Identification and Risk-based Prioritization of Flood Hazards on Highways in Alberta

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ABSTRACT

In June 2013, heavy rainfall in southwestern Alberta, Canada, caused floods with estimated damage costs exceeding CDN $6 billion. Several municipalities, including downtown Calgary, were flooded, and highway infrastructure across the region was damaged. Alberta Transportation (AT) retained BGC Engineering Inc. (BGC) to identify and prioritize flood hazards along 3,400 km of provincially managed highways in southwestern Alberta. The 185,000 km^2 study area included terrain from the southern and western provincial boundaries to the Peace River in the north and Calgary in the east, and excluded national parks.

The study identified 532 sites (approximately 170 km of highway) threatened by channel encroachment, 44 sites (slightly under 100 km of highway) with flood inundation potential, and 1,682 culverts with avulsion potential. Hazard sites were prioritized based on the relative likelihood that an event will occur, impact the highway, and result in an undesirable consequence. Traffic count, high-load status, and nearby roadside facilities were considered in estimating consequence at each hazard site. While not a quantitative risk assessment, the prioritization is risk-based in that it considers both hazard levels and potential consequences. Results were presented on an interactive, searchable web application that supports ongoing hazard assessments and risk reduction planning.

RÉSUMÉ

Les fortes pluies du mois de juin 2013 en Alberta ont provoqué des inondations avec des dommages évalués à plus de 6 milliards de $CAN. Plusieurs municipalités, dont le centre-ville de Calgary, ont été affectées par les inondations, et l'infrastructure routière a été endommagée à travers la région. Alberta Transportation a retenu BGC Engineering Inc. (BGC) pour dresser un inventaire des aléas d'inondation le long de 3,400 km d'autoroute gérés par le gouvernement provincial dans le sud-ouest de l'Alberta. L'étendue de la zone d'étude est de 185,000 km^2 et est délimitée par la frontière provinciale au sud et à l'ouest ainsi que la rivière Peace au nord et la ville de Calgary à l'est, excluant les parcs nationaux.

BGC a identifié 532 sites menacés par empiètement latéral de cours d'eau (approximativement 170 km d'autoroute), 44 sites (un peu moins de 100 km d'autoroute) menacés par un aléa d'inondation, et 1,682 ponceaux pouvant se bloquer et créer un aléa d'avulsion. Ces aléas ont été priorisés suivant leur niveau de risque en tenant compte de l'éventualité qu'un événement se produise, impacte l'autoroute, et entraîne une conséquence indésirable. Une conséquence indésirable tient compte de l'impact sur le volume de la circulation, l'état des axes routiers prioritaire, et les installations routières. Cette étude n'est pas une évaluation quantitative du risque comme telle, mais la priorisation des sites prend en considération le niveau de l'aléa ainsi que les conséquences potentielles. Ces résultats ont été présentés sous forme d'une application web interactive comprenant une fonction de recherche. Cette application peut servir à justifier la reprise d'évaluations futures ainsi que la planification d'un programme de réduction du risque.

1   INTRODUCTION

Two days of intense rainfall in June 2013 triggered floods along all major southern Alberta river systems. Province-wide, four lives were lost, 100,000 people were displaced, and transportation corridors were severed, including closure of the Trans-Canada Highway for one week. Direct damage costs exceeded $6 billion (Wood, 2013).

Following the immediate response and recovery efforts, the Province of Alberta commissioned studies to improve the understanding of flood hazard and risk within the Province.

In this study, we identified mapped, characterized and prioritized flood-related hazards for approximately 3,400 km of highway infrastructure in southwestern Alberta. The study results are presented on a searchable web application termed the "Alberta Hydro Hazard Info Tool" (AHHIT).

1.1   Hazard Types

This paper describes our classification and prioritization of three flood-hazard types: channel encroachment, flood inundation, and culvert avulsion. Debris flow and debris flood fans were also assessed; these are described by Holm et al. (2016).

Encroachment is the lateral movement of a watercourse toward a river-parallel element at risk due to bank erosion. Bank erosion can undermine a road surface where it encroaches upon an embankment (Figure 1). Encroachment poses a hazard to highways near the outside banks of river bends. The hazard is highest near

highway-parallel wandering or braided watercourses, but it also threatens highways near single-thread meander bends.

