Priddis River Hazard Study

Open Water Hydrology Assessment

Final

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Prepared for:

River Engineering and Technical Services
Watershed Adaptation and Resilience
Government of Alberta

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Sign-off Sheet

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Executive Summary

Alberta Environment and Parks (AEP) commissioned Stantec Consulting Ltd. (Stantec) in August 2017 to undertake the Priddis River Hazard Study. The primary purpose of the study is to identify and assess river and flood hazards along Fish and Priddis Creeks. The study area includes about 30 km of Fish Creek, between Range Road 40 (288 St W) and Tsuut'ina Nation; and about 20 km of Priddis Creek, between its confluence with Fish Creek and Tsuut'ina Nation.

This study is being conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards. Project stakeholders include the Government of Alberta, local authorities and the public. Key municipal stakeholders include the Foothills County, including the Hamlets of Priddis and Priddis Greens.

The Priddis River Hazard Study includes multiple components and deliverables. This report documents the open water hydrology assessment for both Fish Creek and Priddis Creek for use in the Priddis River Hazard Study. The primary tasks, services, and deliverables of this component include:

- Flow and Flood Peak Data Review
- 2005 Flood Peak Assessment
- Reservoir Impact Assessment
- Flood Frequency Analysis
- Climate Change Commentary

Existing flow data from Water Survey of Canada (WSC) was used in the analysis. The Government of Alberta (GoA) provided assembled flood peak data from the recent multi-basin provincial hydrology assessment report by Golder (Golder, 2017). The assessment considered the 2005 Loon Lake dam failure that coincided with the 2005 flood of record requiring a process to isolate the natural peak flow. In addition, potential flow regulation by local reservoirs was evaluated to determine if impacts are significant enough to warrant formal flow naturalization and regulation. A hydrologic modeling approach based on the HEC-HMS model was applied to determine reservoir impacts. Analysis showed that the reservoirs do not have a regulating effect on flood peaks for either Priddis or Fish creeks.

Flood frequency estimates were computed for 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year open water floods at the following locations:

- Fish Creek above Priddis Creek (ungauged) – estimated drainage area of 149 km^2;
- Fish Creek near Priddis (WSC hydrometric station 05BK001) – estimated drainage area of 261 km^2; and
- Priddis Creek at the mouth (above Fish Creek; ungauged) – estimated drainage area of 112 km^2.

The HYFRAN+ software package was utilized to fit the statistical distributions to the Fish Creek near Priddis data. Several probability distributions were considered, and best fit distribution selected. As such

log-normal type III probability distribution using the maximum likelihood estimation method was found as the best fit distribution for the data set. Furthermore, frequency analysis based on the USGS Bulletin 17B and 17C methods are provided as an additional flood frequency assessment.

A climate change commentary was provided based on literature review of studies in and around the project site. The review focused on how climate change might affect the frequency and magnitude of peak flow.

1.0 INTRODUCTION

The Priddis River Hazard Study was conducted by Stantec Consulting Ltd. (Stantec) on behalf of the Government of Alberta, in accordance with the study-specific terms of reference and applicable provincial guidelines.

1.1 STUDY BACKGROUND

Alberta Environment and Parks (AEP) commissioned Stantec in August 2017 to undertake the Priddis River Hazard Study. The study is being conducted under the provincial Flood Hazard Identification Program (FHIP), the goals of which include enhancement of public safety and reduction of future flood damages through the identification of river and flood hazards (Alberta Environment 2011). Project stakeholders include the Government of Alberta, local authorities and the public. The key municipal stakeholder is the Foothills County.

1.2 STUDY OBJECTIVES

The primary purpose of the Priddis River Hazard Study is to identify and assess river and flood hazards along Fish and Priddis Creeks. The study includes multiple components and deliverables.

This report documents the open water hydrology assessment for both Fish Creek and Priddis Creek for use in the Priddis River Hazard Study. The primary tasks, services, and deliverables of the Open Water Hydrology Assessment component include:

- Flow and Flood Peak Data Review;
- 2005 Flood Peak Assessment;
- Reservoir Impact Assessment;
- Flood Frequency Analysis; and
- Climate Change Commentary

The reservoir impact assessment considered the 2005 Loon Lake dam failure, and any significant flow regulation from three small dams in the area, to determine appropriate calibration flows and flood frequency estimates for Fish and Priddis Creeks at specific locations. The results of the frequency analysis completed in this study include the flood peak flow estimates for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year open water floods as requested in the Term of Reference (ToR).

The data and information described in this report and associated deliverables will support the Hydraulic Model Creation and Calibration and Open Water Flood Inundation Map Production components.

1.3 STUDY AREA AND REACH

The study area includes about 30 km of Fish Creek, between Range Road 40 (288 St W) and Tsuut'ina Nation; and about 20 km of Priddis Creek, between its confluence with Fish Creek and Tsuut'ina Nation (**Map 1, Appendix A**). The study area is located solely within the Foothills County, and includes the Hamlets of Priddis and Priddis Greens.

Priddis Creek is a tributary of Fish Creek. Both creeks originate in the foothills of the Rocky Mountains before reaching Calgary. The creeks flow through a mix of Subalpine, Montane, and Foothills Parkland natural sub-regions (Downing & Pettapiece, 2006). Cretaceous and Tertiary sedimentary rocks underlie the Montane Natural Subregion. Bedrock exposures do occur, but glacial till deposits, fluvial deposits along river valleys, and occasionally highly calcareous wind deposited materials are prevalent. The land use in the river basins range from urban Calgary, to agricultural lands in parts of the foothills, and to forest in the remainder of the foothills.

2.0 FLOW AND FLOOD PEAK DATA

2.1 EXISTING FLOW DATA

Existing annual maximum instantaneous flow, daily flow, and rating curve data for Water Survey of Canada (WSC) hydrometric station Fish Creek near Priddis (WSC Station 05BK001) was downloaded and reviewed. The station is located on Fish Creek downstream of the Priddis Creek confluence and has a gross drainage area of 261 km^2 (Map 1, Appendix A). The site has been seasonally active since 1908 except for 1917 to 1955, for a total record length of 69 years with 27 years of annual maximum instantaneous flows recorded. The 2005, 2006, 2011, and 2013 maximum instantaneous flows were confirmed by surveyed high water marks.

The 2005 recorded annual maximum instantaneous flow for Fish Creek near Priddis station was influenced by the Loon Lake dam breach upstream of Priddis that occurred on June 18th of that year. WSC hydrometric station 05BK001 did not record the June 18th flood, suggesting the station was washed out during the event. Water Survey of Canada confirmed the annual maximum instantaneous flow that they published for 2005 (482 m^3/s) was based on a surveyed high-water mark; and, that there is not enough information in the record to discern the proportion of flow contributed by the Loon Lake dam breach.

In the GoA's recent multi-basin hydrology assessment titled "Bow, Elbow, Highwood, and Sheep River Hydrology Assessment" (Golder, 2017), the missing annual maximum instantaneous flows for Fish Creek near Priddis Station were estimated by developing a regression relationship between annual maximum daily flows and annual maximum instantaneous flows using WSC recorded data excluding 2005. The June 2005 instantaneous flow at Fish Creek was estimated using a ratio of recorded floods in 2005 and 2013 from Threepoint Creek near Millarville (WSC Station 05BL013). This analysis resulted in natural maximum annual instantaneous peak flow of 385 m^3/s for 2005. **Figure 2-1** presents the instantaneous flood peak data from the "Bow, Elbow, Highwood, and Sheep River Hydrology Assessment" (Golder,

2017). This data series was used to conduct flood frequency analysis with the exception of the 2005 flood peak, which was analyzed and replaced with a peak flow of 213 m^3/s. The 2005 flood peak is discussed in detail in Section 2.2.

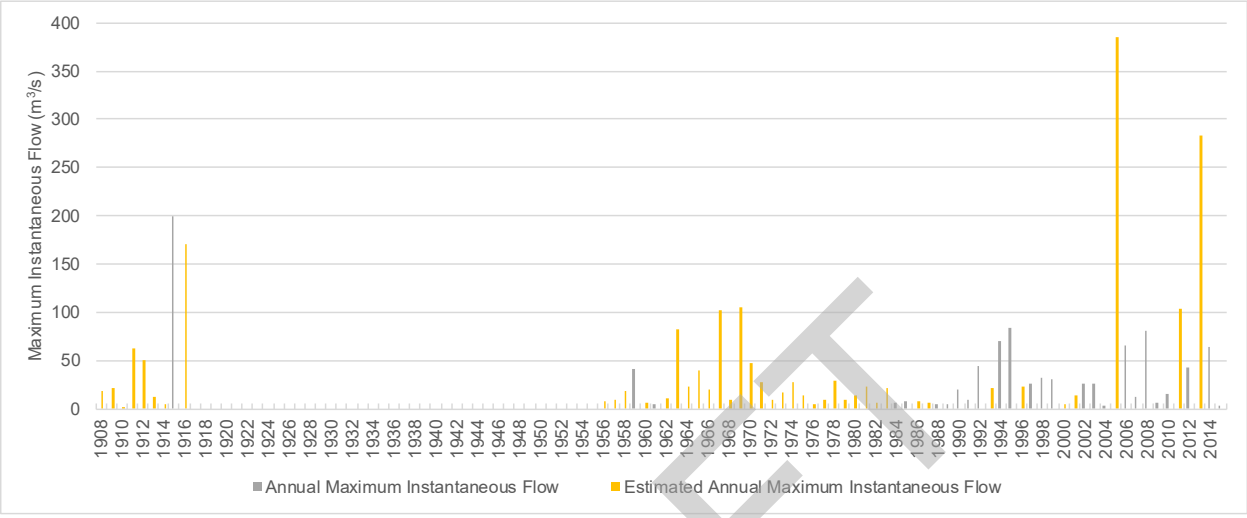

Figure 2-1 Fish Creek near Priddis (WSC 05BK001) Annual Maximum Instantaneous Flow Data (Golder 2017)

River Engineering and Technical Services has high water mark data for the 1993, 1998 and two events from 2005 peak floods, which will be used in the Hydraulic Model calibration of the Priddis River Hazard Study. The 1998 annual maximum instantaneous flow published by WSC is 31.9 m^3/s. WSC does not have an annual maximum instantaneous flow record for 1993; however, the estimated 1993 annual maximum instantaneous flow is 16.2 m^3/s.

2.2 2005 FLOOD PEAK

The 2005 flood of record for Fish Creek near Priddis occurred on June 18, 2005, at 08:20 hrs. This flood also coincided with Loon Lake dam breach and the flood frequency assessment had to remove the effect of the breach to estimate the instantaneous peak flow at Fish Creek near Priddis Station. WSC reported the 2005 maximum instantaneous flow for Fish Creek near Priddis Station as 482 m^3/s. The supplied hydrograph is missing a 3-hour portion of the hydrograph between 06:00 hrs June 18, 2005, and 08:00 hrs June 18, 2005.

The Loon Lake Dam Breach Inundation Study (AMEC 2008) contained a modeled dam breach hydrograph that was created using FLDWAV and with breach parameters similar to those which were observed in 2005. The Loon Lake Dam Breach Inundation Study considered a base flow of 251 m^3/s at Fish Creek near Priddis prior to the dam failure event and determined that the resulting dam failure would result in a total peak of 520 m^3/s. The resulting difference in flow of 269 m^3/s can then be attributed to the additional flow from the dam failure.

Subtracting 269 m^3/s from WSC's published peak flow of 482 m^3/s for the 2005 event yields a 2005 estimated natural peak flow of 213 m^3/s. **Figure 2-2** shows the estimated natural hydrograph (without effects from the Loon Lake dam breach) using the peak flow of 213 m^3/s and the 30-minute flow data published by WSC.

