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ALBERTA ENVIRONMENT AND PARKS

Bow, Elbow, Highwood, and Sheep River Hydrology Assessment

Submitted to:
Alberta Environment and Parks (AEP)
River Engineering and Technical Services
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REPORT

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EXECUTIVE SUMMARY

In July 2015, Alberta Environment and Parks (AEP) commissioned Golder Associates (Golder) to conduct an assessment of the flood hydrology for the Bow River basin, including the Bow, Elbow, Highwood, and Sheep Rivers, as well as their major tributaries. The study scope is summarized below:

- Generation of naturalized daily flow series at the locations of all major storage facilities on the rivers.
- Generation of regulated daily flow series by routing the naturalized daily flows at all major storage facilities and considering water supply diversions.
- Frequency analyses of the flood flow series using the available data up to 2015.
- Commentary on the effects of climate change on the flood frequency estimates and on the seasonality of flood peak occurrences.

The flood frequency estimates obtained in this study are the most up-to-date for various locations along the Bow, Elbow, Highwood and Sheep Rivers and their tributaries. These estimates provide updated flood hydrology information as input to river hazard studies completed under the provincial Flood Hazard Identification Program.

This study includes use of the June 2013 flood flow data for the Bow River Basin and other river basins along the eastern mountain slopes in southern Alberta, and the preliminary estimates of the annual maximum flows in 2013, 2014 and 2015. Inclusion of the additional flow information, particularly for the large 2013 floods, increases the sample sizes for the flood frequency analyses and reliability of the resulting flood frequency estimates.

Consideration of historic flood information (i.e., 1879, 1897 and 1902 floods) in the Bow River, Elbow River, and anecdotal evidence of flooding on the Highwood River in the 1880's for updating the flood frequency estimates for the Bow, Elbow and Highwood Rivers increases the reliability of the flood frequency estimated for these rivers.

Application of the River Basin Assessment Tools (RBAT) and Water Resources Management Model (WRMM) models, including use of Streamflow Synthesis and Reservoir Regulation (SSARR) channel routing parameters, provides an accurate basis to simulate and account for the storage effects of the various reservoirs on the flood flows downstream of these reservoirs. The resulting natural/naturalized and regulated flood flow series provide good data sets for the flood frequency analyses.

Table E1 summarizes the final estimates of the instantaneous flood peak discharges of the various return periods for natural/naturalized flow conditions. The 95% upper and lower confidence intervals are provided in the table where applicable. The final flood frequency estimates for the gauged locations are based on the best fitting distribution. The maximum recorded length available and used in the analyses are less than 100 years, except for two locations on Bow River (Bow at Banff and Bow at Calgary). Hence, there are large uncertainties (i.e., the confidence intervals are very large) with flood frequency estimates for return periods greater than 100 years.

Although a similar analysis was completed for regulated flow conditions, it is important to note that limitations of the regulated analysis methodology do not support the use of regulated flood frequency estimates for flows higher than experienced in the historical record. While reported, regulated flood frequency estimates above the 75-year flood are not recommended for use for design purposes, as they do not consider the capacity of existing reservoirs and over-estimate the ability of regulation to reduce flood peaks.

Table E.1: Final Flood Frequency Flow Estimates – Natural and Naturalized Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Effective Drainage Area (km^2)	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																																						
				1000-yr			750-yr			500-yr			350-yr			200-yr			100-yr			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
				Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
BOW RIVER																																										
05BA001	Bow River at Lake Louise	422	EV2	182	304	95.8	172	279	94.2	159	247	92.3	149	222	90.1	135	191	86.7	118	156	81.9	111	145	80	102	129	77	95.1	117	74.3	84.6	101	70	72.7	83.3	63.9	61.9	68.7	56.7	48.2	51.9	45.4
05BB001	Bow River at Banff	2210	EV2	554	754	425	538	715	418	517	667	410	498	630	401	468	576	389	431	509	369	416	483	360	394	450	346	375	422	333	346	380	313	308	333	285	269	288	253	211	225	200
Node 105	Bow River below Spray River	2993	3P(MLH)	844	1230	593	811	1160	578	769	1070	560	729	997	542	670	883	514	602	763	479	574	716	464	537	653	443	505	598	425	456	524	395	398	440	358	341	368	315	264	283	248
Node 107	Bow River below Cascade River	3727	3P(MLH)	1050	1590	725	1010	1490	707	956	1380	682	905	1270	659	829	1130	621	742	966	577	707	902	559	659	821	533	618	752	509	556	652	474	481	542	426	409	445	374	311	331	291
Node 108	Bow River at Canmore	3870	*Prorated*[1]	1090	1650	753	1050	1550	734	993	1430	708	940	1320	684	861	1170	645	770	1000	599	734	937	580	684	852	553	642	781	529	577	677	492	499	563	442	425	462	388	323	344	302
Node 109	Bow River above Kananaskis	4199	*Interpolated*[2]	1270	2220	773	1210	2040	755	1130	1810	731	1060	1640	708	957	1400	670	843	1140	624	798	1060	605	738	942	578	689	853	554	614	726	515	527	595	464	446	485	407	338	360	317
Node 110	Bow River below Kananaskis	5139	EV2	1770	3850	831	1660	3430	817	1510	2910	795	1400	2540	776	1230	2050	742	1050	1550	694	983	1400	678	894	1200	649	822	1060	624	719	868	582	606	687	526	505	551	462	380	407	358
05BE004 / Node 111	Bow River near Seebe	5170	EV2	1760	3520	903	1650	3160	883	1510	2720	858	1400	2390	837	1240	1940	794	1060	1510	743	994	1370	718	906	1190	687	834	1050	657	731	878	607	616	703	541	513	562	470	384	414	360
Node 318	Bow River above Ghost Reservoir	5473	*Prorated*[1]	1860	3730	956	1750	3340	935	1600	2880	908	1480	2530	886	1310	2050	840	1120	1600	786	1050	1450	760	959	1260	727	883	1110	695	774	929	643	652	744	573	543	595	498	406	438	381
05BE006 / Node 58	Bow River below Ghost Dam (Ghost Reservoir Outflow), historic	6550	*Historical adjustment ratio applied to LP3(MLH)*[3]	2390	4730	1450	2230	4280	1380	2030	3690	1300	1850	3210	1220	1610	2590	1120	1350	1980	994	1260	1770	945	1130	1530	875	1030	1330	817	878	1080	728	718	830	624	577	640	521	408	437	379
05BH005 / Node 114	Bow River near Cochrane, historic	7383	*Interpolated*[2]	3270	*6650*	*1890*	3020	*5890*	*1780*	2690	*5000*	*1650*	2420	*4300*	*1540*	2060	*3410*	*1370*	1680	*2540*	*1190*	1540	*2240*	*1120*	1360	*1890*	*1030*	1220	*1930*	*946*	1010	*1280*	*822*	800	*955*	*683*	619	*696*	*554*	413	*445*	*383*
Node 302	Bearspaw Reservoir Inflow, historic	7672	*Assigned the same flows as Bow River at Calgary*	3580	*7320*	*2040*	3290	*6450*	*1920*	2920	*5460*	*1770*	2620	*4680*	*1650*	2220	*3700*	*1460*	1790	*2730*	*1260*	1630	*2400*	*1180*	1440	*2020*	*1080*	1280	*1730*	*991*	1060	*1350*	*854*	829	*998*	*703*	634	*716*	*566*	415	*448*	*385*
05BH004 / Node 59	Bow River at Calgary, historic	7736	*Historical assessment using Bulletin 17C methodology LP3(MLH)*[4]	4880	*9970*	*2780*	4400	*8630*	*2570*	3790	*7080*	*2300*	3330	*5940*	*2100*	2710	*4510*	*1790*	2090	*3190*	*1480*	1880	*2770*	*1360*	1610	*2260*	*1210*	1400	*1890*	*1080*	1120	*1430*	*902*	845	*1020*	*717*	627	*708*	*560*	401	*433*	*372*
Node 176	Bow River below Elbow River	8995	*Concurrent*[8]	5310	*7930*	*4230*	4820	*7080*	*3840*	4190	*6040*	*3350*	3710	*5240*	*2990*	3050	*4180*	*2470*	2390	*3140*	*1970*	2150	*2780*	*1780*	1860	*2340*	*1560*	1630	*2010*	*1390*	1310	*1560*	*1130*	996	*1150*	*882*	739	*816*	*675*	464	*497*	*434*
Node 158	Bow River below Nose Creek	9656	*Concurrent*[8]	5370	*10500*	*3270*	4880	*9110*	*3050*	4240	*7530*	*2750*	3760	*6370*	*2530*	3090	*4890*	*2170*	2420	*3520*	*1810*	2180	*3070*	*1660*	1890	*2540*	*1490*	1650	*2140*	*1330*	1330	*1640*	*1110*	1010	*1180*	*882*	746	*827*	*679*	465	*497*	*436*
Node 164	Bow River below Fish Creek	10182	*Concurrent*[8]	6100	*8720*	*5020*	5480	*7740*	*4500*	4700	*6550*	*3860*	4120	*5650*	*3400*	3340	*4470*	*2760*	2580	*3330*	*2160*	2310	*2940*	*1940*	1980	*2460*	*1680*	1730	*2110*	*1490*	1380	*1630*	*1200*	1040	*1190*	*926*	762	*839*	*698*	469	*502*	*439*
Node 177	Bow River below Pine Creek	10397	*Concurrent*[8]	6180	*11300*	*4080*	5560	*9790*	*3730*	4770	*8060*	*3280*	4180	*6790*	*2950*	3390	*5190*	*2470*	2620	*3720*	*2010*	2350	*3240*	*1830*	2020	*2670*	*1620*	1760	*2250*	*1440*	1400	*1710*	*1180*	1050	*1220*	*922*	770	*851*	*703*	472	*504*	*443*
Node 331	Bow River above Highwood River	10532	*Prorated*[1]	6260	*8880*	*5180*	5630	*7890*	*4650*	4830	*6680*	*3990*	4240	*5770*	*3520*	3440	*4570*	*2860*	2660	*3410*	*2240*	2380	*3010*	*2010*	2040	*2520*	*1740*	1780	*2160*	*1540*	1420	*1670*	*1240*	1070	*1220*	*956*	780	*857*	*716*	478	*511*	*448*
Node 165	Bow River below Highwood River	14497	EV2	7180	*16300*	*2250*	6390	*13800*	*2150*	5420	*11000*	*2000*	4690	*8980*	*1900*	3750	*6620*	*1740*	2840	*4520*	*1530*	2530	*3860*	*1450*	2150	*3100*	*1330*	1870	*2590*	*1240*	1500	*1950*	*1100*	1140	*1380*	*931*	867	*1000*	*762*	582	*644*	*538*
05BM002 / Node 178	Bow River below Carseland Dam	14696	EV2	6770	15100	2380	6080	12900	2280	5240	10500	2130	4590	8670	2010	3730	6500	1830	2880	4580	1620	2590	3960	1540	2230	3220	1420	1950	2690	1320	1580	2020	1170	1210	1460	983	917	1050	797	604	677	550
Node 180	Bow River at Hwy. 547	15920	*Interpolated*[2]	7090	13000	2860	6370	11300	2720	5480	9480	2510	4790	8010	2340	3890	6460	2070	2990	4580	1800	2690	3970	1700	2310	3240	1540	2010	2720	1420	1620	2060	1230	1230	1480	1010	923	1060	805	599	669	548
Node 181	Bow River at Hwy. 842	16344	*Interpolated*[2]	7210	12300	3030	6470	10800	2870	5560	9120	2650	4870	7770	2450	3950	6450	2160	3030	4580	1860	2720	3970	1750	2330	3250	1580	2030	2730	1450	1630	2070	1250	1240	1490	1020	925	1070	807	597	667	547
Node 189	Bow River below Crowfoot Creek	17672	*Interpolated*[2]	7560	10000	3550	6790	9130	3340	5820	8020	3070	5090	7050	2810	4120	6400	2420	3150	4580	2060	2820	3980	1920	2420	3280	1710	2100	2770	1550	1680	2120	1320	1260	1520	1050	932	1080	816	591	658	545
05BM004 / Node 182	Bow River below Bassano Dam, extended	17751	LP3(MLH)	7580	9900	3580	6810	9030	3370	5840	7950	3090	5100	7010	2830	4130	6400	2440	3160	4580	2070	2830	3980	1930	2420	3280	1720	2100	2770	1560	1680	2120	1320	1260	1520	1050	932	1080	816	591	658	545
Node 184	Bow River at Hwy. 539	18186	*Interpolated*[2]	6660	9490	3270	6030	8660	3090	5240	7640	2840	4620	6740	2610	3790	5960	2280	2950	4350	1940	2660	3810	1820	2300	3170	1630	2010	2690	1480	1620	2070	1260	1230	1490	1020	913	1060	795	581	645	533

Table E.1: Final Flood Frequency Flow Estimates – Natural and Naturalized Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Effective Drainage Area (km^2)	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																																						
				1000-yr			750-yr			500-yr			350-yr			200-yr			100-yr			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
				Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
Node 185	Bow River at Hwy. 36	18544	*Interpolated*[2]	5910	9160	3020	5390	8360	2850	4740	7390	2640	4220	6510	2430	3510	5590	2140	2780	4160	1840	2520	3680	1720	2190	3080	1560	1930	2630	1420	1570	2040	1220	1200	1470	989	898	1050	778	573	635	524
Node 186	Bow River at Hwy. 875	18878	*Interpolated*[2]	5200	8840	2780	4790	8080	2630	4280	7150	2450	3850	6300	2260	3250	5260	2020	2620	3990	1740	2390	3550	1630	2100	3000	1490	1860	2570	1360	1530	2000	1180	1180	1450	964	884	1030	762	565	625	515
05BN012 / Node 187	Bow River near the Mouth	19160	3P(MLH)	4610	8580	2580	4290	7840	2450	3890	6950	2290	3540	6120	2120	3030	4970	1910	2490	3840	1660	2280	3440	1560	2020	2930	1430	1800	2520	1310	1490	1970	1140	1160	1430	942	872	1020	749	559	617	507
Node 188	Bow River at the Mouth	19306	*Assigned the same flows as 05BN012*[6]	4610	8580	2580	4290	7840	2450	3890	6950	2290	3540	6120	2120	3030	4970	1910	2490	3840	1660	2280	3440	1560	2020	2930	1430	1800	2520	1310	1490	1970	1140	1160	1430	942	872	1020	749	559	617	507
BOW RIVER TRIBUTARIES																																										
05BB003 / Node 305	Forty Mile Creek near Banff	133	*Transferred using Redearth Creek based on ratio of drainage area*	57.3	*n/a*	*n/a*	55.9	*n/a*	*n/a*	53.8	*n/a*	*n/a*	51.9	*n/a*	*n/a*	49	*n/a*	*n/a*	45.2	*n/a*	*n/a*	43.7	*n/a*	*n/a*	41.4	*n/a*	*n/a*	39.4	*n/a*	*n/a*	36.2	*n/a*	*n/a*	32.1	*n/a*	*n/a*	27.6	*n/a*	*n/a*	20.8	*n/a*	*n/a*
Node 306	Forty Mile Creek at the Mouth	148	*Transferred using Redearth Creek based on ratio of drainage area*	57.3	*n/a*	*n/a*	55.9	*n/a*	*n/a*	53.8	*n/a*	*n/a*	51.9	*n/a*	*n/a*	49	*n/a*	*n/a*	45.2	*n/a*	*n/a*	43.7	*n/a*	*n/a*	41.4	*n/a*	*n/a*	39.4	*n/a*	*n/a*	36.2	*n/a*	*n/a*	32.1	*n/a*	*n/a*	27.6	*n/a*	*n/a*	20.8	*n/a*	*n/a*
05BC001 / Node 106	Spray River at Banff	751	EV2	432	802	218	402	720	210	363	613	200	332	536	191	287	434	179	240	336	163	222	303	156	199	262	145	180	229	137	154	187	123	125	145	106	99.2	111	88.1	68.2	75.1	62.8
05BD002 / Node 154	Cascade River near Banff	664	EV2	423	938	187	390	824	181	348	686	172	314	583	165	268	453	154	219	336	140	201	296	133	178	248	124	159	214	116	134	169	104	106	125	88.2	82.7	94.4	72.6	54.9	61.6	49.9
Node 307	Cougar Creek at the Mouth	43	*Regionalization*[5]	89	*n/a*	*n/a*	81.4	*n/a*	*n/a*	71.9	*n/a*	*n/a*	64.0	*n/a*	*n/a*	53.0	*n/a*	*n/a*	41.5	*n/a*	*n/a*	37.4	*n/a*	*n/a*	32.0	*n/a*	*n/a*	27.7	*n/a*	*n/a*	21.8	*n/a*	*n/a*	15.6	*n/a*	*n/a*	10.5	*n/a*	*n/a*	4.88	*n/a*	*n/a*
Node 308	Policeman's Creek at Canmore	10	*Regionalization*[5]	22.4	*n/a*	*n/a*	20.5	*n/a*	*n/a*	18.2	*n/a*	*n/a*	16.3	*n/a*	*n/a*	13.6	*n/a*	*n/a*	10.8	*n/a*	*n/a*	9.80	*n/a*	*n/a*	8.47	*n/a*	*n/a*	7.41	*n/a*	*n/a*	5.92	*n/a*	*n/a*	4.32	*n/a*	*n/a*	2.96	*n/a*	*n/a*	1.4	*n/a*	*n/a*
Node 309	Stoneworks Creek at Hwy. 1	6	*Regionalization*[5]	13.5	*n/a*	*n/a*	12.4	*n/a*	*n/a*	11.0	*n/a*	*n/a*	9.9	*n/a*	*n/a*	8.3	*n/a*	*n/a*	6.6	*n/a*	*n/a*	5.99	*n/a*	*n/a*	5.2	*n/a*	*n/a*	4.56	*n/a*	*n/a*	3.66	*n/a*	*n/a*	2.7	*n/a*	*n/a*	1.86	*n/a*	*n/a*	0.886	*n/a*	*n/a*
Node 310	Exshaw Creek at Exshaw	32	*Regionalization*[5]	67.9	*n/a*	*n/a*	62.1	*n/a*	*n/a*	54.9	*n/a*	*n/a*	48.9	*n/a*	*n/a*	40.6	*n/a*	*n/a*	31.9	*n/a*	*n/a*	28.7	*n/a*	*n/a*	24.7	*n/a*	*n/a*	21.4	*n/a*	*n/a*	16.9	*n/a*	*n/a*	12.1	*n/a*	*n/a*	8.18	*n/a*	*n/a*	3.82	*n/a*	*n/a*
05BF025 / Node 56	Kananaskis River below Barrier Dam	899	EV2	691	1510	231	623	1290	222	537	1040	210	472	865	200	386	648	184	300	457	166	270	396	159	234	326	148	205	275	139	168	213	125	130	157	106	100	114	88.3	68	74.8	62.8
05BG010	Ghost River above Waiparous Creek, extended with diversion added	485	EV2	1160	1930	450	990	1610	404	790	1250	343	648	1010	297	474	718	238	320	474	179	272	398	157	216	311	131	175	250	111	126	177	85.2	82.2	114	60	51.7	70.1	40.2	24	30.5	20
05BG006	Waiparous Creek near the Mouth, extended	333	3P(MLH)	692	1200	410	630	1080	378	553	925	339	487	794	303	395	623	253	301	455	200	267	397	181	224	325	155	190	268	135	144	196	105	97.9	127	74.3	61.6	76.4	48.8	26.3	32	21.3
05BG001 / Node 316	Ghost River near Cochrane, extended with diversion added	911	LP3(MLH)	1960	8410	741	1710	6670	680	1420	4860	596	1190	3670	536	909	2420	451	642	1440	352	553	1150	317	446	843	271	367	639	234	267	410	184	174	239	129	108	137	85.3	48.6	59	39.4
Node 317	Ghost River at the Mouth	940	*Assigned the same flows as 05BG001*	1960	8410	741	1710	6670	680	1420	4860	596	1190	3670	536	909	2420	451	642	1440	352	553	1150	317	446	843	271	367	639	234	267	410	184	174	239	129	108	137	85.3	48.6	59	39.4
05BH015	Jumpingpound Creek at Township Road No. 252, extended	474	*Transferred using Jumpingpound Creek near the Mouth - Foothills Region Power*	866	*n/a*	*n/a*	785	*n/a*	*n/a*	686	*n/a*	*n/a*	600	*n/a*	*n/a*	482	*n/a*	*n/a*	363	*n/a*	*n/a*	321	*n/a*	*n/a*	267	*n/a*	*n/a*	225	*n/a*	*n/a*	168	*n/a*	*n/a*	112	*n/a*	*n/a*	68.4	*n/a*	*n/a*	27.3	*n/a*	*n/a*
05BH009	Jumpingpound Creek near the Mouth, extended	571	3P(MLH)	1030	2250	488	936	2000	448	815	1670	404	711	1410	363	568	1070	306	425	747	241	374	638	217	310	505	186	260	407	160	193	287	125	127	177	87.5	76.8	102	56.5	30	39.7	22.3
Node 174	Jumpingpound Creek at the Mouth	601	*Transferred using Jumpingpound Creek near the Mouth - Foothills Region Power*	1087	*n/a*	*n/a*	982	*n/a*	*n/a*	855	*n/a*	*n/a*	744	*n/a*	*n/a*	594	*n/a*	*n/a*	444	*n/a*	*n/a*	390	*n/a*	*n/a*	323	*n/a*	*n/a*	270	*n/a*	*n/a*	200	*n/a*	*n/a*	132	*n/a*	*n/a*	79.3	*n/a*	*n/a*	30.8	*n/a*	*n/a*
Node 322	Bighill Creek at the Mouth	99	*Regionalization*[5]	48.4	*n/a*	*n/a*	45.6	*n/a*	*n/a*	41.8	*n/a*	*n/a*	38.4	*n/a*	*n/a*	33.3	*n/a*	*n/a*	27.4	*n/a*	*n/a*	25	*n/a*	*n/a*	21.8	*n/a*	*n/a*	19.1	*n/a*	*n/a*	15.1	*n/a*	*n/a*	10.5	*n/a*	*n/a*	6.55	*n/a*	*n/a*	2.29	*n/a*	*n/a*

