# KICKING HORSE RIVER DIKE IMPROVEMENT PROJECT
# HYDROTECHNICAL DESIGN REPORT
TOWN OF GOLDEN, BRITISH COLUMBIA

Report Prepared for:
**THE TOWN OF GOLDEN**

Prepared by:
**MATRIX SOLUTIONS INC.**

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Calgary, Alberta

Suite 600, 214 - 11 Ave. SW
Calgary, AB T2R 0K1
T 403.237.0606 F 403.263.2493
www.matrix-solutions.com

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PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
D. N. KUSHNER
# 42649

**David Kushner, P.Eng.**
**Hydrotechnical Engineer**

October 19, 2018

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
K. CURTIS
# 41359

**reviewed by**

**Katy Curtis, P.Eng.**
**Senior Hydrotechnical Engineer**

October 19, 2018

**DISCLAIMER**

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# 1 INTRODUCTION

## 1.1 Project Scope

Matrix Solutions Inc. (Matrix) prepared this Hydrotechnical Design Report to support the Kicking Horse River Dike Improvement project (the Project) which is funded under the 2017 Union of BC Municipalities Strategic Priorities/Federal Gas Tax Fund. The works to be completed include dike improvements and raising, vegetation management, utility relocation, environmental protection and reclamation, and tenure of Crown land for the dike right-of-way. The funding agreement stipulates that construction of the dike improvement project is to be completed by July 1, 2021. Construction is planned to commence in the fall of 2019, pending receipt of all regulatory approvals and utility coordination.

This report provides hydrotechnical design input for the dike improvements and for the associated aquatic and vegetation components. The areas covered under this report are shown on Figure 1 and summarized as follows:

- constructing a concrete dike approximately 220 m long
- raising approximately 1,020 m of earthen dikes
- restoring approximately 300 m of bank armour that has eroded

The concrete dike and earthen dike raising areas will provide 0.6 m or 1.0 m freeboard above the 1:200 year open-water flood level (as shown on Figure 1). The dike upstream of the Highway 95 Bridge along the right bank is maintained by Canadian Pacific Railway (CPR) and is not considered herein for dike improvements.

## 1.2 Project Team

The Project Team consists of the following key consultants:

- Urban Systems Ltd. (USL) is the primary consultant responsible for overall project coordination, design, regulatory approvals, permits, construction management, and budget. USL is also responsible for the vegetation management, utilities relocation, and environmental protection and reclamation.

- Matrix is the hydrotechnical engineering consultant responsible for hydrotechnical input to the design and construction of the Project. Matrix is also providing vegetation management support as related to dike integrity and aquatic enhancements.

- Read Jones Christoffersen Ltd. (RJC) is the structural engineering consultant responsible for design of the concrete dike.

- MP&P Engineering (MP&P) - is the electrical engineering consultant responsible for the electrical design in the area of the concrete dike. Based on the available information it is understood that electrical and/or other utility work for the earthen dikes is not required.

## 1.3 Available Information

The hydrotechnical dike design in this report is based on the following information sources:

- Discharge (flow) and water level data from Water Survey of Canada (WSC) for the hydrometric station on the Kicking Horse River at Golden (Station 08NA006).

- River cross-section surveys that were repeated at the same locations every 100 to 300 m along the Kicking Horse River through the Town. Initial surveys were completed in 1975 with updates in 1987, 1997 (2), 1998, 1999, 2000, 2002 (2), 2005, 2006, 2007, 2008 (2), 2009, 2012, 2013 (2), 2015, and 2017.

- The ice jam hydraulic model developed for the 2018 ice jam study (Matrix 2018a). The ice jam model was based on the 2014 open-water model, uses the same geometry, and is considered to have a medium to low accuracy due to the lack of calibration data.

- The Kicking Horse River open-water hydraulic model that was initially prepared in 1999 by Hydroconsult EN3 Services Limited (Hydroconsult, now Matrix) and has been reviewed and updated several times since with new survey data (Hydroconsult 2004; Matrix 2014). The model extends 3.5 km from the Columbia River to upstream of the municipal campground. The current model is based on river cross-sections surveyed in 2012 and 2013. The model was not updated using 2017 data because it was estimated that there was minimal change in the 1:200 year flood levels (Matrix 2018b).

- The hydrologic review and flood frequency analysis completed as part of the 2004 flood risk assessment by Hydroconsult and confirmed in the 2014 update to the hydraulic model by Matrix.

- A detailed survey of the planned dike improvement areas were completed by WSP in 2018. The survey included the banks, the top of dikes, and the landside slope of the dikes. The 2018 survey included all of the proposed dike improvement areas. A less detailed survey of the entire length of the dike (including areas not surveyed in 2018) was completed in 2013 by Focus Surveys Ltd. A comparison of the surveys showed negligible changes in the dike crest elevations from 2013 to 2018.

- Numerous site visits and site photographs by Matrix (formerly Hydroconsult) from 1999 to present. Matrix has been involved in river engineering along the Kicking Horse River for over 20 years including design, construction supervision, and inspection of the dikes.

- Information contained within the *Kicking Horse River Flood Mitigation Works Operation and Maintenance Manual* (1998). Note that this manual is currently being updated by Matrix on behalf of the Town of Golden under separate cover.

# 2 BACKGROUND AND SITE CONDITIONS

## 2.1 River Basin and Flood Protection

The Kicking Horse River (the 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 of Golden (the Town) collecting numerous tributaries along the way (including the Yoho, Emerald, Amiskwi, Otterhead, Ottertail, and Beverfoot rivers), then flows another 3.5 km through the Town to its confluence with the Columbia River. Key characteristics of the River and basin are summarized in Table 1.

**TABLE 1 Characteristics of the Kicking Horse River and Basin**

| Parameter | Value | Reference/Source |
|---|---|---|
| BC Freshwater Atlas Watershed Code | 380 | B.C. MoE 2018 |
| WSC Station (located in Town) | 08NA006 | WSC 2018 |
| Drainage Area (DA) | 1,850 $km^2$ | WSC 2018 |
| River Length | 84 km | B.C. MoE 2018 |
| Maximum Basin Elevation | 3,472 m asl | Determined using terrain data and GIS software[1] |
| Average Basin Elevation | 1,938 m asl | |
| Minimum Basin Elevation (at the Columbia River Confluence) | 794 m asl | |
| Mean Annual Discharge (MAD) at WSC gauge | 41.5 $m^3/s$ | WSC 2018 |
| Regulated[2] | No | WSC 2018 |
| Glaciated Area | 85 $km^2$ (5%) | MFLRO 2018 |

1. Determined using Global Mapper Version 15.2 Software and ASTER GDEM Version 2 (METI and NASA 2011)
2. Where downstream flow are regulated by major storage such as a large dam
3. asl – above sea level

The Town is situated on the alluvial delta of the Kicking Horse River at its confluence with the Columbia River, upstream of the City of Revelstoke. Locations along the River are referred to herein as meters upstream of the Columbia River (0+000). The River exits from a narrow canyon to the east, flows through the Town and then flows into the Columbia River west of the Town. The Town is susceptible to both spring freshet (open-water) and ice jam induced flooding along the River. Armoured dikes have been built up along the River through the Town over the past century, primarily to contain open-water flood events, but also to protect the Town from ice jam events.

A 2014 hydraulic modeling report by Matrix concluded that in some areas the dikes did not meet the minimum 0.6 m freeboard above the 1:200 year water level as recommended by the Ministry of Water

Land and Air Protection of British Columbia (B.C. MWLAP 2003). In addition, Matrix recommended raising the dike to provide a 1.0 m freeboard in priority areas with high economic value (e.g., upstream of and along the Downtown) to account for variations and uncertainty due to sediment deposition, climate change, flood levels, and ice jam risks. Several areas identified by Matrix, the Town, and the dike inspectors are requiring armour restoration. A summary of the areas recommended for raising the dike and for bank armour restoration are shown on Figure 1.

In 2018, Matrix completed the first ice jam study for the River, which included an ice jam hydraulic model. The model indicated that severe ice jam levels could exceed the 1:200 year flood level by more than 1 m in certain areas. However, changes to the dike crest elevations were only recommended in areas where it is practical to do so, pending further data collection and analysis.

## 2.2 Flow and Water Level Monitoring

The Water Survey of Canada (WSC) has been monitoring the River water level and flow since 1974. The WSC gauge was originally located in the mouth of the canyon (3+500) and was relocated 400 m downstream of the Pedestrian Bridge at 1+500 in 2001. The old station was active from 1912 to 1922 and 1974 to 2001. Gauge locations are shown on Figure 1. WSC has reviewed and published daily records from 1974 to 2014. Preliminary records are available from 2014 to present but are subject to revision.

## 2.3 Open-water Flooding

Flooding on the River has historically occurred during the spring freshet, typically from March through June (see Figure 2). The record of annual maximum instantaneous and daily average flow recorded at the WSC station up to 2017[1] are also shown on Figure 2. The period of record consists of 35 years of instantaneous discharge and 54 years of daily discharge. When not available, maximum instantaneous flow is calculated by multiplying the maximum daily flow values by the average instantaneous to daily ratio (1.074 for flood flows from 1912 to 2002).

A 2004 report by Hydroconsult provided a review of other site-specific and regional flood studies, a review of historic flood events, and a flood frequency analysis. The 2004 report included a single station flood frequency analysis, a two station comparison frequency analysis, and an analysis based on the runoff depth approach as developed by Alberta Transportation. A 1:200 year instantaneous daily discharge of 570 $m^3/s$ was recommended for the design flood. This value was determined by using the upper 95% confidence limit of a Log Pearson Type III fit of the recorded maximum annual daily average discharge at the WSC station times the instantaneous to daily ratio (1.074). The flood frequency analysis was updated by Matrix in 2014 to include additional data from 2002 to 2004. However, the 2014 flood frequency analysis did not change the 1:200 year flood flow.

[1] 2014 to 2017 flows are based on unpublished data subject to revision

## 2.4 River Ice and Ice Jams

The river ice season typically extends from mid-November to late-March during which time flows are typically in the range of 4 to 12 $m^3/s$. Mid-winter[2] ice jam events are a common occurrence on the River through the Town and result in ice thicknesses and water levels that are much greater than those resulting from thermal ice cover[3]. Therefore, freeze-up ice jams represent the governing river ice condition for the Project. The Town experiences both brash[4] ice and frazil[5] ice jams, which can be very dynamic in nature.

The initial formation of an ice jam can result in a 2 to 2.5 m rise in water level in Town within a few hours and can exceed the 1:200 year open-water flood levels by more than 1.0 m in certain areas. Water levels then typically decrease by up to 0.5 m as the ice becomes consolidated and the underside becomes smoother. Warmer temperatures during spring break up cause the ice jam to release into the Columbia River where the ice is transported away from the Town. Spring break-up ice jams have not occurred on the River through the Town.

## 2.5 Sedimentation

The lower 1.3 km reach of the River (0+000 to 1+300) is susceptible to deposition of sediment that form gravel bars and generally raise the riverbed elevation. These gravel bars constrict the flow area causing an increase to open-water flood levels and may contribute to more frequent ice jamming.