In addition, another check was conducted using the peak recorded flow on Threepoint Creek near Millarville. The Threepoint Creek watershed is immediately adjacent to the Fish Creek watershed and has been proven to show "a high level of similarity to the flow regime at Fish Creek near Priddis" (used in past hydrologic studies to estimate peak flows in Fish Creek when no data was available (Golder 2017)). The June 18, 2005 event on Threepoint Creek was a natural flood event and was not impacted by any dam breach flows. WSC (Station 05BL013 – Threepoint Creek near Millarville) measured a peak flow of 389 m^3/s for this event. Based on the ratio of the drainage areas for both stations, the 2005 peak flow in Fish Creek was estimated to be 200 m^3/s.

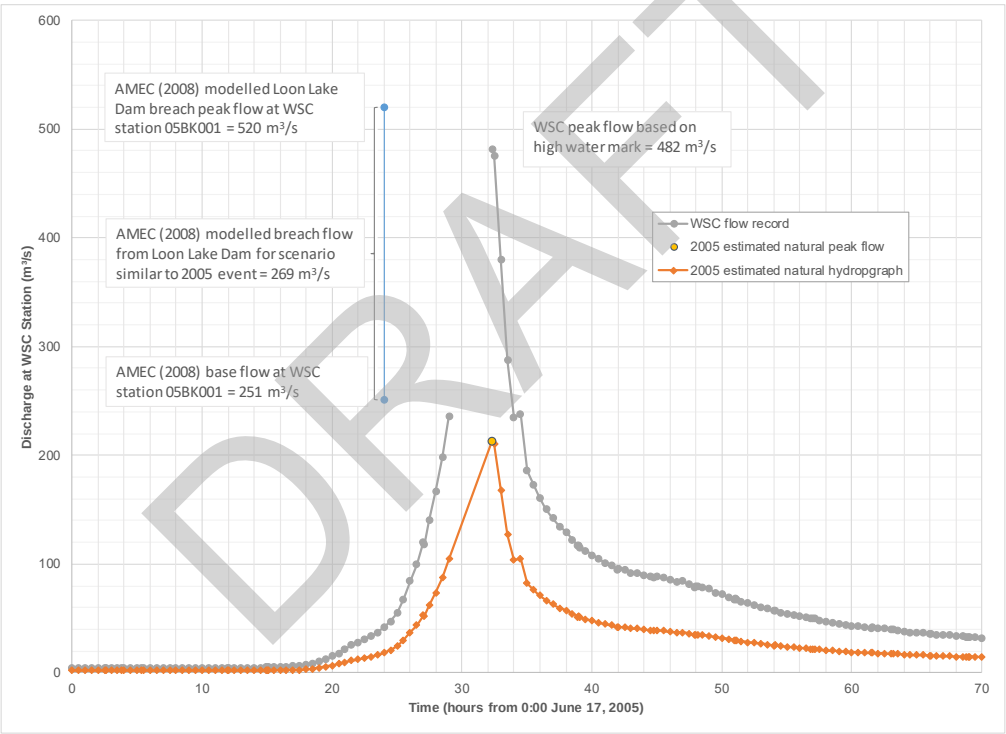

Figure 2-2 June 2005 Observed and Estimated Natural Hydrograph for Fish Creek near Priddis (Water Survey of Canada Station 05BK001, 2018)

The 2005 estimated natural peak flow at Fish Creek near Priddis were used to assess reservoir impacts on peak flow (Section 2.3) and conduct flood frequency analysis (Section 3.0).

2.3 RESERVOIR IMPACTS

Potential flow regulation on the Priddis and Fish Creeks by local reservoirs was evaluated to determine if impacts are significant enough to warrant formal flow naturalization and regulation. Four local reservoirs

were considered in the assessment (Table 2-1). Characteristics for each reservoir is given by **Figures 1 to 4** in **Appendix B**.

Table 2-1 Local Reservoirs in Fish Creek Basin

Reservoir	Legal Land Description	Location	Purpose	Upstream Drainage Area (km^2)
Loon Lake Dam	NW-19-22-3-W5M	Tributary to Priddis Creek	Water supply reservoir for Priddis Greens Golf and Country Club	18
Donald Harvie Reservoir	NE-34-22-3-W5M	Tributary to Fish Creek (upstream of confluence with Priddis Creek)	Stock watering	1
Donald Runge Reservoir	SE-22-22-4-W5M	Tributary to Fish Creek (downstream of confluence with Priddis Creek)	Stock watering	3
Unnamed Reservoir	33-22-3-W5M	Tributary to Fish Creek (downstream of confluence with Priddis Creek)	Unknown	7

Stantec gathered information about the reservoirs such as stage-storage relationships, estimated the 100-year inflow hydrographs for each reservoir (Figure 2-3), and routed the inflow hydrographs through the reservoirs at full supply level (FSL) using discrete models of reservoirs and its upstream catchment using the Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS). The models each contained a single source and a single reservoir element. Source elements were used to define inflow hydrographs to the reservoirs. Stantec then compared the outflow hydrographs regulated by the reservoirs to the natural hydrographs to determine the reservoir impacts.

The stage-storage relationship and rating curve for the spillway at the Loon Lake reservoir were based on information provided by AMEC (AMEC, 2008). For the other reservoirs, a digital elevation model (DEM) surface was generated from the LiDAR captured on July 23, 2005 provided by AEP. Depth-storage relationships and rating curves for the reservoir spillways were derived for the portion of the reservoir that was exposed at the time the LiDAR was captured. The reservoirs were assumed to be at full supply level in June at the time of the historic flood events. Full supply levels were assumed to be the spillway crest elevations. See Appendix B for stage-storage relationships, spillway rating curves, and associated information gathered for each reservoir.

The 2005 estimated natural flood event hydrograph (without the Loon Lake reservoir dam breach) and 2013 flood event (as recorded by WSC) were used as the shapes of the inflow hydrographs and are shown in **Figure 2-3**. The 2005 estimated natural flood event hydrograph (without the Loon Lake reservoir dam breach) at Fish Creek near Priddis is based on hourly flow data published by WSC scaled to a peak flow of 213 m^3/s. Each of these hydrograph shapes were scaled to 100-year flood magnitudes based on their drainage areas and utilizing the flood frequency distributions described in Section 3.0.

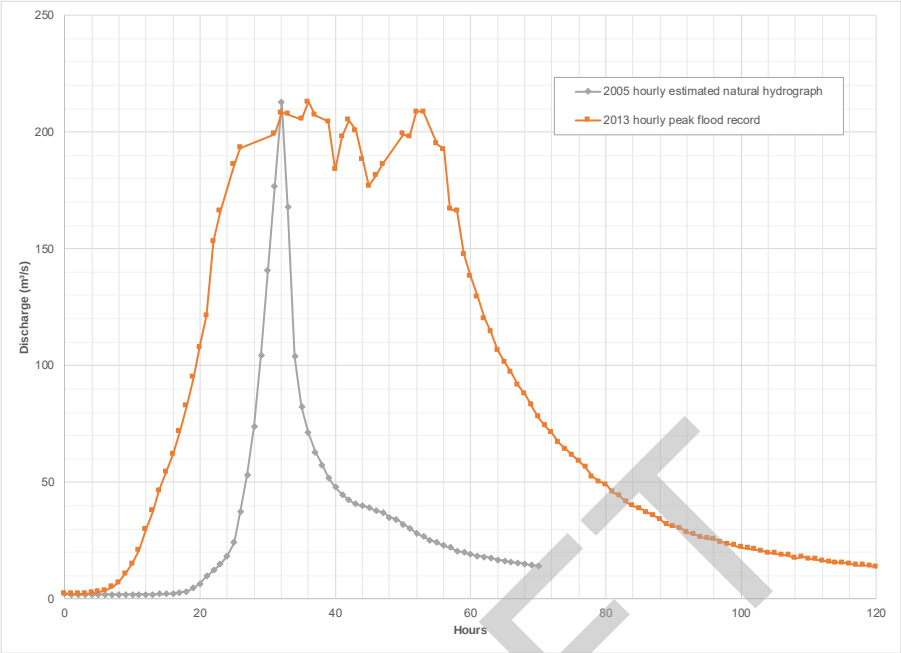

Figure 2-3 **2005 and 2013 Natural Peak Flow Hydrographs for Fish Creek at Priddis (Water Survey of Canada Station 05BK001, 2018)**

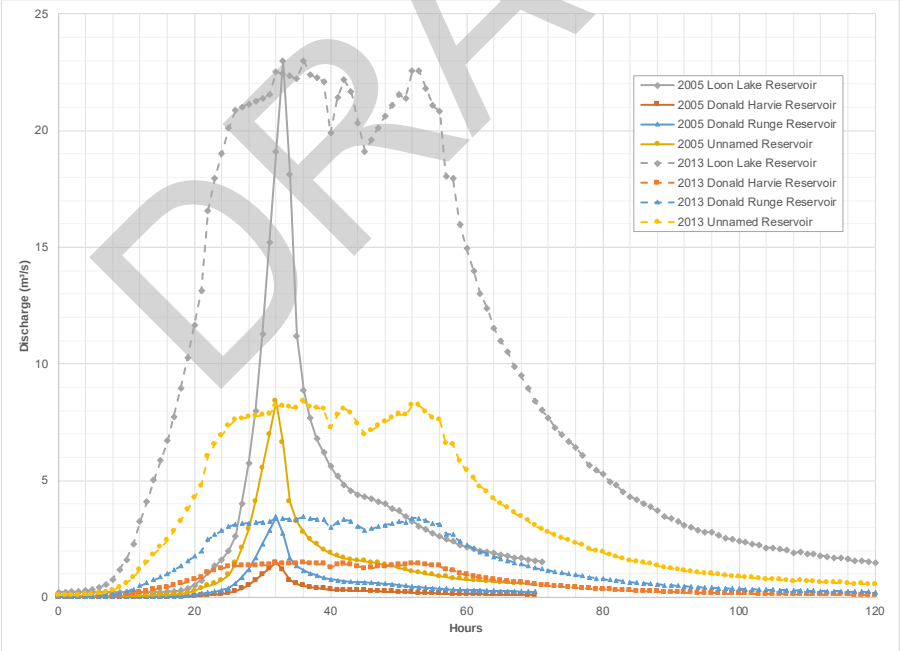

Figure 2-4 **Reservoir Inflow based on the 2005 and 2013 Hydrographs Scaled to 100-year Peak Flow (Water Survey of Canada Station 05BK001, 2018)**

The hydraulic analysis was performed at assumed full supply level, using the volume between assumed FSL and LiDAR based DEM surface. The analysis assessed the available storage and how much of the flow volume from the scaled 2005 and 2013 hydrographs could be captured.

The results of the analysis show that the reservoirs do not have a significant regulating effect on the flood peaks for Priddis and Fish creeks during the 100-year peak flow (**Table 2-2**).

Table 2-2 Reservoir Impact on Peak Flows

Node	Location Description	2005 Hydrograph			2013 Hydrograph		
		Scenario 1: with reservoir	Scenario 2: without reservoir	Reservoir Impact	Scenario 1: with reservoir	Scenario 2: without reservoir	Reservoir Impact
		Peak Flow (m^3/s)	Peak Flow (m^3/s)		Peak Flow (m^3/s)	Peak Flow (m^3/s)	
1	Priddis Creek downstream of Loon Lake reservoir outflow	112	115	-3%	114.6	115.0	-0.3%
2	Fish Creek downstream of Donald Harvie reservoir outflow	85.6	86.5	-1%	86.1	86.5	-0.5%
3	Fish Creek downstream of Donald Runge and Unnamed reservoirs outflow	335.4	342.8	-2%	342.2	342.8	-0.2%

The Loon Lake reservoir had the greatest impact on Priddis Creek, reducing the 2005 hydrograph peak flow by 3%. Because the regulating effect was deemed to be not significant, the Priddis River Hazard Study project components dependent on this assessment will be completed based on the assumption that the reservoirs do not have a regulating effect on either Priddis or Fish Creeks.

3.0 FLOOD FREQUENCY ANALYSIS

Flood frequency analysis was required to determine flow estimates for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year open water floods at the following locations:

- Fish Creek above Priddis Creek (ungauged) – estimated drainage area of 149 km^2.
- Fish Creek near Priddis (WSC hydrometric station 05BK001) – estimated drainage area of 261 km^2.
- Priddis Creek at the mouth (above Fish Creek; ungauged) – estimated drainage area of 112 km^2.

