GOLDEN FLOOD STUDY AND MAPPING
COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK
TOWN OF GOLDEN, BRITISH COLUMBIA

Prepared for:
THE TOWN OF GOLDEN

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TOWN OF GOLDEN, BRITISH COLUMBIA

Report prepared for the Town of Golden, March 2020

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This study was funded by Public Safety Canada (PSC), Emergency Management British Columbia, and the Town of Golden under the risk assessment stream of the Canadian National Disaster Mitigation Program (NDMP). A required deliverable under this NDMP stream is to complete a risk assessment information template (RAIT). This is a basic tool that was developed by PSC in consultation with other government departments, experts in risk assessment best practices, and international leaders in this area. The template allows comparability of information and data outputs from a variety of risk assessment methodologies that may be used. The completed RAIT should outline and describe local risk, including an estimate of the likelihood of occurrence, potential magnitude, and type of consequences or impacts.

EXECUTIVE SUMMARY

The Town of Golden is subject to flooding from three watercourses: the Columbia River, the Kicking Horse River, and Hospital Creek. Flood mapping that was last completed in 1979 by the Province of British Columbia did not consider the protection provided by the dikes that run along the Kicking Horse River through the Town and did not include flood mapping of Hospital Creek.

This study provides updated flood hydrology assessments, updated flood inundation maps for the designated 1:200-year flood, and a dike breach flood hazard map along the Kicking Horse River dikes. The flood elevations and extents were estimated using a hydraulic model and terrain and bathymetric survey data obtained in 2019. The dike breach flood elevations and extents were estimated by using the hydraulic model to simulate dike failures at nine locations along the dikes. The study funding required a risk assessment which is provided for the 1:200-year flood and for the dike breach scenario with the largest consequences; i.e., a dike breach near the municipal campground.

Flood Hydrology

Hydrologic analysis was undertaken to estimate the flood frequency (flood magnitude and return period) for the Columbia River, the Kicking Horse River, and Hospital Creek. The hydrologic analysis included fitting probability distributions to annual maximum flow records on each watercourse, and comparing to flood hydrology for other watercourses in the region. The recommended flood magnitudes (peak instantaneous flow rate) for the designated 1:200-year floods are as follows:

- Columbia River above Kicking Horse River: 786 m^3/s
- Kicking Horse River: 570 m^3/s
- Hospital Creek: 30 m^3/s

There is a relatively small uncertainty with the flood frequency estimates for the Columbia River and Kicking Horse River because of the longer period of record (114 and 54 years, respectively). Furthermore, the recommended flood magnitude for the Kicking Horse River includes a 20% factor of safety, equivalent to the upper 95% confidence bound from the statistical probability distribution. This methodology is consistent with previous studies and the existing design flood for the dikes.

There is significant uncertainty associated with the flood frequency estimates for Hospital Creek because of the short period of record (19 years). But the flood inundation extents on Hospital Creek are primarily driven by topography and the Columbia River floodplain and are not sensitive to flow rate. The recommended freeboard is considered a sufficient contingency for this uncertainty.

Freeboard

The 1:200-year flood inundation maps include 0.6 m freeboard to provide contingency for uncertainties due to climate change and uncertainties in the flood frequency analyses and hydraulic models. This freeboard exceeds the minimum Engineers and Geoscientists of British Columbia (EGBC) guidelines

(0.3 m above the peak instantaneous flood or 0.6 m above the daily average flood; EGBC 2018). The freeboard accommodates the following increases to the 1:200-year flood flow magnitudes: a 40% increase in the Columbia River, a 40% increase in the Kicking Horse River, and more than a 100% increase in Hospital Creek. This allows for an increase in flood magnitudes that exceed the amount recommended for climate change impacts by EGBC (i.e., 20%; EGBC 2018).

Recommendations – Flood Inundation and Dike Breach

The updated 1:200-year flood inundation maps provided herein now include Hospital Creek for the first time and reflect updated conditions in the Columbia River (e.g., 0.3 m higher in the southern area of the Town). Thus, the updated 1:200-year flood inundation maps should be adopted into the Town floodplain bylaw as soon as practical for new development. Exemptions for additions to existing buildings may be considered (e.g., exemptions when adding less than 25% of the existing floor area).

The Kicking Horse River dike system is appropriately armoured and stable, with freeboard that exceeds the provincial engineering association guidelines (EGBC 2018, APEGBC 2017). The dikes have at least 0.6 m freeboard and more than 1.0 m in many areas versus a guideline value of 0.3 m above the peak instantaneous 1:200-year flood. Provided that regular dike inspections and maintenance continue, the likelihood of dike failure is low – but not zero.

As a next step, the Town should consider how to address the dike breach flood hazard area in the Town floodplain bylaw. Three example options are summarized herein and vary from no development restrictions (Option 1) to full floodplain development restrictions (Option 3). The Town may also consider a partial or limited set of development restrictions; examples are described in Option 2. Additional study is required to weigh the options and develop specific amendments or an updated floodplain bylaw.

In the interim, the floodplain bylaw could be updated with the updated 1:200-year flood inundation maps (to reflect the addition of Hospital Creek and changes to the Columbia River) and with interim requirements in the dike breach flood hazard area until additional study is completed. Within the dike breach flood hazard area, the flood construction level (FCL) could be set to 1 m (3 feet) above the adjacent road – matching the existing bylaw requirements and the 1979 flood maps. Alternatively, the most stringent option (Option 3) could be implemented immediately and later scaled back as further study warrants.

1. Apply no specific development restrictions but indicate that property owners are to be aware of potential dike breach flood risks. The bylaw may include the dike breach flood hazard map for information and make reference to this report. This option is not supported by the provincial land use guidelines (B.C. MWLAP 2004).

2. Apply a limited set of development restrictions within the dike breach hazard zone. For example, the first floor of buildings and/or all electrical and mechanical equipment to be a certain height above the adjacent street. For reference, the current Town floodplain bylaw stipulates a FCL that is 1 m (3 feet) above the adjacent street (based on the 1979 flood maps) and no livable space is allowed below the FCL (e.g., basements). Limited development restrictions are used in other jurisdictions and may be considered appropriate mitigation for the flood risk per the EGBC guidelines (EGBC 2018). The provincial land use guidelines (B.C. MWLAP 2004)) do not support limited development restrictions.

3. Apply FCLs and the full floodplain bylaw restrictions within the dike breach inundation hazard zone. For example, livable space below the FCL (e.g., basements) would not be permitted. The bylaw would need to specify a freeboard above the dike breach flood levels that are shown on the dike breach flood hazard maps; a freeboard of 0.6 m is recommended in the provincial land use management guidelines (B.C. MWLAP 2004). This option would comply with the provincial engineering association guidelines (EGBC 2018, APEGBC 2017) and Matrix's interpretation of the provincial land use guidelines (B.C. MWLAP 2004), provide the most limitation of liability for the Town in the event of a dike breach, and reduce the hazard to new development. But this option could be a deterrent to development and would not reduce the hazard for existing development (the majority of the hazard area is existing development).

Note that the provincial land use guidelines (B.C. MWLAP 2004) are somewhat unclear. The guidelines state that the FCL should be equal to the freeboard elevation of the dikes. However; this is considered impractical and extremely conservative for the Town of Golden (the topography of the Town slopes away from the Kicking Horse River, and the resulting FCL would range from 1 to 4 m deep across the southern part of Town versus a depth of 0.3 to 0.6 m from the dike breach model results). Flood levels from a dike breach would slope down moving away from the Kicking Horse River toward the Columbia River. Matrix's interpretation of the provincial land use guidelines is that they support a lower FLC if dike breach modelling is undertaken. Therefore, additional study is recommended to weigh the options and develop specific amendments or an updated floodplain bylaw

Recommendations – Hospital Creek

The culvert along Hospital Creek at Highway 1 may overtop during a flood on the order of a 1:100 to 1:200-year event, and is at risk of overtopping at lower flow if the culvert is partially blocked by debris. If the culvert is overtopped during a flood, an area will be inundated along Highway 1, and between Hospital Creek and Highway 1 north of the culvert. This area is delineated on the 1:200-year flood inundation maps and would generally be subject to shallow depths (less than 0.3 m) and low velocities (less than 0.2 m/s). It is recommended that either this hazard be mitigated, or development restrictions bee implemented within the Town floodplain bylaw for this area; i.e., a FCL of 0.6 m above the natural ground elevation. The Town of Golden is aware of this hazard and further assessment in warranted.

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1 INTRODUCTION

The Town of Golden (the Town) engaged Matrix Solutions Inc. to complete a flood study on three watercourses that flow through or near the Town: the Columbia River, the Kicking Horse River, and Hospital Creek. This report provides updated open-water flood mapping for areas of the Town that are subject to flooding by these watercourses. Flood mapping that was last completed in 1979 by the Province of British Columbia did not consider the protection provided by the dikes that run along the Kicking Horse River through the Town and did not include flood mapping of Hospital Creek.

1.1 Background

The Town is situated on the alluvial fan of the Kicking Horse River and Hospital Creek and adjacent to the Columbia River, as shown on Figure 1 and described below:

The **Columbia River** flows along the south and west borders of the Town and poses a flooding risk to large portions of the south side of the Town, including the airport, a large railway yard, search and rescue building, and wastewater treatment plant.

The **Kicking Horse River** flows from east to west through the centre of the Town before joining the Columbia River. Armoured dikes run along both banks of the river through the Town and can contain greater than a 1:200-year flood. However, there remains a flood risk to large portions of the Town under a potential dike breach scenario. The dikes were constructed over several decades and completed (to near existing height and conditions) in the 1970s. The dikes have never failed or been overtopped during open-water flood events but have briefly overtopped during an ice jam flood event. Ice jam flood risks were recently assessed in a 2018 report by Matrix (2018a) and are not included in the scope of this study. Ice jam-induced dike failure is considered unlikely.

Hospital Creek flows from north to west through the northwest portion of the Town and parallel to the Canadian Pacific Railway (CPR) main line before joining the Columbia River 3 km downstream of the Kicking Horse River confluence. The creek appears to have been relocated from its original location, likely during construction of the CPR main line in the 1880s. Hospital Creek is now constrained by Highway 1 and numerous culverts through the Town. Downstream of the 14 Street North culvert, the creek flows through an excavated channel with a training berm on the one side and built-up CPR tracks on the other before joining the Columbia River floodplain. Hospital Creek poses a flood risk to numerous commercial and residential properties along the TransCanada Highway and the CPR main line.

Open-water flood mapping for the Kicking Horse and Columbia rivers was last completed in 1979 by the Province of British Columbia but did not consider the protection afforded by the Kicking Horse River dikes or flooding resulting from a potential dike breach. Flood mapping has never been completed for Hospital Creek. A draft floodplain hazard map for dike breach scenarios during open-water flood events along the Kicking Horse River was completed in 2004 by Hydroconsult EN3 Services Ltd. (currently Matrix) but was never finalized per the Town's request (Hydroconsult 2004).

1.2 Scope

This report provides updated flood mapping for areas of the Town that are subject to flooding by the Columbia River, the Kicking Horse River, and Hospital Creek. The scope of work includes:

- Survey and base data collection – including Light Detection and Ranging (LiDAR) survey, orthophoto collection, bathymetric survey, and hydraulic structure survey.
- Hydrologic assessments – to review and update (if required) the flood frequency magnitude for return periods up to the 1:200-year flood (the designated flood for floodplain mapping in British Columbia).
- Hydraulic modelling and dike breach simulation – hydraulic models were developed for the Columbia River, Kicking Horse River, and Hospital Creek. The models consist of one-dimensional (1D) and two-dimensional (2D) elements. The analysis includes dike breach scenarios along the Kicking Horse River and 2D modelling of the resulting overland flooding through the Town.
- Flood inundation maps – suitable for incorporation into the Town Floodplain Management Bylaw 963. The flood inundation maps show the designated 1:200-year flood water level and flood extents and include a 0.6 m freeboard. Flood extents for the 1:100 and 1:20-year floods are provided in digital format under separate cover.
- Dike breach flood hazard maps – showing areas that are at flood risk due to a potential breach at any location along the dikes and the corresponding estimated water levels.
- Risk assessment – for a scenario where the 1:200-year flood occurs on each watercourse and for the dike breach scenario with the largest consequences; i.e., near the municipal campground. Risk assessment information template (RAIT) forms were completed for these scenarios and are provided under separate cover.

The hydrology assessment and flood inundation maps include consideration for climate change based on the provincial engineering association guidelines (EGBC 2018).

1.3 Provincial Guidelines

Provincial guidelines are summarized in *Legislated Flood Assessments in a Changing Climate in BC* by the Engineers and Geoscientists of British Columbia (EGBC; 2018). Key considerations for the Town of Golden are summarized below. Further details are available in the referenced Legislation and guidelines.

- Under the *Local Government Act* the Town may designate land as a floodplain. In making bylaws, the Town "must consider provincial guidelines, and comply with the provincial regulations and a plan or program the government has developed under those regulations." While no regulations have been published, provincial guidelines have been published; i.e., *Flood Hazard Area Land Use Management Guidelines* (B.C. MWLAP 2004).

  - The provincial guidelines designate the 1:200-year flood for floodplain mapping and recommend a minimum freeboard of 0.6 m above the 1:200-year flood for areas protected by dikes. It is not specified if the designated flood should be the daily average or peak instantaneous flow. No freeboard recommendation is made for floodplain areas that are unprotected by dikes.

  - The provincial land use guidelines are somewhat unclear on determining the flood construction level (FCL) for areas protected by dikes. The guidelines state that the FCL should be equal to the freeboard elevation of the dikes. However; this is considered impractical and extremely conservative for the Town of Golden (flood depths would range from 1 to 4 m across the southern part of Town versus a depth of 0.3 to 0.6 m from the dike breach model results; e.g., projecting the Kicking Horse River FCL would result in a FCL of approximately 790 m and depth of 4 m at the intersection of 9th Street South and 13th Street South). Flood levels from a dike breach would slope down moving away from the Kicking Horse River towards the Columbia River. Matrix's interpretation of the provincial land use guidelines is that they support a lower FLC if dike breach modelling is undertaken (as is stated for costal dikes).

- Other relevant guidelines include those prepared by the provincial engineering association (EGBC 2018, APEGBC 2017) and guidelines for dikes under the *Dike Maintenance Act* (B.C. MWLAP 2003).

  - The provincial engineering association and dike guidelines recommend a freeboard of 0.3 m above the peak instantaneous 1:200-year flood or 0.6 m above the 1:200-year daily average flood.

1.4 Available Information

This study is based on the following information:

- LiDAR terrain survey and orthophoto completed on July 20, 2019, by Airborne Imaging Inc. The LiDAR has a horizontal accuracy of ±0.45 m, vertical accuracy of ±0.1 m, resolution of 1 m, and complies with requirements of the funding and provincial guidelines (MFLNRORD 2019). The LiDAR and orthophoto extents are shown on Figure 1.

- A site survey completed by Matrix from September 26 to October 3, 2019 using a combination of Real Time Kinematic (RTK) GPS equipment and an Echo Sounder. The site survey included bathymetry of the watercourses, water levels, and hydraulic structures (e.g., culverts and bridges).

Extents of the site survey are shown on Figure 2. Photographs from the site survey are shown in Appendix D.

- Discharge (flow) measurements completed by Matrix during the site survey. One discharge measurement was obtained for each watercourse. Columbia River and Kicking Horse River discharges were measured using an Acoustic Doppler Current Profiler. Hospital Creek flow was measured using an Acoustic Doppler Velocimeter.

- Discharge and water level data from Water Survey of Canada (WSC) for hydrometric stations on the Columbia River (stations 08NA002 and 08NB005), Kicking Horse River (station 08NA006), and Hospital Creek (stations 08NB002, 08NB009, and 08NB010).

- Water level data on the Columbia River and Kicking Horse River used for calibration of the hydraulic model:

  - observed water level on the Kicking Horse River between the pedestrian bridge and the Highway 95 bridge during the 2012 flood (about a 1:10-year flood)
  - the water surface elevation profile from the 2019 LiDAR along the Columbia River and Kicking Horse River
  - the water surface elevation points from the 2019 survey along the Columbia River and the Kicking Horse River

- Anecdotal information on recent large floods on Hospital Creek that occurred in 2008 and 2012 (no flow recorded). During the 2008 flood, the bank upstream of Highway 1 was eroded. During both floods an area downstream and west of the 14 Street culvert was flooded including the CPR line, a residential area, and an industrial area. The Highway 1 culvert did not overtop during these flood events.

- Observations and photographs from site visits by Matrix during the site survey and numerous previous visits for prior work by Matrix (and formerly Hydroconsult).

- Floodplain maps completed in 1979 for the Columbia River and Kicking Horse River. The floodplain maps include estimated water surface elevations for the 1:200-year and 1:20-year floods and were based on a one-dimensional HEC-2 hydraulic model and include a 0.6 m freeboard. The model inputs and estimated flood magnitudes (flow) are not known.

- Design drawings for the planned Kicking Horse River Dike Improvement Project by Urban Systems Ltd., Read Jones Christoffersen Ltd., and Matrix. The Dike Improvement Project includes the construction of a concrete dike and raising of earthen dikes that will be completed in 2020 and 2021. The concrete dike will be located on the north bank along the historical Downtown area, be approximately 220 m long, and will have an elevation up to 1 m above the existing dike crest.

Approximately 1,020 m of the earthen dikes will be raised in several locations along the south bank by up to 0.45 m. Approximately 300 m of bank armour will be restored near the confluence with the Columbia River (note that this area is within the Columbia River floodplain). The floodplain mapping assumes the raising of concrete dike and earthen dike are completed.

- Historical construction and dike inspection records summarized in the Operation and Maintenance Manual for the dikes (Matrix 2019).

- Historical Kicking Horse River cross-section data from 1987 to 2017 provided by BC Ministry of Environment, Land & Parks and the Town of Golden. Comparison of the historical cross-sections have been completed by Matrix (and formerly Hydroconsult) since 2002, with the most recent assessment in 2018 (Matrix 2018b). The Kicking Horse River is subject to ongoing deposition downstream of 7th Street North. Deposition or scour has been insignificant upstream of this location.

2 SITE SURVEY

The site survey was completed from September 26 to October 3, 2019, to the extents shown on Figure 2. Data collected during the survey included:

- River cross-sections – along the Columbia River and Hospital Creek
- Bathymetric and top topographic survey – along the Kicking Horse River and the confluence of the Kicking Horse and Columbia rivers
- Hydraulic structure geometry survey – one bridge over the Columbia River, three bridges over the Kicking Horse River, and three bridges and two culverts along Hospital Creek
- Discharge measurements – one measurement was obtained for each watercourse

The survey was conducted using RTK GPS equipment, for the hydraulic structures, banks, and areas where the water was shallow enough to wade; and RTK GPS with attached echosounder, for deeper areas. Geodetic Control Marker GCM885 and two other temporary control markers were surveyed each day and used to calibrate the survey equipment. RTK survey data have an absolute positional accuracy of ±0.05 m, at 95% confidence. RTK with echosounder survey data have an absolute positional accuracy of ±0.10 m.

Survey data is reported in the appropriate local Universal Transverse Mercator zone 11 referenced horizontally to the Canadian Spatial Reference System, North American Datum of 1983 (NAD83CSRS). The survey data is referenced to the Canadian Geodetic Vertical Datum of 2013 (CGVD2013). Note that the previous 1979 flood maps are referenced to the CGVD1928 vertical datum, which is about 0.455 m lower than CGVD2013 near Golden.

A three-dimensional surface was created from the survey data within the bathymetric survey area. This allowed for the hydraulic model to be developed using a combination of one-dimensional (1D) and two-dimensional (2D) elements, and for 1D cross-sections to be added or removed within the hydraulic model.

3 FLOOD HYDROLOGY

A hydrologic analysis was undertaken to estimate the flood frequency (flood magnitudes and return periods) for the Columbia River, Kicking Horse River, and Hospital Creek. Details of the hydrologic analysis are provided in the following sections.

3.1 Previous Studies

The following summarizes previous hydrology assessments.

Columbia River

In 2004 and 2014, Matrix (and formerly Hydroconsult) completed flood frequency analysis (FFA) of historical data recorded at the WSC station on the Columba River (08NA002), located 8 km upstream of the Town of Golden (Hydroconsult 2004; Matrix 2014). Both these studies provided a very similar 1:200-year instantaneous flood magnitude (782 m^3/s in 2004 and 777 m^3/s in 2014) based on fitting a Log Pearson Type III (method of moments) distribution to the annual maximum flow record.

Kicking Horse River

A comprehensive flood hydrology assessment for the Kicking Horse River was completed in 2004 by Hydroconsult. The assessment included a review of studies completed before 2004, a review of historical floods, a single station FFA, a two-station FFA, and an analysis based on the runoff depth approach as developed by Alberta Transportation. The 2004 study computed a 1:200-year instantaneous flood magnitude of 490 m^3/s based on a single station analysis using the best-fitted Log Pearson Type III theoretical distribution (method of moments). To account for uncertainty, the study recommended a 1:200-year instantaneous flood magnitude of 570 m^3/s, the upper 95% confidence interval of computed distribution.

Other previous estimates of the instantaneous 1:200-year flood magnitude, as summarized in Hydroconsult (2004), have ranged from about 500 m^3/s, for studies based on a single station analysis of the WSC station data; to over 750 m^3/s, for studies based on regional analysis. An extreme upper envelope peak flood of 1,000 m^3/s was estimated.

Hospital Creek

A flood hydrology assessment for the Oster Road Bridge (about 4 km upstream of Highway 1) was completed by Northwest Hydraulics Consultants in 2016 (NHC 2016). The estimated 1:100-year design flow was 21.1 m^3/s for a drainage area of 25.8 km^2 at this location.

3.2 Available Streamflow Records

The FFA for this study is based on discharge records from WSC stations at the locations shown on Figure 1 and listed in Table 1. Figure 1 also shows stations used in a regional analysis by Obedkoff (2002).

Both Columbia River and Kicking Horse River have long periods of record with over 100 years of data on the Columbia River, and over 50 years on the Kicking Horse River. Two stations are located on the Columbia River near the Town: one upstream and one downstream. One station is located on the Kicking Horse River in the middle of the Town.

There are three stations located on Hospital Creek but are all discontinued and only cover short periods. There is a total combined 19 years of data available on Hospital Creek.

TABLE 1 Available Streamflow Records

WSC Station		Drainage Area (km^2)	Years of Record	Period of Record
Columbia River at Nicholson	08NA002	6,660	114	1903 to 2018
Columbia River at Donald	08NB005	9,710	74	1944 to 2018
Kicking Horse River at Golden	08NA006	1,850	54	1911 to 2018
Hospital Creek Near Golden	08NB002	54.1	9	1915 to 1964
Hospital Creek North Fork Near Golden	08NB009	25.1	10	1965 to 1976
Hospital Creek above North Fork Near Golden	08NB010	21.5	10	1966 to 1976

3.3 Columbia River Flow Frequency Analysis

Figure 1 depicts the Columbia River drainage basin and key gauging stations. Columbia River originates at Columbia Lake and flows approximately 140 km north, collecting numerous tributaries along its way, to the Town of Golden where it collects the Kicking Horse River. The Columbia River then continues north another 40 km to Kinbasket Lake. The Columbia River basin above Kicking Horse River has a drainage area of 6,660 km^2, an average elevation of 1,747 m, and approximately 3% of the basin area is glaciated.

Flooding typically occurs in June, driven by snowmelt combined with high precipitation. Hydrographs from the five largest floods show that floods occur over a long duration; on average, flow is within 90% of the peak flood flow for five days.

A FFA was completed using annual maximum instantaneous flow from WSC station 08NA002 (Columbia River at Nicolson, above Kicking Horse River). Where maximum instantaneous flow was not available, it was estimated by the average ratio of instantaneous to daily flow. Various distributions were investigated and the Log Pearson Type III (Method of Moments) distribution was found to give the best fit to the data. The computed 1:200-year flood is 786 m^3/s (118 $L/s/km^2$), which is similar to estimates from previous studies.

For comparison, a FFA was also completed using the 74 years of data from WSC station 08NB005 (Columbia River at Donald, below Kicking Horse River and Blaeberry River), resulting in a 1:200-year flood of 1,270 m^3/s (130 $L/s/km^2$). This result compares well with the result from Columbia River above Kicking Horse River (the unit flow is within the 95% confidence bounds), and suggests that extreme floods on the Columbia and Kicking Horse rivers are roughly coincident (the sum of the 1:200-year flood on Columbia River above Kicking Horse River and Kicking Horse River equals 1,356 m^3/s).

Figure 3 summarizes the hydrologic analysis of the Columbia River above the Kicking Horse River. A 1:200-year instantaneous flood magnitude of 786 m^3/s is recommended.

3.4 Kicking Horse River Flow Frequency Analysis

Figure 1 depicts the Kicking Horse River drainage basin and key gauging stations. Kicking Horse River originates at Wapta Lake, located immediately west of the continental divide in the Rocky Mountains. The River flows approximately 80 km west to the Town collecting numerous tributaries along the way (including the Yoho, Emerald, Amiskwi, Otterhead, Ottertail, and Beaverfoot rivers), then flows another 3.5 km through the Town to its confluence with the Columbia River. The basin has a drainage area of 1,850 km^2 at the Town, an average elevation of 1,938 m, and approximately 5% of the basin area is glaciated.

Flooding typically occurs from March through June and is primarily driven by snowmelt. The most extreme events are a result of rainfall on snowmelt (Hydroconsult 2004). Hydrographs from the six largest floods show that on average, flow is within 90% of the peak flood flow for about one day.

A FFA was completed using annual maximum instantaneous flow from WSC station 08NA006. Where maximum instantaneous flow was not available, it was estimated by the average ratio of instantaneous to daily flow (1.074) resulting in a total record of 54 years. Various distributions were investigated and the Log Pearson Type III (Method of Moments) distribution was found to give the best fit to the data. The computed 1:200-year flood is 465 m^3/s (118 $L/s/km^2$). Compared to the 2004 Hydroconsult study, this analysis generated a similar 1:200-year flood magnitude, but increased flood magnitudes for more frequent return periods.

Figure 4 summarizes the hydrologic analysis of the Kicking Horse River. A 1-200-year flood magnitude of 570 m^3/s is recommended and includes a 20% factor of safety, equivalent to the upper 95% confidence bound of the fitted distribution. This methodology is consistent with previous studies and the existing design flood for the dikes.

3.5 Hospital Creek Flow Frequency Analysis

Figure 1 depicts the Hospital Creek drainage basin and key gauging stations. The drainage area of Hospital Creek at the Town (i.e., at the Highway 1 culvert) was delineated using the 2019 LiDAR where possible (0.7% of the area) and with several topographic maps for the area not covered by the 2019 LiDAR (ESRI 2020; NASA 2011). The resulting drainage area was 53.9 km^2, but for this analysis a conservative drainage of 54.1 km^2 was assumed (the reported value for WSC station 08NA002). The basin has an average elevation of 1,614 m and does not appear to contain any glaciers.

A 19-year record of average daily flows was developed by combining the records from all three WSC stations on Hospital Creek. Flow from station 08NA009 and 08NA0010 were combined (representing a total drainage area of 46.6 km^2). This combined flow was then adjusted to the 08NA002 location (54.1 km^2) by the ratio of the drainage areas to the exponent of 0.75, a recommended equation for BC (Eaton et al. 2002).

A FFA was completed using the 19-year combined flow record. Maximum instantaneous flow was conservatively estimated as 1.3 times the daily flow (for comparison, this ratio is about 1.2 at the nearby Split Creek WSC station with similar drainage area [81.3 km^2]). Various distributions were investigated and the 3-Parameter Lognormal (maximum likelihood) distribution was found to give the best fit to the data. The computed 1:200-year flood is 30 m^3/s (543 $L/s/km^2$), which is similar to the previous 2014 NHC study.

Figure 5 summarizes the hydrologic analysis of Hospital Creek. A 1:200-year instantaneous flood magnitude of 30 m^3/s is recommended.

There is a significant uncertainty associated to the flood frequency estimates for Hospital Creek because of the short period of record. But the resulting flood inundation extents and flood water levels are not sensitive to flow rate and the recommended freeboard is considered a sufficient contingency for this uncertainty (see Section 4, the sensitivity analysis for the Hospital Creek hydraulic model).

For comparison, a regional analysis was used to estimate the 1:200-year flood using an adapted flood envelope curve and regional flood frequency ratios from a previous regional study (Obedkoff 2002). The flood envelope gives a 1:10-year peak instantaneous flood unit discharge of 360 $L/s/km^2$ for Hospital Creek, which is then multiplied by 1.55, the maximum flood frequency ratio of the 1:200 to 1:10-year floods for the regional stations. The result is a 1:200-year peak instantaneous flood magnitude of 30 m^3/s.

Details on the adapted flood envelope curve are provided in the following section.

3.6 Regional Hydrologic Review

A regional hydrologic review was undertaken for comparison to the recommended flood frequency estimates. Regional flood hydrology was investigated using a 2002 provincial regional analysis (Obedkoff 2002), and high-resolution average annual precipitation maps for 1981 to 2010 (Wang et al. 2012).

The 2002 regional hydrology study proposed groups of regions with similar hydrologic characteristics and developed flood frequency envelope curves for these regions. The Columbia River, Kicking Horse River, and Hospital Creek are located within subzone 14x. Plotting 1:10-year flood data for subzone 14x (Figure 5) shows a significant difference in unit flood flow for basins located in the east versus the west side of the Columbia River valley (station locations are shown on Figure 1).

Comparing the average precipitation across these basins reveals a similar trend. The western basins receive annual precipitation between 2,000 and 1,100 mm at high and low elevations, respectively. The eastern basins receive between 1,300 and 700 mm at high and low elevations, respectively.

Considering only stations on the Columbia River and on the east side of the Columbia River valley results in a flood envelope curve that compares well with the single station FFA provided herein.

3.7 Recommended Flood Frequency Estimates

Recommended flood frequency estimates are summarized in Table 2 and are used for the subsequent hydraulic modelling and flood inundation mapping. The table shows instantaneous flood magnitudes for return periods up to the 1:200-year flood, the designated flood in British Columbia for floodplain mapping and assessment. The potential effect of climate change on water levels are accounted for in the freeboard applied to the computed flood elevations as discussed in Section 3.8 below.

TABLE 2 Recommended Flood Frequency Estimates

Watercourse:	Columbia River Above Kicking Horse River	Kicking Horse River	Hospital Creek
Drainage Area (km^2):	6,660	1,850	54.1
Return Period		Instantaneous Flood Magnitude (m^3/s)	
2	428	263	4.9
10	587	368	11.2
20	639	409	14.6
50	701	468	19.9
100	745	517	24.6
200	**786**	**570**	**30.0**

Note:
1. The 1:200-year flood is the designated flood in British Columbia for floodplain mapping and assessment.

3.8 Potential Effects of Climate Change

Climate change projections for British Columbia generally predict a 2.8°C increase in annual temperatures, and between a 6% and 17% increase in precipitation, with the majority increase in precipitation during winter (EGBC 2018). For larger watersheds, such as the Columbia River, flow is expected to increase in the winter, and drier conditions are expected in the summer. For smaller watersheds, such as the Kicking Horse River and Hospital Creek, rain-dominated floods are expected with potentially higher peak flows due to increased storm precipitation and intensity.

The Pacific Climate Impacts Consortium (PCIC) completed a provincial hydrologic model in 2011 that projects future flows based on global climate change model outputs for various emissions scenarios. The hydrologic model is currently not suitable for extreme flood analysis because it uses monthly climate projection inputs at a spatial resolution typically between 250 and 600 km, then employs statistical downscaling techniques to convert the data to a roughly 10 km scale (PCIC 2020). The PCIC is currently working on updating their provincial hydrologic model (which may better predict climate change impacts on extreme flood events) by also downscaling the model inputs from a monthly to daily timestep (Schnorbus 2019, Pers. Comm.).

Significant uncertainty exists in quantifying the hydrologic response and any potential impact on flood magnitude and timing due to the complex nature and inherent uncertainty in climate change projections. (EGBC 2018) currently recommends a 20% increase to estimated flood magnitudes to account for uncertainties on future conditions.

A freeboard of 0.6 m has been applied to the flood elevations provided on the flood inundation maps to provide contingency for increased flood magnitude due to climate change and for other uncertainties. This exceeds the minimum recommended 0.3 m freeboard above peak instantaneous flood levels and allows for the following increase to 1:200-year flood magnitudes; exceeding the recommended 20% for climate change impacts (EGBC 2018).

- Columbia River: 40%
- Kicking Horse River: 70% above the 1:200-year and 40% above the upper 95% confidence bound
- Hospital Creek: more than 100%, because flow readily overtops the banks and enters the Columbia River floodplain

4 HYDRAULIC MODELLING

HEC-RAS hydraulic modelling software (version 5.0.7; USACE 2016) was used to simulate flood levels for design floods associated with various return periods. Two models were created; one for the Columbia and Kicking Horse rivers, and one for Hospital Creek. A combination of 1D and 2D hydraulic modelling elements were used in both models.

4.1 Columbia River and Kicking Horse River Hydraulic Model

The hydraulic model and input parameters are summarized below. A schematic of the model is shown on Figure 2.

- The model domain extends along the Kicking Horse River from the mouth of a 100 m high steep incised canyon on the upstream end of Town, through the confluence with the Columbia River, and 2.3 km downstream and 5.5 km upstream along the Columbia River from the confluence.

- The model was created with a combination of 1D and 2D elements.

  - 1D cross-sections were used to model between the riverbanks / dikes. Cross-sections were spaced about 50 to 100 m apart in the Kicking Horse River, and 100 to 300 m apart in the Columbia River.

  - 2D flow areas were used to model the overbanks, floodplains, and the confluence of the Kicking Horse and Columbia rivers. The overbanks and floodplains were connected to the cross-sections using lateral structures along the Kicking Horse River dikes, and along the Columbia River banks. The confluence was connected to the cross-sections using the appropriate upstream or downstream connection. The 2D cell size generally ranged from 5 m by 5 m in the confluence, to 30 m by 30 m in the floodplain. The lateral structures along the Kicking Horse River were used for the dike breach simulation.

  - Two hydraulic structures were included in the model: the CPR bridge over the Kicking Horse River and Dogtooth bridge over the Columbia River. Because of the large skew to the flow direction, the CPR bridge over the Kicking Horse River was included in the 2D area of the model by entering the piers into the terrain. The bridge deck is not included but its low chord is well above the computed flood levels. The Highway 95 and pedestrian bridges over the Kicking Horse River were not included because they are both clear span (no piers) with bridge low chords above computed flood levels. The Highway 95 Bridges are also set to be replaced within about 5 years and will be constructed to a higher elevation.

- Computational equation set: the model was run with unsteady full momentum equations, compared to steady state equations used in the previous hydraulic model (Matrix 2014). Unsteady full momentum equations typically require a lower Manning roughness coefficient than steady state models.