Table E.1: Final Flood Frequency Flow Estimates – Natural and Naturalized Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Effective Drainage Area (km^2)	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																																						
				1000-yr			750-yr			500-yr			350-yr			200-yr			100-yr			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
				Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
05BH016	West Nose Creek at the Mouth	212	*Transferred using Nose Creek at Calgary - Foothills Region Power*	104.5	n/a	n/a	92.4	n/a	n/a	77.7	n/a	n/a	66.6	n/a	n/a	52.4	n/a	n/a	39	n/a	n/a	34.3	n/a	n/a	28.7	n/a	n/a	24.5	n/a	n/a	19	n/a	n/a	13.6	n/a	n/a	9.37	n/a	n/a	4.76	n/a	n/a
05BH014	Nose Creek above Airdrie	178	*Transferred using Nose Creek at Calgary - Foothills Region Power*	88.4	n/a	n/a	78.3	n/a	n/a	66.2	n/a	n/a	56.8	n/a	n/a	44.9	n/a	n/a	33.6	n/a	n/a	29.7	n/a	n/a	24.9	n/a	n/a	21.4	n/a	n/a	16.6	n/a	n/a	12	n/a	n/a	8.41	n/a	n/a	4.36	n/a	n/a
05BH003 / Node 175	Nose Creek at Calgary, extended	746	EV2	348	495	101	303	426	91.9	249	347	80.9	209	288	72.2	159	219	58.8	113	158	46.5	97.3	138	42.2	79	115	36.2	65.5	98.1	31.3	48.3	75.4	24.5	32.3	53.3	17.7	20.5	35.6	12	8.92	15.6	5.71
05BH901	Nose Creek at the Mouth	878	*Transferred using Nose Creek at Calgary - Foothills Region Power*	407	n/a	n/a	353	n/a	n/a	289	n/a	n/a	242	n/a	n/a	184	n/a	n/a	130	n/a	n/a	111	n/a	n/a	90.1	n/a	n/a	74.4	n/a	n/a	54.5	n/a	n/a	36.1	n/a	n/a	22.7	n/a	n/a	9.68	n/a	n/a
05BK001	Fish Creek near Priddis	261	3P(MLH)	926	3500	465	829	3010	422	713	2440	373	614	1990	328	481	1430	264	350	921	203	305	761	182	248	574	152	204	445	128	148	290	95.5	93.3	160	63.8	53.7	83.9	38.7	19.1	25.7	13.9
Node 163	Fish Creek at the Mouth	440	*Based on Threepoint Creek near Millarville and Fish Creek near Priddis*	1041	n/a	n/a	943	n/a	n/a	823	n/a	n/a	719	n/a	n/a	577	n/a	n/a	434	n/a	n/a	383	n/a	n/a	318	n/a	n/a	267	n/a	n/a	199	n/a	n/a	132	n/a	n/a	80.4	n/a	n/a	31.7	n/a	n/a
Node 330	Pine Creek at the Mouth	212	*Regionalization[5]*	99.7	n/a	n/a	93.1	n/a	n/a	84.2	n/a	n/a	76.4	n/a	n/a	65	n/a	n/a	51.9	n/a	n/a	46.9	n/a	n/a	40.1	n/a	n/a	34.5	n/a	n/a	26.5	n/a	n/a	17.7	n/a	n/a	10.5	n/a	n/a	3.34	n/a	n/a
05BM008	Crowfoot Creek near Cluny	950	3P(MLH)	797	1980	193	701	1700	182	589	1380	170	495	1120	159	373	794	141	259	514	117	220	428	108	174	323	93.8	139	249	79.5	95.5	160	58	56.6	87.7	36.3	30.4	45.1	20.3	10.1	16.3	7.34
05BN006	New West Coulee near the Mouth	102	EV3	11.7	16.8	7.88	11.4	16.1	7.82	11.1	15.2	7.75	10.7	14.4	7.65	10.2	13.2	7.48	9.49	11.8	7.23	9.18	11.2	7.11	8.73	10.4	6.93	8.32	9.79	6.77	7.65	8.8	6.45	6.76	7.58	5.92	5.78	6.36	5.18	4.17	4.61	3.73
05BN002	Twelve Mile Creek near Cecil	124	3P(MLH)	26.9	48.9	16.8	25.5	44.9	16.3	23.6	40	15.7	22	35.7	15.1	19.5	29.8	14.2	16.7	23.7	12.8	15.6	21.5	12.3	14.2	18.6	11.5	12.9	16.3	10.7	11.1	13.1	9.53	9.05	9.99	7.88	7.11	7.93	6.16	4.68	5.54	3.94
Node 179	Arrowwood Creek above Hwy. 547	718	LP3(moment)	298	977		273	824		239	677		212	552		172	398		129	263		113	217		93	165		76.9	128		55	86.5		33.4	50.6		17.4	27.1		4.4	7.9	
ELBOW RIVER AND TRIBUTARIES																																										
05BJ004	Elbow River at Bragg Creek, extended using relationship established with Elbow at Sarcee Bridge based on Instantaneous floods, historic	791	*Historical adjustment ratio applied to 3P(MLH)³*	2150	4000	1260	1930	3520	1150	1660	2980	1010	1440	2520	891	1140	1930	727	840	1340	557	736	1150	497	607	916	420	508	745	359	377	527	277	250	331	191	155	195	125	67.5	79.6	57.4
05BJ010	Elbow River at Sarcee Bridge, combined data from 05BJ001, 05BJ005, 05BJ010 with estimated instantaneous flows from the 1983 AENV floodplain study, historic	1189	*Historical adjustment ratio applied to 3P(MLH)³*	2150	4000	1170	1930	3520	1070	1660	2950	941	1440	2500	834	1140	1900	685	841	1340	531	738	1150	474	610	918	404	509	749	347	379	535	271	253	335	191	157	199	128	70.4	83.1	60.3
Node 161	Elbow River below Glenmore Dam, historic	1236	*Assigned the same flows as 05BJ010*	2150	4000	1170	1930	3520	1070	1660	2950	941	1440	2500	834	1140	1900	685	841	1340	531	738	1150	474	610	918	404	509	749	347	379	535	271	253	335	191	157	199	128	70.4	83.1	60.3
Node 340	Bragg Creek at the Mouth	50	*Regionalization[5]*	103	n/a	n/a	94.6	n/a	n/a	83.5	n/a	n/a	74.3	n/a	n/a	61.4	n/a	n/a	48.1	n/a	n/a	43.2	n/a	n/a	37	n/a	n/a	32	n/a	n/a	25.2	n/a	n/a	18	n/a	n/a	12	n/a	n/a	5.59	n/a	n/a
Node 335	Lott Creek at the Mouth	114	*Regionalization[5]*	55.2	n/a	n/a	52	n/a	n/a	47.5	n/a	n/a	43.6	n/a	n/a	37.7	n/a	n/a	30.8	n/a	n/a	28.1	n/a	n/a	24.4	n/a	n/a	21.3	n/a	n/a	16.7	n/a	n/a	11.6	n/a	n/a	7.14	n/a	n/a	2.45	n/a	n/a
SHEEP RIVER AND TRIBUTARIES																																										
05BL014	Sheep River at Black Diamond	592	3P(MLH)	1900	5010	910	1720	4390	837	1500	3680	751	1310	3100	672	1050	2310	561	787	1600	445	693	1360	401	576	1080	345	484	872	301	361	601	235	240	360	165	148	206	107	61.5	79.6	47.1
05BL012	Sheep River at Okotoks, extended	1494	3P(MLH)	2620	4650	1520	2420	4220	1430	2180	3670	1310	1950	3210	1190	1640	2580	1030	1300	1950	852	1180	1730	784	1020	1460	694	886	1240	616	701	939	507	504	646	377	338	417	261	158	196	127

Table E.1: Final Flood Frequency Flow Estimates – Natural and Naturalized Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Effective Drainage Area (km^2)	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																																						
				1000-yr			750-yr			500-yr			350-yr			200-yr			100-yr			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
				Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
Node 344	Sheep River at the Mouth, extended	1570	*Prorated*[1]	2750	4890	1600	2540	4440	1500	2290	3860	1380	2050	3370	1250	1720	2710	1080	1370	2050	896	1240	1820	824	1070	1530	730	931	1300	648	737	987	533	530	679	396	355	438	274	166	206	134
Node 338	Ware Creek at the Mouth	129	*Regionalization*[5]	265	n/a	n/a	242	n/a	n/a	213	n/a	n/a	188	n/a	n/a	155	n/a	n/a	120	n/a	n/a	108	n/a	n/a	91.5	n/a	n/a	78.7	n/a	n/a	61.2	n/a	n/a	43.1	n/a	n/a	28.4	n/a	n/a	13.1	n/a	n/a
Node 339	Threepoint Creek above Ware Creek	136	*Regionalization*[5]	278	n/a	n/a	254	n/a	n/a	223	n/a	n/a	198	n/a	n/a	162	n/a	n/a	126	n/a	n/a	113	n/a	n/a	95.9	n/a	n/a	82.5	n/a	n/a	64.1	n/a	n/a	45.1	n/a	n/a	29.7	n/a	n/a	13.7	n/a	n/a
05BL013	Threepoint Creek near Millarville	507	3P(MLH)	1140	2690	542	1040	2380	501	914	2010	455	803	1710	410	650	1310	345	495	941	275	439	806	249	368	648	216	312	521	187	235	371	149	158	232	106	98.2	134	69.8	39.8	52	29.4
Node 341	Threepoint Creek at the Mouth	638	*Transferred using Threepoint Creek near Millarville (Mountain Region Power)*	1430	n/a	n/a	1300	n/a	n/a	1140	n/a	n/a	1000	n/a	n/a	810	n/a	n/a	616	n/a	n/a	545	n/a	n/a	457	n/a	n/a	387	n/a	n/a	290	n/a	n/a	192	n/a	n/a	118	n/a	n/a	48.7	n/a	n/a
HIGHWOOD RIVER AND TRIBUTARIES																																										
05BL019	Highwood River at Diebel's Ranch	774	LP3(MLH)	1390	7030	469	1250	5750	446	1080	4370	417	945	3400	390	765	2290	350	583	1430	300	519	1170	282	439	887	254	378	693	231	295	477	195	212	301	155	146	186	115	78.8	92.8	66.6
05BL004	Highwood River below Little Bow Canal, extended, historic	1953	*Historical adjustment ratio applied to EV2*[7]	2830	4100	1560	2490	3570	1410	2090	2950	1240	1790	2490	1090	1400	1900	889	1030	1360	692	905	1180	624	752	972	535	637	814	463	486	611	369	342	426	268	231	286	188	118	142	101
05BL024	Highwood River near the Mouth, extended, historic	3941	*Historical adjustment ratio applied to EV2*[7]	5200	8190	2820	4580	7050	2560	3830	5720	2230	3270	4760	1970	2550	3600	1630	1870	2530	1270	1630	2180	1130	1350	1780	961	1140	1480	829	872	1100	656	612	761	479	413	510	334	213	255	181
Node 172	Highwood River at the Mouth, historic	3964	*Prorated*[1]	5230	8240	2840	4600	7090	2570	3850	5750	2240	3290	4790	1980	2560	3620	1640	1880	2540	1280	1640	2190	1140	1360	1790	967	1150	1490	834	877	1110	660	615	765	482	415	513	336	214	256	182
05BL022	Cataract Creek near Forestry Road	166	EV2	1280	2770	128	1070	2280	122	834	1730	114	670	1350	106	475	934	96.6	309	581	83.6	259	478	78.5	201	363	71.7	161	284	65.2	113	193	55.9	72.4	117	45.4	45.4	67.9	33.9	22.2	29.2	18.4
05BL023	Pekisko Creek near Longview	232	3P(MLH)	680	1770	284	608	1540	262	522	1260	233	449	1040	207	350	764	172	254	511	134	221	428	119	180	332	100	148	262	85.5	106	176	63.9	66.9	102	43.7	38.4	55.5	26.7	13.7	19.9	9.65
05BL007	Stimson Creek near Pekisko	236	3P(MLH)	456	943	227	413	835	209	360	708	188	314	600	169	252	458	141	189	322	112	167	277	102	138	221	86.9	116	179	74.9	86.2	127	58.8	56.6	77.5	40.9	34	44	25.9	12.7	16.6	9.58
05BL027	Trapp Creek near Longview	137	3P(MLH)	819	2020	82.4	719	1740	79.5	602	1410	75.4	505	1150	71.6	379	822	65.5	261	532	57.9	222	438	55.1	175	331	50.3	139	257	46.6	95.8	178	40.7	56.9	119	31.2	31	72.7	20.2	11.3	18.3	7.99

1. Prorated: Instantaneous flood flows were estimated by applying ratio between effective drainage areas at the node in interest and node upstream or downstream of the node in interest using an exponent of 1
2. Interpolated: Instantaneous flood flows were estimated based on interpolation between frequency analysis for upstream and downstream stations
3. Historical Adjustment Ratio Applied: Instantaneous flood flows including historical floods were derived by applying a percentage multiplier to each return period based on ratios of Bow River at Calgary results with and without historic floods
4. Historical Assessment using Bulletin 17C Methodology: Instantaneous flood frequency flow estimates for Bow River at Calgary were derived using the updated Bulletin 17C methodology to incorporate historical floods
5. Regionalization: Instantaneous flood flows were derived based on regional analysis
6. Instantaneous flood flows at Node 188 (Bow River at the Mouth) were assigned the same as 05BN012 (Bow River near the Mouth)
7. Historical Adjustment Ratio Applied: Instantaneous flood flows and confidence bounds including historical floods were derived based on scaling the frequency analysis for Highwood River below Little Bow with and without historic floods (by applying a percentage multiplier to each return period)
8. Concurrent: Instantaneous flood flows were generated based on an examination of the concurrent data records

ACKNOWLEDGEMENTS

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As Project Contracting Manager, Mr. Minke provided overall direction to the study, supplied the relevant information from AEP, coordinated the inputs and participation from AEP, provided AEP's review comments on the various draft technical memoranda submitted by Golder during the study, coordinated the review of the draft report and facilitated the discussion with and inputs of the various AEP team members.

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The contribution of the following staff from Golder team members to this study are acknowledged:

- Ms. Nancy Guo;
- Mr. Apurva Gollamudi;
- Dr. Shouhong Wu;
- Dr. Dejiang Long; and
- Dr. Getu Biftu.

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1.0 INTRODUCTION

1.1 Background

Severe flooding occurred in Alberta in June 2013. The floods in some of the tributary watersheds of the Bow, Elbow, Highwood and Sheep Rivers have estimated return periods of more than 100 years.

Following the June 2013 floods, Alberta Environment and Parks (AEP) commissioned a number of flood peak documentation and frequency analysis studies for the river basins in Southern Alberta. The studies included documentation and determination of the 2013 flood peak discharges using preliminary flow data or analytical methods when the peak flow data were not available. In particular, Golder Associates Ltd. (Golder) completed the Basin-Wide Hydrology Assessment and 2013 Flood Documentation for the Bow and Elbow Rivers for the City of Calgary and AEP (Golder 2014a), and the 2013 Highwood River Flood Hydrology Study for AEP (Golder 2014b).

The most recent basin-wide flood hydrology study (Golder, 2014a) for the Bow and Elbow Rivers was conducted for the City of Calgary and AEP as part of the Bow and Elbow River Hydraulic Model and Flood Inundation Mapping Project. Previous flood hydrology studies for the Bow and Elbow Rivers include those by Golder (2010) and Alberta Environment (AENV 1983).

In July 2015, AEP commissioned Golder to conduct an update and assessment of the flood hydrology for the Bow, Elbow, Highwood, and Sheep Rivers. The purpose of this study is to support river and flood hazard studies completed under the provincial Flood Hazard Identification Program, which are used to help mitigate flood impacts, reduce potential future flood damages, and reduce disaster assistance costs. The outcome of this study will be used to support a variety of other projects, objectives, and stakeholders needs.

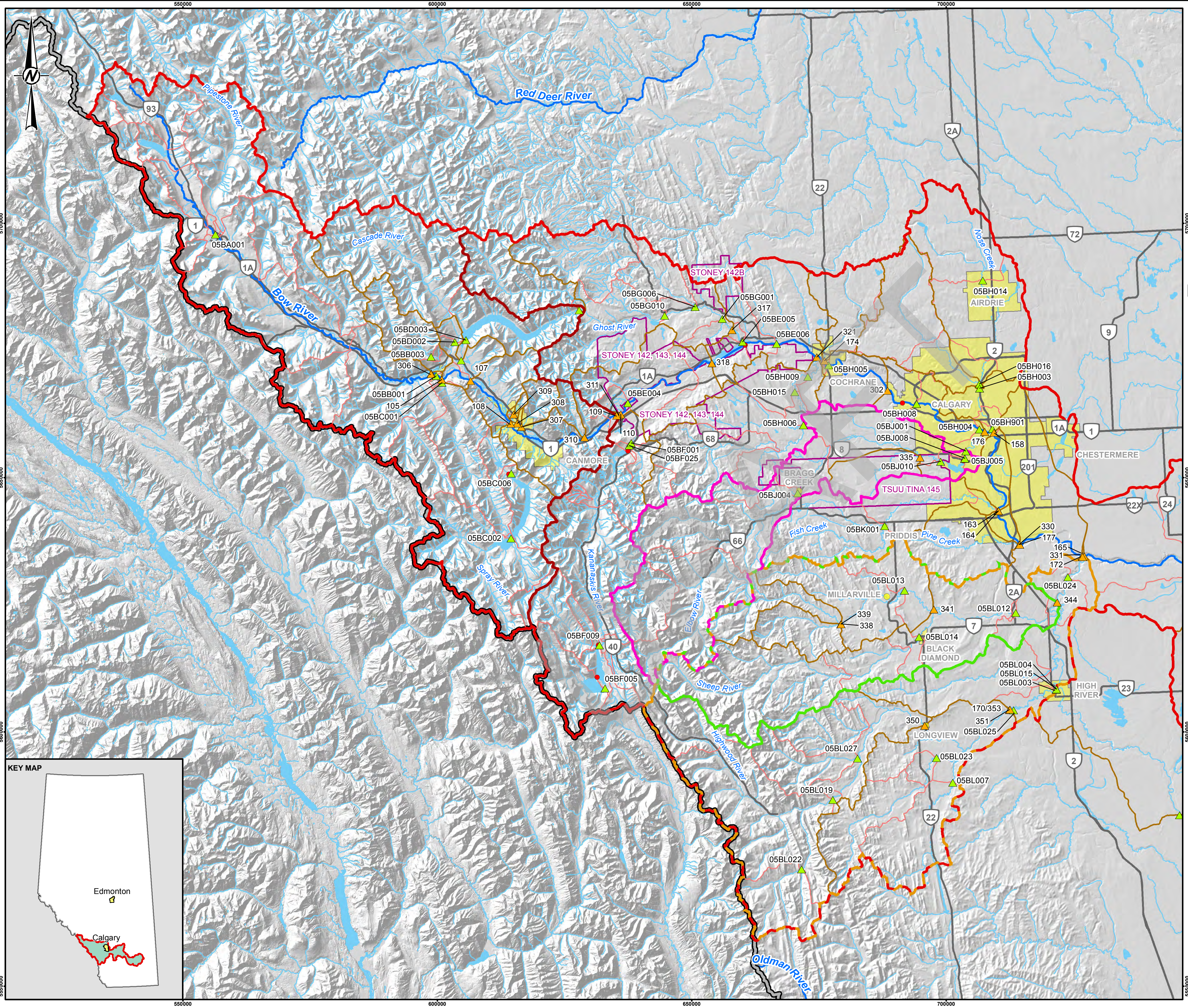
1.2 Study Area

The study area (Figures 1.1 and 1.2) includes the Bow River and its tributaries upstream of its mouth. The major tributaries include the Elbow and Highwood Rivers. The flows along the upstream reach of the Bow River and its tributaries are regulated by several hydropower structures (see Figure B-2 in Appendix B for locations of hydropower structures).

The Bow River within Calgary is joined by several tributaries, including the Elbow River, Nose Creek, Fish Creek and Pine Creek. The Highwood River is a major tributary to the Bow River downstream of Calgary. The Elbow River is the largest tributary to the Bow River within Calgary, and flows into the Glenmore Reservoir before entering the Bow River, just downstream of downtown Calgary.

The Bow River and some of its tributaries (including the Elbow River) originate in the Rocky Mountains and traverse the foothills before reaching Calgary on the edge of the Prairies. The streams flow through a mix of Alpine, Subalpine, Boreal Foothill and Aspen Parkland eco-regions. Land use in the river basin ranges from urban Calgary, to agricultural lands in parts of the foothills, and to forest in the remainder of the foothills and in the mountains.

The Highwood River watershed extends from the eastern slopes of the Rocky Mountains below Peter Lougheed Provincial Park, eastward to the Town of High River, and then north to where the Highwood River joins the Bow River, just southeast of Calgary. The Highwood River flows through the towns of Longview and High River before joining the Bow River. It has no major impoundments, and water use primarily consists of diversions to the Little Bow, and licensed withdrawals for irrigation, livestock watering, and municipal purposes.