Figure 1. Highway encroachment hazard (AT image).

Inundation occurs when the water level during a flood exceeds the elevation of an element at risk (Figure 2). We define an inundation hazard where a highway segment may be inundated by flooding with a 500-year or smaller recurrence interval on an adjacent watercourse. This study considered loss of use during flood duration as the consequence. Running surfaces and embankments can sometimes be damaged by a saturated subgrade but these consequences were judged to be rare and therefore excluded.

Figure 2. Highway flood inundation hazard (AT image).

Culvert avulsion refers to the failure of a culvert(s) to convey flow in a watercourse resulting in inundation and/or damage to the road surface (Figure 3).

Figure 3. Highway culvert erosion hazard (AT image).

2   BACKGROUND

The study covers approximately 3,400 km of highways maintained by the Province and falling within southwestern Alberta's high-runoff zone (Figure 4). The 185,000 km^2 zone includes terrain from the southern and western provincial boundaries to the Peace River in the north and Calgary in the east, and excludes national parks. The study area includes streams and rivers that cross, encroach upon, or occupy floodplains that intersect these highways. Some study watersheds extend into northern Montana and northeastern British Columbia.

The high-runoff zone covers most of the Rocky Mountains, Foothills, Southern Alberta Uplands and Western Alberta Plains physiographic regions (Pettapiece, 1986). There are two main geographical areas of concern for flood hazards: the area encompassing part of the Rocky Mountains and surrounding Foothills, and flatter terrain east of the Foothills.
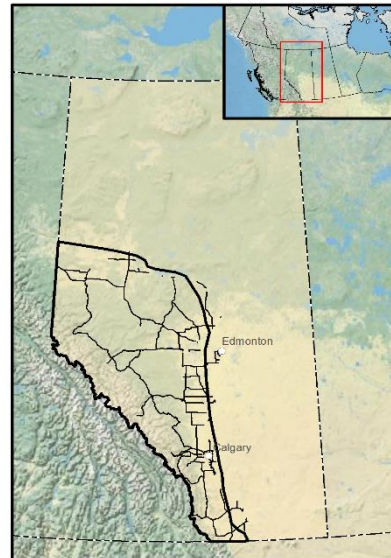

Figure 4. Study area. The thin black lines are in-scope highways. The high-runoff zone is a thick black line. (ESRI)

The Rocky Mountains have a continental climate with warm summers and cold winters. Semi-arid conditions persist towards the east. Winters tend to be warmer with lower snowfall along the eastern flank of the Rocky Mountains due to frequent Chinook winds. East of the Rocky Mountains conditions become more arid and precipitation decreases. The southern and east-central portions of the Province can be prone to drought conditions, sometimes persisting for several years (Alberta WaterPortal, 2013).

The study area intersects four major river basins. Furthest north, the Peace/Slave and Athabasca basins drain northeastward into the Mackenzie continental drainage system. The North and South Saskatchewan River basins drain eastward as part of the Nelson-Churchill continental drainage system. The South Saskatchewan River Basin contains the Red Deer, Bow River and Oldman River sub-basins. Generally, runoff is dominated by snowmelt released from alpine subregions from April through July (Pomeroy et al., 2009). Peak flows typically

occur in the late spring during rain-on-snow events and in the summer due to snowmelt and glacial runoff at higher elevations.

3   METHODS

3.1   Prioritization Framework and Consequences

We prioritized hazard sites based on the relative likelihood that an event will occur, impact the highway, and result in some level of undesirable consequence. Although the approach is risk-based, this study is not a quantitative risk assessment: priority scores are not equivalent to absolute likelihood of some severity of consequence at each hazard site.

We calculated priority scores as follows:

$$P = P_{H,S_i} \times C_i \qquad [1]$$

Where:

P	is the numerical priority score;
P_{H,S_i}	are the weightings for encounter probability, the estimated probability that a hazard event will occur and impact the highway; and,
C_i	are the weightings for consequences given highway impact.

