Appendix C

Hydrologic Assessment Memoranda

Memo

To:	Syed Abbas	**File No:**	CW2174
Company:	Flood Mitigation Task Force	**Date:**	27 February 2014
From:	Gary Beckstead	**cc:**	Geoff Graham
Phone:	(403) 387-1628		
Email:	gary.beckstead@amec.com		
Subject:	Hydrological Assessment of BG1 Dam		

SUMMARY

A hydrological assessment of the BG1 dam proposed by the Flood Advisory Panel was undertaken to determine likely reductions in water levels along the Bow River in Calgary.

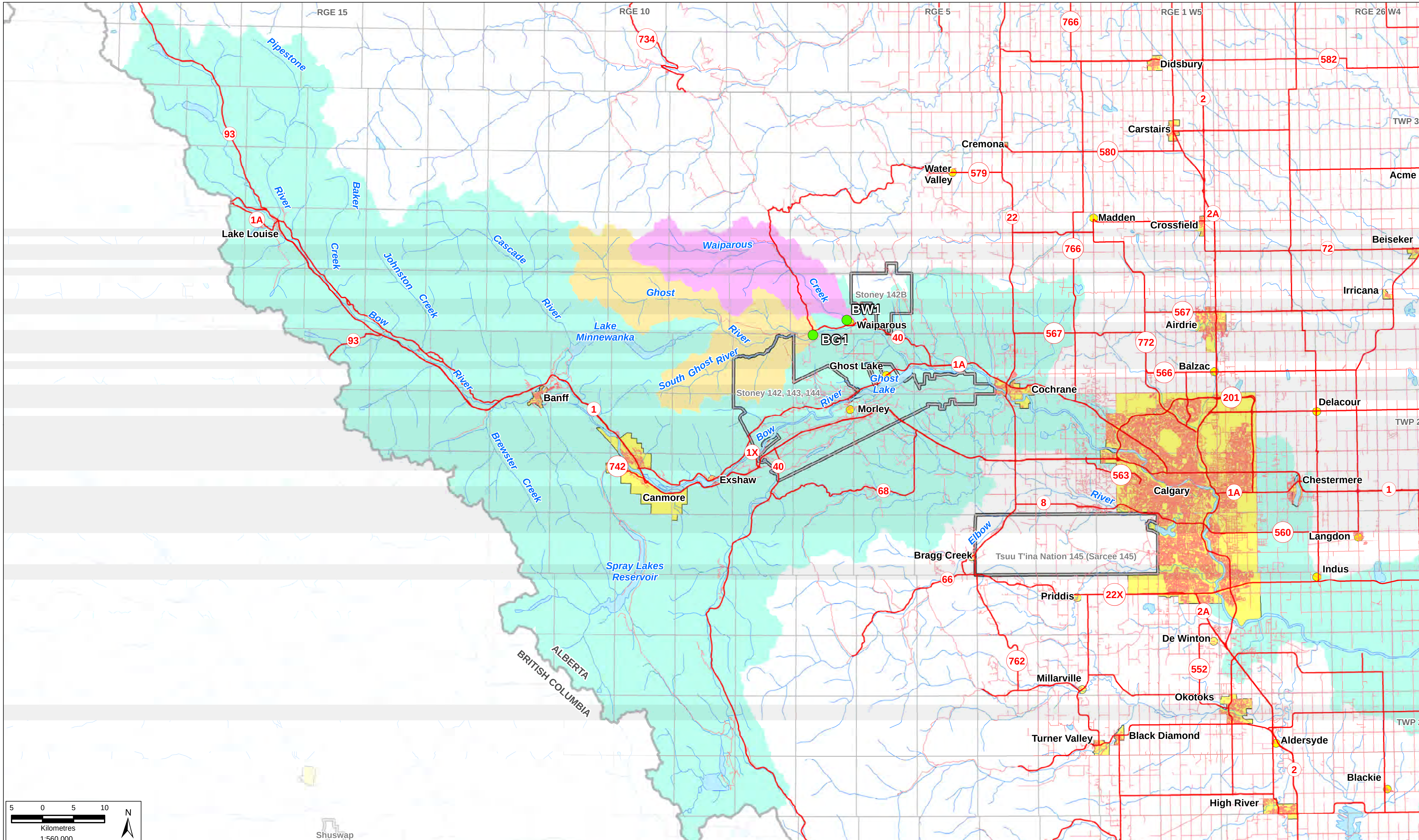
The drainage area of the Ghost River upstream of the proposed BG1 dam is approximately 485 km^2 or approximately 4.2% of the drainage area of the Bow River upstream of the Elbow River confluence. **Figure 1** illustrates the drainage basin upstream of the proposed BG1 Dam in relation to the catchment of the Bow River basin upstream of Calgary; it also shows the location of BW1, which is another site proposed by the Flood Advisory Panel.

The assessment was based on a routing model, which determined the outflows from Ghost Dam based on inflows from the Bow River near Seebe, the Ghost River above Waiparous Creek and from Waiparous Creek near the mouth and characteristics of Ghost Dam and Ghost Lake upstream of the dam. Flows from Jumpingpound Creek were added to the Ghost Dam outflows to provide a representation of the flows in the Bow River at Calgary. To evaluate the effects of the proposed BG1 Dam on the Ghost River, two scenarios were modeled:

1. No outflow from the Ghost River above Waiparous Creek – representative of a dam retaining 100% of the Ghost river flow, which would result in a maximum effect that is likely not attainable; and
2. A 60% reduction in the flows in the Ghost River above Waiparous Creek – representative of a detention dam as proposed by the Flood Advisory Panel at Quirk Creek on the Elbow River.

The key findings from the evaluation were:

- Peak discharges would be reduced by a maximum of 10% (129 m^3/s) with no outflow from BG1, and by 6% (77 m^3/s) for the detention dam scenario (60% outflow).
- Water levels along the Bow River in Calgary would potentially be reduced by a maximum of 0.18 to 0.27 m if 100% of the Ghost River flow is retained. Water level reductions for a detention dam at the BG1 site would more likely be less, in the range of 0.1 to 0.16 m.



Legend

- Township and Range
- Native Reserve
- Urban Location
- Bow River Drainage Basin
- Ghost River Basin Upstream of BG1
- Waiparous Creek Basin Upstream of BW1
- River or Lake
- River or Creek
- Highway
- Road
- Dam Site

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Alberta Flood Recovery Task Force
Flood Mitigation Study

The Bow Basin Upstream of Calgary

DATE:	February 2014
ANALYST:	NH
QA/QC:	TR KK GG
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Figure 1

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1.0 INTRODUCTION

In response to your request of 20 February 2014, AMEC Environment and Infrastructure, a division of AMEC Americas Ltd. (AMEC), has prepared the following hydrological evaluation of the BG1 dam proposed by the Flood Advisory Panel.

1.1 Background

The proposed BG1 dam site is located on the Ghost River upstream of the confluence with Waiparous Creek. Downstream of the mouth of Waiparous Creek, the lower Ghost River flows into Ghost Lake, formed by the Ghost Dam on the Bow River.

The drainage area of the Ghost River upstream of the proposed BG1 dam is approximately 485 km^2 or approximately 4.2% of the drainage area of the Bow River upstream of the Elbow River confluence. **Figure 1** in the Summary section of this report illustrates the drainage basin upstream of the proposed BG1 dam in relation to the catchment of the Bow River basin upstream of Calgary.

From a general perspective, the ability of the proposed BG1 dam to moderate flows at Calgary is in close proportion to it contributing drainage area. Hydrological data obtained at the Water Survey of Canada (WSC) hydrometric gauge 05BG010 located at the proposed dam site, indicate that the June flow volume is, on average, about 10% of that measured on the Bow River at Calgary (i.e., at the WSC gauge 05BH004, located upstream of the Elbow River confluence).

While the contributing area and flow volume are small in proportion to the respective values for the Bow River at Calgary, these do not necessarily indicate the true effectiveness of a flood detention dam on the Ghost River in terms of lowering flood levels at Calgary. Therefore, a more in-depth hydrological analysis was undertaken to further assess the flood mitigation benefits of the proposed BG1 dam.

1.2 Methodology

1.2.1 Approach

The following methodology was employed to evaluate the effectiveness of flood detention by the proposed BG1 Dam on the Ghost River:

- Daily flow data for hydrometric gauges in the area were obtained from the WSC web site (WSC 2014). These stations were:
  - Bow River near Seebe (05BE004)
  - Ghost River above Waiparous Creek (05BG010)
  - Waiparous Creek near the mouth (05BG006)
  - Ghost Lake near Cochrane (05BE005)
  - Ghost Tailrace (05BE999)
  - Jumpingpound Creek near the mouth (05BH009)
  - Bow River at Calgary (05BH004)

- Hydrographs were evaluated and normalized hydrographs were produced for each major inflow to Ghost Lake, for Jumpingpound Creek and for the Bow River at Calgary. In general, the highest flow years were used to characterize the shape of the normalized hydrograph.
- Based on available frequency analyses and the dimensionless hydrographs, stream discharge hydrographs were developed for the major streams to be modeled.
- Information on the storage characteristics of Ghost Lake (stage-storage-area table) and the outflow characteristics of Ghost Dam were obtained from TransAlta Corporation (TAC; Roger Drury, 2014 pers. comm.). Additional information on Ghost Dam (WER, 1981) was used to understand the nature of the service and emergency spillways. Outflow rating curves for Ghost Dam were developed from this information.
- A flood routing model was prepared using HEC-HMS to assess the regulating effect of Ghost Dam on downstream discharges.
- Historical discharges were evaluated in the routing model to confirm the routing of flows through Ghost Dam.
- Hydrographs for the 1% exceedance event on the contributing streams were run through the model to determine an estimate of the unmitigated hydrograph for the Bow River at Calgary. Then the inflow from the Ghost River was deleted to approximate the effect of a flood retention dam at site BG1 (i.e., a dam retaining 100% of the inflow) and to evaluate the difference in flood peak discharge at Calgary versus the unmitigated scenario.
- The evaluation of routed discharges with and without the proposed BG1 dam was extended by determining the effect of lower discharges on the water levels that might occur at the WSC gauge 05BH004, Bow River at Calgary.
- The differences in discharge were used to determine the difference in flow depth, using the rating curve for the WSC gauge.

1.2.2 Assumptions and Limitations

The hydrometric data employed for this assessment was based on the period of record for each of the stations. In general, the period of record employed was not consistent throughout. Data were not extended using regression or other methods to achieve a consistent period of record.

The depth-storage-area data provided by TAC was used as-is. The data were not verified.

Outflows from Ghost Dam result from flow through the turbines and flows over the service and emergency spillways. The spillways have several bays all controlled with stoplogs. A varying number of spillway bays are employed to route incoming flood discharges through the dam; (e.g., one bay was partially open in the June 2005 flood and three bays were open for the 2013 event). For AMEC's modeling, the maximum spillway discharge for a given water level was used (i.e., all bays operating). This maximum rating curve was found to perform well for the 1% event, as lower outflows resulted in over-filling of the reservoir. As the intent of the exercise is to determine the difference in water levels at Calgary for flood mitigation with (and without) the proposed BG1 dam in place, the lack of a known operating procedure for spillway adjustment for a given event is not seen as a appreciable shortcoming.

Inflow discharge hydrographs were available on a mean daily basis. For the purpose of modeling, these data were interpolated to an hourly time step. Although hourly gauged discharge would have been preferred, such data were not readily available for this analysis. The HEC-HMS routing model was run at a 15 minute computational time step.

All basins were assumed to be under 1% exceedance flood discharge conditions simultaneously. Though possibly conservative, this assumption was thought to be reasonable for the upper Bow River basin, based on experience and analysis of prior floods. Flood discharge peak values for the various basins were obtained from the following sources:

- Bow River near Seebe (AENV, 1983).
- Ghost River above Waiparous Creek (Golder, 2013).
- Waiparous Creek near the Mouth (Golder 2013).
- Jumpingpound Creek near the Mouth (AENV, 1990).
- Bow River at Calgary (Golder, 2010).

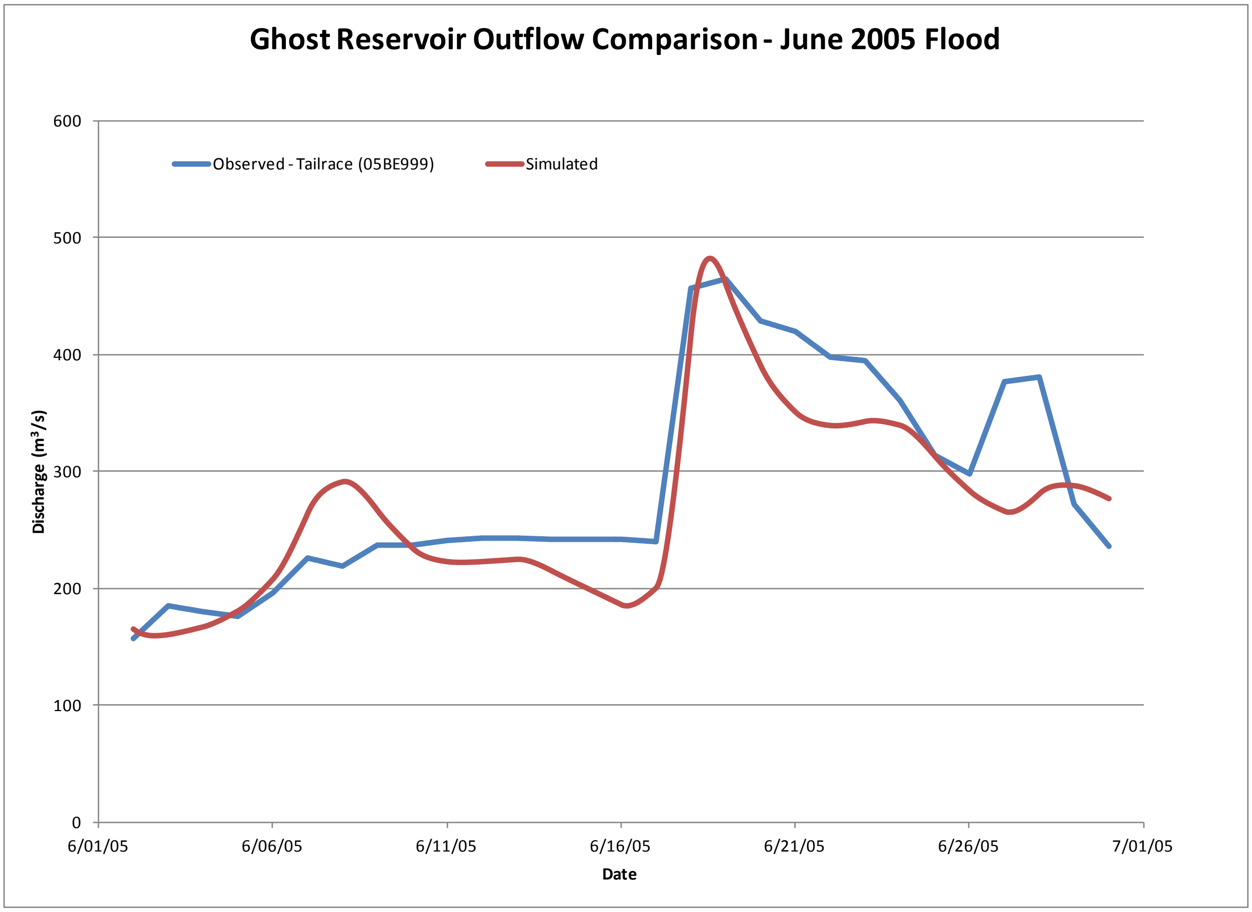
No channel routing effects (i.e., time lag or peak attenuation) between Ghost Lake and Calgary were accounted for in the model, including any potential influence of Bearspaw Reservoir on the hydrograph at Calgary. Bearspaw Dam is commonly operated as a run-of-river facility, and flood peak attenuation would generally be small for large floods.

2.0 RESULTS

2.1 Model Calibration

As discussed in **Section 1.2.2**, the floods in June 2005 were used to test the initial model set-up. **Figure 2** illustrates the measured and simulated outflows from Ghost Dam during June 2005. The agreement was found to be acceptable for the purposes of this assessment.