A flood frequency analysis was carried out at the Fish Creek near Priddis using ten different probability functions. The HYFRAN+ software package was used to fit statistical distributions to the data series. HYFRAN+ is a numerical analysis tool that can be used to: compare multiple frequency distributions; parameter estimation methods; perform goodness-of-fit; and data series characterization tests.

The following probability distributions were analyzed with the distribution parameter estimation methods listed in parentheses (MLE = maximum likelihood estimation, MOM = method of moments, and *SAM = method SAM*):

- Normal (MLE)
- Log-Pearson Type III (SAM)

- Log-Normal (MLE)
- Gumbel (MLE)
- Log-Normal Type III (MLE)
- General Extreme Value (MLE)
- Exponential (MLE)
- Weibull (MLE)
- Pearson Type III (MOM)
- Gamma (MLE)

Prior to fitting an appropriate curve, a variety of statistical tests were performed to determine quality of the input data. These tests evaluate the dataset for randomness, stationarity, homogeneity, independence, and the presence of outliers. The statistical tests include:

- **Randomness**: a random data series experiences deviations and variations in value due to natural factors, not human intervention. Waterbodies that are affected by control structures do not satisfy the randomness criteria.
- **Stationarity**: a stationary data series is constant with respect to time, excluding randomness fluctuations. The most documented types of non-stationarity are jumps, trends, and cycles. The Spearman Rank Order Correlation Coefficient is used to detect jumps in the datasets. The Mann-Whitney Test for jump (Mann and Whitney 1947) and Wald-Wolfowitz runs test (Siegel, 1956) are used to detect trends in the dataset.
  - When using the Spearman Rank Order Correlation Coefficient for runoff discharges, detected trends are normally due to gradual changes in land use.
  - When using the Wald-Wolfowitz Test for runoff discharges, jumps are most often due to a sudden change in a basin or river system like the construction of a dam.
- **Homogeneity**: a homogenous data series originates from a single population. The Mann-Whitney test and Terry test measure whether means for datasets differ for chosen levels of significance.
  - A peak stream discharge data series is an example of a non-homogenous data set because it may contain data resulting from different physical inputs, including: snowmelt runoff; ice jam or beaverdam failure release; groundwater baseflow; and dam failure.
- **Independence**: an independent data series is one where each data point is unaffected by the preceding data point. The three tests for independence include the Spearman Rank Order Correlation Coefficient, Wald-Wolfowitz Test, and Anderson Test.
  - Hydrologic parameters that demonstrate dependence are discharge and volumes. For example, snowmelt may create precursor moisture conditions that increase runoff from spring and summer rainfall even though snow cover is gone.
  - Outliers: points in data sets that significantly depart from the range of the remaining data. While a statistical test may identify a point as an ‘outlier’, that point may very well be the only actual flood in an entire dataset as in extraordinary flood.

A summary of the results of the statistical tests are presented in Section 4.2.

An appropriate probability distribution was selected based on numerical and visual goodness-of-fit tests. These tests are:

- **Kolmogorov-Smirnov Test:** a numerical goodness-of-fit test. To apply this test, the maximum discrepancy (D-statistic) between the empirical probability and the probability distribution for the observed values is calculated and compared to a critical statistic for the data set. If the calculated D-statistic is greater than the critical statistic, the frequency distribution does not match the data set (D'Agostino & Stephens, 1986).
- **Anderson-Darling Test:** a numerical goodness-of-fit test. Like the Kolmogorov-Smirnov Test, a statistic A is compared to a critical statistic calculated from the sample size and significance level to determine if the data series fits with compared probability distribution (Stephens, 1974).
- **Ranking Least Squares Method:** a visual goodness-of-fit test, which compares the fit of multiple distributions to a single data sample. For this method, the sum of squares is calculated for the differences between calculated and observed discharges. A ranking of distributions by order of least standard error based on the sum of squares reveals the ranked goodness-of-fit of each distribution (Kite, 1977).

Although a probability distribution function may visually appear to be the best fit to the dataset, numerical goodness-of-fit tests such as Kolmogorov-Smirnov and Anderson-Darling methods could be considered more robust and objective (D'Agostino & Stephens, 1986). A summary of the results of the goodness-of-fit tests for the ten probability distribution functions are presented in Section 4.2.

The approaches outlined in the United States Geological Survey's Guidelines for Determining Flood Flow Frequency, Bulletin 17B were considered. In addition, the proposed changes to Bulletin 17B which is available as Bulletin 17C (England, et al., 2018) is considered. The U.S. Army Corps of Engineers Hydrologic Engineering Center HEC-SSP software was used to compute flood frequency estimates for Bulletin 17B and 17C methods. Bulletin 17B describes the type of data and procedures for computing flood flow frequency curves. Such statistical analysis is warranted if systematic stream gauging records of sufficient length (at least 10 years) is available. The bulletin uses the Log-Pearson Type III probability distribution for annual peak flows on unregulated streams fit by the method of moments. The bulletin also discusses the treatment of outliers and historic floods which are not part of the systematic record.

Bulletin 17C retains the basic statistical framework used previously in Bulletin 17B, while integrating the following advances:

- A more generalized representation of flood data allowing description of flood peaks as intervals. This allows for a more robust incorporation of data based on historical information.
- The Expected Moments Algorithm (EMA) was adopted as an improved method of moments approach to fitting the Log-Pearson Type III distribution to flood peaks.
- A generalized Grubbs Beck test, the Multiple Grubbs Beck Test (MGBT), was adopted as an improvement to the Grubbs Beck test used in Bulletin 17B. This allows multiple potentially influential low floods to be identified.
- Corrected confidence intervals for the flood frequency curve as the Bulletin 17B computations were acknowledged to be a simplified and incomplete representation of the confidence intervals.
- New methods for estimating regional skew and uncertainty.

The HYFRAN+ and HEC-DSS software only provide flood flow values for the following return periods: 2-, 5-, 10-, 20-, 50-, 100-, 200-, and 1000-year flood estimates. Flood flow estimates for 35-, 75-, 350-, 500-, and 750-year return periods were interpolated using linear interpolation between known data points from the respective flood frequency curve.

The approaches outlined in Alberta Transportation's (AT) "Flood Frequency Analysis" (2001) and "Guidelines on Extreme Flood Analysis" (2004) were considered in the flood frequency analysis conducted. Data assembly and processing followed the instantaneous versus daily maxima method outlined in AT's "Flood Frequency Analysis" (2001). The Fish Creek near Priddis peak data series met the following conditions recommended by AT's "Flood Frequency Analysis" (2001) and "Guidelines on Extreme Flood Analysis" (2004) for extrapolating frequency curves to estimate the 1000-year flood:

- There is a long period of record and the series is free from evident non-stationarity, non-homogeneity, or high outliers.
- The scatter of points around the fitting curve is small.

The probability distributions for flood frequency analysis included the Log-Normal, General Extreme Value, and Log-Pearson Type III specified in AT's "Flood Frequency Analysis" (2001) document.

4.0 FLOOD FREQUENCY ESTIMATES

4.1 FLOOD FREQUENCY DISCHARGES

Flood frequency estimates were completed at the following locations:

- Fish Creek above Priddis Creek (ungauged);
- Fish Creek near Priddis (WSC 05BK001 Station); and
- Priddis Creek at the mouth (above Fish Creek; ungauged).

HYFRAN+, Bulletin 17B, and 17C were used to compute flood frequency estimates at Fish Creek near Priddis using available annual maximum instantaneous flow data. Bulletin 17B and 17C were considered following AEP's Terms of Reference. Statistical characteristics and numerical goodness-of-fit tests for the multiple probability functions of the dataset are presented in Section 4.2. For the HYFRAN+ based analysis the log-normal type III probability distribution using the maximum likelihood estimation method was chosen as the best fit distribution for the data set and is presented in **Table 4-1.** Appendix C presents the other HYFRAN+ probability distributions that were analyzed but did not best fit the data.

Flood frequencies for the ungauged Fish and Priddis Creeks were derived using frequencies from Fish Creek near Priddis and applying a drainage basin area ratio transfer method. This method is reliant upon the single physiographic parameter, drainage area, even though runoff is affected by several other parameters including basin slope, shape, orientation, effective area, antecedent moisture conditions, and, most importantly, storage. Appropriate application of this method assumes the gauged and ungauged sites share the same physiographic and hydrologic characteristics and that scaling is valid. Gross drainage area was provided by WSC for Fish Creek near Priddis and is stated to be equivalent to its

effective drainage area. Gross drainage areas at the ungauged sites were delineated using geographical information system tools and DEM data within ArcGIS.

Table 4-1 summarizes the flood frequency estimates and the upper and lower 95% confidence intervals. Appendix C provides the annual maximum instantaneous flow series used in the frequency analyses, the various frequency distributions, and best distribution fit with 95% confidence intervals.

Table 4-1 Frequency Flow Estimates Calculated Using Various Methods – Natural and Naturalized Flows

Location				Fish Creek near Priddis (WSC 05BK001)						Priddis Creek at the mouth						Fish Creek above Priddis Creek					
Gross Drainage Area (km²)				261						112						149					
Distribution / Method				3PLN (MLE)		Bulletin 17B		Bulletin 17C		3PLN (MLE)		Bulletin 17B		Bulletin 17C		3PLN (MLE)		Bulletin 17B		Bulletin 17C	
Computed Instantaneous Peak Flows with 95% Confidence Intervals (m^3/s)	1000-yr	Flood Est.	Upper	826	1460	1,068	1833	1,014	5923	355	628	459	788	436	2547	471	832	609	788	578	2547
			Lower		196		690		462		84		296		199		112		296		199
	750-yr	Flood Est.	Upper	725	1270	939	1587	895	4746	312	546	404	682	385	2041	413	724	535	682	510	2041
			Lower		190		613		423		82		264		182		108		264		182
	500-yr	Flood Est.	Upper	630	1060	779	1287	748	3465	271	456	335	554	322	1490	359	604	444	554	426	1490
			Lower		185		518		371		80		223		160		105		223		160
	350-yr	Flood Est.	Upper	551	910	659	1069	636	2620	237	391	283	459	274	1127	314	519	376	459	363	1127
			Lower		170		445		329		73		191		142		97		191		142
	200-yr	Flood Est.	Upper	438	722	501	787	489	1682	188	310	216	338	210	723	250	412	286	338	279	723
			Lower		154		347		271		66		149		116		88		149		116
	100-yr	Flood Est.	Upper	322	513	352	530	347	961	138	221	151	228	149	413	184	292	200	228	198	413
			Lower		130		251		207		56		108		89		74		108		89
	75-yr	Flood Est.	Upper	280	440	302	447	299	759	120	189	130	192	128	326	160	251	172	192	170	326
			Lower		120		218		184		52		94		79		68		94		79
	50-yr	Flood Est.	Upper	230	354	241	348	240	542	99	152	104	150	103	233	131	202	137	150	137	233
			Lower		106		177		155		46		76		66		60		76		66
	35-yr	Flood Est.	Upper	190	290	196	277	196	401	82	125	84	119	84	172	108	165	112	119	112	172
			Lower		95		147		131		41		63		56		54		63		56
	20-yr	Flood Est.	Upper	139	203	139	189	140	248	60	87	60	81	60	107	79	116	79	81	80	107
			Lower		75		107		98		32		46		42		43		46		42
	10-yr	Flood Est.	Upper	89	124	87	113	88	134	38	53	37	49	38	58	51	71	49	49	50	58
			Lower		54		69		65		23		30		28		31		30		28
	5-yr	Flood Est.	Upper	52	69	50	62	51	70	22	30	21	27	22	30	30	40	28	27	29	30
			Lower		35		41		39		15		18		17		20		18		17
	2-yr	Flood Est.	Upper	19	24	19	22	19	24	8	10	8	10	8	10	11	14	11	10	11	10
			Lower		14		16		15		6		7		6		8		7		6

- 3PLN (MLH): log-normal type III probability distribution using the maximum likelihood estimation method
- Bulletin 17B and 17C methods are based on a log Pearson III probability distribution using the method of moments with the Expected Moments Algorithm

4.2 UNCERTAINTY AND CONFIDENCE

The 95% upper and lower confidence intervals computed for the frequency estimates are presented in Section 4.1. Confidence intervals can increase when return periods are extrapolated beyond the record length; WSC 05BK001 has a 69-year record length, with 27 data points. Statistical characteristics of the flood frequency dataset, and numerical goodness-of-fit for best fit probability distribution function, are presented in **Table 4-2** and **Table 4-3**.