LEGEND

- WATER SURVEY OF CANADA STATION - (e.g. 05BE004)
- NODE LOCATION - (e.g. 311)
- STORAGE STRUCTURE
- AAFC SUB-BASIN[1]
- DELINEATED SUB-BASIN[5]
- BOW RIVER BASIN
- BOW RIVER ABOVE KANANASKIS RIVER
- ELBOW RIVER BASIN
- HIGHWOOD RIVER BASIN
- SHEEP RIVER BASIN
- MAJOR RIVER
- WATERCOURSE
- WATERBODY
- PRIMARY HIGHWAY
- FIRST NATION LAND
- POPULATED PLACE
- PROVINCIAL BOUNDARY

0 25 50

1:750,000 KILOMETRES

REFERENCE(S)

1. HYDROMETRIC STATIONS, BASIN AND SUB-BASIN DATA OBTAINED FROM AGRICULTURE AND AGRI-FOOD CANADA (AAFC).
2. HILLSHADE AND HIGHWAYS OBTAINED GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
3. HYDROLOGY AND PROVINCIAL BOUNDARY OBTAINED FROM IHS ENERGY INC.
4. POPULATED PLACES AND INDIAN RESERVES OBTAINED FROM ALTALIS © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.
5. SUB-BASINS WERE DELINEATED BASED ON 10 m OR 20 m INTERVAL CONTOURS GENERATED FROM SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM).

DATUM: NAD83 PROJECTION: UTM ZONE 11

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
HYDROLOGY ASSESSMENT - BOW, ELBOW, HIGHWOOD AND SHEEP RIVER

TITLE
UPPER BOW, ELBOW, HIGHWOOD AND SHEEP RIVER BASINS

CONSULTANT
Golder Associates

YYYY-MM-DD	2017-02-07
DESIGNED	NG
PREPARED	SK
REVIEWED	GB
APPROVED	GB

PROJECT NO.	REV.	FIGURE
1532956	1	1.1

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

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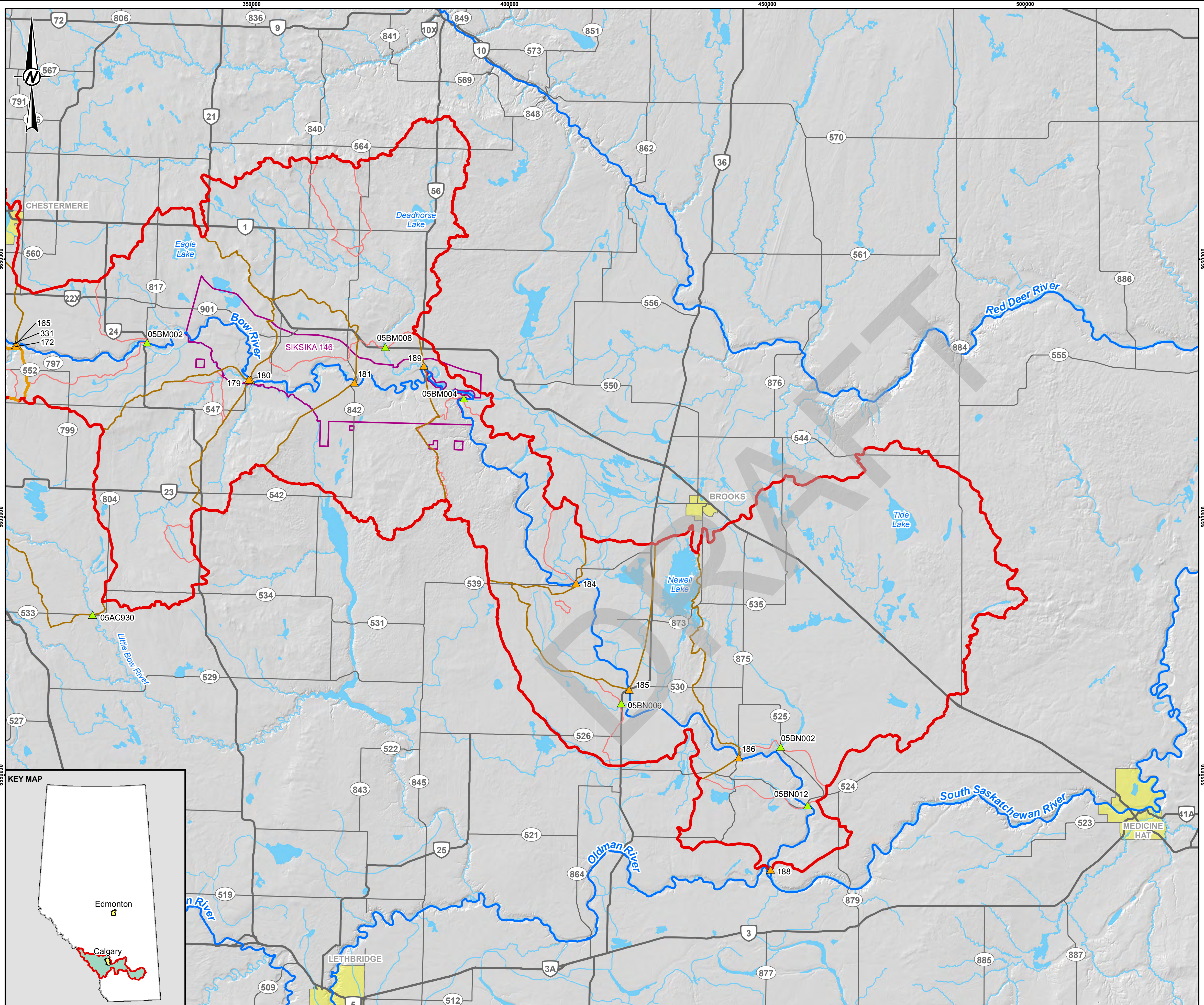

LEGEND

- WATER SURVEY OF CANADA STATION - (e.g. 05BE004)
- NODE LOCATION - (e.g. 311)
- AAFC SUB-BASIN[1]
- DELINEATED SUB-BASIN[5]
- BOW RIVER BASIN
- HIGHWOOD RIVER BASIN
- MAJOR RIVER
- WATERCOURSE
- WATERBODY
- PRIMARY HIGHWAY
- SECONDARY HIGHWAY
- FIRST NATION LAND
- POPULATED PLACE
- PROVINCIAL BOUNDARY

0 25 50

1:750,000 KILOMETRES

REFERENCE(S)

1. HYDROMETRIC STATIONS, BASIN AND SUB-BASIN DATA OBTAINED FROM AGRICULTURE AND AGRI-FOOD CANADA (AAFC).
2. HILLSHADE AND HIGHWAYS OBTAINED GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
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4.POPULATED PLACES AND INDIAN RESERVES OBTAINED FROM ALTALIS © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.
5.SUB-BASINS WERE DELINEATED BASED ON 10 m OR 20 m INTERVAL CONTOURS GENERATED FROM SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM).

DATUM: NAD83 PROJECTION: UTM ZONE 12

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
HYDROLOGY ASSESSMENT - BOW, ELBOW, HIGHWOOD AND SHEEP RIVER

TITLE
LOWER BOW RIVER BASIN

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-02-07
DESIGNED	NG
PREPARED	SK
REVIEWED	GB
APPROVED	GB

PROJECT NO.	REV.	FIGURE
1532956	1	1.2

The Sheep River is a tributary sub-basin of the Highwood River watershed that originates in the mountain valleys of Elbow-Sheep Wildland Provincial Park in the Highwood Mountain Range of Kananaskis Country. The river flows east through Sheep River Provincial Park, connecting with the Highwood River about 8 km east of Okotoks. The Sheep River flows through the towns of Turner Valley, Black Diamond, and Okotoks before joining the Highwood River.

The main weather systems in southern Alberta are cyclonic, traveling from the Pacific Ocean over the cordillera of British Columbia before reaching Alberta. The cordillera is effective at removing moisture from the Pacific air mass, leaving it relatively dry by the time it reaches the leeward side of the mountain ranges. In addition, Alberta receives cold, dry air masses from the Arctic and warm, moist air masses from the Gulf of Mexico. The systems that commonly produce extreme rainfall events in Alberta have a number of key features (AMEC 2014):

- The mid-level cold low and the coupled, long-lived circulation of the surface low and high pressure ridges located east and north of the region.
- Strong, sustained southerly flow from the great plains low level jet stream and the Prairie easterly low level jet stream, which are able to funnel large amounts of moisture from the Gulf of Mexico and Pacific Ocean into Southern Alberta, which is then pushed up against the Rocky Mountains, creating upslope precipitation along the mountains and foot hills and enhanced Meso-scale convective system rainfall across Southern Alberta.
- The upper level ridge of high pressure to the east that prevents the low pressure precipitation system from moving quickly towards the east thereby further increasing the precipitation accumulation within individual basins.

1.3 Major Floods

Major floods occurred on the Bow River in 1879, 1897, 1902, 1915, 1929, 1932, 1995, 2005, and 2013. The available records indicate that major floods occurred on the Elbow River in 1915, 1923, 1929, 1932, 1967, 1995, 2005, 2008, and 2013. The major floods on both rivers were commonly associated with high rainfall or rain-on-snow events during the period from May to July.

Prior to construction of the Bearspaw Dam in 1953 and subsequent winter flow regulation changes, the Bow River, was subject to ice-jam flood events in the City of Calgary. Although ice-jam floods still occur in the vicinity of the Town of Cochrane, they are not as significant as the open-water floods. Ice-jam floods are not the primary concern in flood risk assessment for the Bow River in Calgary and downstream of Calgary.

Major floods were recorded on the Highwood River in 1915, 1923, 1929, 1932, 1942, 1953, 1963, 1967, 1995, 2005, and 2013. Anecdotal evidence suggests flooding on the Highwood River in the 1880's. The Sheep River, and other tributaries, also experienced major floods for many concurrent years. During the June 2013 flood event, a large number of residents were evacuated from their homes for a considerable period of time in the Town of High River due to large volumes of flood water that inundated several neighborhoods.

Large floods along the Sheep River and its tributaries affect several communities including the Town of Turner Valley, the Town of Black Diamond, and the Town of Okotoks as well as the Hamlet of Millarville located along Threepoint Creek.

1.4 Study Objectives

The primary objective of this study is to conduct a basin-wide hydrology assessment and flood frequency analyses for multiple locations along the Bow, Elbow, Highwood and Sheep Rivers, including major communities and the locations of hydrometric gauges, and upstream and downstream of major tributary confluences. The study report includes the updated values of the 2012, 2013, and 2014 flood peak discharges at several locations along these rivers and their tributaries.

The results of the frequency analysis completed in this study include the flood peak discharge estimates for the 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year floods. It is important to note that some of the 2013, 2014 and 2015 flow values used in this study are preliminary and subject to change following finalization by Water Survey of Canada (WSC). Therefore, the flood frequency statistics presented in this report should be used with caution and reviewed when the finalized discharge values are available.

1.5 Study Scope

The scope of this hydrology study is summarized below:

- Generation of naturalized daily flow series at all major storage facilities on the upper Bow River and its tributaries (i.e., Bearspaw Reservoir, Ghost Lake, Horseshoe Reservoir, Kananaskis Reservoir, Lake Minnewanka, Spray Lakes, Barrier Lake, and Lower and Upper Kananaskis Lakes), the Glenmore Reservoir on the Elbow River, the Highwood River below the Highwood Diversion Canal Headgates, and other locations along the Bow River from Banff to the mouth.
- Generation of regulated daily flow series along the Bow and Elbow Rivers by routing the naturalized flows at all major storage facilities on the upper Bow River and Elbow River, and considering water supply diversions by the City of Calgary and the irrigation districts (i.e., Western Irrigation District [WID], Eastern Irrigation District [EID], and Bow River Irrigation District [BRID]), and the operation of water intake structures.
- Frequency analyses of the flood flow series along the Bow, Elbow, Highwood and Sheep Rivers using the available data up to 2015. The frequency analyses are conducted in two parts: (1) analysis of peak flow series using recorded natural flows or naturalized flow series; and (2) analysis of peak flow series using regulated flow series. Final flood frequency estimates for natural/naturalized flow conditions are recommended for use. However, limitations of the frequency analysis methodology do not support the use of regulated flood frequency estimates for flows higher than experienced in the historical record (i.e., above the 75-year flood).
- Commentary on the effects of climate change on the flood frequency estimates as well as on the seasonality of flood peak occurrences.

2.0 DATA SOURCES AND PAST STUDIES

2.1 Data and Information Sources

The hydrology data used in this the study are assembled from various sources including the following:

- historical flow and water level data from the WSC website;
- preliminary 2013, 2014 and 2015 flow and water level data obtained from WSC and AEP;
- hourly data records (1983 to 2015) obtained from TransAlta for the hydro facilities on the Bow River and its tributaries;
- hydro and water supply reservoir operation rules obtained from TransAlta and the City of Calgary;
- the information of times of travel versus flows provided by AEP for the Bow and Highwood Rivers;
- recorded diversion flows and operational rules of Carseland Dam provided by AEP;
- recorded diversion flows (2001 to 2015) and operational rules of Bassano Dam provided by EID; and
- hourly data records (2003 to 2015) obtained from the City of Calgary for the Glenmore Reservoir.

Table 2.1 provides a summary of the basic hydrologic information used to derive the flood frequency estimates for the Bow River and its tributaries. The data details are provided in Appendix A.

2.2 Previous Studies

This study included review of background documents, previous hydrology and flood frequency studies, and historical flood information, including the following:

- Basin-Wide Hydrology Assessment and Flood Documentation for Bow and Elbow Rivers (Golder 2014);
- Bow River and Elbow River Basins, Hydrology of 2013 Flood Event (Golder 2016a);
- Hydrology of Flood Events in Elbow River (Golder 2016b);
- 2013 Highwood River Flood Hydrology Study (Golder 2014);
- Hydrology Study, Bow and Elbow River Updated Hydraulic Model Project (Golder 2010);
- Pine Creek Flood Hazard Mapping Study (AMEC 2013);
- Bow and Elbow Rivers Provincial Flood Damage Assessment Report (IBI and Golder 2015);
- Cougar Creek and Stoneworks Creek, 2013 Forensic Analysis and Short-Term Debris Flood Forensic Analysis and Short-Term Debris Flood Mitigation (BGC Engineering Ltd. 2013a,b);
- Flood Hazard Study for the Bow River and Forty Mile and Echo Creeks at Banff (Northwest Hydraulic Consultants 2013);
- Flood Protection – Elbow River at Calgary (T. Blench and Associates Ltd. 1965); and
- Calgary Floodplain Study Volumes I and II (AENV 1983 - Previous Alberta Department of the Environment Water Resources Management Services Technical Services Division).

The review of previous studies and findings were used to establish the assumptions, and to understand the data limitations and the approaches of the analyses in the past studies. The results of these past studies provide a frame of reference for the interpretation of the results of this study. In addition, the review helped identify both data gaps and apparent discrepancies in the data that may affect their use in subsequent analyses.

Table 2.1: Summary of Data Used for Estimating Flood Frequency

WSC Number	Node ID	WSC Station Name or Location of Interest	Latitude	Longitude	Gross Drainage Area [km²]	Effective Drainage Area [km²]	Period of Record	Recorded Flow		Naturalized Flow	Regulated Flow
								Length of Record [years]	Type of Recorded Hydrologic Data	Length of Record[1] [years]	Length of Record[2] [years]
BOW RIVER											
05BA001	301	Bow River at Lake Louise	51° 25' 44"	-116° 11' 21"	422	422	1910 - 2015	62	Flow	n/a	n/a
05BB001	116	Bow River at Banff	51° 10' 22"	-115° 34' 24"	2210	2210	1909 - 2015	107	Flow	86	n/a
	105	Bow River below Spray River	51° 09' 58"	-115° 33' 28"	2993	2993	n/a	n/a		86	86
	107	Bow River below Cascade River	51° 09' 49"	-115° 28' 37"	3727	3727	n/a	n/a		86	86
	108	Bow River at Canmore	51° 05' 10"	-115° 21' 58"	3870	3870	n/a	n/a		86	86
	109	Bow River above Kananaskis	51° 05' 47"	-115° 04' 06"	4199	4199	n/a	n/a		86	n/a
	110	Bow River below Kananaskis	51° 05' 54"	-115° 03' 26"	5139	5139	n/a	n/a		86	n/a
05BE004	111	Bow River near Seebe	51° 07' 02"	-115° 02' 11"	5170	5170	1923 - 1962 1979 - 2015[3]	77	Flow	93 (1923 - 2015)	86
	318	Bow River above Ghost Reservoir	51° 11' 01"	-114° 47' 51"	5475	5473	n/a	n/a		86	86
05BE006	58	Bow River below Ghost Dam (Ghost Reservoir Outflow)	51° 12' 51"	-114° 36' 50"	6550	6550	1933 - 1989	51	Flow	86	86
05BH005	114	Bow River near Cochrane	51° 10' 25"	-114° 28' 10"	7412	7383	2006 - 2015[3]	10	Flow	86	86
	302	Bearspaw Reservoir Inflow	51° 07' 30"	-114° 18' 23"	7712	7672	n/a	n/a		86	86
05BH008	59	Bow River below Bearspaw Dam	51° 05' 58"	-114° 13' 35"	7770	7730	1983 - 2015	33	Flow	105 (1911 - 2015)	86
		Bow River below Bearspaw Dam, extended					1911 - 2015	104			
05BH004	59	Bow River at Calgary	51° 03' 01"	-114° 03' 12"	7868	7736	1911 - 2015	104	Flow	105 (1911 - 2015)	n/a
	176	Bow River below Elbow River	51° 02' 43"	-114° 02' 19"	9128	8995	n/a	n/a		86	86
	158	Bow River below Nose Creek	51° 02' 38"	-144° 00' 45"	10114	9656	n/a	n/a		86	86
	164	Bow River below Fish Creek	50° 54' 16"	-114° 00' 32"	10640	10182	n/a	n/a		86	86
	177	Bow River below Pine Creek	50° 50' 32"	-113° 57' 09"	10887	10397	n/a	n/a		86	86
	331	Bow River above Highwood River	50° 49' 08"	-113° 46' 51"	11258	10532	n/a	n/a		86	86
	165	Bow River below Highwood River	50° 49' 06"	-113° 46' 31"	15342	14497	n/a	n/a		86	86
05BM002	178	Bow River below Carseland Dam	50° 49' 53"	-113° 25' 07"	15665	14696	1910 - 1914 1956 - 2015	63	Flow	86	86
	180	Bow River at Hwy. 547	50° 46' 19"	-113° 07' 53"	17443	15920	n/a	n/a		86	86
	181	Bow River at Hwy. 842	50° 46' 19"	-112° 50' 43"	18028	16344	n/a	n/a		86	86
	189	Bow River below Crowfoot Creek	50° 48' 15"	-112° 39' 19"	20169	17672	n/a	n/a		86	86
05BM004	182	Bow River below Bassano Dam	50° 44' 57"	-112° 32' 36"	20253	17751	1910 - 1933 1964 - 2015	75	Flow	105 (1910 - 2015)	86
	184	Bow River at Hwy. 539	50° 25' 51"	-112° 13' 36"	20915	18186	n/a	n/a		86	86
	185	Bow River at Hwy. 36	50° 14' 47"	-112° 04' 40"	21423	18544	n/a	n/a		86	86
	186	Bow River at Hwy. 875	50° 07' 49"	-111° 46' 40"	22307	18878	n/a	n/a		86	86
05BN012	187	Bow River near the Mouth	50° 02' 53"	-111° 35' 22"	25280	19160	1965 - 2015	51	Flow	86	86
	188	Bow River at the Mouth	49° 56' 07"	-111° 41' 19"	25612	19306	n/a	n/a		86	86