Consequence, C, is the sum of site significance factors represented as an effective traffic score. The effective traffic score is the sum of values for average daily traffic, high-load status and the presence of roadside facilities. We assigned relative traffic-count values to the latter two consequence classes. A high-load corridor, which is a highway designated to carry overheight and overweight loads, is assigned a value equivalent to an interruption of 10,000 vehicles per day. Each road side facility is assigned a value equivalent to an interruption of 1,000 vehicles per day. Priority scores were placed into High, Moderate, and Low categories based on percentile rank within each hazard type (Table 1); accordingly, the score provides a relative rank for comparing within each hazard type, not an absolute risk value.

Table 1. Hazard site priority categories.

Priority Category	Percentile Rank
High	≥ 90
Moderate	≥ 50 to < 90
Low	< 50

3.2   Analysis of Flood Hydrology

We used a digital watercourse network maintained within BGC's River Network Tools™ (RNT) for hydrological analysis, compiled from the Alberta Hydro Network (AEP 2015) and, where basins extended into British Columbia, the National Hydro Network.

We estimated flood discharge quantiles for 2, 5, 10, 25, 50, 100, 200, and 500 year flood return periods using regional analysis based on publicly available maximum annual peak instantaneous streamflow (Q_{IMAX}) data from Water Survey of Canada (WSC) hydrometric stations

(WSC, 2010). Suitable WSC gauge stations for each watercourse segment were located within 200 km, have long flow data records, have similar catchment areas, and do not fall on a regulated watercourse. Peak flows were estimated for various return periods by first fitting a Generalized Extreme Value (GEV) distribution to the Q_{IMAX} data from the selected gauge station(s) and extrapolating the results to each watercourse segment using a linear regression analysis based on drainage area.

3.3   ENCROACHMENT HAZARDS

We identified and characterized 532 encroachment hazard sites, affecting about 5% of the total length of in-scope highways. We prioritized the hazards based on the framework shown in Equation 1. For this, we estimated encounter probability by beginning with a baseline-case event frequency and using terrain factors to differentiate from this baseline case. We then multiplied by consequence scores to obtain prioritization scores.

3.3.1 Hazard Identification

We identified and mapped encroachment hazard sites using 1.5 m resolution SPOT satellite imagery from 2013 and hillshade images built from 1 m resolution LiDAR Digital Elevation Models (DEM) flown between 2007 and 2013. LiDAR data covers about two thirds of the study area (Figure 4). We identified five typical encroachment scenarios (Figure 5):
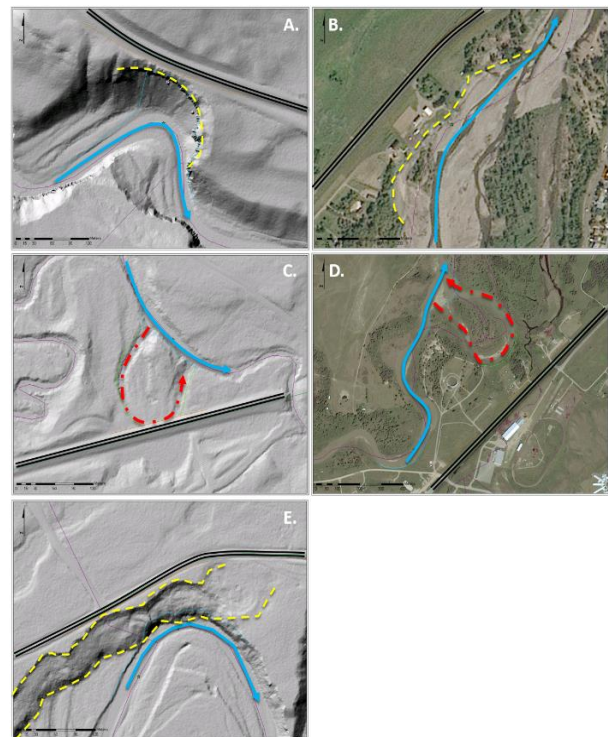

Figure 5. Examples of five different encroachment types: A). Existing encroachment; B). Encroaching with bank erosion; C). Avulsion channel encroachment; D). Avulsion channel encroaching with bank erosion; E). Slope instability encroachment.

