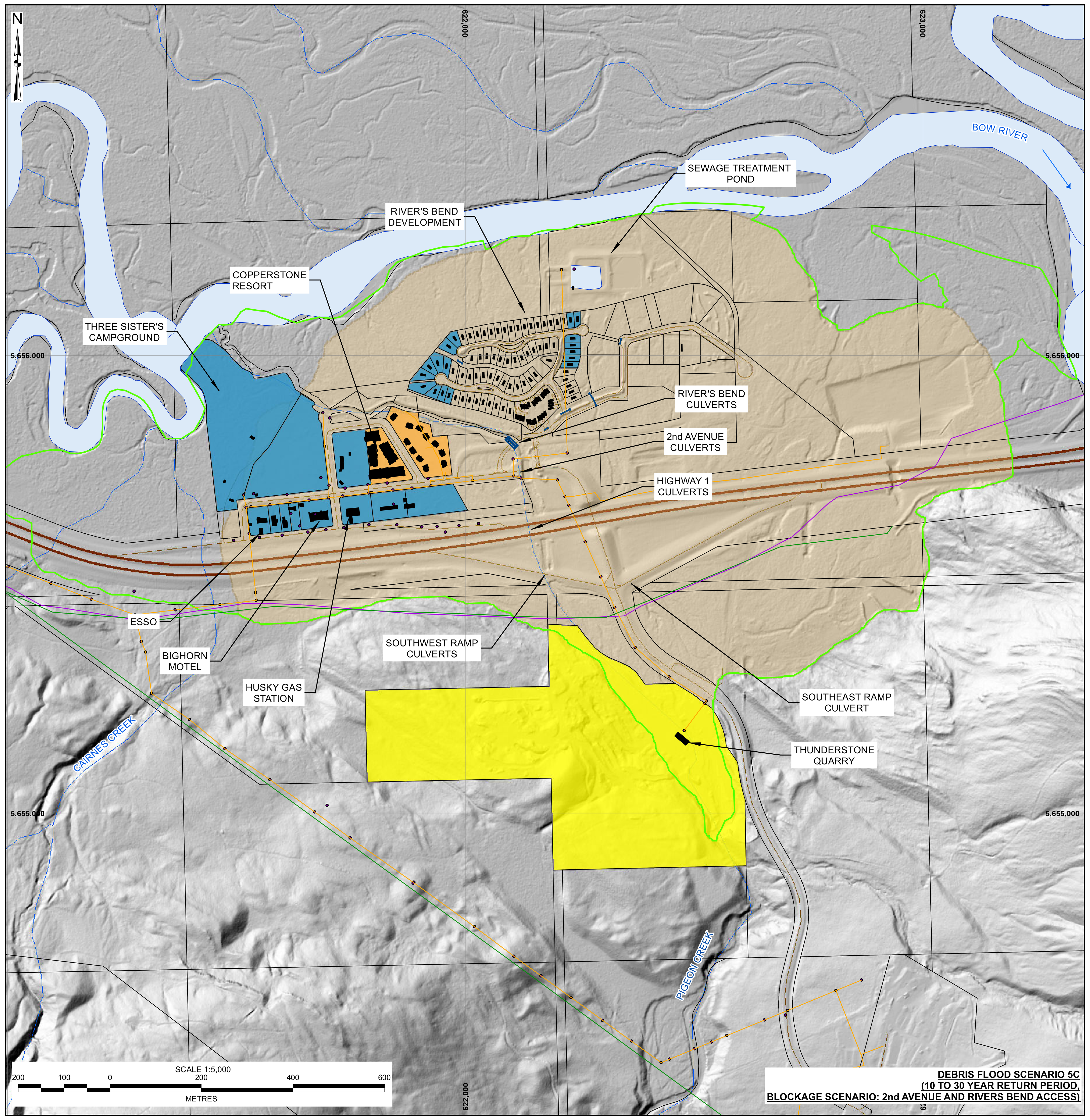
PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