- Manning roughness coefficient (*n*): was selected based on a review of the aerial photographs and suggested values by Chow (1959). The selected coefficients are 0.06 for the overbanks, 0.01 for roads and paved areas, and 0.05 for industrial areas. The coefficients within the channels were adjusted based on the calibration data resulting in values between 0.02 and 0.028. These coefficient values are lower than used in 2014 study (between 0.025 and 0.032) because the current study uses unsteady full momentum equations.

- Boundary conditions: used normal depth for the downstream boundary condition with an energy grade of 0.09%, based on the average channel slope measured from the LiDAR; and flow hydrographs for the upstream boundary conditions along the Columbia and Kicking Horse rivers.

- Flow regime: mixed flow regime calculations (i.e., able to calculate both supercritical and subcritical flow).

4.1.1 Model Calibration

The model was calibrated by adjusting the roughness coefficients of the channel and comparing the results to the water surface from the 2019 LiDAR, the fall 2019 surveyed water surface, and the approximate elevation from an observed 1:10-year flood event on the Kicking Horse River in 2012 (see Figures 6 and 7). Flow during the 2019 LiDAR was taken from WSC real time flow data for the Kicking Horse River and Columbia River. The resulting Manning roughness coefficients are likely conservative because roughness typically decreases with larger flows.

4.1.2 Comparison to Previous Studies

Figures 6 and 7 show a comparison of the computed 1:200-year water level profile to previous studies for the Columbia River and the Kicking Horse River, respectively.

There are some differences between the 1:200-year water level in the Columbia River between the current study and the 1979 flood maps.

Upstream of the Kicking Horse River, the computed 1:200-year water levels are about 0.3 m higher in the Columbia River and in the flooded area of the Town near the airport and CPR yard. The increased flood level is likely due to two structures that were constructed since the 1979 flood maps. The Dogtooth bridge and a 2 m high built-up road beside the airport constrict the Columbia River by about 25% to 30% of the floodplain width. Figure 6 shows that there has not been significant deposition or change to the general elevation of the river thalweg in this area.

Downstream of the Kicking Horse River, the computed 1:200-year water levels in the Columbia River are about 1 m lower from sta. 2+300 to 3+300, and 1 m higher from sta. 0+200 to 2+000. This difference may be due to some deposition in the area. The current study is considered more accurate (or more up to-date) and compares well with the LiDAR and surveyed water levels.

The computed 1:200-year water levels in the Kicking Horse River compare well with the previous 2014 study (Matrix 2014). The difference in water level is typically less than 0.1 m, considered within the uncertainty of the hydraulic model. The water level does vary more than this upstream of the

Highway 95 bridge, between sta. 2+200 and 2+700, but the results of this study are considered more accurate because significantly more detailed bathymetry and double the amount of cross-sections within the hydraulic model are used.

4.1.3 Sensitivity Analysis

A sensitivity analysis was conducted to determine the effects of changing key model parameters and inputs. Flow was varied to account for uncertainty of the flood frequency estimates and the effects of climate change. The results are summarized in Table 3.

The Kicking Horse River shows a greater sensitivity to roughness and flow compared to the Columbia River. Although the Kicking Horse River has a greater slope than the Columbia River, it is entirely constrained within its channel by the dikes. Whereas, the Columbia River generally has access to a wide floodplain.

The Columbia River is constrained by the Dogtooth bridge (immediately downstream of the confluence with the Kicking Horse River), and a built-up road beside the airport (upstream of the confluence). Thus, the upstream end of Columbia River has a greater sensitivity to flow and roughness. The built-up CPR yard and the built-up road beside the airport provide flood protection to the nearby areas of the Town up to about the 1:100-year flood (i.e., the south end of the Town that is within the Columbia River floodplain). But these structures are overtopped during a 1:200-year flood and this area may still be subject to flooding during floods with lower return periods due to high groundwater conditions.

TABLE 3 Columbia and Kicking Horse River Hydraulic Model Sensitivity Analysis

Parameter	Parameter Variance		Effect on Flood Level (m)		
	Columbia	Kicking Horse	Columbia US[1]	Columbia DS[2]	Kicking Horse
Manning Roughness Coefficient (n)	± 0.05	± 0.05	± 0.25	± 0.15	± 0.25
Flow (% above the recommended 1:200-year flood magnitude)	+ 315 m^3/s (+ 40%)	+ 230 m^3/s (+ 40%)	+ 0.6	+ 0.4	+ 0.6

Notes:
1. Upstream of Dogtooth Bridge
2. Downstream of Dogtooth Bridge

4.2 Hospital Creek Hydraulic Model

The hydraulic model and input parameters are summarized below. A schematic of the model is shown on Figure 2.

- The model domain extends about 580 m upstream of Highway 1, along Hospital Creek, to 500 m downstream of the confluence of Hospital Creek with the Columbia River.
- The model was created with a combination of 1D and 2D elements.

- 1D cross-sections were used to model the creek above Highway 1 and Anderson Road bridge. Surveyed cross-sections were used, which are spaced about 40 to 60 m apart.

- 2D areas were used to model the creek downstream of Anderson Road bridge, the Highway 1 culvert and surrounding area, the overbanks and floodplains of Hospital Creek, and the floodplain and channel of the Columbia River. The overbanks and floodplains were connected to the cross-sections using lateral structures along banks. The upstream and downstream ends of the 1D sections were connected to the 2D areas using the appropriate upstream or downstream connection. The 2D cell size generally ranged from 10 m by 10 m to 30 m by 30 m.

- Three hydraulic structures were included in the model; the Highway 1 arch culvert (2D), the 14 Street North arch culvert (1D), and the Anderson Road bridge (1D). The CPR bridge near the Columbia River was not included as a structure because it is a clear span and has a negligible effect on the 1:200-year flood levels[1]; the CPR bridge and tracks are overtopped by the Columbia River and the vast majority of flow from Hospital Creek is over the tracks. A beaver dam was observed at the CPR bridge (Photograph 44) but was not included in the model. Beaver dams at this location are expected to have negligible effect on the 1:200-year flood level (majority of flow over the tracks) but will increase the flood level during smaller floods which do not overtop the CPR tracks.

- Manning roughness coefficient (*n*): a conservative value of *n* = 0.07 was selected for the channel and floodplain areas based on a review of the aerial photographs and suggested values by Chow (1959). Although the selected roughness coefficient for the channel may be high, the model was not stable with n < 0.07. In any event, a sensitivity analysis showed that the model results were not sensitive to the Manning roughness coefficient.

- Boundary conditions: used normal depth for the downstream boundary condition along the Columbia River with an energy grade of 0.09%, based on the average channel slope measured from the LiDAR; and a flow hydrograph for the upstream boundary condition along Hospital Creek upstream of Highway 1.

- Flow regime: mixed flow regime calculations (i.e., able to calculate both supercritical and subcritical flow).

- Computational equation set: the model was run with the full momentum equations.

No calibration data was available for high flow conditions. Although Hospital Creek streamflow was measured during the site survey, the measured flow was so much less than the 1:200-year flood that it was not considered useful for calibration purposes (i.e., 0.22 versus 30 m^3/s, respectively). The model

[1] Also note that it is currently not possible to model bridges within 2D areas in HEC-RAS.

results compare well with anecdotal information from the 2008 and 2012 floods. During the 2008 flood the area downstream and west of the 14 Street culvert was flooded, and velocity upstream of Highway 1 was high enough to cause significant erosion. During the 2012 flood the area downstream of the 14 Street culvert was also flooded.

4.2.1 Sensitivity Analysis

A sensitivity analysis was conducted to determine the effects of changing key model parameters and inputs. Flow was varied to account for the potential effects of climate change to flood magnitude and the significant uncertainty associated with the Hospital Creek flood frequency estimates. Sensitivity results are summarized in Table 4.

TABLE 4 Hospital Creek Hydraulic Model Sensitivity Analysis

Parameter	Parameter Variance	Location	Effect on Flood Level (m)	
			Within the Channel	Overbanks and Floodplain
Manning Roughness Coefficient (n)	+ 0.03 (40%)	All	+ 0.2	+ 0.03
Flow (% above the recommended 1:200-year flood magnitude)	+ 100%	Upstream of HWY 1	+ 0.5	+ 0.5
		Downstream of HWY 1	+ 0.06	+ 0.03

The results show that flood elevations and extents for Hospital Creek are not sensitive to flow or roughness, especially below Highway 1. This is because flood flow easily overtops the creek banks, then pools in large areas before flowing over a long section of the CPR tracks into the Columbia River floodplain. In other words, a large increase in flow over a wide area (over a long section of a railway or road) results in small increase to water levels. Furthermore, about half of the Hospital Creek study extents are within and governed by the 1:200-year Columbia River flood extents and levels.

A sensitivity analysis was completed on the culvert at Highway 1 culvert. The culvert may overtop between 23 and 31 m^3/s (compared to the estimated 1:200-year flood of 30 m^3/s) or may overtop during smaller floods if partially blocked by debris.

If the culvert overtops, flow will primarily follow Highway 1 and its ditches. Some flow may cross the highway and inundate a larger area north of the culvert and between Hospital Creek and Highway 1. This area would be subject to shallow depths (less than 0.3 m) and low velocities (less than 0.2 m/s), except along ditches and roads, with maximum velocity approaching 1 m/s.

5 FLOOD INUNDATION MAPS

Flood inundation maps were prepared using the results of the hydraulic modelling and are provided in Appendix A. Flood depth maps are shown in Appendix E. The flood inundation and depth maps show the designated 1:200-year flood extents and flood levels that include a 0.6 m freeboard.

The freeboard is based on the sensitivity analysis, uncertainty in the flood frequency estimates, and to provide contingency for uncertainty due to climate change. The freeboard is consistent with the previous 1979 flood maps, exceeds the provincial engineering association guidelines (that recommended a minimum of 0.3 m for peak instantaneous flood levels [EGBC 2018]), and exceeds guidelines for potential increase to flood magnitude due to climate change (see Section 3.8).

The flood inundation maps delineate an area at flood risk if Hospital Creek Highway 1 culvert capacity is exceeded or the culvert is partially blocked. This area would be subject to shallow depths (less than 0.3 m) and low velocities (less than 0.2 m/s), except along ditches and roads, with max velocity approaching 1 m/s. Although the 14 Street culvert was not overtopped in the hydraulic model it has in the past when partially blocked by gravels.

6 DIKE BREACH MODELLING

To assess the potential impacts of a dike failure, the Columbia River and Kicking Horse River hydraulic model was used to simulate dike breach scenarios through the lateral structures that connect the 1D Kicking Horse River channel to the 2D overbanks.

Significant uncertainty exists in predicting breach geometry and timing (breach parameters). Breach initiation and progression is complex and affected by many variables that are often unknown or subject to high uncertainty (e.g., the susceptibility and rate of erosion of the dam / dike material). Typically, breach parameters are estimated using simple empirical methods based on historical data on dam failures (Wahl 1998).

An equation developed by Froelich (1995) is considered to provide the most accurate predictions of breach parameters (Wahl 1998). This equation is based on dams mostly between 4 and 30 m high and is a function of reservoir volume and dam height. The equation suggests that a 20 to 30 m wide breach may develop for a 2 m high dike (i.e., the max dike height), and results in a breach formation time of 3.7 hours. Other general guidelines suggest breach widths on the order of 1 to 5 times the dam height; i.e., up to 10 m for a 2 m high dike (Federal Energy Regulatory Commission 2015; USBR 1988).

For assessment purposes, the resulting overland flooding was evaluated using the hydraulic model and the conservative breach parameters resulting from the Froelich (1995) equation. The weir coefficient was set to a theoretical value of 1.7. A total of nine breach locations were selected about every 500 m along the right and left dikes to assess the full range of dike breach flooding throughout the Town.

An extreme flood scenario was simulated with about 800 m^3/s in the Kicking Horse River; 1.4 times the recommended 1:200-year flood magnitude, and comparable to the previously estimated extreme upper bound (Hydroconsult 2004). The flow rate was chosen so that water level within the Kicking Horse River was 0.6 m above the 1:200-year flood level (i.e., the freeboard level). The flow rate in the Kicking Horse River was kept constant; a conservative assumption relative to total volume of flow through the breach.

For comparison, the average flood hydrographs show flow dropping by about 80% within a day after the peak of the flood, which equates to about a 0.5 m drop in water levels in the Kicking Horse River.

The model was run for a total of 30 hours after the breach was initiated – i.e., it was assumed that the breach would be repaired/closed within about 1 day after the breach has fully formed. Reduction of the breach flow during the breach repair was not included in the model simulations. These are considered highly conservative assumptions because:

- There are five contractors with appropriate equipment located within the Town, and there are nearby rock quarries and material stockpiles where large rock, riprap, and other granular materials can be sourced and used to repair the breach. Road barriers, and concrete blocks can also be used in an emergency to temporarily plug the breach.

- Not including a reduction of breach flow due to the breach repair results in a conservative total volume of flow through the breach.

6.1 Dike Breach Results and Discussion

Dike breach hazard areas and dike breach flood water level contours were developed from the hydraulic modelling results and are shown on the dike breach flood hazard map in Appendix A. The dike breach flood hazard area and flood level contours were created by combining results from all the dike breach scenarios and taking the maximum water level resulting from each breach location. A freeboard is not included.

A description of the general characteristics of breaches along the left (south) and right (north) dikes follows. Appendix B shows the hydraulic model results (depth, velocity, flood extents, and depth x velocity; a typical metric of flood hazard) for each of the nine simulated dike breach scenarios / locations. Refer to Appendix B for details and exact locations of high depths and high velocities.

Left (South) Dike

A maximum breach flow of about 30 m^3/s is computed, comparing well with the previous simplified dike breach analysis for backwatered conditions (Hydroconsult 2004). The exception is for a dike breach near the College of the Rockies (sta. 2+800); where the peak breach flow is less than 2 m^3/s because the water surface elevation is only slightly above the land beyond the dikes (i.e., the landside toe of the dikes) as shown on Figure 7.

Breach flow from the left dike is preferentially along roads and ditches and pools behind built-up roads around the Golden Airport (Fisher road area); within the 1:200-year Columbia River flood extents. Near the dike breach, velocity can be up to 1.5 m/s and depth on the order of 1 m. The flow typically spreads out within 100 m of the breach location. Thereafter, velocity is typically less than 0.5 m/s; except along some roads where velocity is on the order of 2 m/s. Depth is typically less than 0.6 to 0.3 m but varies significantly due to variation in the terrain (streets, houses, built-up plots of land, etc.).

Right (north) dike

A maximum breach flow of about 70 m^3/s is computed because the land adjacent to the dike is relatively steep resulting in little backwater effect. This is consistent with the previous simplified analysis for a dike breach with no backwater (Hydroconsult 2004). The exception is for a dike breach upstream of the Highway 95 bridge (upstream of 2+192); where the peak breach flow about 30 m^3/s because of backwater conditions.

Breach flow from the right dike is prevented from re-entering the Kicking Horse River by the dikes. The flow pools within an industrial area on the north side of Town, eventually overtopping the CPR lines to join the Columbia River. In general, the resulting velocity is higher compared to breaches along the south dike because of the higher breach flow rate and the steeper terrain. Near the dike breach, velocity can be up to 2 m/s and depth on the order of 2 m. The flow typically spreads out within 100 m of the breach location. Thereafter, velocity is typically less than 0.7 m/s; exceptions are along some roads where velocity can be on the order of 2 m/s. Depth is typically less than 1.5 to 0.5 m but varies significantly due to variation in the terrain (streets, houses, built-up plots of land, excavated gravel pit etc.).

7 RISK ASSESSMENT

A requirement of the Canadian National Disaster Mitigation Program (NDMP)funding was to complete a risk assessment using the RAIT provided by Public Safety Canada (PSC). A range of flood risks to the Town, its community, and the nearby provincial infrastructure were assessed in the RAIT. The definitions and ratings for likelihood and consequences are provided in Table C2. All definitions and terminology for the risk assessment are adopted from PSC.

Twelve consequence categories were evaluated and assigned a consequence rating ranging from 1 to 5 (low to high consequence). These 12 consequence categories were grouped under 5 impact categories:

a) people and societal impacts
b) environmental impacts
c) local economic impacts
d) local infrastructure impacts
e) public sensitivity impacts

In order to determine a single risk rating, weighting factors of 1 to 3 (low to high) were assigned to the 12 consequence categories to allow for calculation of total weighted risk (Table C2). The fatalities, injuries, environmental impacts, health, food, and water categories were assigned weightings of 3 as these were considered the most critical consequences. Displacement, local economic impacts, and local infrastructure impacts (except health, food and water) were assigned a weighting of 2. Public sensitivity impacts were assigned a weighting factor of 1.

Risk is defined as the consequence level times the likelihood, resulting in a risk rating that can be used to compare and prioritize mitigation of those risks. The possible risk ratings range from 1 to 25 and have been grouped into four categories ranging from low to extreme shown on Table C1.

Two open-water risk scenarios were assessed using the risk matrix approach (Table C1): a coincident 1:200-year flood on each watercourse, and a dike breach along the Kicking Horse River. RAIT forms were completed for these scenarios and are provided under separate cover. A summary of the assessment is provided below.

7.1 Kicking Horse River Dike Breach

Failure Mode

A detailed dike breach risk assessment was completed by Hydroconsult in 2004, and an ice jam dike breach risk assessment was completed by Matrix in 2018 (Matrix 2018a). In summary, the most likely failure mode is overtopping of the dikes due to an extreme flood (greater than the 1:200-year flood). Other failure modes are considered much more unlikely as summarized below. A 2018 ice jam risk assessment by Matrix (Matrix 2018a) indicated that the likelihood and consequences of dike failure during ice jams are low compared to dike failure during open-water flooding (a RAIT form was completed for ice jam flooding as part of the 2018 study).

- Bank erosion failure (the bank and dikes erode due to high velocity during a flood): This failure mode is unlikely because the dikes are fully armoured with riprap material with adequate gradation, quality, thickness, and at a sufficiently stable slope to protect the bank during a 1:200-year flood. The riprap may gradually degrade overtime, but this risk is offset by annual inspections and regular maintenance. For example, the Town is planning a 2020/2021 Dike Improvement Project which includes restoration of areas with degraded riprap.

- Geotechnical failure; i.e., Piping (seepage through the dike causes internal erosion and failure), or soughing of the dike slopes – This failure mode is unlikely for several reasons:

  - The hydraulic gradient across the dikes is small compared to typical dams (i.e., the dikes have a maximum dike height of 2 m with a base width more than 8 m). This reduces the pressure forces that drive geotechnical failure.

  - The duration of high-water events is relatively low, on the order of days.

- The dikes have shallow landside slopes, and wide crests, which reduce the chance of sloughing. Landside slopes are minimum 2H:1V and up to 5H:1V in some areas. The dike crests are minimum 4 m wide, except near the College of the Rockies where the dike crest is 3 m wide but the dike height is small (less than 0.6 m).

- Available dike construction and inspection records by the Town indicate that the dikes were constructed with competent compacted granular material, with a low proportion of fine silt.

- Although some seepage has been observed through the dikes during high-water events, active boiling (a sign of piping) has not been observed. Some seepage is normal and acts to relieve hydraulic pressure and reduce the risk of geotechnical failure.

- Photos of dike construction show that some of the construction used car bodies for the core of the dikes which may mitigate erosion and reduce flow in the event of dike failure.

Risk Scenario: Total Weighted Risk = Low

For this risk scenario, a hypothetical situation was evaluated where an extreme flood occurs and overtops the dike. The breach is then repaired after about 1 day.

The breach location with the highest expected consequences is assessed; i.e., near the municipal campground on the left (south) dike. Affected areas, key structures and important locations are shown on Figure 8.

This assessment is limited to the consequences of the dike breach but flooding of the Columbia and Kicking Horse rivers are likely coincident. Thus, consequences within the Columbia River floodplain were not included in the assessment.

Likelihood

The dikes may overtop during an extreme flood with a magnitude equal to or greater than about 800 m^3/s (about 1.4 times the 1:200-year flood). Using a logarithmic extrapolation of the flood frequency curve and the upper 95% confidence bound results in a return period estimate between 1:1,000 and 1:2,000-years.

A likelihood rating of 2 was assigned (between a 1:500 and 1:5,000-year return period) and is considered a highly conservative estimate.

Consequences

The consequences of the dikes overtopping would include overland flooding of about 72 ha of the developed land within the Town with damage to infrastructure, and numerous commercial and residential buildings. Environmental impacts would be low because the flooding is within an urban area.

Contaminates from the urban area will enter the river but will be greatly diluted and likely have a negligible impact.

Peak water levels would be present for 12 to 24 hours and the flow would drain into and pool within the Columbia River 1:200-year flood extents. Low-lying areas and basements would remain inundated for a long period of time that could be for several weeks. Total recovery time could be on the order of months for road and infrastructure repair.

The following is a summary of the potential consequences as per the NDMP definitions:

- Could result in 1 to 4 fatalities based on the following:
  - There will likely be adequate time to evacuate the immediate area near the breach (even at night) because there will be days of lead up time to the peak of the flood. Once overtopping of the dike occurs, it is easily noticed, and the total time from the dike overtopping to failure is expected to be on the order of 6 hours (it is expected that the breach initiation time[2] for the dike is on the order of one to two hours plus a breach formation time of about 4 hours).
  - Within 100 m of the breach, depth and velocity in most areas would be less than 1 m and 1 m/s, respectively; typically considered a threshold for non-life-threatening conditions. Velocity and depth can be higher along some roads, or local depressions, respectively but these areas are generally small and easily avoided. However, there could be some fatalities for some people who require help evacuating. For comparison during the 2013 Alberta floods, there were five fatalities, with only one in Calgary (Calgary Herald 2014).
- Widespread injuries or illnesses that can not be addressed by the local healthcare. Support from other areas within the region is likely required.
- Displacement of more than 15% of the local population (about 550 people) for up to 1 week.
- Impacts to a majority of the local commercial sectors of the Town.
- Local road closures for several months, but temporary / alternative routes would be made available within 72 hours.

[2] During an overtopping failure, a headcut erosion process will first start on the downstream side of the dike. The headcut will erode back toward the crest of the dike. During this time (referred to as the breach initiation time) the flow is limited by the dike crest, and there is opportunity to evacuate the area. Once the headcut reaches the dike crest the flow through the breach begins to increase as the headcut erodes down and the breach widens to the full breach size. The time from the end of the breach initiation to when the breach is fully formed is called the breach formation time.

- Flooding of the BC Hydro substation and Potential temporary loss of power and utilities (estimated up to 24 hours).

- Potential loss of communication due to power loss (up to 24 hours).

- Minor delays for accessing potable water, food, sanitation services, or healthcare services for up to 24 hours.

7.2 1:200-Year Flood (Columbia, Kicking Horse, and Hospital)

Risk Scenario: Total Weighted Risk = <u>Moderate</u>

For this risk scenario, a coincident flood in the order of a 1:200-year event for the Columbia River, Kicking Horse River, and Hospital Creek was evaluated. The Hospital Creek culvert at Highway 1 is overtopped, flooding areas along Highway 1 and between Highway 1 and the CPR main line. The dikes along the Kicking Horse River are not overtopped and do not fail (i.e., the Kicking Horse River would remain within its channel).

Flooded areas are shown on the attached inundation maps (Appendix A).

Likelihood

A likelihood rating of 3 was assigned (between a 1:50 and 1:500 return period).

Consequences

The consequences would include overland flooding of up to 2.3 km^2 of developed land within the Town with damage to infrastructure and numerous commercial, industrial, and residential buildings. Environmental impacts would be low because the majority of the natural areas that are flooded are within the normal floodplain of the Columbia River. Contaminants from the urban area will enter the river but will be greatly diluted and likely have a negligible impact.

Hospital Creek would account for about 0.3 km^2 (15%) of the total flooded developed area including Highway 1, the CPR main line, and a nearby commercial and residential area on the north side of Town.

The Columbia River would account for about 2.0 km^2 (85%) of the total flooded developed area mostly though the south west side of the Town including the airport, wastewater facility, and CPR railyard. On the north side of Town, the Columbia River would inundate the CPR main line and industrial areas. Water level would remain near the peak for about one week. Low-lying areas and basements would remain inundated for a long period of time that could be for several weeks. Total recovery time could be on the order of months for road and infrastructure repair.

The following is a summary of the potential consequences as per the NDMP definitions:

- Could result in one to four fatalities based on the following.
  - The onset of flooding due to Hospital Creek would occur rapidly. There are hazardous conditions upstream of Highway 1, where velocity is greater than 2.5 m/s and depth is in the order of 2 to 5 m. Although these hazardous conditions are within the creek, it is possible that a person could venture too close. The bank of the creek in this area was armoured in 2008, likely preventing significant erosion and damage to homes situated above the bank. Downstream of Highway 1 depth and velocity are generally low and not hazardous.
  - The onset of flooding due to the Columbia River would be slow, providing adequate time to evacuate the area, and the velocity within the residential areas would be low. However, there could be some fatalities for some people who require help evacuating. For comparison during the 2013 Alberta floods, there were five fatalities, with only one in Calgary (Calgary Herald 2014).
- Widespread injuries or illnesses that cannot be addressed by local health care. Support from other areas within the region is likely required.
- Displacement of more than 15% of the local population (about 550 people) for less than four weeks.
- Impacts more than 15% of the local commercial sectors of the Town.
- Local road closures for several months with temporary / alternative routes available within weeks. National impacts due to closure of the CPR mainline for more than one week, and closure of Highway 1 for up to 24 hours.
- Loss of power and utilities in the flooded area (30% of the Town) for up to 1 week.
- Minor delays for accessing potable water, food, sanitation services, or healthcare services for up to 24 hours.

8 RECOMMENDATIONS AND NEXT STEPS

Flood Inundation Maps

This study has provided updated 1:200-year flood inundation maps based on recent LiDAR and bathymetric survey data, and up-to-date flow records. Compared to the previous 1979 maps, the updated flood inundation maps show similar flood extents along the Columbia River but updated FCLs, now include flood mapping for Hospital Creek, and no longer show flooding in the area protected by the Kicking Horse River dikes. A separate dike breach flood hazard map was prepared showing potential flooding due to dike breach inundation. The 1:200-year flood inundation maps should be adopted into the Town floodplain bylaw for new development. Exemptions for additions to existing buildings may be considered (e.g., exemptions when adding less than 25% of the existing floor area).

Dike Breach Inundation

The Kicking Horse River dike system is appropriately armoured and stable, with freeboard that exceeds the provincial engineering association guidelines (EGBC 2018, APEGBC 2017). The dikes have at least 0.6 m freeboard and more than 1.0 m in many areas versus a guideline value of 0.3 m above the peak instantaneous 1:200-year flood. Provided that regular dike inspections and maintenance continue, the likelihood of dike failure is low – but not zero.

As a next step, the Town should consider how to address the dike breach flood hazard area in the Town floodplain bylaw. Three example options are summarized herein and vary from no development restrictions (Option 1) to full floodplain development restrictions (Option 3). The Town may also consider a partial or limited set of development restrictions; examples are described in Option 2. Additional study is required to weigh the options and develop specific amendments or an updated floodplain bylaw. Input would be required from Town staff including legal, insurance, and development.

In the interim, the floodplain bylaw could be updated with the updated 1:200-year flood inundation maps (to reflect the addition of Hospital Creek and changes to the Columbia River) and with interim requirements in the dike breach flood hazard area until additional study is completed. Within the dike breach flood hazard area, the FCL could be set to 1 m (3 feet) above the adjacent road – matching the existing bylaw requirements and the 1979 flood maps. Alternatively, the most stringent option (Option 3) could be implemented immediately and later scaled back as further study warrants.

1. Apply no specific development restrictions but indicate that property owners are to be aware of potential dike breach flood risks. The bylaw may include the dike breach flood hazard map for information and make reference to this report. This option is not supported by the provincial land use guidelines (B.C. MWLAP 2004).

2. Apply a limited set of development restrictions within the dike breach hazard zone. For example, the first floor of buildings and/or all electrical and mechanical equipment to be a certain height above the adjacent street. For reference, the current Town floodplain bylaw stipulates a FCL that is 1 m (3 feet) above the adjacent street (based on the 1979 flood maps) and no livable space is allowed below the FCL (e.g., basements). Limited development restrictions are used in other jurisdictions and may be considered appropriate mitigation for the flood risk per the EGBC guidelines (EGBC 2018). The provincial land use guidelines (B.C. MWLAP 2004) do not support limited development restrictions.

3. Apply FCLs and the full floodplain bylaw restrictions within the dike breach inundation hazard zone. For example, livable space below the FCL (e.g., basements) would not be permitted. The bylaw would need to specify a freeboard above the dike breach flood levels that are shown on the dike breach flood hazard maps; a freeboard of 0.6 m is recommended in the provincial land use management guidelines (B.C. MWLAP 2004). This option would comply with the provincial engineering association guidelines (EGBC 2018, APEGBC 2017) and Matrix's interpretation of the provincial land use guidelines (B.C. MWLAP 2004), provide the most limitation of liability for the Town in the event of a dike breach, and reduce the hazard to new development. But this option could be a deterrent to development and would not reduce the hazard for existing development (the majority of the hazard area is existing development).

Hospital Creek Highway 1 Culvert

The Highway 1 culvert is susceptible to overtopping during an extreme flood. The flood inundation maps delineate an area at flood risk if the culvert capacity is exceeded or the culvert is partially blocked. This area would be subject to shallow depths (less than 0.3 m) and low velocities (less than 0.2 m/s), except along ditches and roads, with maximum velocity approaching 1 m/s. It is recommended that either this hazard be mitigated, or development restrictions be implemented within the Town floodplain bylaw for this area. The Town of Golden is aware of this hazard and further assessment is warranted.

9 REFERENCES

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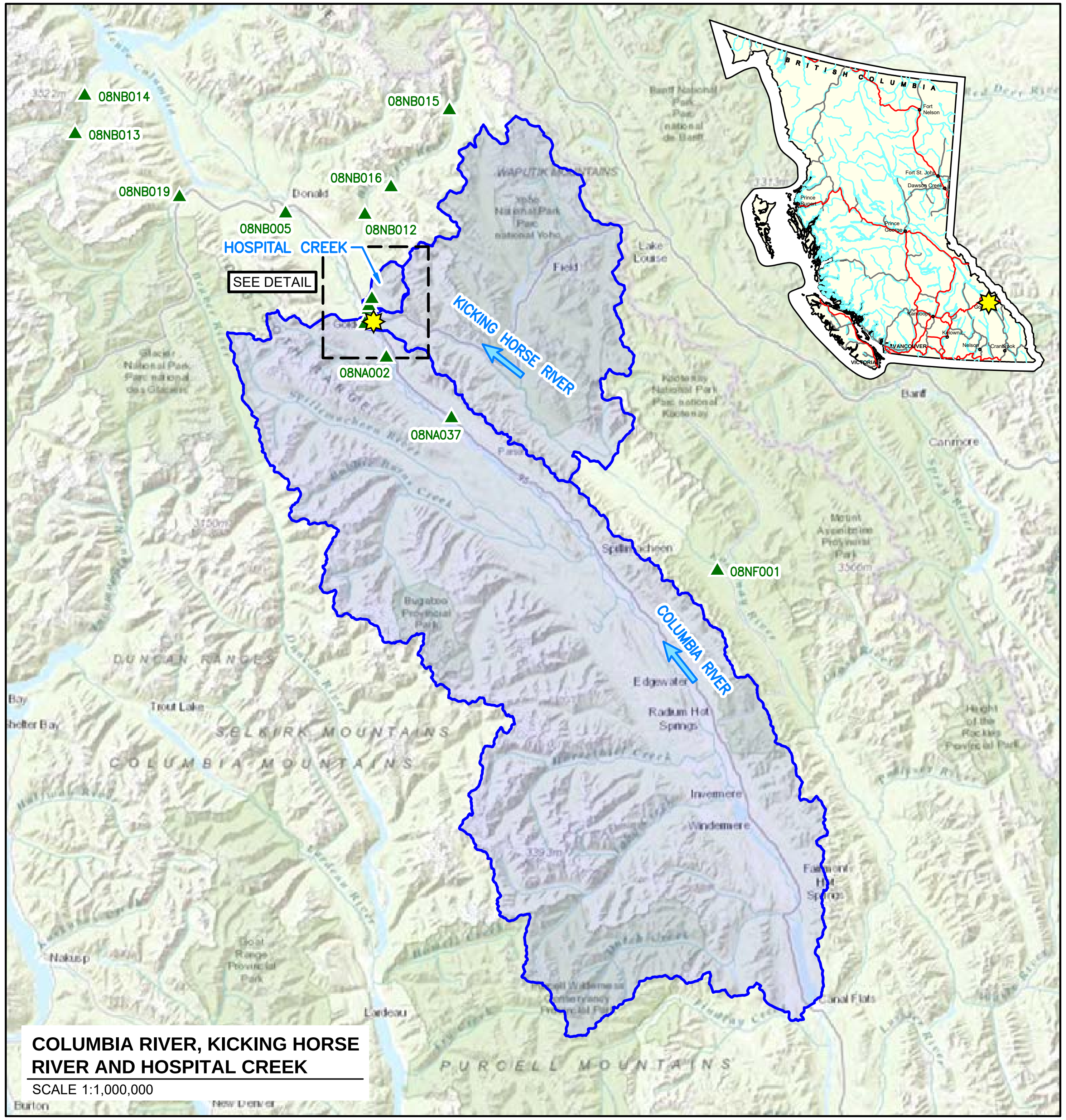
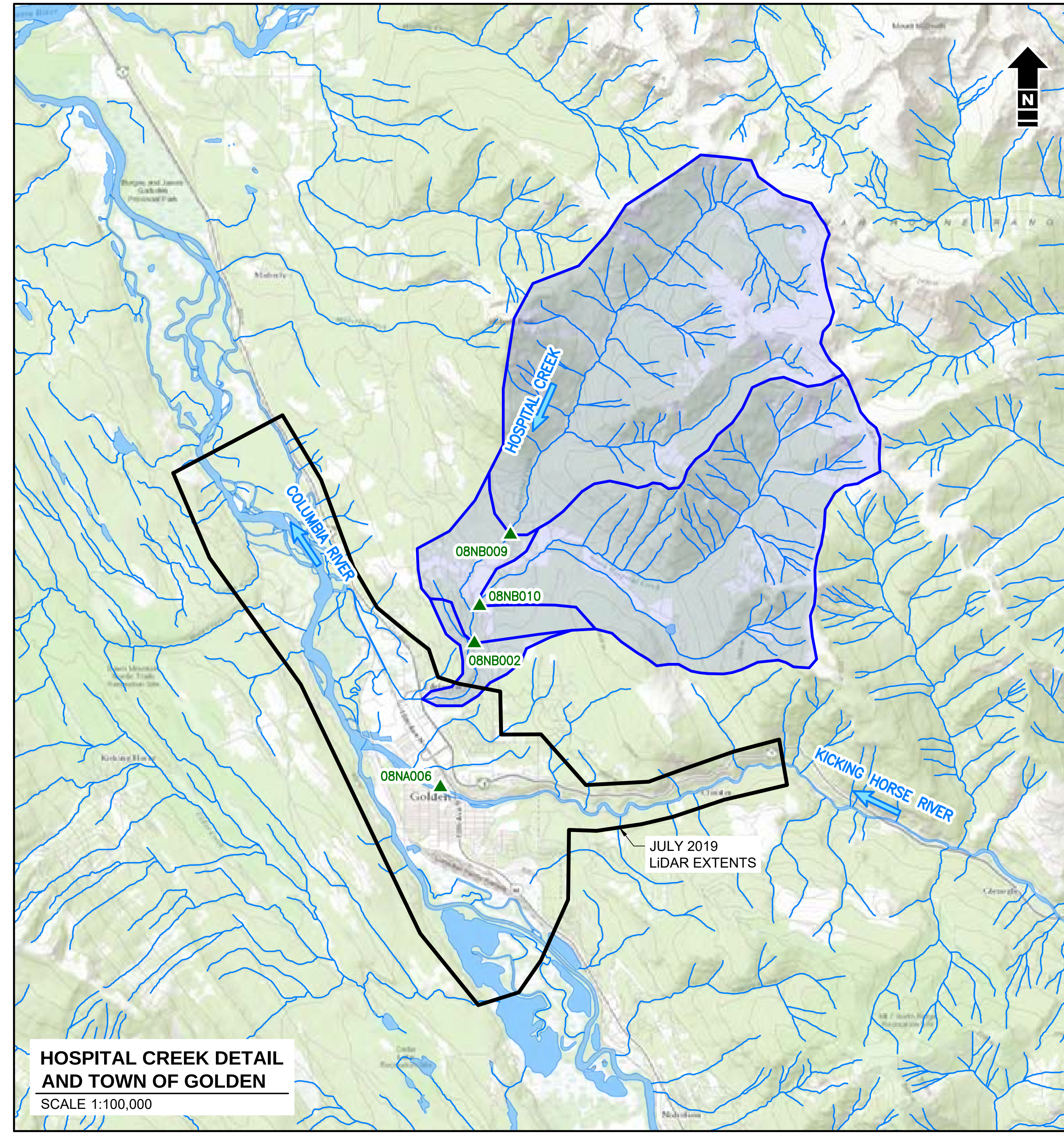


COLUMBIA RIVER, KICKING HORSE RIVER AND HOSPITAL CREEK

SCALE 1:1,000,000



HOSPITAL CREEK DETAIL AND TOWN OF GOLDEN

SCALE 1:100,000

LEGEND

- TOWN OF GOLDEN
- FLOW DIRECTION
- HYDROGRAPHY
- WATER SURVEY OF CANADA HYDROMETRIC STATION
- DRAINAGE AREA

NOTES:

1. FIGURES MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

1 : 100,000 metres
1000 0 1000 2000

1 : 1,000,000 metres
10000 0 10000 20000

NAD 1983 UTM ZONE 11N

REFERENCE: BASEMAP AND HYDROGRAPHY FROM ESRI WORLD TOPOGRAPHY MAP.