A. Existing encroachment – the main channel has a bank that intersects a road prism.
B. Encroaching with bank erosion – the main channel will intersect the road prism if additional bank erosion occurs.
C. Existing avulsion channel encroachment – an abandoned channel on the floodplain is encroaching upon the road prism. The old channel could be reoccupied in a flood.
D. Avulsion channel encroaching with bank erosion – an abandoned channel will encroach upon the road prism if additional bank erosion occurs after it is reoccupied.
E. Slope instability encroachment – the watercourse is eroding the toe of a landslide in the road prism.

3.3.2 Encounter Probability

The encounter probability for encroachment hazards refers to the frequency of the flood event that would erode to reach the highway embankment. At each site, encounter probability is a baseline-case event frequency (P_B) multiplied by site-specific terrain factors (F_i):

$$P_{H,F_i} = P_B \times \prod F_i \qquad [2]$$

The baseline-case event frequency assumes a wandering or braided river system eroding banks with coarse sand to gravel soil. We apply terrain factors to account for conditions that differentiate each site from this baseline case.

P_B depends on a setback ratio, D, defined here as the number of equivalent bank full widths between a river and the road embankment.

$$D = d/W_B \qquad [3]$$

Where:
d is the shortest distance from the channel bank to the toe of the road embankment.
W_B is the bankfull width of the main channel.

At each site, we used LiDAR and orthophotographs to measure the shortest distances between the highway embankment and channel banks. We use these to attribute each site with a setback ratio for the main channel (D_M).

In addition, we account for avulsion for hazard sites with abandoned channels between the main channel and the highway. We attribute these hazard sites with a setback ratio for the abandoned channel closest to the highway (D_A). These abandoned channels might or might not be occupied during a flood event. The likelihood of this depends on the river's susceptibility to avulse (k^*). For these potential avulsion sites, the normalized set-back ratio (D_N) becomes:

$$D_N = D_M \left(1 - \frac{k^*}{2}\right) + D_A \frac{k^*}{2} \qquad [4]$$

Where:
D_M is the setback ratio from the main channel.

D_A is the setback ratio from closest abandoned channel to the highway within the same floodplain, provided one lies between the main channel and highway.
k^* is the avulsion susceptibility of the reach (Table 2).

Table 2. Avulsion susceptibility k^* according to avulsion presence, channel pattern, and floodplain ratio.

Avulsion present	Channel pattern	Floodplain ratio	k^*
No	Single-thread	<4	0
		>4	0.25
	Multi-thread	Any	0.5
Yes	Single-thread	Any	0.75
	Multi-thread	Any	1

We related the baseline-case event frequency to normalized setback ratio by (1) considering the results of a physical bank-erosion model run on a subset of hazard sites that conform to the baseline-case conditions and (2) examining aerial photographs, orthophotographs and encroachment-related highway damage following the 2013 storm event in the southwestern Alberta mountains and foothills.

Figure 6 presents a decision tree we used to estimate the setback ratio the baseline-case event frequency for each site. Baseline-case event frequencies (P_B) are for setback ratio ranges; for example, $P_B = 0.2$ applies to the range of Q values between 0 and 0.5.
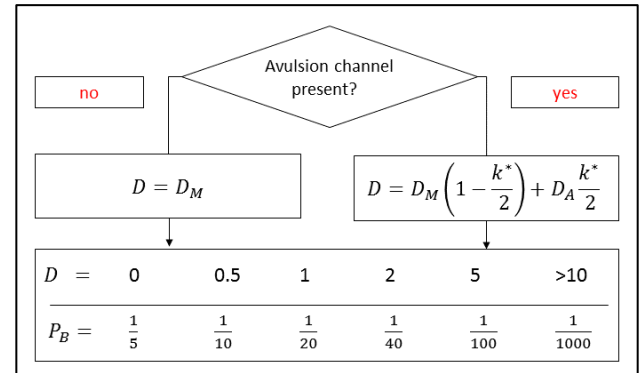

Figure 6. Decision tree used to estimate the encroachment hazard frequency as a function of setback ratio, *D*.