Table 2.1: Summary of Data Used for Estimating Flood Frequency

WSC Number	Node ID	WSC Station Name or Location of Interest	Latitude	Longitude	Gross Drainage Area [km²]	Effective Drainage Area [km²]	Period of Record	Recorded Flow		Naturalized Flow	Regulated Flow
								Length of Record [years]	Type of Recorded Hydrologic Data	Length of Record[1] [years]	Length of Record[2] [years]
BOW RIVER TRIBUTARIES											
05BC006	201	Spray Reservoir at Three Sisters Dam	50° 59' 51"	-115° 22' 04"	481	481	1949-2015	n/a	Level	n/a	86
05BC002	51	Spray River near Spray Lakes	50° 52' 58"	-115° 22' 23"	362	362	1915-1939	25	Flow	n/a	86
05BC001	106	Spray River at Banff	51° 09' 38"	-115° 33' 26"	751	751	1911 - 2015	105	Flow	86	n/a
05BD002	154	Cascade River near Banff	51° 13' 55"	-115° 31' 07"	664	664	1911-1941	31	Flow	86	86
05BD003	207	Lake Minnewanka near Banff	51° 14' 07"	-115° 29' 15"	647	647	1916-2015	100	Level	n/a	86
05BB005	358	Readearth Creek near the Mouth	51° 13' 22"	115° 48' 40"	147	147	1976-1996	21	Flow	n/a	n/a
05BB003	305	Forty Mile Creek near Banff	51° 12' 25"	-115° 35' 10"	133	133	1913 - 1948 1972 - 1977	15	Flow	n/a	n/a
	306	Forty Mile Creek at the Mouth	51° 10' 35"	-115° 35' 15"	148	148	n/a	n/a		n/a	n/a
	307	Cougar Creek Upstream of Bow River	51° 04' 45"	-115° 20' 11"	49	49	n/a	n/a		n/a	n/a
	308	Policeman's Creek at Canmore	50° 05' 09"	-115° 20' 56"	10	10	n/a	n/a		n/a	n/a
	309	Stoneworks Creek at Hwy. 1	51° 06' 07"	-115° 21' 27"	6	6	n/a	n/a		n/a	n/a
	310	Exshaw Creek at Exshaw	51° 03' 30"	-115° 09' 39"	33	33	n/a	n/a		n/a	n/a
	311	Kananaskis River at the Mouth	51° 05' 44"	-115° 03' 43"	937	937	n/a	n/a		n/a	n/a
05BF005	204	Upper Kananaskis Lake	50° 36' 50"	-115° 07' 16"	151	151	1932-2015	n/a	Level	n/a	86
05BF009	312	Lower Kananaskis Lake	50° 41' 25"	-115° 07' 59"	359	359	1932-2015	n/a	Level	n/a	86
05BF025	56	Kananaskis River below Barrier Dam	51° 02' 31"	-115° 02' 07"	899	899	1975 - 2015[3]	41	Flow	86	n/a
05BF001	313	Kananaskis River near Seebe, extended	51° 02' 46"	-115° 01' 49"	933	933	1912 - 2015	91	Flow	n/a	n/a
05BG010	314	Ghost River above Waiparous Creek	51° 16' 12"	-114° 55' 34"	485	485	1983 - 2015	33	Flow	n/a	n/a
		Ghost River above Waiparous Creek, extended					1912 - 2015	96			
05BG006	315	Waiparous Creek near the Mouth	51° 17' 01"	-114° 50' 22"	333	333	1966 - 2015	50	Flow	n/a	n/a
		Waiparous Creek near the Mouth, extended					1912 - 2015	96			
05BG001	316	Ghost River near Cochrane	51° 15' 40"	-114° 45' 50"	911	911	1912 - 1982	63	Flow	n/a	n/a
		Ghost River near Cochrane, extended					1912 - 2015	96			
	317	Ghost River at the Mouth	51° 14' 28"	-114° 44' 15"	940	940	n/a	n/a		n/a	n/a
05BE005	210	Ghost Lake near Cochrane	51° 13' 10"	-114° 42' 32"	6480	6480	n/a	n/a	Level	n/a	86
05BH006	319	Jumpingpound Creek near Jumpingpound	51° 04' 07"	-114° 32' 44"	455	455	1908 - 1933[3]	13	Flow	n/a	n/a
05BH015	320	Jumpingpound Creek at Township Road No. 252	51° 07' 41"	-114° 34' 01"	474	474	2006 - 2015	9	Flow	n/a	n/a
		Jumpingpound Creek at Township Road No. 252, extended					1908 - 1933 1966 - 2015	63			
05BH009	321	Jumpingpound Creek near the Mouth	51° 09' 15"	-114° 31' 44"	571	571	1966 - 2005	39	Flow	n/a	n/a
		Jumpingpound Creek near the Mouth, extended					1908 - 1933 1966 - 2015	63			
	174	Jumpingpound Creek at Cochrane	51° 11' 18"	-114° 30' 06"	601	601	n/a	n/a		50 (1966 - 2015)	n/a
	322	Bighill Creek at Cochrane	51° 10' 53"	-114° 28' 50"	177	99	n/a	n/a		n/a	n/a
05BH016	324	West Nose Creek at Calgary	51° 07' 49"	-114° 02' 54"	324	212	n/a[4]	n/a[4]	n/a[4]	n/a	n/a
05BH014	325	Nose Creek above Airdrie	51° 18' 46"	-114° 01' 37"	247	178	2005 - 2015	10	Flow	n/a	n/a
05BH901	326	Nose Creek near the Mouth	51° 03' 00"	-114° 01' 00"	986	878	1980 - 1989[3]	10	Flow	n/a	n/a
05BH003	175	Nose Creek at Calgary	51° 07' 20"	-114° 02' 52"	893	746	1911 - 1916 1970 - 1986	27	Flow	77 (1930 - 1995 2005 - 2015)	n/a
05BK001	327	Fish Creek near Priddis	50° 53' 09"	-114° 19' 41"	261	261	1908 - 2015	69	Flow	n/a	n/a

Table 2.1: Summary of Data Used for Estimating Flood Frequency

WSC Number	Node ID	WSC Station Name or Location of Interest	Latitude	Longitude	Gross Drainage Area [km^2]	Effective Drainage Area [km^2]	Period of Record	Recorded Flow		Naturalized Flow	Regulated Flow
								Length of Record [years]	Type of Recorded Hydrologic Data	Length of Record[1] [years]	Length of Record[2] [years]
05BK003	359	Fish Creek at Bow Bottom Trail	50° 54' 25"	114° 00' 56"	442	442	1989-1993	4	Flow	n/a	n/a
	163	Fish Creek at the Mouth	50° 54' 15"	-114° 00' 38"	440	440	n/a	n/a		60 (1956 - 2015)	n/a
	330	Pine Creek at the Mouth	50° 50' 30"	-113° 57' 11"	217	190	n/a	n/a		n/a	n/a
	179	Arrowwood Creek above Hwy. 547	50° 46' 22"	-113° 08' 09"	830	718	n/a	n/a		50 (1966 - 2015)	n/a
05BM008	332	Crowfoot Creek near Cluny	50° 50' 07"	-112° 45' 47"	1374	950	1951 - 2015	65	Flow	n/a	n/a
05BN002	191	Twelve Mile Creek near Cecil	50° 08' 59"	-111° 39' 51"	2803	124	1951 - 2015	65	Flow	n/a	n/a
05BN006	192	New West Coulee near the Mouth	50° 13' 19"	-112° 05' 55"	318	102	1957 - 2015	59	Flow	n/a	n/a
ELBOW RIVER and TRIBUTARIES											
05BJ004	333	Elbow River at Bragg Creek	50° 56 '57"	-144° 34' 06"	791	791	1935 - 2015	81	Flow	n/a	n/a
		Elbow River at Bragg Creek, extended					1908 - 2015	107		n/a	n/a
05BJ010	334	Elbow River at Sarcee Bridge	50° 59' 45"	-144° 09' 55	1189	1189	1979 - 2015	35	Flow	n/a	n/a
		Elbow River at Sarcee Bridge, plus 1983 value					1915 - 2015	58		n/a	n/a
05BJ005	116	Elbow River above Glenmore Dam (Elbow River Inflow into Glenmore Reservoir)	50° 59' 58"	-144° 05' 53"	1220	1220	1930 - 2015	86	Flow	n/a	n/a
05BJ008	213	Glenmore Reservoir at Calgary (Glenmore Dam Outflow)	51° 00' 00"	-144° 05' 50"	1224	1224	1976-2015	40	Level	n/a	86
05BJ001	161	Elbow River below Glenmore Dam	51° 00' 46"	-144° 05' 37"	1236	1236	1908 - 2015	107	Flow	n/a	86
	335	Lott Creek near Calgary	51° 00' 17"	-144° 13' 21"	114	114	n/a	n/a		n/a	n/a
SHEEP RIVER and TRIBUTARIES											
05BL014	337	Sheep River at Black Diamond	50° 41' 15"	-114° 14' 38"	592	592	1909 - 1916 1969 - 2015	55	Flow	n/a	n/a
	338	Ware Creek at the Mouth	50° 42' 54"	-114° 27' 36"	129	129	n/a	n/a		n/a	n/a
	339	Threepoint Creek above Ware Creek	50° 42' 56"	-114° 27' 34"	136	136	n/a	n/a		n/a	n/a
05BL012	342	Sheep River at Okotoks	50° 43' 26"	-113° 58' 21"	1494	1494	1908 - 1968 2006 - 2015	25	Flow	n/a	n/a
		Sheep River at Okotoks, extended					1908 - 1919 1958 - 2015	70			
	344	Sheep River at the Mouth	50° 44' 21"	-113° 51' 21"	1575	1570	n/a	n/a		n/a	n/a
05BL013	340	Threepoint Creek at Millarville	50° 46' 15"	-114° 16' 46"	507	507	1909 - 1916 1965 - 2015	56	Flow	n/a	n/a
	341	Threepoint Creek at the Mouth	50° 44' 08"	-114° 11' 59"	638	638	n/a	n/a		n/a	n/a
HIGHWOOD RIVER and TRIBUTARIES											
05BL019	346	Highwood River at Diebel's Ranch	50° 24' 19"	-114° 29' 56"	774	774	1951 - 2015	65	Flow	n/a	n/a
	350	Highwood River near Longview	50° 31' 50"	-114° 14' 16"	1196	1196	n/a	n/a		n/a	n/a
	351	Highwood River Upstream of Highwood Diversion Canal	50° 33' 10"	-114° 00' 04"	1913	1913	n/a	n/a		n/a	n/a
05BL025	352	Highwood Diversion Canal near Headgates	50° 33' 07"	-113° 59' 23"	n/a[5]	n/a[5]	1977 - 2015	39	Flow	n/a	n/a
	353	Highwood River Downstream of Highwood Diversion Canal	50° 33' 13"	-113° 59' 58"	1914	1914	n/a	n/a		n/a	n/a
05BL004	354	Highwood River Below the Little Bow Canal	50° 35' 07"	-113° 52' 09"	1953	1953	1909 - 19151986 - 2015	37	Flow	n/a	n/a
		Highwood River Below the Little Bow Canal, extended					1905 - 1915 1970 - 2015	53		53 (1905 - 2015)	n/a
05BL024	357	Highwood River near the Mouth	50° 46' 60"	-113° 49' 25"	3952	3941	1970 - 2015	46	Flow	n/a	n/a
		Highwood River near the Mouth, extended					1905 - 1915 1970 - 2015	53		53 (1905 - 2015)	n/a
	172	Highwood River at the Mouth	50° 49' 03"	-113° 46' 46"	3991	3964	n/a	n/a		65 (1951 - 2015)	86

Table 2.1: Summary of Data Used for Estimating Flood Frequency

WSC Number	Node ID	WSC Station Name or Location of Interest	Latitude	Longitude	Gross Drainage Area [km²]	Effective Drainage Area [km²]	Period of Record	Recorded Flow		Naturalized Flow	Regulated Flow
								Length of Record [years]	Type of Recorded Hydrologic Data	Length of Record[1] [years]	Length of Record[2] [years]
05BL022	345	Cataract Creek near Forestry Road	50° 17' 04"	-114° 35' 29"	166	166	1966 - 2015	50	Flow	n/a	n/a
05BL023	347	Pekisko Creek near Longview	50° 28' 23"	-114° 12' 28"	232	232	1967 - 2015	48	Flow	n/a	n/a
05BL007	348	Stimson Creek near Pekisko	50° 25' 42"	-114° 09' 56"	236	236	1911 - 1919 1938 - 2015	87	Flow	n/a	n/a
05BL027	349	Trapp Creek near Longview	50° 28' 38"	-114° 25' 37"	137	137	1979 - 2015	37	Flow	n/a	n/a
05BL015	355	Little Bow Canal at High River	50° 35' 09"	-113° 52' 06"	n/a[5]	n/a[5]	1910 - 2015	103	Flow	n/a	n/a
05AC930	356	Little Bow River at Highway No. 553	50° 21' 15"	-113° 32' 35"	792	312	1999 - 2015	13	Flow	n/a	n/a

1. Period of record for naturalized flows is 1930 to 2015 for a total of 86 years, unless otherwise stated.
2. Period of record for regulated flows is 1930 to 2015 for a total of 86 years, unless otherwise stated.
3. No frequency analysis performed on recorded flows.
4. Data not available on Water Survey of Canada website.
5. Drainage areas for points of diversion cannot be defined.
n/a - not applicable (i.e., no flow series of this type).

3.0 FLOOD FLOW SERIES

3.1 Flow Naturalization

The hydrology of the Bow River is affected by 13 dams, 4 weirs and 8 reservoirs, making it the most regulated river in Alberta (Bow River Basin Council, 2010). In 1911, Calgary Power (which would evolve into TransAlta Utilities over the next century) began constructing Alberta's first significant hydroelectric plant, Horseshoe dam on the Bow River. Two years later (1913) Calgary Power opened another two hydroelectric plants on the Bow River (Kananaskis at Seebe) and its tributary (i.e., dam at Lake Minnewanka). Both Kananaskis plant and Horseshoe plants are run-of-the-river plants. Instead of storing water in a reservoir, the plants generate power from the river's natural water flow.

Ghost Dam, which has relatively significant flood storage capacity on the upper Bow River, was built in 1929 and started operation in 1930. Development of the power plant on Spray River was completed in 1951 (i.e., Rundle, Spray and Three Sisters power plants) and Bearspaw dam was built in 1954. TransAlta built a new dam and power plant on the Cascade River to replace the original in 1942. In 1947, the Barrier Plant was developed on the Kananaskis River as one of the three TransAlta hydro plants in the Kananaskis System, with Interlake and Pocaterra being the other two built in 1955.

On the lower reach of Bow River, the Bow River supplies water for three irrigation districts in southern Alberta: the Eastern, Western, and Bow River irrigation districts. The water for the Eastern Irrigation District is diverted at Bassano Dam (1914), the water for the Western Irrigation District is diverted at Calgary Weir (1904), and the water for the Bow Irrigation District is diverted at the Carseland weir (1909). The Ghost Dam is the major structure on the main stem that has a significant effect on the flood flow of the Bow River. Hence, significant regulation of flows of the Bow River started from 1930, when the Ghost Dam became operational. Hydropower plants developed before 1930, had little effect (if any) on the Bow River flows since the two upstream plants (Horseshoe and Kananaskis at Seebe) are run-of-the-river plants.

3.1.1 Methodology

Naturalized daily flow series from 1930 to 2015 were developed following the same methodology as those used for the 2010 and 2014 studies completed by Golder. This methodology involves use of the River Basin Assessment Tools (RBAT) model (Optimal Solutions Ltd. 2009) from the Prairie Provinces Water Board (PPWB), the Streamflow Synthesis and Reservoir Regulation (SSARR) channel routing procedures (USACE 1991), and the coefficients built into RBAT and provided by AEP. Details of the Natural Flow Computation software are provided in Appendix B. The methods used to derive naturalized flows at each location are described in the following sections, and in Appendix B.

3.1.2 Upper Reach of Bow River and Its Tributaries

The flow naturalization was conducted for the following locations along the upper reach of the Bow River and its tributaries: Spray Lake, Upper and Lower Kananaskis Lakes, Rundle Canal, Lake Minnewanka, Bow River downstream of Spray River, Bow River near Seebe, Ghost Lake, Bow River at Cochrane, and Bearspaw Reservoir. The naturalization was based on the recorded reservoir levels and outflows from the date each structure started its operation. The data necessary for the naturalization were obtained from TransAlta, the City of Calgary, and AEP's Hydrol database. The data include TransAlta's and Calgary's rule curves for normal operating and flood conditions.

Spray River

- Development of the power plant on Spray River was completed by TransAlta in 1951 (i.e., Rundle, Spray and Three Sisters power plants).
- Prior to 1951, WSC Station 05BC001 (Spray River at the Mouth) recorded natural flow (1910 to 1951) from the entire drainage area of 730 square kilometres (km^2).
- The runoff that came from the additional drainage area of 391 km^2 between Spray Lake and the mouth of the Spray River for the period 1915 to 1939 was generated based on the recorded natural flow at WSC Stations 05BC001 (Spray River at Banff) and 05BC002 (Spray River near Spray Lakes).
- A non-linear relationship between the runoff from the 391 km^2 drainage area and the Spray River flow at the mouth (drainage area 730 km^2) was established based on the data from 1915 to 1939 (see Figure B-3 in Appendix B).
- The naturalized flow for Spray River at the Mouth for the period 1951 to 1975 was estimated based on the non-linear relationship mentioned above.
- Naturalization of flow from 1975 to 2015 was conducted using the water level data at Three Sisters hydro-Plant and the flow data for Rundle hydro-plant recorded at WSC Station 05BE007 (Spray Power Diversion at Canmore) and obtained from TransAlta.

Cascade River

- Calgary Power (which would evolve into TransAlta Utilities) opened a hydroelectric plant on Cascade River using the dam at Lake Minnewanka in 1913. TransAlta built a new dam and power plant on the Cascade River to replace the original power plant in 1942.
- Naturalization of flow from 1917 to 2015 was conducted using the water level and flow data recorded at Cascade hydro-Plant and obtained from TransAlta.
- Ghost Diversion was considered as part of natural inflow to Lake Minnewanka (see the explanation in Appendix B).
- Sensitivity of Ghost River Diversion on the estimated Bow River flood flows between Lake Minnewanka and Ghost Lake was evaluated.
- Sensitivity of the effect of missing Ghost Diversion flow data (1995 to 2015) on flood flow estimates along Ghost River was evaluated.

Kananaskis River at Kananaskis Lakes (Upper and Lower)

- TransAlta built the Interlake and Pocaterra hydro plants in 1955 on Kananaskis River at the Upper Kananaskis and Lower Kananaskis, respectively.
- Naturalization of flow was conducted for the period from 1975 to 2015.
- The two lakes were considered as a single waterbody from 1975 to 1985 since the record of outflow was available only from the Lower Kananaskis Lake.
- Prior to 1975, there is no recorded outflow data for both Upper and Lower Kananaskis Lakes. Hence, naturalized flows for Kananaskis River at the two lakes were not developed for period prior to 1975.

Kananaskis River at Barrier Lake

- TransAlta built the Barrier hydro plant in 1947 by constructing Barrier Dam at the lower reach of Kananaskis River.
- Recorded flow data are available at WSC Stations 05BF001 (Kananaskis River near Seebe) for the period 1911 to 1962, and 05BF024 (Barrier Lake near Seebe) for the period 1975 to 2011. Additional hourly data for the period 1985 to 2015 were obtained from TransAlta.
- Channel flow routing was conducted to route flow from Lower Kananaskis Lake to Barrier Lake.
- The missing data in the period 1963 to 1974 were filled using weekly natural flow data from the AEP database (AEP 2002).

Bow River at Canmore

- Naturalizing daily flows in the Bow River at Canmore included removing the effects of the Spray Lake diversion for the period from 1951 to 2015.
- A complete data set was available and used to conduct the flow naturalization for the period from 1975 to 2015.
- Estimated median power generation in each month for the period 1975 to 2015 was used to estimate the outflow through Rundle system for the period 1951 to 1975. The typical daily turbine flows were between 11 and 13 cubic metres per second (m^3/s), but the flows were higher than 20 m^3/s on rare occasions.

Bow River at Seebe

- Flow naturalization for Bow River at Seebe was conducted for the periods from 1923 to 1962 and 1979 to 2015.
- Data are missing for the period 1962 to 1979. The generated flow at this location for this period only reflects the routed flow from the upstream location (i.e., Bow River at Canmore).

Bow River at Ghost Lake

- Ghost Reservoir started operation in August 1929. Therefore, naturalization of flow at this location was conducted for the period from 1930 to 2015.
- Few missing data points were filled using linear interpolation of the available flows on the previous and subsequent days.
- Corrections to recorded data were made for the instances where there were obvious data errors such as decimal place shifted by one or two places from its expected position and data for February 30 and April 31 in some instances.

Bow River at Cochrane and Bearspaw

- TransAlta built the Bearspaw hydro plant in 1954 by constructing Bearspaw Dam on the Bow River, just upstream from the City of Calgary.
- Flow naturalization at locations between Cochrane and Bearspaw include flows from tributary creeks (e.g., flow from Jumpingpound Creek) when the flow data were available.

- Flow recoded at two WSC Stations (05BH008: Bow River below Bearspaw Dam; and 05BH004: Bow River at Calgary), and hourly data obtained from TransAlta were used to naturalize flow at Bearspaw and Cochrane.
- Withdrawals by the City of Calgary from Bearspaw were considered in the flow naturalization.

3.1.3 Lower Reach of Bow River – Below Bearspaw Reservoir

Naturalized daily flow series for the Bow River below Bearspaw Reservoir were generated using the methods similar to those used for the upper reach of the Bow River, including the following:

- Adding and routing naturalized flows for Bow River downstream of Bearspaw, natural or naturalized flows from its tributaries (Elbow River, Nose Creek, Fish Creek, Highwood River), and estimated local runoff from intervening catchments between individual locations.
- Considering water supply diversions to the irrigation districts (i.e., WID, EID, and BRID).
- Considering operations of the water intake structures at Carseland and Bassano dams.

The following data and methods were used to develop naturalized flow at each location on the Bow River downstream of the Highwood River confluence:

- WID and BRID data are available except for short and sporadic periods of missing data that were filled using linear interpolation.
- There are two return flows from WID to the Bow River and the Red Deer River. Return flow from WID was added to the Bow River reach downstream of the confluence with the Highwood River. The estimated return flows to the Bow River were about 16.3% of gross diversion at WID weir with an estimated lag time of three weeks based on information extracted from South Saskatchewan River Basin natural flow database.
- Naturalized flow series were derived by adding the historic diversions to river flows at appropriate locations, and routing the combined flow further downstream.
- For diversion to EID, data are not available prior to 1990. Historic water uses have some relationship with areas irrigated (Table 3.1) based on the EID Integrated Resources Management Strategy (EID, 1995). This relationship was used to estimate annual diversion and return flows prior to 1990. The annual diversion and return flow rates were assumed to be the same for each month from April to October.