Table 4-2 Statistical Characteristics of Fish Creek near Priddis (WSC 05BK001) Annual Peak Instantaneous Flow Data Set (1908-2013)

Statistical Tests		Fish Creek near Priddis Station Annual Peak Instantaneous Flow (1908-2013)
Stationarity	Spearman Rank Order Correlation Coefficient (Trend)	no significant trend at 0.05 significance level
	Mann-Whitney Test for Jump	no jump at 0.05 significance level
	Wald-Wolfowitz Test (Jump)	no jump at 0.05 significance level
Homogeneity	Mann-Whitney U Test	sample is homogenous at 0.05 significance level
	Terry Test	sample is homogenous at 0.05 significance level
Independence	Spearman Rank Order Correlation Coefficient	data is independent at 0.05 significance level
	Wald-Wolfowitz Test for Independence	data is independent at 0.05 significance level
	Anderson Test	data is independent at 0.05 significance level
Outliers	Grubbs and Beck Test	no high outliers

Table 4-3 Numerical Goodness-of-Fit Tests for WSC 05BK001 (Fish Creek near Priddis) Annual Peak Instantaneous Flow Data Set (1908-2013)

Distribution Type	Anderson Darling Test	Kolmogorov-Smirnov Test	Least Squares Ranking	Ranking of Probability Distribution
Normal	10	10	9	10
Lognormal	3	3	2	2
Lognormal III	**1**	**1**	**4**	**1**
Exponential	8	6	7	8
Pearson III	7	7	3	6
Log Pearson III	2	2	5	3
Gumbel	9	9	8	9
GEV	4	4	10	7
Weibull	6	8	1	4
Gamma	5	5	6	5
Bold indicates best fit probability distribution based on numerical tests				

4.3 COMPARISON TO PREVIOUS STUDIES

Stantec compared the flood frequency estimates for Fish Creek near Priddis, presented in this report, to those reported in the "Bow, Elbow, Highwood, and Sheep River Hydrology Assessment" (Golder, 2017) (**Table 4-4**). The flood frequency estimates presented in this report reduce the flood peaks from a maximum of 14% from the previously reported flood frequency estimates.

These analyses differed in the way the 2005 peak discharge was naturalized, by removing the Loon Lake dam breach discharge. In the multi-basin study the recorded June 2005 instantaneous peak flow at Fish Creek near Priddis were adjusted using the ratio of recorded floods in 2005 and 2013 for Threepoint Creek near Millarville (WSC Station 05BL013) and multiplying the ratio by the 2013 recorded flood for Fish Creek near Priddis. This has resulted in an estimated natural instantaneous peak flow for June 2005 of 385 m^3/s for Fish Creek near Priddis. A more detailed analysis was deemed necessary that resulted in a lower flow for the 2005 flood peak. Using the methods described in this report the June 2005 peak flood is estimated to be 213 m^3/s.

Table 4-4 Comparison of Frequency Flow Estimates

WSC Station ID				**05BK001**					**Percent difference from the current estimate using 3PLN (MLH) to the Bow, Elbow, Highwood, and Sheep River Hydrology Assessment (3PLN (MLH)) (Golder 2017)**
WSC Station Name / Location of Interest				**Fish Creek near Priddis**					
Gross Drainage Area (km^2)				**261**					
Distribution / Method				**3PLN (MLH)**		**Bow, Elbow, Highwood, and Sheep River Hydrology Assessment (3PLN (MLH))** (Golder, 2017)		**Priddis Flood Risk Mapping Study** (Alberta Environment, 2004)	
Computed Instantaneous Flood Flows with 95% Confidence Bonds (m3/s)	**1000-yr**	Flood Est.	Upper	826	1460	926	3500	-	-12%
			Lower		196		465		
	750-yr	Flood Est.	Upper	725	1270	829	3010	-	-14%
			Lower		190		422		
	500-yr	Flood Est.	Upper	630	1060	713	2440	-	-13%
			Lower		185		373		
	350-yr	Flood Est.	Upper	551	910	614	1990	-	-12%
			Lower		170		328		
	200-yr	Flood Est.	Upper	438	722	481	1430	-	-10%
			Lower		154		264		
	100-yr	Flood Est.	Upper	322	440	350	921	251	-9%
			Lower		120		203		
	75-yr	Flood Est.	Upper	280	354	305	761	-	-9%
			Lower		106		182		
	50-yr	Flood Est.	Upper	230	290	248	574	169	-8%
			Lower		95		152		
	35-yr	Flood Est.	Upper	190	203	204	445	-	-7%

Table 4-4 Comparison of Frequency Flow Estimates

WSC Station ID				05BK001					Percent difference from the current estimate using 3PLN (MLH) to the Bow, Elbow, Highwood, and Sheep River Hydrology Assessment (3PLN (MLH)) (Golder 2017)
WSC Station Name / Location of Interest				Fish Creek near Priddis					
Gross Drainage Area (km^2)				261					
Distribution / Method				3PLN (MLH)		Bow, Elbow, Highwood, and Sheep River Hydrology Assessment (3PLN (MLH)) (Golder, 2017)		Priddis Flood Risk Mapping Study (Alberta Environment, 2004)	
			Lower		75		128		
	20-yr	Flood Est.	Upper	139	124	148	290	96	-6%
			Lower		54		96		
	10-yr	Flood Est.	Upper	89	69	93	160	60	-4%
			Lower		35		64		
	5-yr	Flood Est.	Upper	52	24	54	84	36	-4%
			Lower		14		39		
	2-yr	Flood Est.	Upper	19	1460	19	26	15	0%
			Lower		196		14		

Notes:
"-" – not available

4.4 SENSITIVITY OF FLOOD FREQUENCY ANALYSIS TO 2005 PEAK

As a check, Stantec completed a sensitivity analysis to determine the impact of various 2005 peak flow estimates of Fish Creek downstream of Priddis Creek on the flood frequency results. The sensitivity analysis considered:

1. a peak estimate (385 m^3/s) as published in Bow, Elbow, Highwood and Sheep River Hydrology Assessment Report (Golder, 2017) and derived from the method described in Section 4.3;

2. a peak estimate (213 m^3/s) using the method described in Section 2.2 of this report and which is recommended for use in this study;

3. a peak estimate assuming that the June 18, 2005 event was solely caused by the Loon Lake dam breach (269 m^3/s); and,

4. an un-naturalized peak estimate that included the Loon Lake Dam breach (482 m^3/s).

Scenarios 3 and 4 were selected to provide 'bookend' sensitivity that reflect the upper and lower limit of the possibilities of the impact of the dam breach on the peak flow estimates (ie. sole contribution to or no

contribution to the flow recorded at the gauge). Table 4-5 illustrates the results of the sensitivity analysis for these different 2005 peak flow estimates.

Table 4-5 2005 Peak Flow at Fish Creek Downstream of Priddis Creek Sensitivity Analysis

Estimated 2005 Peak Flow Estimate	Flood Frequency Results			
	385 m³/s	213 m³/s	269 m³/s	482 m³/s
Return Period (years)	**Golder 2017**	**Stantec Analysis (3PLN (MLH))**		
1000	926	826	769	931
750	829	725	692	834
500	713	630	594	710
350	614	551	517	614
200	481	438	412	484
100	**350**	**322**	**304**	**352**
75	305	280	266	306
50	248	230	219	249
35	204	190	182	205
20	148	139	133	148
10	93.3	88.9	86	93.6
5	53.7	51.9	50.8	53.8
2	19.1	19	18.9	19.1

The sensitivity analysis indicated that the 100-year return period flow varied from by up to 48 m^3/s for the above noted 2005 peak flow estimates. Based on discussions with the Government of Alberta project team, Stantec has proceeded with the 2005 peak flow estimate (213 m³/s) as described in Section 2.2 of this report.

5.0 CLIMATE CHANGE COMMENTARY

Historical precipitation and temperature data tend to exhibit discernable trends over time. This non-stationarity may be evident in spikes, trends, or cycles, but it may also be evident in climate-dependent hydrologic parameters such as frequency and magnitude of peak flow. Climate change refers to a phenomenon outside of the expected natural variability in meteorological and climate-dependent parameters attributed directly or indirectly to anthropogenic activity that alters the composition of the global atmosphere (Alberta Transportation, 2004). Due to the complexity of climate change, quantification of change in climate-dependent hydrologic parameters is difficult to predict and is subject to a certain level of uncertainty. Climate change continues to affect meteorological and hydrological data so that traditional methods of predicting flood frequency and magnitude based on historical records should be combined with climate change adaption processes. The following describes current and future climate change adaption approaches in Alberta.

5.1 ALBERTA CLIMATE CHANGE ADAPTATION

The impacts of climate change on spring flooding in the Elbow River watershed were studied using statistical analysis of historical hydro-climatological data and a modeling analysis using the Canadian Regional Climate Model (CRCM) and the SSARR Watershed model (Valeo, Xiang, Bouchart, Yeung, & Ryan, 2007). Statistical analyses revealed that there were significantly increasing trends in annual mean temperature caused by significant trends in specific months of the year. The months showing significant trends were February and March for the eastern most part of the watershed and January, March, April, July, and August for the western most part of the watershed. In the eastern part of the watershed, observations showed significant decreases in snowfall but no trends in total annual precipitation. Conversely, increases in snowfall were observed in the western portion near the foothills. No significant trends were observed in discharges within the watershed but modeling spring freshet flooding showed that spring time flooding due to expected increases in precipitation during the month of May can nearly double flood peaks.

The hydrological regime of the Elbow River watershed in Alberta was studied to determine how future scenarios of land-use and climate change might affect it (Marceau, Wijesekara, & Farjad, 2014). This was investigated using an integrated modeling system including a cellular automated and spatially-distributed hydrological model (MIKE SHE/MIKE 11) for scenario simulation. The study concluded that climate change might cause a decrease in average annual overland flow, baseflow, and streamflow while there may be an increase in evapotranspiration, creating conditions for water scarcity. In addition, an increase in temperature during winter and spring will increase snowmelt and peak river flow, creating an increased flood risk from April to June.

The Elbow River watershed borders the north boundary of the Fish Creek watershed (Map 2, Appendix A). The Elbow River and Fish Creek watersheds are located in the same natural subregion; foothills parkland (Downing and Pettapiece 2006). The natural subregions are subdivisions of natural regions and are characterized by vegetation, climate, elevation, and latitudinal or physiographic differences within a given region. Therefore, the results of the climate change studies completed for the Elbow River watershed are applicable to the Fish Creek watershed.