3.3.3 Terrain Factors

Terrain factors considered included the following:

$$F_i = C \cdot G \cdot S \cdot I_b \cdot I_r \cdot M \qquad [5]$$

Where:
C is the channel type.
G is the local river geometry.
S is the soil erodibility.
Ib is the river bank instability.
Ir is the road prism instability.
M is existing site mitigations.

Estimates of terrain factors (F_i) range from 0.02 to 1.30, where higher values represent a higher likelihood the river will encroach on the road. Values for each terrain factor were assigned based on the amount that site factors deviate from an idealized encroachment hazard case. The terrain factors described below were assigned by reviewing LiDAR, orthophoto, Google Street View, and existing technical report information.

River Channel Type: at each hazard site, the channel was classified using morphological criteria developed by Church (2006). Channel type is controlled dominantly by sediment supply and gradient. For example, single channel, meandering rivers tend to have low rates of bank erosion. Hence, a lower weighting factor is applied to these types, compared to braided and wandering rivers.

Local River Geometry: rivers tend to erode their outer banks at bends. At tighter bends, the river's flow tends be concentrated along its outside bank, so most of the erosion typically occurs there. At straight reaches, erosion should be about equal along each bank.

Soil Erodibility: the rate at which a bank erodes toward a highway depends, in part, on the erodibility of the surficial materials between them. Loose, cohesionless silts, sands and gravels are relatively erodible. Soils that are dense or stiff, cohesive, or coarser-grained are typically less erodible (Briaud, 2008; Renard et al., 1997). Soils were characterized using many data sources (e.g. Shaw and Kellerhals, 1982; Bayrock and Reimchen, 2007; Edwards and Budney, 2009; Fenton et al., 2013).

River Bank Instability: a river bank with a landslide should erode farther in a given event than one without, as high flows will undermine those landslides. Sites with river-bank landslides were identified from LiDAR and orthophotos. Evidence for landsliding includes steep soil banks, tension cracks, disturbed vegetation, or slide scars.

Road Prism Instability: where a road prism shows signs of instability, roadway damage should be more likely when a river erodes to its toe. The road prism instability weighting factor is a proxy for the embankment stability and is based on surface evidence for slope deformation in the road prism observed on LiDAR and orthophotographs.

Existing Mitigations: mitigation should reduce the encounter probability. Typical mitigation structures include flow control structures (e.g., jetties, rip-rap spurs) and bank erosion protection (e.g., river bank armor, vegetated slopes). Railway lines, secondary roads, or other infrastructure positioned between the roadway and river bank are considered to provide basic protection: the railway embankment will likely function as a non-engineered dike and limit the advancement of the eroding bank.

3.3.4 Consequence

Consequence, C, is the sum of site significance factors represented as an effective traffic score (E), as described in Section 3.1, multiplied by the estimated vulnerability of the road surface to bank erosion within the road embankment. (V):

$$C = E \, x \, V \qquad\qquad [6]$$

Erosion may undermine a road embankment, causing damage to the road surface without necessarily reaching the road itself. Vulnerability, V, is the likelihood that the roadway is damaged, given that erosion reaches the embankment. We assigned weighting scores for the vulnerability based on estimates for permitted traffic passage if the road was damaged (Table 3).

Table 3. Summary of vulnerability ratings.

Rating	Description	Weighting score
Low	Event unlikely to cause traffic interruption.	0.1
Moderate	Event will probably impact the roadway but some traffic can pass.	0.5
High	Likely full closure for more than 24 hours.	0.9

3.4 INUNDATION HAZARDS

We prioritized a total of 44 sites where inundation of the road surface may occur at or below 500-year flood levels. We identify candidate sites lying within or beside floodplains and then examined each site individually and removed those sites not considered a hazard. We characterized key stream channel properties for the remaining sites and prioritized them based on the framework in Equation 1. We used a model based on Manning's (1981) equation to determine flood magnitude required to inundate the road (the encounter frequency) and multiplied by consequences to achieve the final prioritization scores.

We only considered sites where inundation is caused by the flow exceeding the stream capacity, without hydraulic interference from confining structures (e.g. bridges). Two inundation mechanisms were excluded including inundation at bridge crossings, as the potential for flooding is related to bridge hydraulics and capacity, and inundation adjacent to lakes, where flooding is dependent on the flood hydrograph, available storage, and the hydraulic capacity of the lake outlet.