Table 3.1: Irrigated Area and Water Diverted for Irrigation (EID 1995)

Year	Area to be Irrigated [acres]	Other Areas [acres]	Total Water Diverted [acres-feet]	Water Returned to River Systems [acres-feet]	Total Consumptive Use [acres-feet]
1991	235,966	29,490	629,872	Not Available	Not Available
1990	225,436	36,625	723,364	149,585	573,779
1989	222,877	36,967	601,954	168,640	433,314
1988	221,327	35,617	721,698	139,623	582,075
1987	217,875	32,889	643,099	147,039	496,060
1986	218,747	30,963	672,924	146,074	526,850
1985	217,919	30,031	647,613	139,986	507,627
1984	214,893	30,628	666,947	150,128	516,819
1983	214,830	30,513	601,378	162,062	439,316
1982	213,308	27,578	490,132	161,283	328,849

3.1.4 Lower Reach of Elbow River

Glenmore Dam and Reservoir were built on the Elbow River in 1932. Natural flow data for the Elbow River upstream of Glenmore Reservoir are available at WSC Station 05BJ005 (Elbow River above Glenmore Dam) for the period 1933 to 1977. Records of natural and regulated flows below Glenmore Reservoir are available at WSC Station 05BJ001 (Elbow River below Glenmore Dam) for the periods 1908 to 1932 and 1934 to 2015, respectively. The drainage areas at WSC Stations 05BJ005 and 05BJ001 provided by WSC are 1,220 and 1,236 km^2, respectively. Because the difference between the two drainage areas is less than 2% and considered negligible, the 1908-1932 data at 05BJ001 and the 1934-1977 data at 05BJ005 were used as the representative natural flow series at Glenmore Reservoir.

The regulated flow series at 05BJ001 from 1978 to 2015 were naturalized using historic reservoir water level, outflow, and water supply withdrawal data. Rule curve and the flood operating guidelines for Glenmore Reservoir were obtained from the City of Calgary and used in the assessment of naturalized and regulated flows.

The naturalized flow series generated for the period 1978 to 2015 were compared to the recorded daily flow series at WSC Station 05BJ010 (Elbow River at Sarcee Bridge). The two flow series appear consistent and comparable, with the two drainage areas differing by less than 4% (see Figure B-12 in Appendix B).

3.1.5 Lower Reach of Highwood River

For the Highwood River downstream of the Highwood Diversion Canal, the naturalized flow series were generated by adding the recorded diversion flows at WSC Station 05BL025 (Highwood Diversion Canal near Headgates) and WSC Station 05BL015 (Little Bow Canal at High River) to the recorded daily flow series at WSC Station 05BL004 (Highwood River below Little Bow Canal) and at WSC Station 05BL024 (Highwood River near the Mouth).

3.2 Flow Regulation

3.2.1 Bow River and Its Tributaries

The Ghost Dam is the major structure that has a significant effect on the flood flow of the Bow River. Hence, significant regulation of flows of the Bow River started from 1930, when the Ghost Dam became operational. Hydropower plants developed before 1930, had little effect (if any) on the Bow River flows since the two upstream plants (Horseshoe and Kananaskis at Seebe) are run-of-the-river plants.

Regulated daily flows for the Bow River and its tributaries were obtained by running the Water Resources Management Model (WRMM) (AENV, 2002) in daily interval for the period 1930 to 2015 using the naturalized flow series. The model simulations were carried out based on available current operating rules, reservoir routing channel flow routing, and estimates of current water use.

TransAlta's operation rules for their reservoirs have four components (Figure 3.1) as summarized below:

- mandatory key level (called seasonal full supply level) governed by Probable Maximum Flood considerations;
- rules that govern operating in the ideal operating zone, also termed the Top and Bottom comfort zones; and
- minimum operating levels, driven by operational constraints and the turbine capacities.

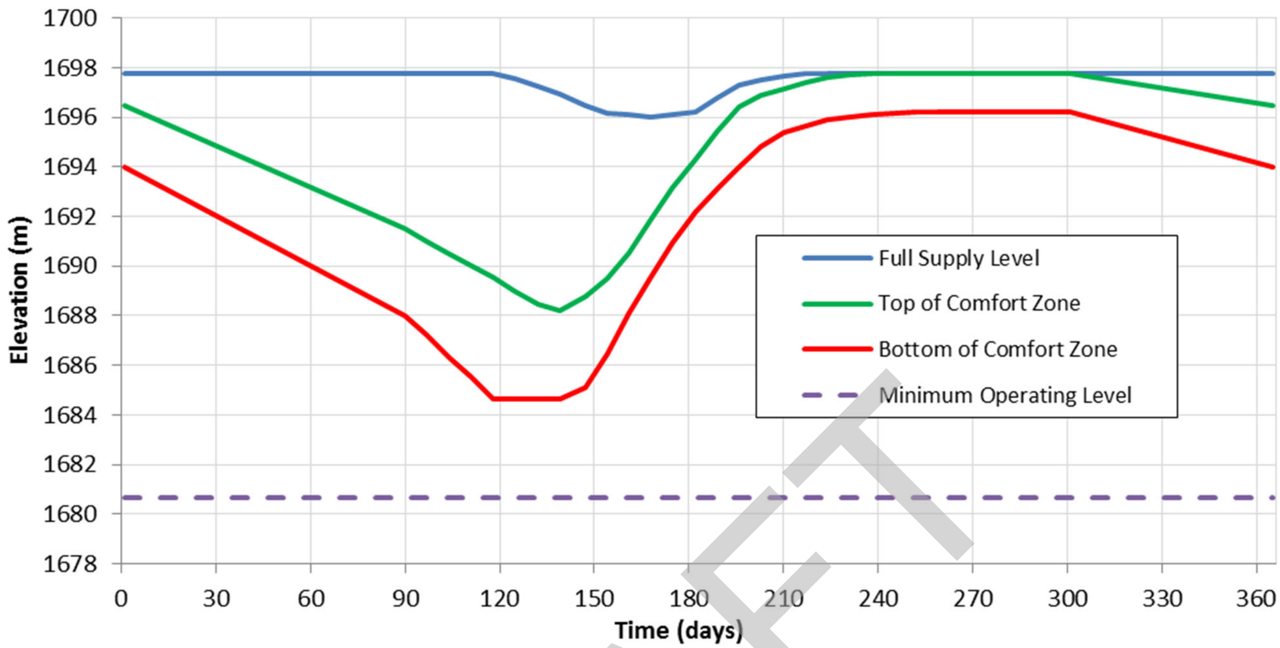


Figure 3.1: Typical Shape of Operating Zones for TransAlta's Reservoirs

The model attempted to maintain the reservoir levels at the top of the comfort zone (i.e., the green line in Figure 3.1). This was not always possible due to a combination of downstream water demands from the three major irrigation districts, Calgary, and AEP. These demands require maintaining a minimum instream flow of 34 m^3/s below Bearspaw Dam at all times. In addition, the target elevation at the top of the comfort zone was violated occasionally during flood events. This occurred when there was insufficient outflow capacity to discharge the excess inflow volumes to maintain the water levels at the top of the comfort zone.

The operating rules for all TransAlta structures on the Bow River and its tributaries are provided in Appendix B.

3.2.2 Elbow River at Glenmore Dam

Glenmore Dam and Reservoir were built on the Elbow River in 1932 to provide water supply for the City of Calgary. Although dedicated reservoir storage is not formally reserved for flood regulation purposes, there are operational guidelines that inform operations during high flow events. To support this study, the City of Calgary provided its reservoir drawdown instructions and release policies for the low-level outlet and spillway.

Considerable operator judgement is required to drawdown reservoir levels (ranging from 2 to 4 metres [m]) during a flood event using the low-level outlet. Operating rules are based on the general assumption of hourly decision-making. At any point in time, low-level outlet releases are linked to inflows and the drawdown that has actually been achieved. The maximum total low-level outlet flow is 165 m^3/s. This is the maximum flow that can be achieved to lower the reservoir level before outflow occurs through the spillway, and outflow will be reduced or be set equal to inflow when the target drawdown is reached. If inflow exceeds 165 m^3/s, the reservoir level will begin to rise since the low-level outlet flow cannot exceed 165 m^3/s. Once the reservoir level exceeds the spillway crest, water will be discharged through both the low-level outlet and the spillway, with a gradual shut down of the low-level outlet until the level reaches 1 m above the spillway crest. When the reservoir level reaches 1 m above the spillway crest, the low-level outlet is closed and the spillway continues to discharge as there is sufficient head to provide adequate outflow capacity.

As noted, the above rules are based on hourly decision-making for dam operations. When a daily time step is used in the model, flood flows are so large that the inflows and outflows may quickly exceed 165 m^3/s within a day. Reservoir levels are typically targeted at the seasonal operating levels, but this is not always possible due to the withdrawals by the City of Calgary and the requirement to maintain the minimum outflow of 1.2 m^3/s at all times.

Regulated daily flows in the Elbow River at Glenmore were obtained by running the WRMM in daily interval for the period 1932 to 2015 using the naturalized daily inflows to Glenmore Reservoir. The simulations were carried out based on the operating rules described above. Because of limited availability of recorded extreme flood events with return periods greater than 100 years, the base simulation results do not properly reflect the reservoir attenuation effects of extreme flood events. Therefore, the flood frequency estimates of large return periods based on the base simulation results have relatively high uncertainty.

In order to provide a better understanding of the ability of Glenmore Reservoir to attenuate extreme flood peaks, an alternative methodology was investigated, by routing the inflow flood hydrographs with peak discharges of various return periods through the reservoir (see Section 4.4 for more details). This alternative methodology was able to incorporate reservoir capacity and the corresponding results reflect more reasonable attenuation effects of Glenmore Reservoir for the full range of flood events (i.e. 2-year to 1,000-year floods). The routing of the flows through the reservoir was completed based on flood operating procedure prior to completion of the upgraded gates.

3.3 Annual Maximum Instantaneous Flow Series

Flood frequencies were estimated based on the annual maximum instantaneous flow series. When these data were not available, the annual maximum daily flow series were converted to annual maximum instantaneous flow peaks based on the relationships established at the gauging stations. The flow series for the Bow River and its tributaries were derived as follows:

- For the locations where there is no upstream flow regulation (i.e., Bow River at Banff, Elbow River at Bragg Creek, Highwood River at Diebel's Ranch, Sheep River at Black Diamond, etc.), the reported WSC instantaneous flow peaks were used for flood frequency analysis.
- For natural flow records, relationships between the recorded annual maximum daily and instantaneous flow peaks were established. These relationships were used to fill in any data gaps and generate a complete annual maximum instantaneous flow series for the periods of record.
- For the locations where there are natural and regulated flow records (e.g., the recorded flows for Spray River prior to 1951 were natural flows, and after 1951 regulated flows), the natural and regulated data series were considered separately to establish the relationships between annual maximum daily and instantaneous flow peaks.
- Daily flows were generated for the naturalized and regulated scenarios, and these were converted to annual maximum instantaneous flow peaks based on the above-mentioned relationships.
- Along the Bow River, the annual maximum daily flow series were converted to annual maximum instantaneous flow peaks based on the relationships established at the gauging stations. For example, relationships (Figure 3.2) were established for the Bow River at Calgary for both the natural flow series (i.e., the recorded data prior to 1932) and the regulated flow series (i.e., the recorded data after 1932).These relationships were used for all locations between Bearspaw Dam and Pine Creek.
- For the Elbow River at Sarcee Bridge, the relationship (Figure 3.3) was established based on the recorded data at WSC Station 05BJ010 and the historic large floods estimated by T. Blench & Associates (1965).
- If the reported annual maximum daily and instantaneous flow values for the same year are not for the same flood event, the annual maximum daily values are replaced by the daily values for the events corresponding to the annual maximum instantaneous flows. For example, the annual maximum daily flow values reported for Elbow River at Bragg Creek for 1973, 1974, 1983, 1991, 2003 and 2012 were replaced by the daily flow values for the same events as the annual maximum instantaneous flows. In addition, the 1974 data points for the Elbow River at Bragg Creek were not used for developing the relationship, because there was an unrealistically large difference between the annual maximum daily and instantaneous flow values.
- For some locations along the Bow River and its tributaries, the annual maximum instantaneous flow series were extended based on the relationships established between upstream and downstream locations using the recorded annual maximum daily flow series for the overlapping periods. For example, the annual maximum instantaneous flow series for the Elbow River at Bragg Creek were extended to the period 1908 to 1935 using the relationship established with the data from the combined three (3) stations (i.e., Elbow River at Sarcee Bridge, Elbow River above Glenmore and Elbow River below Glenmore) (see Figures A-30 and A-31 in Appendix A).

- The annual maximum instantaneous flow series for the Elbow River at Sarcee Bridge were extended by combining the annual maximum daily flow series recorded at three WSC Stations (i.e., 05BJ001, 05BJ005, and 05BJ010), because these stations are located close to each other and the maximum difference in their drainage areas is less than four percent (i.e., 1,189 km^2 at WSC Station 05BJ010, 1,220 km^2 at WSC Station 05BJ005, and 1,236 km^2 at WSC Station 05BJ001).

Appendix A presents the relationships established between annual maximum daily and instantaneous flow peaks for the Bow River and its tributaries. Each relationship was evaluated and selected based on both the statistical best-fit, as well as professional judgement. Appendix A also presents plots showing the recorded and estimated annual maximum instantaneous flow series. Tables A-1 and A-2 show the multiplication factors used for converting maximum daily flow to maximum instantaneous flow peaks.

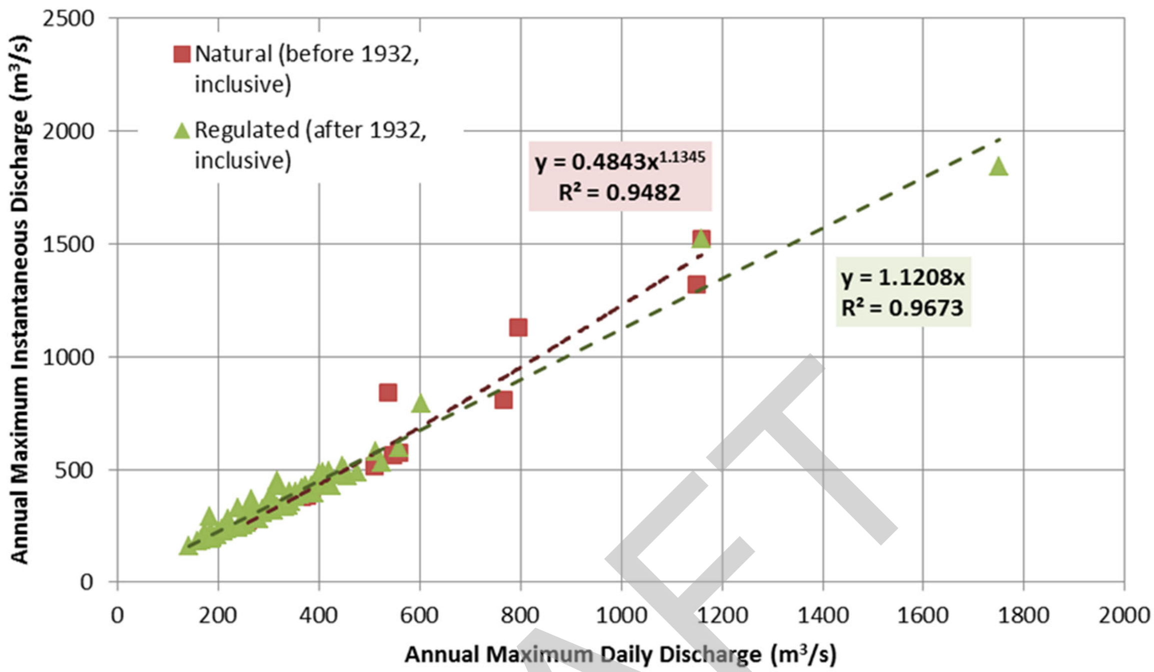


Figure 3.2: Relationship between Annual Maximum Daily and Instantaneous Flows for the Bow River at Calgary

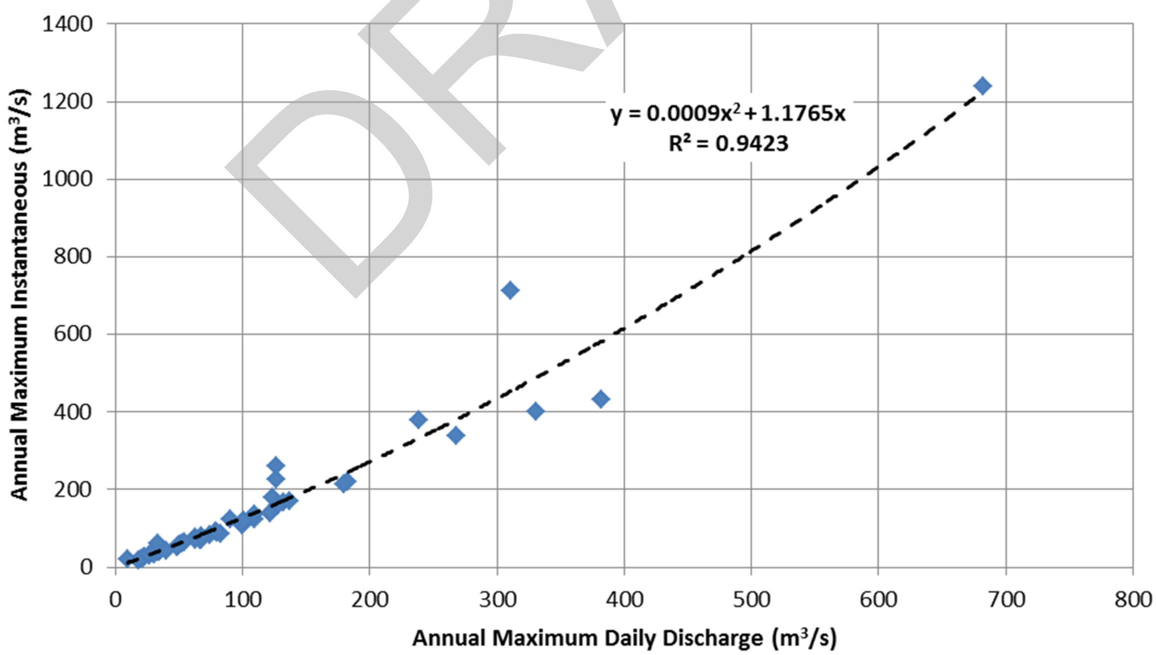


Figure 3.3: Relationship between Annual Maximum Daily and Instantaneous Flows for the Elbow River at Sarcee Bridge

4.0 FLOOD FREQUENCY ANALYSIS

4.1 Statistical Tests

4.1.1 Methods

Prior to fitting the appropriate frequency distribution to the flood flow data, a number of statistical tests were performed to determine the quality of the flood flow data series. A Golder software tool similar to Environment Canada's Consolidated Frequency Analysis (CFA), but with enhanced methodology, was used for the following: flood frequency analyses and statistical tests for independence (not serially correlated), trend, randomness, and homogeneity. The software tool includes modern boot strapping and estimation of confidence intervals.

The following probability distributions were analyzed with select parameter estimation methods (i.e., method of moments [moment], maximum likelihood estimation [MLH], and Method of L-moments [MLM]):

- Three-parameter Log Normal (moment and MLH);
- Generalized Extreme Value Distribution that includes Extreme Value 1, 2, and 3 distributions (MLM);
- Log Pearson Type III (LP3, moment and MLH); and
- Weibull (moment).

Numerical goodness-of-fit test was performed using the non-parametric Anderson-Darling test (Stephens, 1974).

Frequency analyses of the annual maximum instantaneous flow series (for the natural and naturalized as well as regulated flood flow series) were conducted for estimating the flood peak discharges of various return periods (i.e., 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year floods). The methods of fitting statistical probability distributions followed the standard approach. While this approach produced reasonable and appropriate results, accurate flood frequency estimates depend on sufficient data sample size. Estimates of return periods greater than 100 years, which are based on relatively short periods of record, are expected to have a high level of uncertainty. The level of uncertainty is represented by the upper and lower 95% confidence intervals. Therefore, extra care should be used for estimates that have very large confidence intervals.

As noted elsewhere, limitations of the analysis methodology do not support the use of regulated flood frequency estimates for flows higher than experienced in the historical record. While reported, regulated flood frequency estimates above the 75-year flood are not recommended for use for design purposes, as they do not consider the capacity of existing reservoirs and over-estimate the ability of regulation to reduce flood peaks.

4.1.2 Results

Tables A-3 and A-4 in Appendix A provide the results of statistical tests on the recorded, naturalized, and regulated annual maximum instantaneous flow series at various locations along the Bow River and its tributaries. The results show that most of the annual maximum instantaneous flow series are independent, random, homogeneous, and do not display any significant trends. The results are highlighted and discussed below:

- The annual maximum instantaneous natural flow series for the Bow River at Banff display a trend at the 1% and 5% level of significance. However, the trend does not appear to be due to any large-scale climatic change. Five of the flood flows recorded prior to 1933 were higher than any of the flood flows recorded after 1934 with the exception of the 2012 and 2013 flood flows. Statistical tests were performed on the 1934-2015 flow data. The test results show that the data do not display trend at the 1% and 5% level of significance.

- The annual maximum instantaneous naturalized flow series for the Bow River below Bassano Dam, at Highway 36 and near the Mouth, display non-randomness at the 1% and 5% level of significance. However, the annual maximum instantaneous naturalized flow series for the Bow River at Highway 539, Highway 875, and Bow River at the Mouth, which are located a few kilometers from Bassano Dam and Highway 36, are random. Therefore, the non-randomness results for the Bow River below Bassano Dam, at Highway 36 and near the Mouth, do not appear to be due to any large-scale climatic change. Statistical tests were performed using the flood flow data for the Bow River at Bassano Dam after removing two of the largest floods (i.e., 1915 and 1929 floods). The test results show that the flood flow series are independent and random at 5% level of significance.
- The annual maximum instantaneous regulated flow series for the Bow River near Seebe, below Ghost Dam, below Bearspaw Dam, at Calgary, and below Bassano Dam, display trends, non-homogeneous and non-randomness at the 1% and 5% level of significance. These results are mainly due to reservoir regulation and river diversions. They do not appear to be due to any large-scale climatic change, because the statistical tests of the flood flow series for the other locations immediately upstream and downstream of the above-mentioned locations do not display significant serial dependence or trend and appear to be random and homogeneous.
- The annual maximum instantaneous natural and naturalized flow series for the Spray River at Banff, Kananaskis River near Seebe, Ghost River above Waiparous Creek, and Jumpingpound Creek at Cochrane, display trend, non-homogeneous and non-randomness at the 1% and 5% level of significance.