Figure 2 **Comparison of Measured and Simulated Outflows from Ghost Dam in June 2005**

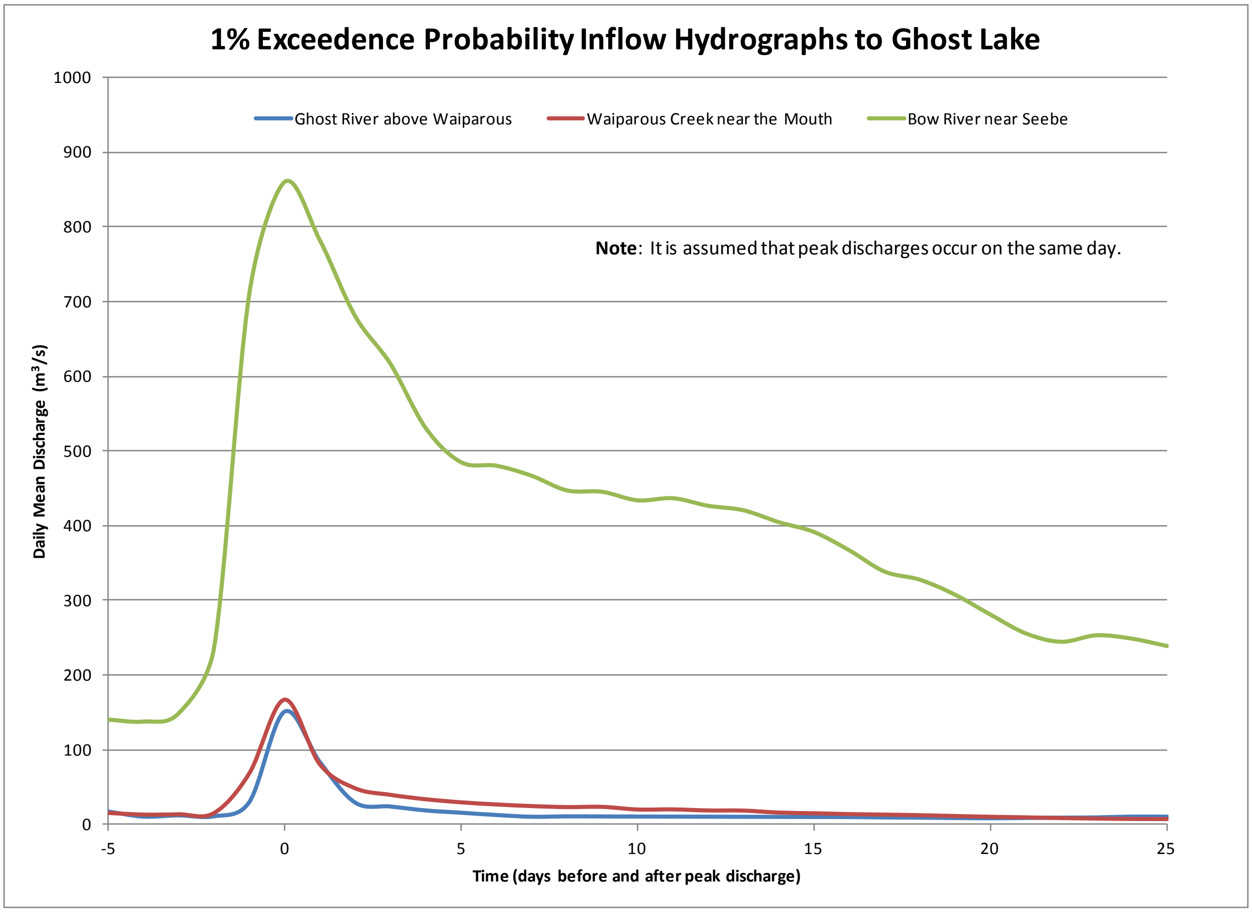


2.2 Discharges for 1% Exceedence Flood

2.2.1 Discharges with Contributions from the Ghost River

Figure 3 illustrates the 1% exceedance probability hydrographs for the streams entering Ghost Lake. Based on a review of the available information, it was determined that the peak discharge for all streams, except the Bow River at Calgary, would generally occur on the same day, while the Bow River at Calgary would peak one day later than the rest.

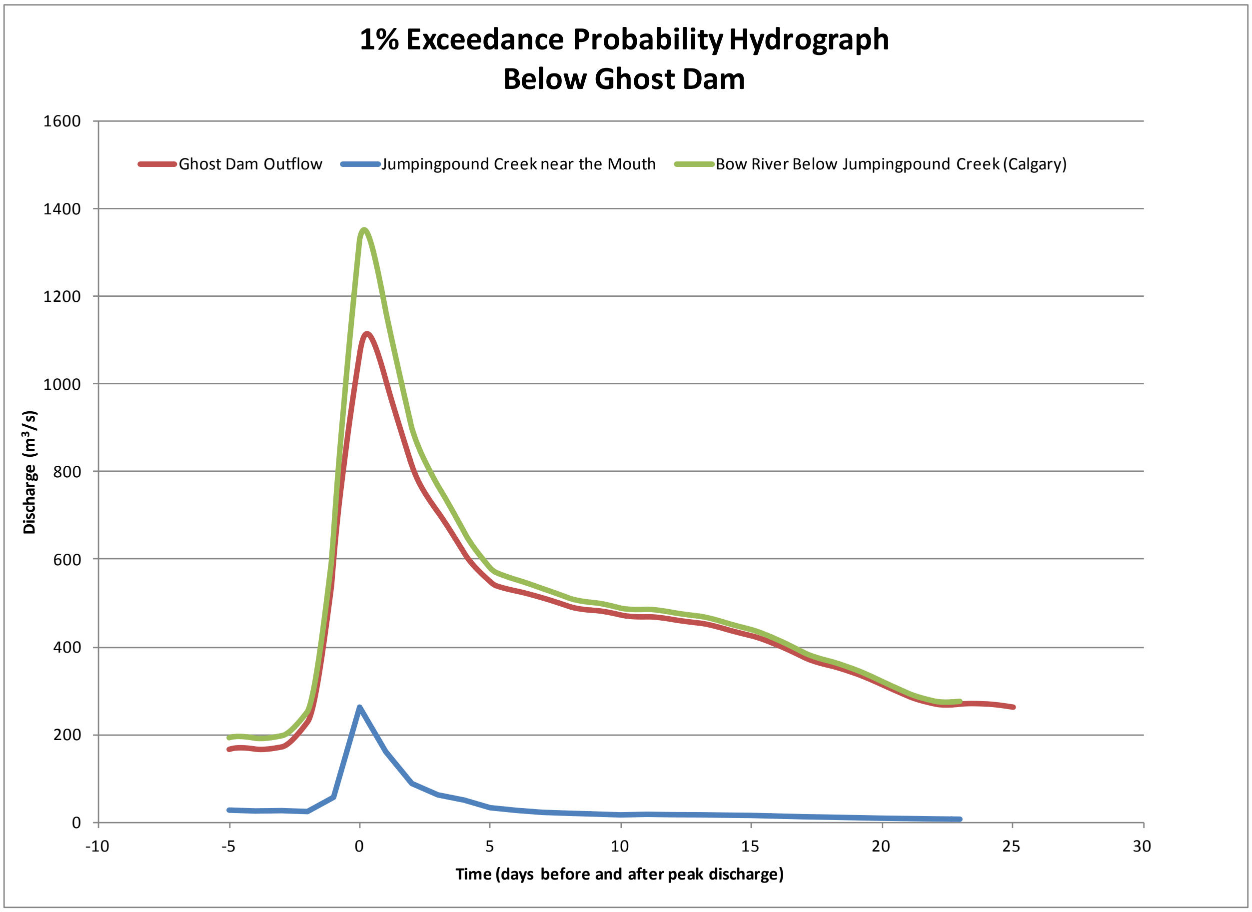
Figure 3 Hydrographs for Streams Entering Ghost Lake



Routing of the Bow River, Ghost River and Waiparous Creek inflows through Ghost Lake results in some reduction in the peak discharge. For example, and considering the limitations of the modeling used for this assessment, the sum of the peak inflows is approximately 1,180 m^3/s, while the maximum outflow is computed to be 1,115 m^3/s, a reduction of 5%.

Figure 4 illustrates the outflow from Ghost Dam, the flow from Jumpingpound Creek that flows into the Bow River upstream of Cochrane, and the sum of these two discharges (1,353 m^3/s).

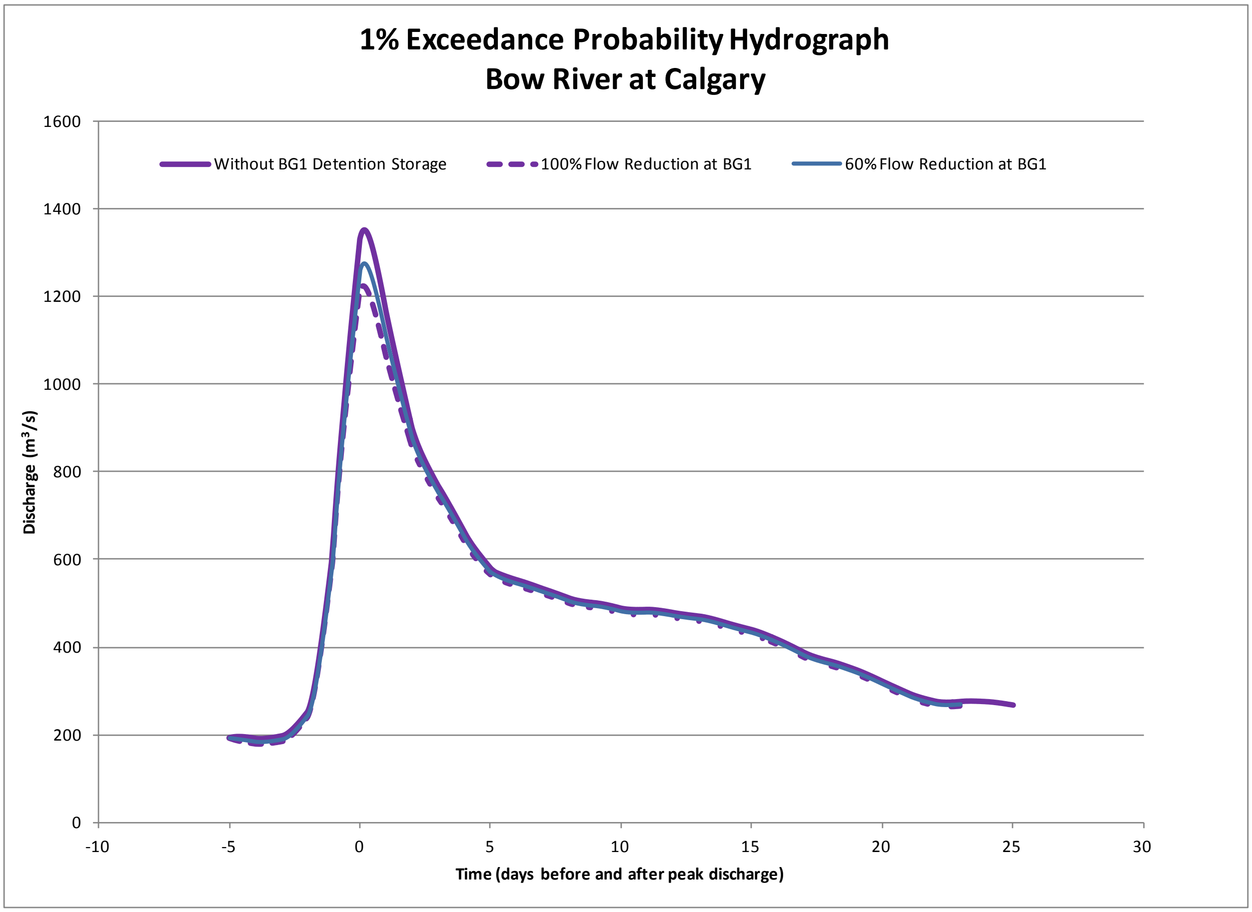
Figure 4 Hydrographs Below Ghost Dam



2.2.2 Effects on Discharges with BG1 Detention Dam

The proposed detention dam BG1 will hold back flows from the Ghost River. If the assumption is made that flows are entirely retained (outflow is zero), then the flow contribution from the Ghost River in the model can be simply deleted. For this case, the routing of the flow through Ghost Dam results in a peak daily mean outflow discharge of 980 m^3/s. Adding the Jumpingpound flow results in a modeled peak daily discharge of 1,224 m^3/s at Calgary. This is 129 m^3/s less than was modeled with the inflow from the Ghost River included (a reduction of 10%). **Figure 4** illustrates the outflow from Ghost Dam with and without the contribution from the Ghost River at BG1.

Figure 4 Comparison of 1% Exceedance Probability Flood Hydrographs for the Bow River at Calgary With and Without Proposed BG1 Detention Storage



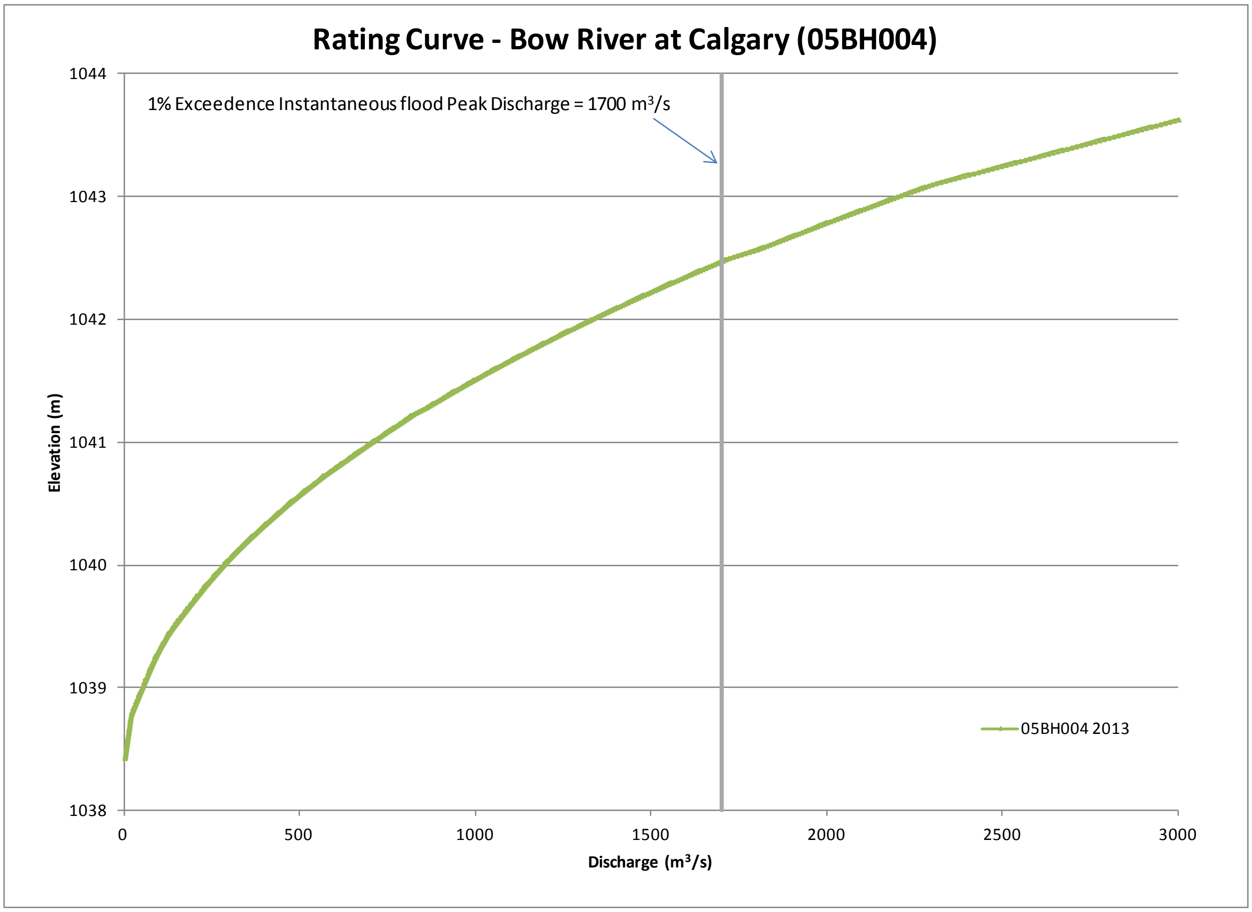
The effect modeled above was for a retention facility, which would effectively retain all of the flow from the Ghost River basin upstream of Waiparous Creek. For the detention type of facility envisaged by the Flood Advisory Panel, some flow would be released during the event. Based on modeling conducted by AMEC using the Flood Advisory Panel's representation of a similar facility (detention dam EQ1 on the Elbow River), AMEC determined that the maximum outflow from the structure would be approximately 40% of the inflow (i.e., a 60% reduction). This percentage was applied to the Ghost River hydrograph, and the modified flow was incorporated into the model as an input to Ghost Lake. The net effect is that the maximum discharge at Calgary would be lowered by approximately 77 m^3/s (6% reduction).

2.3 Water Levels

2.3.1 Water Level Changes at WSC Gauge Site

Water levels for the various modeled discharges were estimated using the rating curve for the WSC hydrometric station, Bow River at Calgary (05BH004). **Figure 5** illustrates the curve, which is dated 10 April 2013.

Figure 5 Rating Curve – Bow River at Calgary



The difference in water levels resulting from the reduction in discharges discussed in **Section 2.2** can be determined from the rating curve. **Table 1** illustrates the changes in discharge and water level from the modeling.

Table 2.1
Comparison of Discharges and Water Levels at Calgary

Case	Maximum Daily Discharge at Calgary (m^3/s)	Water Level at WSC Station 05BH004 (m)
No dam on Ghost River	1,353	1,042.03
BG1 Dam on Ghost River – Retention dam (no outflow)	1,224	1,041.85
BG1 Dam on Ghost River – Detention dam (60% inflow reduction)	1,276	1,041.93

From **Table 1** the effect of the proposed BG1 would be to reduce water levels at Calgary by approximately 0.18 m (7 inches) if 100% of the flow is held back from the Ghost River upstream of Waiparous Creek. For the flood detention structure the 60% reduction in flow from the Ghost River would produce a reduction in water level from the no dam case of approximately 0.1 m (4 inches).

2.3.2 Water Level Changes at Other Locations

As the hydraulic conditions at the WSC gauging site might not be representative of other sites along the Bow River, two additional locations that are known to be flood prone were selected for assessment. The sites selected were at Sunnyside (downstream of the 10th Street (Hillhurst/Louise) Bridge and in Bowness along Bowness Crescent. Water levels were obtained from the results of floodplain modeling presented in Golder 2012. **Table 2** and **Table 3** present the results for Sunnyside and Bowness, respectively.

Table 2.2
Comparison of Discharges and Water Levels at Sunnyside

Case	Maximum Daily Discharge at Calgary (m^3/s)	Water Level at HEC-RAS Station 50553 (m)
No dam on Ghost River	1,353	1,046.70
BG1 Dam on Ghost River – Retention dam (no outflow)	1,224	1,046.49
BG1 Dam on Ghost River – Detention dam (60% inflow reduction)	1,276	1,046.58

Table 2.3
Comparison of Discharges and Water Levels at Bowness

Case	Maximum Daily Discharge at Calgary (m^3/s)	Water Level at HEC-RAS Station 60788 (m)
No dam on Ghost River	1,353	1,066.05
BG1 Dam on Ghost River – Retention dam (no outflow)	1,224	1,065.78
BG1 Dam on Ghost River – Detention dam (60% inflow reduction)	1,276	1,065.90

From **Table 2** and **Table .3** the effect of the proposed BG1 would be to reduce water levels at Sunnyside and at Bowness by approximately 0.21 m (8.5 inches) and 0.27 m (10.6 inches), respectively. For the flood detention structure the 60% reduction in flow from the Ghost River would produce a reduction in water level from the no dam case at Sunnyside and at Bowness by approximately 0.12 m (5 inches) and 0.15 m (6.2 inches), respectively.