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ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

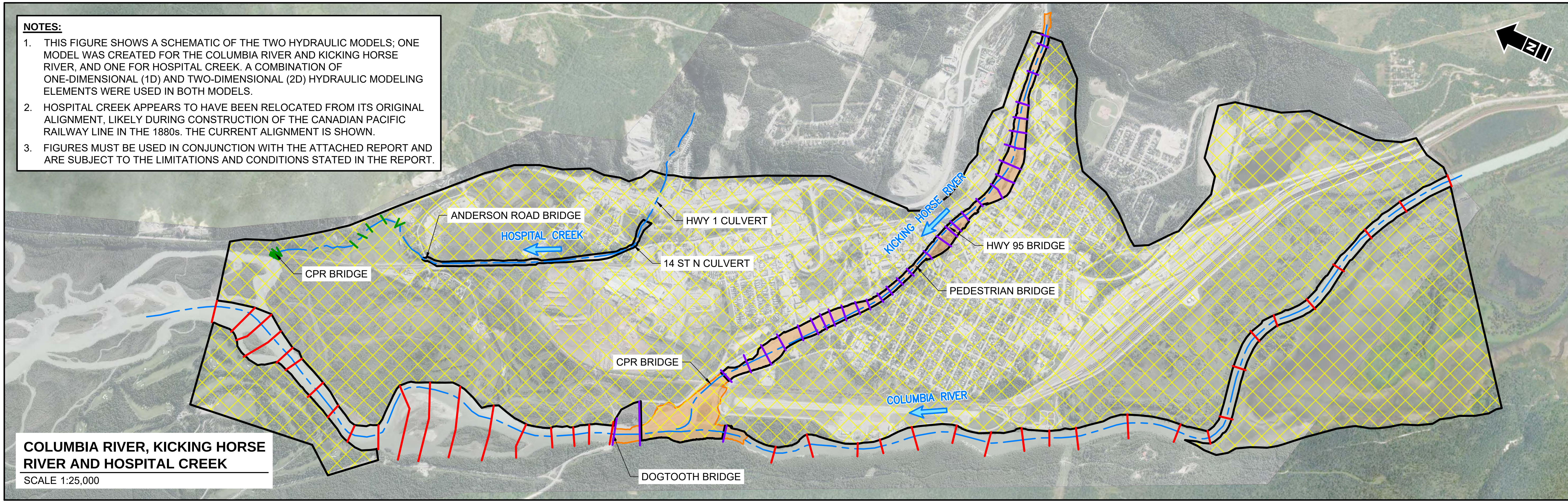
LOCATION PLAN

Date:	Project:	Submitter:	Reviewer:
FEBRUARY 2020	5635-LP	D. KUSHNER	M. SHOME

Figure 1

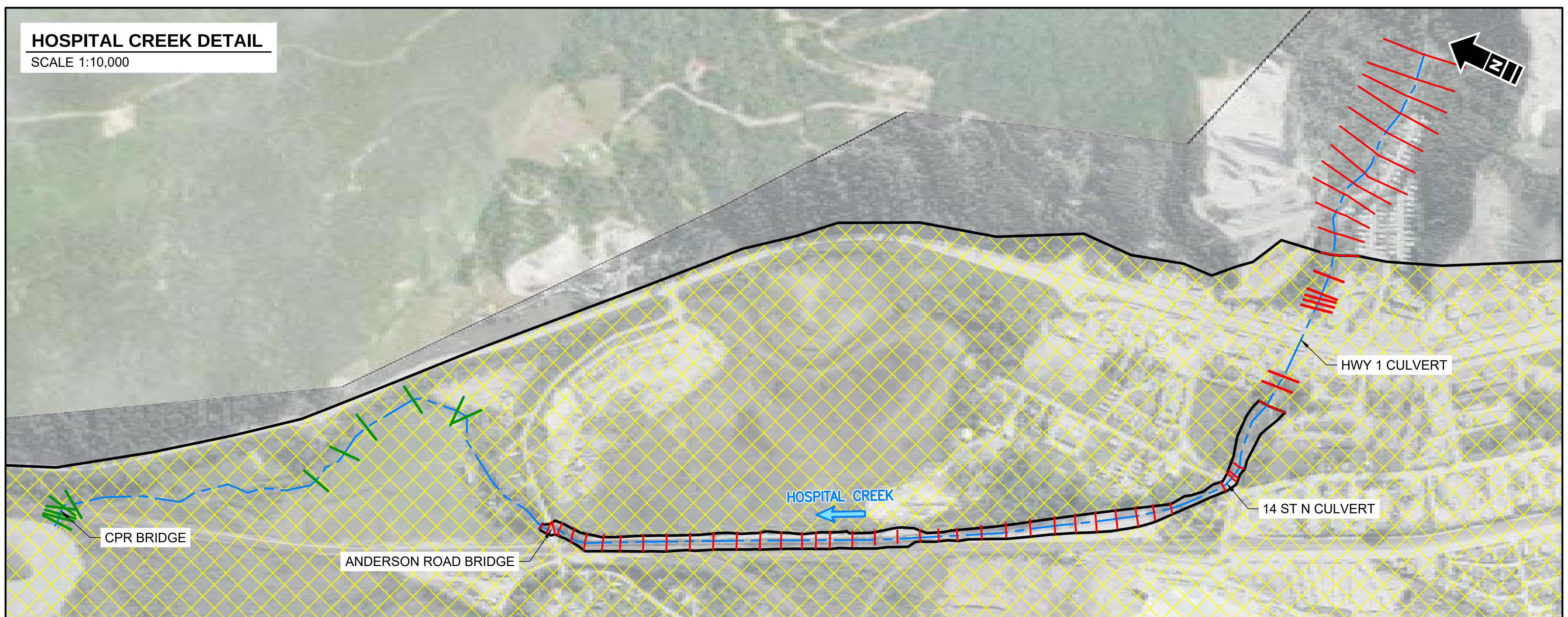
NOTES:

1. THIS FIGURE SHOWS A SCHEMATIC OF THE TWO HYDRAULIC MODELS; ONE MODEL WAS CREATED FOR THE COLUMBIA RIVER AND KICKING HORSE RIVER, AND ONE FOR HOSPITAL CREEK. A COMBINATION OF ONE-DIMENSIONAL (1D) AND TWO-DIMENSIONAL (2D) HYDRAULIC MODELING ELEMENTS WERE USED IN BOTH MODELS.
2. HOSPITAL CREEK APPEARS TO HAVE BEEN RELOCATED FROM ITS ORIGINAL ALIGNMENT, LIKELY DURING CONSTRUCTION OF THE CANADIAN PACIFIC RAILWAY LINE IN THE 1880s. THE CURRENT ALIGNMENT IS SHOWN.
3. FIGURES MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.



COLUMBIA RIVER, KICKING HORSE RIVER AND HOSPITAL CREEK

SCALE 1:25,000



HOSPITAL CREEK DETAIL

SCALE 1:10,000

LEGEND

- FLOW DIRECTION
- HYDRAULIC MODEL RIVER/CREEK ALIGNMENT
- BATHYMETRIC SURVEY
- SURVEYED SECTION USED IN THE 1D PORTION OF THE HYDRAULIC MODEL
- SECTION CREATED WITH BATHYMETRIC SURVEY AND USED IN THE 1D PORTION OF THE HYDRAULIC MODEL
- SURVEYED SECTION USED TO MODIFY THE TERRAIN IN THE 2D AREA OF THE HYDRAULIC MODEL
- 2D AREA EXTENTS OF THE HYDRAULIC MODELS

1 : 10,000 metres
100 0 100 200

1 : 25,000 metres
250 0 250 500

NAD 1983 UTM ZONE 11N

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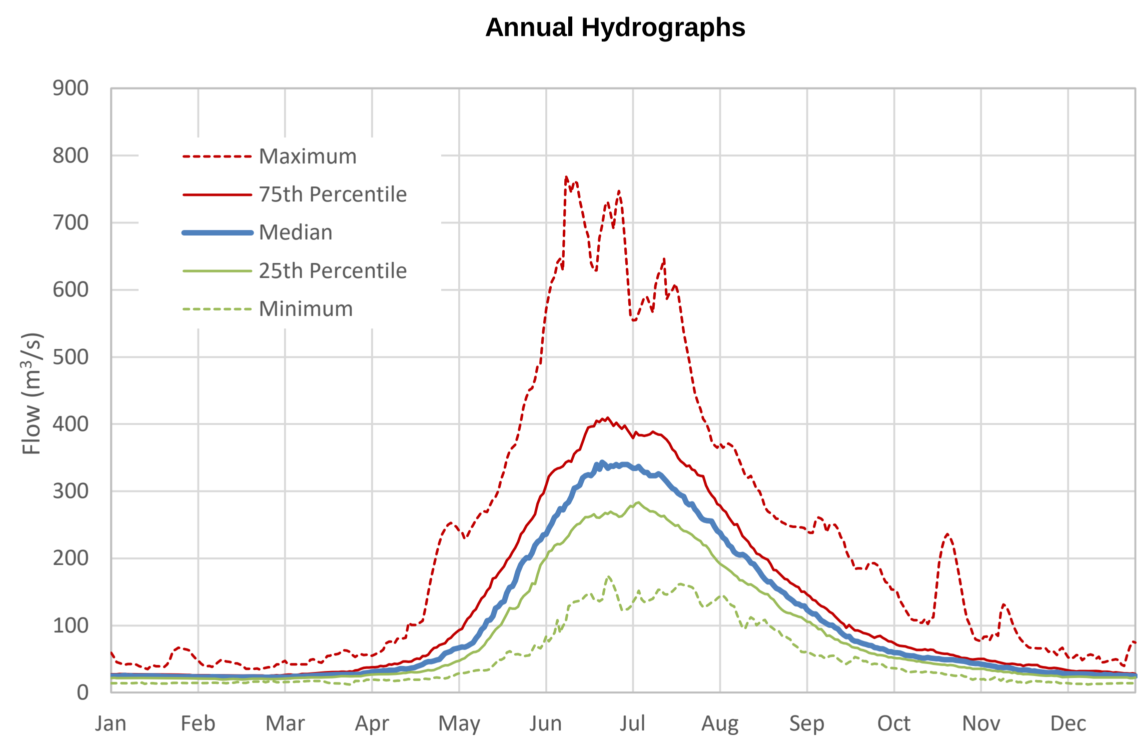
TOWN OF GOLDEN
FLOOD STUDY

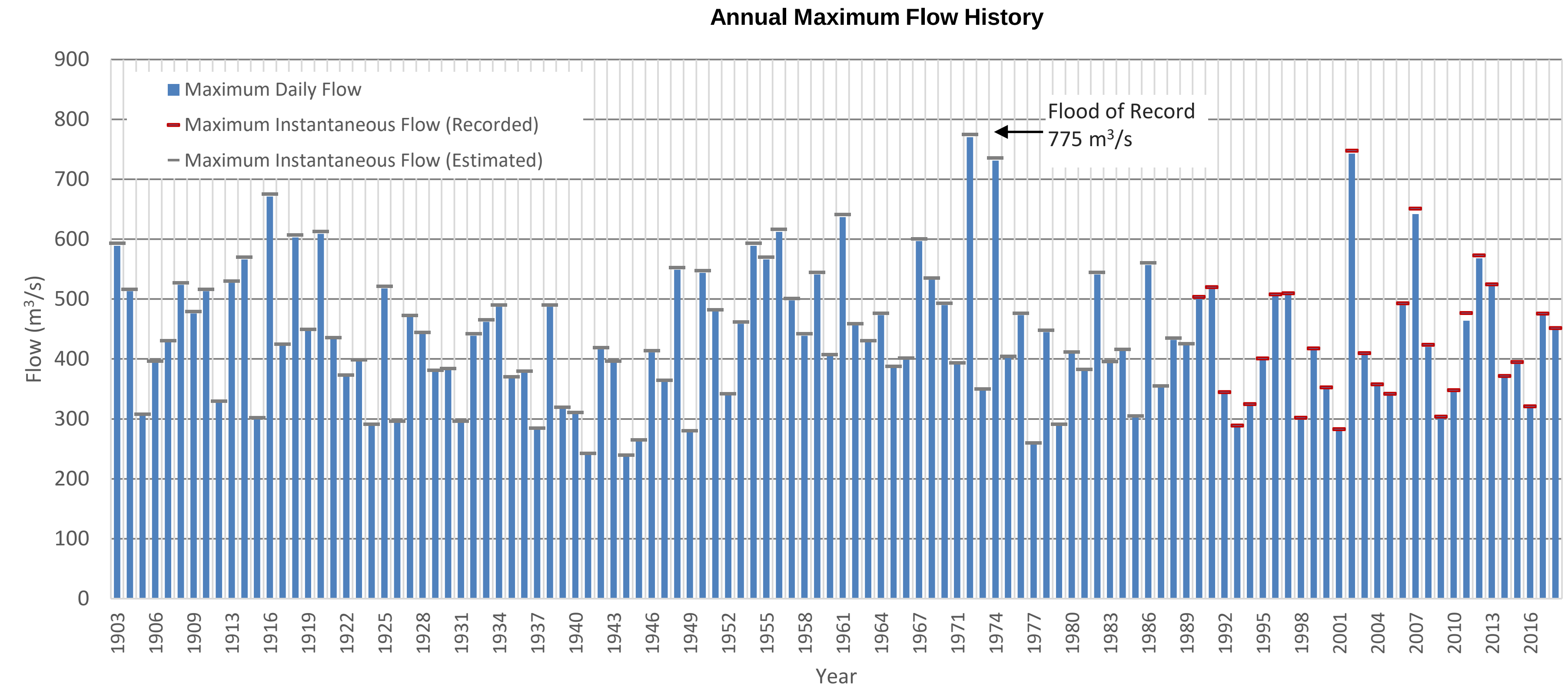
SURVEY EXTENTS AND HYDRAULIC MODEL EXTENTS

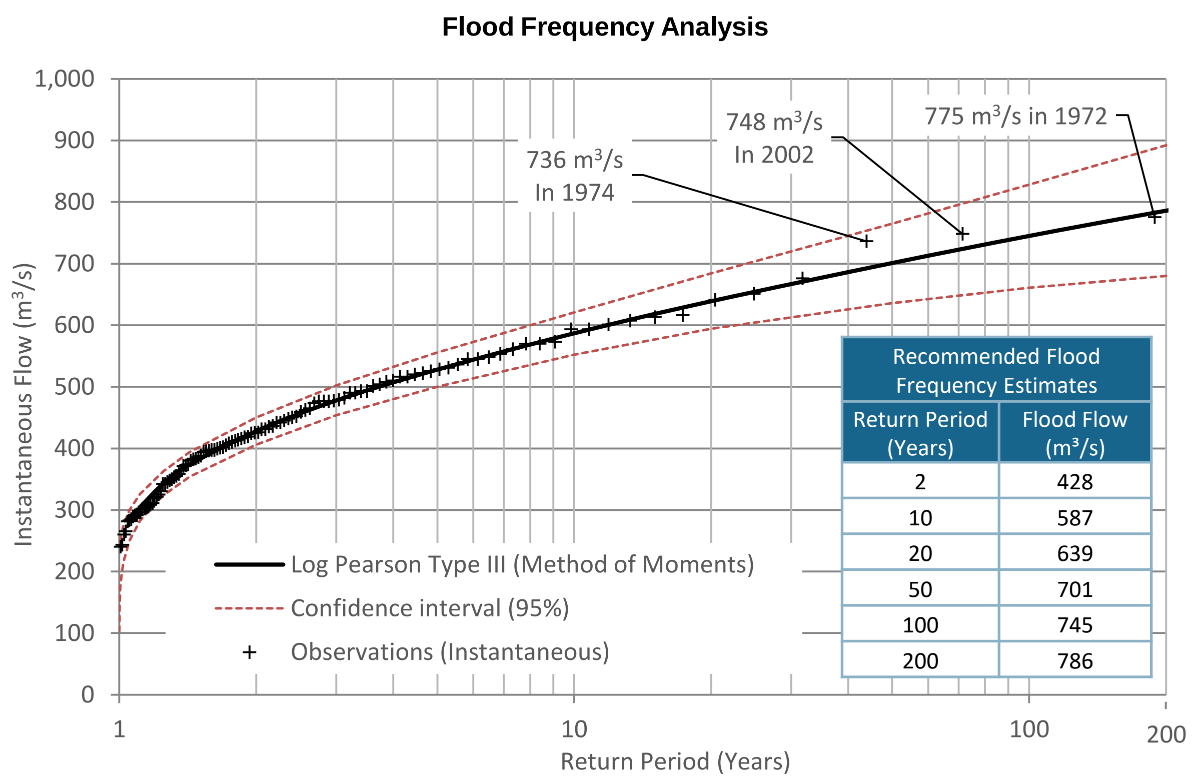
Date: FEBRUARY 2020	Project: 5635-SP	Submitter: D. KUSHNER	Reviewer: M. SHOME

Figure 2

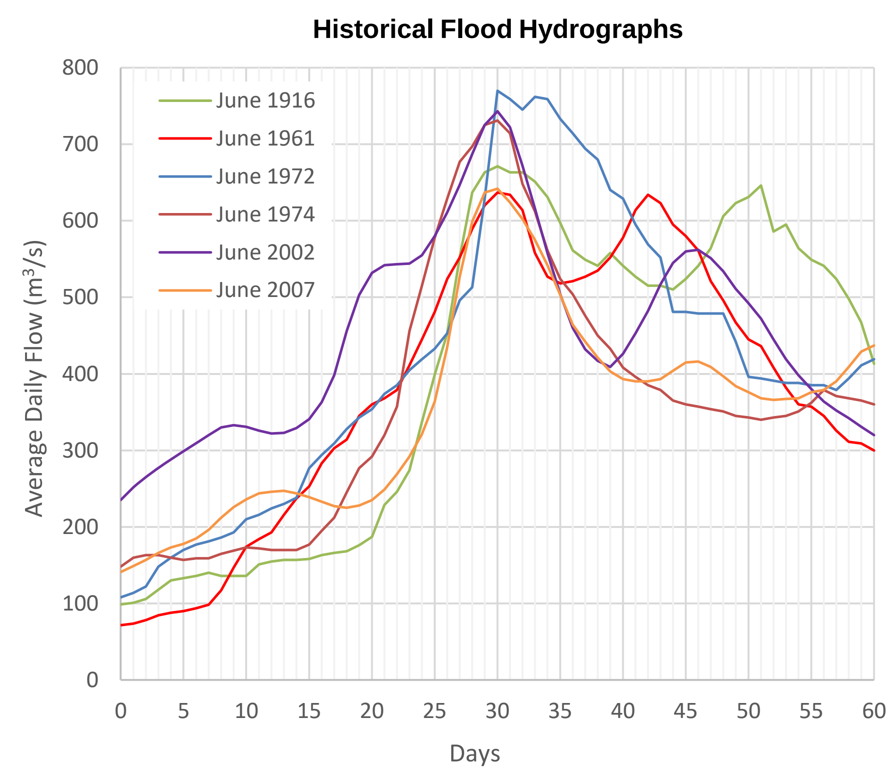
REFERENCE: ORTHOPHOTO BY AIRBORNE IMAGING DATED JULY 21, 2019 AND ESRI WORLD IMAGERY DATE UNKNOWN.

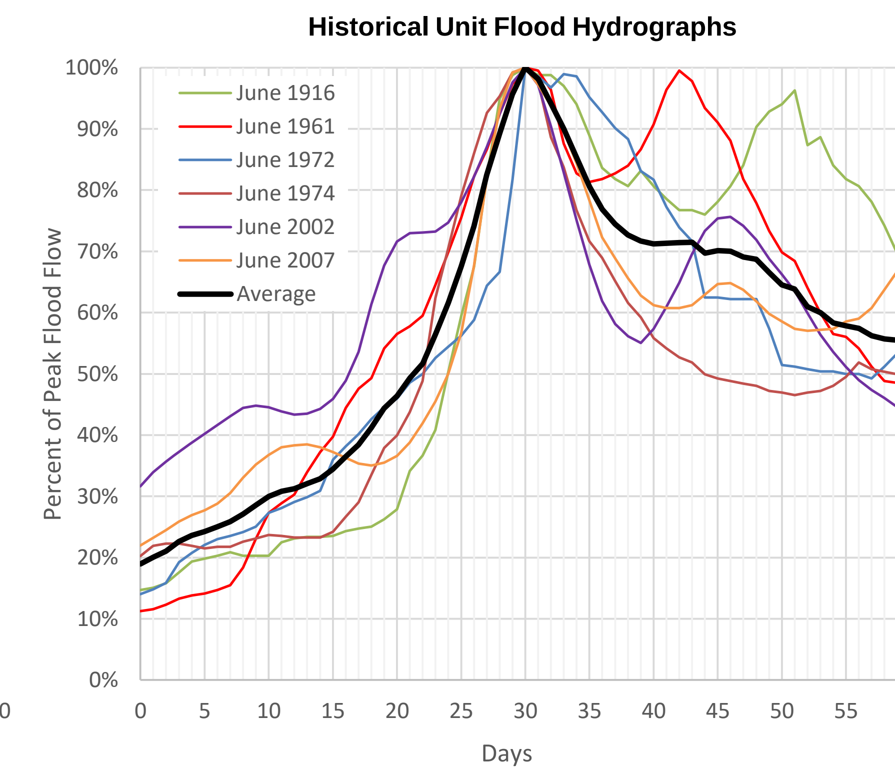






Recommended Flood Frequency Estimates	
Return Period (Years)	Flood Flow (m³/s)
2	428
10	587
20	639
50	701
100	745
200	786





NOTES:

1. FLOODING TYPICALLY OCCURS IN JUNE, DRIVEN BY SNOWMELT COMBINED WITH HIGH PRECIPITATION.
2. FLOW RECORDS TAKEN FROM WATER SURVEY OF CANADA HYDROMETRIC STATION 08NA002, LOCATED ON THE COLUMBIA RIVER ABOVE THE CONFLUENCE WITH THE KICKING HORSE RIVER.
3. WHEN NOT AVAILABLE, MAXIMUM INSTANTANEOUS FLOW IS ESTIMATED FROM DAILY AVERAGE FLOW BY APPLYING THE AVERAGE RATIO OF MAXIMUM INSTANTANEOUS TO DAILY AVERAGE FLOW (1.0068).
4. FIGURES MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

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TOWN OF GOLDEN
FLOOD STUDY

COLUMBIA RIVER ABOVE KICKING HORSE RIVER HYDROLOGIC ANALYSIS

Date:	Project:	Submitter:	Reviewer:
FEBRUARY 2020	5635-HA	D. KUSHNER	M. SHOME

Figure 3

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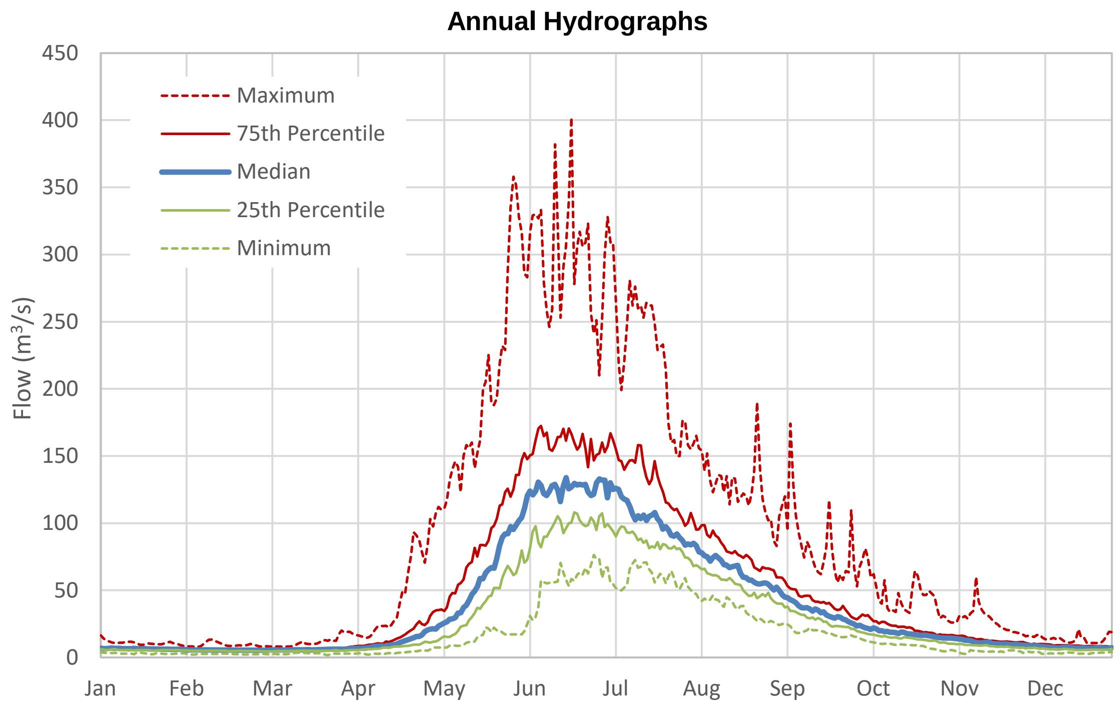
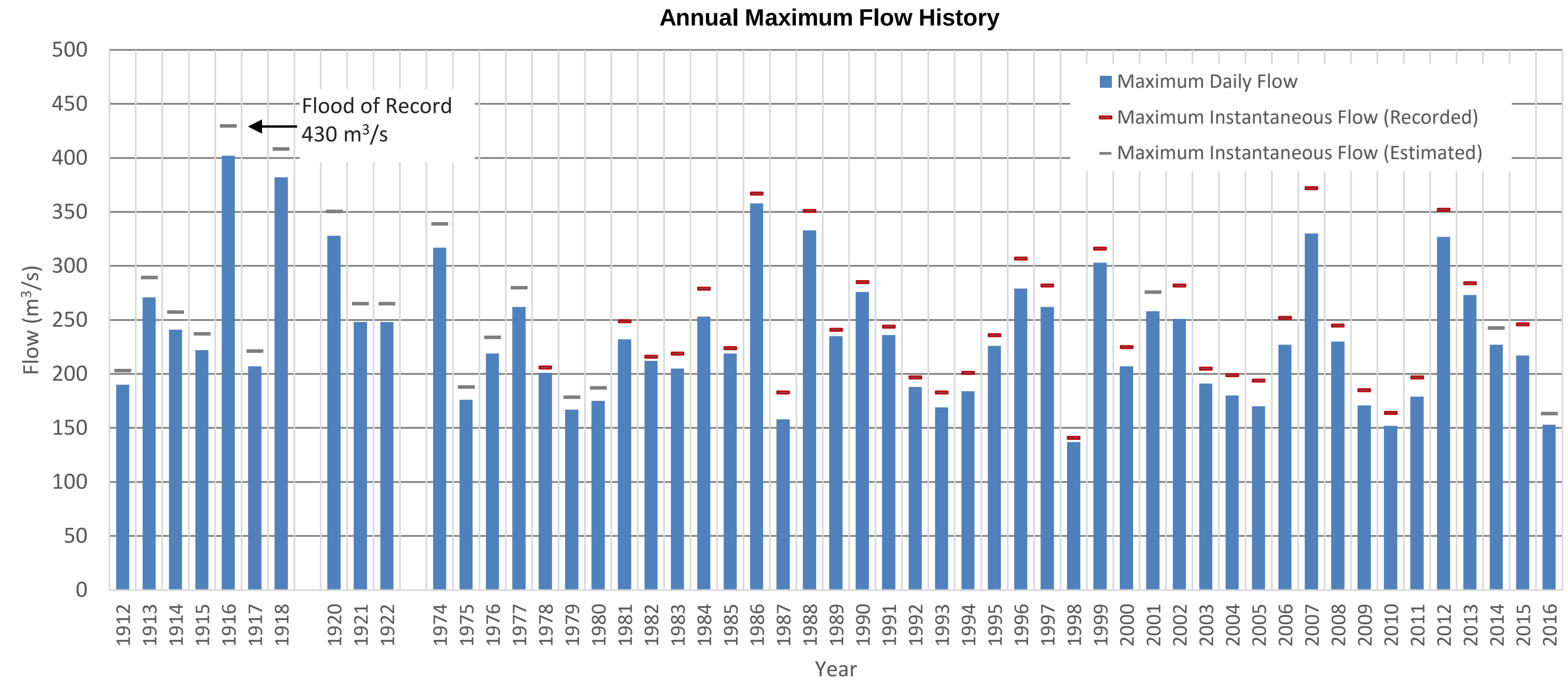
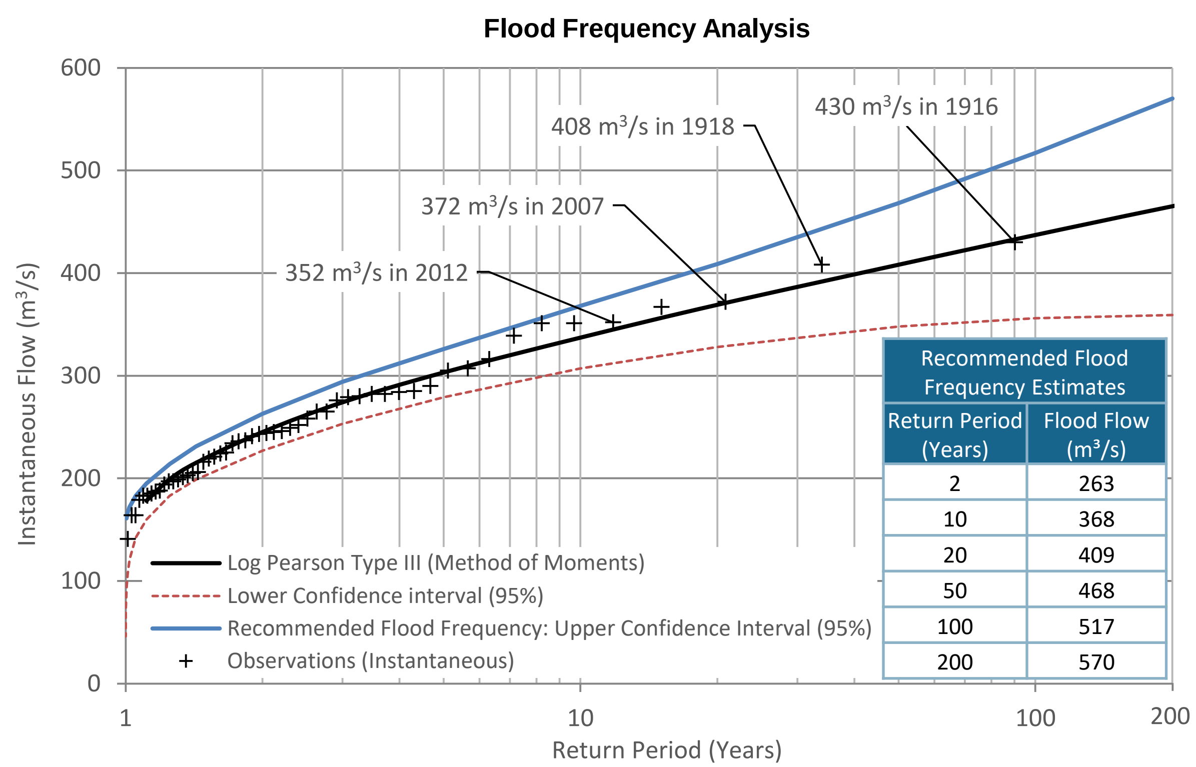
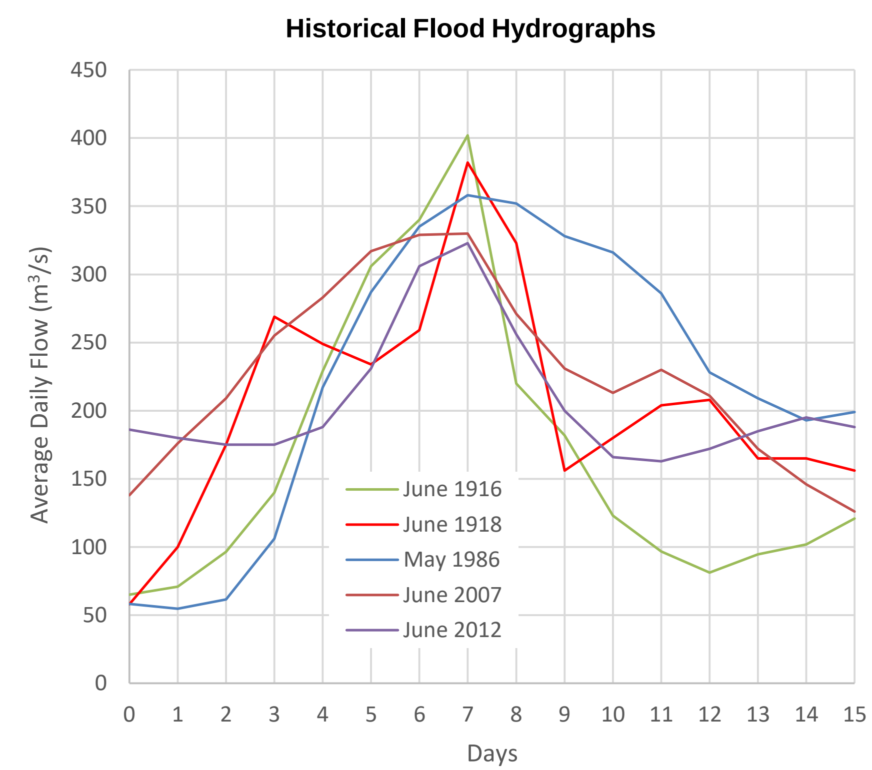
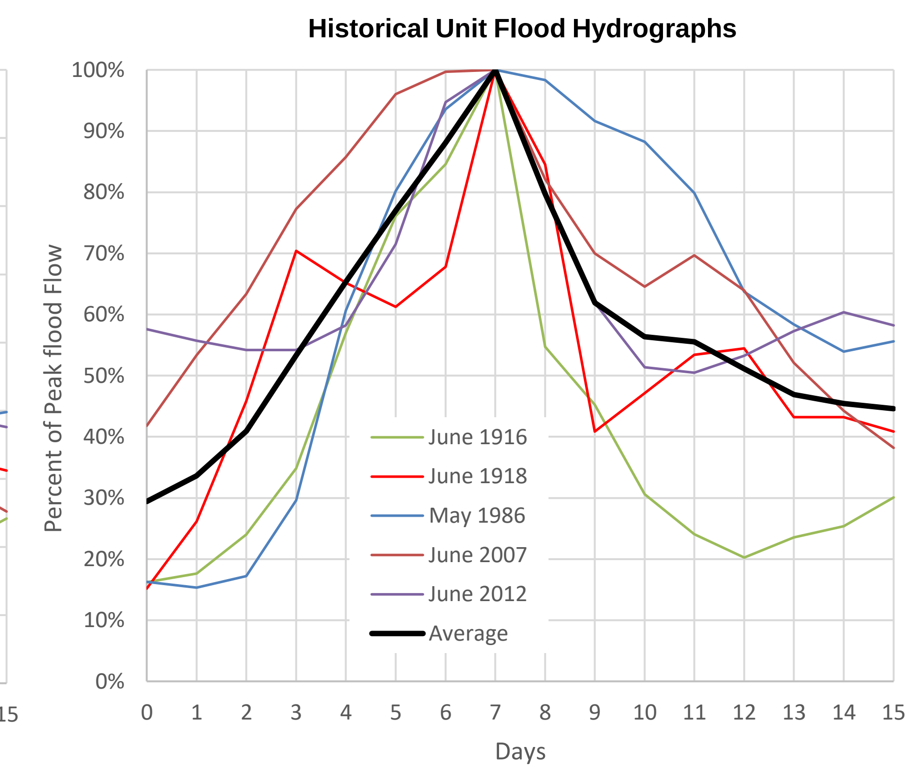