3.4.1 Hazard Identification

To identify preliminary inundation hazard sites we identified all roads that intersected terrain mapped as fluvial, colluvial, or glaciofluvial on the provincial 1:1,000,000-scale surficial geology compilation (Fenton et al. 2013) and the 100-year floodplains compiled by AEP (2015).

We partitioned highways meeting these criteria into segments with approximately consistent floodplain width and the following river reach characteristics including (1) Strahler order remains the same throughout the reach, (2) no major tributaries enter the section, (3) consistent gradient and (4) a consistent channel pattern.

We further subdivided these into segments of constant consequence (i.e. traffic volume, roadside facilities, and high-load status), resulting in 736 candidate sites. We then examined each site using orthophotos, LiDAR, Google Earth and Google Street View to confirm that there is a credible flood potential and the flooding mechanism is channel capacity exceedance.

After the imagery review, we found that 540 sites did not meet the criteria and removed them from further consideration. We then completed hazard characterization at the remaining 198 sites, 35 of which were covered by AEP's (2015) flood mapping.

3.4.2 Hazard Characterization

At each highway segment, we estimated the frequency ted with which it would be inundated by comparing the minimum river-to-road elevation difference to flow depths predicted using Manning's (1891) equation. This required the following inputs:

- A representative cross section
- A channel gradient
- In-channel and floodplain roughness coefficient (Chow 1959) estimated using Google Street View or Google Earth photographs. At 33 sites where neither were available, we inferred bed particle size using channel gradient, channel pattern, and physiographic region.
- Peak discharge estimates for a range of return periods.

The road surface was above the 500-year flood elevation at 152 of the 196 potential inundation sites. We removed these sites, leaving 44 prioritized sites.

3.4.3 Encounter Probability and Consequence

The encounter probability of an inundation hazard site refers to the frequency of the flood event that would overtop the road surface (F_H):

$$P_{H,S_i} = F_H \qquad [7]$$

This is determined by comparing the minimum road elevation within the hazard site with the minimum flood event required to produce a flood depth that will overtop the road. The inverse of this flood event return period is equal to the likelihood of inundation. Consequence was estimated as described in Section 3.1.

3.5   CULVERT AVULSION HAZARDS

Three main mechanisms can cause culvert avulsion:
1. A culvert undersized for the flood event;
2. A culvert inlet or outlet blocked with debris; or,
3. Erosion of the road embankment surrounding the culvert inlet or outlet.

Of these three mechanisms, only the undersized culvert mechanism was assessed, as there was insufficient data to analyze the other mechanisms.

3.5.1 Hazard Identification

Highway segments subject to culvert avulsion were identified by intersecting highway alignments with the stream network discussed in Section 3.2 resulting in 2,772 crossings. We then examined Alberta Transportation (AT)'s culvert and bridge database to relate watercourse crossing sites to documented culverts using a spatial proximity queries and review of imagery to identify:

- A combination of culvert(s), bridges, or bridge culvert(s)
- A single culvert

- Multiple culverts
- No documented culvert.

Duplicate locations (83) where a culvert crossed both sections of a divided highway were removed from the dataset. Sites with bridges or bridge-sized culverts (995 crossings) were not included. A summary of the potential avulsion sites is shown in Table 5.

Table 5. Summary of potential avulsion sites.

Scenario	Total number
Crossings with culvert data	452
Crossings without culvert data	1,258
Culverts without crossing data	4,773

3.5.2 Hazard Characterization

We characterized hazards separately for the following three scenarios:
1. Watercourse crossings coincident with a culvert in AT's database.
2. Watercourse crossings without a coincident culvert in AT's database.
3. Culverts in AT's database without a coincident watercourse crossing.

For the first two scenarios, we estimated flood quantiles at the intersection of the stream network and highway using the RNT. We performed no further analysis for Scenario 3 as the culverts are not linked to a watercourse in the stream network except to present the location of and relevant information on AHHIT.