4.1.3 Discussion of the Results

Data non-homogeneities are caused when artificial changes that affect the statistical properties of the observations through time. In reality, obtaining perfectly homogeneous data is almost impossible, because the changes such as flow regulation, forestry operations, and water diversions often affect the flood flow magnitudes.

The above-mentioned changes have increased since the start of systematic streamflow monitoring in 1908 (AENV 1983). There was evidence that extensive forest fires occurred during the late 1800s and early 1900s in the vicinity of the Bow River basin. In a study of the landscape change in Banff National Park, Byrne (1968) expressed the opinion that climatic conditions during the latter half of the nineteenth century were relatively dry and conducive to forest fire. The reduced forest cover might have resulted in increased peak runoff rates in the early period of flood flow record for the Bow River.

Conversely, the recovery of the forest cover might have resulted in reduction of peak runoff rates in the later period of record. This may partially account for non-homogeneity of the flood flow record. However, forest cover may be depleted or replenished at any time by man or nature and should not be considered as a permanent change in the flood flow pattern. Therefore, the pre-1934 records and the post-1933 flow records have been combined.

The magnitudes of consumptive water diversions from the Bow and Elbow Rivers upstream of Calgary are relatively low. These diversion quantities are very small in comparison to flood peak flows in the Bow and Elbow Rivers. There are two non-consumptive water diversions from the Bow River upstream of Calgary (i.e., the Smith-Dorrien Creek and Ghost River diversions). There are three consumptive water diversions along the lower reach of the Bow River (i.e., diversions to the irrigation districts at Calgary Weir, Carseland Dam and Bassano Dam). There are two major consumptive water diversions from the Highwood River (Highwood and Little Bow Diversions for Irrigation).

A system of 8 reservoirs and 11 hydropower plants was established in the Bow River basin between 1911 and 1955. Detailed analysis of the storage effects of this system is presented in Appendix A. The dependence, trends and non-randomness at some of these locations may be due to a combination of long-term variability in the region's climate regime and alteration of flow patterns by major storage facilities. Notwithstanding the trend and non-homogeneity in some of the flood flow series, all of the flow series are considered appropriate for the flood frequency analysis.

4.2 Analysis of the Natural and Naturalized Flood Flow Series

4.2.1 Bow River

Frequency analyses of the annual maximum instantaneous flow series, including the preliminary estimates of the 2013, 2014 and 2015 flood flows, for the natural and naturalized flood flows at the various locations along the Bow River, were conducted for estimating the flood peak discharges of various return periods (i.e., 2-, 5-, 10-, 20-, 35-, 50-, 75-, 100-, 200-, 350-, 500-, 750-, and 1000-year floods). 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 the best distribution fit with 95% confidence intervals.

The flood frequency estimates along the Bow River through Calgary, downstream of the Elbow River, Nose Creek, Fish Creek, and Pine Creek confluences were obtained using the following alternative approach:

- Flood frequency estimates for the Bow River downstream of tributaries were not based on a simple coincident flood peak assumption, which would have over-estimated the probable increase in Bow River main-stem flows through Calgary. Instead, Bow River flows were determined using a more sophisticated analysis based on an examination of both instantaneous and maximum daily flow records for the Bow River and its tributaries. See Table C.4.1 in Appendix C for these results, which are also reported in Table 6.1.

- Flood frequency estimates for the Bow River below the Elbow River involved development of a maximum annual instantaneous flow series at this location based on an examination of the concurrent maximum daily and instantaneous flow records for both river for each year. The most realistic combined Bow River flow series was used for the frequency analysis, based on the following options:

  - simultaneous occurrence of instantaneous peak flows in the Bow and Elbow Rivers;
  - instantaneous peak flow in the Bow River plus daily peak flow in the Elbow River;
  - daily peak flow in the Bow River and instantaneous peak flow in the Elbow River; and
  - daily peak flow in the Bow River and daily peak flow in the Elbow River.

  The highest flow combination was selected to represent the maximum instantaneous flow for each year. Criteria 2) (i.e., combination of instantaneous peak flow in the Bow River plus daily peak flow in the Elbow River) governs for 81 years out of 104 years. Criteria 1, 3 and 4 governs for 12 years, 11 years, and zero years out of 104 years, respectively.

- Flood frequency estimates for the Bow River below Nose Creek, Fish Creek, and Pine Creek involved calculating appropriate tributary contributions, based on frequency analysis of maximum daily tributary flows that occurred on the same day as annual instantaneous Bow River flows using the following methods:

  1) Generate annual daily flow series for Nose and Fish Creeks corresponding to the date when we had instantaneous maximum flood flows on Bow River at Calgary. The annual daily flow series will be derived only for the years that we have recorded flows for the two creeks.

  2) Using the annual daily flow series derived in Step 1 for the two creeks, complete flood frequency estimates.

  3) Using estimated regional/local peaking factor, derive flood frequency estimates for daily flows for Pine Creek based on the flood frequency estimates already completed for Pine Creek based on regional analysis. A peaking factor of 1.23 that was developed for Meadow Creek near the Mouth (i.e. WSC Station No. 05BA029) was used.

  4) Using the flood frequency estimates generated in Steps 2 and 3 for tributary creeks and flood frequency estimated for Bow River at Calgary, derive flood frequency estimates for Bow River below each tributary.

Table 4.1: Flood Frequency Flow Estimates Calculated Using Various Methods - Natural and Naturalized Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Flow Type[1]	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																																						
						1000-yr			750-yr			500-yr			350-yr			200-yr			100-yr			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
						Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
BOW RIVER																																												
05BA001	Bow River at Lake Louise	422	422	N	EV2	182	304	95.8	172	279	94.2	159	247	92.3	149	222	90.1	135	191	86.7	118	156	81.9	111	145	80.0	102	129	77.0	95.1	117	74.3	84.6	101	70.0	72.7	83.3	63.9	61.9	68.7	56.7	48.2	51.9	45.4
05BB001	Bow River at Banff	2210	2210	N	EV2	554	754	425	538	715	418	517	667	410	498	630	401	468	576	389	431	509	369	416	483	360	394	450	346	375	422	333	346	380	313	308	333	285	269	288	253	211	225	200
Node 105	Bow River below Spray River	2993	2993	NZ	3P(MLH)	844	1230	593	811	1160	578	769	1070	560	729	997	542	670	883	514	602	763	479	574	716	464	537	653	443	505	598	425	456	524	395	398	440	358	341	368	315	264	283	248
Node 107	Bow River below Cascade River	3727	3727	NZ	3P(MLH)	1040	1540	718	995	1460	701	942	1350	677	892	1260	652	818	1110	616	733	950	572	698	889	554	652	810	528	611	742	505	550	644	470	477	537	422	406	441	371	309	329	289
Node 108	Bow River at Canmore	3870	3870	NZ	3P(MLH)	1090	1650	753	1050	1550	734	993	1430	708	940	1320	684	861	1170	645	770	1000	599	734	937	580	684	852	553	642	781	529	577	677	492	499	563	442	425	462	388	323	344	302
Node 109	Bow River above Kananaskis	4199	4199	NZ	3P(MLH)	1120	1640	780	1080	1550	762	1020	1440	736	968	1340	711	890	1190	675	799	1030	629	763	964	610	713	879	582	670	809	558	605	704	519	526	590	468	449	487	412	343	366	321
Node 110	Bow River below Kananaskis	5139	5139	NZ	EV2	1770	3850	831	1660	3430	817	1510	2910	795	1400	2540	776	1230	2050	742	1050	1550	694	983	1400	678	894	1200	649	822	1060	624	719	868	582	606	687	526	505	551	462	380	407	358
05BE004 / Node 111	Bow River near Seebe	5170	5170	NZ	EV2	1760	3520	903	1650	3160	883	1510	2720	858	1400	2390	837	1240	1940	794	1060	1510	743	994	1370	718	906	1190	687	834	1050	657	731	878	607	616	703	541	513	562	470	384	414	360
Node 318	Bow River above Ghost Reservoir	5475	5473	NZ	EV2	1630	3480	790	1530	3130	776	1400	2670	757	1300	2330	739	1150	1890	709	989	1450	666	928	1310	647	847	1130	621	781	996	598	686	824	560	581	657	506	486	530	445	367	393	346
05BE006 / Node 58	Bow River below Ghost Dam (Ghost Reservoir Outflow)	6550	6550	NZ	LP3(MLH)	1680	3320	1020	1590	3050	987	1480	2690	946	1380	2390	912	1240	1990	860	1080	1580	794	1020	1440	767	936	1270	726	868	1130	692	767	940	636	651	753	566	543	602	490	402	431	374
	Bow River below Ghost Dam (Ghost Reservoir Outflow), historic			NZ	*Historical adjustment ratio applied to Lp3(MLH)*[2]	2390	*4730*	*1450*	2230	*4280*	*1380*	2030	*3690*	*1300*	1850	*3210*	*1220*	1610	*2590*	*1120*	1350	*1980*	*994*	1260	*1770*	*945*	1130	*1530*	*875*	1030	*1330*	*817*	878	*1080*	*728*	718	*830*	*624*	577	*640*	*521*	408	*437*	*379*
05BH005 / Node 114	Bow River near Cochrane	7412	7383	NZ	LP3(MLH)	1840	4320	1030	1740	3860	997	1600	3300	964	1490	2880	929	1330	2300	874	1140	1780	805	1080	1610	775	983	1390	736	906	1220	703	794	996	646	667	786	574	550	614	494	401	432	370
	Bow River near Cochrane, historic			NZ	*Historical adjustment ratio applied to LP3(MLH)*[2]	2620	*6160*	*1470*	2440	*5410*	*1400*	2190	*4520*	*1320*	2000	*3870*	*1250*	1730	*2990*	*1140*	1430	*2230*	*1010*	1330	*1980*	*955*	1180	*1670*	*887*	1070	*1440*	*830*	909	*1140*	*740*	736	*867*	*633*	585	*653*	*525*	407	*438*	*375*
Node 302	Bearspaw Reservoir Inflow	7712	7672	NZ	LP3(MLH)	2030	4820	1060	1910	4300	1030	1740	3660	979	1600	3160	940	1410	2540	878	1190	1940	802	1110	1720	770	1010	1470	727	917	1270	689	791	1020	629	650	780	549	523	592	464	367	399	335
	Bearspaw Reservoir Inflow, historic			NZ	*Historical adjustment ratio applied to LP3(MLH)*[2]	2890	*6870*	*1510*	2680	*6030*	*1440*	2380	*5020*	*1340*	2150	*4240*	*1260*	1840	*3310*	*1140*	1490	*2430*	*1000*	1370	*2120*	*949*	1220	*1770*	*876*	1080	*1500*	*814*	906	*1170*	*720*	717	*860*	*605*	556	*629*	*493*	372	*405*	*340*
05BH008 / Node 59	Bearspaw Reservoir Outflow (assigned same flows as Bow River at Calgary)	7770	7730	NZ	LP3(MLH)	2380	5260	1150	2220	4720	1110	2020	4080	1060	1850	3590	1020	1610	2920	947	1350	2210	867	1250	1960	831	1120	1670	783	1020	1440	739	872	1150	673	709	861	587	564	646	496	389	423	357
05BH004 / Node 59	Bow River at Calgary, extended	7868	7736	NZ	LP3(MLH)	2510	5130	1430	2350	4610	1370	2130	3980	1290	1950	3480	1230	1700	2830	1120	1430	2180	1010	1330	1960	959	1190	1670	893	1080	1460	836	925	1180	745	751	904	637	597	674	533	409	442	379
	Bow River at Calgary, historic			NZ	*Historical adjustment ratio applied to LP3(MLH)*[2]	4880	*9970*	*2780*	4400	*8630*	*2570*	3790	*7080*	*2300*	3330	*5940*	*2100*	2710	*4510*	*1790*	2090	*3190*	*1480*	1880	*2770*	*1360*	1610	*2260*	*1210*	1400	*1890*	*1080*	1120	*1430*	*902*	845	*1020*	*717*	627	*708*	*560*	401	*433*	*372*
Node 176	Bow River below Elbow River	9128	8995	NZ	LP3(MLH)	3200	7480	1440	2970	6690	1390	2670	5670	1320	2430	4890	1260	2090	3880	1160	1720	2880	1060	1590	2550	1010	1410	2130	945	1270	1830	889	1070	1430	804	853	1050	693	665	769	575	443	486	403
	Bow River below Elbow River, historic			N	*Concurrent*[6]	5310	*7930*	*4230*	4820	*7080*	*3840*	4190	*6040*	*3350*	3710	*5240*	*2990*	3050	*4180*	*2470*	2390	*3140*	*1970*	2150	*2780*	*1780*	1860	*2340*	*1560*	1630	*2010*	*1390*	1310	*1560*	*1130*	996	*1150*	*882*	739	*816*	*675*	464	*497*	*434*
Node 158	Bow River below Nose Creek	10114	9656	NZ	LP3(MLH)	3210	7500	1440	2980	6720	1390	2680	5650	1320	2430	4910	1260	2090	3880	1170	1730	2900	1060	1590	2570	1010	1410	2140	947	1270	1840	891	1070	1430	806	855	1060	695	667	772	577	444	487	404
	Bow River below Nose Creek, historic			N	*Concurrent*[6]	5370	*10500*	*3270*	4880	*9110*	*3050*	4240	*7530*	*2750*	3760	*6370*	*2530*	3090	*4890*	*2170*	2420	*3520*	*1810*	2180	*3070*	*1660*	1890	*2540*	*1490*	1650	*2140*	*1330*	1330	*1640*	*1110*	1010	*1180*	*882*	746	*827*	*679*	465	*497*	*436*

Table 4.1: Flood Frequency Flow Estimates Calculated Using Various Methods - Natural and Naturalized Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Flow Type[1]	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																									
						1000-yr		750-yr		500-yr		350-yr		200-yr		100-yr		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
Node 164	Bow River below Fish Creek	10640	10182	NZ	LP3(MLH)	3350	8020 / 1440	3100	7110 / 1390	2780	5990 / 1330	2520	5160 / 1270	2160	4080 / 1180	1780	3010 / 1080	1640	2650 / 1020	1450	2210 / 959	1310	1890 / 903	1100	1470 / 819	871	1080 / 706	676	785 / 585	447	492 / 406
	Bow River below Fish Creek, historic			N	*Concurrent*[6]	6100	*8720 / 5020*	5480	*7740 / 4500*	4700	*6550 / 3860*	4120	*5650 / 3400*	3340	*4470 / 2760*	2580	*3330 / 2160*	2310	*2940 / 1940*	1980	*2460 / 1680*	1730	*2110 / 1490*	1380	*1630 / 1200*	1040	*1190 / 926*	762	*839 / 698*	469	*502 / 439*
Node 177	Bow River below Pine Creek	10887	10397	NZ	LP3(MLH)	3310	7900 / 1430	3070	7020 / 1380	2750	5900 / 1320	2500	5100 / 1260	2140	4040 / 1170	1760	2980 / 1070	1620	2620 / 1020	1440	2190 / 950	1300	1870 / 896	1090	1460 / 815	866	1070 / 702	673	780 / 583	446	490 / 405
	Bow River below Pine Creek, historic			N	*Concurrent*[6]	6180	*11300 / 4080*	5560	*9790 / 3730*	4770	*8060 / 3280*	4180	*6790 / 2950*	3390	*5190 / 2470*	2620	*3720 / 2010*	2350	*3240 / 1830*	2020	*2670 / 1620*	1760	*2250 / 1440*	1400	*1710 / 1180*	1050	*1220 / 922*	770	*851 / 703*	472	*504 / 443*
Node 331	Bow River above Highwood River	11258	10532	NZ	LP3(MLH)	2650	5670 / 1280	2480	5120 / 1240	2260	4400 / 1190	2080	3850 / 1140	1820	3140 / 1070	1530	2430 / 986	1430	2160 / 949	1290	1850 / 894	1170	1620 / 851	1010	1300 / 780	824	997 / 686	661	752 / 584	462	501 / 425
	Bow River above Highwood River, historic			N	*Prorated*[7]	6260	*8880 / 5180*	5630	*7890 / 4650*	4830	*6680 / 3990*	4240	*5770 / 3520*	3440	*4570 / 2860*	2660	*3410 / 2240*	2380	*3010 / 2010*	2040	*2520 / 1740*	1780	*2160 / 1540*	1420	*1670 / 1240*	1070	*1220 / 956*	780	*857 / 716*	478	*511 / 448*
Node 165	Bow River below Highwood River	15342	14497	NZ	EV2	7180	16300 / 2250	6390	13800 / 2150	5420	11000 / 2000	4690	8980 / 1900	3750	6620 / 1740	2840	4520 / 1530	2530	3860 / 1450	2150	3100 / 1330	1870	2590 / 1240	1500	1950 / 1100	1140	1380 / 931	867	1000 / 762	582	644 / 538
05BM002 / Node 178	Bow River below Carseland Dam	15665	14696	NZ	EV2	6770	15100 / 2380	6080	12900 / 2280	5240	10500 / 2130	4590	8670 / 2010	3730	6500 / 1830	2880	4580 / 1620	2590	3960 / 1540	2230	3220 / 1420	1950	2690 / 1320	1580	2020 / 1170	1210	1460 / 983	917	1050 / 797	604	677 / 550
Node 180	Bow River at Hwy. 547	17443	15920	NZ	EV2	5800	12800 / 2100	5250	11100 / 2030	4560	9020 / 1920	4020	7520 / 1830	3310	5670 / 1670	2590	4060 / 1490	2340	3540 / 1420	2030	2880 / 1320	1790	2420 / 1230	1460	1860 / 1100	1140	1360 / 932	870	994 / 761	580	648 / 529
Node 181	Bow River at Hwy. 842	18028	16344	NZ	EV2	5160	12100 / 1930	4700	10400 / 1860	4110	8480 / 1770	3650	7130 / 1680	3030	5380 / 1550	2410	3830 / 1400	2180	3360 / 1340	1910	2770 / 1250	1690	2330 / 1170	1390	1780 / 1050	1090	1300 / 897	842	955 / 737	566	632 / 516
Node 189	Bow River below Crowfoot Creek	20169	17672	NZ	EV2	5030	11800 / 1890	4570	10100 / 1820	4000	8260 / 1720	3560	6950 / 1640	2950	5240 / 1510	2350	3730 / 1370	2130	3270 / 1310	1860	2700 / 1220	1650	2270 / 1140	1360	1730 / 1030	1060	1270 / 876	822	932 / 720	552	617 / 503
05BM004 / Node 182	Bow River below Bassano Dam, extended	20253	17751	NZ	LP3(MLH)	7580	9900 / 3580	6810	9030 / 3370	5840	7950 / 3090	5100	7010 / 2830	4130	6400 / 2440	3160	4580 / 2070	2830	3980 / 1930	2420	3280 / 1720	2100	2770 / 1560	1680	2120 / 1320	1260	1520 / 1050	932	1080 / 816	591	658 / 545
Node 184	Bow River at Hwy. 539	20915	18186	NZ	3P(MLH)	4590	8600 / 2640	4270	7820 / 2500	3870	6860 / 2330	3520	6040 / 2170	3010	4890 / 1940	2470	3790 / 1680	2270	3380 / 1580	2000	2880 / 1440	1780	2490 / 1310	1480	1950 / 1140	1150	1420 / 937	870	1010 / 752	562	618 / 508
Node 185	Bow River at Hwy. 36	21423	18544	NZ	3P(MLH)	4380	8170 / 2480	4080	7440 / 2350	3700	6560 / 2200	3350	5780 / 2060	2870	4690 / 1840	2350	3600 / 1590	2150	3220 / 1490	1900	2740 / 1360	1690	2360 / 1250	1400	1850 / 1080	1090	1340 / 891	825	953 / 714	534	588 / 484
Node 186	Bow River at Hwy. 875	22307	18878	NZ	3P(MLH)	4240	7790 / 2420	3940	7080 / 2290	3570	6230 / 2140	3250	5500 / 2000	2780	4480 / 1780	2280	3460 / 1550	2090	3100 / 1460	1850	2630 / 1330	1650	2270 / 1220	1370	1790 / 1060	1070	1300 / 876	811	932 / 704	530	583 / 481
05BN012 / Node 187	Bow River near the Mouth	25280	19160	NZ	3P(MLH)	4610	8580 / 2580	4290	7840 / 2450	3890	6950 / 2290	3540	6120 / 2120	3030	4970 / 1910	2490	3840 / 1660	2280	3440 / 1560	2020	2930 / 1430	1800	2520 / 1310	1490	1970 / 1140	1160	1430 / 942	872	1020 / 749	559	617 / 507
Node 188	Bow River at the Mouth	25612	19306	NZ	3P(MLH)	4450	8230 / 2500	4140	7470 / 2380	3760	6620 / 2230	3420	5820 / 2080	2930	4750 / 1860	2410	3700 / 1620	2220	3310 / 1530	1960	2810 / 1390	1750	2430 / 1280	1450	1910 / 1120	1130	1390 / 925	856	991 / 737	552	608 / 500
BOW RIVER TRIBUTARIES																															
05BC001 / Node 106	Spray River at Banff, before 1951	751	751	N	3P(MLH)	224	341 / 153	218	325 / 150	209	306 / 147	201	287 / 143	188	260 / 137	173	228 / 130	166	215 / 126	157	199 / 121	149	184 / 116	136	163 / 109	120	139 / 99.5	102	116 / 88.4	74.6	83.6 / 66.8
	Spray River at Banff	751	751	NZ	EV2	432	802 / 218	402	720 / 210	363	613 / 200	332	536 / 191	287	434 / 179	240	336 / 163	222	303 / 156	199	262 / 145	180	229 / 137	154	187 / 123	125	145 / 106	99.2	111 / 88.1	68.2	75.1 / 62.8
05BD002 / Node 154	Cascade River near Banff	664	664	NZ	EV2	423	938 / 187	390	824 / 181	348	686 / 172	314	583 / 165	268	453 / 154	219	336 / 140	201	296 / 133	178	248 / 124	159	214 / 116	134	169 / 104	106	125 / 88.2	82.7	94.4 / 72.6	54.9	61.6 / 49.9
05BF001	Kananaskis River near Seebe, before 1946	933	933	N	EV2	797	1320 / 223	722	1180 / 217	629	991 / 207	556	853 / 199	458	678 / 187	360	511 / 170	325	456 / 163	281	389 / 152	247	338 / 143	201	271 / 131	154	202 / 114	115	149 / 93.3	72.3	90.7 / 63.3
05BF025 / Node 56	Kananaskis River below Barrier Dam	899	899	NZ	EV2	691	1510 / 231	623	1290 / 222	537	1040 / 210	472	865 / 200	386	648 / 184	300	457 / 166	270	396 / 159	234	326 / 148	205	275 / 139	168	213 / 125	130	157 / 106	100	114 / 88.3	68	74.8 / 62.8
05BG010	Ghost River above Waiparous Creek, extended with diversion added	485	485	NZ	EV2	1160	1930 / 450	990	1610 / 404	790	1250 / 343	648	1010 / 297	474	718 / 238	320	474 / 179	272	398 / 157	216	311 / 131	175	250 / 111	126	177 / 85.2	82.2	114 / 60.0	51.7	70.1 / 40.2	24.0	30.5 / 20.0
05BG006	Waiparous Creek near the Mouth	333	333	N	3P(MLH)	1000	2650 / 378	900	2290 / 350	776	1890 / 315	670	1550 / 285	528	1150 / 240	388	764 / 193	339	645 / 175	278	508 / 153	230	397 / 134	169	270 / 106	109	159 / 74.7	65.5	88.4 / 47.5	26.9	36.8 / 20.1
	Waiparous Creek near the Mouth, extended			N	3P(MLH)	692	1200 / 410	630	1080 / 378	553	925 / 339	487	794 / 303	395	623 / 253	301	455 / 200	267	397 / 181	224	325 / 155	190	268 / 135	144	196 / 105	97.9	127 / 74.3	61.6	76.4 / 48.8	26.3	32.0 / 21.3