Recommended Flood Frequency Estimates	
Return Period (Years)	Flood Flow (m³/s)
2	263
10	368
20	409
50	468
100	517
200	570





NOTES:

1. FLOODING TYPICALLY OCCURS FROM MARCH THROUGH JUNE AND IS PRIMARILY DRIVEN BY SNOWMELT. THE MOST EXTREME FLOODS ARE A RESULT OF RAINFALL ON SNOWMELT.
2. FLOW RECORDS TAKEN FROM WATER SURVEY OF CANADA HYDROMETRIC STATION 08NA006, LOCATED ON THE KICKING HORSE RIVER AT THE TOWN OF GOLDEN.
3. WHEN NOT AVAILABLE, MAXIMUM INSTANTANEOUS FLOW IS ESTIMATED FROM DAILY AVERAGE FLOW BY APPLYING THE AVERAGE RATIO OF MAXIMUM INSTANTANEOUS TO DAILY AVERAGE FLOW (1.074).
4. FIGURES MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

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Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

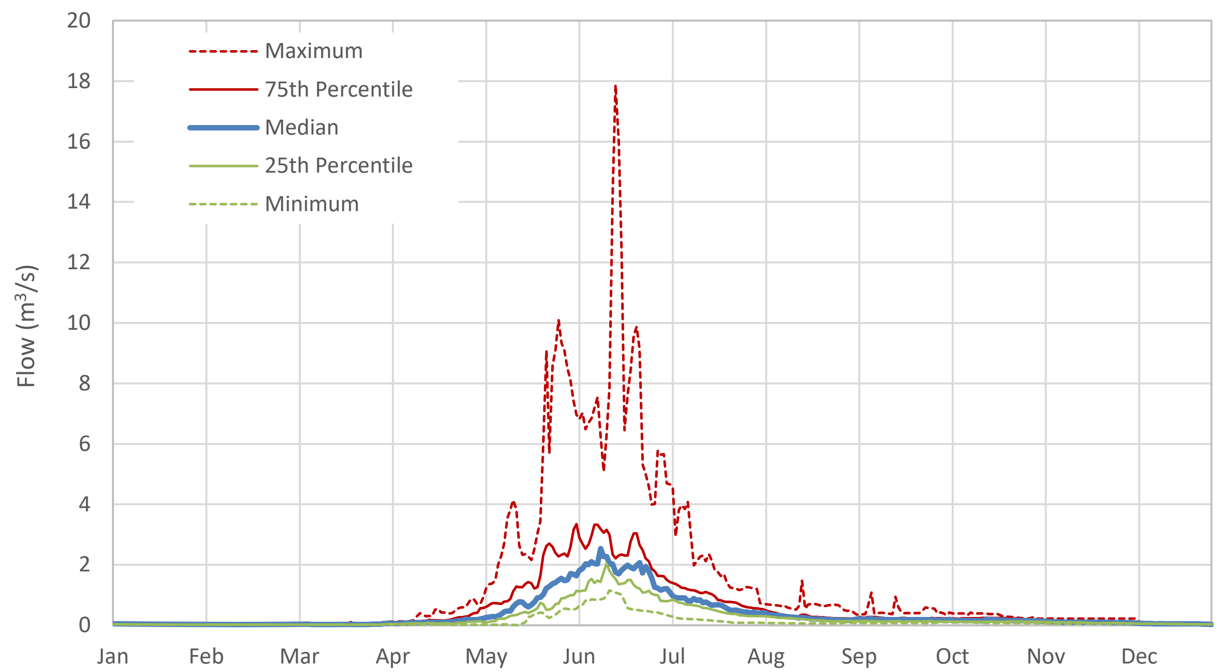
TOWN OF GOLDEN
FLOOD STUDY

KICKING HORSE RIVER HYDROLOGIC ANALYSIS

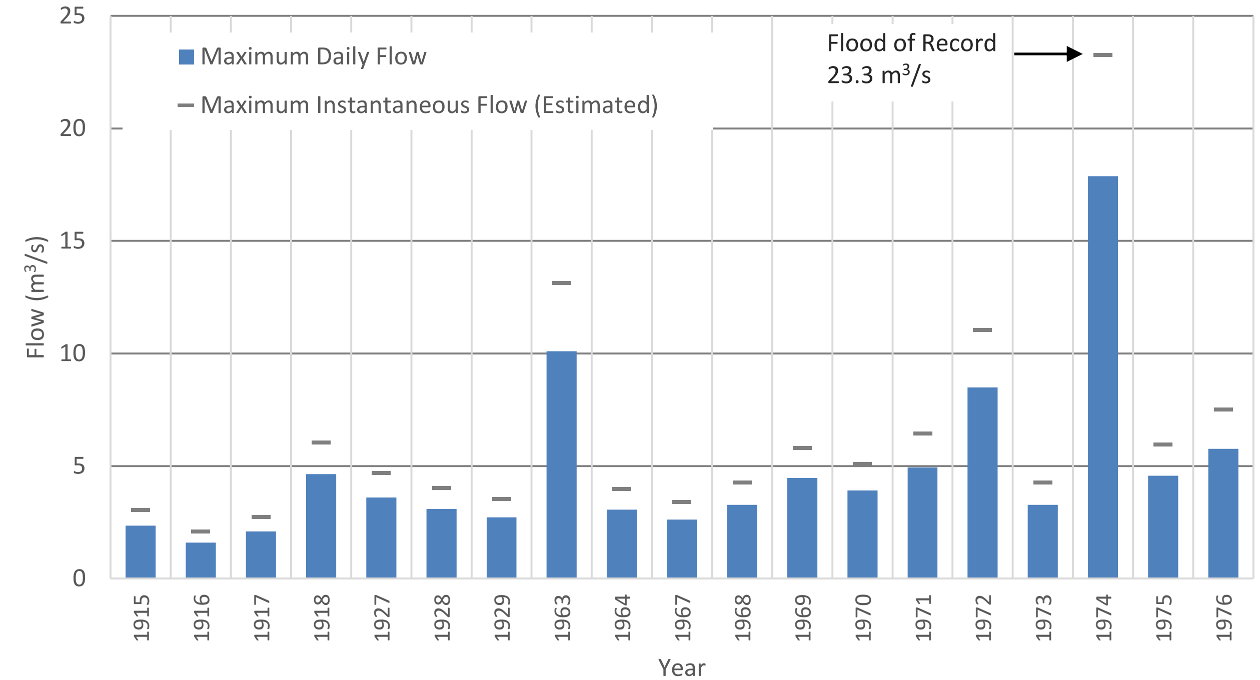
Date:	Project:	Submitter:	Reviewer:
FEBRUARY 2020	5635-HA	D. KUSHNER	M. SHOME

Figure 4

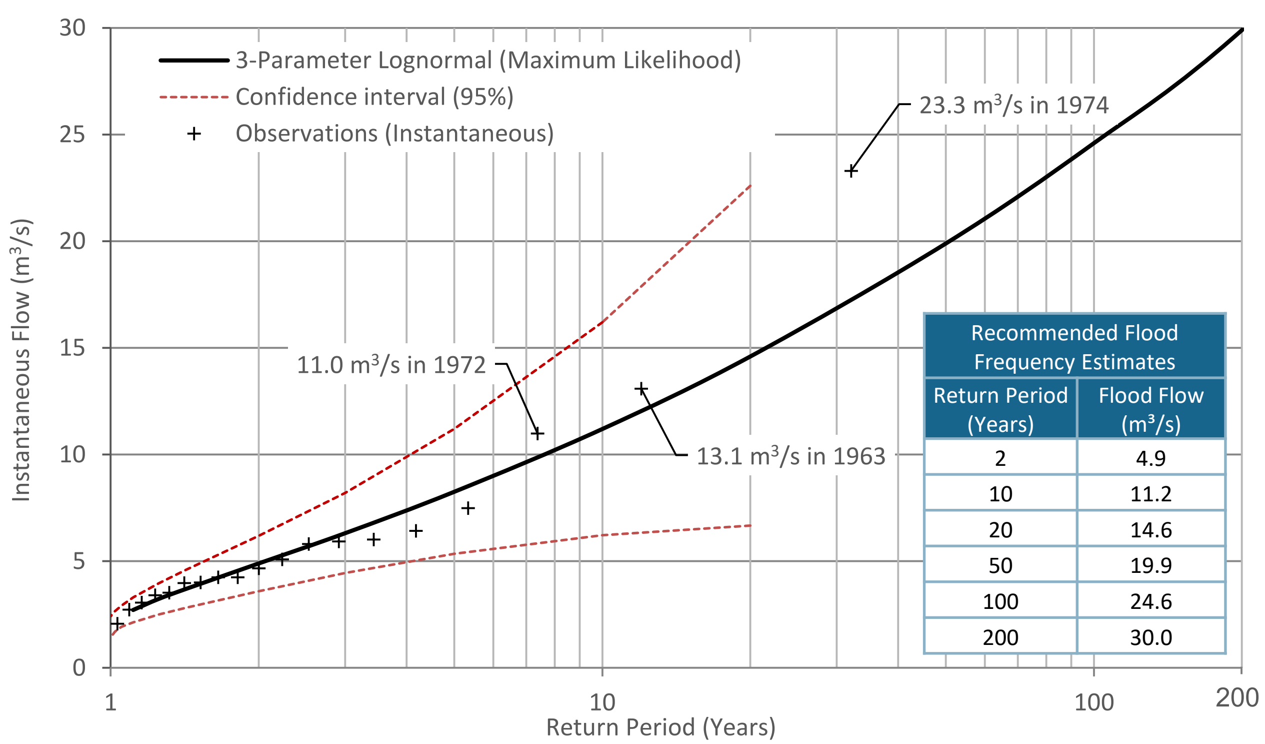
Annual Hydrographs



Annual Maximum Flow History

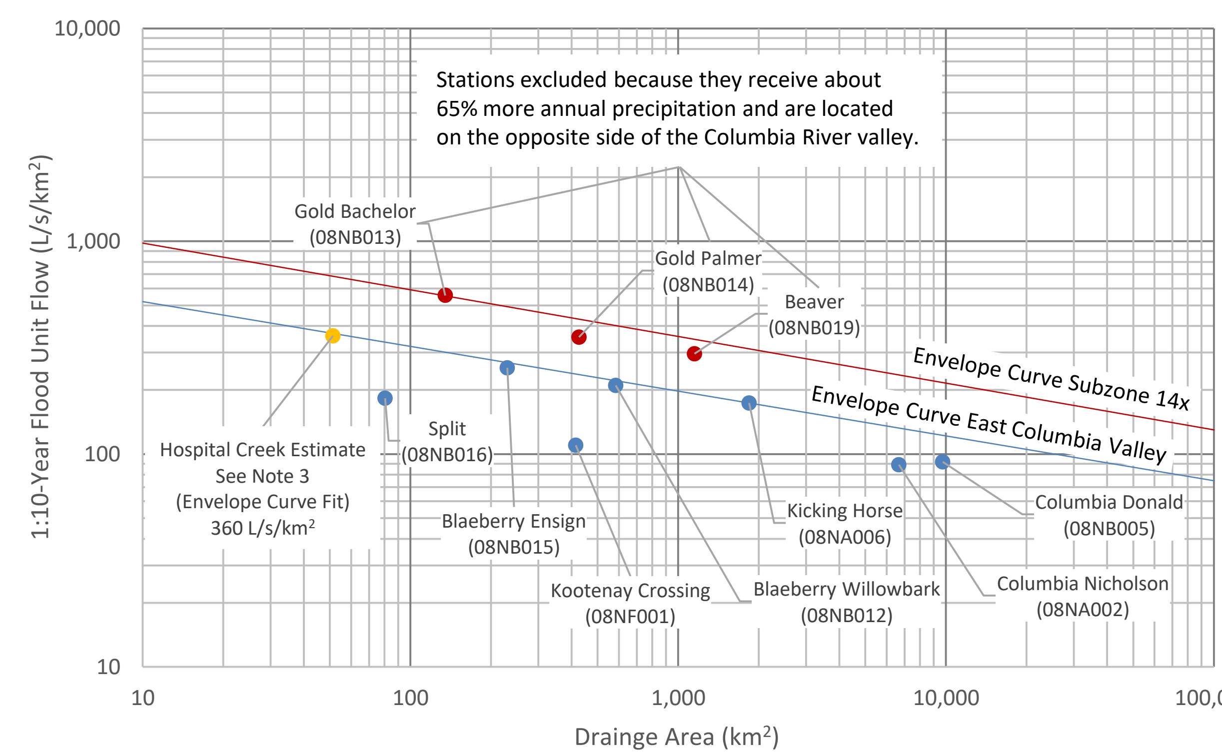


Flood Frequency Analysis



Recommended Flood Frequency Estimates	
Return Period (Years)	Flood Flow (m³/s)
2	4.9
10	11.2
20	14.6
50	19.9
100	24.6
200	30.0

Regional Analysis (Adapted From Obedkoff 2002 Subzone 14x)



NOTES:

1. THE HOSPITAL CREEK DRAINAGE AREA AT THE HIGHWAY 1 CULVERT IS 54.1 km².
2. A 19-YEAR RECORD OF AVERAGE DAILY FLOW WAS DEVELOPED BY COMBINING THE RECORDS FROM THREE WATER SURVEY OF CANADA (WSC) STATIONS ON HOSPITAL CREEK. FLOW DATA FROM STATION 08NA009 AND 08NA0010 WERE COMBINED (REPRESENTING A TOTAL DRAINAGE AREA OF 46.6 km²). THIS COMBINED FLOW WAS THEN ADJUSTED TO WSC 08NA002 LOCATION (54.1 km²) BY THE RATIO OF THE DRAINAGE AREAS TO THE EXPONENT OF 0.75, A RECOMMENDED EQUATION FOR BRITISH COLUMBIA (EATON 2002). PEAK INSTANTANEOUS FLOW WAS CONSERVATIVELY ESTIMATED AS 1.3 TIMES THE DAILY AVERAGE FLOW.
3. FROM THE REGIONAL ANALYSIS, THE HOSPITAL CREEK 1:200-YEAR FLOOD MAGNITUDE IS ESTIMATED AS 360 L/s/km² x 54.1 km² X 1.55 (1.55 IS THE MAXIMUM RATIO OF THE 1:200 TO 1:20-YEAR FLOOD FOR THE REGIONAL STATIONS FROM OBEDKOFF 2002) = 30 m³/s, WHICH IS SIMILAR TO RESULT FROM THE FLOOD FREQUENCY ANALYSIS.
4. FIGURES MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

REFERENCES:

1. EATON, B., CHRUCH, M., AND HAM, D. (EATON). 2002. SCALING AND REGIONALIZATION OF FLOOD FLOWS IN BRITISH COLUMBIA. HYDROLOGICAL PROCESSES, 16, 3245-3263.
2. OBEDKOFF W. 2002. STREAMFLOW IN THE KOOTENAY REGION. WATER INFORMATION SECTION, AQUATIC INFORMATION BRANCH, MINISTRY OF SUSTAINABLE RESOURCE MANAGEMENT, BRITISH COLUMBIA. 2002.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

HOSPITAL CREEK
HYDROLOGIC ANALYSIS

Date:	Project:	Submitter:	Reviewer:
FEBRUARY 2020	5635-HA	D. KUSHNER	M. SHOME

Figure
5

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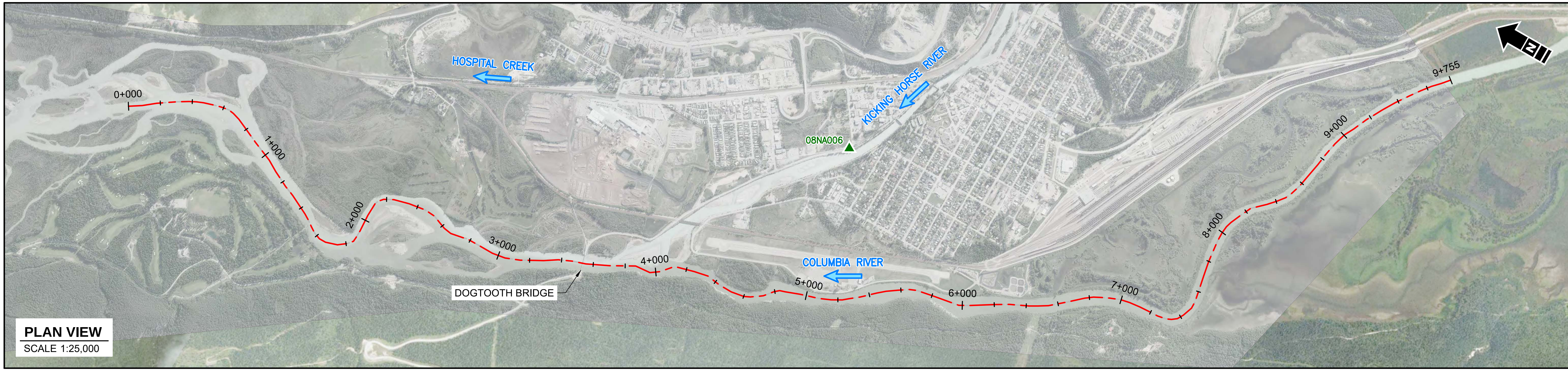
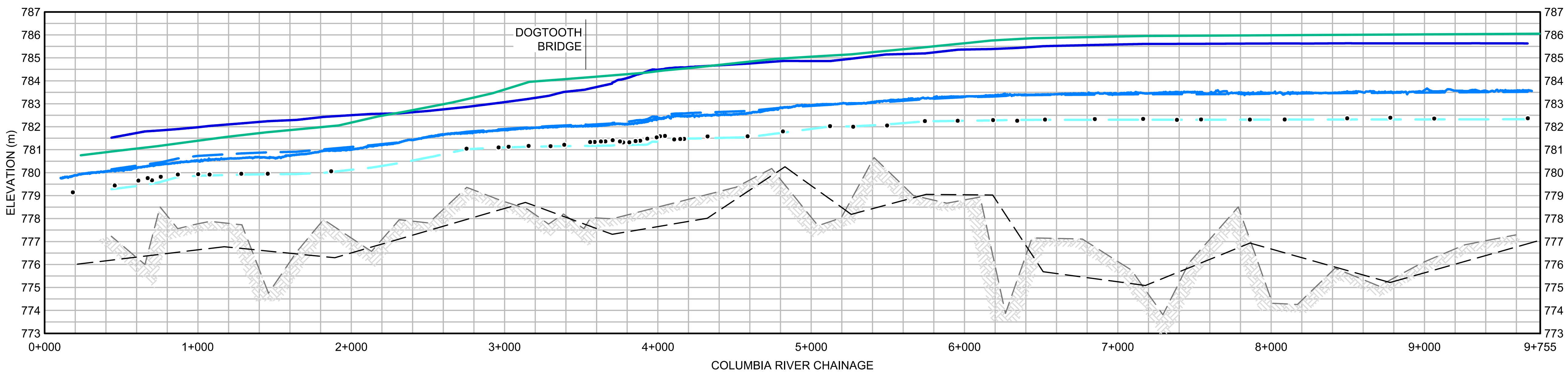
Plot 1:1 = Tabloid (L)



PLAN VIEW
SCALE 1:25,000



PROFILE
HORIZONTAL SCALE 1:30,000
VERTICAL SCALE 1:200

LEGEND

- FLOW DIRECTION
- WATER SURVEY OF CANADA HYDROMETRIC STATION
- 1+500 COLUMBIA RIVER CHAINAGE
- THALWEG - OCTOBER 2019
- THALWEG - 1979 FLOOD MAP
- 1:200 YEAR COMPUTED WATER LEVEL - 2020 MODEL
- 1:200 YEAR WATER LEVEL - 1979 FLOOD MAP (MINUS 0.6 m FREEBOARD)
- JULY 20, 2019 WATER LEVEL (Q = 84.5 m^3/s) - 2019 LiDAR
- JULY 20, 2019 WATER LEVEL - 2019 MODEL
- OCTOBER 2, 2019 SURVEYED WATER LEVEL
- OCTOBER 2, 2019 COMPUTED WATER LEVEL - 2020 MODEL

REFERENCE: LiDAR FROM AIRBORNE IMAGING DATED JULY 21, 2019.
ORTHOPHOTO BY AIRBORNE IMAGING DATED JULY 21, 2019 AND ESRI WORLD IMAGERY DATE UNKNOWN.
WATER LEVELS FROM KICKING HORSE RIVER HYDRAULIC MODEL (REV 2), MATRIX 2014.
FLOW RECORDS FROM WATER SURVEY OF CANADA STATION 08NA006.
1979 FLOOD MAP BY MINISTRY OF ENVIRONMENT.

NOTES:

1. ALL ELEVATIONS SHOWN IN VERTICAL DATUM CGVD2013.
2. FIGURES MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

1 : 100 metres 1 0 1 2
1 : 25,000 metres 250 0 250 500
1 : 30,000 metres 300 0 300 600
NAD 1983 UTM ZONE 11N

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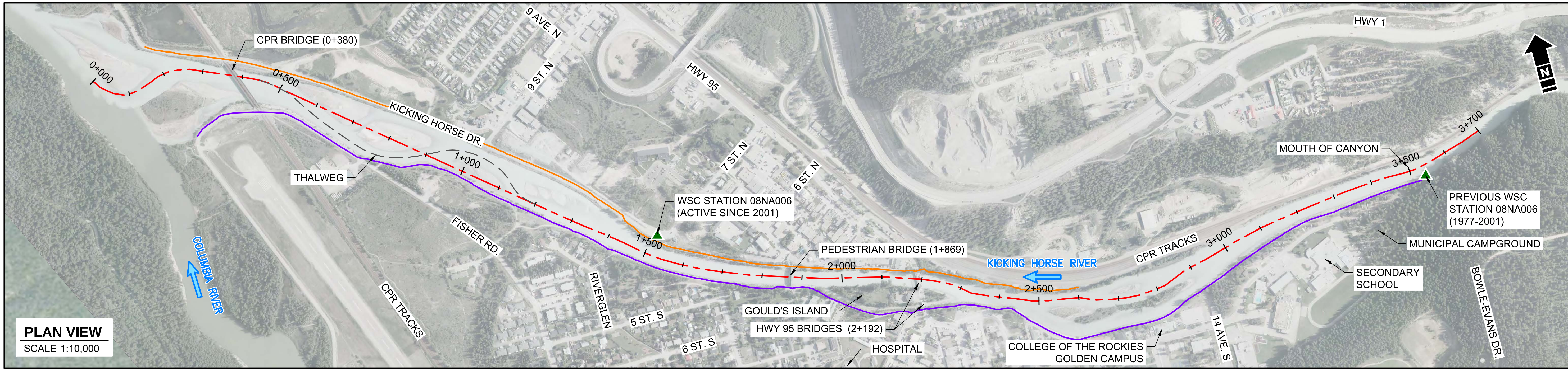
TOWN OF GOLDEN
FLOOD STUDY

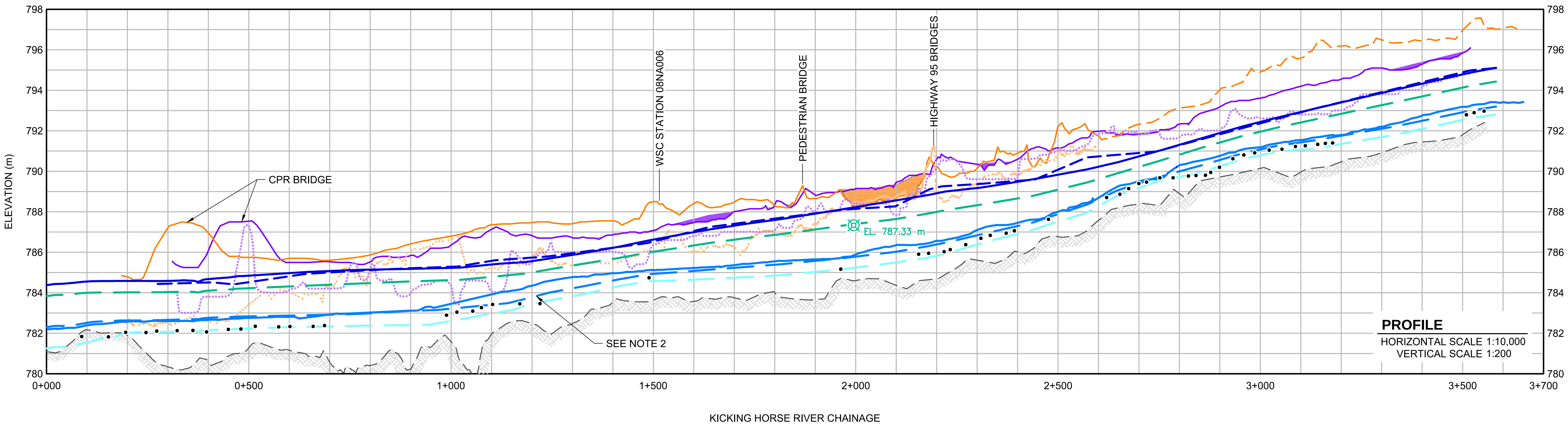
COLUMBIA RIVER
PLAN AND WATER LEVEL PROFILES

Date:	Project:	Submitter:	Reviewer:
FEBRUARY 2020	5635-DI-TH	D. KUSHNER	M. SHOME

Figure 6

F:\5635\Drafting\C3D\Dike Upgrades 2018\Production\Figs\5635-DI-TH.dwg - Columbia-WL - Wednesday, March 25, 2020 10:52:20 AM - Zachary Steele





LEGEND

- FLOW DIRECTION
- WATER SURVEY OF CANADA HYDROMETRIC STATION
- 1+500 KICKING HORSE RIVER CHAINAGE (SEE NOTE 1)
- THALWEG - OCTOBER 2019
- 1:200 YEAR COMPUTED WATER LEVEL - 2020 MODEL
- 1:200 YEAR COMPUTED WATER LEVEL - 2014 MODEL
- JULY 20, 2019 WATER LEVEL (Q = 84.5 m^3/s) - 2019 LiDAR
- JULY 20, 2019 WATER LEVEL - 2020 MODEL
- OCTOBER 2, 2019 SURVEYED WATER LEVEL
- OCTOBER 2, 2019 COMPUTED WATER LEVEL - 2020 MODEL
- JUNE 6, 2012 WATER LEVEL (Q = 352 m^3/s) - OBSERVED
- JUNE 6, 2012 WATER LEVEL - 2020 MODEL
- RIGHT DIKE CREST - 2019 LiDAR
- RIGHT TOP OF BANK - 2019 LiDAR
- RIGHT DIKE LANDSIDE TOE - 2019 LiDAR
- PLANNED RIGHT DIKE RAISING
- LEFT DIKE CREST - 2019 LiDAR
- LEFT DIKE LANDSIDE TOE - 2019 LiDAR
- PLANNED LEFT DIKE RAISING

REFERENCE: LiDAR FROM AIRBORNE IMAGING DATED JULY 21, 2019.
ORTHOPHOTO BY AIRBORNE IMAGING DATED JULY 21, 2019 AND ESRI WORLD IMAGERY DATE UNKNOWN.
WATER LEVELS FROM KICKING HORSE RIVER HYDRAULIC MODEL (REV 2), MATRIX 2014.
FLOW RECORDS FROM WATER SURVEY OF CANADA STATION 08NA006.