Previous flood frequency analyses conducted in Alberta from the late 1960's to the late 1990's were evaluated to better define the problem of inconsistency regarding flood frequency analyses prepared for water management projects (Niel & Watt, 2001). The study found that many flood records in Alberta exhibit a high degree of statistical variability and/or high degree of irregularity in their time series. This study advised to expend considerable effort on scrutinizing the data and possibly extending the series by using other stations on the stream or in nearby basins subject to the same meteorological events. When interpreting the results of this analyses, the user should consider the likely magnitude of missing events in an incomplete record. Associated meteorological and basin conditions should be investigated where issues arise from data reliability, period of record, and time series irregularity. It was suggested by the same study that it may be advisable to adopt the simplest distribution, often Log-Normal, and to tend towards higher estimates for long return periods for certain cases where the fitting distribution may make a considerable difference to flood-frequency estimates. Three parameter distributions selected for use in this study should be viewed with caution, since the reliability of skew coefficients derived from short

records is generally low. Extrapolation to return periods exceeding record lengths should be reviewed with caution. No mention was made regarding use of climate change adaption methods in any of the highlighted case studies for flood frequency analyses.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

Stantec reviewed existing flow data for WSC 05BK001, Fish Creek near Priddis, and estimated the natural annual maximum instantaneous flow for 2005 at 213 m^3/s based on the WSC instantaneous flow record and the results presented in the "Loon Lake Dam Breach Inundation Study" (AMEC, 2008). In addition, potential flow regulation by local reservoirs was evaluated to determine if impacts are significant enough to warrant formal flow naturalization and regulation. A simple modeling approach based on HEC-HMS model was applied to determine reservoir impacts. From the analysis it was concluded that the reservoirs do not have a regulating effect on the flood peaks for Priddis and Fish creeks and that flow naturalization to account for the effect of these reservoirs was not warranted.

Flood frequency estimates were completed at the following locations: Fish Creek near Priddis (WSC 05BK001); and ungauged basins at Fish Creek above Priddis Creek and Priddis Creek at the mouth. Flood frequency estimates were computed using the WSC annual maximum instantaneous flow data at Fish Creek near Priddis Station including Stantec's estimate for the 2005 natural instantaneous flow using HYFRAN+, Bulletin 17B, and 17C.

Commentary on the potential effects of climate change was completed, including interpretation of available research and a review of standards applied to flood frequency analysis in Alberta. A study in Alberta found that it may be advisable to adopt the simple distribution, Log-Normal, for certain cases where the fitting distribution may make a considerable difference to flood-frequency estimates. Stantec presented flood frequency results based on the three-parameter log normal distribution because it best fit the data series from the Fish Creek near Priddis Station (**Table 4-3**).

6.2 RECOMMENDATIONS

Stantec recommends that the computed, naturalized instantaneous flood flows provided in **Table 6-1** for Fish and Priddis Creeks be used to assess and identify river and flood hazards and in subsequent phases of the Priddis River Hazard Study.

Table 6-1 Recommended Naturalized Instantaneous Flood Flows (m^3/s) for the Priddis River Hazard Study

Return Period (years)	Priddis Creek at the Mouth	Fish Creek upstream of Priddis Creek	Fish Creek downstream of Priddis Creek
2	8	11	19
5	22	30	52
10	38	51	89
20	60	79	139
35	82	108	190
50	99	131	230
75	120	160	280
100	138	184	322
200	188	250	438
350	237	314	551
500	271	359	630
750	312	413	725
1000	355	471	826

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Appendix A MAPS

JUMPINGPOUND CREEK AT BATEMAN'S RANCH (05BH011)

ELBOW RIVER BELOW GLENMORE DAM (05BJ001)

ELBOW RIVER ABOVE GLENMORE DAM (05BJ005)

GLENMORE RESERVOIR AT CALGARY (05BJ008)

ELBOW RIVER AT SARCEE BRIDGE (05BJ010)

ELBOW RIVER AT FULLERTON'S RANCH (05BJ003)

ELBOW RIVER AT BRAGG CREEK (05BJ004)

FISH CREEK NEAR MIDNAPORE (05BK002)

FISH CREEK AT BOW BOTTOM TRAIL (05BK003)

FISH CREEK NEAR PRIDDIS (05BK001)

THREEPOINT CREEK NEAR MILLARVILLE (05BL013)

Donald Runge

Unnamed

Loon Lake

Donald Harvie

Bragg Creek

Elbow River

Iron Creek

Millburn Creek

Priddis Creek

Fish Creek

Whiskey Creek

Fisher Creek

Pine Creek

Bow River

8

2

560

758

66

22

22X

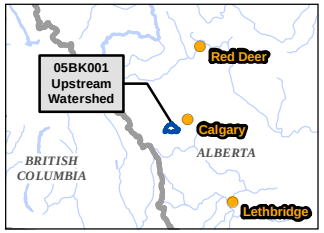
2A

552

549

762

DRAFT



Legend

- Water Survey of Canada Hydrometric Station
- Fish Creek Ungauged Subwatershed Outlet
- Priddis Creek Ungauged Subwatershed Outlet
- Reservoir
- Major Road
- Railway
- Watercourse
- Waterbody
- Fish Creek Subwatershed
- Priddis Creek Subwatershed
- Study Area

0 2 4 Kilometres

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Notes
1. Coordinate System: NAD 1983 UTM Zone 11N
2. Base features obtained from the Province of Alberta and the Government of Canada

Stantec

Project Location: Priddis, Alberta

110773627

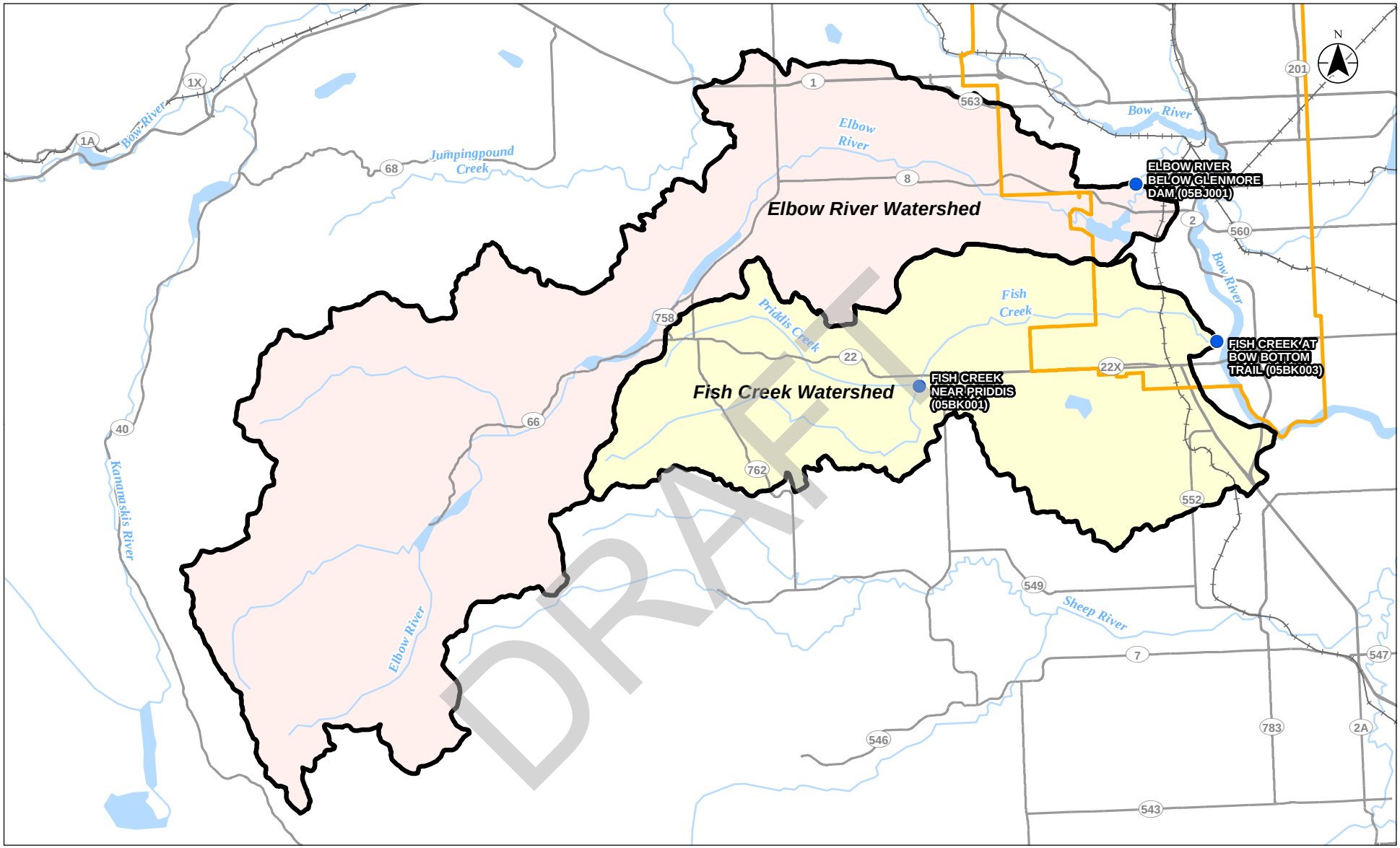
Prepared by ACampigotto on 2018-11-15
Technical Review by AKneale on 2018-11-15

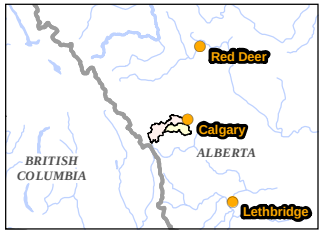
Client: Alberta Government

Project: Priddis River Hazard Study

Map No. 1

Title: Location Map and Subwatersheds





Legend

- Water Survey of Canada Hydrometric Station
- Major Road
- Railway
- Watercourse
- Waterbody
- Elbow River watershed
- Fish Creek Watershed
- City of Calgary

0 5 10 Kilometres

1:400,000 (At original document size of 8.5x11)

Notes
1. Coordinate System: NAD 1983 UTM Zone 11N
2. Base features obtained from the Province of Alberta and the Government of Canada

Stantec

Project Location
Priddis, Alberta

110773627

Prepared by ACampigotto on 2018-11-15
Technical Review by AKneale on 2018-11-15

Client
Alberta Government

Project
Priddis River Hazard Study

Map No.
2

Title
Watersheds

Appendix B FIGURES

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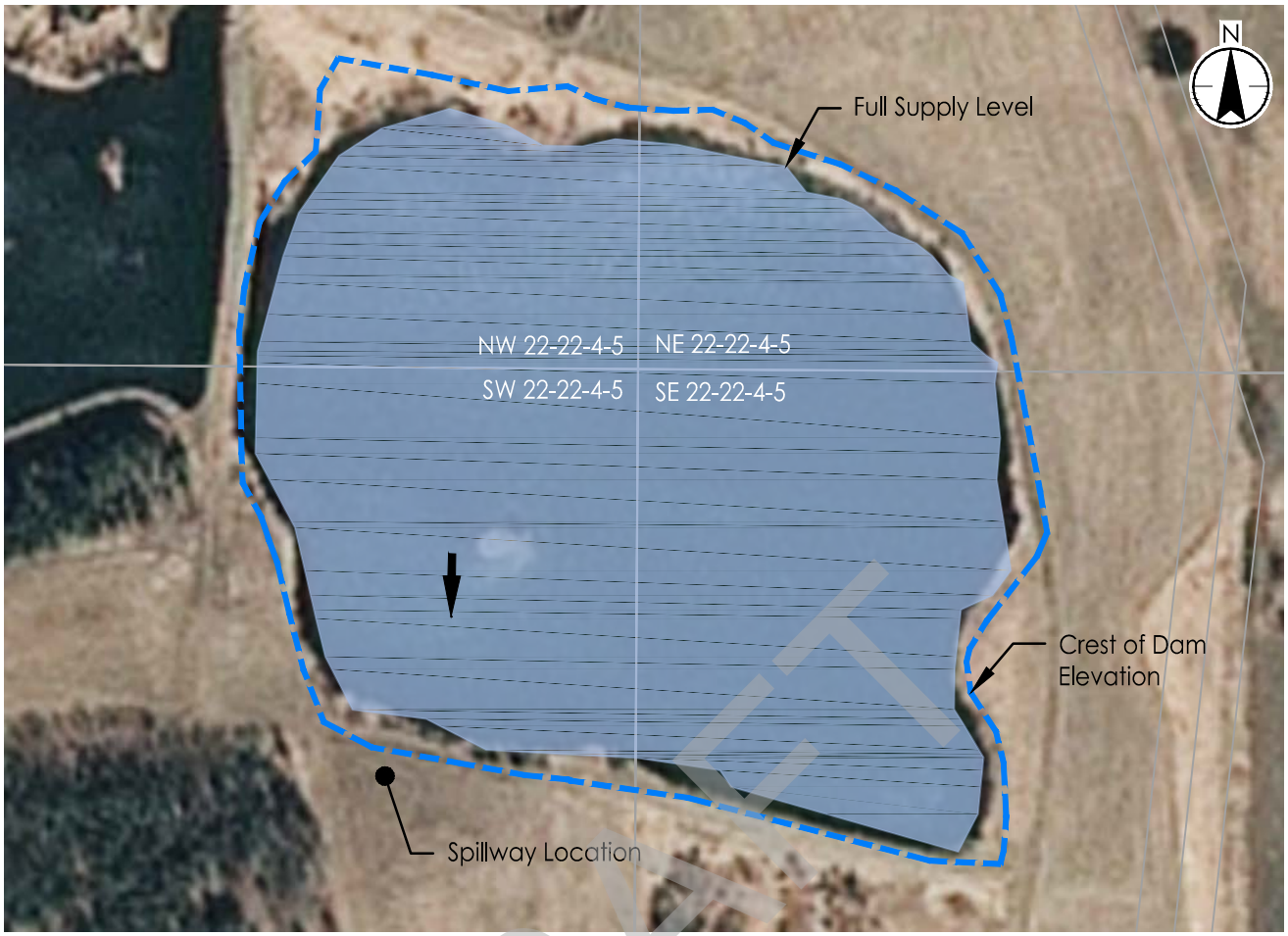