Table 4.1: Flood Frequency Flow Estimates Calculated Using Various Methods - Natural and Naturalized Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m³/s)																																						
						1000-yr			750-yr			500-yr			350-yr			200-yr			100-yr			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
						Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
05BG001 / Node 316	Ghost River near Cochrane, extended with diversion added	911	911	NZ	LP3(MLH)	1960	8410	741	1710	6670	680	1420	4860	596	1190	3670	536	909	2420	451	642	1440	352	553	1150	317	446	843	271	367	639	234	267	410	184	174	239	129	108	137	85.3	48.6	59	39.4
	Ghost River near Cochrane, sensitivity analysis			NZ	EV2	1630	2620	699	1430	2250	639	1180	1810	563	1000	1500	502	773	1130	422	557	784	336	485	674	303	398	544	261	333	450	228	251	331	181	173	223	131	114	145	91.0	55.8	68.1	46.8
05BH015	Jumpingpound Creek at Township Road No. 252, extended	474	474	N	3P(MLH)	878	1930	435	795	1710	403	695	1430	362	608	1220	327	489	929	273	369	657	218	326	563	196	271	448	169	228	363	146	171	257	114	113	160	80.2	69.5	93.3	51.6	27.8	36.6	20.9
05BH009	Jumpingpound Creek near the Mouth	571	571	N	3P(MLH)	655	1870	267	595	1640	248	522	1370	225	459	1150	204	371	887	176	282	615	145	250	517	131	210	410	114	177	328	100	134	229	80.1	90.3	139	58.2	56.3	81.7	39.0	23.4	33.0	16.6
	Jumpingpound Creek near the Mouth, extended			N	3P(MLH)	1030	2250	488	936	2000	448	815	1670	404	710	1410	363	568	1070	306	425	747	241	374	638	217	310	505	186	260	407	160	193	287	125	127	177	87.5	76.8	102.0	56.5	30	39.7	22.3
Node 174	Jumpingpound Creek at the Mouth	601	601	NZ	3P(MLH)	821	1990	358	746	1760	334	655	1460	303	575	1230	276	465	930	237	353	660	193	313	563	176	262	447	154	222	360	136	167	254	108	112	158	77.7	69.8	93.3	51	28.6	39.5	20.2
05BH003 / Node 175	Nose Creek at Calgary, extended	893	746	N	EV2	348	495	101	303	426	91.9	249	347	80.9	209	288	72.2	159	219	58.8	113	158	46.5	97.3	138	42.2	79	115	36.2	65.5	98.1	31.3	48.3	75.4	24.5	32.3	53.3	17.7	20.5	35.6	12	8.92	15.6	5.71
Node 163	Fish Creek at the Mouth	440	440	NZ	3P(MLH)	1220	3260	443	1080	2820	406	907	2290	355	766	1860	311	581	1310	252	406	849	194	347	702	171	275	529	142	221	404	120	154	261	89.4	92	144	59.1	50.1	74.8	35.1	16.9	23.1	12.4
05BK001	Fish Creek near Priddis	261	261	N	3P(MLH)	926	3500	465	829	3010	422	713	2440	373	614	1990	328	481	1430	264	350	921	203	305	761	182	248	574	152	204	445	128	148	290	95.5	93.3	160	63.8	53.7	83.9	38.7	19.1	25.7	13.9
05BM008	Crowfoot Creek near Cluny	1374	950	N	3P(MLH)	797	1980	193	701	1700	182	589	1380	170	495	1120	159	373	794	141	259	514	117	220	428	108	174	323	93.8	139	249	79.5	95.5	160	58	56.6	87.7	36.3	30.4	45.1	20.3	10.1	16.3	7.34
05BN006	New West Coulee near the Mouth	318	102	N	EV3	11.7	16.8	7.88	11.4	16.1	7.82	11.1	15.2	7.75	10.7	14.4	7.65	10.2	13.2	7.48	9.49	11.8	7.23	9.18	11.2	7.11	8.73	10.4	6.93	8.32	9.8	6.77	7.65	8.8	6.45	6.76	7.58	5.92	5.78	6.36	5.18	4.17	4.61	3.73
05BN002	Twelve Mile Creek near Cecil	2803	124	N	3P(MLH)	26.9	48.9	16.8	25.5	44.9	16.3	23.6	40	15.7	22	35.7	15.1	19.5	29.8	14.2	16.7	23.7	12.8	15.6	21.5	12.3	14.2	18.6	11.5	12.9	16.3	10.7	11.1	13.1	9.53	9.05	9.99	7.88	7.11	7.93	6.16	4.68	5.54	3.94
Node 179	Arrowwood Creek above Hwy. 547	830	718	NZ	LP3(moment)	298	977	97.1	273	824	92.5	239	677	86.8	212	552	81.9	172	398	73.2	129	263	61.3	113	217	56.1	93	165	49.3	76.9	128	42.8	55	86.5	32.2	33.4	50.6	20.3	17.4	27.1	10.8	4.4	7.9	2.52
ELBOW RIVER																																												
05BJ004	Elbow River at Bragg Creek	791	791	N	3P(MLH)	1280	2750	637	1170	2450	595	1040	2100	541	918	1810	490	753	1420	419	583	1030	343	521	898	315	442	735	277	379	607	245	292	440	199	204	285	149	133	172	103	62.3	74.7	51.8
	Elbow River at Bragg Creek, extended using relationship established with Elbow at Sarcee Bridge based on maximum daily floods			N	3P(MLH)	1560	2920	909	1420	2600	839	1250	2240	755	1100	1920	676	895	1500	565	686	1100	450	610	953	408	514	779	353	437	642	307	333	470	243	229	303	175	146	184	117	66.1	78.7	55.7
	Elbow River at Bragg Creek, extended using relationship established with Elbow at Sarcee Bridge based on maximum daily floods, historic			N	*Historical adjustment ratio applied to 3P(MLH)*[2]	2220	*4160*	*1300*	1990	*3650*	*1180*	1710	*3070*	*1030*	1480	*2580*	*908*	1160	*1950*	*735*	859	*1380*	*563*	752	*1170*	*503*	619	*938*	*425*	516	*758*	*363*	381	*538*	*278*	253	*334*	*193*	155	*196*	*124*	67.1	*79.8*	*56.5*
	Elbow River at Bragg Creek, extended using relationship established with Elbow at Sarcee Bridge based on instantaneous floods			N	3P(MLH)	1510	*2810*	*885*	1380	*2510*	*819*	1210	*2170*	*736*	1070	*1880*	*664*	873	*1490*	*559*	671	*1070*	*445*	597	*932*	*404*	504	*761*	*349*	430	*631*	*304*	329	*460*	*241*	227	*300*	*173*	146	*183*	*117*	66.5	*78.4*	*56.5*
	Elbow River at Bragg Creek, extended using relationship established with Elbow at Sarcee Bridge based on instantaneous floods, historic			N	*Historical adjustment ratio applied to 3P(MLH)*[2]	2150	*4000*	*1260*	1930	*3520*	*1150*	1660	*2980*	*1010*	1440	*2520*	*891*	1140	*1930*	*727*	840	*1340*	*557*	736	*1150*	*497*	607	*916*	*420*	508	*745*	*359*	377	*527*	*277*	250	*331*	*191*	155	*195*	*125*	67.5	*79.6*	*57.4*
05BJ010	Elbow River at Sarcee Bridge, combined data from 05BJ001, 05BJ005, 05BJ010	1189	1189	N	3P(MLH)	1410	2650	750	1280	2370	697	1130	2040	630	997	1760	565	813	1380	477	625	1010	385	556	879	351	470	718	307	401	593	268	307	435	216	212	282	159	138	172	109	64.2	76.2	54.5
	Elbow River at Sarcee Bridge, combined data from 05BJ001, 05BJ005, 05BJ010 with estimated instantaneous flows from the 1983 AENV floodplain study			N	3P(MLH)	1510	2810	821	1380	2510	762	1210	2150	687	1070	1860	621	874	1460	526	672	1070	424	599	930	385	506	762	335	431	634	294	331	467	237	229	304	173	148	187	120	69.4	81.9	59.4
	Elbow River at Sarcee Bridge, combined data from 05BJ001,			N	*Historical adjustment ratio*	2150	*4000*		1930	*3520*		1660	*2950*		1440	*2500*		1140	*1900*		841	*1340*		738	*1150*		610	*918*		509	*749*		379	*535*		253	*335*		157	*199*		70.4	*83.1*	

Table 4.1: Flood Frequency Flow Estimates Calculated Using Various Methods - Natural and Naturalized Flows

Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Flow Type[1]	Distribution / Method	1000-yr Flood Est.	1000-yr Upper	1000-yr Lower	750-yr Flood Est.	750-yr Upper	750-yr Lower	500-yr Flood Est.	500-yr Upper	500-yr Lower	350-yr Flood Est.	350-yr Upper	350-yr Lower	200-yr Flood Est.	200-yr Upper	200-yr Lower	100-yr Flood Est.	100-yr Upper	100-yr Lower	75-yr Flood Est.	75-yr Upper	75-yr Lower	50-yr Flood Est.	50-yr Upper	50-yr Lower	35-yr Flood Est.	35-yr Upper	35-yr Lower	20-yr Flood Est.	20-yr Upper	20-yr Lower	10-yr Flood Est.	10-yr Upper	10-yr Lower	5-yr Flood Est.	5-yr Upper	5-yr Lower	2-yr Flood Est.	2-yr Upper	2-yr Lower
	05BJ005, 05BJ010 with estimated instantaneous flows from the 1983 AENV floodplain study, historic				applied to 3P(MLH)[2]			1170			1070			941			834			685			531			474			404			347			271			191			128			60.3
05BJ001 / Node 161	Elbow River below Glenmore Dam	1236	1236	NZ	EV2	2590	4500	976	2220	3780	881	1780	2950	764	1470	2360	672	1090	1680	544	748	1100	420	639	922	371	511	720	314	419	583	271	306	413	212	204	266	154	132	169	107	65.2	79.5	56.6
	Elbow River below Glenmore Dam, historic			NZ	Historical adjustment ratio applied to EV2[2]	3690	6410	1390	3110	5300	1240	2440	4040	1050	1970	3170	903	1420	2190	708	936	1380	526	787	1140	457	616	867	378	495	689	320	350	473	243	225	293	170	140	180	114	66.1	80.6	57.4
SHEEP RIVER AND TRIBUTARIES																																												
05BL014	Sheep River at Black Diamond	592	592	N	3P(MLH)	1900	5010	910	1720	4390	837	1500	3680	751	1310	3100	672	1050	2310	561	787	1600	445	693	1360	401	576	1080	345	484	872	301	361	601	235	240	360	165	148	206	107	61.5	79.6	47.1
05BL012	Sheep River at Okotoks	1494	1494	N	3P(MLH)	9220	31900	1500	8160	26900	1430	6910	21700	1330	5860	17400	1250	4470	12100	1120	3150	7640	947	2700	6220	872	2150	4560	770	1740	3460	688	1210	2150	547	729	1150	382	395	612	228	125	265	72.6
	Sheep River at Okotoks, extended			N	3P(MLH)	2620	4650	1520	2420	4220	1430	2180	3670	1310	1950	3210	1190	1640	2580	1030	1300	1950	852	1180	1730	784	1020	1460	694	886	1240	616	701	939	507	504	646	377	338	417	261	158	196	127
Node 344	Sheep River at the Mouth	1575	1570	N	Prorated[3]	9690	33500	1580	8580	28300	1500	7260	22800	1400	6160	18300	1310	4700	12700	1180	3310	8030	996	2840	6540	917	2260	4790	809	1830	3640	723	1270	2260	575	766	1210	402	415	643	240	131	279	76.3
	Sheep River at the Mouth, extended			N	Prorated[3]	2750	4890	1600	2540	4440	1500	2290	3860	1380	2050	3370	1250	1720	2710	1080	1370	2050	896	1240	1820	824	1070	1530	730	931	1300	648	737	987	533	530	679	396	355	438	274	166	206	134
05BL013	Threepoint Creek near Millarville	507	507	N	3P(MLH)	1140	2690	542	1040	2380	501	914	2010	455	803	1710	410	650	1310	345	495	941	275	439	806	249	368	648	216	312	521	187	235	371	149	158	232	106	98.2	134	70	39.8	52	29
HIGHWOOD RIVER AND TRIBUTARIES																																												
05BL019	Highwood River at Diebel's Ranch	774	774	N	LP3(MLH)	1390	7030	469	1250	5750	446	1080	4370	417	945	3400	390	765	2290	350	583	1430	300	519	1170	282	439	887	254	378	693	231	295	477	195	212	301	155	146	186	115	78.8	92.8	66.6
05BL004	Highwood River below Little Bow Canal	1953	1953	NZ	3P(MLH)	6300	14100	1240	5560	12200	1180	4690	9910	1070	3960	8140	974	3000	5940	848	2100	3890	698	1800	3250	640	1430	2530	561	1150	1970	484	804	1290	393	490	744	285	276	437	187	108	178	84.3
	Highwood River below Little Bow Canal, extended			NZ	EV2	2670	3870	1470	2360	3380	1340	1990	2800	1180	1710	2370	1040	1340	1820	852	994	1310	667	875	1140	603	730	943	519	620	792	451	476	598	361	337	419	264	229	283	186	118	142	101
	Highwood River below Little Bow Canal, extended, historic			NZ	Historical adjustment ratio applied to EV2[5]	2830	4100	1560	2490	3570	1410	2090	2950	1240	1790	2490	1090	1400	1900	889	1030	1360	692	905	1180	624	752	972	535	637	814	463	486	611	369	342	426	268	231	286	188	118	142	101
05BL024	Highwood River near the Mouth	3952	3941	NZ	3P(MLH)	4590	14200	1850	4200	12600	1740	3720	10500	1590	3300	8740	1460	2700	6600	1260	2100	4630	1040	1870	3980	957	1590	3150	851	1360	2500	759	1050	1780	623	726	1110	467	468	644	328	208	265	154
	Highwood River near the Mouth, extended			NZ	EV2	4910	7740	2660	4340	6680	2420	3640	5440	2120	3120	4540	1880	2440	3450	1560	1800	2440	1220	1580	2110	1090	1310	1730	933	1110	1440	807	853	1080	642	602	749	471	409	505	331	212	254	181
	Highwood River near the Mouth, extended, historic			NZ	Historical adjustment ratio applied to EV2[5]	5200	8190	2820	4580	7050	2560	3830	5720	2230	3270	4760	1970	2550	3600	1630	1870	2530	1270	1630	2180	1130	1350	1780	961	1140	1480	829	872	1100	656	612	761	479	413	510	334	213	255	181
Node 172	Highwood River at the Mouth	3991	3964	NZ	Prorated[4]	4940	7780	2680	4360	6720	2430	3660	5470	2130	3140	4570	1890	2450	3470	1570	1810	2450	1230	1590	2120	1100	1320	1740	938	1120	1450	812	858	1090	646	605	753	474	411	508	333	213	255	182
	Highwood River at the Mouth, historic			NZ	Prorated[4]	5230	8240	2840	4600	7090	2570	3850	5750	2240	3290	4790	1980	2560	3620	1640	1880	2540	1280	1640	2190	1140	1360	1790	967	1150	1490	834	877	1110	660	615	765	482	415	513	336	214	256	182
05BL022	Cataract Creek near Forestry Road	166	166	N	EV2	1280	2770	128	1070	2280	122	834	1730	114	670	1350	106	475	934	96.6	309	581	83.6	259	478	78.5	201	363	71.7	161	284	65.2	113	193	55.9	72.4	117	45.4	45.4	67.9	33.9	22.2	29.2	18.4
05BL023	Pekisko Creek near Longview	232	232	N	3P(MLH)	680	1770	284	608	1540	262	522	1260	233	449	1040	207	350	764	172	254	511	134	221	428	119	180	332	100	148	262	85.5	106	176	63.9	66.9	102	43.7	38.4	55.5	26.7	13.7	19.9	9.65
05BL007	Stimson Creek near Pekisko	236	236	N	3P(MLH)	456	943	227	413	835	209	360	708	188	314	600	169	252	458	141	189	322	112	167	277	102	138	221	86.9	116	179	74.9	86.2	127	58.8	56.6	77.5	40.9	34	44	25.9	12.7	16.6	9.58
05BL027	Trapp Creek near Longview	137	137	N	3P(MLH)	819	2020	82.4	719	1740	79.5	602	1410	75.4	505	1150	71.6	379	822	65.5	261	532	57.9	222	438	55.1	175	331	50.3	139	257	46.6	95.8	178	40.7	56.9	119	31.2	31	72.7	20.2	11.3	18.3	7.99

1. Series Type: N: Natural Flows (recorded data); NZ: Naturalized Flows
2. Historical Adjustment Ratio Applied: Instantaneous flood flows and confidence bounds including historical floods were derived based on scaling results for Bow River at Calgary with and without historic floods (by applying a percentage multiplier to each return period)
3. Prorated: Instantaneous flood flows and confidence bounds were estimated by applying ratio between effective drainage areas at Node 344 and WSC station 05BL012 using an exponent of 1.
4. Prorated: Instantaneous flood flows and confidence bounds were estimated by applying ratio between effective drainage areas at Node 172 and WSC station 05BL024 using an exponent of 1.
5. Historical Adjustment Ratio Applied: Instantaneous flood flows and confidence bounds including historical floods were derived based on scaling result for Highwood River below Little Bow with and without historic floods (by applying a percentage multiplier to each return period)
6. Instantaneous flood flows were generated based on an examination of the concurrent data records
7. Prorated: Instantaneous flood flows were estimated by applying ratio between effective drainage areas at the node in interest and node upstream or downstream of the node in interest using an exponent of 1

The flood frequency statistics at the ungauged locations were estimated as follows.

- Drainage areas at WSC stations were obtained from WSC hydrometric data. Drainage areas at ungauged locations were estimated from the known drainage areas at upstream or downstream WSC stations by adding or subtracting, respectively, the estimated local areas between the WSC stations and locations of interest.
- The naturalized flood frequency estimates for the Bow River downstream of Spray River were estimated as follows:
  - Prior to 1951, WSC Station 05BC001 recorded natural flow (1910 to 1951).
  - Naturalized flows for Spray River at Banff were derived from 1951 to 2015 as described in Section 3.1.2.
  - Natural/Naturalized flows time series for Bow River downstream of Spray River were then derived by using recorded flows for Bow River at Banff (WSC Station 05BB001) and natural/naturalized flows from Spray River.
  - Return period flood estimates were then obtained from a frequency analysis of natural/naturalized maximum annual instantaneous flows at Bow River downstream of Spray River.
- The naturalized flood frequency estimates for the Bow River below Cascade confluence were estimated as follows:
  - Naturalized flows for Cascade River near Banff were derived from 1917 to 2015 as described in Section 3.1.2.
  - Natural/Naturalized flows time series for Bow River below Cascade confluence were then derived by using routed flows for Bow River downstream of Spray River and natural/naturalized flows from Cascade River near Banff.
  - Return period flood estimates were then obtained from a frequency analysis of natural/naturalized maximum annual instantaneous flows at Bow River below Cascade confluence.
- The naturalization flow series at ungauged locations along the Bow River are the routed flow series from upstream locations without accounting for the contributing runoff from the additional drainage areas between the upstream and ungauged locations. Hence, maximum annual peak flow series that can be extracted from the naturalized daily flow series at ungagged locations will not represent expected peak flow at that location since did not include contribution from tributary watersheds. To account for the local runoff contributions along the Bow River, the following methods were used to estimate the peak flows at the ungauged locations:
  - The return period flood estimates for the Bow River at Canmore were derived using the estimated values for the Bow River below Cascade River based on the ratio of the total drainage areas of the two locations. Given a small difference in drainage area contributing additional flow between Bow River below Cascade River and Bow River at Canmore (i.e., less than 4%) an exponent of 1.0 for the ratio of the drainage area is a reasonable assumption (Haan et al 1994).
  - The return period flood estimates for the Bow River above Kananaskis River were derived based on interpolation of the flood estimated for the Bow River at Canmore and the Bow River below Kananaskis River using the drainage area contributing flows at each locations.