The Town periodically dredges (or scalps) the gravel bars in order to maintain channel conveyance. Since 2003, the Town has had a sedimentation monitoring program that includes regular surveys of river cross-sections, assessments of the gravel bars, and recommendations of when bar scalping should be completed. The latest assessment was completed in 2018 (Matrix 2018b). Under this program, gravel bar scalping is recommended when a threshold level of 0.3 m cumulative average deposition (the average across all the gravel bars) is reached above the April 1997 conditions. This threshold was developed in 2003 (Hydroconsult) and has not been updated since. A pilot program to complete bar scalping and monitoring the effects on ice jams is being considered. This may lead to a different bar scalping threshold.

Historically, there have been minimal changes in the riverbed elevation and channel shape upstream of the Highway 95 Bridge (2+192).

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[2] Mid-winter ice jams refers to ice jams that occur before spring break-up.

[3] Thermal ice cover forms a solid ice cover, for example ice on a skating pond.

[4] Brash ice is the accumulation of floating ice made up of fragments; the wreckage of other forms of ice.

[5] Frazil is ice that forms in turbulent fast moving water that is slightly below freezing; it looks similar to ice shavings, has a slushy consistency, and tends to group together. Frazil ice formation occurs on nucleation sites (also called seed particles) usually consisting of impurities in the water such as tiny particles of dust, sediment, organic material, snow particles, frozen droplets from splashing, etc. Formation can also occur in pure water when water temperatures are -30 to -40 $^{\circ}C$ (which is understandably rare).

# 3 REGULATORY CRITERIA AND GUIDELINES

## 3.1 Hydrotechnical

Regulatory criteria and hydrotechnical guidelines for the dike design are summarized in Table 2.

**TABLE 2 Regulatory Criteria and Hydrotechnical Guidelines for Dike Design**

| Reference | Section | Hydrotechnical Design Criteria |
|---|---|---|
| *Dike Design and Construction Guide Best Management Practices for British Columbia* (B.C. MWLAP 2003) | 1.5 | • The standard **design flood** in British Columbia is the "designated flood" which means "a flood, which may occur in any given year, of such magnitude as to equal a flood having a **200 year recurrence period** interval, based on a frequency analysis of unregulated historic flood records or by regional analysis where there is inadequate streamflow data available. |
| | 2.8.9 | • The current standard **crest width of 4.0 m** has now been adopted.<br>• The crest of the dike shall be sloped or cambered to promote drainage and minimize surface ponding. |
| | 2.9.7 | • The standard for river dike crest elevation is the higher of 1 in 200 year instantaneous flow plus 0.3 m freeboard, or the 1 in 200 year maximum daily flow plus **0.6 m freeboard**. |
| *Riprap Design and Construction Guide* (B.C. MELP 2000) | 4.7 | • Rock dimensions may be successfully designed to resist failure based on local experience, empirical guidelines, or hydraulic relationships that predict stable riprap sizes, based on bank slope and stream characteristics. |
| | 4.9 | • Riprap thickness normal to the slope should meet the following criteria:<br>• not less than 350 mm<br>• not less than 1.5 × $D_{50}$<br>• not less than a $D_{100}$ |
| | 4.10 | • **The design (riprap) bank slope should not be steeper than 2H:1V**, except in special circumstances. Further limits on side slope steepness may be imposed by slope instability, groundwater flows, or rapid water level recession and piping failure, all of which should be carefully considered in slope design. |

## 3.2 Construction Timing

Habitat officers are designated under the BC Water Sustainability Regulation (BC Regulation 36/2016) and have the authority to set terms and conditions for changes (i.e. construction) in and about a stream. Habitat officers have published guidance on instream construction timing, called periods of least risk for instream works, to minimize any risk to fish and wildlife species. Based on Bull Trout, Rainbow Trout, Kokanee, Mountain Whitefish, and Brook Trout observations (B.C. MoE 2018), the regional period of least risk for instream works for the Project area is July 16 to August 31 (B.C. MoE 2009). Instream construction can still occur outside of this window but requires recommendations from a qualified aquatic professional and may require other additional analysis or mitigate measures to gain regulatory approval. The construction season and associated water levels are further discussed in Section 5.1.

## 3.3 Vegetation Management

Guidelines for vegetation management of the River were developed in a 2014 Vegetation Management Plan by Carolla Environmental Consulting (Carolla 2014). The plan provides site-specific prescriptions for vegetation management with the goal of balancing the biological functions with meeting regulatory requirements and the requirements of dike inspection needs and dike integrity. The plan calls for removal of large trees from the dikes that pose a risk to the dike integrity.

General guidelines regarding extent of vegetation that should be permitted to grow on dikes have been published by the Ministry of Environment, Lands and Parks and Fisheries and Oceans (MOE and DFO) in 1999.

# 4 HYDROTECHNICAL DESIGN

## 4.1 Open-water Design Flow, Water Level, and Freeboard

The flood frequency analysis was updated for this study with peak flow information up to 2017 as shown on Figure 2. This analysis generated the same 1:200 year flood flow magnitude compared to previous estimates, but with increased flood flow magnitudes for more frequent return periods. The 1:200 year open-water design flow is 570 $m^3/s$.

For the purposes of the Project, the measurement of freeboard is the vertical distance from the dike crest elevation to the estimated 1:200 year water level based on the 2014 hydraulic model. The 1:200 year water level is shown on Figure 3 together with the 2013 and 2018 top of dike surveys. Figure 4 shows the existing and proposed dike freeboard and identifies areas where 0.6 m or 1.0 m freeboard is proposed. The right bank upstream of the Highway 95 Bridge was raised by CPR in 2014, but this area has not been surveyed following these changes (location is noted on the figures).

## 4.2 Ice Level and Ice Freeboard

The ice jam study (Matrix 2018a) included the development of a hydraulic ice jam model and was used to model the ice jam of record (winter of 2004/05). The model was calibrated to observed ice levels at the WSC gauge (water level measured by WSC) and at the Highway 95 Bridge (visually observed at the lower bridge chord elevation).

The 2018 ice jam study also included a preliminary ice jam level frequency analysis using maximum winter stage (maximum winter water level) recorded at the WSC station. The 1:200 year ice stage at the WSC gauge was estimated at 0.5 m above the jam of record based on this frequency analysis. Figure 5 shows the winter stage frequency analysis, history of ice stages recorded at the WSC gauge and images of historical ice jams.

Where it is practical to do so, a design ice level is recommended for the Project equal to the estimated ice jam of record plus 0.5 m of freeboard (roughly equivalent to the preliminary 1:200 year ice jam level estimate). The estimated design ice jam and ice freeboard are shown on Figure 6. Ice jam levels were not included as a design criterion in the Project funding application. Additional dike raises for ice conditions is considered beyond the scope of this Project.

The proposed concrete dike section represents the most costly portion of the project and provides protection to the highest value portion of the Town (the historic downtown). Fortunately, there is a higher level of confidence in the ice jam model in this area (between the two ice level calibration points) and the proposed concrete dike crest is 0.8 m above the ice jam of record (satisfying the ice level freeboard). The majority of the proposed earthen dike crests are above the ice jam of record; with the exception being the left bank from approximately 2+300 to 2+900, upstream of Highway 95 to near the secondary school.

Additional dike raises are not recommended at this time for the following reasons:

- The left bank area (2+300 to 2+900) is heavily constrained by nearby development and additional dike raises are not practical.
- Only limited calibration information was available for the hydraulic model and the results are considered to have a medium to high uncertainty; whereas, the dikes have largely contained ice jam water levels in the past. When overtopping has occurred it has been localized, brief (less than 1 hour), and resulted in relatively minor consequences (ponding and seepage).
- The underside of the ice jam is expected to be well below the dike crest elevations (1.5 to 2.0 m below), which would prevent excessive flow over the dikes as water has to percolate through the ice.
- Additional dike raises for ice conditions are outside the scope of this Project.

## 4.3 Ice Loading

Ice loading parameters have been estimated based on the ice jam model results and the Canadian Highway Bridge Design Code (CHBDC) CSA S6-14. Table 3 summarizes the estimated, potential ice loading parameters on the concrete dike section. Ice considerations for the earthen dikes are discussed in Section 4.5 with respect to the riprap design. The governing design ice condition is a brash ice jam during extreme cold conditions. Frazil ice jams can also occur at similar stages and thicknesses; however, frazil ice has a very low internal strength. A detailed profile of the ice jam model is shown on Figure 6.

**TABLE 3 Concrete Dike Ice Loading Parameters**

| Ice Conditions | Thickness | Elevation | Strength | Velocity |
|---|---|---|---|---|
| Brash Ice Jam | Up to 3 m | From an elevation of 787.63 m at station 2+200 to 787.28 m at station 1+840. | Very high internal strength. Brash ice jams have at times occurred during extreme cold weather. The highest strength CHBDC value of 1,500 kPa is recommended. | Less than 1.5 m/s at an angle less than $10^{\circ}$ to the face of the proposed concrete wall. |

## 4.4 Bank Design

### 4.4.1 Bank Slope

Where possible, the earthen dike banks should be constructed with 2H:1V slopes and the banks should intrude into the River as little as possible so as not to increase flood water levels. Examples of some exceptions include:

- Where there are significant space constraints other measures may be considered such as 1.5H:1V bank slopes or cut stone that can be stacked near-vertical for the upper 0.3 to 0.6 m (within the freeboard area).

- Where there are significant space constraints and/or local erosion has over-steepened and widened the channel, the banks may be extended into the River. A hydraulic assessment of these areas will be completed to ensure that there are minimal or negligible effects to the design 1:200 year water level.

Since the proposed dike raises are only adding to the freeboard, there is no change to the hydraulic forces on the dikes. Therefore, it is not considered a requirement that a geotechnical assessment of dike stability be completed provided the dikes can be constructed with a minimum 1.5H:1V bank slope and 2H:1V landside slope.

### 4.4.2 Rock Armour (Riprap)

Class II riprap (500 mm nominal diameter) rock has been used to armour the banks and dikes along the River. Class II riprap is an outdated specification which was revised in 2012 (MOTH 1999 revised to MOTI 2012). The most similar riprap class is now referred to as the 250 kg class, which has a slightly larger nominal diameter of 565 mm (the median diameter). Therefore 250 kg class riprap will be used for this Project to conform to the latest provincial specifications.

The existing riprap has generally performed well both in open-water and ice jam conditions, and has required minimal maintenance (based on annual dike inspection records, available since 2009, and Town records).

As a check, the minimum riprap size was calculated using an empirical method developed by the US Army Corps of Engineers (USACE 1991) and recommended in the MELP riprap design and construction guide (2000). Based on this method, Class II riprap (and 250 kg class) is acceptable up to the 1:200 year flood for the dike improvement areas except for about 200 m along the left bank (approximately 1+400 to 1+600, currently armoured with Class II). If bank erosion issues are experienced in this area in the future, replacing the riprap to a 500 kg class ($D_{50}$ = 715 mm) should be evaluated. Upgrading of the riprap in this area with a larger class is not recommended at this time based on the following rational.

- This area is already armoured with Class II riprap and the scope of work is currently limited to raising the dike only. It would be beyond the scope of this Project to replace the riprap at this time.
- No significant maintenance or erosional issues have been noted here in the past.
- The existing Class II riprap is acceptable up to and including the 1:50 year flood using the USACE 1991 method.
- The existing armour was observed to be in good condition during a June 2018 site visit by Matrix.
- Replacement of the riprap would result in larger construction impacts than the proposed dike raising works in this area.