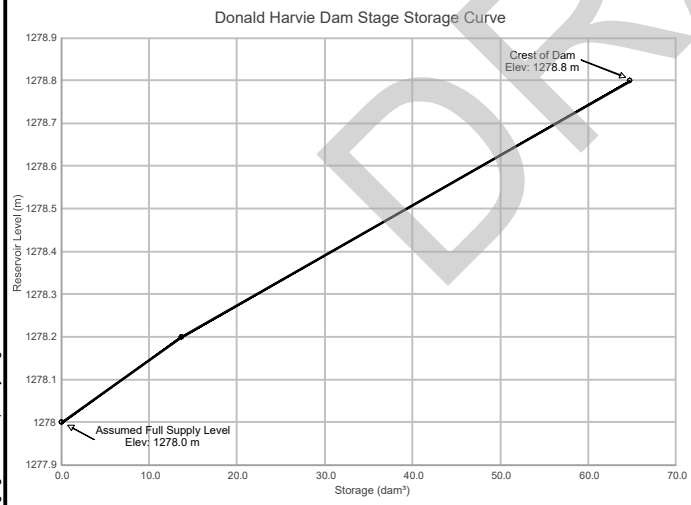

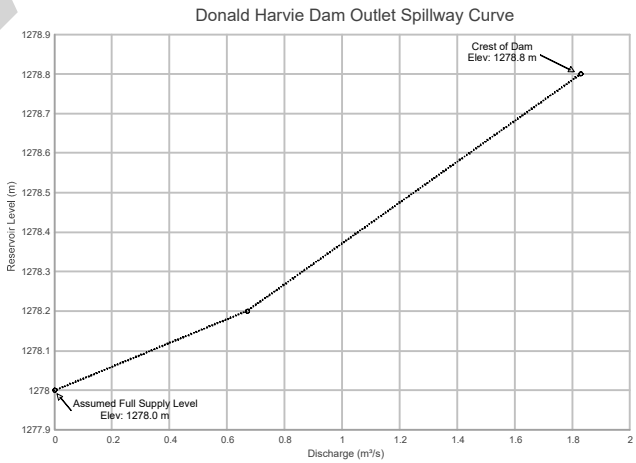

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Stantec

Client/Project
Alberta Government
Priddis River Hazard Study

Figure No.
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Donald Harvie Dam

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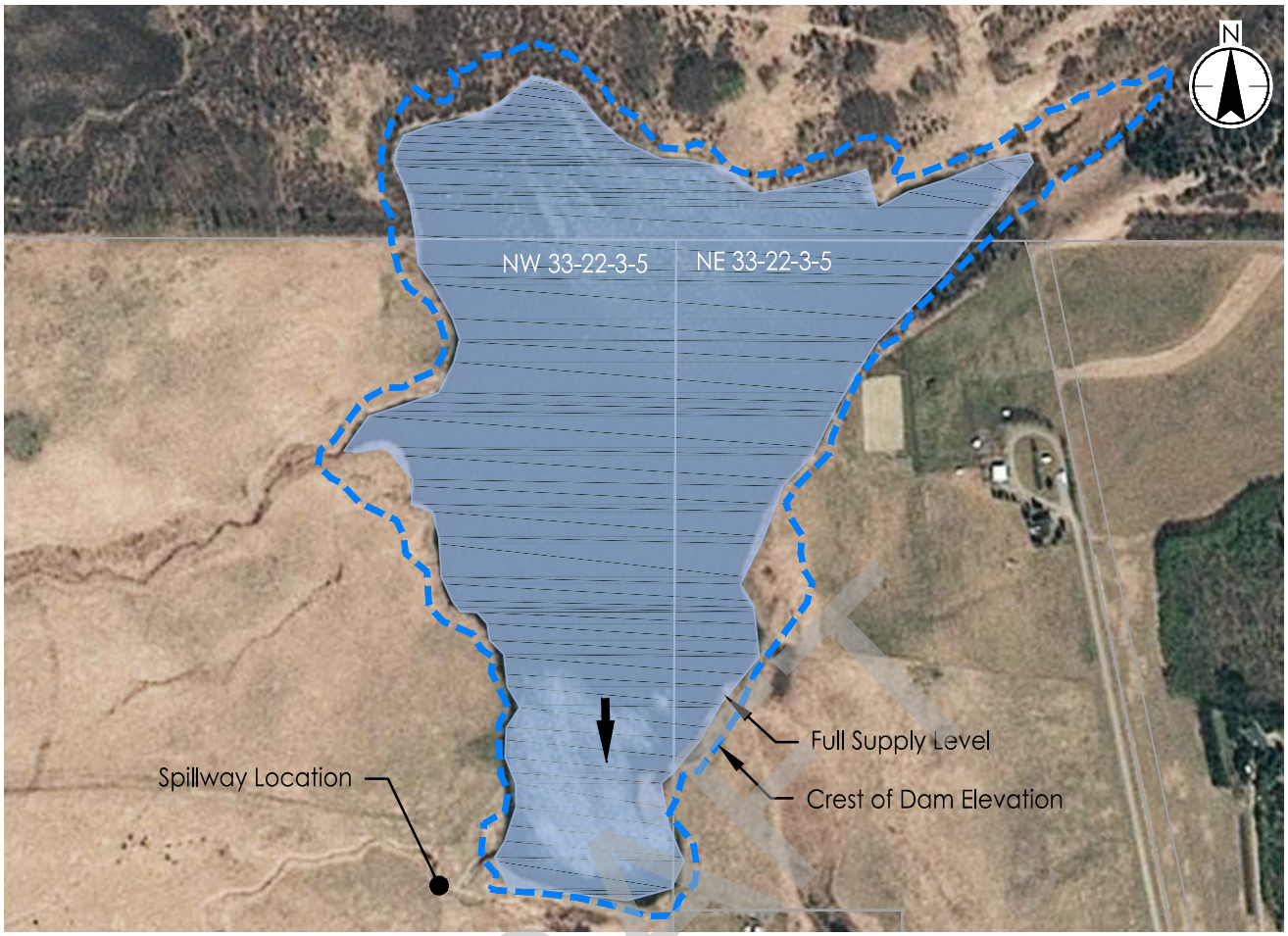

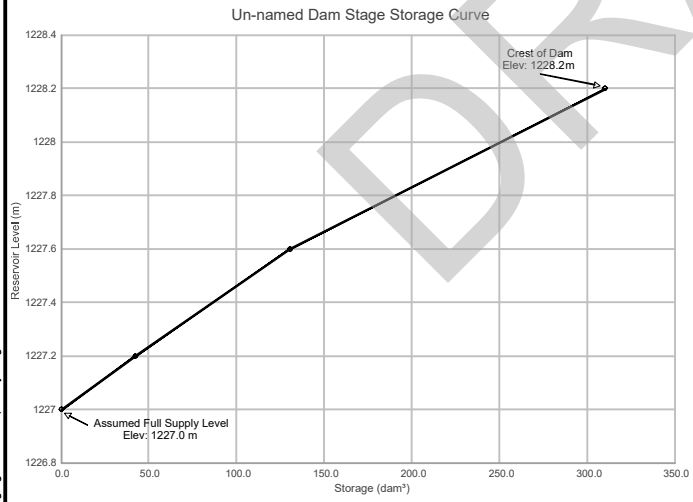

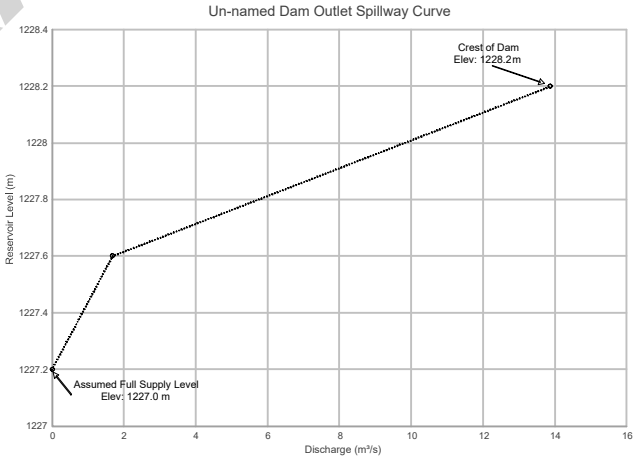

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Priddis River Hazard Study

Figure No.
2.0

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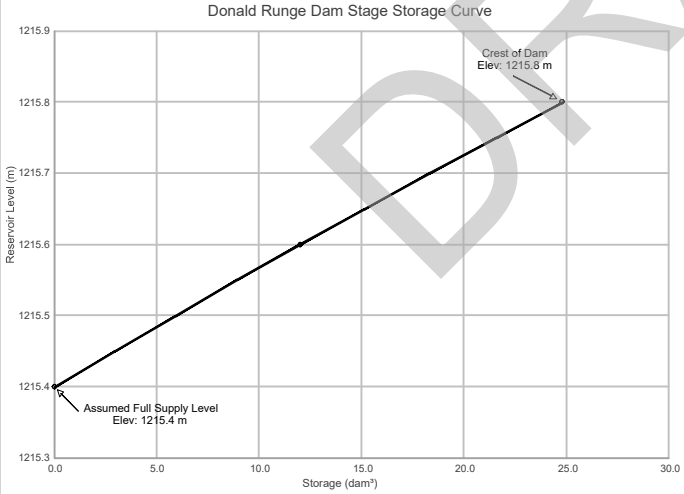

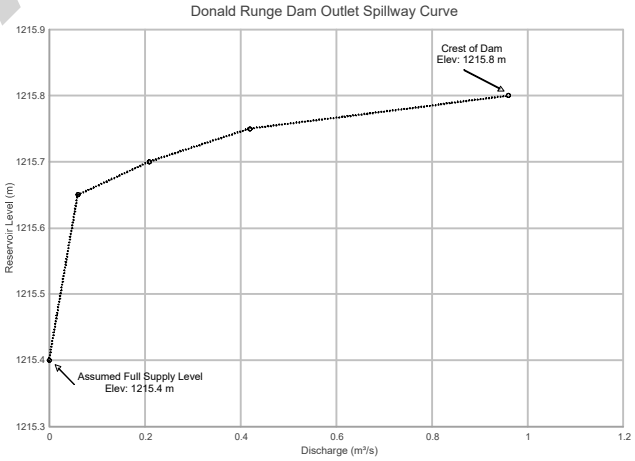

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Client/Project
Alberta Government
Priddis River Hazard Study