3.0 CONCLUSIONS

Modeling of the potential effects of the proposed BG1 detention dam on the Ghost River above Waiparous Creek has indicated that the estimated water level reduction on the Bow River at Calgary might potentially be reduced by a maximum of 0.18m to 0.27 m. Water level reductions for a detention dam at the BG1 site would more likely be less, in the range of 0.1 m to 0.16 m.

4.0 CLOSURE

This report has been prepared for the exclusive use of the Flood Recovery Task Force. This report is based on, and limited by, the interpretation of data, circumstances, and conditions available at the time of completion of the work as referenced throughout the report. It has been prepared in accordance with generally accepted engineering practices. No other warranty, express or implied, is made.

Yours truly,

AMEC Environment & Infrastructure

Gary Beckstead, M.SC. P.Eng.
Principal Engineer – Water Resources

GREB/elf

References

Alberta Environment (AENV). 1983. *City of Calgary Floodplain Study.*

Alberta Environment (AENV). 1990. *Cochrane Floodplain Study*.

Golder Associates Ltd. (Golder). 2010. *Hydrology Study, Bow and Elbow River Updated Hydraulic Model Project, Rev.A*. Prepared for Alberta Environment.

Golder Associates Ltd. (Golder). 2012. *Bow and Elbow River Updated Hydraulic Model Project, Hydraulic Modelling and Inundation Mapping*. Prepared for City of Calgary and Alberta Environment and Water.

Golder Associates Ltd. (Golder). 2013. *Estimate of the Return Period of the Peak Discharge in the Ghost River at Benchlands During the June 2013 flood*. Prepared for TransAlta Corporation.

Roger Drury 2014, personal communication. Telephone conversation and email, 20 February 2014.

Water Survey of Canada (WSC). 2014. Archived Hydrometric Data, obtained from the following site on various dates between 20 and 25 February 2014. http://www.wsc.ec.gc.ca/applications/H2O/index-eng.cfm

W-E-R Engineering Ltd. (WER). 1981. *South Saskatchewan River Basin Structure Inventory. Appendix 2 to Volume 1 (Main Report); Bow River Sub-Basin (1 of 2)*. Prepared for Alberta Environment.

Memo

To:	File	File No:	CW2174
		Date:	21 May 2014
From:	Agata Hall	cc:	Gary Beckstead
	Neil van der Gugten		Ken Kress
Phone:			
Email:			
Subject:	Southern Alberta Flood Recovery Task Force Flood Mitigation Measures for the Bow, Elbow and Oldman Basins Preliminary Inflow Design Floods for Flood Control Dams on the Elbow and Bow Rivers		

1.0 PURPOSE AND LIMITATIONS

The purpose of this Memorandum is to present the results of hydrologic analyses conducted to develop preliminary inflow design flood (IDF) hydrographs for several flood control dams being considered on the Elbow and Bow Rivers, and to document the methodology and the data used. This work is limited to statistical frequency flood analyses; evaluations to estimate probable maximum flood (PMF) hydrographs were not undertaken.

The results presented herein are based on standard hydrologic methods of analysis considered appropriate for conceptual design. For subsequent preliminary and detailed design of flood mitigation measures, more detailed hydrologic analyses should be conducted.

2.0 ELBOW RIVER DAM SITES

2.1 Overview

Two potential dam sites are being considered for the Elbow River upstream of the Glenmore Reservoir - one site is on the main stem above McLean Creek (Site MC1) and the other site is off the main stem near Springbank Road (Site SR1). The two sites would provide flood control at about the same point on the Elbow River, thus one set of IDF hydrographs are considered applicable to both sites.

2.2 Available Data

The two dam sites are both located relatively near the Glenmore Reservoir, thus the hydrometric data for the Elbow River at or near Glenmore Reservoir are applicable. Three Water Survey of Canada (WSC) hydrometric stations are, or have been, operated at or near the Glenmore Reservoir, as listed in Table 1. The current operating station upstream of the reservoir is Station 05BJ010 - Elbow River at Sarcee Bridge (1979 to the present). Prior to 1979, Station 05BJ005 - Elbow River above Glenmore Dam was operational from 1933 to 1977.

Another current operating station is Station 05BJ001 - Elbow River below Glenmore Dam - which was established in 1908. The data from that station can be used for the period prior to 1932 before the Glenmore Dam was constructed.

Table 1 shows that the drainage areas for the three stations are within a few percent of the 1220 km^2 of the central value. Data for all three stations can therefore be combined without adjustment to represent an extended data set for Elbow River inflows to Glenmore Reservoir.

2.3 Annual Flood Peak Discharge Data Series

The combined annual peak instantaneous and daily discharge data for the Elbow River near Glenmore Reservoir are listed in Table 2. The WSC data extend to 2012. Estimated peak discharge values for 2013 were obtained from the City of Calgary. The combined data series consists of 103 years of data, covering the period 1908 through 2013 (with missing data for 1933, 1978 and 1991).

Instantaneous discharges were not monitored prior to 1979, and were also missing for a few other years. Missing values for annual peak instantaneous discharges (Q_{inst}) were estimated from peak daily discharge values (Q_{daily}) using a relationship derived from observed data; that relationship was found to be:

$$Q_{inst} = 0.0010\ Q_{daily}^2 + 1.0135\ Q_{daily}$$

The derivation of this relationship is shown in Figure 1. A time series of the instantaneous peak discharges is illustrated in Figure 2.

2.4 Characteristics of Annual Peak Hydrographs

A cursory review was undertaken of annual peak hydrographs to assess the variability in the timing and the duration of peak runoff events, and to evaluate whether they are generated by snowmelt, rainfall, or a combination of snowmelt and rainfall. The following characteristics were noted:

- The annual peak most often occurs in the period mid-May to mid-June, and has a highly variable hydrograph shape:
  - A minority of the annual peak hydrographs have simple rising and recession limbs, indicating a single primary generating mechanism of either snowmelt or rainfall.
  - Most hydrographs have one or more secondary peaks, with variable overall durations, indicating complex watershed runoff processes involving a combination of rainfall and snowmelt.
- A few annual peaks occur before mid-May - as early as the beginning of April - due to early snowmelt.
- Approximately 20 percent of annual peaks occur in the period July - September and are rainfall-only events.

The noted characteristics indicate that thorough hydrologic analyses should include investigation of the following aspects:

- Separate frequency analyses of annual snowmelt peaks and rainfall peaks
- Partial duration (peaks over threshold) frequency analyses

- Runoff hydrograph volume analyses using various durations to capture the effects of complex, overlapping and/or sequential runoff events; durations should cover a range adequate to evaluate and optimize combinations of flood storages and discharge capacities for the flood control dams being considered.

Due to inherent limitations associated with the current conceptual design phase, the above-noted aspects were not considered in this preliminary hydrologic study, however they should be part of subsequent phases.

2.5 Flood Peak Frequency Analysis

The annual peak discharges were used, as published, as the basis for frequency analyses, without consideration of the generating mechanism or time of year. Flood peak frequency analyses were conducted separately for the annual peak daily and the annual peak instantaneous discharge data sets. The lognormal, 3-parameter lognormal, Pearson Type III and log-Pearson Type III probability distributions were tested as well as each available parameter estimation technique including method of moments and maximum likelihood. It was found that for specific probability distributions, some parameter estimation techniques produced excessively high peak discharge estimates for exceedance probabilities less than 1%. Evaluation of the results indicated that the log-Pearson Type III (LP3) distribution, with the method of moments (MOM) parameter estimation technique, produced the best fit with to the data. The results of the flood frequency analyses are provided in Table 3.

Table 3 includes the median values derived from the data directly (see Table 2). The fitted 1:2 year values should ideally equal the median values, but as is often the case when fitting a theoretical probability distribution, they deviate slightly from the median values. The median value is the more correct definition of the 1:2 year value[1], however it may be more consistent to use the fitted 1:2 year value when other return period values are being considered in design computations.

2.6 Flood Volume Frequency Analysis

The typical shape of major flood hydrographs was evaluated by examining plots of recorded daily discharges for several selected larger flood events, normalized on the peak day value, as shown in Figure 3. The selected hydrographs were chosen to represent events with a single main peak and a minimum of secondary peaks. The plotted hydrographs indicated that the typical main peak involves a 7-day duration and a 2-day rise to peak, with the peak occurring on Day 2. In addition, a base flow amount is typically present at the start of the hydrograph rise.

A unit hydrograph approach to IDF development was initially considered, but was found inapplicable due to the fact that return period values for hydrograph volumes were found to be discordant with return period values for hydrograph peak discharges (i.e. ratios of V_N:V_2 did not agree with ratios of Q_N:Q_2). Separate frequency analyses were therefore conducted on flood runoff volumes. The methodology involved the following steps:

[1] Thus in Table 3 the instantaneous value is slightly higher than the daily value for the medians, as expected, while that is not the case for the fitted 1:2 year values.

- First, data series of annual maximum flood volumes were developed for consecutive durations of 1 day through 7 days, for the combined daily discharge data provided by the three WSC stations. No attempt was made to restrict the search window to a specific runoff event. Thus, although the annual 1-day duration peak volume would automatically occur on the same day as the annual peak daily discharge, annual 2-day or longer duration volumes could correspond to a different runoff event than the one that produced the annual peak daily discharge. The data series so produced should therefore be considered as synthetic.

- Second, a frequency analysis was conducted on the data set for each duration. The log-Pearson Type III (LP3) distribution, with the method of moments (MOM) parameter estimation technique, was used for consistency with the frequency analysis of flood peaks. The results are listed in Table 4.

2.7 IDF Hydrographs

Return periods of 20, 100 and 500 years were selected for hydrograph volume development, based on guidance from the dam design team. Synthetic hydrographs were then constructed for each return period as follows:

- Day 2 (the day of the peak) receives the 1-day return period value,
- Day 3 (the first day of the recession limb) receives the net of the 2-day value minus the 1-day value,
- Day 1 (the rising limb) receives the net of the 3-day value minus the 2-day value,
- Day 4 receive the net of the 4-day value minus the 3-day value,
- Days 5, 6 and 7 each receive in descending order the net volume per day of the remaining days.
- The base flow amount prior to Day 1 is shown on Day 0.

The total 7-day volume for the hydrograph so obtained was compared with the volume obtained from the frequency analysis for the 7-day duration to verify the results. The Day 0 base flow amount is not included in the 7-day volume.

The resulting 20-year, 100-year and 500-year return period daily discharge hydrographs are presented in Figures 4, 5 and 6 respectively, and are summarized in Table 5 below.

2.8 Flood Volumes - Flood Peaks Relationships

The relationship between flood runoff volume and the annual instantaneous peak discharge as well as the annual daily peak discharge was determined by plotting the return period values as shown in Figures 7 and 8 respectively. The relationships are given below:

$$\text{IDF 7-Day Volume (dam}^3\text{)} = 2086\ (Q_{inst})^{0.605}$$

$$\text{IDF 7-Day Volume (dam}^3\text{)} = 1344\ (Q_{daily})^{0.728}$$

2.9 Incorporation of Historical Flood Data

2.9.1 Flood Peak Analyses - Previous Studies

Several large historically observed floods occurred in 1879, 1897, and 1902 on the Bow and Elbow Rivers prior to the beginning of systematic hydrometric monitoring. Estimates of peak instantaneous discharges for those floods, based on high water marks and/or anecdotal descriptions, have been made for the Bow River at Calgary, as reported in AENV 1983. Those peak discharges were estimated at 2270 m^3/s (80,000 cfs) for both the 1879 and 1897 floods, and 1560 m^3/s (55,000 cfs) for the 1902 flood.

As part of the noted 1983 study, Alberta Environment conducted frequency analyses for annual peak discharges on the Bow River above the Elbow River, for both the hydrometric record period of 1908 to 1980, and the extended period of 1879 to 1980 which included the three noted flood peaks. The Pearson Type III distribution was used for those analyses. The analyses found that the estimated instantaneous peaks derived from the frequency analysis for the extended period were higher than the corresponding estimates for the hydrometric record period only. The relationships between the two estimates are given in Table 6. The 1983 study also examined the relationship between flood frequencies of the Elbow River near Glenmore Dam and those of the Bow River above the Elbow, and found that the two sets of flood frequencies exhibited the same properties, such that the Table 6 values were directly applicable to the Elbow River. The ratios in Table 6 for the 1:200 and 1:500 year frequencies were obtained from a subsequent study (W-E-R *et al.* 1986).

2.9.2 Flood Peak Analyses - Current Study

For the current study, the 1983 approach was applied to the Bow River at Calgary (WSC Station 05BH004) using the period of hydrometric record 1911 to 2013, and the extended period 1879 to 2013. The extended period data set (1879 to 2013) was created by adding the three pre-1911 flood peak data and then filling in the missing years with the median value of the 1911 to 2013 data set. The log-Pearson Type III (LP3) distribution and the method of moments (MOM) parameter estimation technique was used for both periods. The results are given in Table 7.

The Table 7 ratios are smaller than the Table 6 ratios obtained in the previous studies. That is to be expected, as the Table 7 ratios incorporate the effects of both a longer period of record and the large 2013 flood peak, both of which reduce the influence of the three historic flood peaks in the extended period. Based on the finding by previous studies of flood frequency similarity between the Bow and Elbow Rivers, it is considered that the Table 7 ratios are directly applicable to the Elbow River near Glenmore Reservoir. The Table 7 ratios were thus applied to the instantaneous flood peak frequency results obtained for the period of record 1908 - 2013 as shown in Table 3, to estimate values for the extended period 1879 to 2013; the results are listed in Table 8.

Table 8 also lists, for the extended period 1879 to 2013, the peak daily discharges corresponding to the peak instantaneous discharges. Those daily values were computed using the two relationships found for 7-day flood runoff volume and the annual instantaneous peak discharge and the annual daily peak discharge as presented above in Section 2.8. This method was used to maintain consistency between flood peaks and volumes in the IDF hydrographs.

2.9.3 Adjustment of Flood Volumes

As indicated above, return period 7-day flood volumes corresponding to the flood peaks obtained by up-scaling using the extended period data set (1879 to 2013) were obtained by applying the instantaneous peak vs 7-day flood volume relationship presented in Section 2.7. The 7-Day flood volumes for both the 1908 to 2013 and the 1987 to 2013 periods, and their ratios, are summarized in Table 9.

2.10 Historically Adjusted IDF Hydrographs

The 1:20 year, 1:100 year and 1:500 year IDF hydrographs as derived from the recorded data for the period 1908 to 2013 were adjusted to account for the three large historical floods, by increasing the flood volumes and daily discharges in accordance with the adjustment ratios and values found as reported in the preceding sections. The adjustments to daily discharges were made as follows:

- The total 7-day runoff volume was adjusted to equal the adjusted value as reported in Table 9.
- The hydrograph peak day value, i.e. the Day 2 value, was increased to the adjusted peak daily value as per the last column of Table 8. It was found that the incremental increase for that day represented 40 % (for the 1:20 year event) to 54 % (for the 1:500 year event) of the total 7-day volume increase.
- The remainder of the 7-day volume increase was proportionately distributed between Day 1 and Day 3, in order to provide a conservative hydrograph shape for design, which was focussed on providing flood storage volume above a specific threshold.
- Days 4 through 7 were retained unchanged.

The resulting daily discharge values for each IDF are summarized in Table 10.

In addition to the above, quasi-instantaneous hydrographs were estimated from the adjusted daily discharge hydrographs, as follows:

- Assign the adjusted peak instantaneous value (Table 8 second last column) to the beginning of the peak day (Day 2).
- Select other instantaneous values at 6-hour point intervals for the rising limb and the recession limb so as to preserve the runoff volume corresponding to the daily discharge volume for each day.

The resulting 6-hour (quarter-day) point discharge values for each IDF are summarized in Table 11.

The adjusted IDF hydrographs are illustrated in Figures 9, 10 and 11 for the 1:20 year, 1:100 year and 1:500 year return periods, respectively. In each case the daily discharge IDF is shown as a bar chart, while the quasi-instantaneous IDF is shown as quarter-day point values with connecting lines.

3.0 BOW RIVER DAM SITES

3.1 Overview

The only location currently under consideration for flood control dams on the Bow River is a dam site near Morley.

3.2 Available Data

There are four WSC hydrometric stations relevant to developing flood hydrology for the Bow River near Morley; those stations and their periods of record are listed in Table 12. One WSC station - Bow River near Morley (05BE001) - was located at the site of interest, but was only operated in 1910 and 1911. However, an active station - Bow River near Seebe (05BE004) - is located just upstream of Morley. The Seebe station has a drainage area within 4 % of that of the Morley Station and the data for Seebe can therefore be used without adjustment. The Seebe station began operation in 1923, but has a large data gap extending from 1963 to 1978. Various correlations with regional stations were attempted to fill in the missing 16 years of data, but the results were not considered acceptable.

The Station 05BE004 data set was extended back to 1912 using two upstream stations - Bow River near Kananaskis (05BE003) and Kananaskis River near Seebe (05BF001). Those two stations combined (drainage areas of 4160 km^2 and 933 km^2 respectively) closely approximate the discharge at Station 05BE004 (drainage area 5170 km^2).

3.3 Annual Flood Peak Discharge Data Series

The combined annual peak instantaneous and daily discharge data for the Bow River near Morley are listed in Table 13. The WSC data extend to 2011. Estimated peak discharge values for 2013 were obtained from TransAlta Corp. The combined data series consists of 85 years of data, covering the period 1912 through 2013, with missing data for the years 1963 to 1978 and 2012.