The bank protection may require some maintenance depending upon the degree and frequency of exposure to high flows and velocities.

### 4.4.3 Filter Bedding

A filter bedding layer is a layer of material placed between the riprap and the underlying soil surface to prevent loss of the soil through the riprap while continuing to allow for water pressure to drain through the filter. Filters typically consist of a layer of granular material or a non-woven geotextile. Filters are required when the underlying soil surface contains small particle sizes compared to large riprap rock sizes.

### 4.4.4 Riprap Apron

A riprap apron is included at the toe of the bank. This apron is designed to self-adjust as scour occurs at the toe of the bank, falling into and armouring the scour hole. A 3 m long (perpendicular to flow) by 1.5 m high apron is recommended based on 20 years of observed scour shown in various survey cross sections (Matrix 2018b). Large boulders will also be placed at the toe for additional scour protection and fish habitat enhancement. Similar launching aprons have successfully been used in the past on the River in Golden.

### 4.4.5 Vegetation and Bio-engineering

Bio-engineering features are incorporated into the dike design. These features are designed based on the River vegetation management plan (Carolla 2014). Bio-engineering features are expected to provide the following benefits:

- improved riparian, aquatic and terrestrial ecosystems
- reduced dike maintenance and improved erosion resistance and sustainability
- improved aesthetics of the River and Town

Some commonly used bio-engineering techniques that were considered for the Project are:

- Vegetation and live staking of the bank to improve dike stability, increase erosion resistance and reduce the growth of vegetation that negatively impacts the dike stability (e.g. cottonwoods). Note that dike vegetation management has already been recommended in Carolla's 2014 report, including removal of certain tree species that are known to negatively impact the dikes. Large trees that contribute to dike stability were not recommended for removal pending review by an engineer. In locations where large, mature trees are removed, the void will be replaced with a combination of riprap and plantings. These specific trees and other large trees should be reviewed with an engineer and the Town on a case-by-case basis. Trees that are located in the River (i.e., at the toe of the bank) may not need to be removed.

- Planting of live stakes in bank armour to improve erosion resistance and improve aquatic habitat.

- Installation of non-linear bank armour (at the toe) to create habitat variability and resting locations for fish.

- Inclusion of other fish-enhancement techniques such as the placement of larger rocks near the toe to create boulder clusters which provide additional habitat variability and resting locations for fish. These large rocks also contribute to erosion and scour resistance.

Some techniques are not considered appropriate for the River as they would present hazards to the public and negatively impact dike stability and erosion resistance. These include locked logs, root wads, log cribs and other techniques that involve large woody debris that pose a safety hazard to users of the River and may contribute to a debris jam.

Large trees that pose a risk to the dike integrity should be removed. Trees to be removed will be identified by qualified professionals and in consultation with the Town and the hydrotechnical engineer. Tree removal shall be completed by qualified professionals and in consultation with the hydrotechnical engineer to ensure dike armoring and dike integrity are not compromised during tree removal (or adequately repaired afterwards).

# 5 CONSTRUCTION CONDITIONS

## 5.1 Open-water

Where practical, instream construction will be limited to the period of least risk for instream works: July 16 to August 31. However, due to water and ice levels throughout the year, instream construction may be required in other months. As an aid to construction planning, mean monthly water levels for open water conditions are shown on Figure 3. Figure 7 shows river discharge rating curves near the dike improvement areas. A table of flow and water levels is included on Figure 7.

Low flow and ice-free conditions are advantageous for construction and typically occur from September to mid-November and in April (see Figure 4). Note that the river ice season can vary significantly from year to year and largely depends on air temperatures. Freeze-up has occurred as early as October 23 and as late as December 18. Break-up has occurred as early as February 11 and as late as April 27 (Matrix 2018a). Figure 2 shows hydrographs for the daily median, maximum, minimum, and quartile flows (the 25% and 75% percentile). Figure 2 includes a table of (minimum, mean, and maximum) monthly flow characteristics, and shows the river ice season and the least risk instream timing window (B.C. MoE 2009).

## 5.2 Ice Jams During Construction

Ice jams result in highly variable water levels and are highly unpredictable. Ice jams normally form near the confluence of the Kicking Horse and Columbia rivers but do not always extend upstream through the entire Town. There is currently not enough information on ice jams to estimate the probability (or return period) of the extent of ice jams in a given year.

The River also experiences ice jams (dynamic flood waves of ice and water) that can result in temporary high ice levels at any location for several hours. Therefore, for the purposes of construction planning it is assumed that an ice jam could extend through the entire town in any given year. Table 4 shows the estimated ice levels and return periods for construction, using preliminary ice stage frequency analysis at the WSC gauge, and relative to the estimated ice jam of record.

Construction activities for the concrete dike may extend into the winter, but it is understood that construction of the earthen dike improvements will not.

**TABLE 4 Estimated Construction Ice Jam Levels and Return Periods**

| Return Period (Years) | Ice Stage at the WSC Gauge[1] (m) | Difference from Ice Jam of Record (2005) (m)[2] |
|---|---|---|
| Typical Winter Open-water Level | - | -3.3 |
| 2 | 4.4 | -0.9 |
| 5 | 4.9 | -0.5 |
| 10 | 5.1 | -0.3 |
| 20 | 5.3 | -0.1 |
| **30 (Ice Jam of Record)** | **5.4** | **0.0** |
| 50 | 5.5 | 0.2 |
| 100 | 5.7 | 0.3 |
| **200** | **5.8** | **0.5** |

1. As per the ice stage frequency analysis (Figure 5). Ice elevations can be estimated by increasing or decreasing the profile of the ice jam of record by the difference in stage (3rd column; Note 2).
2. For example this means that the typical winter open-water level is 3.3 m lower than the ice jam of record.

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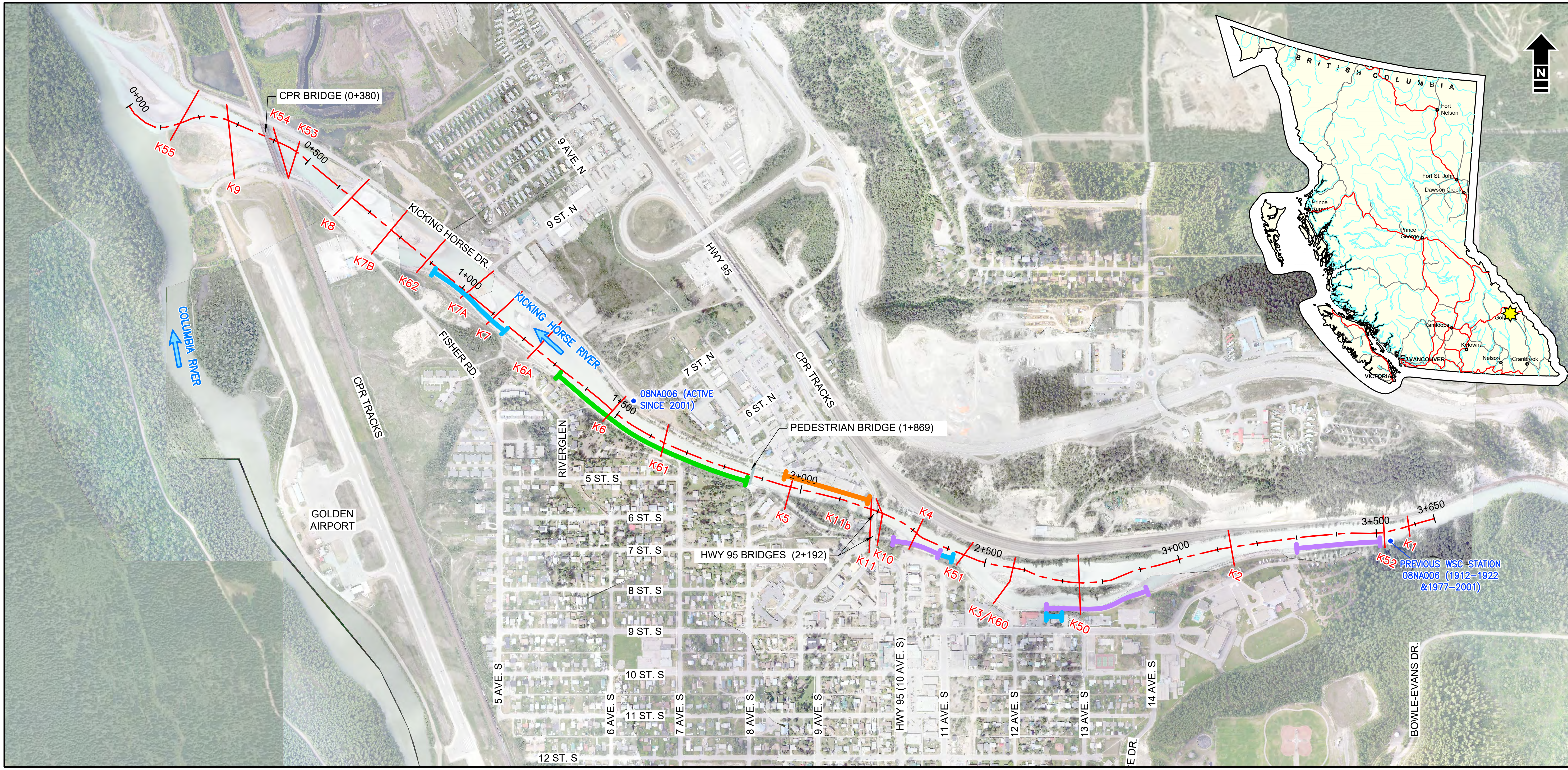



**LEGEND**

1+500 — KICKING HORSE RIVER CHAINAGE, MEASURED FROM 0+000 AT CONFLUENCE WITH COLUMBIA RIVER AND BASED ON CURRENT RIVER ALIGNMENT

K8 — SURVEYED CROSS-SECTION

WATER SURVEY OF CANADA (WSC) STATION

**PROPOSED DIKE IMPROVEMENTS**

RAISING EARTH DIKE TO PROVIDE 0.6 m FREEBOARD, 540 m

RAISING EARTH DIKE TO PROVIDE 1.0 m FREEBOARD, 475 m

CONSTRUCTING CONCRETE WALL TO PROVIDE 1.0m FREEBOARD, 220 m

ARMOURING, 305 m
AS REQUIRED, ADDITIONAL ARMOURING WILL ALSO BE COMPLETED AT THE DIKE RAISING LOCATIONS.

1 : 10,000 metres
100 0 100 200
UTM83-11

REFERENCE: ORTHOPHOTO PROVIDED BY THE TOWN OF GOLDEN DATED 2008, 2013 AND AERIAL IMAGERY FROM WORLD IMAGERY.
ICE JAM FREEBOARD AREAS FROM KICKING HORSE RIVER ICE JAM STUDY, MATRIX 2018.
0.6 m AND 1.0 m FREEBOARD AREAS AS PER FIGURES 6 AND 7 OF THE KICKING HORSE RIVER HYDRAULIC MODEL (REV 2), MATRIX 2014.
CROSS-SECTIONS MOST RECENTLY SURVEYED IN OCTOBER 2017 BY WSP GLOBAL INC.