Figure No.
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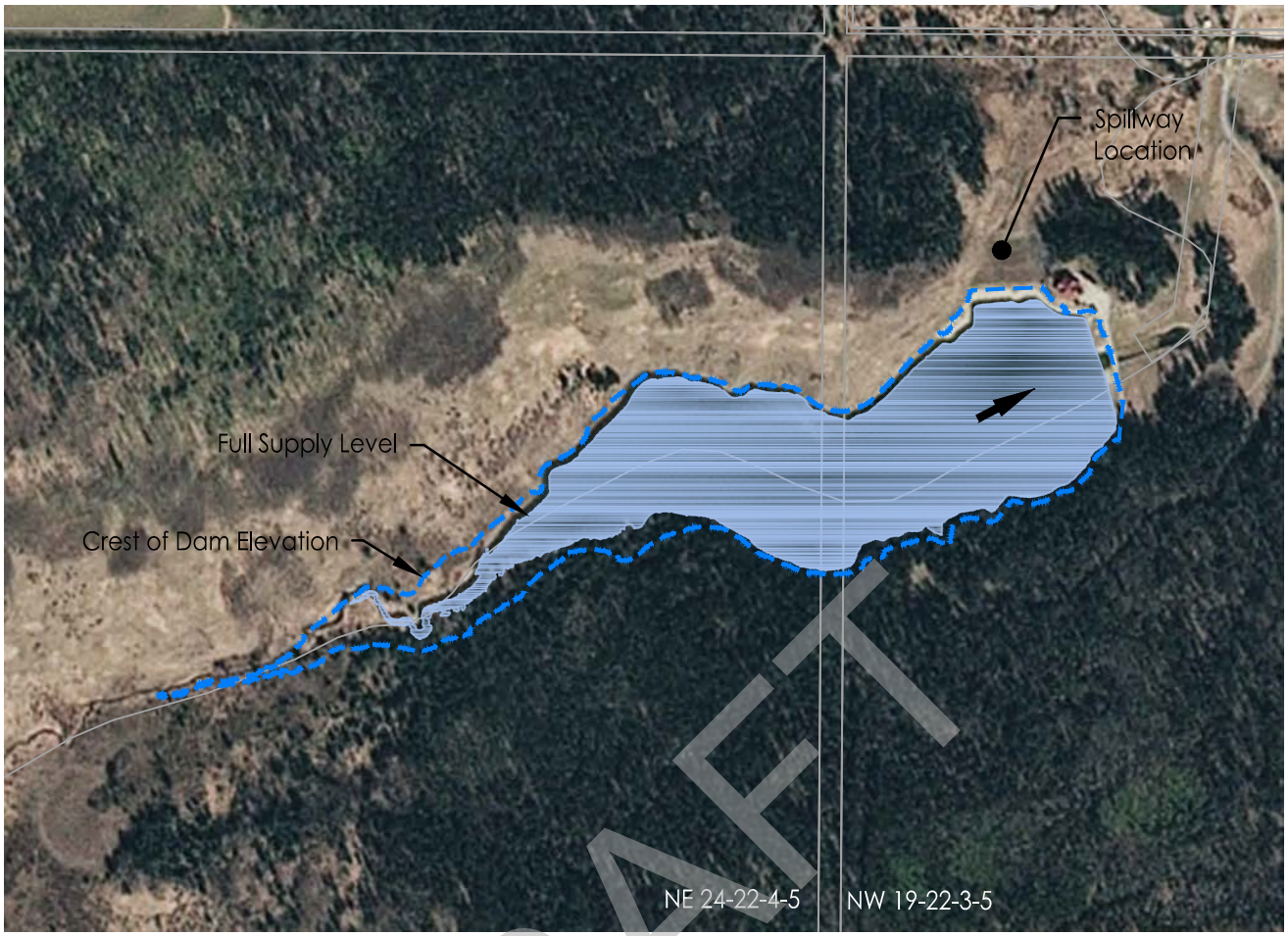

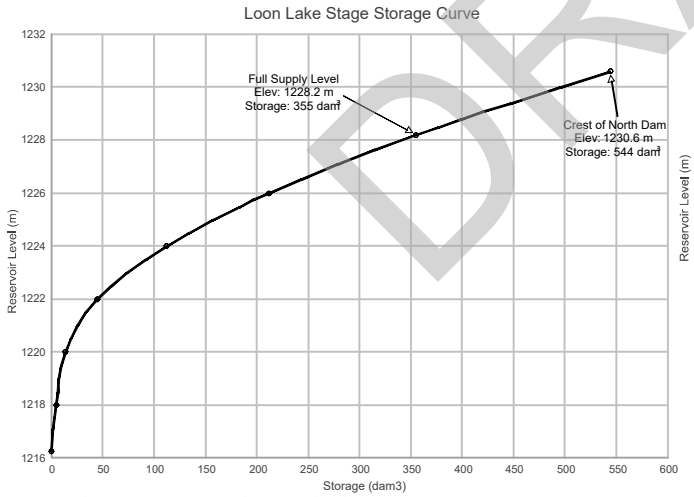

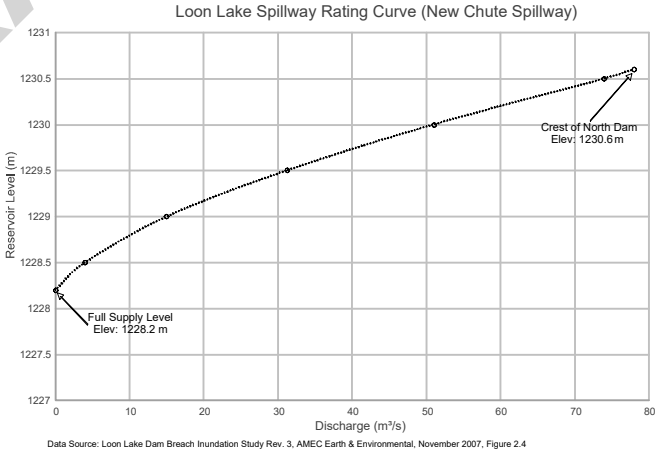

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November 2018
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Priddis River Hazard Study

Figure No.
4.0

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Loon Lake Dam

Appendix C TABLES

Table C1 Maximum Annual Instantaneous Flow (Fish Creek near Priddis, WSC Gauge 05BK001)

Year	Maximum Annual Instantaneous Flow (m^3/s)	Data Source
1908	18.8	Golder 2017
1909	21.2	Golder 2017
1910	1.6	Golder 2017
1911	62.6	Golder 2017
1912	51.1	Golder 2017
1913	11.7	Golder 2017
1914	4.0	Golder 2017
1915	200.0	Water Survey of Canada measured
1916	171.1	Golder 2017
1956	7.5	Golder 2017
1957	9.7	Golder 2017
1958	18.3	Golder 2017
1959	41.3	Water Survey of Canada measured
1960	6.3	Golder 2017
1961	4.1	Water Survey of Canada measured
1962	11.5	Golder 2017
1963	81.9	Golder 2017
1964	23.4	Golder 2017
1965	40.0	Golder 2017
1966	20.0	Golder 2017
1967	101.3	Golder 2017
1968	9.6	Golder 2017
1969	105.3	Golder 2017
1970	47.4	Golder 2017
1971	27.0	Golder 2017
1972	9.5	Golder 2017
1973	16.2	Golder 2017
1974	28.1	Golder 2017
1975	13.4	Golder 2017
1976	4.2	Golder 2017
1977	9.1	Golder 2017
1978	28.7	Golder 2017
1979	8.5	Golder 2017
1980	14.5	Golder 2017

Table C1 Maximum Annual Instantaneous Flow (Fish Creek near Priddis, WSC Gauge 05BK001)

Year	Maximum Annual Instantaneous Flow (m^3/s)	Data Source
1981	23.0	Golder 2017
1982	6.1	Golder 2017
1983	21.6	Golder 2017
1984	5.6	Water Survey of Canada
1985	8.3	Water Survey of Canada
1986	7.8	Golder 2017
1987	6.5	Golder 2017
1988	4.1	Water Survey of Canada
1989	5.0	Water Survey of Canada
1990	20.0	Water Survey of Canada
1991	9.7	Water Survey of Canada
1992	45.0	Water Survey of Canada
1993	21.9	Golder 2017
1994	70.3	Water Survey of Canada
1995	84.2	Water Survey of Canada
1996	22.3	Golder 2017
1997	26.6	Water Survey of Canada
1998	31.9	Water Survey of Canada
1999	31.3	Water Survey of Canada
2000	5.1	Golder 2017
2001	13.2	Golder 2017
2002	26.0	Water Survey of Canada
2003	25.6	Water Survey of Canada
2004	3.9	Water Survey of Canada
2005	213.0	As described in Section 2.2
2006	64.8	Water Survey of Canada
2007	12.6	Water Survey of Canada
2008	80.6	Water Survey of Canada
2009	5.5	Water Survey of Canada
2010	15.6	Water Survey of Canada
2011	104.0	Golder 2017
2012	42.5	Water Survey of Canada
2013	283.1	Golder 2017
2014	63.4	Water Survey of Canada
2015	3.1	Water Survey of Canada

C.1 FREQUENCY ANALYSIS RESULTS FOR FISH CREEK NEAR PRIDDIS

Table C2 Normal Distribution

Maximum Likelihood Parameters					
mu	38.291304				
sigma	52.654006				
Return Period	**Non-exceedance Probability**	**Flow**	**Standard Deviation**	**Confidence Interval (95%)**	
				Lower CI	**Upper CI**
10000	0.9999	234.0	17.9	199.0	269.0
2000	0.9995	212.0	16.2	180.0	243.0
1000	0.999	201.0	15.3	171.0	231.0
200	0.995	174.0	13.2	148.0	200.0
100	0.99	161.0	12.3	137.0	185.0
50	0.98	146.0	11.2	124.0	168.0
20	0.95	125.0	9.8	106.0	144.0
10	0.9	106.0	8.6	89.0	123.0
5	0.8	82.6	7.4	68.1	97.1
3	0.6667	60.9	6.6	48.0	73.9
2	0.5	38.3	6.3	25.9	50.7
1.4286	0.3	10.7	6.8	N/D	24.0
1.25	0.2	N/D	7.4	N/D	N/D
1.1111	0.1	N/D	8.6	N/D	N/D
1.0526	0.05	N/D	9.8	N/D	N/D
1.0204	0.02	N/D	11.2	N/D	N/D
1.0101	0.01	N/D	12.3	N/D	N/D
1.005	0.005	N/D	13.2	N/D	N/D
1.001	0.001	N/D	15.3	N/D	N/D
1.0005	0.0005	N/D	16.2	N/D	N/D
1.0001	0.0001	N/D	17.9	N/D	N/D

Table C3 Lognormal Distribution

Maximum Likelihood Parameters

mu	2.991005
sigma	1.139269

Return Period	Non-exceedance Probability	Flow	Standard Deviation	Confidence Interval (95%)	
				Lower CI	Upper CI
10000	0.9999	1380.0	535.0	329.0	2430.0
2000	0.9995	846.0	296.0	266.0	1430.0
1000	0.999	673.0	223.0	236.0	1110.0
200	0.995	375.0	107.0	164.0	585.0
100	0.99	282.0	74.9	135.0	429.0
50	0.98	207.0	50.2	108.0	305.0
20	0.95	130.0	27.4	76.0	183.0
10	0.9	85.7	15.9	54.5	117.0
5	0.8	51.9	8.3	35.6	68.2
3	0.6667	32.5	4.7	23.4	41.6
2	0.5	19.9	2.7	14.6	25.3
1.4286	0.3	11.0	1.6	7.8	14.1
1.25	0.2	7.6	1.2	5.2	10.0
1.1111	0.1	4.6	0.9	2.9	6.3
1.0526	0.05	3.1	0.6	1.8	4.3
1.0204	0.02	1.9	0.5	1.0	2.8
1.0101	0.01	1.4	0.4	0.7	2.1
1.005	0.005	1.1	0.3	0.5	1.7
1.001	0.001	0.6	0.2	0.2	1.0
1.0005	0.0005	0.5	0.2	0.1	0.8
1.0001	0.0001	0.3	0.1	0.1	0.5