The catchment areas for many of the culverts are small compared to the catchment areas of the hydrometric gauges used in the regional FFA. This can result in peak flow estimates with a high level of uncertainty. We compared the flood quantiles estimated using the RNT to other traditional methods (e.g., Rational Methods, Basin Runoff Potential and Unit Flow). We found that the flood quantiles produced by the RNT for small catchments aligned well to the observed flood quantiles from the hydrometric gauges whereas the alternative methods were found to predict significantly larger flows.

Watercourse Crossings with a Coincident Culvert
For watercourse locations with culvert information, we calculated the capacity of the culvert(s) using the following assumptions:

- Inlet controlled flow
- A headwater of 2 m
- A loss coefficient, k_e = 0.5
- Where multiple culverts are present, the total capacity at the crossing is the sum of individual capacities of each culvert.

We then compared the total capacity of the culvert(s) to the 2, 5, 10, 20, 25, 50, 100, 200 and 500-year peak discharge estimates for the crossing.

Watercourse Crossings without a Coincident Culvert
For watercourse crossings without a coincident culvert we estimated the required minimum capacity and diameter

required to pass the design flow. Table 6 summarizes the design flood return periods which were used for the study.

Table 6. Culvert design guidelines (AI, 1999).

Highway Type	Return Period
Primary Highway	100 years
Secondary Highway	50 years
Low Volume Local Road	25 years

The maximum culvert diameter was limited to 1,400 mm as anything greater would be considered a bridge-sized culvert as defined by AT. When the design flood exceeded the capacity of a single 1,400 mm culvert, multiple culverts of a same diameter were specified.

3.5.3 Encounter Probability

We calculated encounter probability for crossings where culvert information was known. This was not possible for crossings without a coincident culvert, so we used a simplified prioritization based on the magnitude of the design flood and the consequence.

Watercourse Crossings with a Coincident Culvert

The encounter probability for a culvert avulsion, P_H is the likelihood of a flood event occurring which exceeds the design capacity of the culvert defined as:

$$P_H = 1/T \qquad [8]$$

Where T is the return period of the flood equal to the capacity of the existing culvert(s).

We calculated the priority score by taking the product of the peak flow of the design flood, Q_{Design}, its encounter probability P_H and the consequence score C and then assigned a percentile rank and prioritization:

$$Priority = Q_{Design} \times P_H \times C \qquad [9]$$

Watercourse Crossings without a Coincident Culvert

For crossings without a coincident culvert, the prioritization is based on the product of the normalized design flood and the normalized consequence:

$$Priority = 100\frac{Q_{Design}}{max(Q_{Design})} \times 100\frac{C}{max(C)} \qquad [10]$$

Where

Q_{Design} is the discharge of the design flood at the crossing.

$max(Q_{Design})$ is the maximum discharge of all the design floods of all the crossings.

C is the consequence at the crossing.

$max(C)$ is the maximum consequence of all the crossings

3.5.4 Consequence

We calculated hazard consequence using the methods described in section 3.1.

4 RESULTS

4.1 Encroachment

Encroachment affected 532 sites, or about 5% of the in-scope highways. A total of 53 encroachment sites were rated as High priority, 213 as Moderate priority, and 266 as Low priority (Figure 7A).

4.2 Inundation

Inundation affected 44 sites at estimated recurrence intervals of 500 years or less. Of the 44 prioritized sites, four are high priority, 18 are moderate priority and 22 are low priority (Figure 7B).
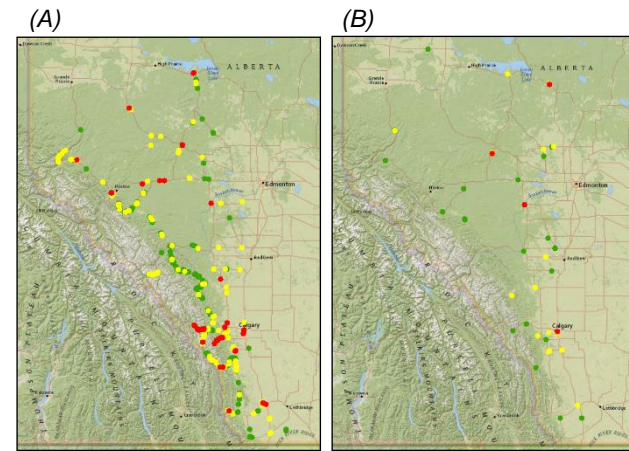

Figure 7. Point locations of encroachment (A) and inundation (B) hazards, coloured by priority rating (red are high priority, yellow are medium, and green are low).