Missing values for annual peak instantaneous discharges (Q_{inst}) were estimated from peak daily discharge values (Q_{daily}) using a relationship derived from the observed data (but excluding 2013); that relationship was found to be a linear relationship as follows:

$$Q_{inst} = 1.147\ Q_{daily}$$

The derivation of this relationship is shown in Figure 12. A time series of the instantaneous peak discharges is illustrated in Figure 13.

3.4 Characteristics of Annual Peak Hydrographs

Characteristics of the annual peak hydrograph for the Bow River appear to resemble Elbow River hydrographs in terms of variability and complexity. Due to inherent limitations associated with the current conceptual design phase, special studies related to hydrograph characteristics were not included in this preliminary hydrologic study, however they should be part of subsequent phases. For consistency in this study, the same hydrologic methods were used for the Bow River as were used for the Elbow.

3.5 Flood Peak Frequency Analysis

Flood frequency analyses were performed only on the annual peak daily discharges. As for the Elbow River analyses, the log-Pearson Type III (LP3) distribution with the method of moments (MOM) parameter estimation technique was determined to best fit the data. Frequency values for annual peak instantaneous discharges were not computed by frequency analysis of the instantaneous discharge data series, but were estimated by applying the linear relationship between the instantaneous and daily peaks found above. Table 14 lists the return period values for both the annual daily and the annual instantaneous peaks.

3.6 Flood Volume Frequency Analysis

The typical shape of major flood hydrographs was evaluated by examining plots of recorded daily discharges for several selected larger flood events, normalized on the peak day value, as shown in Figure 14. The selected hydrographs were chosen to represent events with a single main peak and a minimum of secondary peaks. The plotted hydrographs indicated that the typical main peak involves a 10-day duration and a 5-day rise to peak, with the peak occurring on Day 5. In addition, a base flow amount is typically present at the start of the hydrograph rise.

Using the same method as described above for the Elbow River (Section 2.6), frequency analyses of 1-day to 10-day annual maximum flood volumes yielded the results as summarized in Table 15.

3.7 IDF Hydrographs

Return periods of 20, 100, 500 and 1000 years were selected for hydrograph volume development, based on guidance from the dam design team. Synthetic hydrographs were then constructed for each return period as follows:

- Day 5 (the day of the peak) receives the 1-day return period value,
- Day 6 (the first day of the recession limb) receives the net of the 2-day value minus the 1-day value,
- Day 4 (the day before the peak) receives the net of the 3-day value minus the 2-day value,
- Day 7 receive the net of the 4-day value minus the 3-day value,
- Days 8, 2, 9, 10 and 1 then each receive in descending order the net volume per day of the remaining days.
- The base flow amount prior to Day 1 is shown on Day 0.

The total 10-day volume for the hydrograph so obtained was compared with the volume obtained from the frequency analysis for the 10-day duration to verify the results. The Day 0 base flow amount is not included in the 10-day volume. The resulting 20-year, 100-year, 500-year and 1000-year return period daily discharge hydrographs are presented in Figures 15, 16, 17 and 18 respectively; their daily values are summarized in Table 16 below.

3.8 Flood Volumes - Flood Peaks Relationships

The relationship between flood runoff volume and the annual instantaneous peak discharge as well as the annual daily peak discharge was determined by plotting the return period values as shown in Figures 19 and 20 respectively. The relationships are given below:

$$\text{IDF 10-Day Volume (dam}^3\text{)} = 2894\ (Q_{inst})^{0.754}$$

$$\text{IDF 10-Day Volume (dam}^3\text{)} = 3210\ (Q_{daily})^{0.754}$$

Note that the above equations are not independent and reflect the fact that the instantaneous peak discharge return period values were estimated from the corresponding daily values by the constant factor 1.147 (Section 3.3).

3.9 Incorporation of Historical Flood Data

3.9.1 Flood Peak Analysis

The three large historical flood peaks of 1879, 1897 and 1902 were used to scale up the flood peak frequency results for the Bow River near Morley derived from the hydrometric data set using the same approach as described in Section 2.9.2 above, i.e., derive a set of scaling ratio values based on frequency analyses of the Bow River at Calgary using first the 1911 to 2013 data set and then the extended 1879 to 2013 data set. However, in this case the 1911 to 2013 data set was revised by removing the data for the period 1963 to 1978, in order to correspond to the Bow River near Morley data set which has data missing for that period. The resulting frequency results and scaling ratios are summarized in Table 17. The noted scaling ratios are then applied to the previously obtained Bow River near Morley values from Table 14 to produce adjusted values as summarized in Table 18.

3.9.2 Adjustment of Flood Volumes

Return period 10-day flood volumes corresponding to the flood peaks obtained by up-scaling using the extended period data set (1879 to 2013) were obtained by applying the 10-day flood volume vs. instantaneous peak discharge relationship presented in Section 3.8. The 10-day flood volumes for both the 1912 to 2013 and the 1987 to 2013 data sets, and their ratios, are summarized in Table 19.

3.10 Historically Adjusted IDF Hydrographs

The 1:20 year, 1:100 year, 1:500 and 1:1000 year IDF hydrographs as derived from the recorded data for the period 1912 to 2013 were adjusted to account for the three large historical floods, by increasing the flood volumes and daily discharges in accordance with the adjustment ratios and values found as reported in the preceding sections. The adjustments to daily discharges were made as follows:

- The total 10-day runoff volume was adjusted to equal the adjusted value as reported in Table 19.
- The hydrograph peak day value, i.e. the Day 5 value, was increased to the adjusted peak daily value as per the second last column of Table 18. It was found that the incremental increase for that day represented 18 % (for the 1:20 year event) to 20 % (for the 1:1000 year event) of the total 10-day volume increase.
- The remainder of the 10-day volume increase was proportionately distributed between the three days before and the three days after Day 5.
- Days 1, 9 and 10 were retained unchanged.

The resulting daily discharge values for each IDF are summarized in Table 20. The adjusted IDF hydrographs are illustrated in Figures 21, 22, 23, and 24 for the 1:20 year, 1:100 year, 1:500 year and 1:1000 year return periods, respectively. In addition, a quasi-instantaneous hydrograph is shown for the 1:100 year IDF using the same approach as described above for the Elbow River in Section 2.10. Inspection of the daily and quasi-instantaneous 1:100 year IDF hydrographs shows little difference between the two, therefore quasi-instantaneous versions for the other IDFs were not prepared at this stage.

4.0 REFERENCES

Alberta Environment (AENV) 1983. City of Calgary Floodplain Study.

Northwest Hydraulic Consultants Ltd. (NHC), 1992. Little Bow River Project, Little Bow River Dam, Volume II – Ancillary Report 2, Flood Frequency Analyses, Highwood and Little Bow Rivers. Prepared for Alberta Public Works, Supply & Services.

W-E-R Engineering Ltd, IBI Group, Ecos Engineering Services, Ltd., 1986. Elbow River Floodplain Management Study. Prepared for Alberta Environment.

Table 1: Elbow River near Glenmore Reservoir Hydrometric Stations

Station Number	Station Name	Record Period	Drainage Area (km^2)
05BJ001	Elbow River below Glenmore Dam	1908 to present	1240
05BJ005	Elbow River above Glenmore Dam	1933 to 1977	1220
05BJ010	Elbow River at Sarcee Bridge	1979 to present	1190

Table 2: Elbow River near Glenmore Reservoir Annual Peak Discharge Data Stations 05BJ001, 05BJ005, 05BJ010 (1908-2013)

Station Number	Year	Peak Instantaneous Discharge[2] (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date
05BJ001	1908	*186*		159	June 2
05BJ001	1909	*104*		94	June 3
05BJ001	1910	*19.2*		18.6	Sept 19
05BJ001	1911	*98.7*		89.5	Aug 8
05BJ001	1912	*139*		122	June 16
05BJ001	1913	*40.8*		38.8	Aug 10
05BJ001	1914	*30.1*		28.9	June 18
05BJ001	1915	*299*		239	June 26
05BJ001	1916	*169*		146	June 29
05BJ001	1917	*171*		147	June 3
05BJ001	1918	*37.1*		35.4	June 10
05BJ001	1919	*78.7*		72.5	Aug 6
05BJ001	1920	*73.2*		67.7	July 13
05BJ001	1921	*39.3*		37.4	May 25
05BJ001	1922	*27.6*		26.5	May 17
05BJ001	1923	*445*		331	June 1
05BJ001	1924	*63.8*		59.5	Aug 4
05BJ001	1925	*71.8*		66.5	June 12
05BJ001	1926	*97.1*		88.1	Sept 11
05BJ001	1927	*91.4*		83.3	June 10
05BJ001	1928	*111*		100	June 19
05BJ001	1929	*533*		382	June 3
05BJ001	1930	*31.9*		30.6	May 31
05BJ001	1931	*23.7*		22.9	April 8
05BJ001	1932	726[3]		311	June 3
	1933	-		-	
05BJ005	1934	*25.3*		24.4	June 10

[2] Italicized instantaneous discharge values were computed using the following relationship derived from observed data: $Q_{inst} = 0.0010*Q_{daily}^2 + 1.0135*Q_{daily}$.
[3] The 1932 instantaneous discharge is provided in W-E-R *et al.,* 1986.

Station Number	Year	Peak Instantaneous Discharge[2] (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date
05BJ005	1935	*30.4*		29.2	June 18
05BJ005	1936	*33.8*		32.3	June 2
05BJ005	1937	*56.7*		53.2	June 14
05BJ005	1938	*64.8*		60.3	July 3
05BJ005	1939	*100*		90.6	June 17
05BJ005	1940	*38.0*		36.2	Sept 6
05BJ005	1941	*41.2*		39.1	June 2
05BJ005	1942	*145*		127	May 11
05BJ005	1943	*32.5*		31.1	April 4
05BJ005	1944	*24.8*		23.9	June 13
05BJ005	1945	*81.4*		74.8	June 1
05BJ005	1946	*54.0*		50.7	June 7
05BJ005	1947	*73.8*		68.2	May 11
05BJ005	1948	*145*		127	May 23
05BJ005	1949	*20.4*		19.7	May 22
05BJ005	1950	*36.8*		35.1	June 16
05BJ005	1951	*158*		137	Aug 31
05BJ005	1952	*86.3*		79	June 23
05BJ005	1953	*151*		132	June 4
05BJ005	1954	*51.1*		48.1	Aug 25
05BJ005	1955	*48.6*		45.9	May 20
05BJ005	1956	*39.3*		37.4	July 4
05BJ005	1957	*31.6*		30.3	June 9
05BJ005	1958	*58.7*		54.9	July 14
05BJ005	1959	*52.4*		49.3	June 27
05BJ005	1960	*31.3*		30	June 4
05BJ005	1961	*54.3*		51	May 27
05BJ005	1962	*28.9*		27.8	June 17
05BJ005	1963	*141*		124	June 30
05BJ005	1964	*67.7*		62.9	June 9
05BJ005	1965	*116*		104	June 18
05BJ005	1966	*38.3*		36.5	July 3
05BJ005	1967	*241*		199	May 31
05BJ005	1968	*54.6*		51.3	June 8
05BJ005	1969	*142*		125	June 30
05BJ005	1970	*108*		97.1	June 14
05BJ005	1971	*93.6*		85.2	June 6
05BJ005	1972	*44.2*		41.9	June 1
05BJ005	1973	*48.0*		45.3	May 27
05BJ005	1974	*66.7*		62	June 18
05BJ005	1975	*52.1*		49	June 21
05BJ005	1976	*39.8*		37.9	Aug 6
05BJ005	1977	*16.8*		16.3	Aug 15
	1978	-		-	
05BJ010	1979	41.3	May 27	36	May 27
05BJ010	1980	59.7	June 4	52.9	June 4
05BJ010	1981	121	May 26	101	May 26
05BJ010	1982	38.2	June 15	32.3	June 15

Station Number	Year	Peak Instantaneous Discharge[2] (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date
05BJ010	1983	42.8	April 25	30.4	April 25
05BJ010	1984	21.9	June 9	20.7	June 9
05BJ010	1985	71.7	Sept 13	63.2	Sept 13
05BJ010	1986	54.1	May 29	49.7	May 29
05BJ010	1987	29.6	July 19	27.4	July 19
05BJ010	1988	35.1	June 8	29.4	June 8
05BJ010	1989	23	June 10	22.4	June 10
05BJ010	1990	158	May 26	128	May 26
05BJ010	1991	-		-	
05BJ010	1992	122	June 15	110	June 15
05BJ010	1993	*93.1*		84.8	June 17
05BJ010	1994	*72.4*		67	June 7
05BJ010	1995	*261*		213	June 7
05BJ010	1996	*46.9*		44.3	June 9
05BJ010	1997	*64.2*		59.8	June 1
05BJ010	1998	*114*		102	May 28
05BJ010	1999	63.4	July 15	54.9	July 15
05BJ010	2000	19	June 11	18.3	June 11
05BJ010	2001	*45.8*		43.3	June 5
05BJ010	2002	89	June 17	80.4	June 17
05BJ010	2003	60.1	April 26	35.2	May 26[4]
05BJ010	2004	*38.2*		36.4	Aug 26
05BJ010	2005	338	June 18	268	June 18
05BJ010	2006	140	June 16	122	June 16
05BJ010	2007	76.1	June 7	68.9	June 18
05BJ010	2008	220	May 25	183	May 25
05BJ010	2009	43.6	July 14	40.2	July 14
05BJ010	2010	51.9	June 18	49.1	June 18
05BJ010	2011	215	May 27	180	May 27
05BJ010	2012[5]	146	June 6	113	June 6
	2013[6]	1240	June 20	682	June 21
basic statistics of the data					
maximum		1240		682	
mean		107		85.7	
median		63.4		54.9	
min		16.8		16.3	

[4] For the derivation of the instantaneous peak vs daily peak relationship, the actual April 26 daily discharge of 33.9 m^3/s was used.
[5] The 2012 discharge is preliminary and was provided by WSC.
[6] The 2013 discharge is preliminary and was provided by the City of Calgary.

Table 3: Elbow River near Glenmore Reservoir
Annual Peak Discharge Frequency Analysis (1908 to 2013 Data)

Return Period (years)	Daily Discharge (m^3/s)	Instantaneous Discharge (m^3/s)
1000	812	1480
500	686	1230
200	537	933
100	438	737
50	350	564
20	248	372
10	182	252
5	124	155
2	58.7	57.4
median	54.9	63.4

Table 4: Elbow River near Glenmore Reservoir
Annual Peak 1-Day to 7-Day Runoff Volumes (1908 to 2013 Data)

Return Period years)	Cumulative Discharge Volume over N Consecutive Days (m^3/s - days)							7-Day Volume (dam^3)
	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days	
1000	812	1310	1610	1790	1890	1970	2040	176256
500	686	1110	1370	1540	1640	1730	1800	155520
200	537	880	1090	1240	1340	1430	1510	130464
100	438	724	903	1030	1130	1220	1300	112320
50	350	584	735	851	945	1030	1100	95040
20	248	422	539	635	717	791	858	74131
10	182	316	410	490	561	626	686	59270
5	124	221	293	357	416	470	520	44928
2	58.7	110	153	194	232	269	303	26179

Table 5: Elbow River near Glenmore Reservoir IDF Hydrograph Values (1908 to 2013 Data)

Return Period (years)	Daily Discharge by Hydrograph Day (m^3/s)								7 Day Volume (dam^3)
	0	1	2	3	4	5	6	7	
500	90	260	686	424	170	100	90	70	155,520
100	60	179	438	286	127	100	90	80	112,320
20	30	117	248	174	96	82	74	67	74,131

Table 6: Bow River above Elbow River Annual Peak Instantaneous Discharge Comparison of Frequency Analyses 1908 to 1980 Data vs. 1879 to 1980 Data (from AENV 1983; WER *et al.* 1986)

Return Period (years)	Ratio of Estimated Instantaneous Peaks (1879-1980)/(1908-1980)
1000	-
500	1.57
200	1.52
100	1.47
50	1.42
20	1.33
10	1.23
5	1.12
2	0.96

Table 7: Bow River at Calgary Annual Peak Instantaneous Discharge Comparison of Frequency Analyses 1911 to 2013 Data vs. 1879 to 2013 Data

Return Period (years)	Instantaneous Discharge (m^3/s) (1911-2013)	Instantaneous Discharge (m^3/s) (1879-2013)	Ratio of Instantaneous Peaks (1879-2013)/(1911-2013)
1000	2290	3070	1.34
500	1960	2590	1.32
200	1590	2040	1.28
100	1340	1690	1.26
50	1120	1380	1.23
20	871	1030	1.18
10	702	798	1.14
5	549	596	1.09
2	357	354	0.99

amec

Table 8: Elbow River near Glenmore Reservoir Annual Peak Discharges 1908 to 2013 Data and 1879 to 2013 Data

Return Period (years)	1908 to 2013		Ratio of Instantaneous Peaks (1879-2013)/(1908-2013)	1879 to 2013	
	Peak Daily (m^3/s)	Peak Instantaneous (m^3/s)		Peak Instantaneous (m^3/s)	Peak Daily (m^3/s)
1000	812	1480	1.34	1984	1013
500	686	1230	1.32	1625	858
200	537	933	1.28	1197	665
100	438	737	1.26	930	539
50	350	564	1.23	695	423
20	248	372	1.18	440	289
10	182	252	1.14	286	202
5	124	155	1.09	168	130
2	58.7	57.4	0.99	57	53

Table 9: Elbow River near Glenmore Reservoir Annual Flood 7-Day Volume 1908 to 2013 Data and 1879 to 2013 Data

Return Period (years)	7-Day Volume (1908 - 2013) (dam^3)	7-day Volume (1879 - 2013) (dam^3)	Ratio of Volumes
1000	176256	206659	1.172
500	155520	183139	1.178
200	130464	152203	1.167
100	112320	130640	1.163
50	95040	109523	1.152
20	74131	83049	1.120
10	59270	63987	1.080
5	44928	46369	1.032
2	26179	24104	0.921

Table 10: Elbow River near Glenmore Reservoir IDF Hydrograph Daily Values (1879 to 2013 Data)