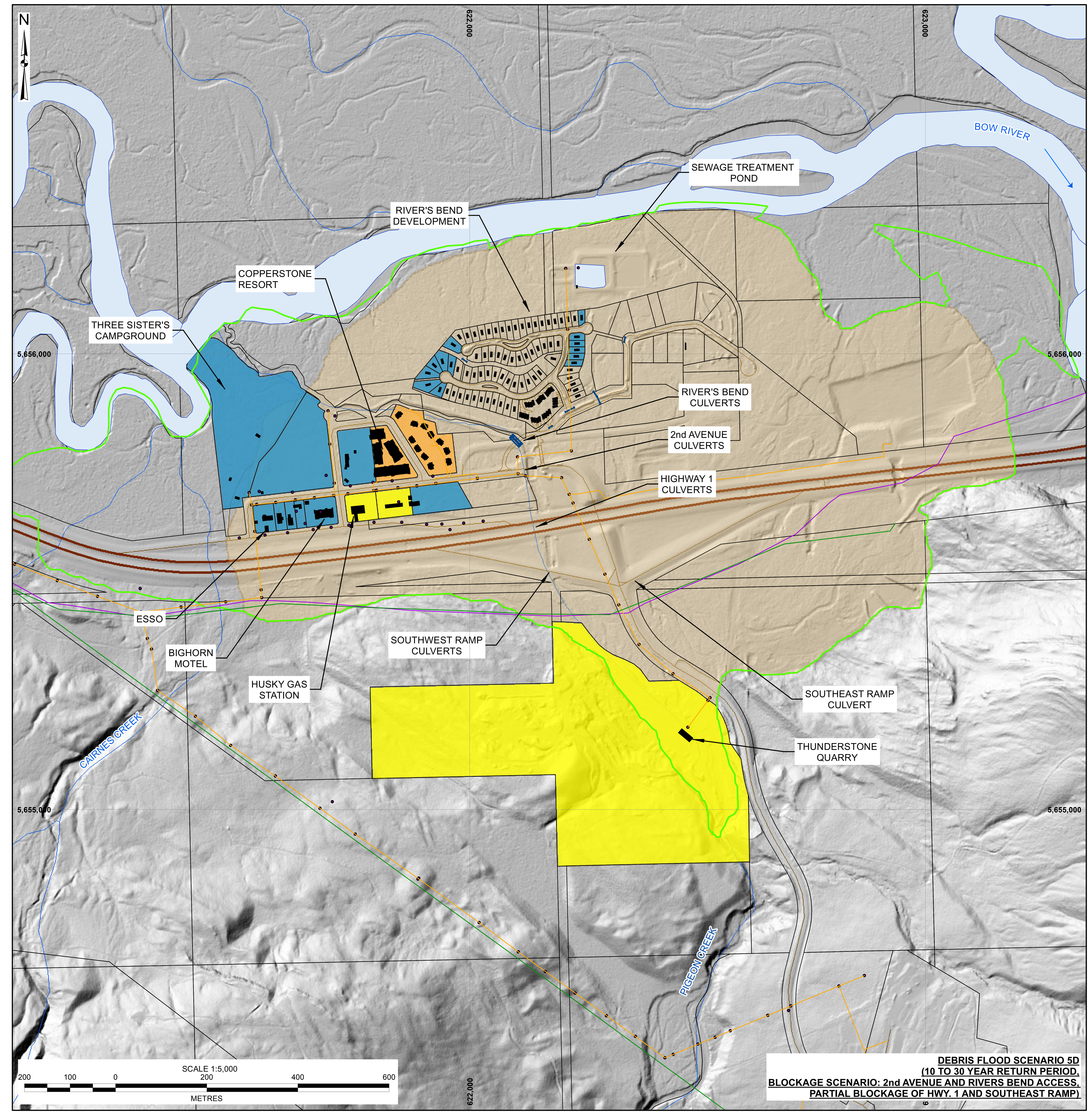
TITLE: DIRECT DAMAGE COSTS, BUILDINGS: DEBRIS-FLOOD SCENARIOS 4B-5B

PROJECT No.: 1261014

DWG No.: 09

THIS BAR MEASURES 100 mm AT FULL SIZE. ALL SCALES REFERENCED TO FULL SIZE





THIS DRAWING MAY HAVE BEEN REDUCED OR ENLARGED. ALL FRACTIONAL SCALE NOTATIONS INDICATED ARE BASED ON ORIGINAL FORMAT DRAWINGS.