Note: Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

TOWN OF GOLDEN - KICKING HORSE RIVER
DIKE IMPROVEMENT PROJECT HYDROTECHNICAL DESIGN REPORT

## OVERALL PLAN OF PROPOSED DIKE IMPROVEMENT AREAS

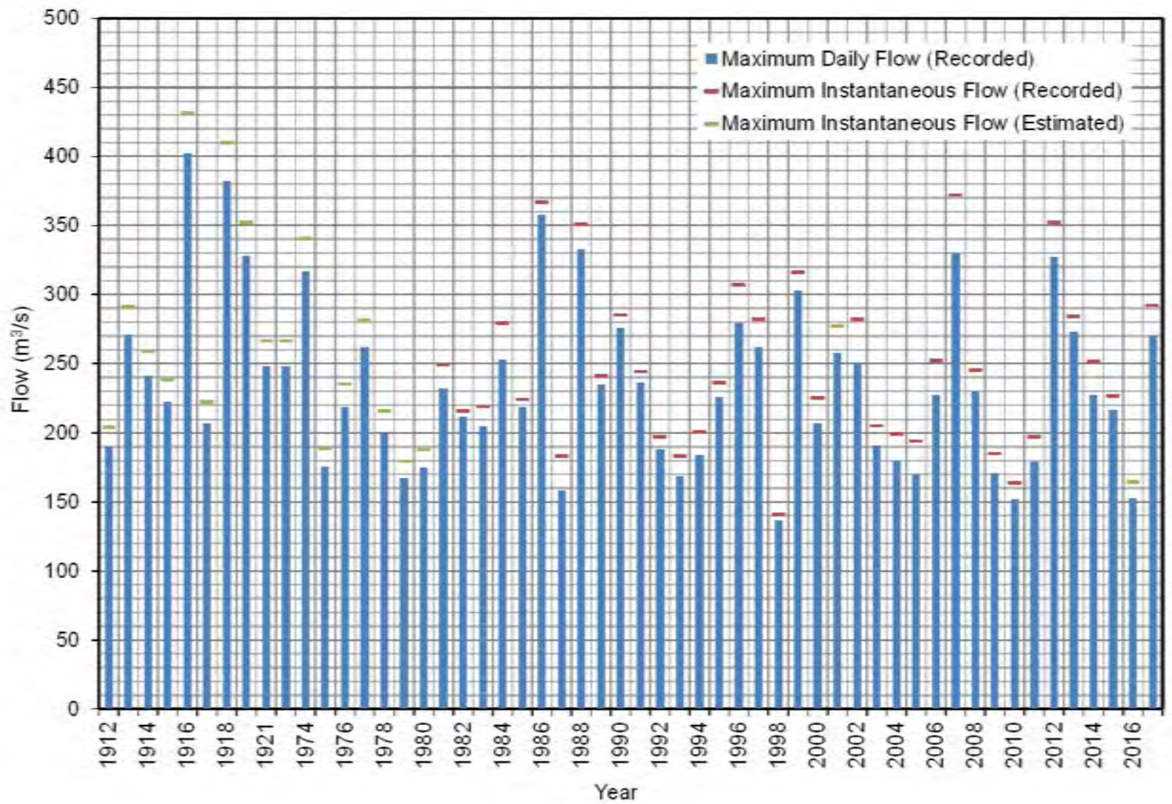
| Date: | Project: | Submitter: | Reviewer: |
| --- | --- | --- | --- |
| AUGUST 2018 | 5635-DIHD | D. KUSHNER | K. CURTIS |



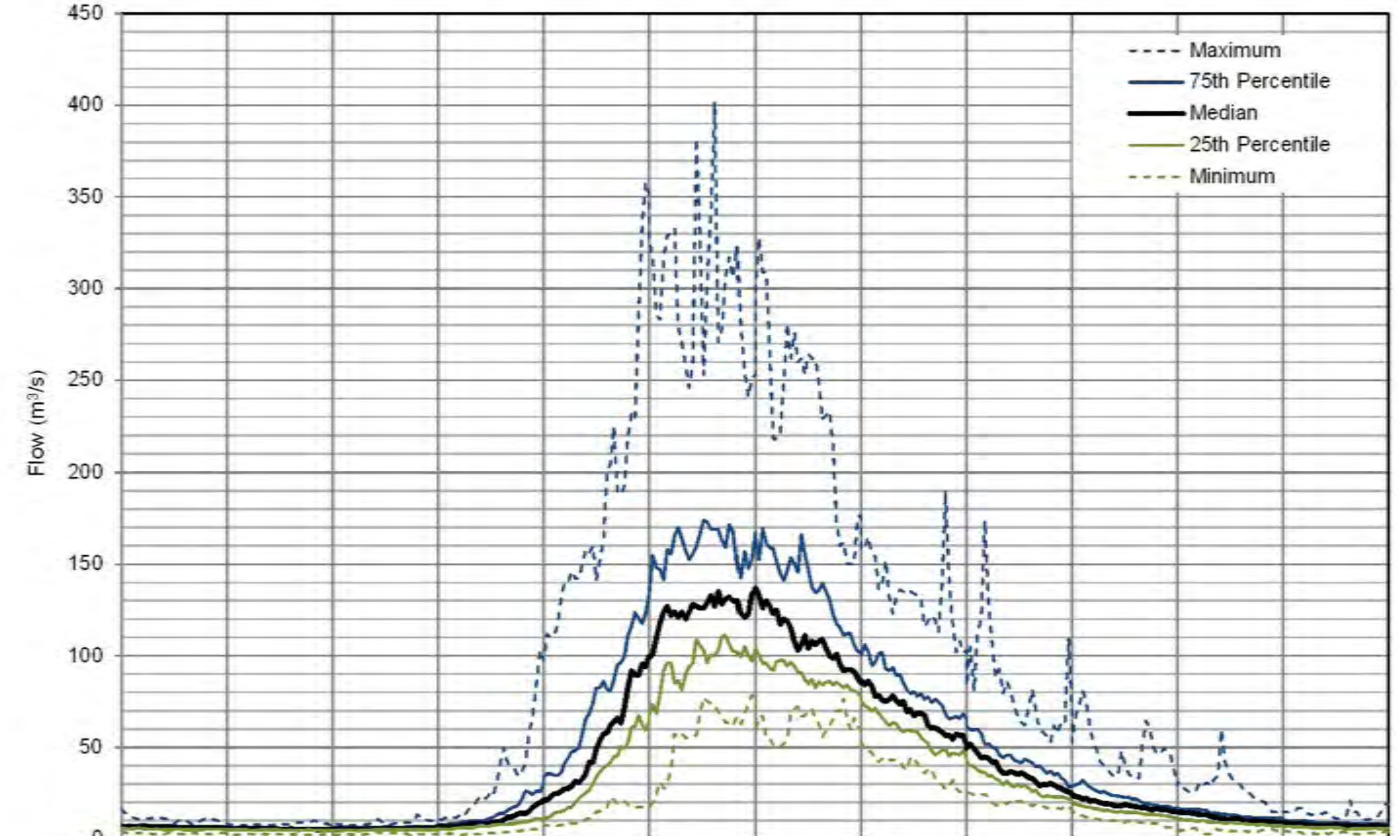
Figure 1

## ANNUAL MAXIMUM DAILY AND MAXIMUM INSTANTANEOUS FLOWS (1912-1918, 1920-1922, & 1974-2017)

(SEE NOTE 2)




## ANNUAL HYDROGRAPHS




| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Min. Monthly[6] Flow | 3 | 3 | 3 | 4 | 20 | 80 | 74 | 48 | 25 | 9 | 6 | 4 |
| Mean Monthly[6] Flow | 6 | 5 | 6 | 12 | 61 | 133 | 117 | 72 | 39 | 20 | 12 | 8 |
| Max. Monthly[6] Flow | 9 | 8 | 9 | 24 | 119 | 199 | 228 | 112 | 75 | 38 | 22 | 11 |

TYPICAL RIVER ICE SEASON (ICE JAM POTENTIAL) TO EARLY-APRIL

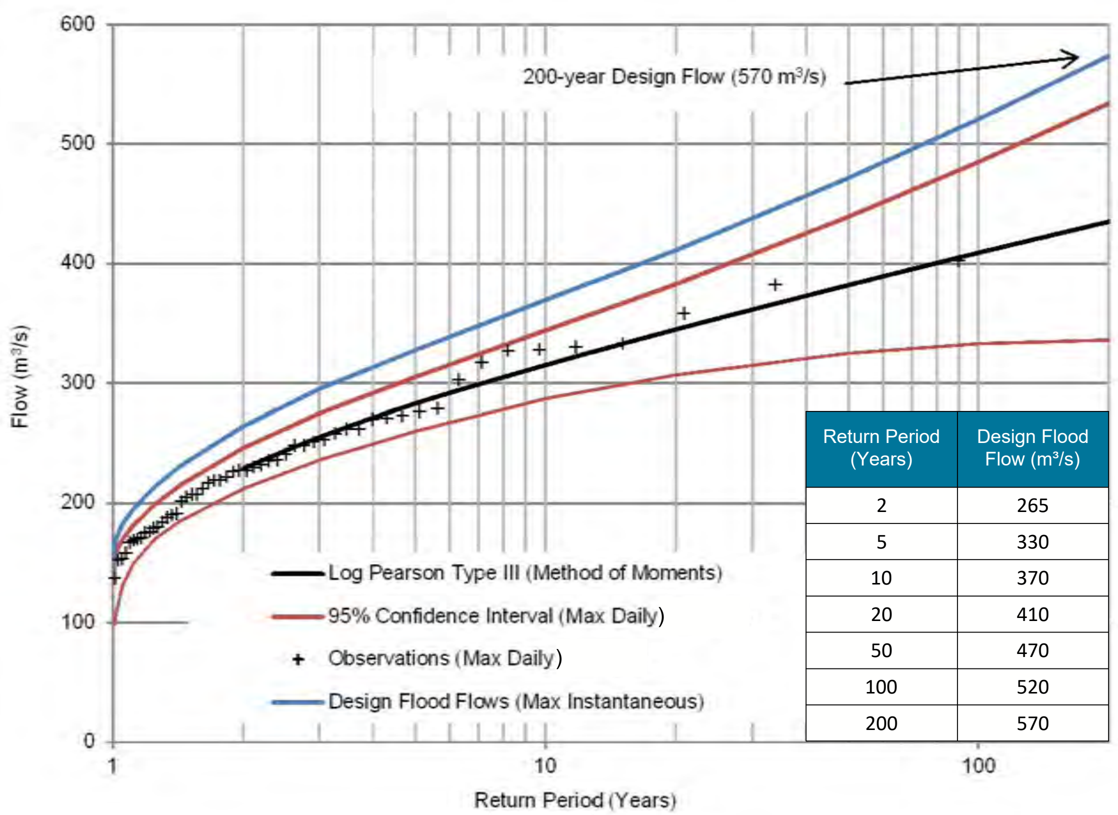
FROM MID-NOV

SEE FIGURE 5 FOR ICE CONDITIONS

PERIOD OF LEAST RISK FOR INSTREAM WORKS JULY 16 TO AUG 31 (SEE NOTE 4)