Return Period (years)	Daily Discharge by Hydrograph Day (m^3/s)								7 Day Volume (dam^3)
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	
500	90	316	858	516	170	100	90	70	183,139
100	60	222	539	354	127	100	90	80	130,640

20	30	142	289	211	96	82	74	67	83,049

Table 11: Elbow River near Glenmore Reservoir
IDF Hydrograph 6-Hour Values (1879 to 2013 Data)

Time (days)	Discharge (m^3/s)		
	1:500 Year	**1:100 Year**	**1:20 Year**
0.00	90	60	30
0.25	90	60	30
0.50	90	60	30
0.75	90	60	30
1.00	90	60	30
1.25	90	60	50
1.50	115	100	100
1.75	200	233	185
2.00	1625	930	440
2.25	900	580	295
2.50	750	475	265
2.75	655	430	250
3.00	630	410	245
3.25	590	400	235
3.50	530	385	220
3.75	470	325	195
4.00	320	200	140
4.25	200	135	100
4.50	150	115	90
4.75	110	105	85
5.00	105	103	84
5.25	103	101	83
5.50	100	100	82
5.75	98	99	81
6.00	95	97	78
6.25	92	94	75
6.50	90	90	73
6.75	88	87	72
7.00	86	81	70
7.25	80	80	68
7.50	75	80	67
7.75	70	80	66
8.00	65	80	65

Table 12: Bow River near Morley Hydrometric Stations

Station Number	Station Name	Record Period	Drainage Area (km^2)
05BE001	Bow River near Morley	1910 to1911	5380
05BF001	Kananaskis River near Seebe	1911 to1962	933
05BE003	Bow River near Kananaskis	1912 to 1922	4160
05BE004	Bow River near Seebe	1923 to 1963 1978 to 2011	5170

Table 13: Bow River near Morley Annual Peak Discharge Data Stations 05BE003+05BF001, 05BE004 (1912 to 2013)

Station Number	Year	Peak Instantaneous Discharge[7] (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date
05BE003+05BF001	1912	*363*		317	July 14
05BE003+05BF001	1913	*425*		371	June 13
05BE003+05BF001	1914	*411*		358	June 18
05BE003+05BF001	1915	*572*		499	June 28
05BE003+05BF001	1916	*876*		764	June 21
05BE003+05BF001	1917	*406*		354	June 18
05BE003+05BF001	1918	*516*		450	June 14
05BE003+05BF001	1919	*360*		314	June 23
05BE003+05BF001	1920	*506*		442	July 13
05BE003+05BF001	1921	*420*		366	June 9
05BE003+05BF001	1922	*430*		375	June 5
05BE004	1923	697	June 15	663	June 15
05BE004	1924	337	July 5	334	July 5
05BE004	1925	362	June 23	343	June 23
05BE004	1926	274	July 10	212	July 8
05BE004	1927	583	June 27	411	June 11
05BE004	1928	515	June 29	493	June 29
05BE004	1929	699	June 3	555	June 3
05BE004	1930	453	June 9	374	June 9
05BE004	1931	275	June 19	265	June 19
05BE004	1932	903	June 2	762	June 3

[7] Italicized instantaneous discharge values were computed using the following relationship derived from observed data: Q_{inst} 1.147*Q_{daily}.

Station Number	Year	Peak Instantaneous Discharge[7] (m^3/s)	Date	Peak Daily Discharge (m^3/s)	Date
05BE004	1933	705	June 17	583	June 18
05BE004	1934	430	May 31	416	May 31
05BE004	1935	309	June 1	289	June 17
05BE004	1936	343	May 30	334	June 2
05BE004	1937	306	June 19	232	June 18
05BE004	1938	453	June 22	419	June 23
05BE004	1939	328	July 3	306	July 2
05BE004	1940	306	May 27	280	May 26
05BE004	1941	279	June 19	173	June 15
05BE004	1942	459	June 9	289	June 9
05BE004	1943	368	July 27	320	July 10
05BE004	1944	340	July 7	215	June 13
05BE004	1945	419	May 31	274	June 22
05BE004	1946	402	May 28	323	May 29
05BE004	1947	413	June 3	306	June 12
05BE004	1948	498	May 25	419	May 24
05BE004	1949	248	May 16	193	June 8
05BE004	1950	348	June 22	343	June 22
05BE004	1951	385	July 7	331	July 7
05BE004	1952	283	July 6	249	July 6
05BE004	1953	368	June 13	354	June 14
05BE004	1954	334	June 16	323	July 9
05BE004	1955	368	June 24	281	June 24
05BE004	1956	411	June 4	297	June 6
05BE004	1957	220	June 5	203	May 21
05BE004	1958	340	June 11	215	June 11
05BE004	1959	317	June 23	249	June 24
05BE004	1960	258	July 1	217	July 2
05BE004	1961	411	June 6	368	June 6
05BE004	1962	276	June 27	250	June 27
05BE004	1979	*190*		166	May 28
05BE004	1980	*304*		265	June 19
05BE004	1981	379	May 28	343	May 27
05BE004	1982	312	June 17	257	June 23
05BE004	1983	245	May 31	212	June 1
05BE004	1984	*292*		255	July 1
05BE004	1985	*235*		205	May 26
05BE004	1986	*469*		409	June 2
05BE004	1987	*252*		220	May 14
05BE004	1988	331	June 9	318	June 9
05BE004	1989	*306*		267	June 16
05BE004	1990	*439*		383	June 2

Station Number	Year	Peak Instantaneous Discharge[7] (m³/s)	Date	Peak Daily Discharge (m³/s)	Date
05BE004	1991	*403*		351	July 5
05BE004	1992	*221*		193	June 15
05BE004	1993	*235*		205	June 3
05BE004	1994	*214*		187	June 8
05BE004	1995	*487*		425	June 7
05BE004	1996	*358*		312	June 10
05BE004	1997	*313*		273	June 7
05BE004	1998	*274*		239	May 29
05BE004	1999	*284*		248	July 16
05BE004	2000	*200*		174	July 3
05BE004	2001	*226*		197	May 29
05BE004	2002	*411*		358	June 29
05BE004	2003	*257*		224	June 2
05BE004	2004	*247*		215	June 13
05BE004	2005	*370*		323	June 19
05BE004	2006	*279*		243	June 17
05BE004	2007	*483*		421	June 8
05BE004	2008	*289*		252	July 2
05BE004	2009	*218*		190	June 18
05BE004	2010	*218*		190	June 25
05BE004	2011	*337*		294	June 24
	2013[8]	818		720	June 21
basic statistics of the data					
maximum		903		764	
mean		379		325	
median		348		306	
min		190		166	

[8] The 2013 discharge data were provided by TransAlta Corporation and are preliminary.

Table 14: Bow River near Morley
Annual Peak Discharge Frequency Analysis (1912 to 2013 Data)

Return Period (years)	Daily Discharge (m^3/s)	Instantaneous Discharge (m^3/s)
1000	1050	1204
500	950	1090
200	831	953
100	745	855
50	664	762
20	560	642
10	484	555
5	408	468
2	300	344
median	306	348

Table 15: Bow River near Morley
Annual Peak 1-Day to 10-Day Runoff Volumes (1912 to 2013 Data)

Return Period years)	Cumulative Discharge Volume over N Consecutive Days (m^3/s - days)										10-Day Volume (dam^3)
	1 Day	2 Days	3 Days	4 Days	5 Days	6 Days	7 Days	8 Days	9 Days	10 Days	
1000	1050	2030	2870	3660	4340	4940	5460	5970	6470	6980	603072
500	950	1840	2620	3350	3990	4570	5070	5570	6040	6540	565056
200	831	1620	2310	2960	3550	4090	4570	5030	5480	5940	513216
100	745	1450	2080	2680	3230	3730	4190	4630	5060	5490	474336
50	664	1290	1870	2410	2910	3380	3820	4230	4640	5040	435456
20	560	1090	1590	2050	2500	2920	3310	3690	4060	4430	382752
10	484	946	1380	1790	2190	2570	2930	3270	3610	3940	340416
5	408	799	1170	1520	1870	2200	2520	2830	3130	3420	295488
2	300	588	866	1130	1390	1640	1890	2130	2370	2600	224640

Table 16: Bow River near Morley
IDF Hydrograph Daily Values (1912 to 2013 Data)

Return Period (years)	Daily Discharge by Hydrograph Day (m^3/s)											10-Day Volume (dam^3)
	0	1	2	3	4	5	6	7	8	9	10	
1000	300	500	520	680	840	1050	980	790	600	510	510	603,072
500	275	470	500	640	780	950	890	730	580	500	500	565,056
100	225	430	460	550	630	745	705	600	500	440	430	474,336
20	175	370	390	450	500	560	530	460	420	380	370	382,752

Table 17: Bow River at Calgary Annual Peak Instantaneous Discharge
Comparison of Frequency Analyses 1911 to 1962/1978 to 2013 Data vs 1879 to 2013 Data

Return Period (years)	Instantaneous Discharge (m^3/s) (1911 to 1962 and 1978 to 2013)	Instantaneous Discharge (m^3/s) (1879 to 2013)	Ratio of Instantaneous Peaks (1879-2013)/(1911-1962 and 1978 to 2013)
1000	2380	3070	1.29
500	2060	2590	1.26
200	1670	2040	1.22
100	1420	1690	1.19
50	1190	1380	1.16
20	919	1030	1.12
10	738	798	1.08
5	573	596	1.04
2	363	354	0.98

Table 18: Bow River near Morley Annual Peak Discharges
1912 to 2013 Data and 1879 to 2013 Data

Return Period (years)	1912 to 2013		Ratio of Peaks	1879 to 2013	
	Peak Daily (m^3/s)	Peak Instantaneous (m^3/s)		Peak Daily (m^3/s)	Peak Instantaneous (m^3/s)
1000	1050	1204	1.29	1355	1554
500	950	1090	1.26	1197	1373
200	831	953	1.22	1014	1163
100	745	855	1.19	887	1017
50	664	762	1.16	770	883
20	560	642	1.12	627	719
10	484	555	1.08	523	600
5	408	468	1.04	424	487

2	300	344	0.98	294	337

Table 19: Bow River near Morley Annual Flood 10-Day Volume 1912 to 2013 Data and 1879 to 2013 Data

Return Period (years)	10-Day Volume (1912 to 2013) (dam^3)	10-Day Volume (1879 - 2013) (dam^3)	Ratio of Volumes
1000	603072	739762	1.23
500	565056	673895	1.19
200	513216	594532	1.16
100	474336	537311	1.13
50	435456	483224	1.11
20	382752	413848	1.08
10	340416	360695	1.06
5	295488	308184	1.04
2	224640	233668	1.04

Table 20: Bow River near Morley IDF Hydrograph Daily Values (1879 to 2013 Data)

Return Period (years)	Daily Discharge by Hydrograph Day (m^3/s)											10-Day Volume (dam^3)
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
1000	300	500	671	877	1083	1355	1264	1019	774	510	510	739,762
500	275	470	623	797	972	1197	1109	909	723	500	500	673,895
100	225	430	538	644	737	887	825	702	585	440	430	537,311
20	175	370	432	498	553	627	586	509	465	380	370	413,848

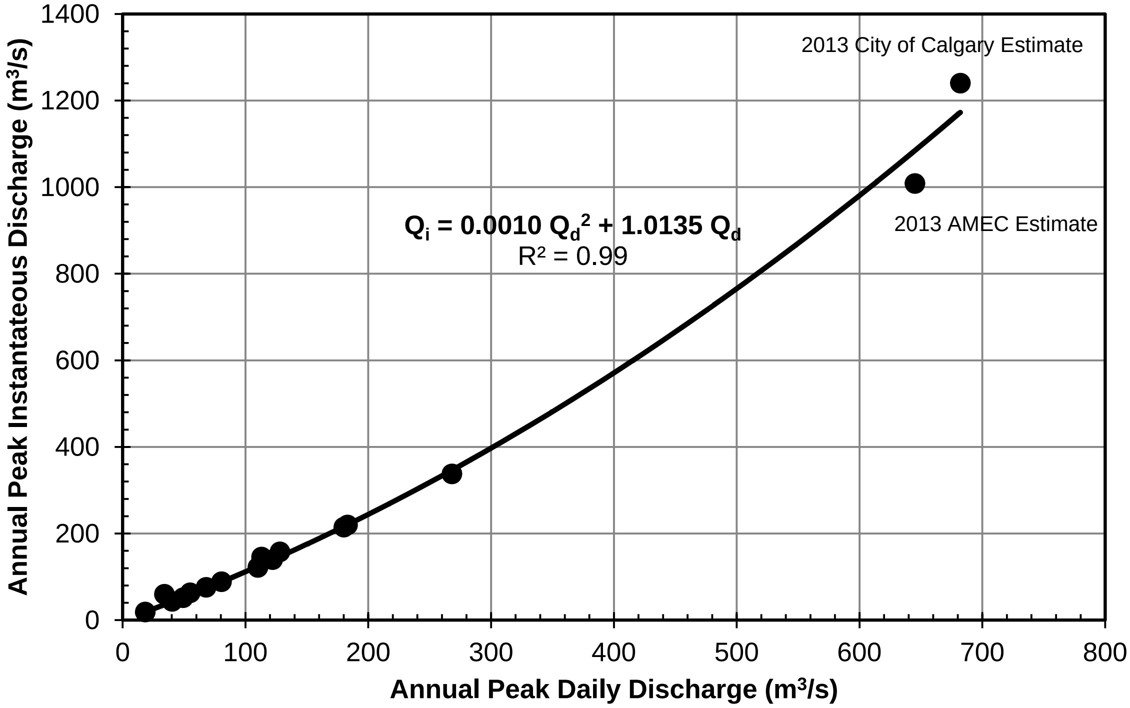


Figure 1: Elbow River near Glenmore Reservoir Annual Peak Instantaneous vs. Annual Peak Daily Discharges (1908-2013 Data)

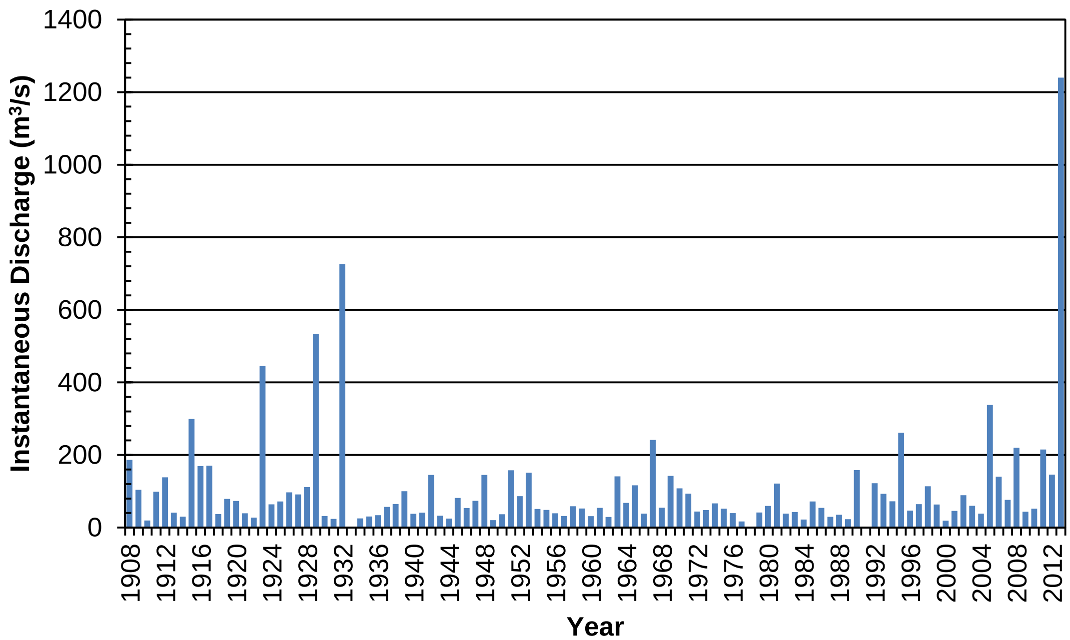


Figure 2: Elbow River near Glenmore Reservoir Annual Peak Instantaneous Discharges (1908 to 2013).