LEGEND

BUILDING DAMAGE COST
- ≤$0.1M DAMAGE
- >$0.1M TO $1M DAMAGE
- >$1M TO $10M DAMAGE
- >$10M DAMAGE
- TRANSMISSION POLE
- ELECTRICAL CONDUCTOR LINE (138kV)
- ELECTRICAL CONDUCTOR LINE (LOCAL)
- ATCO PIPELINE
- CULVERTS
- ROAD
- HIGHWAY
- WATERCOURSE
- BUILDING
- PROPERTY BOUNDARIES (PARCELS)
- STUDY AREA BOUNDARY
- APPROXIMATE MODERN FAN
- WATERBODY

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT" AND DATED SEPTEMBER 2016.
3. PROJECTION IS NAD 83 UTM ZONE 11N.
4. THE STUDY AREA BOUNDARY EXTENDS BEYOND THE GEOMORPHIC EXTENT OF THE FAN TO INCLUDE AREAS IMPACTED BY MODELLED DEBRIS-FLOODS.
5. BUILDINGS, PARCELS, AND UTILITIES WERE OBTAINED FROM TOWN OF CANMORE.
6. WATERCOURSES, WATERBODIES, ROADS AND RAILWAY WERE OBTAINED FROM CANVEC.
7. HILLSHADE WAS DERIVED FROM LIDAR PROVIDED BY LIDAR SERVICES IN C. (LSI), DATED JUNE 28, 2013.
8. MODEL RUNS (DEBRIS FLOOD SCENARIOS) ARE LABELLED IN THE LOWER RIGHT HAND CORNER OF EACH MAP INSET.
9. THIS MAP SHOULD NOT BE RELIED UPON AT A SCALE LARGER THAN (MORE DETAILED) THAN SHOWN ON THIS MAP.
10. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT THE RE-DRAWING OF CERTAIN AREAS.
11. THIS DRAWING SHOWS ESTIMATED BUILDING STRUCTURE DAMAGE PROPORTIONS FOR INDIVIDUAL PARCELS.
12. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

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APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: DIRECT DAMAGE COSTS, BUILDINGS: DEBRIS-FLOOD SCENARIOS 5C-5D

PROJECT No.: 1261014

DWG No.: 10

THIS BAR MEASURES 100 mm AT FULL SIZE. ALL SCALES REFERENCED TO FULL SIZE

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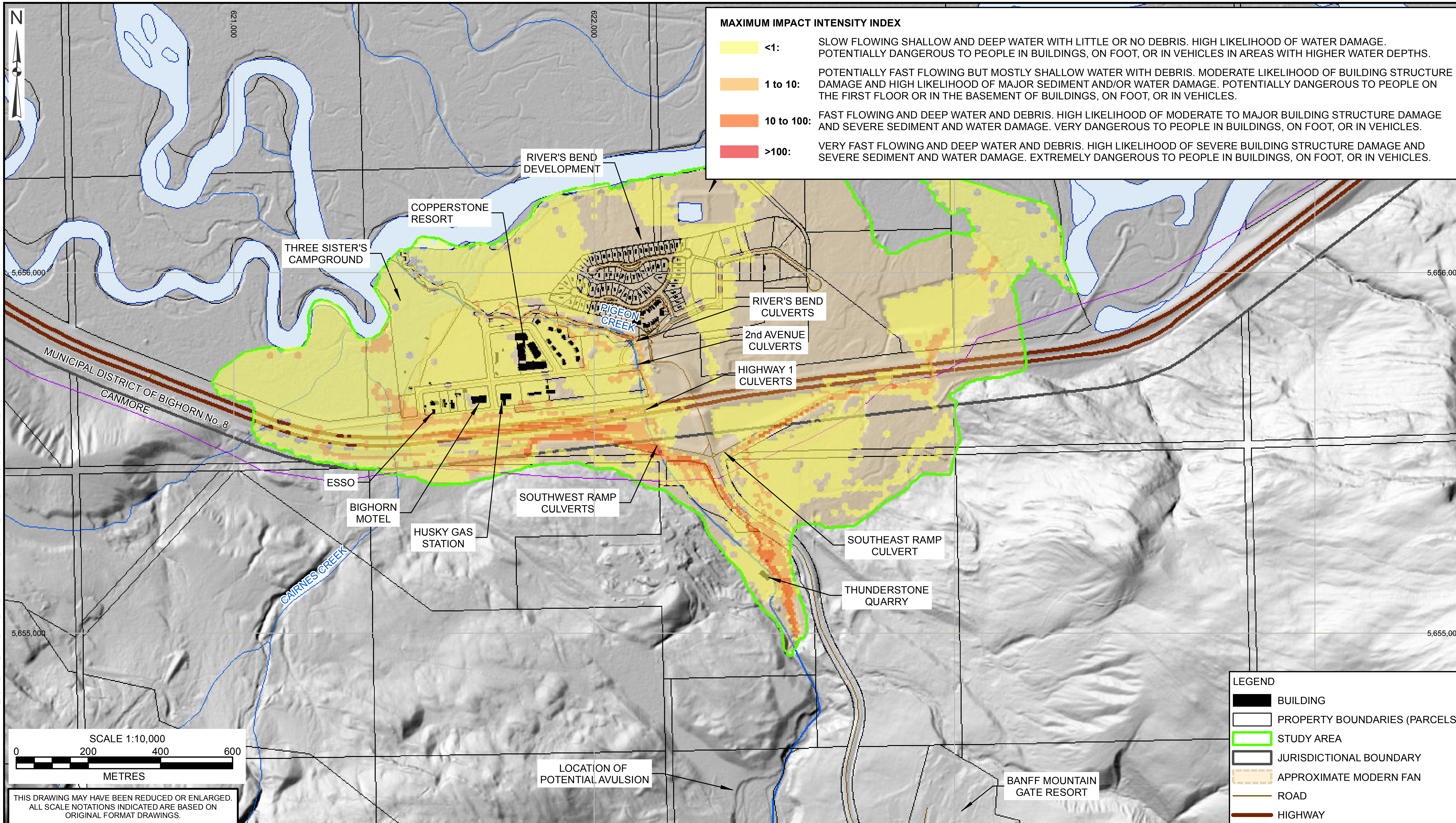