## FLOOD FREQUENCY ANALYSIS

(SEE NOTE 3)




| Return Period (Years) | Design Flood Flow (m³/s) |
|---|---|
| 2 | 265 |
| 5 | 330 |
| 10 | 370 |
| 20 | 410 |
| 50 | 470 |
| 100 | 520 |
| 200 | 570 |

NOTES:

1. FLOWS TAKEN FROM THE WATER SURVEY OF CANADA (WSC) RECORDS FOR STATION 08NA006 (KICKING HORSE RIVER AT GOLDEN). PUBLISHED RECORDS AVAILABLE FOR 1912 TO 1922 AND 1974 to 2014. PRELIMINARY RECORDS (SUBJECT TO REVISION) ARE AVAILABLE FROM 2014 TO PRESENT.
2. WHEN NOT AVAILABLE, MAXIMUM INSTANTANEOUS FLOWS WERE ESTIMATED FROM DAILY AVERAGE FLOW BY APPLYING THE AVERAGE RATIO OF MAXIMUM INSTANTANEOUS TO DAILY AVERAGE FLOW (1.074).
3. FLOWS ARE EQUAL TO THE UPPER 95% CONFIDENCE LIMIT OF THE FLOOD FREQUENCY ANALYSIS TIMES THE AVERAGE MAXIMUM INSTANTANEOUS TO MAXIMUM DAILY FLOW (1.074).
4. REFERENCE: KOOTENAY REGION (REGION 4) PERIODS OF LEAST RISK FOR INSTREAM WORKS BY FISH SPECIES, MINISTRY OF ENVIRONMENT OF BRITISH COLUMBIA, 2009.
5. SEE RATING CURVES ON FIGURE 7 FOR WATER LEVELS.
6. MONTHLY FLOW IS THE AVERAGE OF THE DAILY FLOWS WITHIN THAT MONTH FOR A GIVEN YEAR.

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Matrix Solutions Inc. ENVIRONMENT & ENGINEERING

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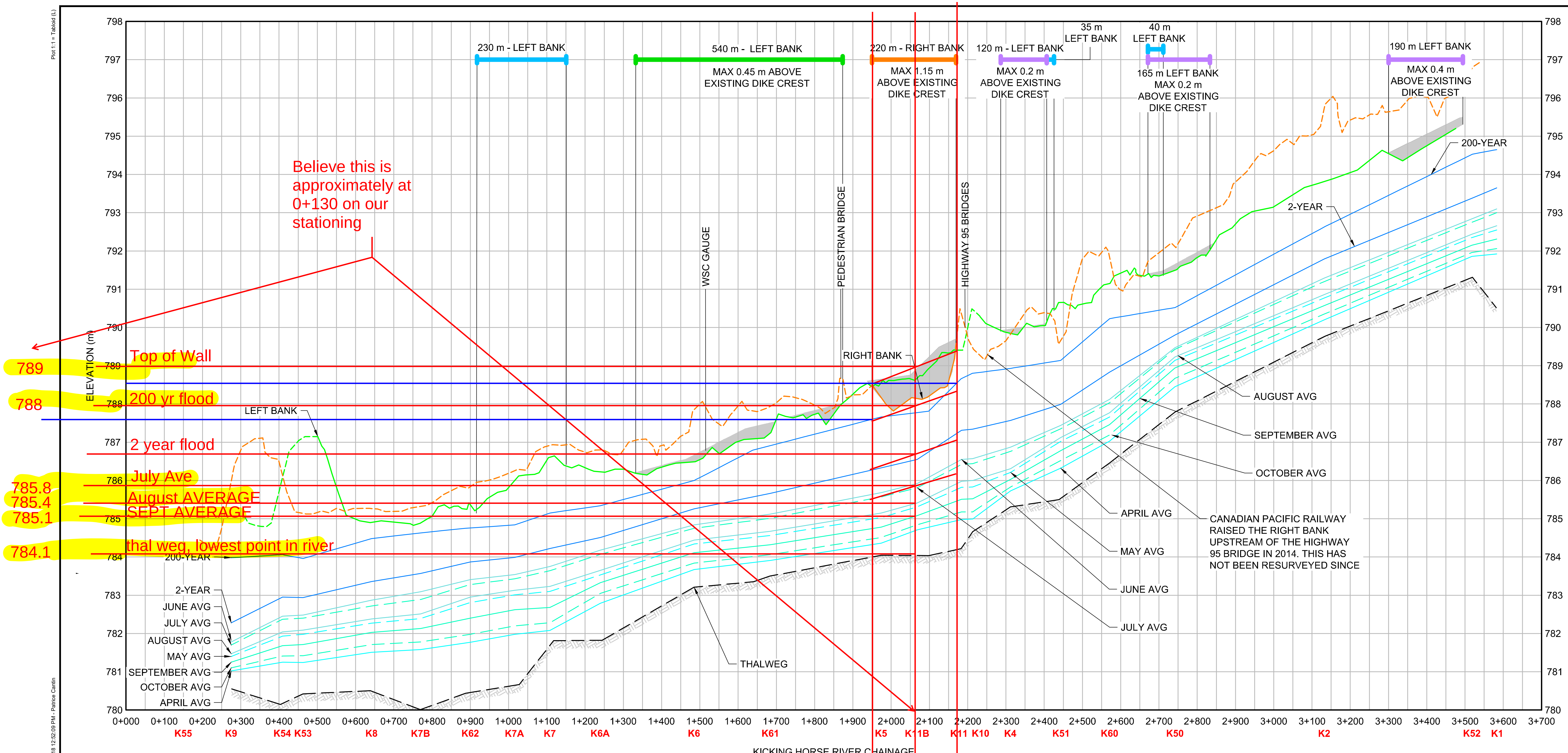
### OPEN-WATER FLOW CONDITIONS

| Date: | Project: | Submitter: | Reviewer: |
|---|---|---|---|
| AUGUST 2018 | 5635-DIHD | D. KUSHNER | K. CURTIS |



Figure 2




**LEGEND**

- 1+500 — KICKING HORSE RIVER CHAINAGE, MEASURED FROM 0+000 AT CONFLUENCE WITH COLUMBIA RIVER AND BASED ON CURRENT RIVER ALIGNMENT
- THALWEG - OCTOBER 2017
- DESIGN FLOOD WATER LEVELS
- MONTHLY WATER LEVELS
- SURVEYED RIGHT BANK - JUNE 2018
- SURVEYED LEFT BANK - JUNE 2018
- SURVEYED RIGHT BANK - JUNE 2013
- SURVEYED LEFT BANK - JUNE 2013
- K9 — SURVEYED CROSS-SECTION (LOCATIONS ARE SHOWN ON FIGURE 1)
- AREA TO BE RAISED

**PROPOSED DIKE IMPROVEMENTS**

- RAISING EARTH DIKE TO PROVIDE 0.6 m FREEBOARD, 540 m
- RAISING EARTH DIKE TO PROVIDE 1.0 m FREEBOARD, 475 m
- CONSTRUCTING CONCRETE WALL TO PROVIDE 1.0m FREEBOARD, 220 m
- ARMOURING, 305 m
  AS REQUIRED, ADDITIONAL ARMOURING WILL ALSO BE COMPLETED AT THE DIKE RAISING LOCATIONS.

**PROFILE**

HORIZONTAL SCALE 1:10000
VERTICAL SCALE 1:100

REFERENCE: 2018 BANK SURVEY PROVIDED BY URBAN SYSTEMS LIMITED ON JULY 23, 2018; 2017 SURVEY BY WSP GLOBAL INC., OCTOBER 2017; 2013 BANK SURVEY PROVIDED BY FOCUS SURVEY LIMITED; WATER LEVELS FROM KICKING HORSE RIVER HYDRAULIC MODEL (REV 2), MATRIX 2014.

1 : 10,000 metres 100 0 100 200
UTM83-11

Note: Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

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DIKE IMPROVEMENT PROJECT HYDROTECHNICAL DESIGN REPORT

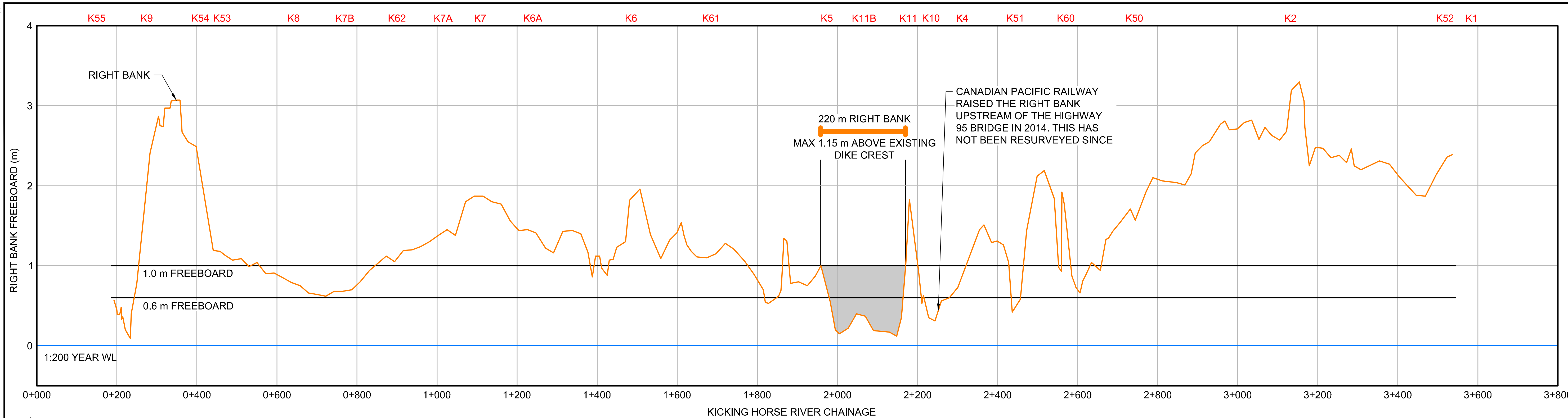
**EXISTING AND PROPOSED DIKE CREST LEVELS VS. OPEN-WATER LEVELS**

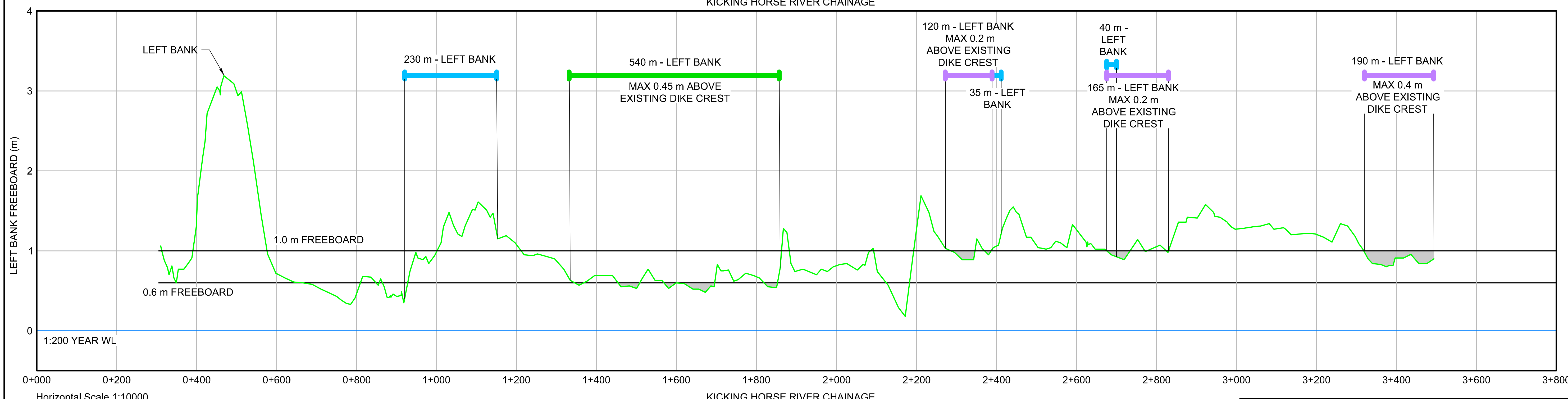
| Date: | Project: | Submitter: | Reviewer: |
|---|---|---|---|
| SEPTEMBER 2018 | 5635-DIHD | D. KUSHNER | K. CURTIS |