NOTES:

1. FOR CONSISTENCY, CHAINAGE FROM THE 2014 MODEL WAS USED.
2. THE HYDRAULIC MODEL WAS DEVELOPED FOR FLOOD FLOW CONDITIONS. AT LOW FLOW (E.G., DURING THE 2019 LiDAR), THE FLOW PATH IS ALONG THE THALWEG AND SIGNIFICANTLY LONGER THAN AT HIGH FLOW. THIS IS CONSIDERED THE REASON FOR THE DIFFERENCE BETWEEN THE LiDAR AND MODELED WATER LEVEL AT THIS LOCATION.
3. ALL ELEVATIONS SHOWN IN VERTICAL DATUM CGVD2013.
4. FIGURES MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

1 : 200 metres
2 0 2 4

1 : 10,000 metres
100 0 100 200

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TOWN OF GOLDEN
FLOOD STUDY

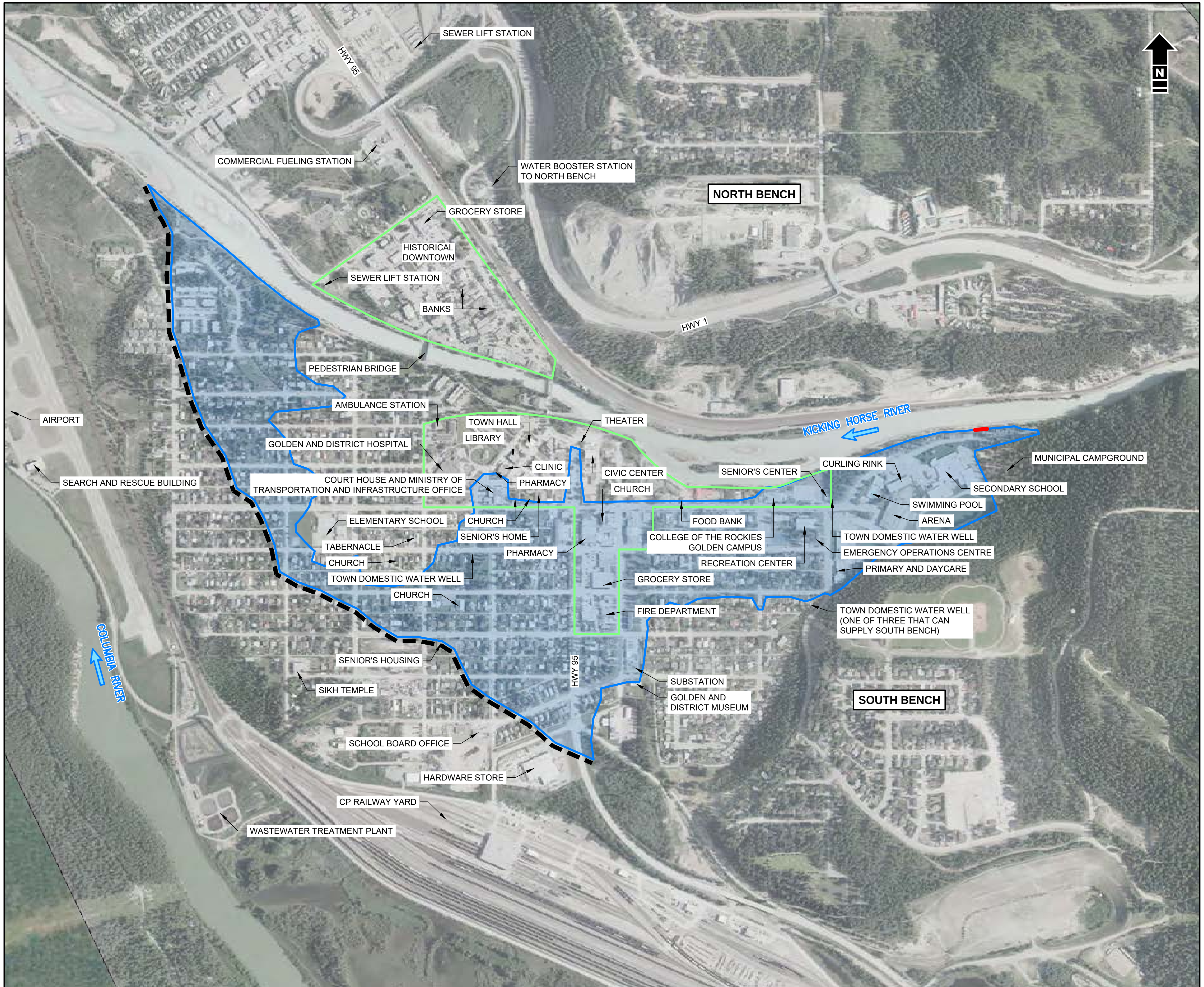
KICKING HORSE RIVER PLAN AND WATER LEVEL PROFILES

Date: FEBRUARY 2020	Project: 5635-DI-TH	Submitter: D. KUSHNER	Reviewer: M. SHOME

Figure 7

Plot 1:1 = Tabloid (L)

F:\5635\Drafting\C3D\Dike Upgrades 2018\Production\Figs\5635-DI-TH.dwg - Bank 2019 - Wednesday, March 25, 2020 10:52:20 AM - Zachary Steele



NOTES:

1. THIS FIGURE SHOWS THE FLOOD EXTENTS FOR THE ASSESSED DIKE BREACH SCENARIO: AN EXTREME FLOOD OF THE KICKING HORSE RIVER WHICH RESULTS IN OVERTOPPING AND FAILURE OF THE DIKE NEAR THE MUNICIPAL CAMPGROUND. A 30 m WIDE DIKE BREACH WAS ASSUMED.
2. COINCIDENT FLOODING OF THE KICKING HORSE AND COLUMBIA RIVER ARE LIKELY, AND ONLY CONSEQUENCES DUE TO THE DIKE BREACH ARE ASSESSED.
3. HYDRAULIC MODELING WAS UNDERTAKEN TO SIMULATE THE DIKE BREACH FLOODING. RESULTS FOR OTHER DIKE BREACH LOCATIONS ARE SHOWN IN APPENDIX B OF THE 2020 FLOOD STUDY REPORT. A 30 m WIDE DIKE BREACH WAS ASSUMED.
4. FIGURES MUST BE USED IN CONJUNCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

LEGEND

- FLOW DIRECTION
- COMMERCIAL AREA
- DIKE BREACH FLOOD EXTENT (71.8 ha)
- SIMULATED DIKE BREACH LOCATION
- COLUMBIA RIVER FLOODPLAIN

1 : 10,000 metres
100 0 100 200
NAD 1983 UTM ZONE 11N

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FLOOD STUDY

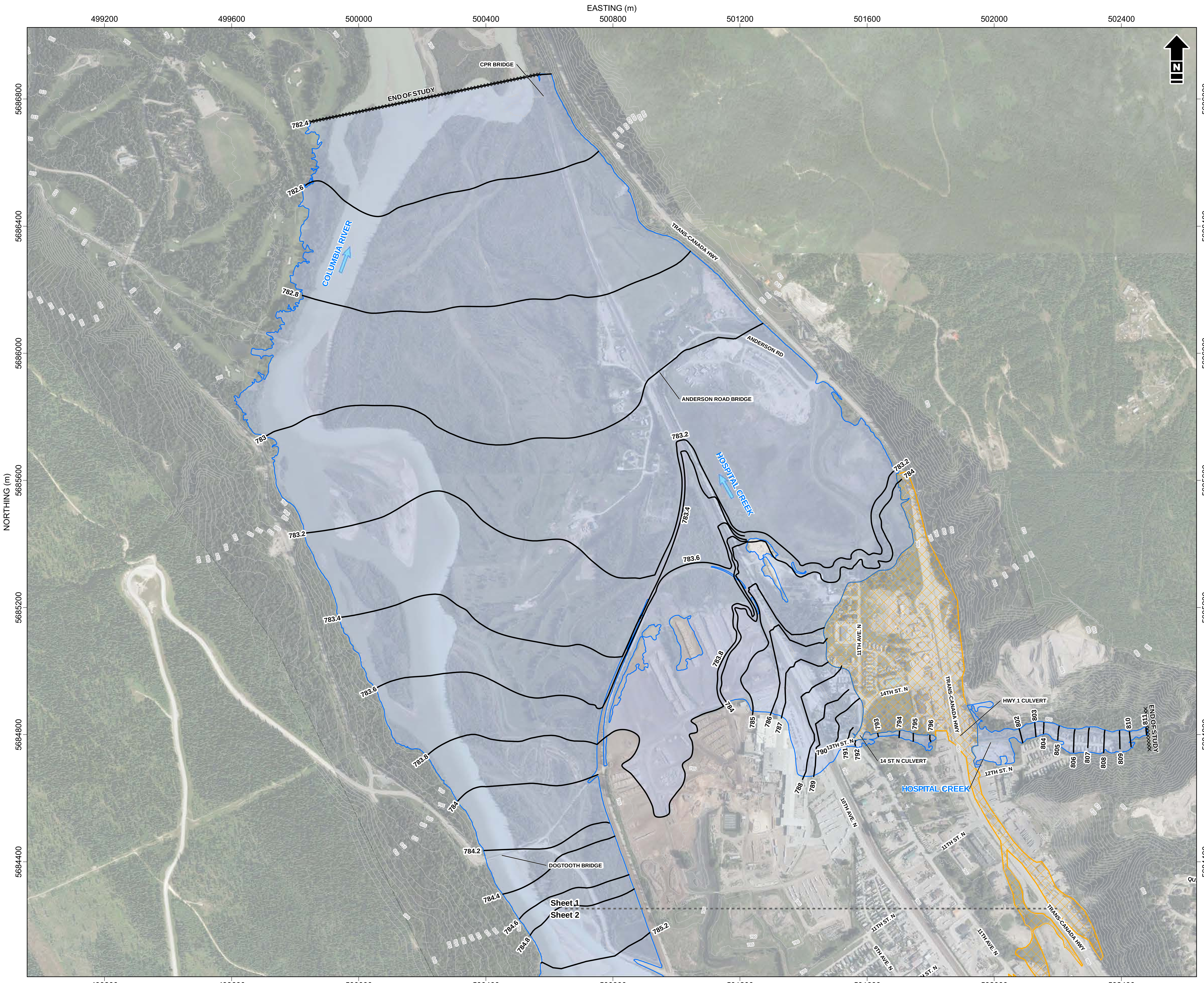
**KICKING HORSE RIVER
DIKE BREACH HAZARD MAP
BREACH AT THE MUNICIPAL CAMPGROUND**

Date:	Project:	Submitter:	Reviewer:
FEBRUARY 2020	5635-IN	D. KUSHNER	M. SHOME

Figure 8

REFERENCE: ORTHOPHOTO BY AIRBORNE IMAGING DATED JULY 21, 2019 AND ESRI WORLD IMAGERY DATE UNKNOWN.

APPENDIX A
Flood Inundation and Dike Breach Flood Hazard Maps



LEGEND

- FLOW DIRECTION
- CONTOUR INTERVAL (5 m; masl)
- STUDY LIMIT
- 1:200 YEAR FLOOD EXTENT (SEE NOTE 3)
- 1:200 YEAR WATER LEVEL (masl)
- CULVERT OVERTOPPING HAZARD AREA (SEE NOTE 4)
- MATCHLINE

NOTES:

1. THIS MAPPING RECOGNIZES THE PROTECTION PROVIDED BY THE DIKES ALONG THE KICKING HORSE RIVER, AND ASSUMES THE PLANNED DIKE UPGRADES TO PROVIDE MINIMUM 0.6 m FREEBOARD ARE COMPLETED.

2. THE 1:200-YEAR FLOOD IS THE DESIGNATED FLOOD IN BRITISH COLUMBIA, AND IS ESTIMATED TO HAVE A PEAK INSTANTANEOUS DISCHARGE OF 786 m^3/s, 570 m^3/s, AND 30 m^3/s FOR THE COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK, RESPECTIVELY.

3. FLOODPLAIN EXTENTS AND FLOOD LEVELS INCLUDE ALLOWANCE FOR 0.6 m FREEBOARD.

4. IF THE HOSPITAL CREEK CULVERT AT HIGHWAY 1 IS OVERTOPPED OR BLOCKED BY DEBRIS THIS AREA WILL BE INUNDATED. GENERALLY, DEPTH WILL BE LESS THAN 0.3 m AND VELOCITY LESS THAN 0.2 m/s EXCEPT ALONG DITCHES AND ROADS, WITH UP TO 1 m/s MAX VELOCITY.

5. VERTICAL DATUM | CGVD2013

6. HORIZONTAL DATUM | NAD83

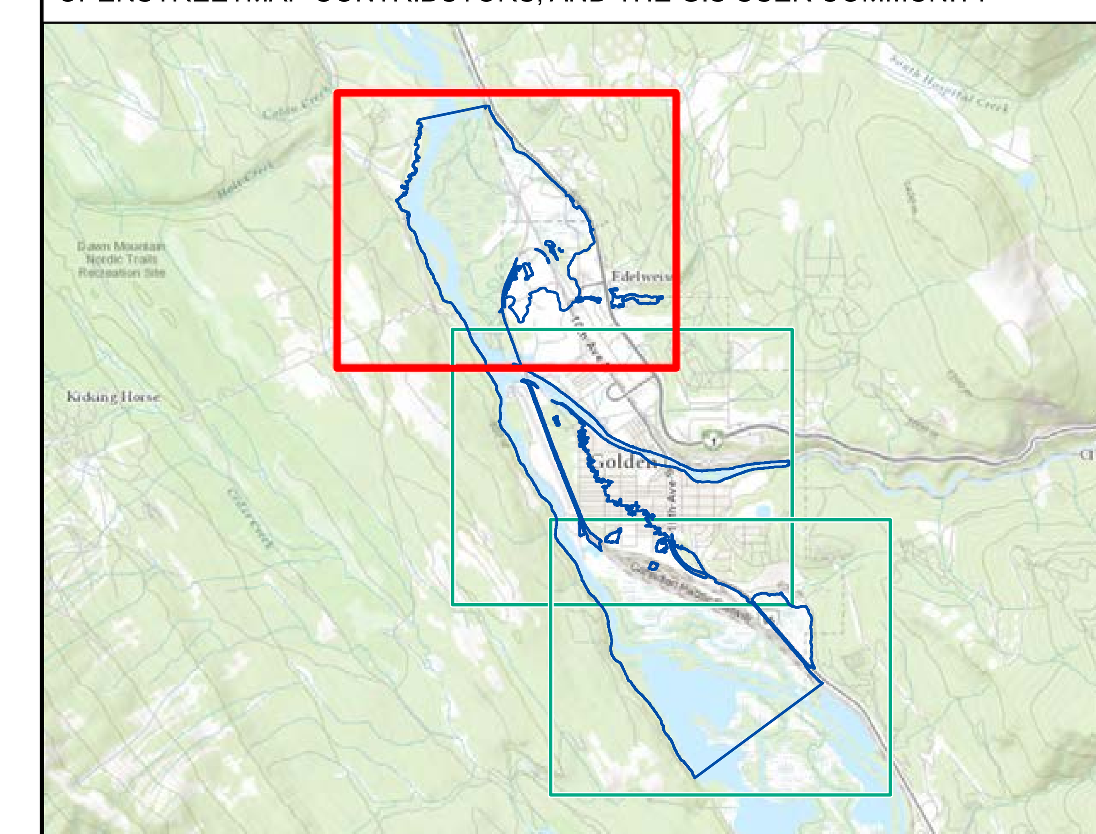
REFERENCES:

1. 2019 LIDAR ACQUIRED FROM AIRBORNE IMAGING USED UNDER LICENCE.

2. 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE.

3. FLOOD ANALYSIS AND HYDRAULIC MODELING SUMMARIZED IN "GOLDEN FLOOD STUDY AND MAPPING REPORT" MATRIX SOLUTIONS INC., MARCH 2020.

4. SERVICE LAYER CREDITS (AIR PHOTO OUTSIDE OF 2019 LIDAR EXTENT): SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY\NSOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY



1:6,000 metres

150 0 150 300

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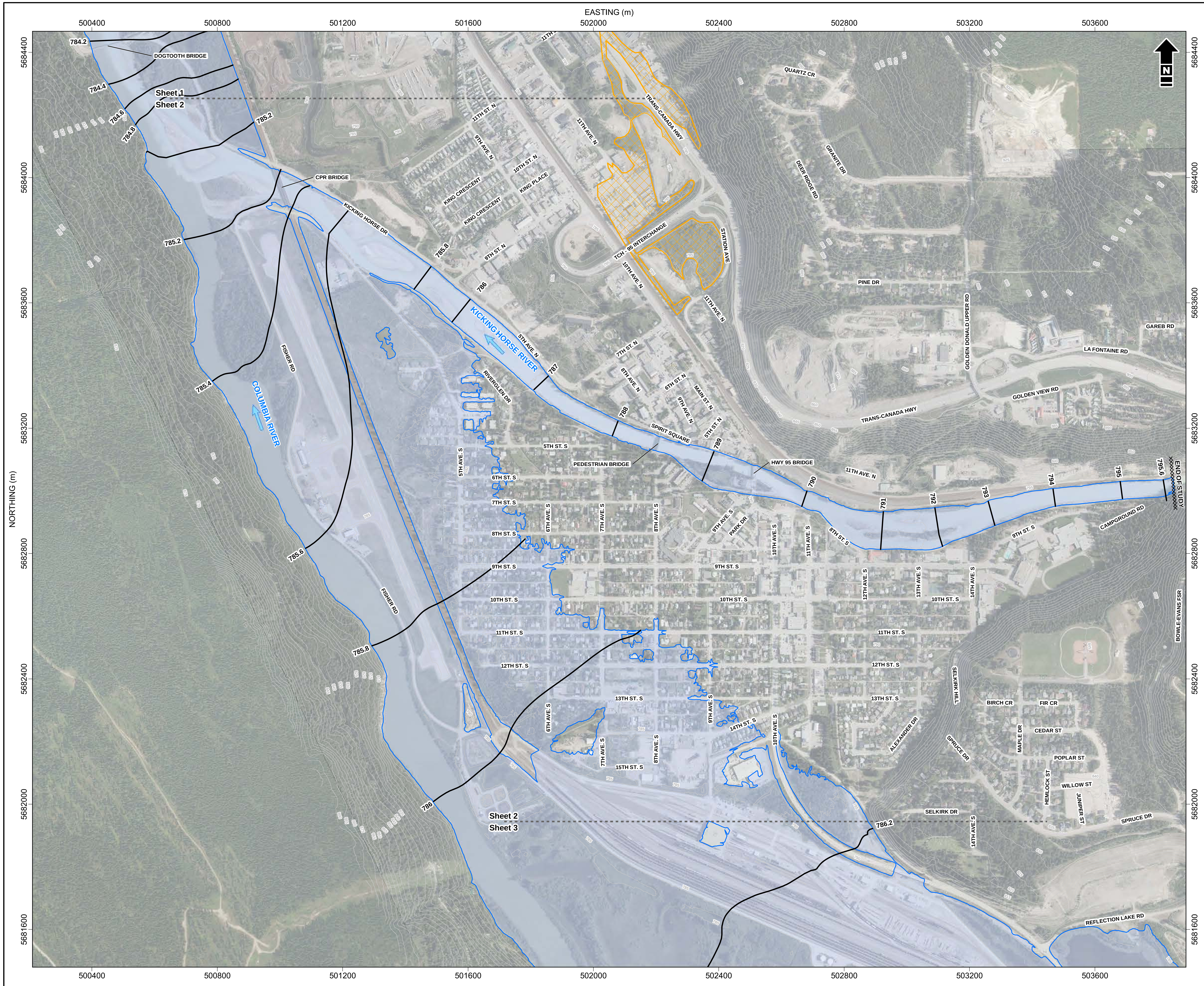
FLOOD STUDY

FLOODPLAIN MAPPING
COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	E. JOHNSTON	D. KUSHNER

Sheet
1 of 3



LEGEND

- FLOW DIRECTION
- CONTOUR INTERVAL (5 m; masl)
- STUDY LIMIT
- 1:200 YEAR FLOOD EXTENT (SEE NOTE 3)
- 1:200 YEAR WATER LEVEL (masl)
- CULVERT OVERTOPPING HAZARD AREA (SEE NOTE 4)
- MATCHLINE

NOTES:

1. THIS MAPPING RECOGNIZES THE PROTECTION PROVIDED BY THE DIKES ALONG THE KICKING HORSE RIVER, AND ASSUMES THE PLANNED DIKE UPGRADES TO PROVIDE MINIMUM 0.6 m FREEBOARD ARE COMPLETED.

2. THE 1:200-YEAR FLOOD IS THE DESIGNATED FLOOD IN BRITISH COLUMBIA, AND IS ESTIMATED TO HAVE A PEAK INSTANTANEOUS DISCHARGE OF 786 m^3/s, 570 m^3/s AND 30 m^3/s FOR THE COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK, RESPECTIVELY.

3. FLOODPLAIN EXTENTS AND FLOOD LEVELS INCLUDE ALLOWANCE FOR 0.6 m FREEBOARD.

4. IF THE HOSPITAL CREEK CULVERT AT HIGHWAY 1 IS OVERTOPPED OR BLOCKED BY DEBRIS THIS AREA WILL BE INUNDATED. GENERALLY, DEPTH WILL BE LESS THAN 0.3 m AND VELOCITY LESS THAN 0.2 m/s EXCEPT ALONG DITCHES AND ROADS, WITH UP TO 1 m/s MAX VELOCITY.

5. VERTICAL DATUM | CGVD2013

6. HORIZONTAL DATUM | NAD83

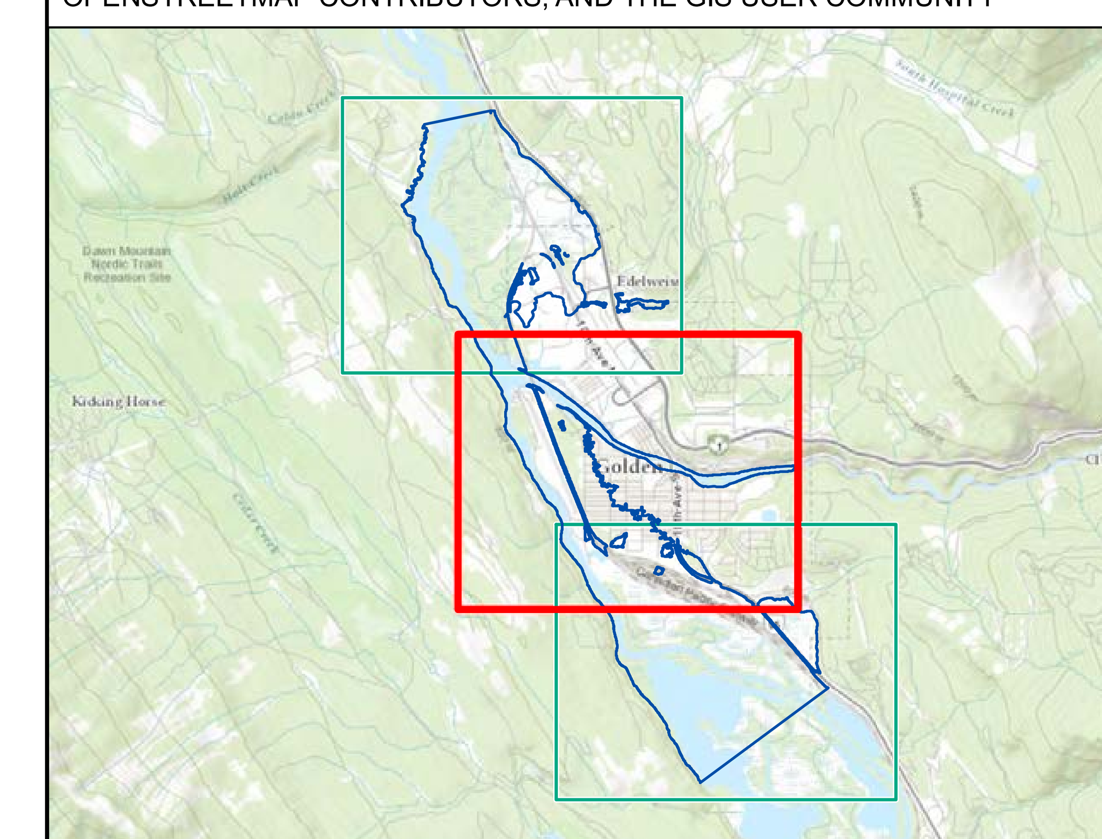
REFERENCES:

1. 2019 LIDAR ACQUIRED FROM AIRBORNE IMAGING USED UNDER LICENCE.

2. 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE.

3. FLOOD ANALYSIS AND HYDRAULIC MODELING SUMMARIZED IN "GOLDEN FLOOD STUDY AND MAPPING REPORT" MATRIX SOLUTIONS INC., MARCH 2020.

4. SERVICE LAYER CREDITS (AIR PHOTO OUTSIDE OF 2019 LIDAR EXTENT): SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY\NSOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY



1:6,000 metres
150 0 150 300
NAD 1983 UTM ZONE 11N

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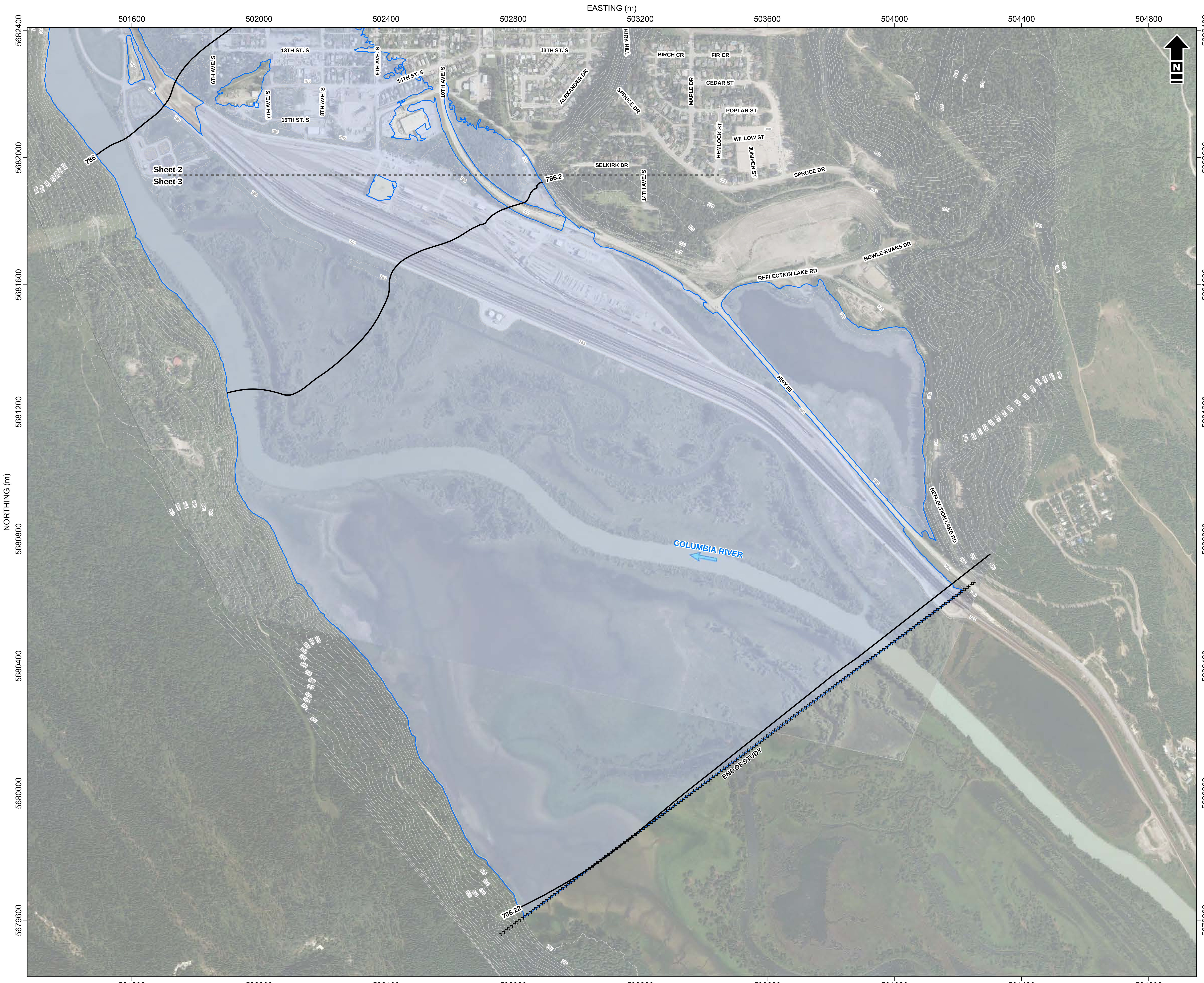
TOWN OF GOLDEN
FLOOD STUDY

FLOODPLAIN MAPPING
COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	E. JOHNSTON	D. KUSHNER

= 2 cm when printed on ANSI D - 22" x 34" (L)

I:\Town\Golden\5635\FiguresAndTables\FLD\2019\Report\Inundation_MapSheets\Figure-1-Floodplain_Mapping_Columbia_River_Kicking_Horse_River_and_Hospital_Creek.mxd - Tabloid_L - 26-Mar-20, 11:26 AM - dbosak - Ti0005



LEGEND

- FLOW DIRECTION
- CONTOUR INTERVAL (5 m; masl)
- STUDY LIMIT
- 1:200 YEAR FLOOD EXTENT (SEE NOTE 3)
- 1:200 YEAR WATER LEVEL (masl)
- CULVERT OVERTOPPING HAZARD AREA (SEE NOTE 4)
- MATCHLINE

NOTES:

1. THIS MAPPING RECOGNIZES THE PROTECTION PROVIDED BY THE DIKES ALONG THE KICKING HORSE RIVER, AND ASSUMES THE PLANNED DIKE UPGRADES TO PROVIDE MINIMUM 0.6 m FREEBOARD ARE COMPLETED.

2. THE 1:200-YEAR FLOOD IS THE DESIGNATED FLOOD IN BRITISH COLUMBIA, AND IS ESTIMATED TO HAVE A PEAK INSTANTANEOUS DISCHARGE OF 786 m^3/s, 570 m^3/s, AND 30 m^3/s FOR THE COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK, RESPECTIVELY.

3. FLOODPLAIN EXTENTS AND FLOOD LEVELS INCLUDE ALLOWANCE FOR 0.6 m FREEBOARD.

4. IF THE HOSPITAL CREEK CULVERT AT HIGHWAY 1 IS OVERTOPPED OR BLOCKED BY DEBRIS THIS AREA WILL BE INUNDATED. GENERALLY, DEPTH WILL BE LESS THAN 0.3 m AND VELOCITY LESS THAN 0.2 m/s EXCEPT ALONG DITCHES AND ROADS, WITH UP TO 1 m/s MAX VELOCITY.

5. VERTICAL DATUM | CGVD2013

6. HORIZONTAL DATUM | NAD83

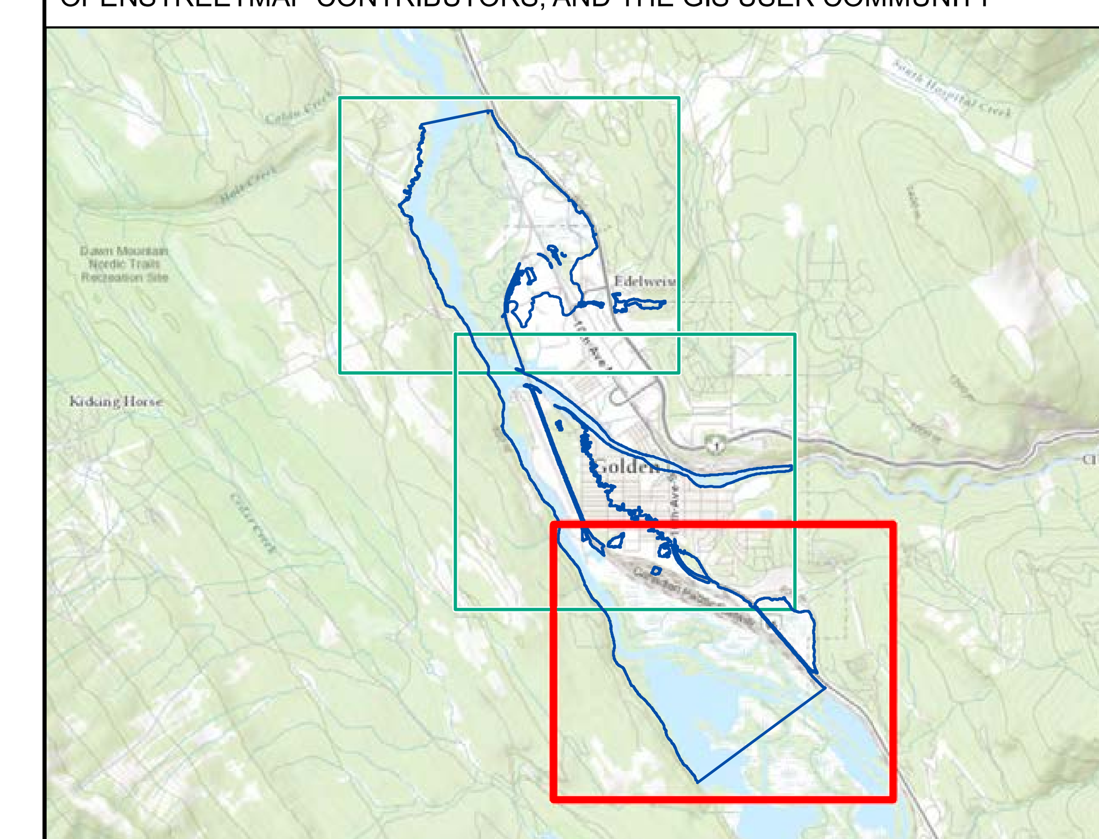
REFERENCES:

1. 2019 LIDAR ACQUIRED FROM AIRBORNE IMAGING USED UNDER LICENCE.

2. 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE.

3. FLOOD ANALYSIS AND HYDRAULIC MODELING SUMMARIZED IN "GOLDEN FLOOD STUDY AND MAPPING REPORT" MATRIX SOLUTIONS INC., MARCH 2020.

4. SERVICE LAYER CREDITS (AIR PHOTO OUTSIDE OF 2019 LIDAR EXTENT): SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY\NSOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY



1:6,000 metres

150 0 150 300

NAD 1983 UTM ZONE 11N

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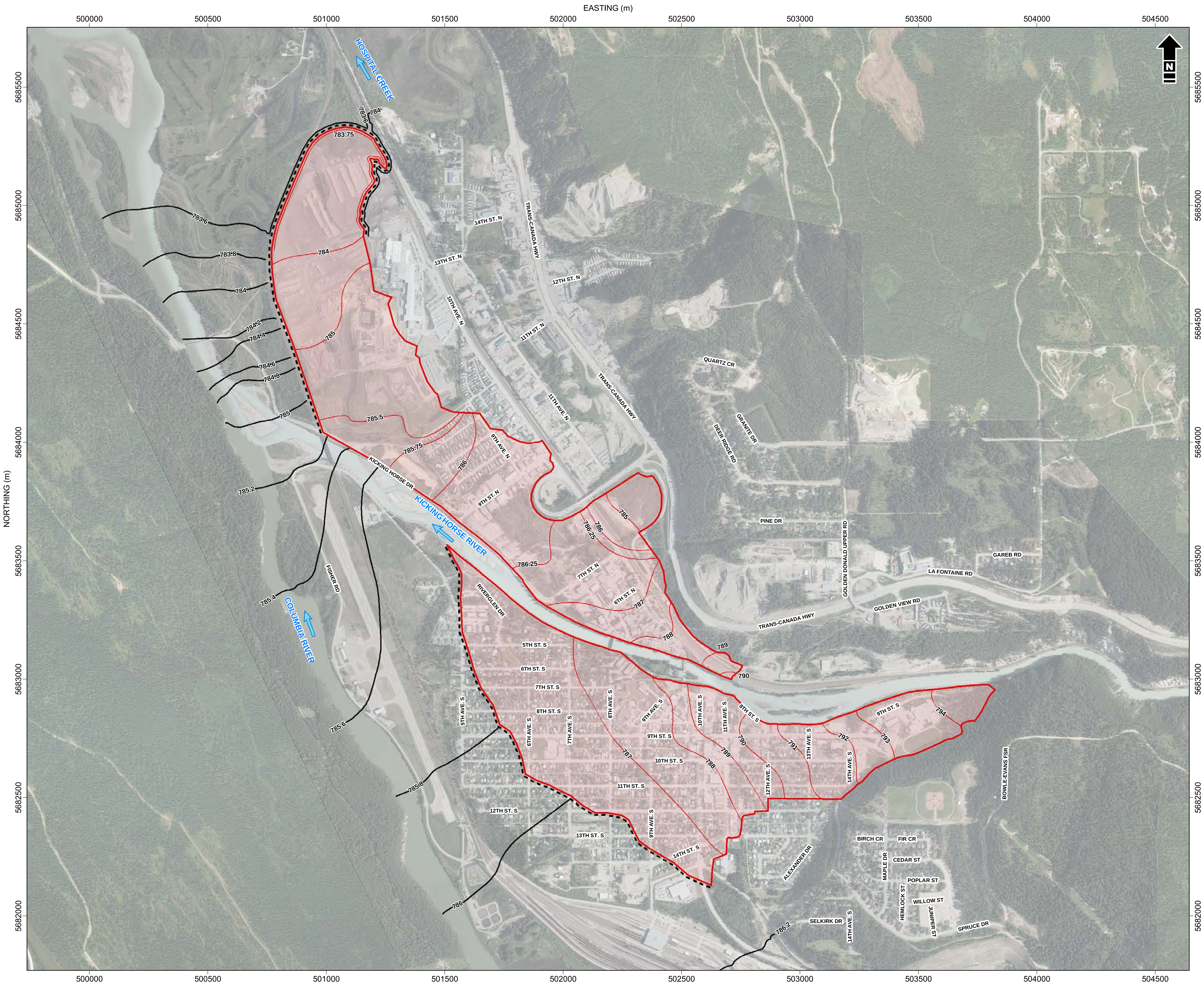
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

FLOODPLAIN MAPPING
COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	E. JOHNSTON	D. KUSHNER

= 2 cm when printed on ANSI D - 22" x 34" (L)



LEGEND

FLOW DIRECTION

1:200 YEAR WATER LEVEL CONTOURS (INCLUDES 0.6m FREEBOARD) (masl)

DIKE BREACH INUNDATION WATER LEVEL CONTOUR (masl)

DIKE BREACH FLOOD HAZARD AREA

1:200 YEAR FLOODPLAIN (APPROXIMATE)

NOTES:

1. THIS MAP SHOWS AREAS AT RISK OF FLOODING AND THE POTENTIAL FLOOD LEVEL DUE TO A DIKE BREACH. A FREEBOARD HAS NOT BEEN INCLUDED IN THE DIKE BREACH FLOOD LEVELS.