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NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING IS BASED ON NUMERICAL DEBRIS-FLOOD MODELING PERFORMED BY EBA (2016).
3. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT", AND DATED SEPTEMBER 2016.
4. FOOTPRINT OF EXISTING BUILDINGS OBTAINED FROM CANMORE. FOOTPRINT OF RIVER'S BEND DEVELOPMENT FROM MD BIGHORN VIA CANMORE.
5. THIS MAP DISPLAYS THE COMBINED HAZARD EXTENT AND INTENSITY OF ALL HAZARD SCENARIOS. AS SUCH, IT DOES NOT REPRESENT ANY PARTICULAR SCENARIO RETURN PERIOD. WHERE DIFFERENT HAZARD SCENARIOS OVERLAP, THE MAXIMUM HAZARD INTENSITY VALUE IS SHOWN ON THIS MAP.
6. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY McELHANNEY, DATED AUGUST AND OCTOBER 2013.
7. PROJECTION IS NAD83 UTM ZONE 11N.
8. THE STUDY AREA BOUNDARY EXTENDS BEYOND THE GEOMORPHIC EXTENT OF THE FAN TO INCLUDE AREAS IMPACTED BY MODELLED DEBRIS-FLOODS.
9. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
10. THIS MAP ASSUMES THAT EXISTING AND FUTURE EROSION PROTECTION WORKS PERFORM AS INTENDED.
11. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

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CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Town of CANMORE

PROJECT:
PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE:
COMPOSITE HAZARD INTENSITY MAP: ALL HAZARD SCENARIOS

PROJECT No.:	DWG No.:
1261-014	11

X:\Projects\1261\014_Pigeon_Creek_Risk_Assessment\GIS\Production\Report\20160519_Pigeon_Creek_Debris_Flood_Risk_Assessment\11_Composite_Hazard_Intensity_Map_All_Hazards_Scenarios.mxd

NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT," AND DATED SEPTEMBER 2016.
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 PROVIDED BY LIDAR SERVICES INC. (LSI), DATED JUNE 28, 2013. CONTOUR INTERVAL IS 5 m.
6. PROJECTION IS NAD 83 UTM ZONE 11N.
7. SEE THE REPORT FOR METHODS AND LIMITATIONS OF INDIVIDUAL RISK ESTIMATES.
8. "PDI" CORRESPONDS TO "PROBABILITY OF DEATH OF AN INDIVIDUAL".
9. RESULTS ARE SHOWN AT A PARCEL LEVEL OF DETAIL AND CONSIDER ONLY PERSONS INSIDE BUILDINGS.
10. THIS MAP SHOULD NOT BE RELIED UPON AT A SCALE LARGER THAN (MORE DETAILED) THAN SHOWN ON THIS MAP.
11. THIS MAP REPRESENTS A SNAPSHOT IN TIME. FUTURE CHANGES (DEVELOPMENT, DEBRIS FLOOD MITIGATION, GEOHAZARD EVENTS) MAY WARRANT THE RE-DRAWING OF CERTAIN AREAS.
12. THE STUDY AREA BOUNDARY EXTENDS BEYOND THE GEOMORPHIC EXTENT OF THE FAN TO INCLUDE AREAS IMPACTED BY MODELLED DEBRIS-FLOODS.
13. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:5,000
DATE:	SEP 2016
DRAWN:	JDC
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT: Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: RESULTS: RISK TO INDIVIDUALS: DEBRIS-FLOOD SCENARIOS 1A - 5D (CALCULATED)

PROJECT No.:	DWG No.:
1261014	12

THIS BAR MEASURES 100 mm AT FULL SIZE. ALL SCALES REFERENCED TO FULL SIZE.

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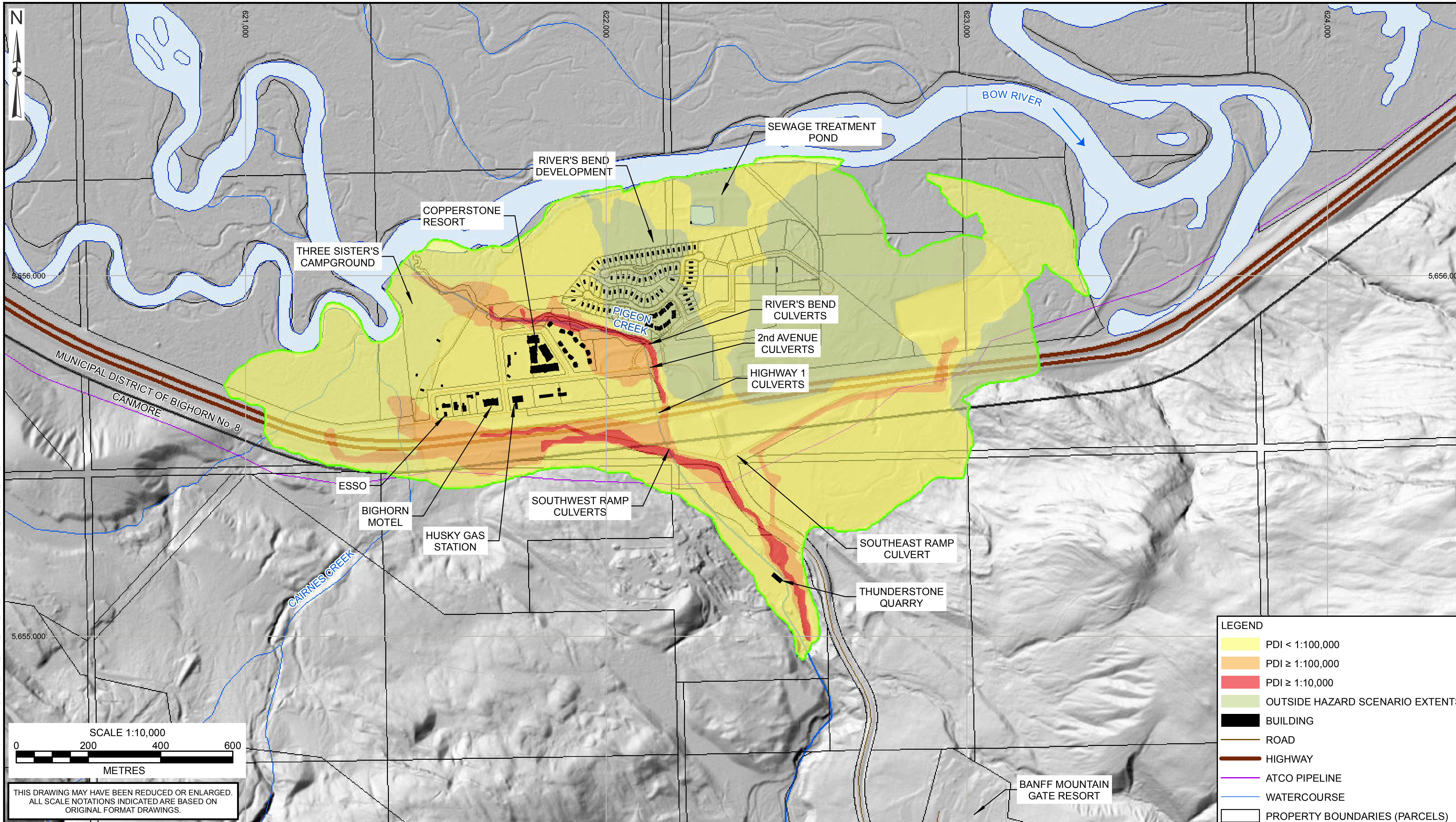