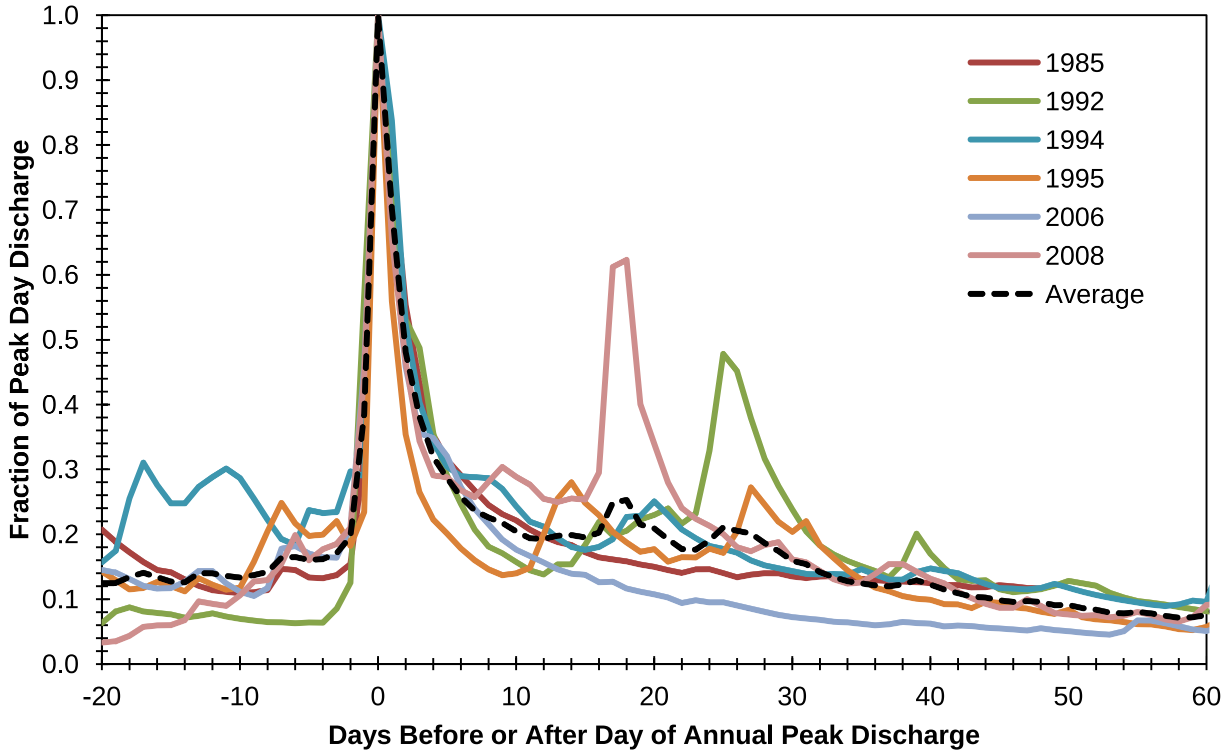


Figure 3: Elbow River near Glenmore Reservoir Normalized Hydrographs for Selected Years

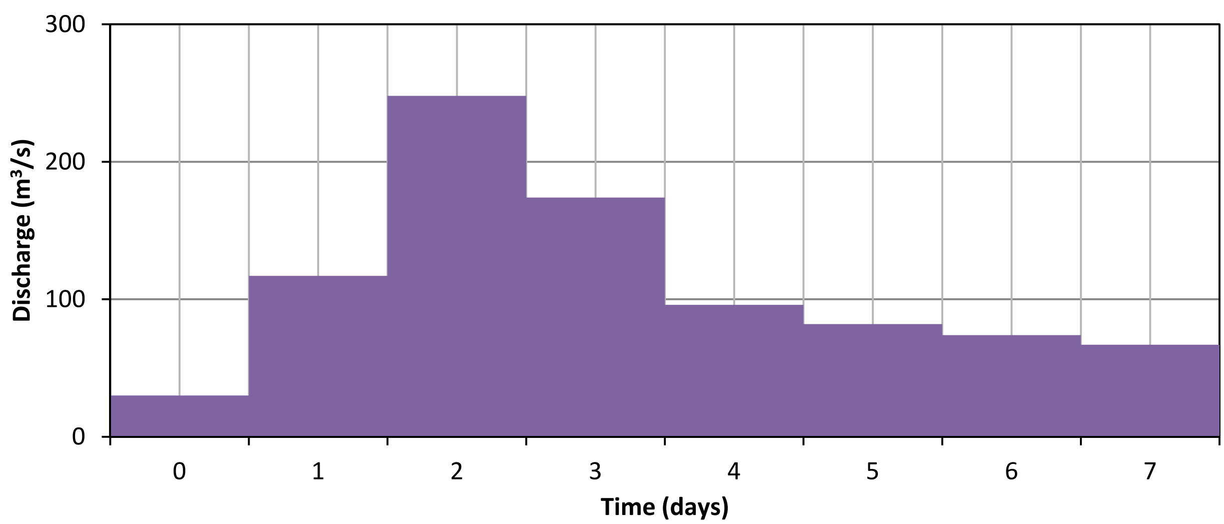


Figure 4: Elbow River near Glenmore Reservoir 1:20 Year Inflow Design Flood Daily Discharge Hydrograph (1908 to 2013 Data)

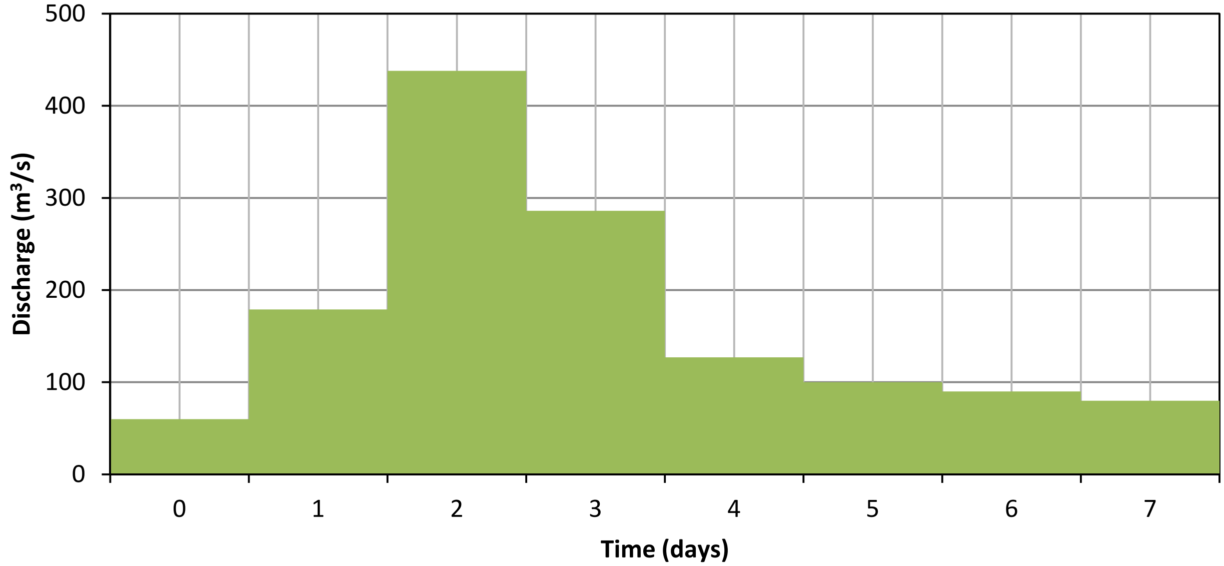


Figure 5: Elbow River near Glenmore Reservoir 1:100 Year Inflow Design Flood Daily Discharge Hydrograph (1908 to 2013 Data)

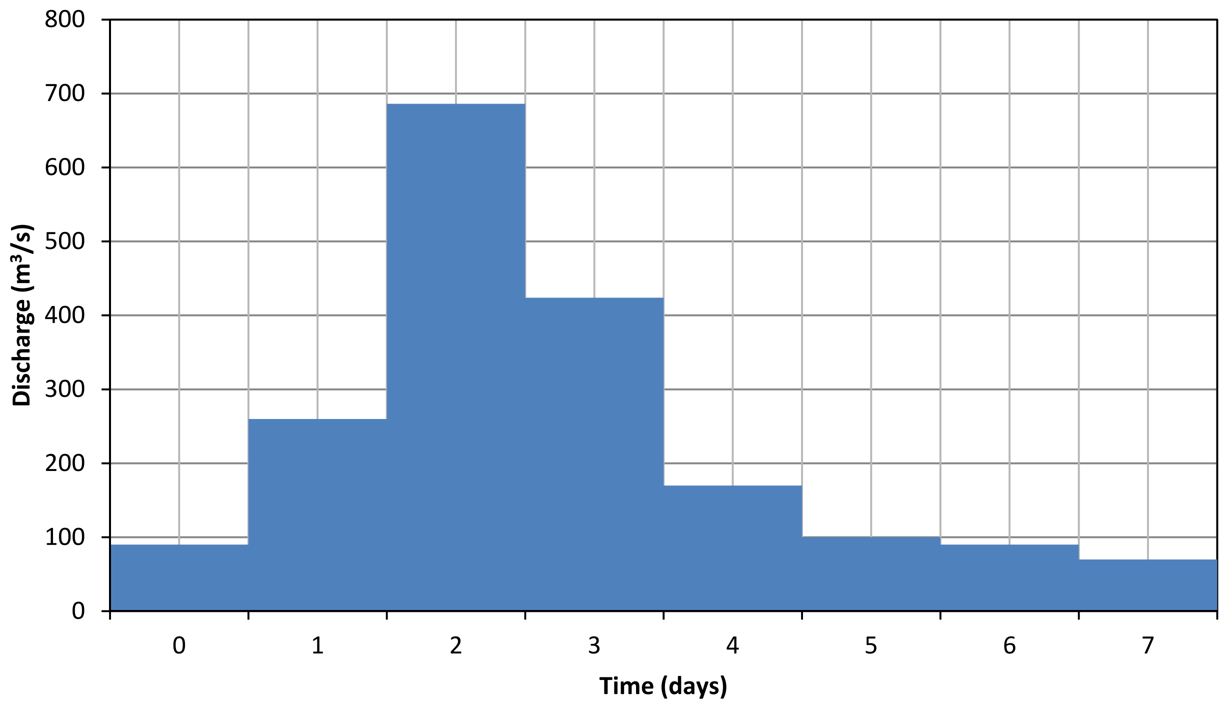


Figure 6: Elbow River near Glenmore Reservoir 1:500 Year Inflow Design Flood Daily Discharge Hydrograph (1908 to 2013 Data)

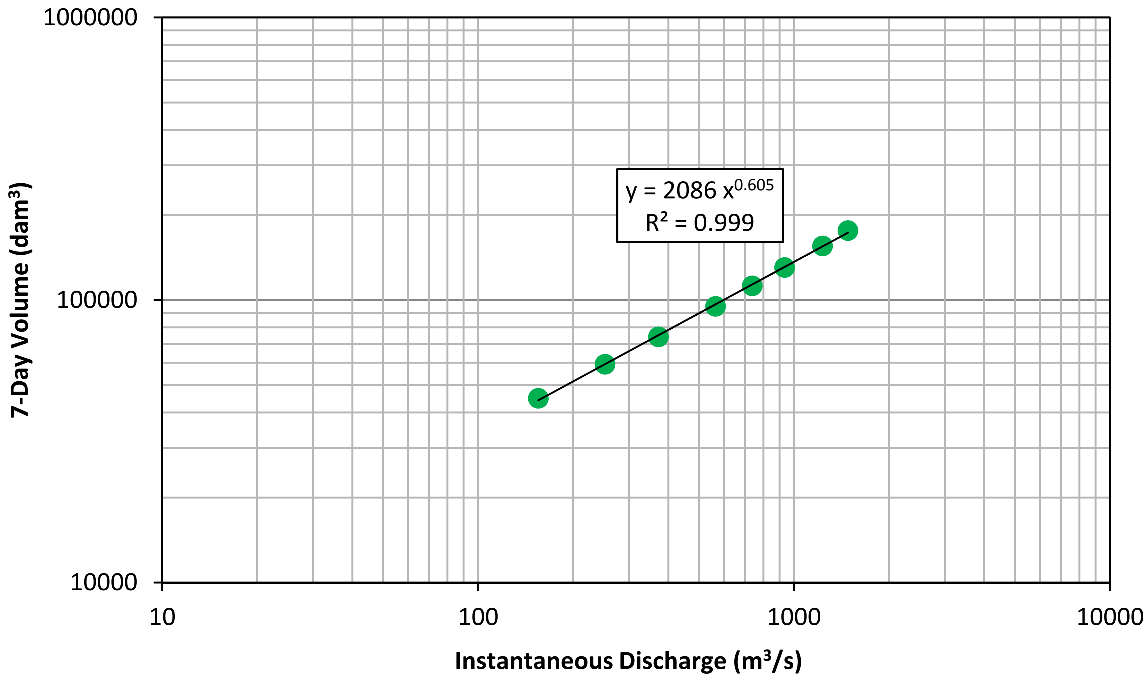


Figure 7: Elbow River near Glenmore Reservoir, Annual Peak 7-Day Volume vs Instantaneous Discharge (1908 to 2013 Data)

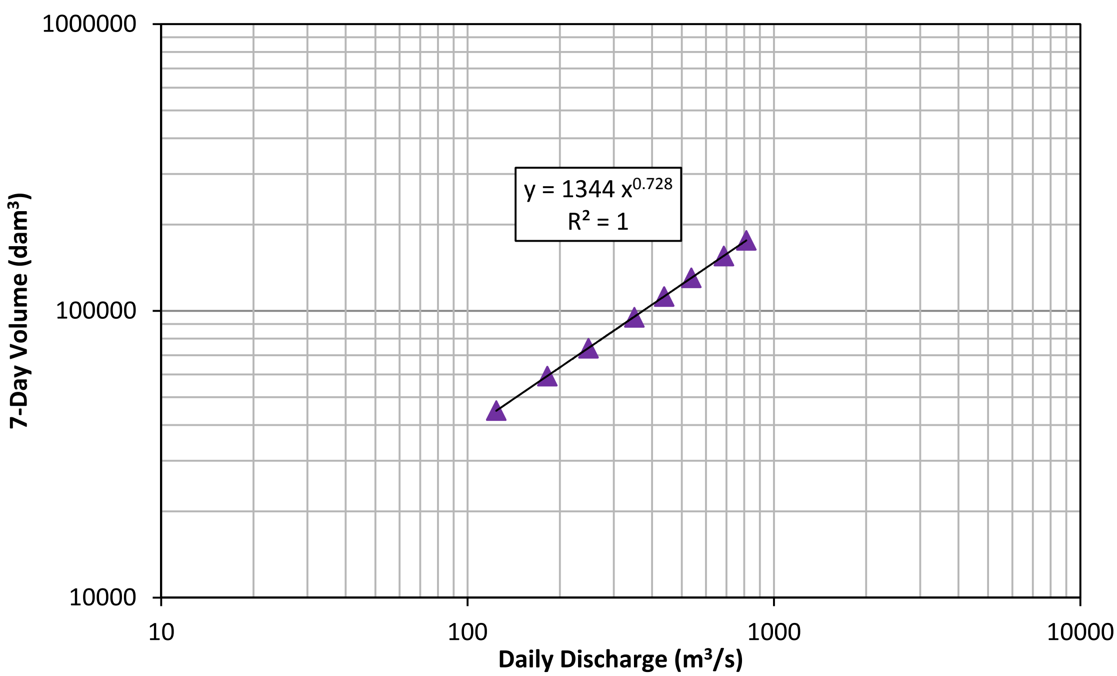


Figure 8: Elbow River near Glenmore Reservoir, Annual Peak 7-Day Volume vs Daily Discharge (1908 to 2013 Data)

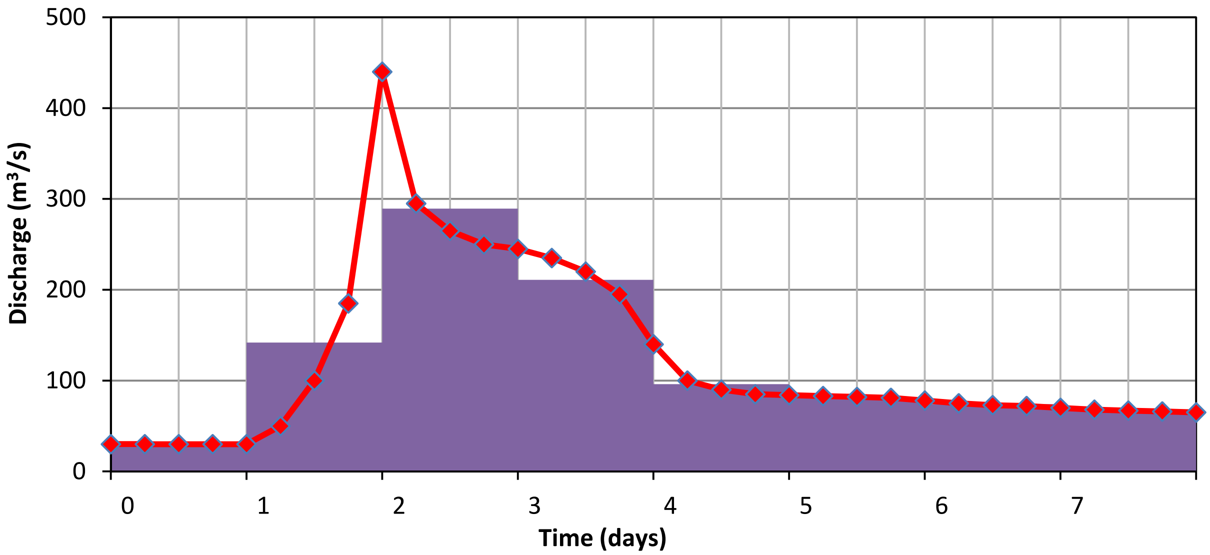


Figure 9: Elbow River near Glenmore Reservoir 1:20 Year Inflow Design Flood Daily and Quasi-Instantaneous Hydrographs (1879 to 2013 Extended Data)

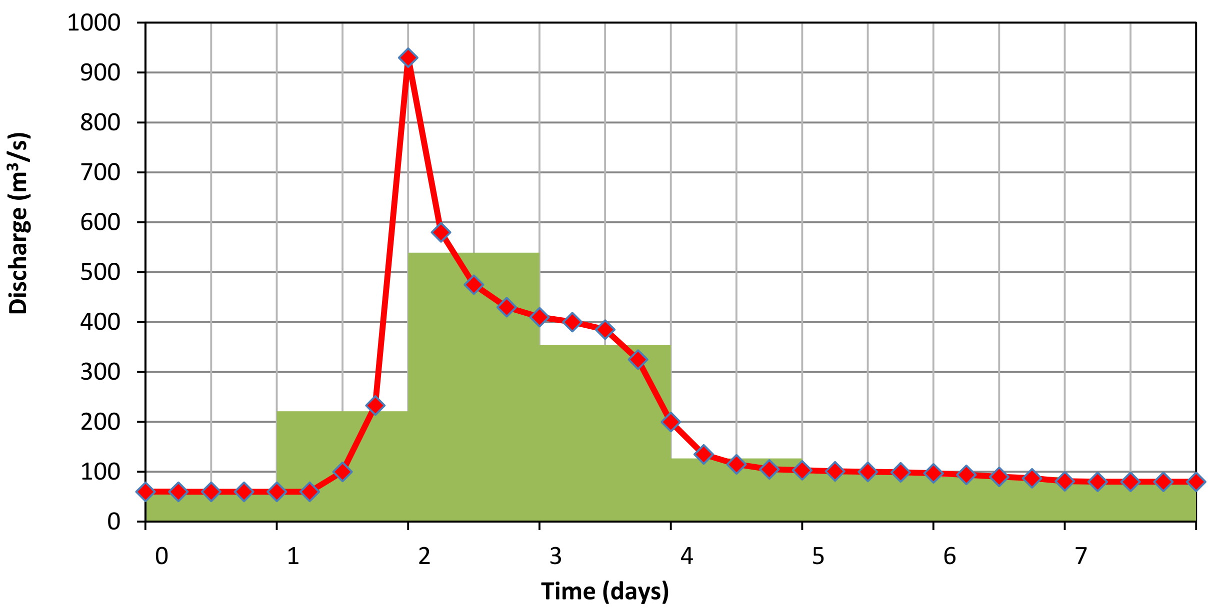


Figure 10: Elbow River near Glenmore Reservoir 1:100 Year Inflow Design Flood Daily and Quasi-Instantaneous Hydrographs (1879 to 2013 Extended Data)