2. HYDRAULIC MODELING WAS UNDERTAKEN TO SIMULATE DIKE BREACH FLOODING FROM A RANGE OF DIKE BREACH LOCATIONS ALONG THE KICKING HORSE RIVER. A 30 m WIDE DIKE BREACH WAS ASSUMED.

3. THE DIKE BREACH FLOOD HAZARD AREA AND DIKE BREACH FLOOD LEVEL ARE BASED ON TAKING THE MAXIMUM FLOOD EXTENT AND LEVEL RESULTING FROM ANY OF THE SIMULATED DIKE BREACH LOCATIONS.

4. 1:200-YEAR FLOOD LEVEL CONTOURS ARE SHOWN ALONG THE EDGE OF THE 1:200-YEAR FLOODPLAIN FOR INFORMATION. REFER TO THE 2020 FLOODPLAIN MAPPING COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK.

5. VERTICAL DATUM | CGVD2013

6. HORIZONTAL DATUM | NAD83

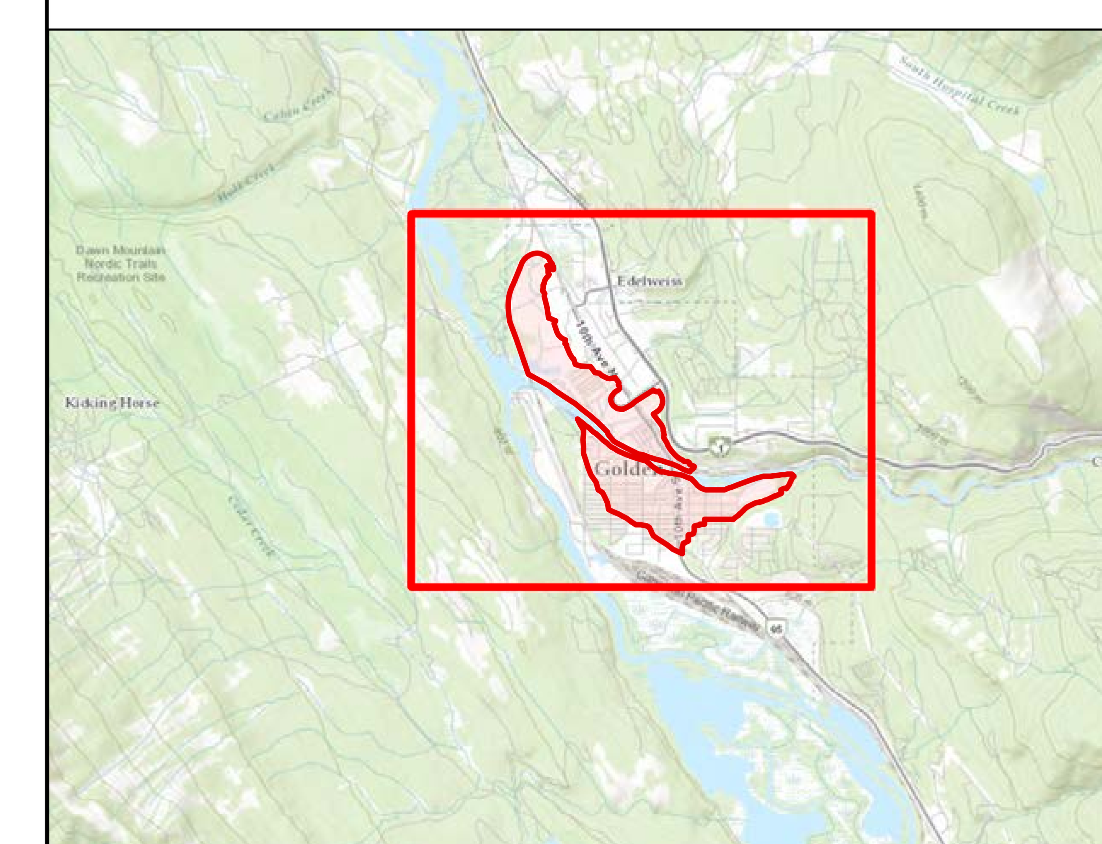
REFERENCES:

1. 2019 LIDAR ACQUIRED FROM AIRBORNE IMAGING USED UNDER LICENCE.

2. 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE.

3. DIKE BREACH HYDRAULIC MODELING SUMMARIZED IN "GOLDEN FLOOD STUDY AND MAPPING REPORT" BY MATRIX SOLUTIONS INC., MARCH 2020.

4. SERVICE LAYER CREDITS (AIR PHOTO OUTSIDE OF 2019 LIDAR EXTENT): SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITYINSOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY



1:8,000 metres

200 0 200 400

NAD 1983 UTM ZONE 11N

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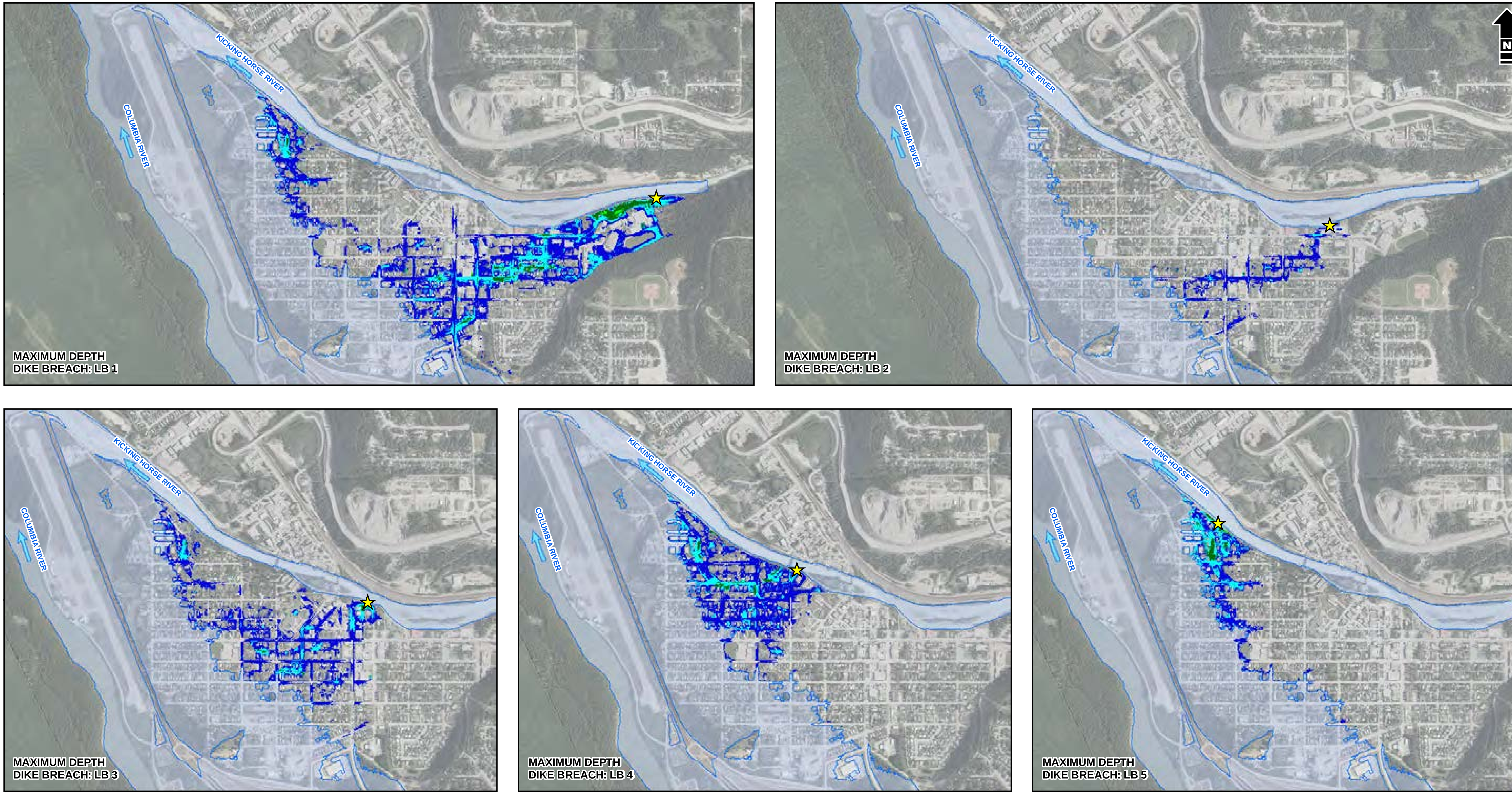
TOWN OF GOLDEN
FLOOD STUDY

KICKING HORSE RIVER DIKE BREACH FLOOD HAZARD MAP

Date: MARCH 2020	Project: 5635	Submitter: D. KUSHNER	Reviewer: M. SHOME

= 2 cm when printed on ANSI D - 22" x 34" (L)

APPENDIX B
Dike Breach Hydraulic Model Results



LEGEND

- SIMULATED DIKE BREACH LOCATION
- 1:200 YEAR FLOOD EXTENTS (INCLUDING 0.6 m FREEBOARD)
- FLOW DIRECTION

DEPTH (m)

- > 3.0
- 3.0 (or less)
- 2.0 (or less)
- 1.5 (or less)
- 1.0 (or less)
- 0.6 (or less)
- 0.3 (or less)

1:20,000 metres

200 0 200 400

NAD 1983 UTM ZONE 11N

NOTES:

1. FIGURE SHOWS RESULTS FROM A HYDRAULIC MODEL FOR AN ASSUMED 30 m WIDE DIKE BREACH DURING AN EXTREME FLOOD EVENT ON THE KICKING HORSE RIVER, WHERE THE WATER LEVEL IS 0.6 m ABOVE THE 1:200-YEAR FLOOD (I.E., THE FREEBOARD LEVEL).
2. FIGURES MUST BE USED IN CONJUCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

REFERENCE: 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE. IMAGERY (2015) SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

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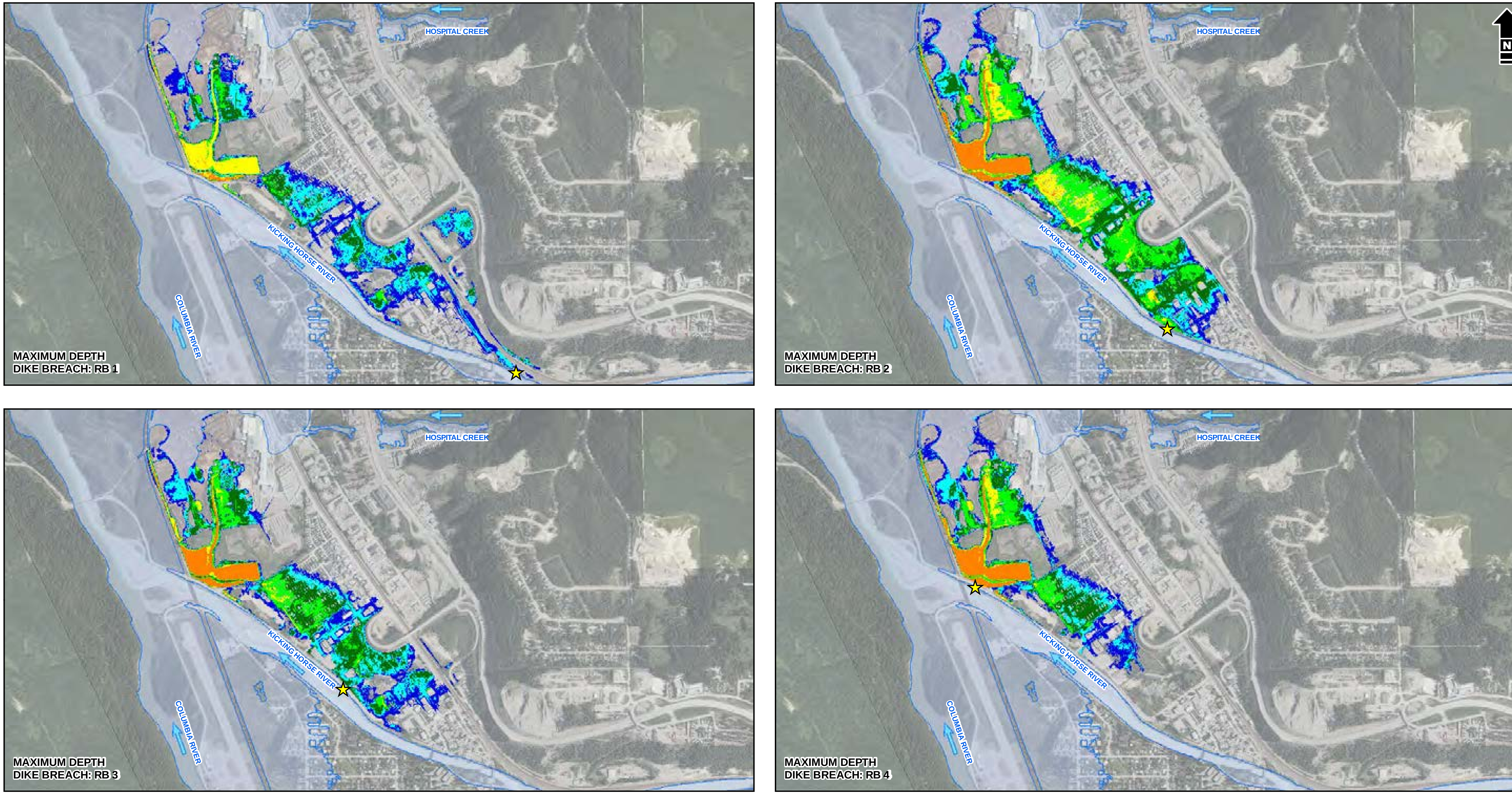
FLOOD STUDY

DIKE BREACH HYDRAULIC MODEL RESULTS MAXIMUM DEPTH (1 OF 2)

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	D. KUSHNER	M. SHOME

Figure B1



LEGEND

- SIMULATED DIKE BREACH LOCATION
- 1:200 YEAR FLOOD EXTENTS (INCLUDING 0.6 m FREEBOARD)
- FLOW DIRECTION

DEPTH (m)

- > 3.0
- 3.0 (or less)
- 2.0 (or less)
- 1.5 (or less)
- 1.0 (or less)
- 0.6 (or less)
- 0.3 (or less)

1:20,000 metres
200 0 200 400
NAD 1983 UTM ZONE 11N

NOTES:

1. FIGURE SHOWS RESULTS FROM A HYDRAULIC MODEL FOR AN ASSUMED 30 m WIDE DIKE BREACH DURING AN EXTREME FLOOD EVENT ON THE KICKING HORSE RIVER, WHERE THE WATER LEVEL IS 0.6 m ABOVE THE 1:200-YEAR FLOOD (I.E., THE FREEBOARD LEVEL).
2. FIGURES MUST BE USED IN CONJUCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

REFERENCE: 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE. IMAGERY (2015) SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

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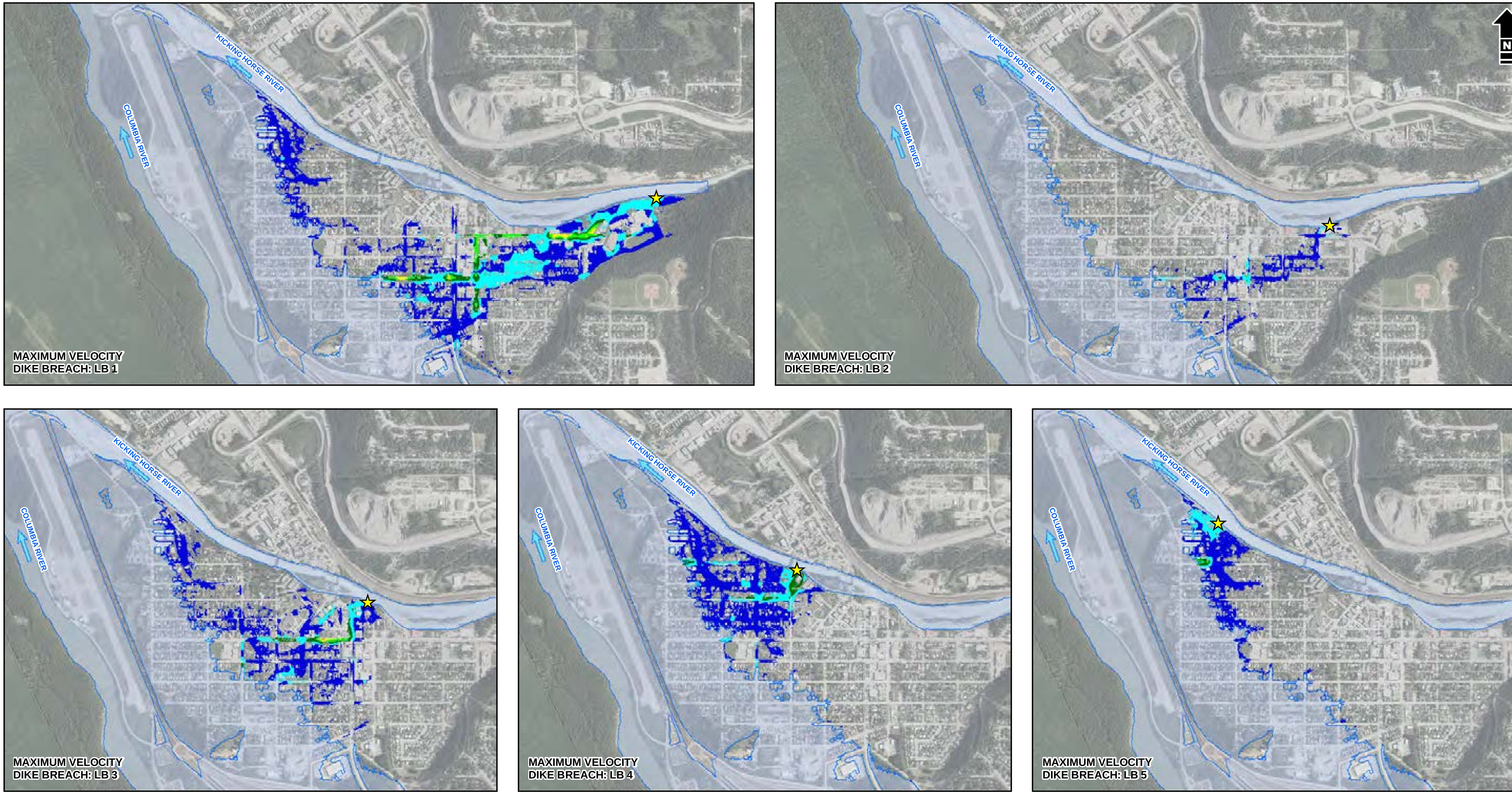
TOWN OF GOLDEN
FLOOD STUDY

DIKE BREACH HYDRAULIC MODEL RESULTS MAXIMUM DEPTH (2 OF 2)

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	D. KUSHNER	M. SHOME

Figure
B2



LEGEND

- ★ SIMULATED DIKE BREACH LOCATION
- 1:200 YEAR FLOOD EXTENTS (INCLUDING 0.6 m FREEBOARD)
- FLOW DIRECTION

VELOCITY (m/s)

- > 3.0
- 3.0 (or less)
- 2.5 (or less)
- 2.0 (or less)
- 1.5 (or less)
- 1.0 (or less)
- 0.5 (or less)

1:20,000 metres
200 0 200 400
NAD 1983 UTM ZONE 11N

NOTES:

1. FIGURE SHOWS RESULTS FROM A HYDRAULIC MODEL FOR AN ASSUMED 30 m WIDE DIKE BREACH DURING AN EXTREME FLOOD EVENT ON THE KICKING HORSE RIVER, WHERE THE WATER LEVEL IS 0.6 m ABOVE THE 1:200-YEAR FLOOD (I.E., THE FREEBOARD LEVEL).
2. FIGURES MUST BE USED IN CONJUCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

REFERENCE: 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE. IMAGERY (2015) SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

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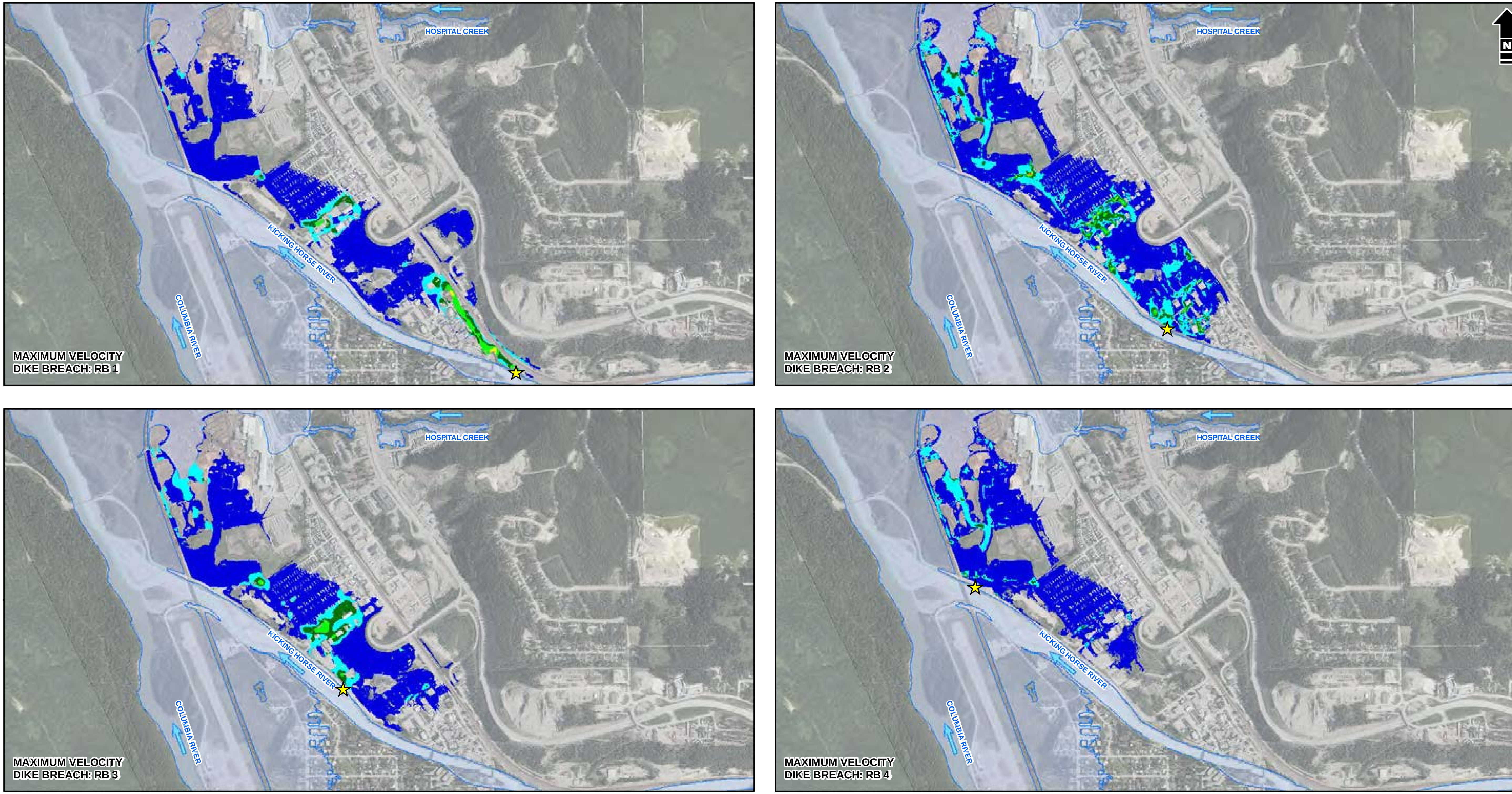
FLOOD STUDY

DIKE BREACH HYDRAULIC MODEL RESULTS MAXIMUM VELOCITY (1 OF 2)

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	D. KUSHNER	M. SHOME

Figure B3

I:\TownOfGolden\5635\FiguresAndTables\FLD\2019\Report\DikeBreach\Figure-B-3-Dike_Breach_Hydraulic_Model_Results_Max_Velocity.mxd - Tabloid_L - 26-Mar-20, 11:04 AM - dbosak - TID004



LEGEND

- ★ SIMULATED DIKE BREACH LOCATION
- 1:200 YEAR FLOOD EXTENTS (INCLUDING 0.6 m FREEBOARD)
- FLOW DIRECTION

VELOCITY (m/s)

- > 3.0
- 3.0 (or less)
- 2.5 (or less)
- 2.0 (or less)
- 1.5 (or less)
- 1.0 (or less)
- 0.5 (or less)

1:20,000 metres
200 0 200 400
NAD 1983 UTM ZONE 11N

NOTES:

1. FIGURE SHOWS RESULTS FROM A HYDRAULIC MODEL FOR AN ASSUMED 30 m WIDE DIKE BREACH DURING AN EXTREME FLOOD EVENT ON THE KICKING HORSE RIVER, WHERE THE WATER LEVEL IS 0.6 m ABOVE THE 1:200-YEAR FLOOD (I.E., THE FREEBOARD LEVEL).
2. FIGURES MUST BE USED IN CONJUCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

REFERENCE: 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE. IMAGERY (2015) SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

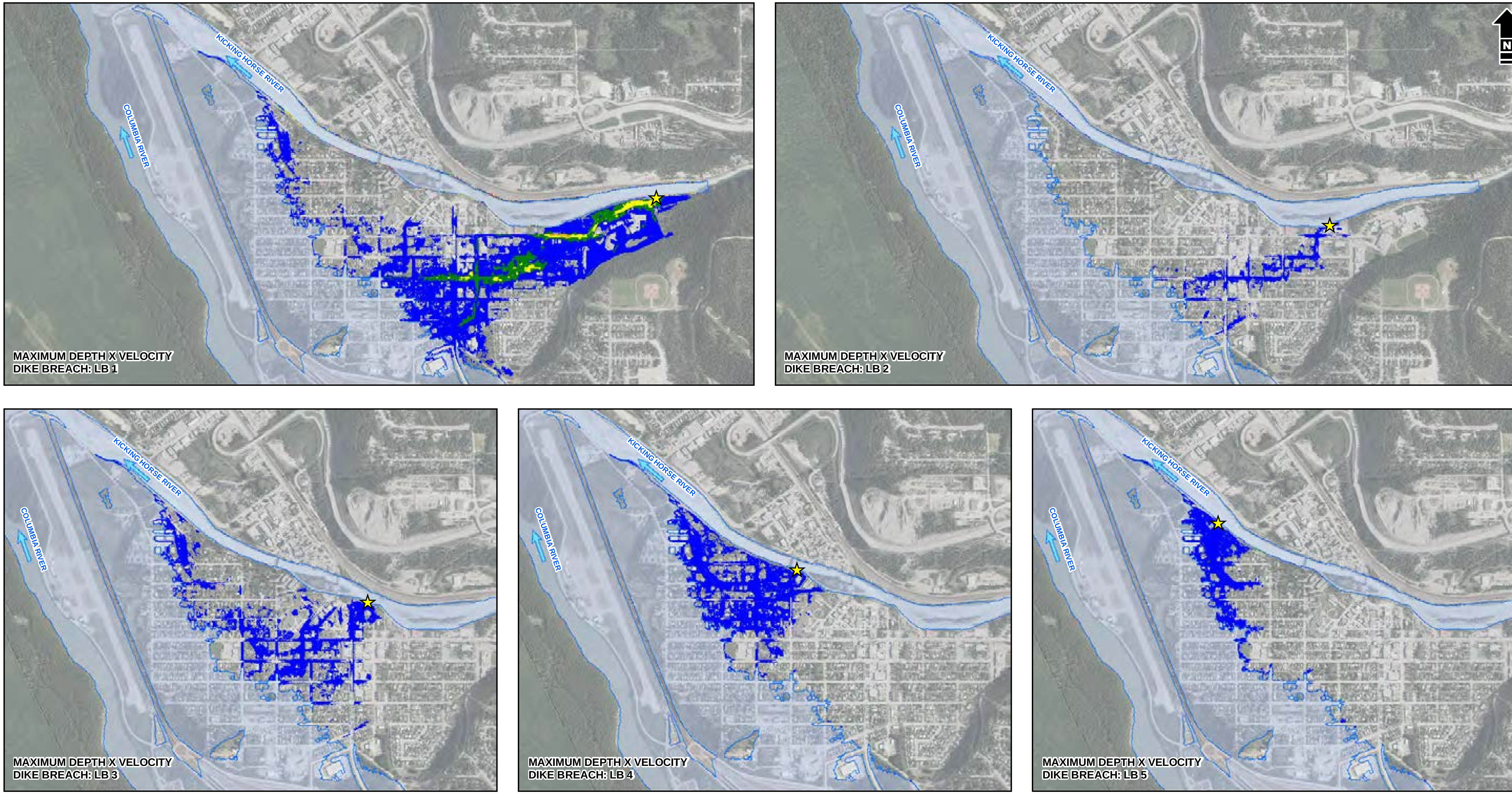
Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

DIKE BREACH HYDRAULIC MODEL RESULTS MAXIMUM VELOCITY (2 OF 2)

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	D. KUSHNER	M. SHOME

Figure B4



LEGEND

- SIMULATED DIKE BREACH LOCATION
- 1:200 YEAR FLOOD EXTENTS (INCLUDING 0.6 m FREEBOARD)
- FLOW DIRECTION

DEPTH X VELOCITY (m^2/s)

- > 2.0
- 2.0 (or less)
- 1.5 (or less)
- 1.0 (or less)
- 0.5 (or less)

1:20,000 metres
200 0 200 400
NAD 1983 UTM ZONE 11N

NOTES:
1. FIGURE SHOWS RESULTS FROM A HYDRAULIC MODEL FOR AN ASSUMED 30 m WIDE DIKE BREACH DURING AN EXTREME FLOOD EVENT ON THE KICKING HORSE RIVER, WHERE THE WATER LEVEL IS 0.6 m ABOVE THE 1:200-YEAR FLOOD (I.E., THE FREEBOARD LEVEL).
2. FIGURES MUST BE USED IN CONJUCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

REFERENCE: 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE. IMAGERY (2015) SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

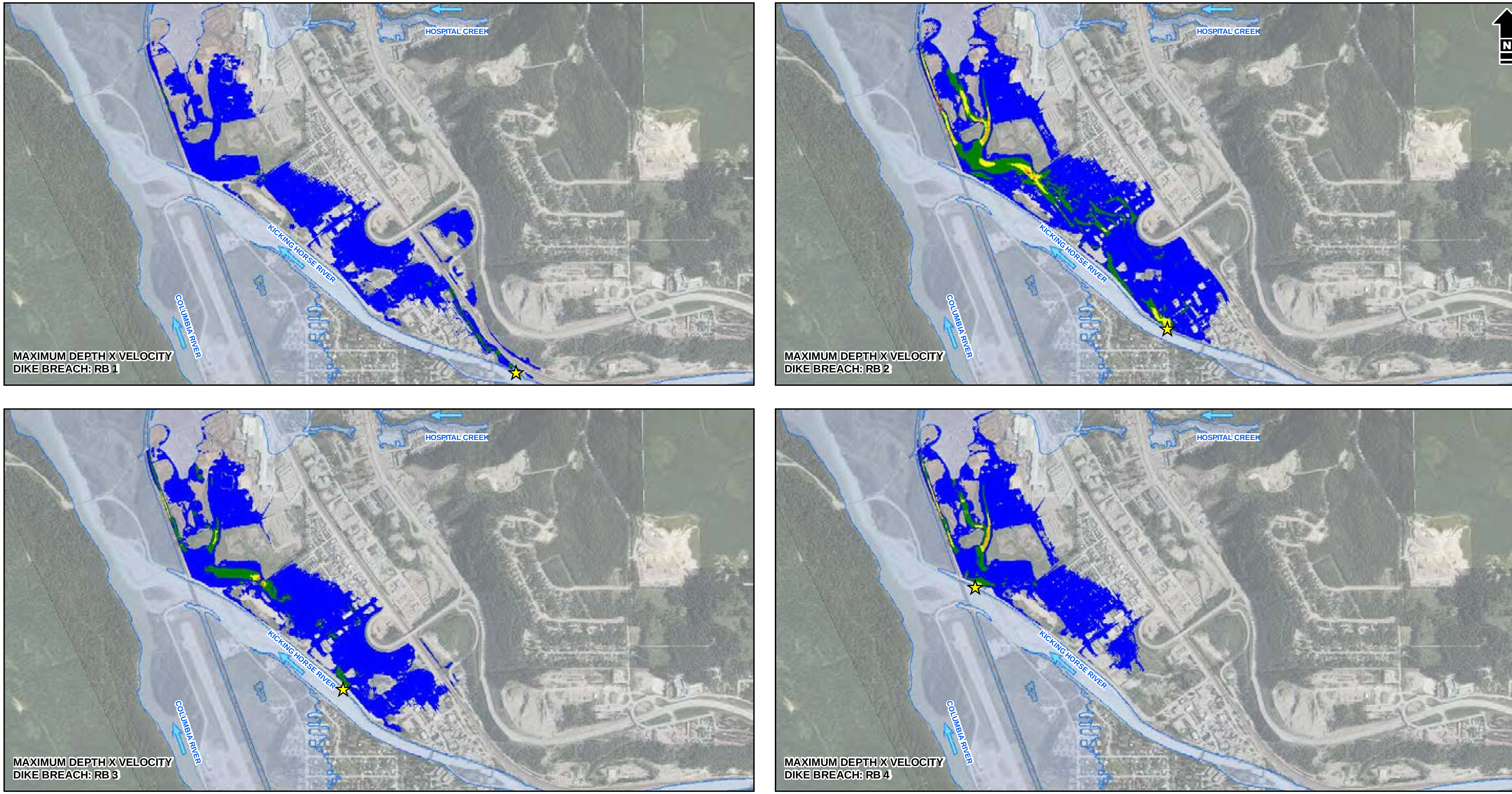
TOWN OF GOLDEN
FLOOD STUDY

DIKE BREACH HYDRAULIC MODEL RESULTS DEPTH X VELOCITY (1 OF 2)

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	D. KUSHNER	M. SHOME

Figure
B5

I:\TownOfGolden\5635\FiguresAndTables\FLD\2019\Report\DikeBreach\Figure-B-5-Dike_Breach_Hydraulic_Model_Results_Depth_X_Velocity.mxd - Tabloid_L - 26-Mar-20, 11:06 AM - dbosak - TID004



LEGEND

- SIMULATED DIKE BREACH LOCATION
- 1:200 YEAR FLOOD EXTENTS (INCLUDING 0.6 m FREEBOARD)
- FLOW DIRECTION

DEPTH X VELOCITY (m^2/s)

- > 2.0
- 2.0 (or less)
- 1.5 (or less)
- 1.0 (or less)
- 0.5 (or less)

1:20,000 metres
200 0 200 400
NAD 1983 UTM ZONE 11N

NOTES:
1. FIGURE SHOWS RESULTS FROM A HYDRAULIC MODEL FOR AN ASSUMED 30 m WIDE DIKE BREACH DURING AN EXTREME FLOOD EVENT ON THE KICKING HORSE RIVER, WHERE THE WATER LEVEL IS 0.6 m ABOVE THE 1:200-YEAR FLOOD (I.E., THE FREEBOARD LEVEL).
2. FIGURES MUST BE USED IN CONJUCTION WITH THE ATTACHED REPORT AND ARE SUBJECT TO THE LIMITATIONS AND CONDITIONS STATED IN THE REPORT.