Table C4 Lognormal III Distribution

Maximum Likelihood Parameters	
m	1.022337
mu	2.888084
sigma	1.238528

Return Period	Non-exceedance Probability	Flow	Standard Deviation	Confidence Interval (95%)	
				Lower CI	Upper CI
10000	0.9999	1800.0	831.0	N/D	N/D
2000	0.9995	1060.0	436.0	203.0	1910.0
1000	0.999	826.0	321.0	196.0	1460.0
200	0.995	438.0	145.0	154.0	722.0
100	0.99	322.0	97.7	130.0	513.0
50	0.98	230.0	63.2	106.0	354.0
20	0.95	139.0	32.6	75.0	203.0
10	0.9	88.9	18.0	53.6	124.0
5	0.8	51.9	8.9	34.6	69.3
3	0.6667	31.6	4.8	22.3	41.0
2	0.5	19.0	2.7	13.6	24.3
1.4286	0.3	10.4	1.5	7.4	13.4
1.25	0.2	7.4	1.1	5.2	9.6
1.1111	0.1	4.7	0.7	3.2	6.2
1.0526	0.05	3.4	0.5	2.3	4.4
1.0204	0.02	2.4	0.4	1.6	3.2
1.0101	0.01	2.0	0.4	1.3	2.8
1.005	0.005	1.8	0.4	1.1	2.5
1.001	0.001	1.4	0.4	0.7	2.2
1.0005	0.0005	1.3	0.4	0.6	2.1
1.0001	0.0001	1.2	0.4	0.4	2.0

Table C5 Exponential Distribution

Maximum Likelihood Parameters					
alpha	37.230882				
m	1.060422				
Return Period	**Non-exceedance Probability**	**Flow**	**Standard Deviation**	**Confidence Interval (95%)**	
				Lower CI	**Upper CI**
10000	0.9999	344.0	41.5	263.0	425.0
2000	0.9995	284.0	34.3	217.0	351.0
1000	0.999	258.0	31.1	197.0	319.0
200	0.995	198.0	23.9	152.0	245.0
100	0.99	173.0	20.7	132.0	213.0
50	0.98	147.0	17.6	112.0	181.0
20	0.95	113.0	13.5	86.2	139.0
10	0.9	86.8	10.3	66.5	107.0
5	0.8	61.0	7.2	46.8	75.1
3	0.6667	42.0	4.9	32.3	51.6
2	0.5	26.9	3.1	20.8	33.0
1.4286	0.3	14.3	1.6	11.1	17.5
1.25	0.2	9.4	1.1	7.2	11.5
1.1111	0.1	5.0	0.7	3.7	6.3
1.0526	0.05	3.0	0.6	1.9	4.1
1.0204	0.02	1.8	0.5	0.8	2.9
1.0101	0.01	1.4	0.5	0.4	2.5
1.005	0.005	1.3	0.5	0.2	2.3
1.001	0.001	1.1	0.5	0.0	2.2
1.0005	0.0005	1.1	0.5	0.0	2.1
1.0001	0.0001	1.1	0.5	0.0	2.1

Table C6 Pearson Type III Distribution

Maximum Likelihood Parameters					
alpha	0.018728				
lambda	0.774816				
m	1.6				
Return Period	**Non-exceedance Probability**	**Flow**	**Standard Deviation**	**Confidence Interval (95%)**	
				Lower CI	**Upper CI**
10000	0.9999	457.0	53.3	352.0	562.0
2000	0.9995	373.0	44.1	287.0	460.0
1000	0.999	337.0	40.1	259.0	416.0
200	0.995	254.0	30.8	194.0	315.0
100	0.99	219.0	26.8	166.0	271.0
50	0.98	184.0	22.8	139.0	228.0
20	0.95	137.0	17.5	103.0	172.0
10	0.9	103.0	13.4	76.8	129.0
5	0.8	69.3	9.2	51.3	87.4
3	0.6667	46.3	6.1	34.3	58.4
2	0.5	27.1	3.3	20.7	33.5
1.4286	0.3	13.1	N/D	N/D	N/D
1.25	0.2	8.1	N/D	N/D	N/D
1.1111	0.1	4.1	N/D	N/D	N/D
1.0526	0.05	2.5	N/D	N/D	N/D
1.0204	0.02	1.8	N/D	N/D	N/D
1.0101	0.01	1.7	N/D	N/D	N/D
1.005	0.005	1.8	N/D	N/D	N/D
1.001	0.001	2.1	N/D	N/D	N/D
1.0005	0.0005	2.2	N/D	N/D	N/D
1.0001	0.0001	2.4	N/D	N/D	N/D

Table C7 Log Pearson Type III Distribution

Maximum Likelihood Parameters

alpha	20.268087
lambda	93.623032
m	-3.320257

Return Period	Non-exceedance Probability	Flow	Standard Deviation	Confidence Interval (95%)	
				Lower CI	Upper CI
10000	0.9999	1950.0	2050.0	N/D	N/D
2000	0.9995	1080.0	906.0	N/D	N/D
1000	0.999	824.0	617.0	N/D	N/D
200	0.995	418.0	227.0	N/D	N/D
100	0.99	303.0	138.0	N/D	N/D
50	0.98	215.0	80.3	N/D	N/D
20	0.95	129.0	35.5	59.7	199.0
10	0.9	83.2	17.5	48.9	118.0
5	0.8	49.6	8.2	33.6	65.6
3	0.6667	31.2	4.6	22.2	40.3
2	0.5	19.2	2.8	13.7	24.6
1.4286	0.3	10.9	1.6	7.7	14.1
1.25	0.2	7.8	1.2	5.5	10.1
1.1111	0.1	5.0	0.8	3.4	6.6
1.0526	0.05	3.5	0.7	2.2	4.8
1.0204	0.02	2.4	0.6	1.2	3.5
1.0101	0.01	1.8	0.6	0.7	2.9
1.005	0.005	1.5	0.5	0.4	2.5
1.001	0.001	0.9	0.5	0.0	1.9
1.0005	0.0005	0.8	0.5	-0.1	1.7
1.0001	0.0001	0.5	0.4	-0.3	1.4

Table C8 Gumbel Distribution

Maximum Likelihood Parameters					
u	19.802446				
alpha	25.255121				
Return Period	**Non-exceedance Probability**	**Flow**	**Standard Deviation**	**Confidence Interval (95%)**	
				Lower CI	**Upper CI**
10000	0.9999	252.0	23.3	207.0	298.0
2000	0.9995	212.0	19.4	174.0	250.0
1000	0.999	194.0	17.8	159.0	229.0
200	0.995	154.0	14.0	126.0	181.0
100	0.99	136.0	12.4	112.0	160.0
50	0.98	118.0	10.8	97.2	139.0
20	0.95	94.8	8.7	77.8	112.0
10	0.9	76.6	7.1	62.8	90.5
5	0.8	57.7	5.5	46.9	68.5
3	0.6667	42.6	4.4	34.0	51.2
2	0.5	29.1	3.6	22.1	36.0
1.4286	0.3	15.1	3.1	9.1	21.2
1.25	0.2	7.8	3.1	1.8	13.8
1.1111	0.1	N/D	N/D	N/D	N/D
1.0526	0.05	N/D	N/D	N/D	N/D
1.0204	0.02	N/D	N/D	N/D	N/D
1.0101	0.01	N/D	N/D	N/D	N/D
1.005	0.005	N/D	N/D	N/D	N/D
1.001	0.001	N/D	N/D	N/D	N/D
1.0005	0.0005	N/D	N/D	N/D	N/D
1.0001	0.0001	N/D	N/D	N/D	N/D

Table C9 General Extreme Value Distribution

Maximum Likelihood Parameters

alpha	12.108654
k	-0.848845
u	12.318498

Return Period	Non-exceedance Probability	Flow	Standard Deviation	Confidence Interval (95%)	
				Lower CI	Upper CI
10000	0.9999	35400.0	42000.0	N/D	N/D
2000	0.9995	9040.0	8690.0	N/D	N/D
1000	0.999	5020.0	4350.0	N/D	N/D
200	0.995	1280.0	827.0	N/D	N/D
100	0.99	706.0	392.0	N/D	N/D
50	0.98	390.0	181.0	N/D	N/D
20	0.95	176.0	61.3	55.4	296.0
10	0.9	94.4	25.3	44.8	144.0
5	0.8	49.0	9.7	30.1	67.9
3	0.6667	28.7	4.5	19.9	37.6
2	0.5	17.5	2.4	12.8	22.3
1.4286	0.3	10.2	1.4	7.6	12.9
1.25	0.2	7.6	1.0	5.6	9.6
1.1111	0.1	5.1	0.8	3.6	6.6
1.0526	0.05	3.7	0.7	2.4	5.0
1.0204	0.02	2.5	0.6	1.3	3.8
1.0101	0.01	2.0	0.7	0.7	3.3
1.005	0.005	1.5	0.7	0.2	2.9
1.001	0.001	0.8	0.8	-0.7	2.4
1.0005	0.0005	0.6	0.8	-1.0	2.2
1.0001	0.0001	0.2	0.9	-1.5	2.0

Table C10 Weibull Distribution

Maximum Likelihood Parameters

alpha 31.769071

c 0.739113

Return Period	Non-exceedance Probability	Flow	Standard Deviation	Confidence Interval (95%)	
				Lower CI	Upper CI
10000	0.9999	641.0	154.0	339.0	943.0
2000	0.9995	494.0	111.0	276.0	712.0
1000	0.999	434.0	94.5	249.0	619.0
200	0.995	303.0	60.4	185.0	422.0
100	0.99	251.0	47.8	157.0	345.0
50	0.98	201.0	36.6	129.0	273.0
20	0.95	140.0	24.0	93.2	187.0
10	0.9	98.2	16.2	66.4	130.0
5	0.8	60.5	10.0	40.8	80.1
3	0.6667	36.1	6.4	23.6	48.6
2	0.5	19.3	3.9	11.7	27.0
1.4286	0.3	7.9	2.0	4.0	11.8
1.25	0.2	4.2	1.2	1.8	6.6
1.1111	0.1	1.5	0.6	0.4	2.6
1.0526	0.05	0.6	0.3	0.1	1.1
1.0204	0.02	0.2	0.1	N/D	N/D
1.0101	0.01	0.1	0.0	N/D	N/D
1.005	0.005	0.0	0.0	N/D	N/D
1.001	0.001	0.0	0.0	N/D	N/D
1.0005	0.0005	0.0	0.0	N/D	N/D
1.0001	0.0001	0.0	0.0	0.0	0.0

Table C11 Gamma Distribution

Maximum Likelihood Parameters

alpha 0.02329

lambda 0.891795

Return Period	Non-exceedance Probability	Flow	Standard Deviation	Confidence Interval (95%)	
				Lower CI	Upper CI
10000	0.9999	382.0	62.7	259.0	505.0
2000	0.9995	313.0	50.2	215.0	412.0
1000	0.999	284.0	44.9	196.0	372.0
200	0.995	216.0	32.8	152.0	280.0
100	0.99	187.0	27.7	133.0	241.0
50	0.98	158.0	22.8	113.0	202.0
20	0.95	119.0	16.5	87.1	152.0
10	0.9	90.7	12.0	67.1	114.0
5	0.8	62.2	8.0	46.6	77.7
3	0.6667	42.3	5.5	31.6	53.0
2	0.5	25.3	3.6	18.2	32.4
1.4286	0.3	12.3	2.4	7.7	16.9
1.25	0.2	7.4	1.8	3.9	10.9
1.1111	0.1	3.2	1.1	1.0	5.4
1.0526	0.05	1.4	0.7	0.1	2.7
1.0204	0.02	0.4	0.3	N/D	N/D
1.0101	0.01	0.2	0.1	N/D	N/D
1.005	0.005	0.1	0.0	0.0	0.2
1.001	0.001	0.2	0.2	N/D	N/D
1.0005	0.0005	0.3	0.2	N/D	N/D
1.0001	0.0001	0.5	0.3	N/D	N/D