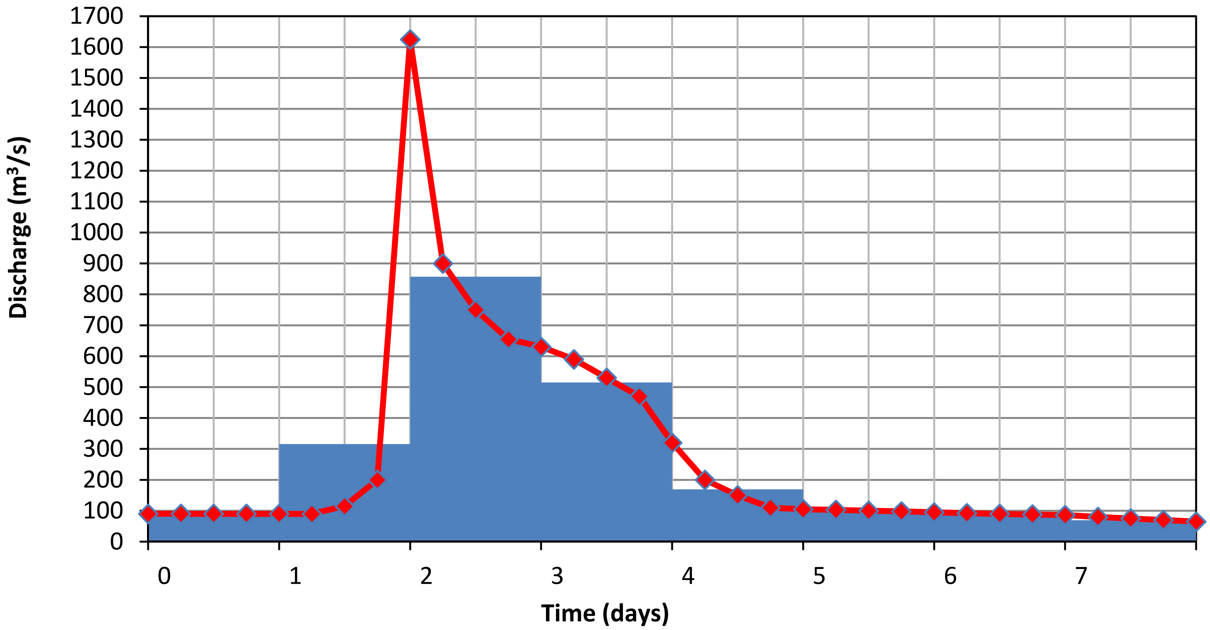


Figure 11: Elbow River near Glenmore Reservoir 1:500 Year Inflow Design Flood Daily and Quasi-Instantaneous Hydrographs (1879 to 2013 Extended Data)

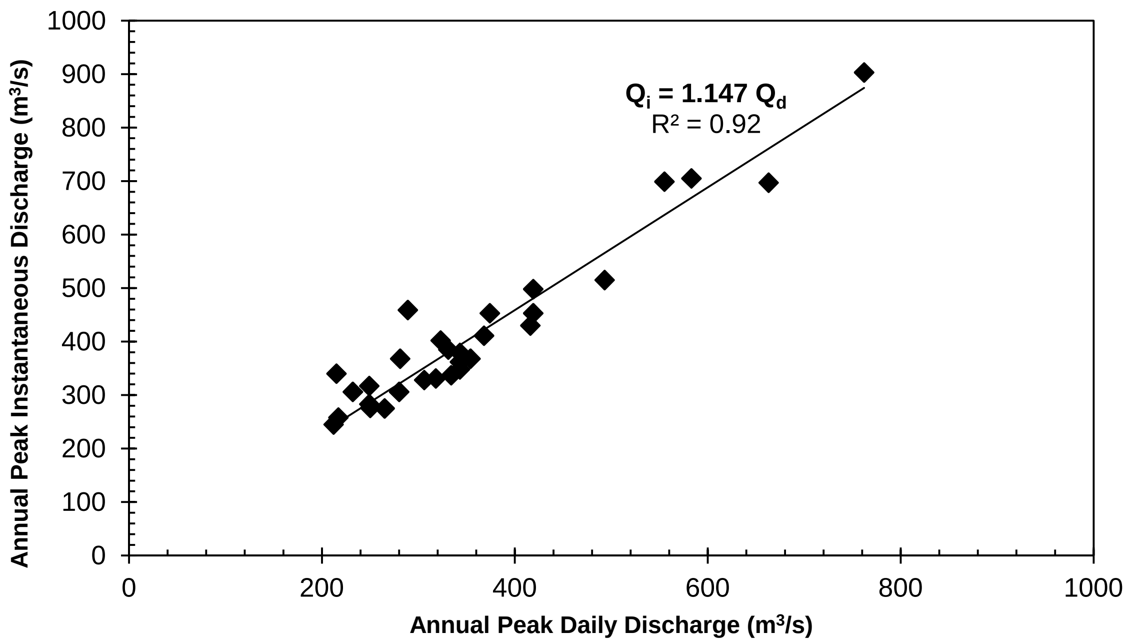


Figure 12: Bow River near Morley Annual Peak Instantaneous vs. Annual Peak Daily Discharges, (1912 to 2011)

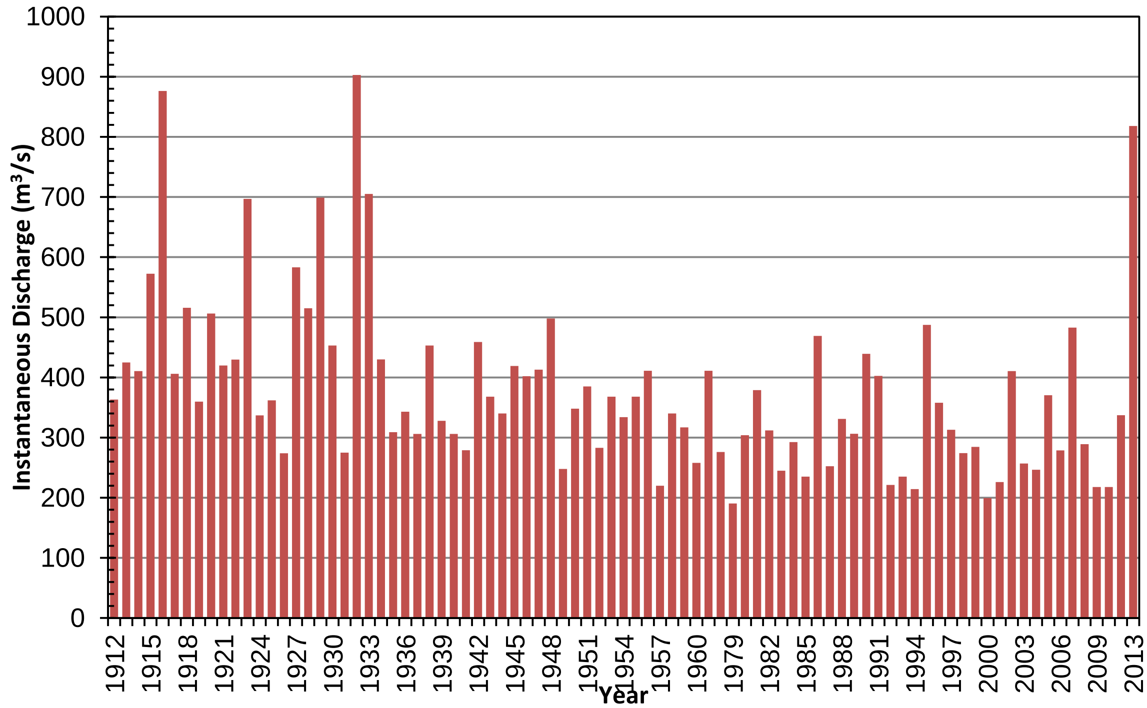


Figure 13: Bow River near Morley Annual Peak Instantaneous Discharges (1912 to 2013)

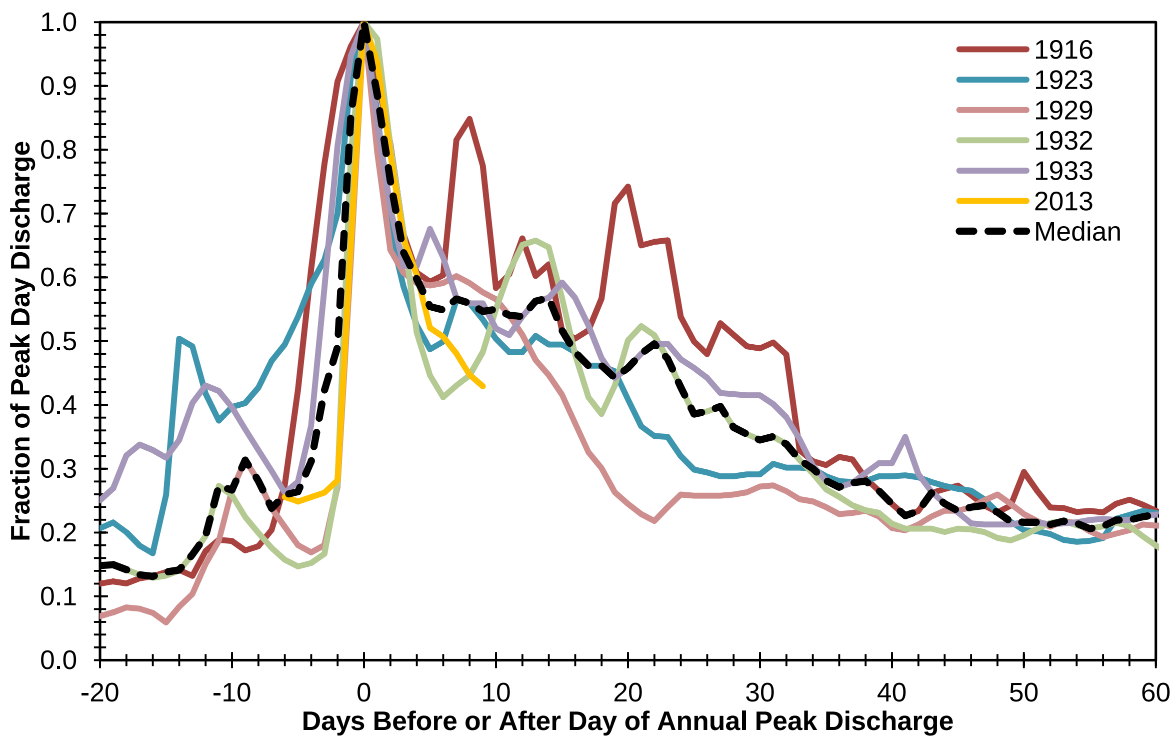


Figure 14: Bow River near Morley Normalized Hydrographs for Selected Years

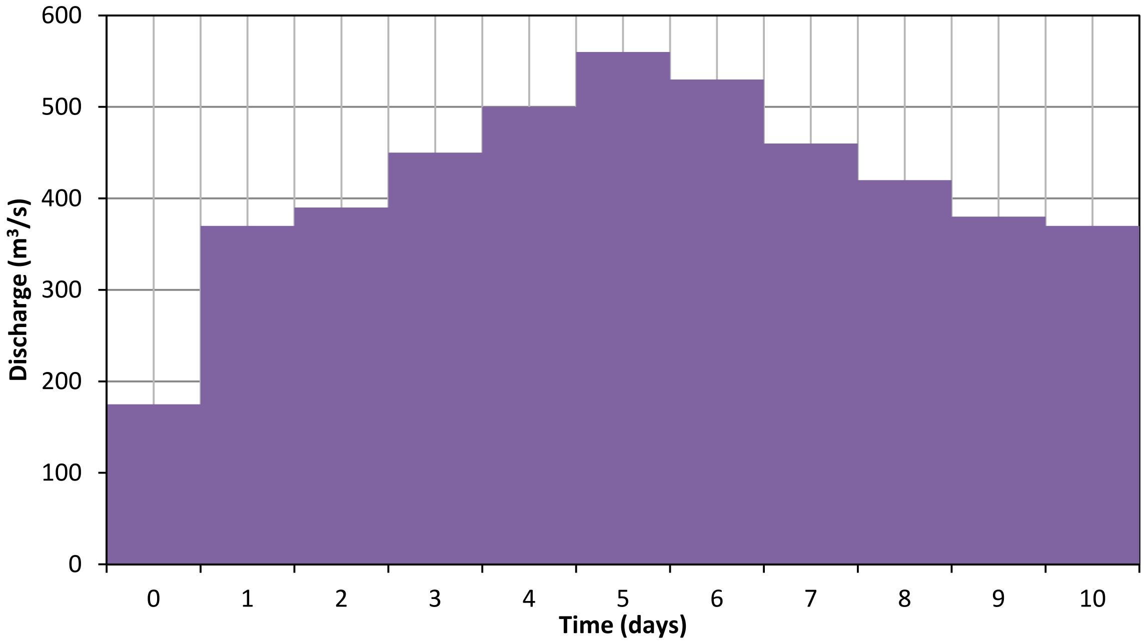


Figure 15: Bow River near Morley 1:20 Year Inflow Design Flood Daily Discharge Hydrograph (1912 to 2013 Data)

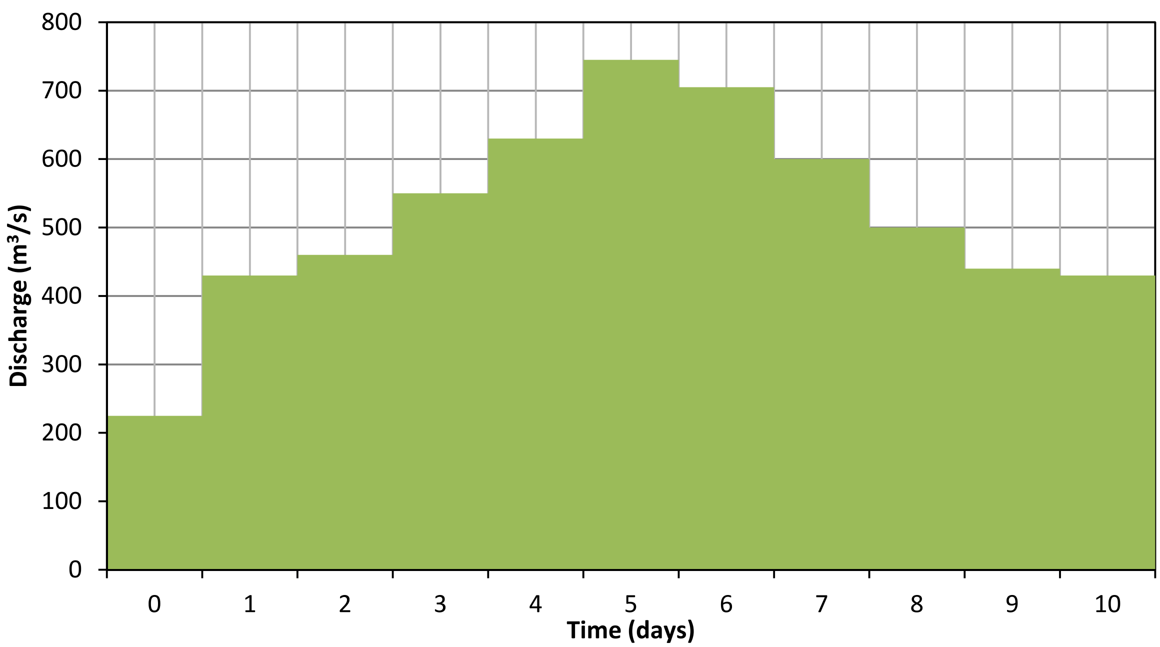


Figure 16: Bow River near Morley 1:100 Year Inflow Design Flood Daily Discharge Hydrograph (1912 to 2013 Data)