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NOTES:
1. ALL DIMENSIONS ARE IN METRES UNLESS OTHERWISE NOTED.
2. THIS DRAWING IS BASED ON NUMERICAL DEBRIS-FLOOD MODELING PERFORMED BY EBA (2016).
3. THIS DRAWING MUST BE READ IN CONJUNCTION WITH BGC'S REPORT TITLED "PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT", AND DATED SEPTEMBER 2016.
4. FOOTPRINT OF EXISTING BUILDINGS OBTAINED FROM CANMORE. FOOTPRINT OF RIVER'S BEND DEVELOPMENT FROM MD BIGHORN VIA CANMORE.
5. BASE TOPOGRAPHIC DATA BASED ON LIDAR PROVIDED BY McELHANNEY, DATED AUGUST AND OCTOBER 2013.
6. PROJECTION IS NAD83 UTM ZONE 11N.
7. THE FAN BOUNDARY AS DRAWN IS APPROXIMATE AND DELINEATES THE LANDFORM. THE BOUNDARY SHOULD NOT BE CONSTRUED AS A HAZARD MAP, NOR DOES IT SHOW THE SPATIAL EXTENT OF POTENTIAL FLOODING.
8. THIS MAP ASSUMES THAT EXISTING EROSION PROTECTION WORKS PERFORM AS INTENDED.
9. THIS MAP EXCLUSIVELY SHOWS ESTIMATED DEBRIS-FLOOD SAFETY RISK TO INDIVIDUALS WITHIN BUILDINGS. A UNIFORM LEVEL OF VULNERABILITY WAS ASSUMED FOR BASELINE RISK ESTIMATION. CRITERIA FOR ASSESSING VULNERABILITY ARE DESCRIBED IN THE ASSOCIATED REPORT. OTHER RISKS ARE NOT SHOWN.
10. "PDI" CORRESPONDS TO "PROBABILITY OF DEATH OF AN INDIVIDUAL". METHODS TO ESTIMATE PDI ARE PROVIDED IN THE ASSOCIATED REPORT.
11. UNLESS BGC AGREES OTHERWISE IN WRITING, THIS DRAWING SHALL NOT BE MODIFIED OR USED FOR ANY PURPOSE OTHER THAN THE PURPOSE FOR WHICH BGC GENERATED IT. BGC SHALL HAVE NO LIABILITY FOR ANY DAMAGES OR LOSS ARISING IN ANY WAY FROM ANY USE OR MODIFICATION OF THIS DOCUMENT NOT AUTHORIZED BY BGC. ANY USE OF OR RELIANCE UPON THIS DOCUMENT OR ITS CONTENT BY THIRD PARTIES SHALL BE AT SUCH THIRD PARTIES' SOLE RISK.

SCALE:	1:10,000
DATE:	SEP 2016
DRAWN:	JDC
CHECKED:	SK
APPROVED:	KH

BGC ENGINEERING INC.
AN APPLIED EARTH SCIENCES COMPANY

CLIENT:
Town of CANMORE

PROJECT: PIGEON CREEK DEBRIS-FLOOD RISK ASSESSMENT

TITLE: INDIVIDUAL SAFETY RISK ZONE MAP

PROJECT No.:	DWG No.:
1261-014	13

X:\Projects\1261014_Pigeon_Creek_Risk_Assessment\GIS\Production\Report\20160519_Pigeon_Creek_Debris_Flood_Risk_Assessment\13_Individual_Safety_Risk_Zone_Map.mxd