Figure 3

F:\5635\Drafting\C3D\Dike Upgrades 2018\Production\Figs\5635-DIHD.dwg - Bank - Tuesday, August 28, 2018 12:52:09 PM - Patrice Cantin
Plot 1:1 = Tabloid (L)




Horizontal Scale 1:10000
Vertical Scale 1:50

**LEGEND**

- 1+500 KICKING HORSE RIVER CHAINAGE, MEASURED FROM 0+000 AT CONFLUENCE WITH COLUMBIA RIVER AND BASED ON CURRENT RIVER ALIGNMENT
- SURVEYED RIGHT BANK - JUNE 2013
- SURVEYED LEFT BANK - JUNE 2013
- K9 SURVEYED SECTION (LOCATIONS ARE SHOWN ON FIGURE 1)
- AREA TO BE RAISED

**PROPOSED DIKE IMPROVEMENTS**

- RAISING EARTH DIKE TO PROVIDE 0.6 m FREEBOARD, 540 m
- RAISING EARTH DIKE TO PROVIDE 1.0 m FREEBOARD, 475 m
- CONSTRUCTING CONCRETE WALL TO PROVIDE 1.0m FREEBOARD, 220 m
- ARMOURING, 305 m
  AS REQUIRED, ADDITIONAL ARMOURING WILL ALSO BE COMPLETED AT THE DIKE RAISING LOCATIONS.

1 : 50 metres 0.5 0 0.5 1

1 : 10,000 metres 100 0 100 200

UTM83-11

REFERENCE: 2013 SURVEY BY FOCUS SURVEYS LIMITED.
2017 SURVEY BY WSP GLOBAL INC., OCTOBER 2017.
WATER LEVELS FROM KICKING HORSE RIVER HYDRAULIC MODEL (REV 2), MATRIX 2014.

Note: Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

TOWN OF GOLDEN - KICKING HORSE RIVER
DIKE IMPROVEMENT PROJECT HYDROTECHNICAL DESIGN REPORT

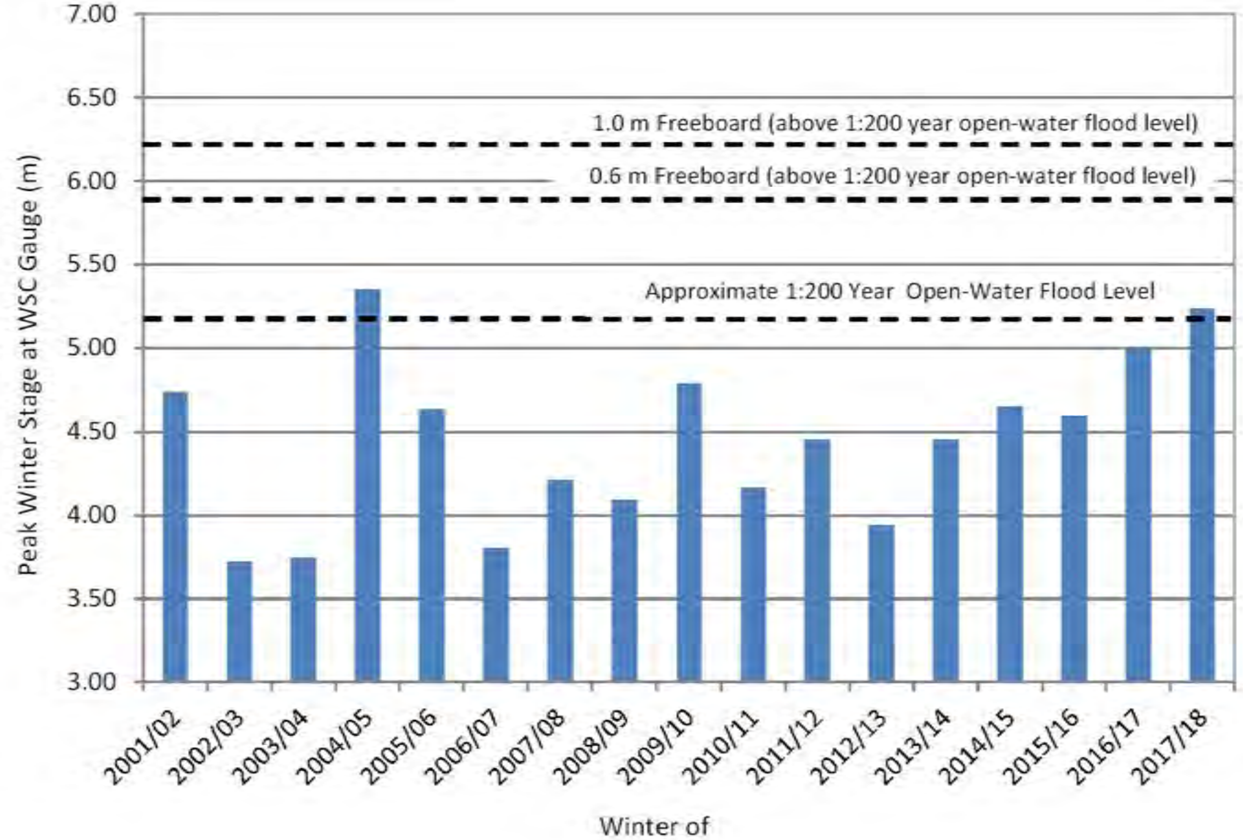
# FREEBOARD AT RIGHT AND LEFT DIKE CRESTS FOR OPEN-WATER LEVELS

| Date: | Project: | Submitter: | Reviewer: |
|---|---|---|---|
| SEPTEMBER 2018 | 5635-DIHD | D. KUSHNER | K. CURTIS |

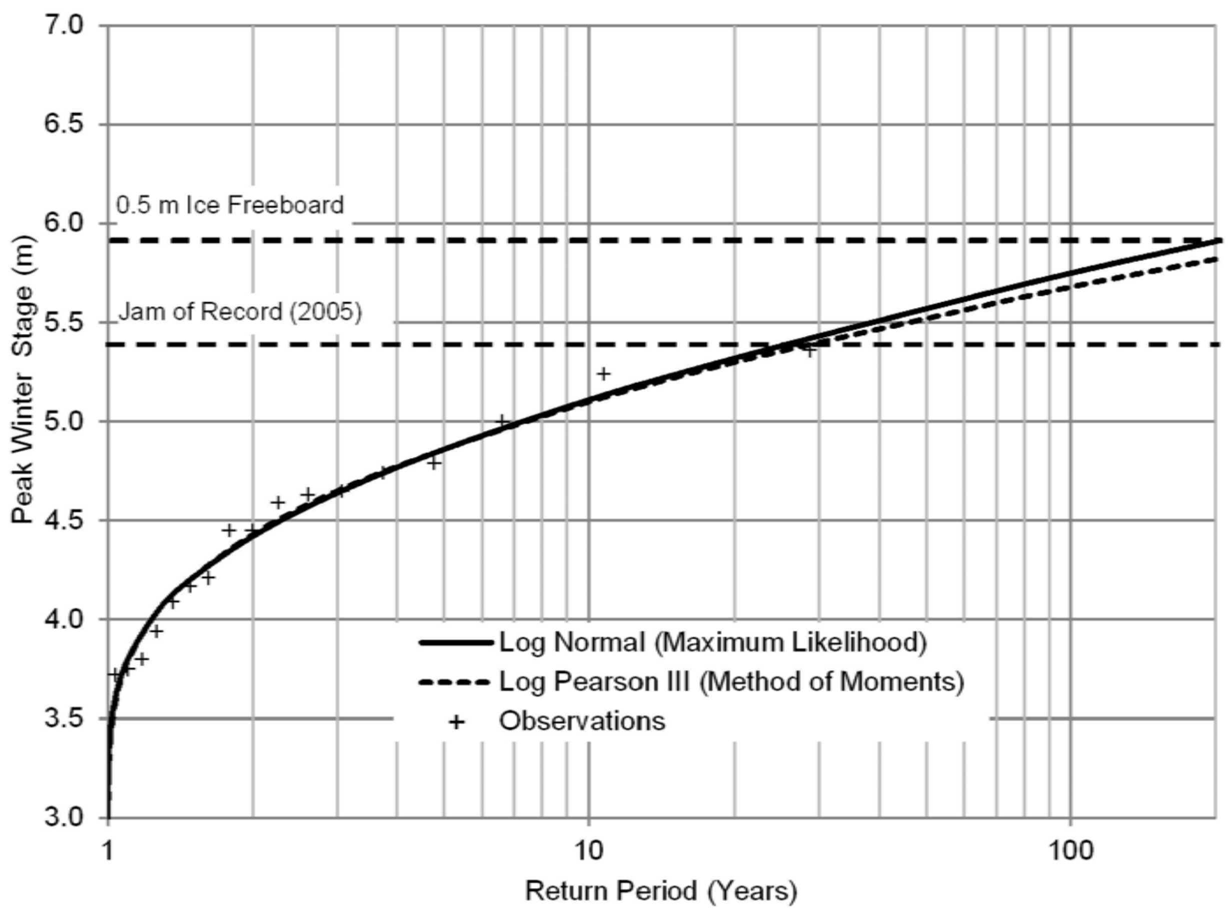


Figure 4

## MAXIMUM WINTER STAGE RECORD AT WSC GAUGE (1+500)




## PRELIMINARY WINTER STAGE FREQUENCY ANALYSIS AT WSC GAUGE 1+500




## JAM OF RECORD (2005)


LOOKING DOWNSTREAM AT HIGHWAY 95 BRIDGE. PHOTO TAKEN JANUARY 7, 2005 BY PAUL DOYLE.

## 2015 ICE JAM


LOOKING DOWNSTREAM AT PEDESTRIAN BRIDGE FROM HIGHWAY 95 BRIDGE. PHOTO TAKEN DECEMBER 1, 2015 BY DWAIN BOYER.