4.3 Culvert Avulsion

A total of 50 culvert avulsion sites with culvert information were rated as high priority, 180 as moderate priority, and 222 as low priority (Figure 8A). A total of 138 of the sites without culvert information were rated as high priority, 498 as moderate priority, and 594 as low priority (Figure 8B).

Of the crossings where the culvert information was known, 79% (359 out of 452) have sufficient capacity to pass the design inflow rate; 67% can pass 500-year or larger flows; 21% are undersized; and 5% can pass only 2-year or smaller flows. Capacity reductions due to blockage from debris were not considered. Of the 528 culverts examined, 108 (or 20%) did not meet the minimum 800 mm diameter requirements for maintenance and freeze-up, as specified by AI (1999).

4.4 Limitations

Several dataset limitations proved to be impossible to avoid without adding a field component to the study. The most significant were a lack of high-resolution elevation data for approximately 30% of sites where LiDAR was unavailable which impacted channel characteristics derived from

spatial data such as gradients. As well, the culvert analysis was hindered by incomplete culvert data and no reliable way to calculate stream channel discharges where no stream network was available. Additionally, previous floodplain mapping data only covered 35 of 198 inundation sites. As well, multiple sources were used to estimate soil erodibility and river bed grain sizes.
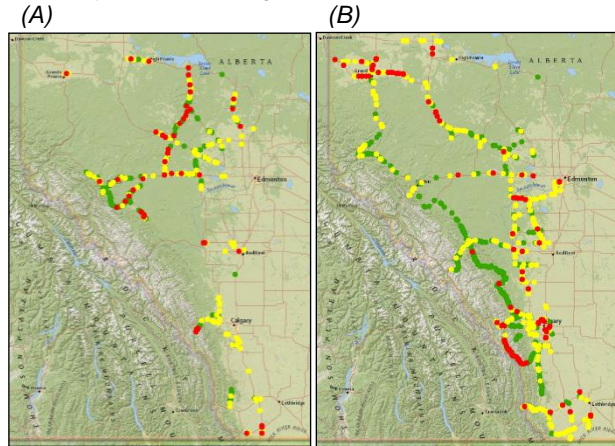

(A)   (B)

Figure 8. Point locations of culvert avulsion hazards with (a) and without (b) culvert information available, coloured by priority rating.

5   CONCLUSIONS

This study provides an inventory and risk-based prioritization of three different types of flood-related hazards: encroachment, inundation, and culvert avulsion. We characterized and prioritized 532 encroachment hazards, 44 inundation hazards, and 452 culverts with potential for avulsion based on hazard levels and presence and value of elements at risk. A further 1,258 stream crossings without culvert data available were prioritized based on design flood discharge and consequence.

The study results are presented on a geospatial web application (Figure 9) that allows the user to review flood hazards, identify risks, and prioritize for further assessment and risk reduction planning. It is important to note that the prioritization scores are relative and not actual annual occurrence probabilities or estimates of risk.
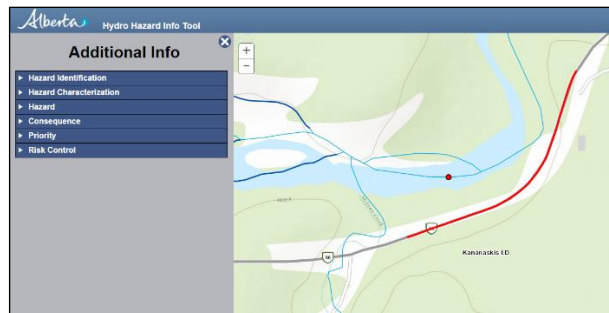

Figure 9. Screen-capture of the Alberta Hydro Hazard Info Tool (AHHIT) at a highway encroachment flood hazard.

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