REFERENCE: 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE. IMAGERY (2015) SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

DIKE BREACH HYDRAULIC MODEL RESULTS DEPTH X VELOCITY (2 OF 2)

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	D. KUSHNER	M. SHOME

Figure
B6

APPENDIX C
Risk Assessment Tables

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

Table C1: Assessment of Risks Due to Open-Water Flooding in The Town of Golden

Scenario	Short Description of the Risk Scenario	Short Consequence Description	Likelihood Rating	Risk							Consequence Ratings / Consequence Weighting											
						Impact Category					A) People and societal impacts				B) Environmental Impacts	C) Local economic impacts	D) Local Infrastructure impacts					E) Public sensitivity impacts
													Displacement									
				Total Weighted Risk	Total Weighted Risk	A) People and societal impacts	B) Environmental Impacts	C) Local economic impacts	D) Local Infrastructure impacts	E) Public sensitivity impacts	Fatalities	Injuries	Percentage of Displaced Individuals	Duration			Transportation	Energy and Utilities	Information and Communications Technology	Health, flood, and Water	Safety and Security	
											3	3	2	2	3	2	2	2	2	3	2	1
Dike Breach Along the Kicking Horse River	Dikes overtop during an extreme flood (greater than a 1:500-year flood) and fail near the municipal campground	A portion of the Town south of the River is flooded (as shown on Figure 8).	2	Low	4.7	Moderate	Low	Moderate	Low	Low	2	2	5	2	1	5	4	2	2	2	1	1
1:200-Year Flood Event	A 1:200-Year flood occurs on the Columbia River, Kicking Horse River, and Hospital Creek. The dikes do not overtop and do not fail	A portion of the Town near the airport and between Highway 1 and Hospital Creek is flooded.	3	Moderate	7.8	Moderate	Low	High	Moderate	Low	2	2	5	3	1	5	4	5	1	2	1	1

Notes:
1. Consequence and Likelihood ratings are according to definitions by NDMP (see Table B2)
2. Risk is calculated using risk matrix and the equation below
3. The possible risk ratings range from 1 to 25 and have been grouped into four categories ranging from low to extreme as shown below

Risk Rating Matrix (Consequence x Likelihood)					
	Likelihood Rating				
Consequence Rating	1	2	3	4	5
5	5	10	15	20	25
4	4	8	12	16	20
3	3	6	9	12	15
2	2	4	6	8	10
1	1	2	3	4	5

Risk	Risk Rating (x)
Extreme	x > 15
High	15 ≤ x ≤ 20
Moderate	5 ≤ x < 15
Low	x <5

$$Risk = Liklihood\ Rating \times \frac{\sum Consequence\ Rating\ \times Consequence\ Weighting}{\sum Consequence\ Weighting}$$

Table C2: NDMP Likelihood and Consequence Rating Definitions

LIKELIHOOD RATING				
Likelihood Rating	Likelihood Definition			
5	The event is expected and may be triggered by conditions expected over a 30 year period.			
4	The event is expected and may be triggered by conditions expected over a 30 - 50 year period.			
3	The event is expected and may be triggered by conditions expected over a 50 - 500 year period.			
2	The event is expected and may be triggered by conditions expected over a 500 - 5000 year period.			
1	The event is possible and may be triggered by conditions expected over a 5000 year period.			
CONSEQUENCES				
A) People and societal impacts				
		Weighting[1] (3=high , 1=low)	Consequence Rating	Consequence Definition
Fatalities		3	5	Could result in more than 50 fatalities
			4	Could result in 10 - 49 fatalities
			3	Could result in 5 - 9 fatalities
			2	Could result in 1 - 4 fatalities
			1	Not likely to result in fatalities
Injuries		3	5	Injuries, illness and/or psychological disablements cannot be addressed by local, regional, or provincial/territorial healthcare resources; federal support or intervention is required
			4	Injuries, illnesses and/or psychological disablements cannot be addressed by local or regional healthcare resources; provincial/territorial healthcare support or intervention is required.
			3	Injuries, illnesses and/or psychological disablements cannot be addressed by local or regional healthcare resources additional healthcare support or intervention is required from other regions, and supplementary support could be required from the province/territory
			2	Injuries, illnesses and/or psychological disablements cannot be addressed by local resources through local facilities; healthcare support is required from other areas such as an adjacent area(ies)/municipality(ies) within the region
			1	Any injuries, illnesses, and/or psychological disablements can be addressed by local resources through local facilities; available resources can meet the demand for care
Displacement	Percentage of displaced individuals	2	5	> 15% of total local population
			4	10 - 14.9% of total local population
			3	5 - 9.9% of total local population
			2	2 - 4.9% of total local population
			1	0 - 1.9% of total local population
	Duration of displacement	2	5	> 26 weeks (6 months)
			4	4 weeks - 26 weeks (6 months)
			3	1 week - 4 weeks
			2	72 hours - 168 hours (1 week)
			1	Less than 72 hours

Notes:
1. Consequence Weighting by Matrix Solutions and Town of Golden
2. Reference: National Disaster Mitiation Program (NDMP) Risk Assessment Information Template. 2018

		Weighting[1] (3= high , 1 = low)	Consequence Rating	Consequence Definition
B) Environmental impacts				
		3	5	> 75% of flora or fauna impacted or 1 or more ecosystems significantly impaired; Air quality has significantly deteriorated; Water quality is significantly lower than normal or water level is > 3 meters above highest natural level; Soil quality or quantity is significantly lower (i.e., significant soil loss, evidence of lethal soil contamination) than normal; > 15% of local area is affected
			4	40 - 74.9% of flora or fauna impacted or 1 or more ecosystems considerably impaired; Air quality has considerably deteriorated; Water quality is considerably lower than normal or water level is 2 - 2.9 meters above highest natural level; Soil quality or quantity is moderately lower than normal; 10 - 14.9% of local area is affected
			3	10 - 39.9% of flora or fauna impacted or 1 1 or more ecosystems moderately impaired; Air quality has moderately deteriorated; Water quality is moderately lower than normal or water level is 1 - 2 meters above highest natural level; Soil quality is moderately lower than normal; 6 - 9.9 % of area affected
			2	< 10 % of flora or fauna impacted or little or no impact to any ecosystems; Little to no impact to air quality and/or soil quality or quantity; Water quality is slightly lower than normal, or water level is than 0.9 meters above highest natural level and increased for less than 24 hours; 3 - 5.9 % of local area is affected
			1	Little to no impact to flora or fauna, any ecosystems, air quality, water quality or quantity, or to soil quality or quantity; 0 -
C) Local economic impacts				
		2	5	> 15 % of local economy impacted
			4	10 - 14.9 % of local economy impacted
			3	6 - 9.9 % of local economy impacted
			2	3 - 5.9 % of local economy impacted
			1	0 - 2.9 % of local economy impacted
D) Local infrastructure impacts				
Transportation		2	5	Local activity stopped for more than 72 hours; > 20% of local population affected; lost access to local area and/or delivery of crucial service or product; or having an international level impact
			4	Local activity stopped for 48 - 71 hours; 10 - 19.9% of local population affected; significantly reduced access to local area and/or delivery of crucial service or product; or having a national level impact
			3	Local activity stopped for 25 - 47 hours; 5 - 9.9% of local population affected; moderately reduced access to local area and/or delivery of crucial service or product; or having a provincial/territorial level impact
			2	Local activity stopped for 13 - 24 hours; 2 - 4.9% of local population affected; minor reduction in access to local area and/or delivery of crucial service or product; or having a regional level impact
			1	Local activity stopped for 0 - 12 hours; 0 - 1.9% of local population affected; little to no reduction in access to local area and/or delivery of crucial service or product

Notes:
1. Consequence Weighting by Matrix Solutions and Town of Golden
2. Reference: National Disaster Mitiation Program (NDMP) Risk Assessment Information Template. 2018

		Weighting[1] (3= high , 1 = low)	Consequence Rating	Consequence Definition
D) Local infrastructure impacts (Continued…)				
Energy and Utilities		2	5	Duration of impacts > 72 hours; > 20% of local population without service or product; or having an international level impact
			4	Duration of impact 48 - 71 hours; 10 - 19.9% of local population without service or product; or having a national impact
			3	Duration of impact 25 - 47 hours; 5 - 9.9% of local population without service or product; or having a provincial/territorial level impact
			2	Duration of impact 13 - 24 hours; 2 - 4.9% of local population without service or product; or having a regional level impact
			1	Local activity stopped for 0 - 12 hours; 0 - 1.9% of local population affected; little to no reduction in access to local area and/or delivery of crucial service or product
Information and Communications Technology		2	5	Service unavailable for > 72 hours; > 20 % of local population without service; or having an international level impact
			4	Service unavailable for 48 - 71 hours; 10 - 19.9 % of local population without service; or having a national level impact
			3	Service unavailable for 25 - 47 hours; 5 - 9.9 % of local population without service; or having a provincial/territorial level impact
			2	Service unavailable for 13 - 24 hours; 2 - 4.9 % of local population without service; or having a regional level impact
			1	Service unavailable for 0 - 12 hours; 0 - 1.9 % of local population without service
Health, Food, and Water		3	5	Inability to access potable water, food, sanitation services, or healthcare services for > 72 hours; non-essential services cancelled; > 20 % of local population impacted; or having an international level impact
			4	Inability to access potable water, food, sanitation services, or healthcare services for 48-72 hours; major delays for nonessential services; 10 - 19.9 % of local population impacted; or having a national level impact
			3	Inability to access potable water, food, sanitation services, or healthcare services for 25-48 hours; moderate delays for nonessential services; 5 - 9.9 % of local population impacted; or having a provincial/territorial level impact
			2	Inability to access potable water, food, sanitation services, or healthcare services for 13-24 hours; minor delays for nonessential; 2 - 4.9 % of local population impacted; or having a regional level impact
			1	Inability to access potable water, food, sanitation services, or healthcare services for 0-12 hours; 0 - 1.9 % of local population impacted
Safety and Security		2	5	> 20 % of local population impacted; loss of intelligence or defence assets or systems for > 72 hours; or having an international level impact
			4	10 - 19.9 % of local population impacted; loss of intelligence or defence assets or systems for 48 – 71 hours; or having a national level impact
			3	5 - 9.9 % of local population impacted; loss of intelligence or defence assets or systems for 25 – 47 hours; or having a provincial/territorial level impact
			2	2 - 4.9 % of local population impacted; loss of intelligence or defence assets or systems for 13 – 24 hours; or having a regional level impact
			1	0 - 1.9 % of local population impacted; loss of intelligence or defence assets or systems for 0 – 12 hours

Notes:
1. Consequence Weighting by Matrix Solutions and Town of Golden
2. Reference: National Disaster Mitiation Program (NDMP) Risk Assessment Information Template. 2018

		Weighting[1] (3= high , 1 = low)	Consequence Rating	Consequence Definition
E) Public sensitivity impacts				
		1	5	Sustained, long term loss in reputation/public perception of public institutions and/or sustained, long term loss of trust and confidence in public institutions; or having an international level impact
			4	Significant loss in reputation/public perception of public institutions and/or significant loss of trust and confidence in public institutions; significant resistance; or having a national level impact
			3	Some loss in reputation/public perception of public institutions and/or some loss of trust and confidence in public institutions; escalating resistance
			2	Isolated/minor, recoverable set-back in reputation, public perception, trust, and/or confidence of public institutions
			1	No impact on reputation, public perception, trust, and/or confidence of public institutions

Notes:
1. Consequence Weighting by Matrix Solutions and Town of Golden
2. Reference: National Disaster Mitiation Program (NDMP) Risk Assessment Information Template. 2018

APPENDIX D
Site Photographs

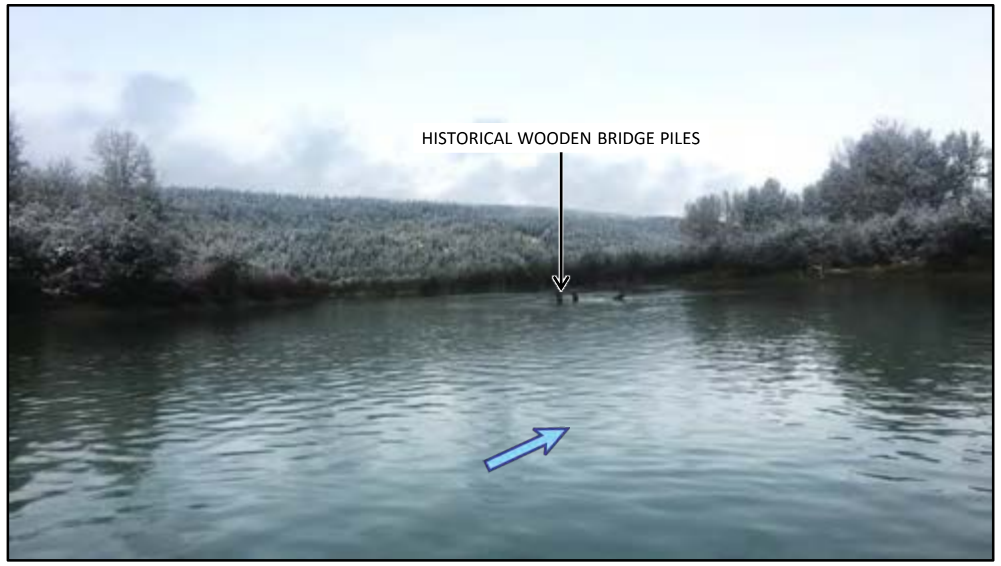


Photo 1 - September 30, 2019 (9+000): Near the upstream end of Town and CPR Yard. Historical wooden bridge piles visible in photo.

Photo 2 - September 30, 2019 (8+000): Near upstream end of Town. Channel and banks are well defined.

Photo 3 - September 30, 2019 (6+300): Near the municipal wastewater facility. Golden search and rescue building visible in background. Note the steep left bank.

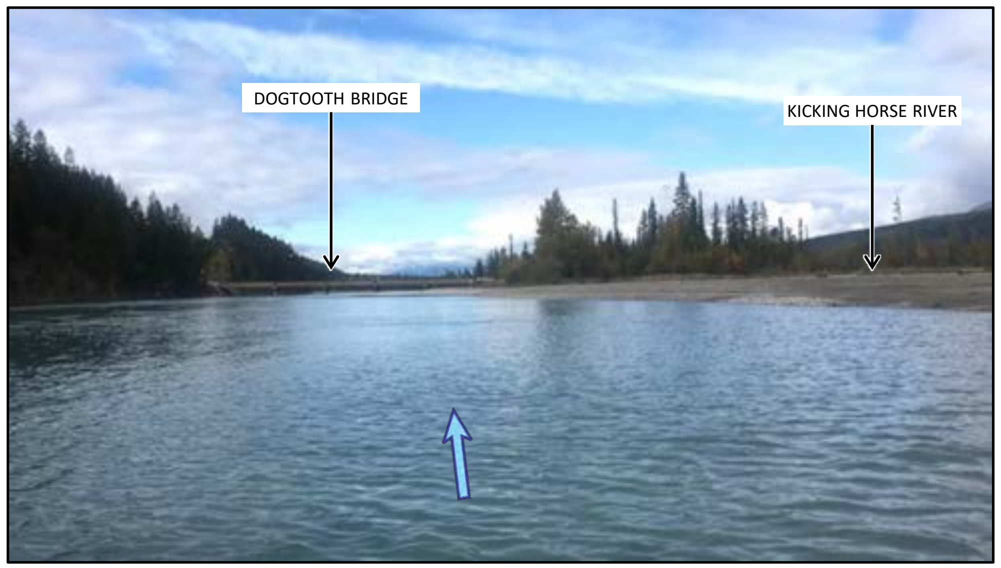


Photo 4 - September 30, 2019 (4+300): Upstream of the confluence of Columbia and Kicking Horse Rivers.

Photo 5 - September 30, 2019 (3+700): Downstream of the confluence of Columbia and Kicking Horse Rivers at the upstream end of a large gravel bar.

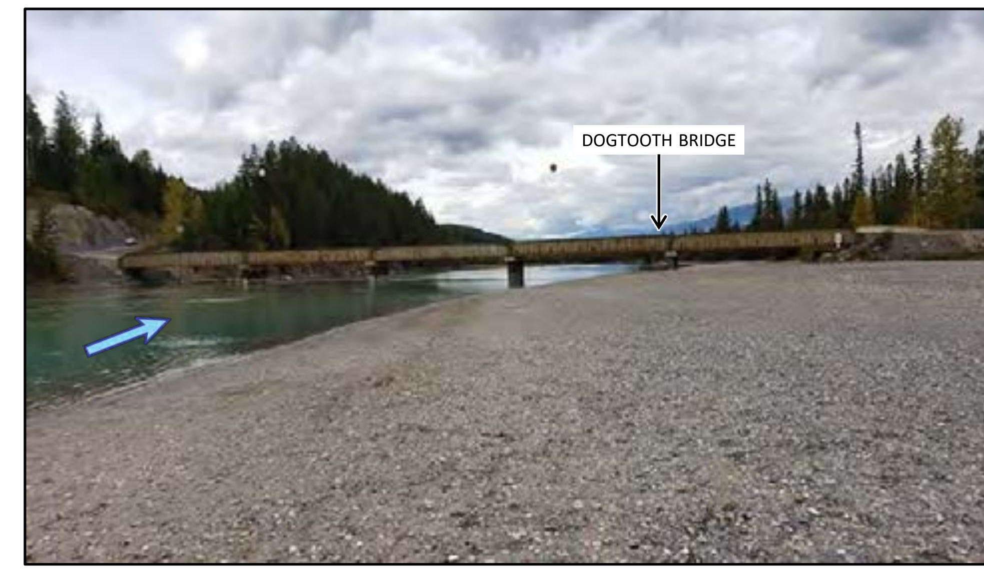


Photo 6 - September 30, 2019 (3+400): Downstream of the confluence of Columbia and Kicking Horse Rivers. Looking at upstream side of Dogtooth Bridge.

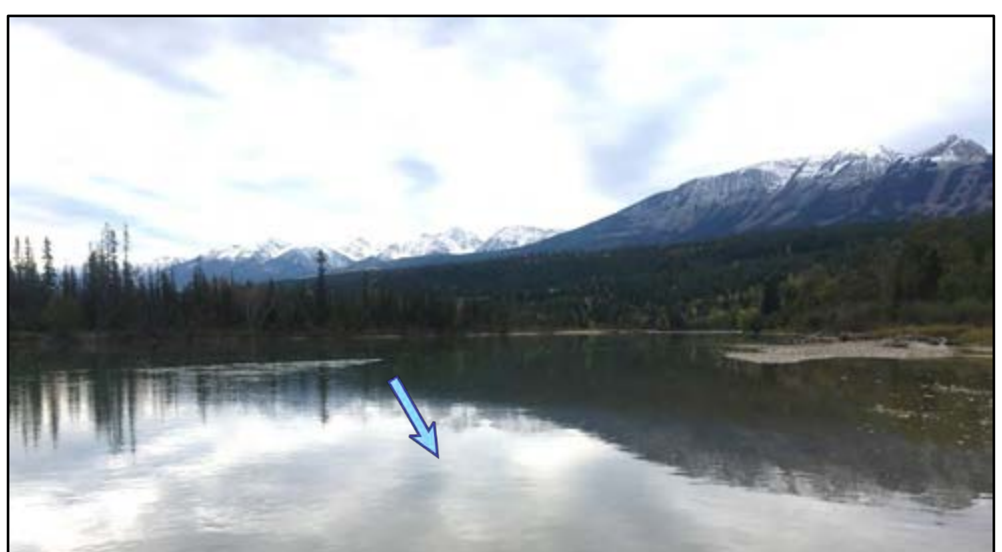


Photo 7 - September 30, 2019 (0+800): Near the downstream study limit. The river splits into multiple sub-channels in this area. (only the main channel is visible in this photo).

Photo 8 - September 30, 2019 (0+700): Near the downstream study limit. The river splits into multiple sub-channels in this area (only the main channel is visible in this photo).

LEGEND

FLOW DIRECTION

REFERENCE: PHOTOS TAKEN DURING THE FALL 2019 SURVEY.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

COLUMBIA RIVER PHOTOS

Date:	Project:	Submitter:	Reviewer:
FEBRUARY 2020	5635-CP	E. JOHNSTON	D. KUSHNER

Figure D1

F:\5635\2019 Flood Study\Report\Appendix D\Site Photos Columbia.pptx

Photo 9 - September 27, 2019 (3+300): Looking at the mouth of canyon taken from the municipal campground. Bathymetry survey conducted from a boat using an Echo Sounder.

Photo 10 - September 27, 2019 (3+300): Taken from the municipal campground.

Photo 11 - September 27, 2019 (2+900): Taken from gravel bar beside the left bank.

Photo 12 - September 26, 2019 (2+800): Taken on the island near the College of The Rockies.

Photo 13 - September 29, 2019 (2+400): Taken from top of dike near the Mad Trapper pub and the College of The Rockies.

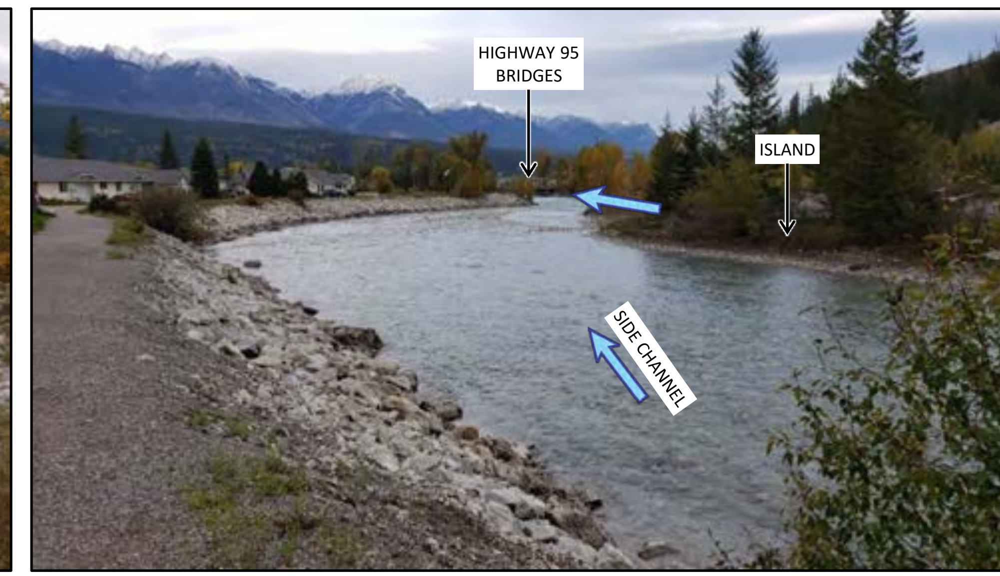


Photo 14 - September 29, 2019 (2+400): Taken from top of dike near the island near the College of The Rockies.

Photo 15 - September 29, 2019 (2+300): Taken from Gould's Island. The side channel was dry during the survey.

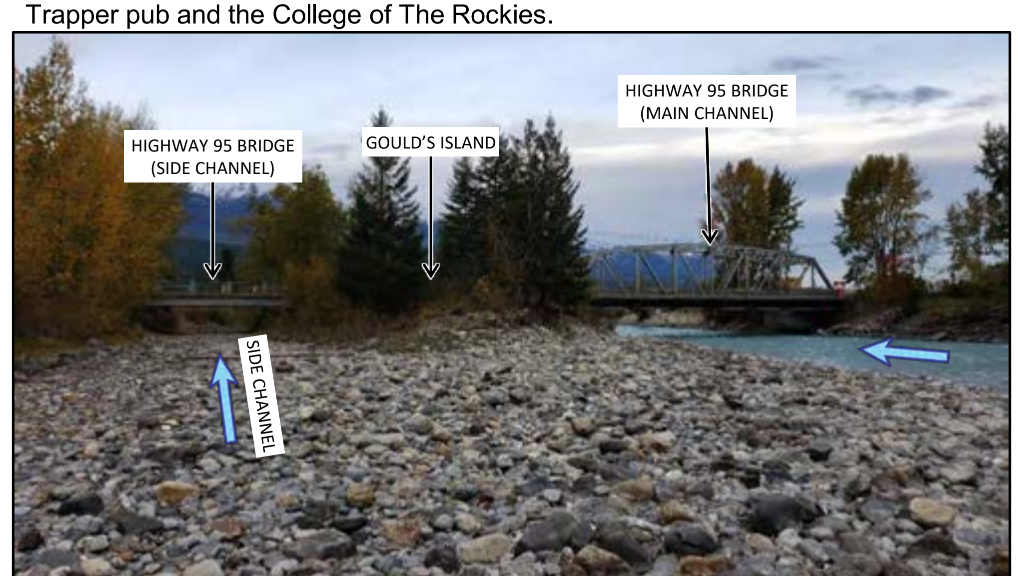


Photo 16 - September 29, 2019 (2+300): Highway 95 Bridges across Gould's Island.

LEGEND

FLOW DIRECTION

REFERENCE: PHOTOS TAKEN DURING THE FALL 2019 SURVEY.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

KICKING HORSE RIVER PHOTOS

Date:	Project:	Submitter:	Reviewer:
FEBRUARY 2020	5635-KP	E. JOHNSTON	D. KUSHNER

Figure D2

F:\5635\2019 Flood Study\Report\Appendix D\Site Photos KHR.pptx

Photo 17 - September 29, 2019 (2+250): Highway 95 Bridges across Gould's Island.

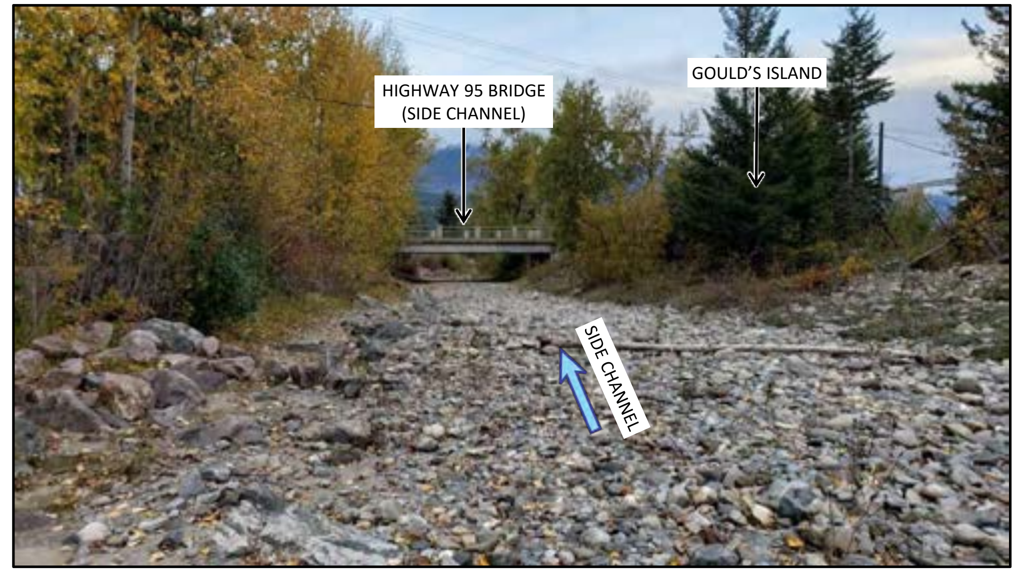


Photo 18 - September 29, 2019 (2+250): Side channel beside Gould's Island.

Photo 19 - September 29, 2019 (1+900): Highway 95 Bridges across Gould's Island.

Photo 20 - September 29, 2019 (1+900): Pedestrian bridge.

Photo 21 - September 27, 2019 (1+950): Taken from the pedestrian bridge.

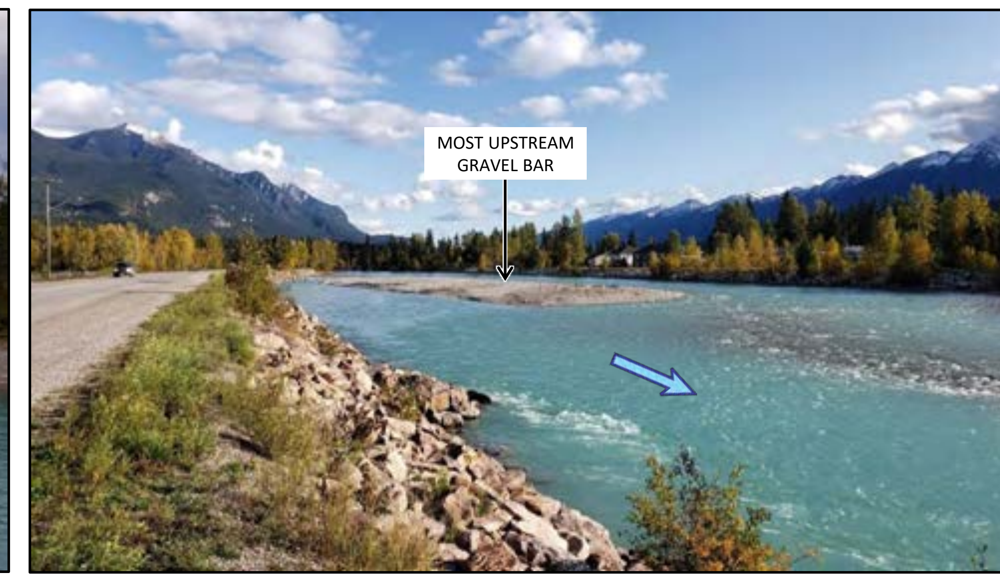


Photo 22 - September 27, 2019 (1+400): Taken at upstream end of gravel bars.

Photo 23 - September 27, 2019 (1+400): Instream gravel bars.

Photo 24 - September 26, 2019 (0+900): Taken on a gravel bar beside the left bank.

LEGEND

FLOW DIRECTION

REFERENCE: PHOTOS TAKEN DURING THE FALL 2019 SURVEY.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

KICKING HORSE RIVER PHOTOS

Date: FEBRUARY 2020	Project: 5635-KP	Submitter: E. JOHNSTON	Reviewer: D. KUSHNER

Figure D3

F:\5635\2019 Flood Study\Report\Appendix D\Site Photos KHR.pptx

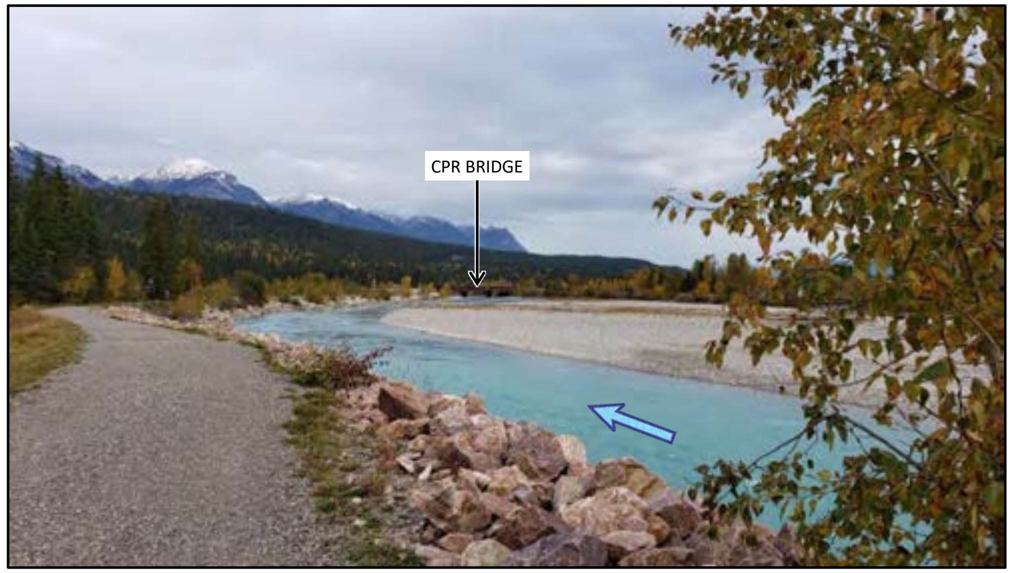


Photo 25 - September 29, 2019 (0+800): Taken from top of dike.

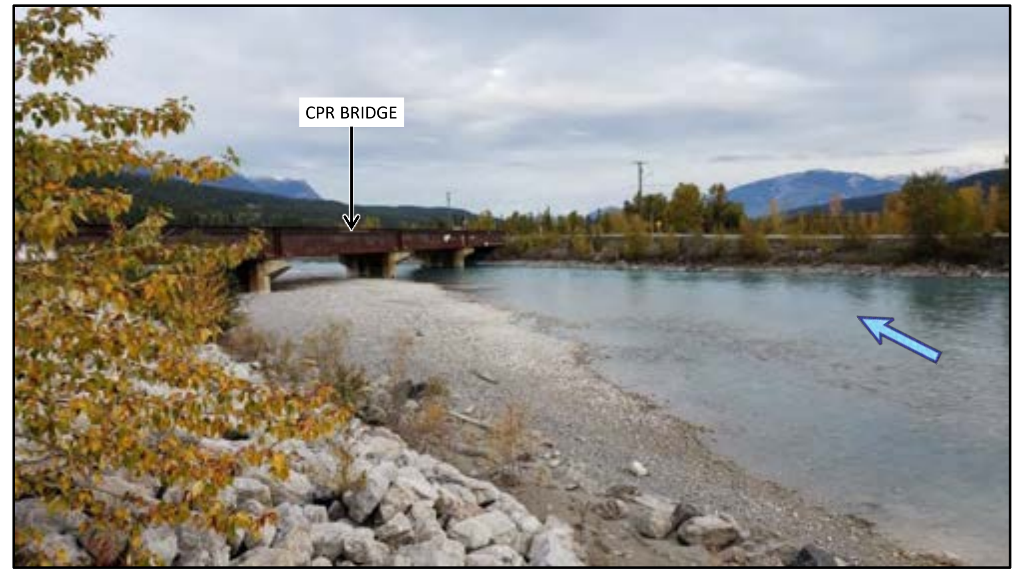


Photo 26 - September 29, 2019 (0+500): CPR Bridge.