NOTES:

1. ICE STAGE TAKEN FROM THE WATER SURVEY OF CANADA (WSC) RECORDS FOR STATION 08NA006 (KICKING HORSE RIVER AT GOLDEN) AT ITS CURRENT LOCATION (1+500). GAUGE WAS RELOCATED FROM ITS PREVIOUS LOCATION (3+500) IN 2001.
2. ICE STAGE FREQUENCY ANALYSIS IS CONSIDERED PRELIMINARY UNTIL ADDITIONAL YEARS OF DATA ARE GATHERED.
3. ICE STAGE AND FREQUENCY ANALYSIS IS ONLY VALID FOR THE WSC GAUGE LOCATION.

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TOWN OF GOLDEN - KICKING HORSE RIVER
DIKE IMPROVEMENT PROJECT HYDROTECHNICAL DESIGN REPORT

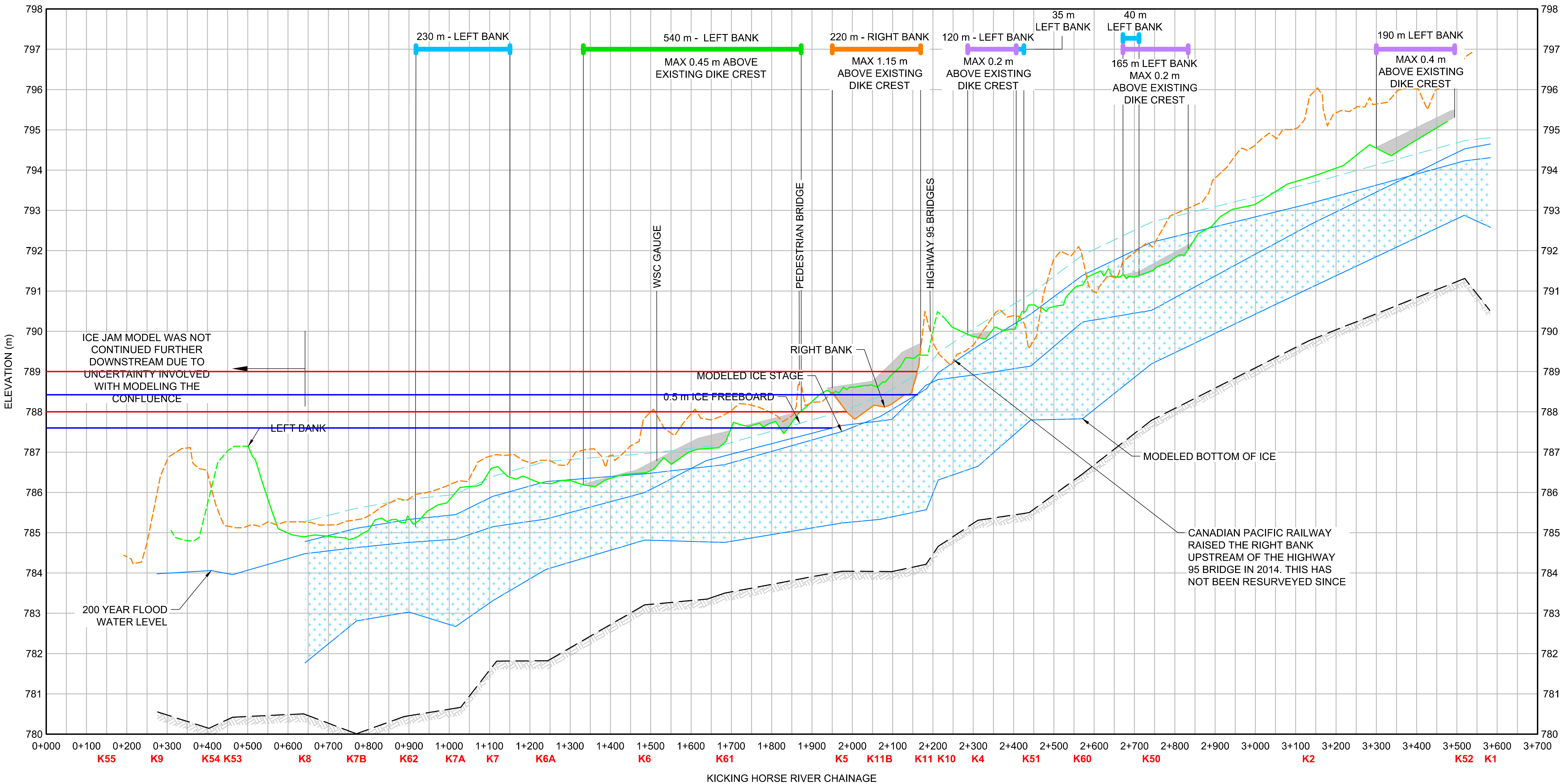
# ICE CONDITIONS

| Date: AUGUST 2018 | Project: 5635-DIHD | Submitter: D. KUSHNER | Reviewer: K. CURTIS |
|---|---|---|---|



Figure 5

Plot 1:1 = Tabloid (L)
F:\5635\Drafting\C3D\Dike Upgrades 2018\Production\Figs\5635-DIHD.dwg - Ice - Thursday, August 09, 2018 2:29:26 PM - Cathy Zhang




<u>LEGEND</u>

- 1+500 — KICKING HORSE RIVER CHAINAGE, MEASURED FROM 0+000 AT CONFLUENCE WITH COLUMBIA RIVER AND BASED ON CURRENT RIVER ALIGNMENT
- THALWEG - OCTOBER 2017
- MODELED ICE LEVEL/BOTTOM OF ICE
- 0.5 m ICE FREEBOARD
- SURVEYED RIGHT BANK - JUNE 2018
- SURVEYED LEFT BANK - JUNE 2018
- SURVEYED RIGHT BANK - JUNE 2013
- SURVEYED LEFT BANK - JUNE 2013
- K9 — SURVEYED CROSS-SECTION (LOCATIONS ARE SHOWN ON FIGURE 1)
- AREA TO BE RAISED

<u>PROPOSED DIKE IMPROVEMENTS</u>

- RAISING EARTH DIKE TO PROVIDE 0.6 m FREEBOARD, 540 m
- RAISING EARTH DIKE TO PROVIDE 1.0 m FREEBOARD, 475 m
- CONSTRUCTING CONCRETE WALL TO PROVIDE 1.0m FREEBOARD, 220 m
- ARMOURING, 305 m
  AS REQUIRED, ADDITIONAL ARMOURING WILL ALSO BE COMPLETED AT THE DIKE RAISING LOCATIONS.

**PROFILE**

HORIZONTAL SCALE 1:10000
VERTICAL SCALE 1:100

REFERENCE: 2018 BANK SURVEY PROVIDED BY URBAN SYSTEMS LIMITED ON JULY 23, 2018.
2017 SURVEY BY WSP GLOBAL INC., OCTOBER 2017.
WATER LEVELS FROM KICKING HORSE RIVER HYDRAULIC MODEL (REV 2), MATRIX 2014.

1 : 10,000 metres
100 0 100 200
UTM83-11

Note: Figure(s) must be used in conjunction with the attached report and is subject to the limitations and conditions stated in the report.

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DIKE IMPROVEMENT PROJECT HYDROTECHNICAL DESIGN REPORT

**EXISTING AND PROPOSED DIKE CREST LEVELS VS. ICE JAM LEVELS**

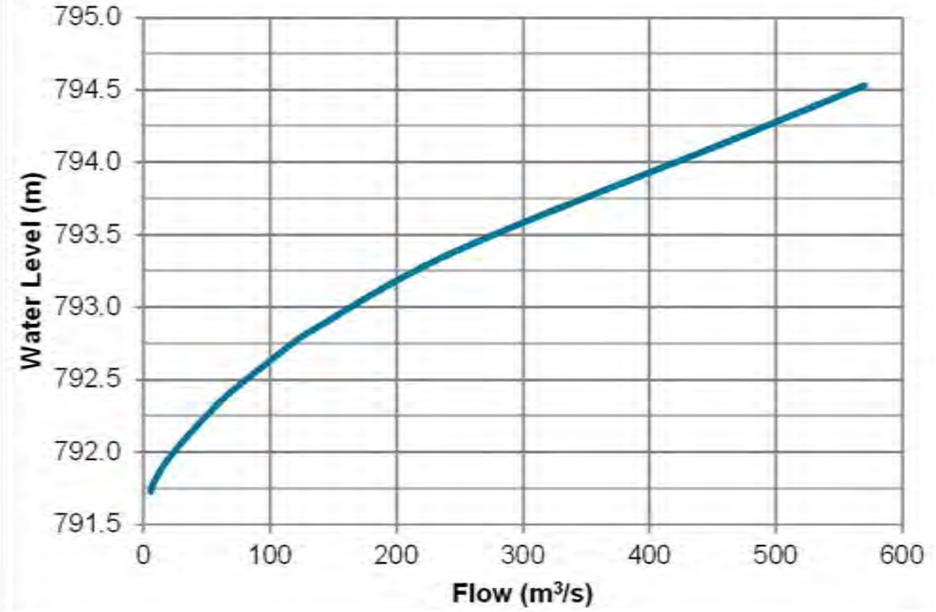
| Date: | Project: | Submitter: | Reviewer: |
|---|---|---|---|
| AUGUST 2018 | 5635-DIHD | D. KUSHNER | K. CURTIS |



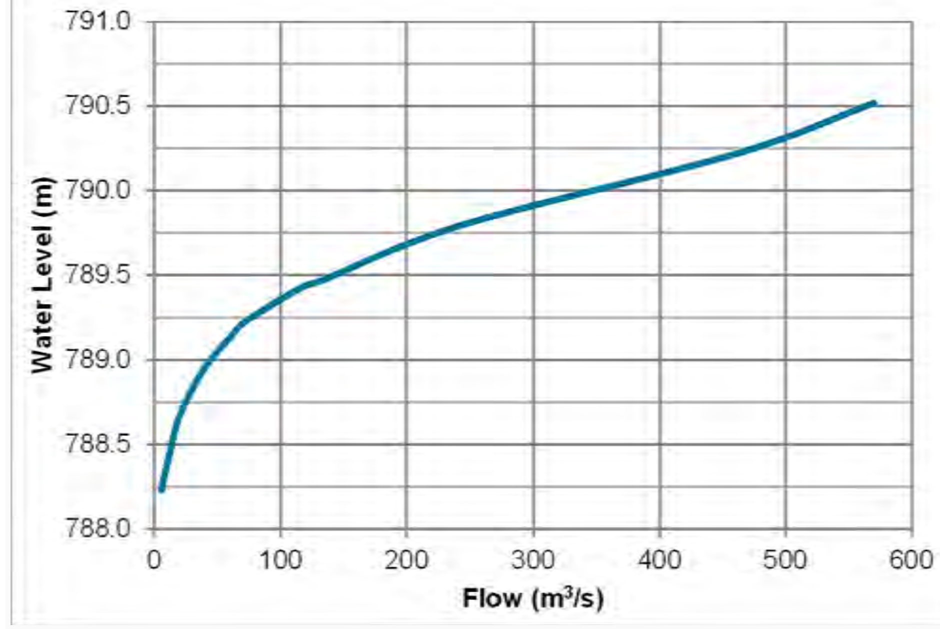
Figure 6

Plot 1:1 = Tabloid (L)
F:\5635\Drafting\C3D\Dike Upgrades 2018\Production\Figs\5635-DIHD.dwg - Ice Jam - Tuesday, August 28, 2018 12:52:09 PM - Patrice Cantin