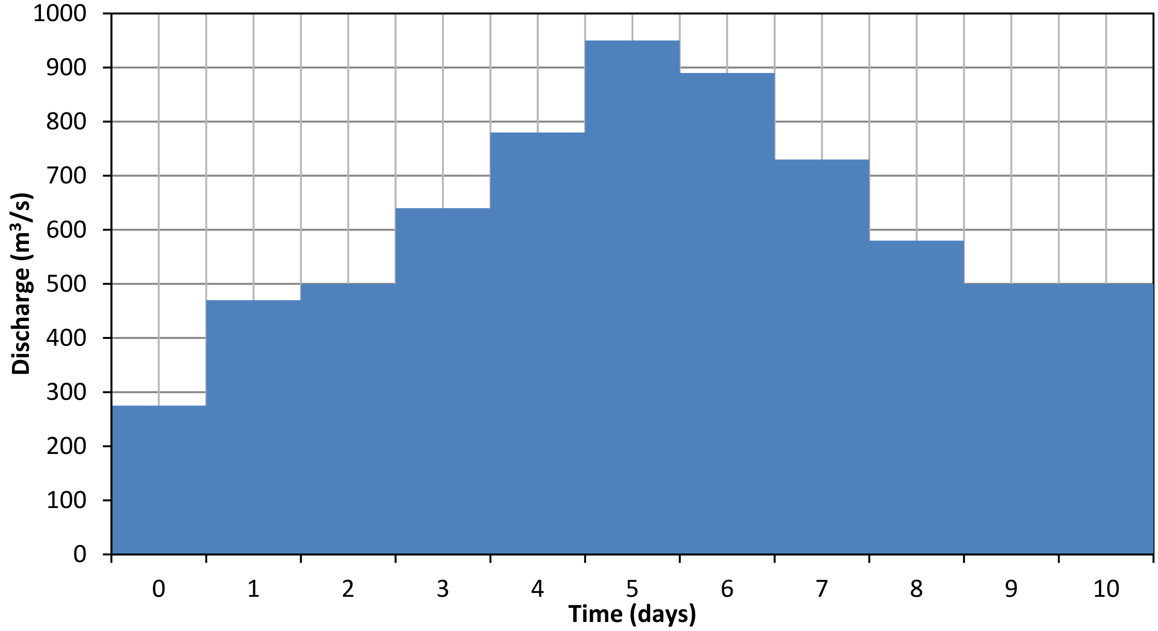


Figure 17: Bow River near Morley 1:500 Year Inflow Design Flood Daily Discharge Hydrograph (1912 to 2013 Data)

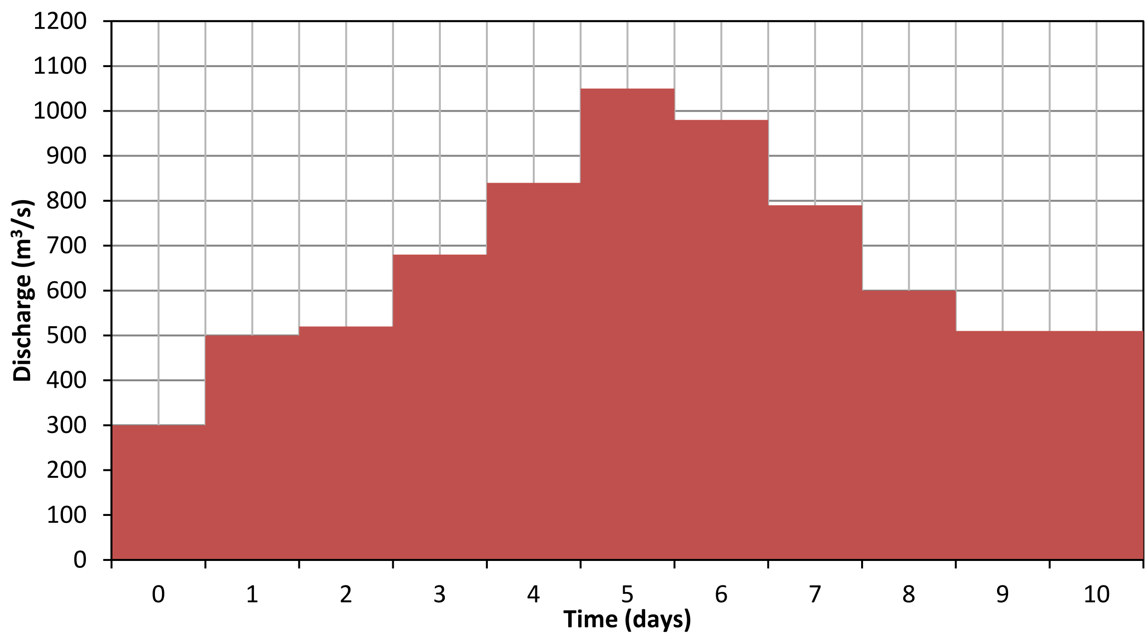


Figure 18: Bow River near Morley 1:1000 Year Inflow Design Flood Daily Discharge Hydrograph (1912 to 2013 Data)

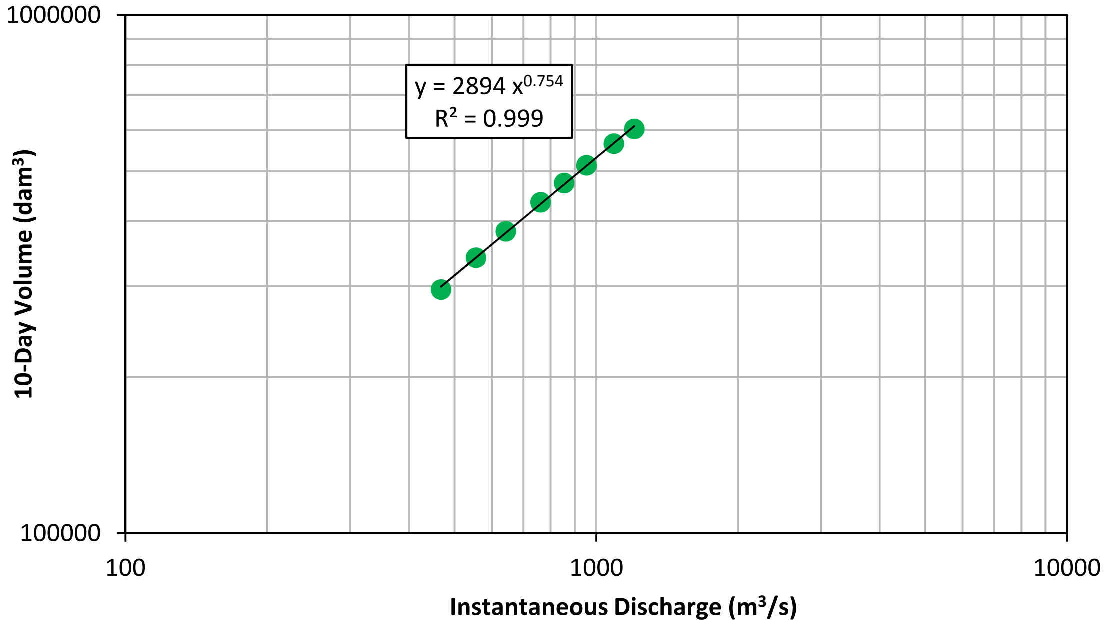


Figure 19: Bow River near Morley Annual Peak 10-Day Volume vs Instantaneous Discharge (1912 to 2013 Data)

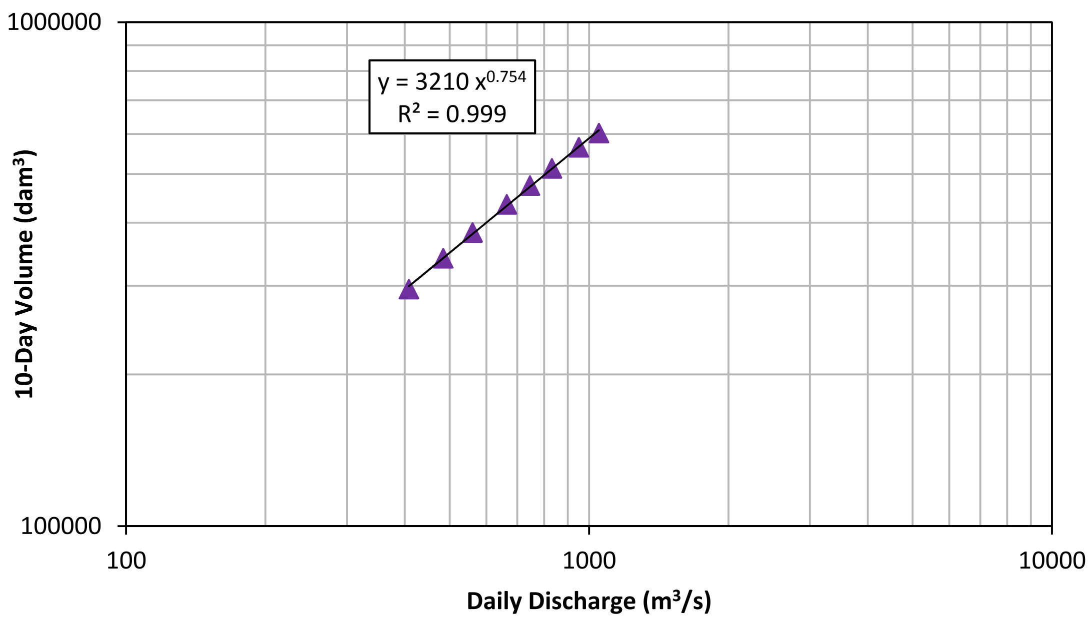


Figure 20: Bow River near Morley Annual Peak 10-Day Volume vs Daily Discharge (1912 -to 2013 Data)

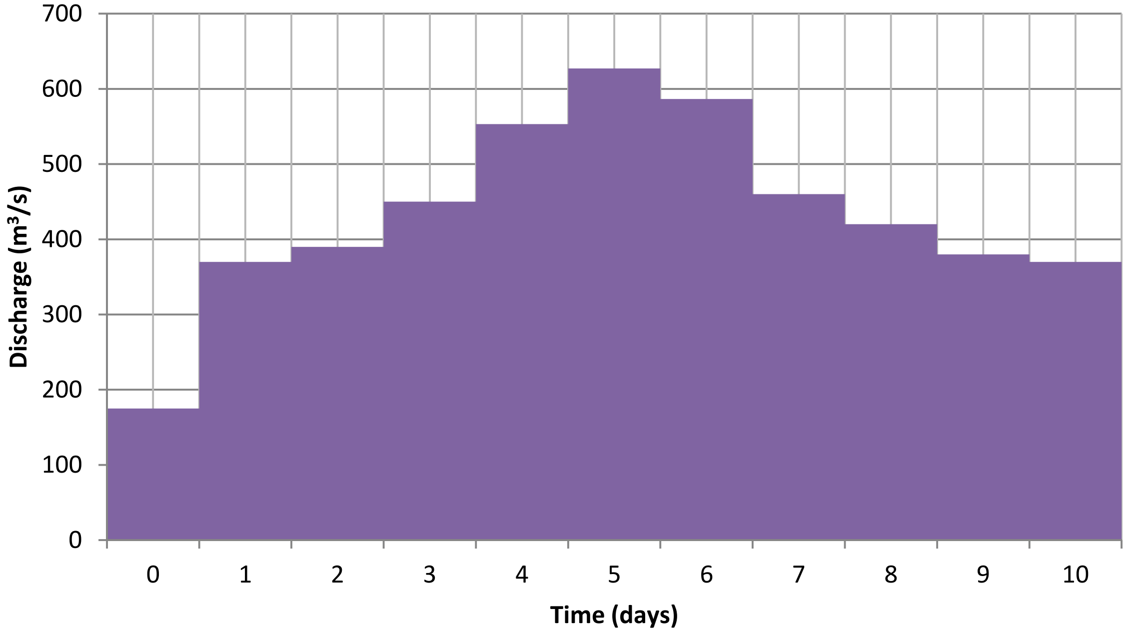


Figure 21: Bow River near Morley 1:20 Year Inflow Design Flood Daily Discharge Hydrograph (1897 to 2013 Extended Data)

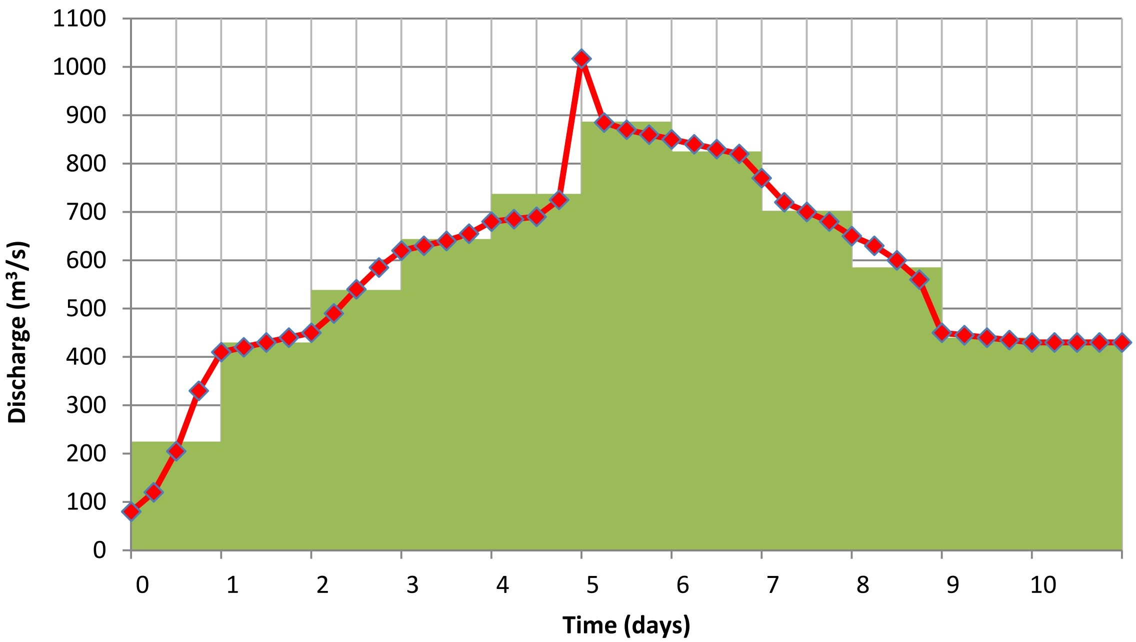


Figure 22: Bow River near Morley 1:100 Year Inflow Design Flood Daily and Quasi-Instantaneous Hydrographs (1897 to 2013 Extended Data)

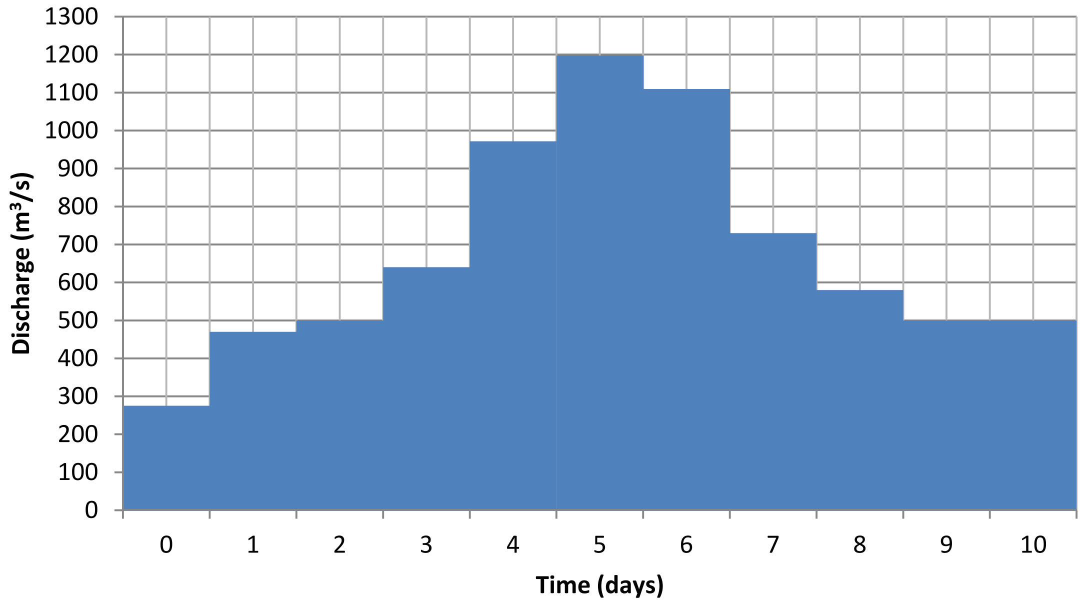


Figure 23: Bow River near Morley 1:500 Year Inflow Design Flood Daily Discharge Hydrograph (1897- to 013 Extended Data)

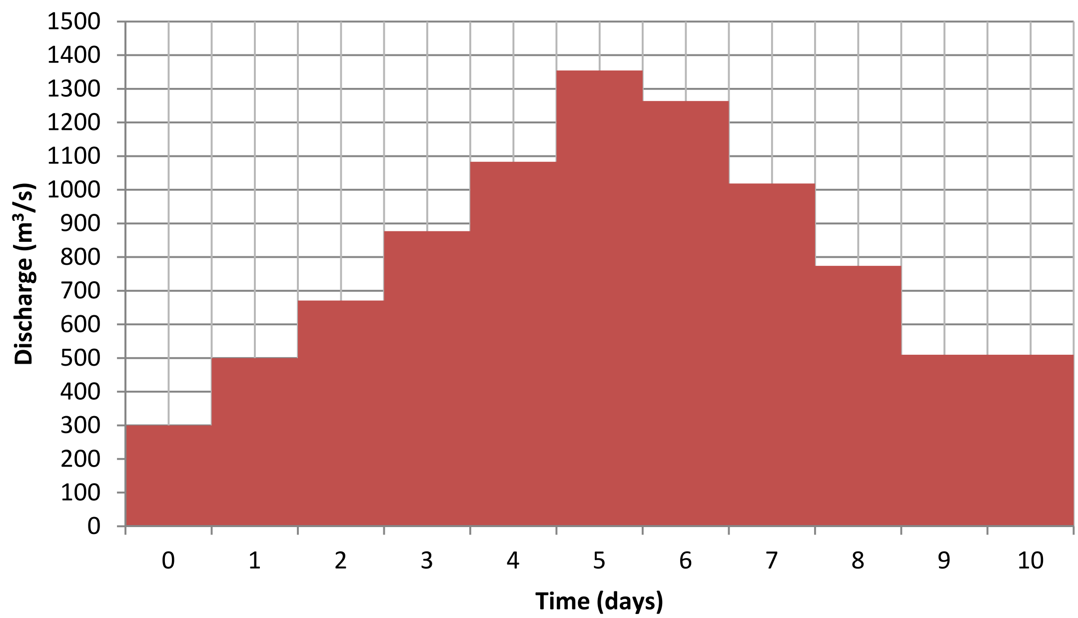


Figure 24: Bow River near Morley 1:1000 Year Inflow Design Flood Daily Discharge Hydrograph (1897 to 2013 Extended Data)