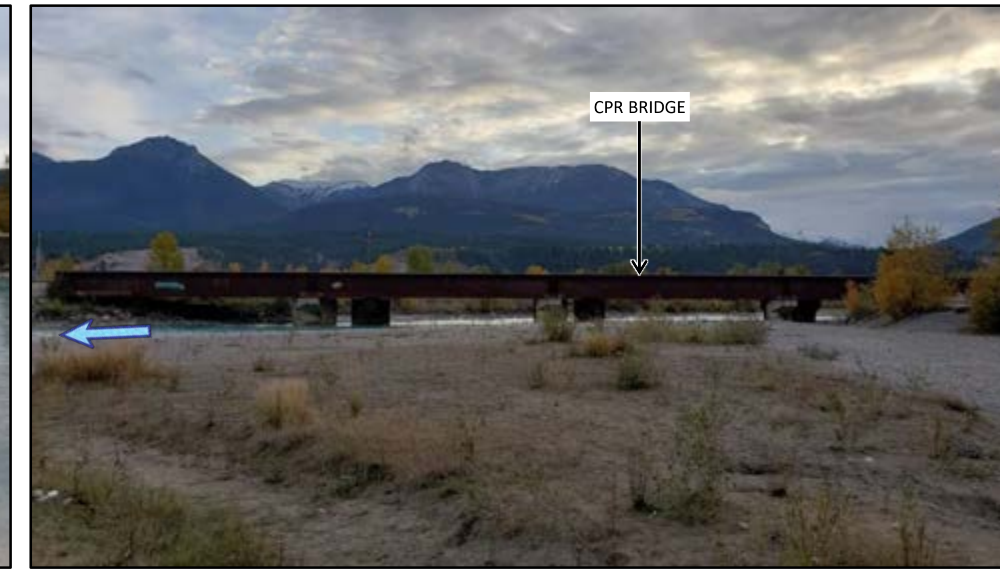


Photo 27 - September 27, 2019 (0+200): CPR Bridge.

Photo 28 - June 9, 2012 (2+100): Flood of 2012 (highest since 2007). Peak flow of 352 m^3/s was reported by the Water Survey of Canada, which occurred about 3 days before photo was taken (June 6). The Town installed barriers and water filled rubber dams to mitigate potential flooding of the historical downtown. Peak water level compared to the dike crest was observed by Town staff on June 6 and used to validate the hydraulic model.

Photo 29 – June 9, 2012 (2+192): Water level at Highway 95 bridge abutment during the flood of 2012 (highest since 2007). Peak water level occurred about 3 days before photo was taken.

Photo 30 - September 27, 2019 (0+200): Confluence of the Columbia River and the Kicking Horse River.

LEGEND

FLOW DIRECTION

REFERENCE: PHOTOS TAKEN DURING THE FALL 2019 SURVEY AND BY THE TOWN OF GOLDEN DURING THE 2012 FLOOD.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

KICKING HORSE RIVER PHOTOS

Date: FEBRUARY 2020	Project: 5635-KP	Submitter: E. JOHNSTON	Reviewer: D. KUSHNER

Figure D4

Photo 31 - September 28, 2019: Upstream of Highway 1 culvert.

Photo 32 - September 28, 2019: Highway 1 culvert.

Photo 33 - September 28, 2019: Highway 1 culvert.

Photo 34 - September 28, 2019: Highway 1 culvert.

Photo 35 - September 28, 2019: 14 Street culvert.

Photo 36 - September 28, 2019: 14 Street culvert.

LEGEND

FLOW DIRECTION

REFERENCE: PHOTOS TAKEN DURING THE FALL 2019 SURVEY AND BY THE TOWN OF GOLDEN DURING THE 2012 FLOOD.

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

HOSPITAL CREEK PHOTOS

Date: February 2020	Project: 5635-HP	Submitter: E. Johnston	Reviewer: D. Kushner

Figure D5

F:\5635\2019 Flood Study\Report\Appendix D\Site Photos HospitalCreek.pptx

Photo 37 - September 28, 2019: 14 Street culvert.

Photo 38 - September 28, 2019: Channel 300 m downstream of 14 Street culvert. In this area, Canadian Pacific Railway has dredged the channel and used the dredged material to construct training berms on both sides of the creek.

Photo 39 - September 28, 2019: Channel 300 m downstream of 14 Street culvert. In this area, Canadian Pacific Railway has dredged the channel and used to construct training berms on both sides of the creek.

Photo 40 - September 28, 2019: Channel 700 m downstream of 14 Street culvert.

Photo 41 - September 28, 2019: Anderson Road Bridge.

Photo 42 - September 28, 2019: Anderson Road Bridge.

LEGEND

FLOW DIRECTION

REFERENCE: PHOTOS TAKEN DURING THE FALL 2019 SURVEY AND BY THE TOWN OF GOLDEN DURING THE 2012 FLOOD.

F:\5635\2019 Flood Study\Report\Appendix D\Site Photos HospitalCreek.pptx

Matrix Solutions Inc.
ENVIRONMENT & ENGINEERING

TOWN OF GOLDEN
FLOOD STUDY

HOSPITAL CREEK PHOTOS

Date:	Project:	Submitter:	Reviewer:
February 2020	5635-HP	E. Johnston	D. Kushner

Figure
D6

Photo 43 - September 28, 2019: Hospital Creek Channel between Anderson Road bridge and CPR Bridge.

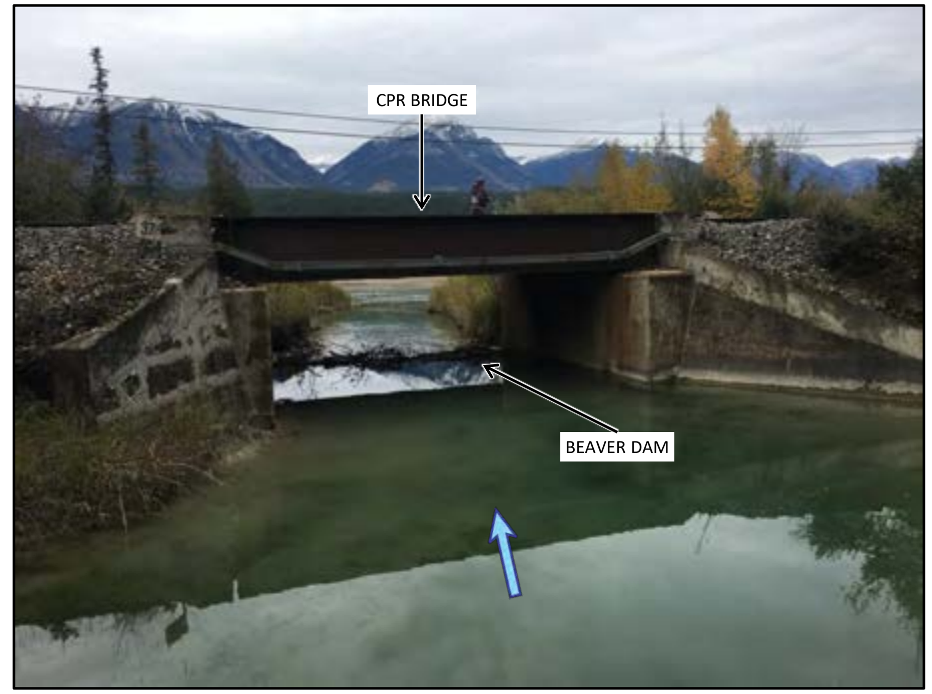


Photo 44 - October 28, 2019: CPR Bridge.

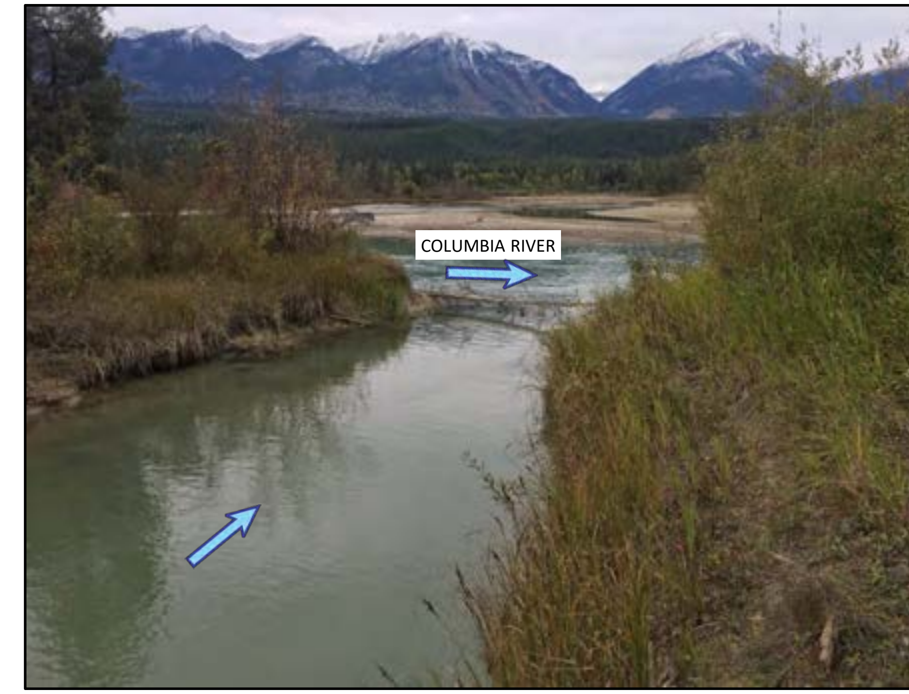


Photo 45 - October 4, 2019: Confluence of Hospital Creek and Columbia River.

Photo 46 - September 28, 2019: Measuring flow upstream of the 14 Street culvert with an Acoustic Doppler Velocimeter.

LEGEND

FLOW DIRECTION

REFERENCE: PHOTOS TAKEN DURING THE FALL 2019 SURVEY AND BY THE TOWN OF GOLDEN DURING THE 2012 FLOOD.

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FLOOD STUDY

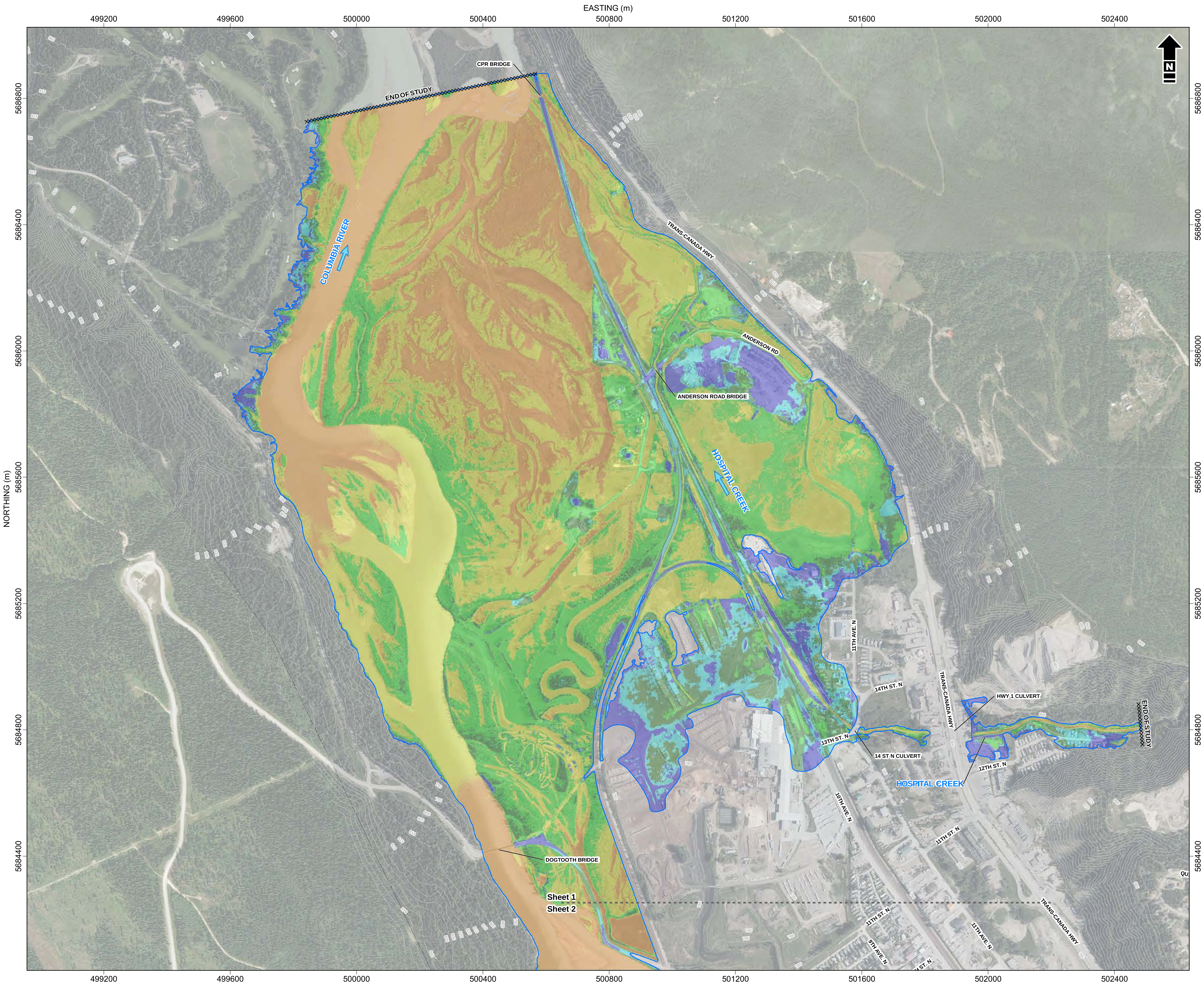
HOSPITAL CREEK PHOTOS

Date: February 2020	Project: 5635-HP	Submitter: E. Johnston	Reviewer: D. Kushner

Figure D7

F:\5635\2019 Flood Study\Report\Appendix D\Site Photos HospitalCreek.pptx

APPENDIX E
1:200-Year Flood Depth Maps



LEGEND

- FLOW DIRECTION
- CONTOUR INTERVAL (5 m; masl)
- STUDY LIMIT
- 1:200 YEAR FLOOD EXTENT (SEE NOTE 3)
- MATCHLINE

DEPTH (m)

- > 3.0
- 3.0 (or less)
- 2.0 (or less)
- 1.5 (or less)
- 1.0 (or less)
- 0.6 (or less)
- 0.3 (or less)

NOTES:

1. THIS MAPPING IS FOR INFORMATION ONLY AND IS INDENDED TO SHOW 1:200-YEAR FLOOD DEPTHS IN THE FLOODPLAIN AREAS. REFER TO THE FLOODPLAIN MAPS FOR 1:200-YEAR FLOOD LEVELS.

2. RIVER BATHYETRY IS NOT INCLUDED AND DEPTHS ARE CALCULATED USING THE 2019 LIDAR. DEPTH WITHIN THE COLUMBIA RIVER CHANNEL WOULD BE ABOUT 2 TO 5 m DEEPER THAN SHOWN. DEPTH WITHIN THE KICKING HORSE RIVER CHANNEL WOULD BE ABOUT 0.5 TO 1 m DEEPER THAN SHOWN. DEPTH WITHIN THE HOSPITAL CREEK CHANNEL WOULD BE 0 TO 0.5 m DEEPER THAN SHOWN .

3. FLOOD EXTENTS AND DEPTHS INCLUDE ALLOWANCE FOR 0.6 m FREEBOARD.

4. VERTICAL DATUM | CGVD2013

5. HORIZONTAL DATUM | NAD83

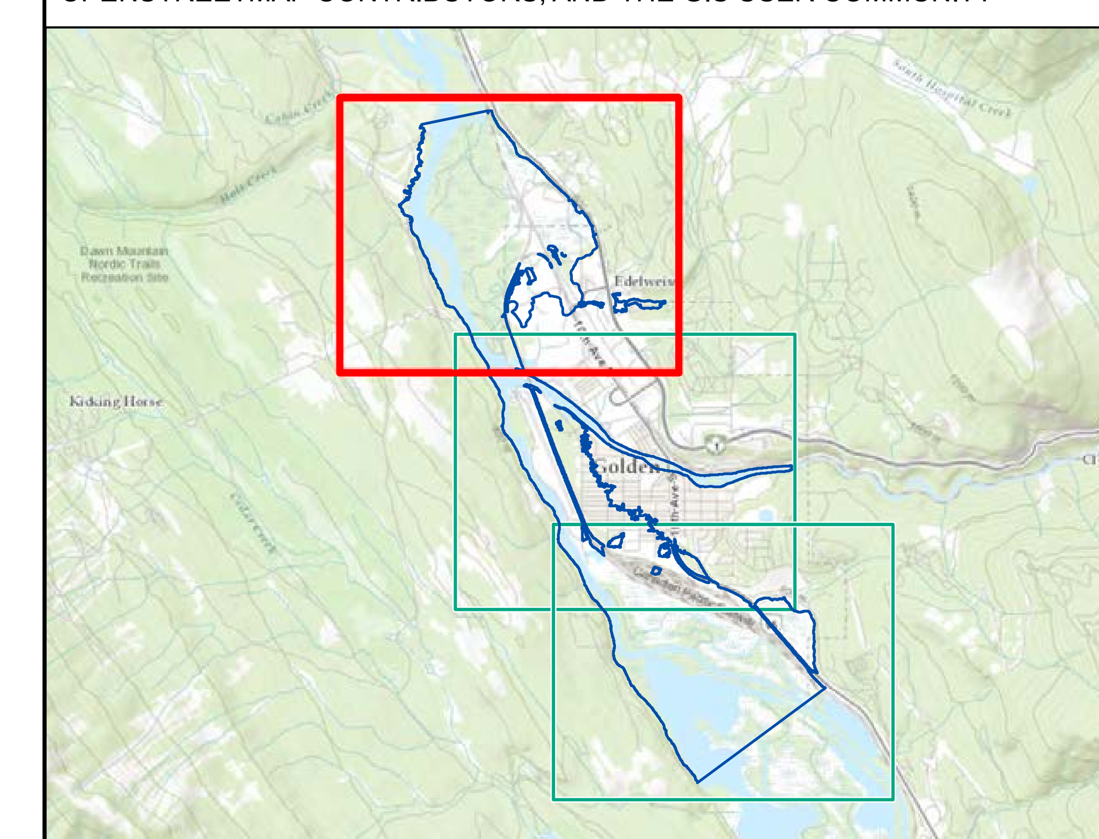
REFERENCES:

1. 2019 LIDAR ACQUIRED FROM AIRBORNE IMAGING USED UNDER LICENCE.

2. 2019 AIR PHOTO ACQUIRED FROM AIRBORNE IMAGING WITHIN 2019 LIDAR EXTENTS USED UNDER LICENCE.

3. FLOOD ANALYSIS AND HYDRAULIC MODELING SUMMARIZED IN "GOLDEN FLOOD STUDY AND MAPPING REPORT" MATRIX SOLUTIONS INC., MARCH 2020.

4. SERVICE LAYER CREDITS (AIR PHOTO OUTSIDE OF 2019 LIDAR EXTENT): SOURCE: ESRI, DIGITALGLOBE, GEOEYE, EARTHSTAR GEOGRAPHICS, CNES/AIRBUS DS, USDA, USGS, AEROGRID, IGN, AND THE GIS USER COMMUNITY\NSOURCES: ESRI, HERE, GARMIN, INTERMAP, INCREMENT P CORP., GEBCO, USGS, FAO, NPS, NRCAN, GEOBASE, IGN, KADASTER NL, ORDNANCE SURVEY, ESRI JAPAN, METI, ESRI CHINA (HONG KONG), (C) OPENSTREETMAP CONTRIBUTORS, AND THE GIS USER COMMUNITY



1:6,000 metres

150 0 150 300

NAD 1983 UTM ZONE 11N

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ENVIRONMENT & ENGINEERING

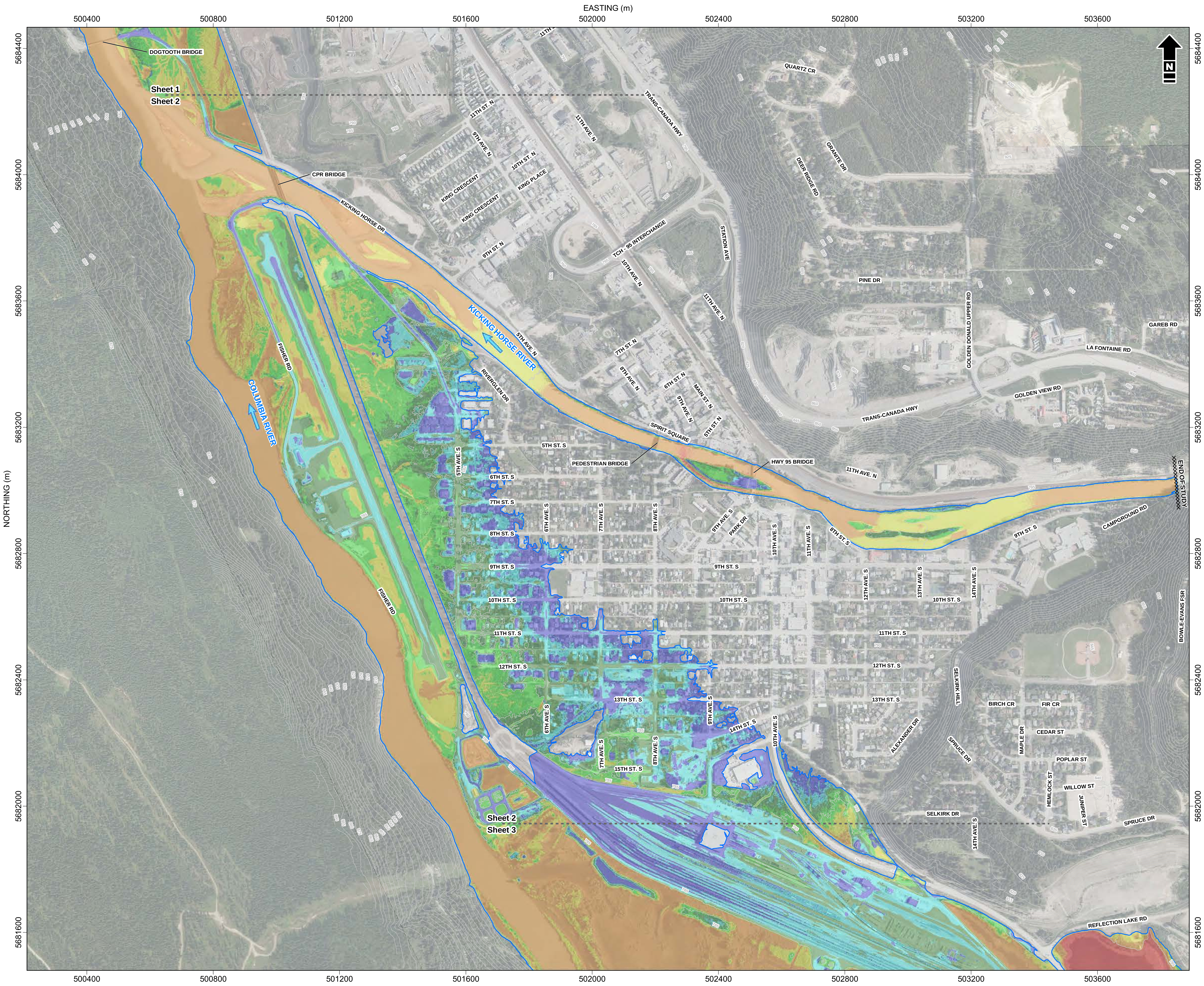
TOWN OF GOLDEN
FLOOD STUDY

1:200-YEAR FLOOD DEPTH MAP COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	E. JOHNSTON	D. KUSHNER

Appendix
E1

= 2 cm when printed on ANSI D - 22" x 34" (L)



LEGEND

FLOW DIRECTION

CONTOUR INTERVAL (5 m; masl)

STUDY LIMIT

1:200 YEAR FLOOD EXTENT (SEE NOTE 3)

MATCHLINE

DEPTH (m)

- > 3.0
- 3.0 (or less)
- 2.0 (or less)
- 1.5 (or less)
- 1.0 (or less)
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- 0.3 (or less)

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3. FLOOD EXTENTS AND DEPTHS INCLUDE ALLOWANCE FOR 0.6 m FREEBOARD.

4. VERTICAL DATUM | CGVD2013

5. HORIZONTAL DATUM | NAD83

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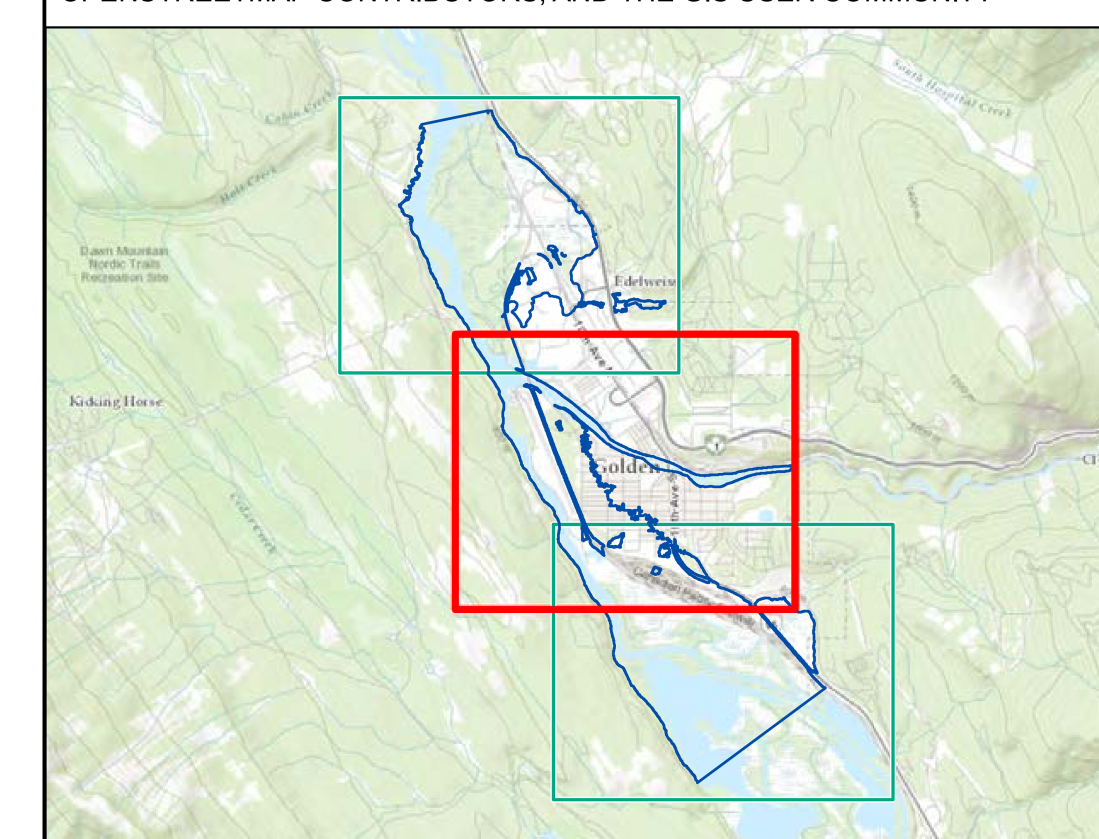

1:6,000 metres

150 0 150 300

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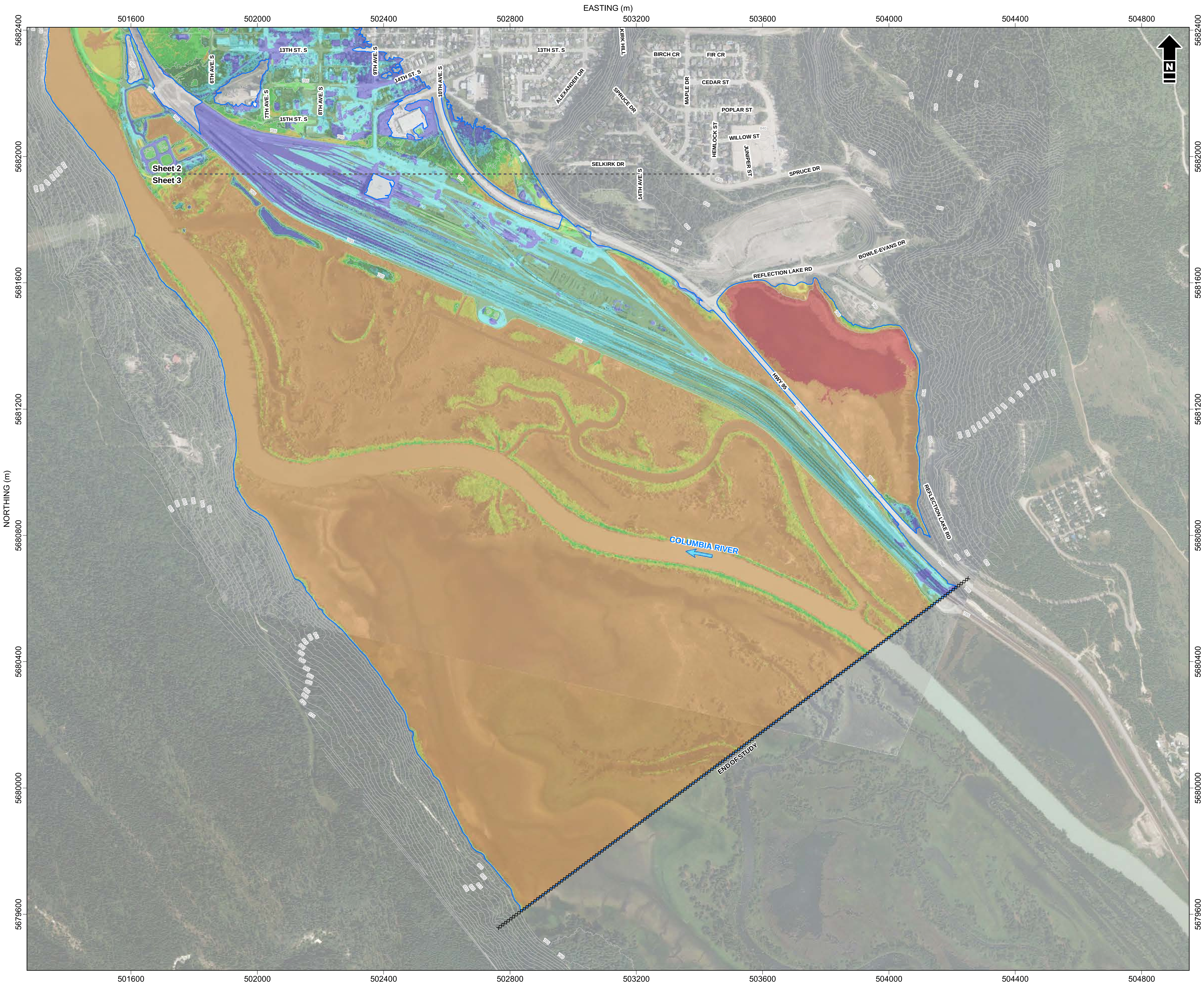
TOWN OF GOLDEN
FLOOD STUDY

1:200-YEAR FLOOD DEPTH MAP COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK

Date:	Project:	Submitter:	Reviewer:
MARCH 2020	5635	E. JOHNSTON	D. KUSHNER

Appendix E2

= 2 cm when printed on ANSI D - 22" x 34" (L)



LEGEND

FLOW DIRECTION

CONTOUR INTERVAL (5 m; masl)

STUDY LIMIT

1:200 YEAR FLOOD EXTENT (SEE NOTE 3)

MATCHLINE

DEPTH (m)

- > 3.0
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4. VERTICAL DATUM | CGVD2013

5. HORIZONTAL DATUM | NAD83

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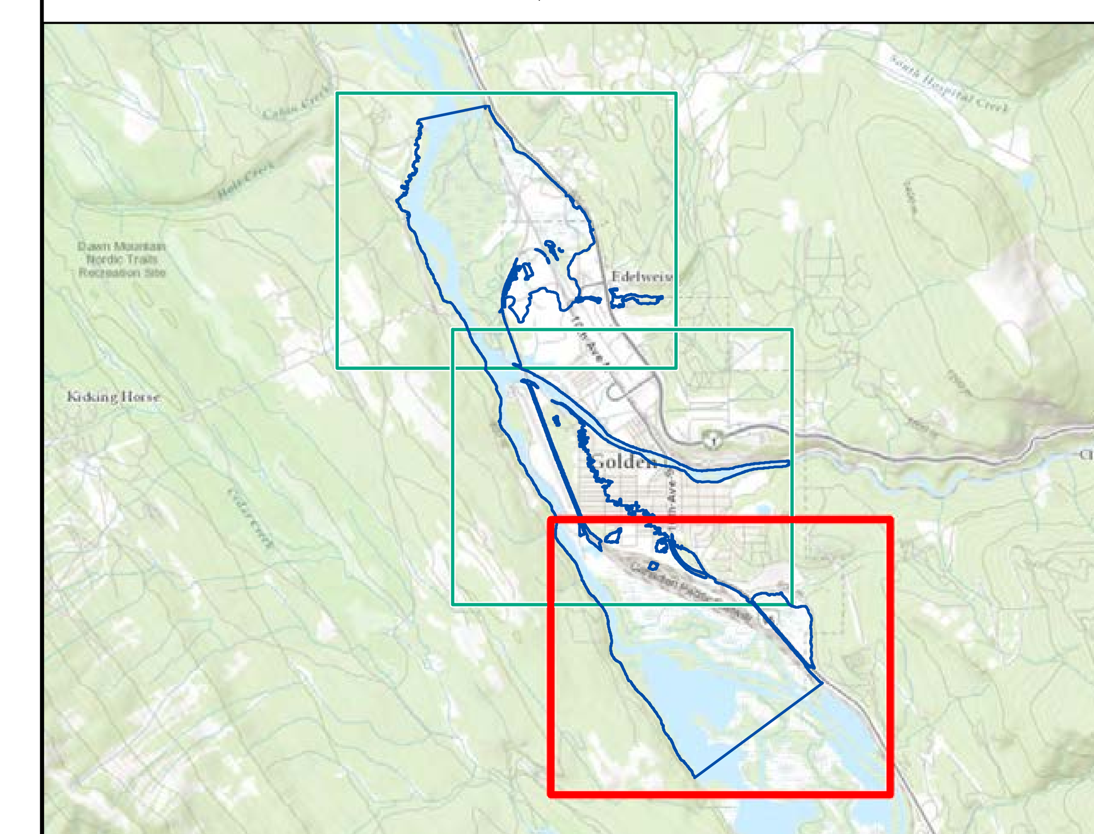

1:6,000 metres

150 0 150 300

NAD 1983 UTM ZONE 11N

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TOWN OF GOLDEN
FLOOD STUDY

1:200-YEAR FLOOD DEPTH MAP COLUMBIA RIVER, KICKING HORSE RIVER, AND HOSPITAL CREEK

Date: MARCH 2020	Project: 5635	Submitter: E. JOHNSTON	Reviewer: D. KUSHNER

Appendix E3

= 2 cm when printed on ANSI D - 22" x 34" (L)