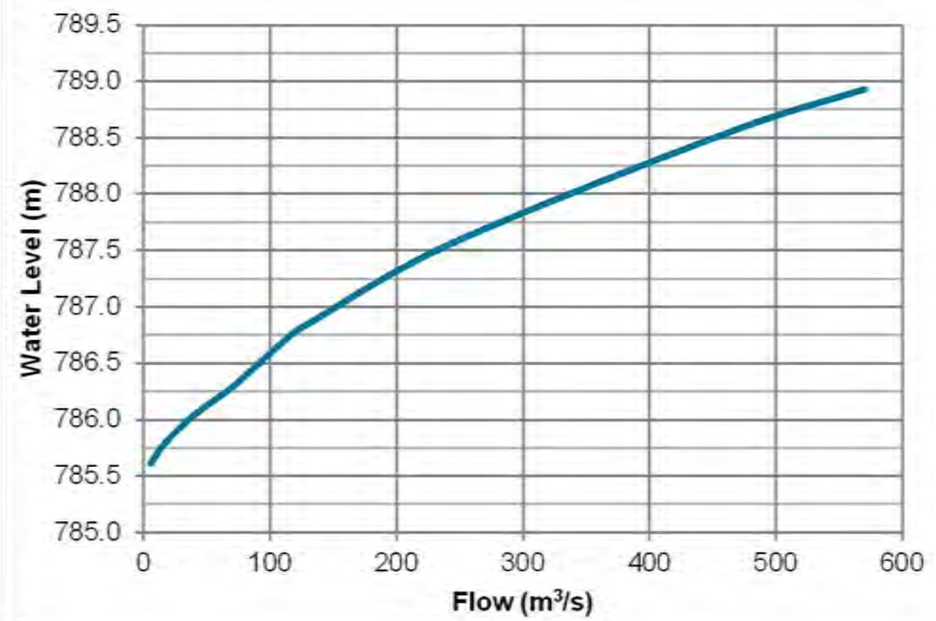
RATING CURVE SECTION K52



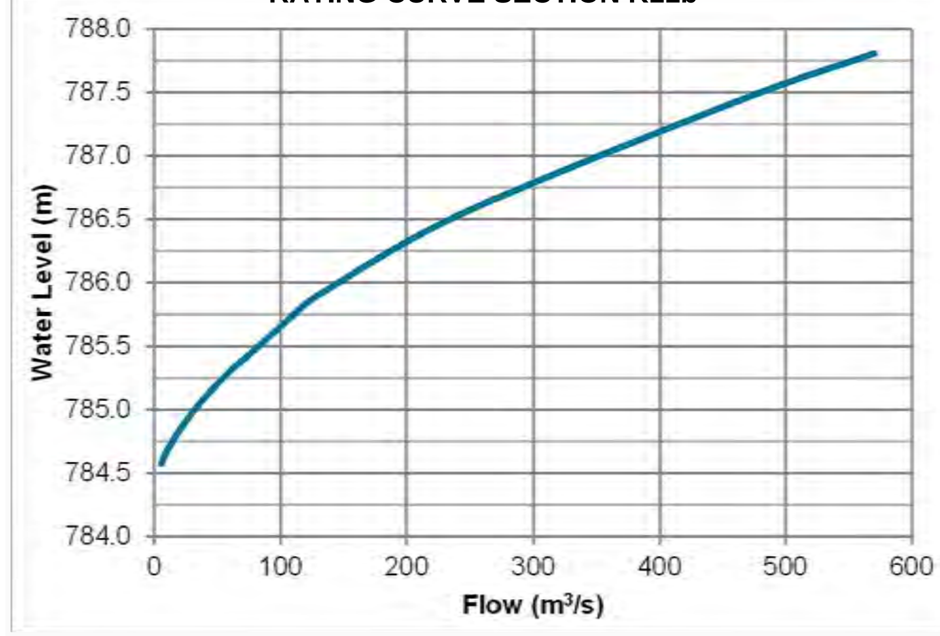

RATING CURVE SECTION K50



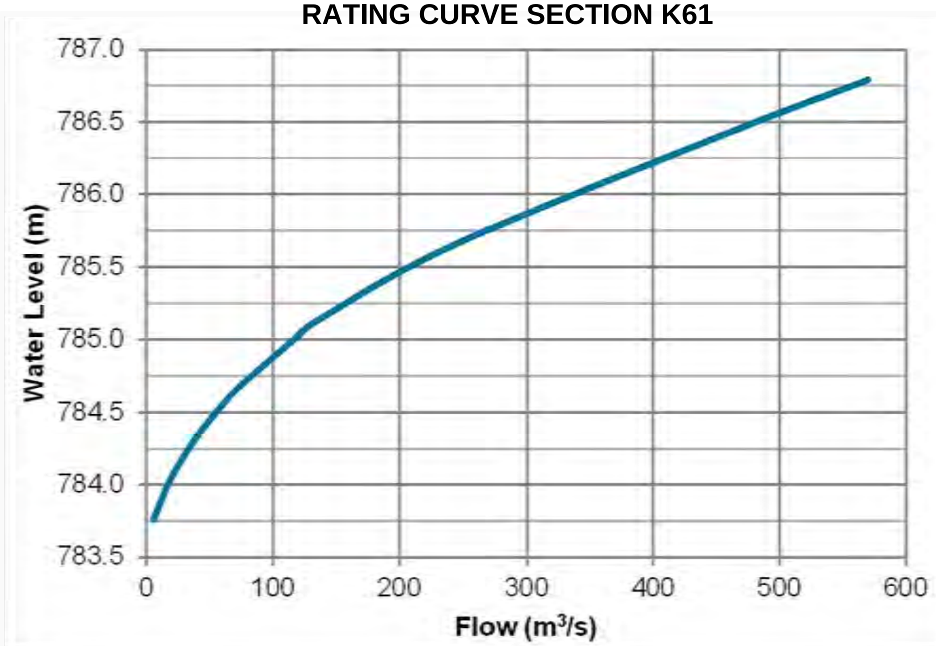

RATING CURVE SECTION K4



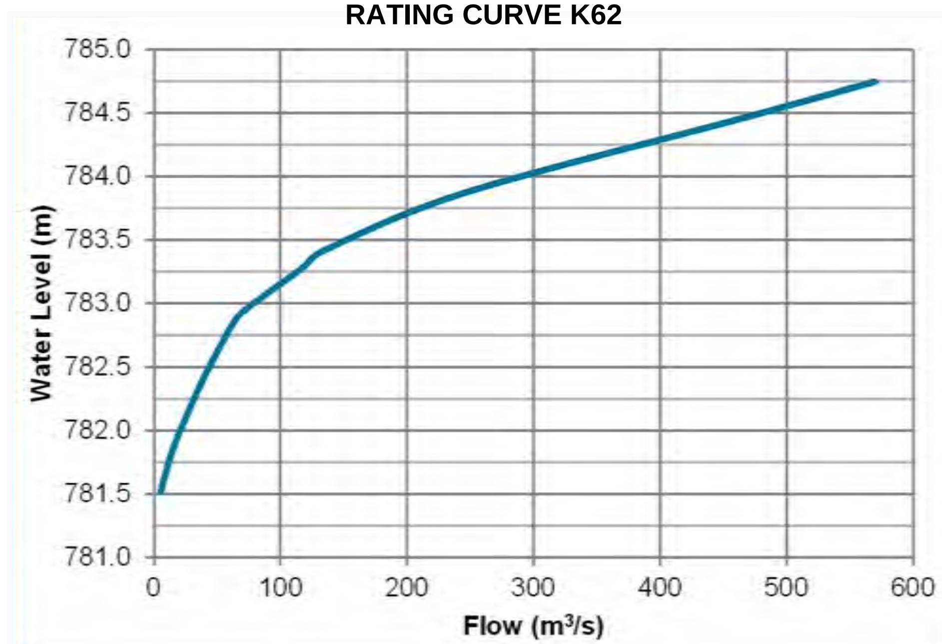

RATING CURVE SECTION K11b




RATING CURVE SECTION K61




RATING CURVE K62




## TABLE OF FLOWS AND OPEN-WATER LEVELS

| | FLOW ($m^3$/s) | SECTION | | | | | |
|---|---|---|---|---|---|---|---|
| | | K52 | K50 | K4 | K11b | K61 | K62 |
| | | WATER LEVEL (m) | | | | | |
| FEB MEAN [3] | 5.5 | NORMALLY ICE AFFECTED (SEE NOTE 3) | | | | | |
| MAR MEAN [3] | 5.8 | | | | | | |
| JAN MEAN [3] | 6.3 | | | | | | |
| DEC MEAN [3] | 7.6 | | | | | | |
| NOV MEAN [3] | 12.0 | 791.9 | 788.4 | 785.7 | 784.7 | 783.9 | 781.8 |
| APR MEAN [3] | 12.0 | | | | | | |
| OCT MEAN | 20.0 | 792.0 | 788.7 | 785.8 | 784.8 | 784.1 | 782.0 |
| SEP MEAN | 39.0 | 792.2 | 788.9 | 786.0 | 785.1 | 784.3 | 782.4 |
| MAY MEAN | 61.0 | 792.4 | 789.1 | 786.2 | 785.3 | 784.6 | 782.8 |
| AUG MEAN | 72.0 | 792.4 | 789.2 | 786.3 | 785.4 | 784.7 | 783.0 |
| JUL MEAN | 117.0 | 792.8 | 789.4 | 786.8 | 785.8 | 785.0 | 783.3 |
| JUN MEAN | 133.0 | 792.8 | 789.5 | 786.9 | 785.9 | 785.1 | 783.4 |
| 2-YEAR | 245.0 | 793.4 | 789.8 | 787.6 | 786.6 | 785.7 | 783.9 |
| 50-YEAR | 461.0 | 794.1 | 790.2 | 788.5 | 787.4 | 786.4 | 784.5 |
| 200-YEAR | 570.0 | 794.5 | 790.5 | 788.9 | 787.8 | 786.8 | 784.8 |

NOTES:
1. RATING CURVES SHOWN AT THE NEAREST SURVEYED SECTION FOR EACH DIKE IMPROVEMENT AREA.
2. LOCATIONS OF THE CROSS SECTIONS ARE SHOWN ON FIGURE 1.
3. DECEMBER TO MARCH ARE NORMALLY ICE AFFECTED AND SUBJECT TO HIGHER WATER LEVELS COMPARED TO OPEN-WATER CONDITIONS. NOVEMBER AND APRIL MAY ALSO BE ICE AFFECTED.
4. WATER LEVELS HAVE BEEN ROUNDED TO THE NEAREST 0.1 m.

REFERENCE: WATER LEVELS AND RATING CURVES FROM THE KICKING HORSE RIVER HYDRAULIC MODEL (REV 2), MATRIX 2014.

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TOWN OF GOLDEN - KICKING HORSE RIVER
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## STAGE VS. OPEN-WATER FLOW RATING CURVES

| Date: | Project: | Submitter: | Reviewer: |
|---|---|---|---|
| AUGUST 2018 | 5635-DIHD | D. KUSHNER | K. CURTIS |



Figure 7