- The return period flood estimates for the Bow River upstream of Ghost Reservoir were derived using the values for the Bow River near Seebe based on the ratio of the total drainage areas of the two locations. Given a small difference in drainage area contributing additional flow between the two locations (i.e., less than 6%) an exponent of 1.0 for the drainage area ratio is a reasonable assumption (Haan et al 1994).
- The return period flood estimates for the Bow River at Cochrane were derived based on interpolation of the flood estimated for the Bow River below Ghost Reservoir and the Bow River above Bearspaw using the drainage area contributing flows at each locations.
- The return period flood estimates for multiple locations on the Bow River below Carseland Dam (i.e., Bow River at Highways 547, 842, 539, 36 and 875) were derived by interpolation of the flood flows estimated at the three gauging stations along the river (i.e., Bow River below Carseland Dam (05BM002), Bow River below Bassano Dam (05BM004), and Bow River near the Mouth (05BN012)) using the ration of drainage area contributing flows at each locations. This approach is basically a linear transfer of return period flood estimates at WSC Stations 05BM002, 05BM004 and 05BN012 to locations on the Bow River that are in between two adjacent stations. The approach, that essentially constrains the flood estimates at a location to a value between those at the upper and lower WSC stations, is considered reasonable as the relationship between effective runoff contributing areas and flood flows at locations in the lower reaches of the Bow River becomes complex.
- The return period flood estimates for the Bow River at the mouth were assumed to be the same as return period flood estimates for the Bow River near the Mouth (i.e., at WSC Station 05BN012) given there is less than 1% increase in drainage between the two locations.

4.2.2 Major Bow River Tributaries

Frequency analyses of the annual maximum instantaneous flow series for the major tributaries of the Bow River were performed in previous studies (Golder 2010, 2014a, 2014b). Similar approaches as previous studies were used to update the return period flood estimates for these tributaries in this study. The flood frequency estimates for tributaries between Bow River below Elbow River and Bow River above Highwood River were then used to conservatively estimate flood flows along the Bow River below the tributary confluences assuming coincident occurrence of flood peak flows. The analyses and results for all major Bow River tributaries are described below.

Forty Mile Creek

The period of record for Forty Mile Creek near Banff (WSC Station 05BB003), with a drainage area of 133 km^2, is relatively short. The available data are for the periods from 1912 to 1919, 1945 to 1948 and 1972 to 1977. The data sample size is not sufficient for reliable flood frequency estimates. Therefore, the flood frequency estimates for Forty Mile Creek near Banff were made using the following method:

1) The relationship between the annual maximum daily and instantaneous flow peaks for Forty Mile Creek near Banff was established based on six years of data recorded for the period 1972 to 1977.
2) The recorded annual maximum daily flow series for the three year period (1975 to 1977) for Forty Mile Creek near Banff and Redearth Creek near the Mouth (WSC Station 05BB005, drainage area of 147 km^2) show that the flood events at the two locations occurred on the same days.

3) The regression relationship established between the recorded maximum daily flow series for Redearth Creek near the Mouth and Bow River at Banff (WSC Station 05BB001) for the concurrent period 1974 to 1996, shows relatively good correlation (R^2 of 75.1% as shown in Appendix A, Fig. A-14). This relationship was used to extend the annual maximum daily flow series for Redearth Creek near the Mouth for the period 1909 to 1973 and 1997 to 2015.

4) The annual maximum daily flow series for Redearth Creek near the Mouth derived in Step 3) was used to develop the annual maximum daily flood series for Forty Mile Creek near Banff based on the ratio of drainage areas.

5) The annual maximum instantaneous flow series for Forty Mile Creek near Banff were derived using the annual maximum daily flow series from Step 4) and the relationship established in Step 1). This flow series was then used to develop the flood frequency estimates for Forty Mile Creek near Banff (see Table 4.1).

Ghost River and Waiparous Creek

Ghost River near Cochrane has a drainage area of 911 km^2. Most of the Ghost River flow comes from the high mountains and meadows. The gradual snowmelt maintains high river flow well into the summer. Groundwater springs feed the river flow in the winter. Flow records for the Ghost River are available at the following two stations:

- Ghost River above Waiparous Creek (WSC Station 05BG010) with a drainage area of 485 km^2 for the period 1983 to 2012; and
- Ghost River near Cochrane (WSC Station 05BG001) with a drainage area of 911 km^2 for the period 1911 to 1983, with data missing from 1920 to 1928.

Flood flows in the Ghost River are affected by the Ghost River diversion that has been in operation since 1941. Diversion flow data are available from WSC Station 05BG003 (Ghost River Diversion to Lake Minnewanka) for the period 1941 to 1994. The annual maximum instantaneous "naturalized" flow series for the Ghost River near the mouth were generated for the period 1929 to 2015 as follows (see Table 4.2 for a summary):

- For the period 1929 to 1940, the annual maximum instantaneous flows for the Ghost River near the mouth were assumed to be the same as those recorded at WSC Station 05BG001.
- For the period from 1941 to 1982, the annual maximum instantaneous flows for the Ghost River near the mouth were estimated by adding the diversion flows recorded at WSC Station 05BG003 to the flood flow series recorded at WSC Station 05BG001.
- For the period from 1983 to 1994, the annual maximum instantaneous flows for the Ghost River near the mouth were derived using a systematic combination of the flood flow data recorded at the Ghost River above Waiparous Creek (WSC Station 05BG010) and the flood flow data recorded at Waiparous Creek near the Mouth (WSC Station 05BG006). In addition, the diversion flows recorded at WSC Station 05BG0003 were added to generate the naturalized flood flow series (see Table 4.2 for description of the methodology).
- For the period 1995 to 2015, the same method was used as for the period 1983 to 1994, with the exception that Ghost River Diversion data were not available after 1994. A diversion flow of 8 m^3/s was assumed to generate the naturalized flows, because 90% of the recorded diversion flows over the period of 12 years (i.e., 1983 to 1994) were less than 8 m^3/s (see Figure A-21). A sensitivity analysis was conducted to assess if the assumed diversion flow will have any significant effect on the estimated flood frequency by considering a diversion flow of 30 m^3/s.

- The flood peak flow for the June 2013 event was estimated to be about 670 m^3/s for the Ghost River near the mouth. The estimate was based on the available high water marks using a hydraulic model. See TransAlta's flood assessment for the Hamlet of Benchlands (Golder 2013).

The flood frequency estimates for the Ghost River above Waiparous Creek (WSC Station 05BG010) and Waiparous Creek near the Mouth (WSC Station 05BG006) were made using the flow data series extended back to 1912. The estimation methods for maximum daily flow series are described below:

- For the period 1912 to 1940, the annual maximum daily flow series for both 05BG010 and 05BG006 were derived by applying a direct station transfer approach to the recorded data at the Ghost River near Cochrane.
- For the period 1941 to 1965, the annual maximum daily flow series for 05BG006 was derived using the relationship established (see Figure A-19 in Appendix A) between 05BG006 and the Ghost River near Cochrane based on the recorded data at the two locations for the period 1966 to 1982.
- For the period 1941 to 1982, the annual maximum daily flow series for the Ghost River near Cochrane were recorded, and those for 05BG010were derived by subtracting the generated/recorded flows for 05BG006 from the recorded flows at the Ghost River near Cochrane.

Table 4.2: Derivation of Naturalized Flows for the Ghost River near the Mouth

Time Period	Annual Maximum Instantaneous Flow Estimates	Comment
1929-1940	Recorded flood flows at WSC Station 05BG001.	No diversion to Lake Minnewanka.
1941-1982	Flood flows recorded at WSC Station 05BG001 + Ghost River Diversion flows recorded at WSC Station 05BG003.	Ghost Diversion commenced in 1941.
1983-1994	Based on the flood flows recorded at WSC Station 05BG010 and 05BG006. If the instantaneous flood peaks in the Ghost River and Waiparous Creek occurred on same day, then: • $Qinst_{\text{Ghost above Waiparous}} + Qinst_{\text{Waiparous near Mouth}} + Qdaily_{\text{Ghost Diversion}}$ Otherwise, take the maximum of the following two values: • $Qinst_{\text{Ghost above Waiparous}} + k * Qdaily_{\text{Waiparous near Mouth}} + Qdaily_{\text{Ghost Diversion}}$ • $k*Qdaily_{\text{Ghost above Waiparous}} + Qinst_{\text{Waiparous near Mouth}} + Qdaily_{\text{Ghost Diversion}}$ Where Qinst is the annual maximum instantaneous flow, Qdaily the daily flow on the same day as Qinst, and k a multiplier to convert daily flow to instantaneous flow.	The WSC station Ghost River near Cochrane was decommissioned. New gauges on the Ghost River and Waiparous Creek were subsequently installed. The diversion flows were measured.
1995-2015	Used the same method as that for the period 1983-1994, but the daily Ghost Diversion flow was assumed at an average rate of 8 m^3/s.	The Ghost River diversion gauge was decommissioned in 1994. A sensitivity analysis was performed with an assumed high diversion daily flow rate of 30 m^3/s.
2013	670 m^3/s + assumed flow (8 m^3/s) in the Ghost diversion.	Estimated based on available high water marks

Jumpingpound Creek

Recorded flows for Jumpingpound Creek are available at the following three stations:

- Jumpingpound Creek near Jumping Pound (WSC Station 05BH006, gross drainage area of 455 km^2) for the period 1908 to 1933;
- Jumpingpound Creek at Township Road 252 (WSC Station 05BH015, gross drainage area of 474 km^2) for the period 2006 to 2015; and

- Jumpingpound Creek near the Mouth (WSC Station 05BH009, gross drainage area of 571 km^2) for the period 1965 to 2006.

Because these three stations are located close to each other, the flow data from these stations were combined and adjusted based on the proportions of drainage areas, to generate the long-term flood flow series for the two locations (i.e., Jumpingpound Creek at Township Road 252 and Jumping Pound Creek near the Mouth). The resulting flow series used for the flood frequency analyses are provided in Appendix A. The resulting flood frequency estimates are provided in Table 4.1.

Elbow River

The flood frequency estimates for the Elbow River at Sarcee were obtained based on the combined flow records at the WSC Stations 05BJ001, 05BJ005 and 05BJ010, instantaneous flood peak estimates from the 1983 study report (AENV, 1983), and the extended flow data derived using the flow relationship established for the Elbow River at Sarcee location.

The flood frequency estimates for the Elbow River at Bragg Creek were obtained based on the recorded flow data at WSC Station 05BJ004 and the extended flow data derived using the correlation relationship established between this location and the combined flow records at the WSC Stations 05BJ001, 05BJ005 and 05BJ010.

The flood frequency estimates for the Elbow River below Glenmore Reservoir were obtained based on the naturalized flow data for the WSC Station 05BJ001 and the extended flow data derived using the correlation relationship between this location and the Sarcee location.

Nose Creek at Calgary

The available flow records for Nose Creek at Calgary (WSC Station 05BH003, gross drainage area of 893 km^2 and effective drainage area of 746 km^2) were for the periods 1911 to 1919 and 1973 to 1986. This station was discontinued after 1986. Flow records are available for Nose Creek near the Mouth (WSC Station 05BH901, gross drainage area of 986 km^2) for the period 1980 to 1989.

The annual maximum instantaneous flows recorded at the two locations for the concurrent period (1980 to 1986) are inconsistent. For example, the annual maximum instantaneous flow recorded at WSC Station 05BH003 on September 26, 1986 was 8.4 m^3/s, while the annual maximum instantaneous flow recorded at Station 05BH901 on September 25, 1986 was 24.6 m^3/s.

The recorded daily flood flow series at WSC Station 05BH901 for 1984, 1987, 1988 and 1989 were used to fill the data gaps and to extend the recorded flow data for Nose Creek at Calgary. The annual maximum instantaneous flows used for the flood frequency analysis are provided in Appendix A. A relationship between annual maximum daily and instantaneous flow series was established and shown in Figure A-28 in Appendix A.

An attempt was made to establish a regional relationship between Nose Creek and other streams (Fish, Jumpingpound, and Threepoint Creeks) to extend the flood flow series. However, coincident floods in Nose Creek and other regional creeks occurred only for two or three years over a recording period of more than 20 years. Therefore, it was not possible to establish a meaningful regional relationship to extend the flood flow series for Nose Creek. In addition, the Nose Creek watershed has a much larger proportion of non-contributing drainage areas compared to the other regional watersheds.

The flood frequency estimates for Nose Creek at Calgary are provided in Table 4.1. It is recognized that these estimates are different than previous estimates, including those prepared in 2010 and 2014 (Golder 2010, 2014). It is also recognized that the limited data record results in significant uncertainty in any flood frequency estimates, and that flood flows in some years may be impacted by local point inflows, including from stormwater management systems. Variation in frequency estimates undertaken at different times and using different lengths of record are expected, and different analysis techniques can result in different estimates even when the same data is assessed. However, Golder considers the current estimates to reflect the best available data at this time, and to be generally consistent with previous estimates when confidence limits of the statistical analysis are considered.

Fish Creek at the Mouth

The flow records for Fish Creek at the mouth (represented by WSC Station 05BK003, officially named Fish Creek at Bow Bottom Trail) are available only for the period 1989 to 1993. The flood flow series for Fish Creek at the mouth were derived using the flow data recorded at Fish Creek near Priddis (WSC Station 05BK001) and Threepoint Creek near Millarville (WSC Station 05BL013) using the following procedure:

1) Conduct flood frequency analysis for Fish Creek near Priddis and Threepoint Creek near Millarville using annual maximum daily flows.

2) Establish a relationship between drainage areas and flood estimates generated for various return periods from annual maximum daily flows to generate power factors (provided in Appendix C, Table C.3.3).

3) Transfer the flood flows from Fish Creek near Priddis to Fish Creek at the mouth based on the relationship established (i.e., power factors) in Step 2.

4) Generate instantaneous flood flows for Fish Creek at the mouth using the relationship established between the annual maximum daily and instantaneous flow series for Fish Creek near Priddis.

Threepoint Creek near Millarville has a drainage area of 507 km^2. A review of the recorded flow data at this station indicated a high level of similarity to the flow regime at Fish Creek near Priddis (drainage area of 261 km^2). Over a period of 48 years (i.e., 1967 to 2014), the annual maximum daily flows at the two stations occurred on the same dates for 32 years, and for 5 years the maximum daily flows lagged by one day. The similarity between the closely-located Fish and Threepoint Creek watersheds supports the establishment of a relationship that can be used to transfer of the annual maximum daily flow series from Fish Creek near Priddis to Fish Creek at the mouth.

A relationship between annual maximum daily discharges and annual maximum instantaneous discharge was established for Fish Creek near Priddis using recorded data but excluding 2005 (Figure A-33 Appendix A). The recorded annual maximum instantaneous flood flow for Fish Creek near Priddis in June 2005 was affected by a breach of the Loon Lake Dam upstream of Priddis. Since there has been no detailed assessment of the impact on flood flows, the flood peak for 2005 was not considered in the relationship established between annual maximum daily discharge and annual maximum instantaneous discharge for Fish Creek near Priddis.

For the flood frequency analysis of annual instantaneous flood series for Fish Creek near Priddis, the recorded June 2005 instantaneous flood was adjusted using the ratio of recorded floods in 2005 and 2013 for Threepoint Creek near Millarville (i.e., the ratio of 2005 to 2013 floods for Threepoint near Millarville was multiplied by the 2013 recorded flood for Fish Creek near Priddis to estimate the peak flood flow for 2005).

Pine Creek at the Mouth

The flow data available for Pine Creek was collected by Golder between 2005 and 2007 as part of a monitoring program for the City of Calgary (Golder 2008).

Flood frequency estimates for several locations along Pine Creek through the Municipal District of Foothills and Calgary were conducted as part of a currently unpublished AEP flood hazard mapping study (AMEC 2013). AMEC provided two sets of flood frequency estimates, one based on the HSPF hydrologic model and the other based on a regression analysis of flood flows recorded on regional streams. In consideration of the uncertainties associated with estimating flood discharges in Pine Creek, AMEC recommended and used the more conservative estimates based on the HSPF modelling for the Pine and Radio Tower Creek flood hazard study.

In this current study, flood frequency estimates for Pine Creek were made based on a regional analysis only. Table 4.3 provides a comparison of the flood frequency estimates. The flood frequency estimates produced by Golder for this current study generally have higher magnitudes than those produced by AMEC for return period greater 50-years. This variation in frequency estimates was expected given the substantially different analysis techniques used by Golder and AMEC.

Table 4.3: Comparison of Flood Frequency Estimates for Pine Creek

Return Period [years]	Regional Analysis (Current Study) [m^3/s]	HSPF Hydrologic Model (AMEC 2013) [m^3/s]
2	3.30	3.90
5	10.5	12.9
10	17.7	19.8
20	26.5	27.3
50	40.1	38.1
100	51.9	47.0
200	65.0	56.7
500	84.2	70.8
1,000	99.7	82.4

m^3/s = cubic metres per second.

Highwood River and its Tributaries

Flood Frequency estimates for various locations along the Highwood River and its tributaries were obtained based on the recorded flood flow series. For locations where there is no upstream flow regulation and the natural flow was recorded (i.e., Cataract, Pekisko, Stimson, and Trap Creeks), the flood frequency estimates were based on the annual maximum instantaneous flow series (see Section 3.3 and Appendix A). The flood flow series for the lower reach of the Highwood River were extended using the following procedure:

1) Established the relationships among the recorded annual maximum daily flow series and annual maximum Instantaneous flow series for Highwood River below the Little Bow Canal (WSC Station 05BL004) and Highwood River near the Mouth (WSC Station 05BL024).
2) The annual maximum daily flow series for Highwood River below the Little Bow Canal was extended by 70 years (i.e. the period 1916 to 1985) by using the recorded annual maximum daily flow series for Highwood River near Aldersyde (WSC Station 05BL009). The extended annual maximum instantaneous flow series were then generated using the relationship established in step 1).

3) Based on the relationship between Highwood River near Aldersyde and Highwood River near the Mouth, the flood flow series for Highwood River near the Mouth was extended by 53 years (i.e., for the period 1916 to 1969).

4) Based on the relationship between Highwood River below the Little Bow Canal and Highwood River near the Mouth, the flood flow series for Highwood River near the Mouth was extended by seven years (i.e., for the period 1909 to 1915).

5) The 1932 historical flood estimated for Highwood River near Aldersyde based on high-water marks (NHC 1974) was also used to estimate 1932 flood data for Highwood River below the Little Bow Canal and Highwood River near the Mouth.

The naturalized flood flow series for the Highwood River below the two diversions were derived by accounting for the diversion flows at Highwood Diversion Canal near Headgates (WSC Station 05BL025) and Little Bow Canal at High River (WSC Station 05BL015).

The flood frequency estimates for Highwood River at the Mouth were obtained by adjusting the estimates for WSC Station 05BL024 (i.e., Highwood River near the Mouth) to account for the larger drainage area at the mouth.

For Highwood River below Little Bow Canal, the June 2013 instantaneous flood flow is estimated to be 1,100 m^3/s. This is based on the preliminary WSC estimate at Hogg Park of 1,770 m^3/s and the predicted overflow calculated by preliminary hydraulic modelling completed to support the Highwood River Hazard Study.

The flood frequency estimates for the Highwood River and its tributaries are provided in Table 4.1.

Sheep River and Threepoint Creek

The flood frequency estimates for various locations along Sheep River and Threepoint Creek were based on the recorded data. Since there is no upstream flow regulation and natural flow was recorded, the flood frequency estimates were based on the annual maximum instantaneous flow series (see Section 3.3 and Appendix A). The flood flow series for Sheep River at Okotoks (WSC Station 05BL012) were extended based on the relationship that was established using the recorded annual maximum daily flow series for Sheep River at Black Diamond (WSC Station 05BL014).

The flood frequency estimates for Sheep River at the Mouth were made based on the flood frequency estimates for Sheep River at Okotoks and the ratio of the drainage areas.

The flood flow series for Threepoint Creek at the mouth were derived using the flood estimates for Threepoint Creek near Millarville using the following procedure:

- Conduct flood frequency analysis for Threepoint Creek near Millarville using recorded annual maximum daily flows.
- Transfer the flood flows from Threepoint Creek near Millarville to Threepoint Creek at the mouth based on the power factors provided in Appendix C, Table C.3.3.
- Generate instantaneous flood flows for Threepoint Creek at the mouth using the relationship established between the annual maximum daily and instantaneous flow series for Threepoint Creek near Millarville.

The flood frequency estimates for the Sheep River and its tributaries are provided in Table 4.1.

4.2.3 Ungauged Tributaries

The flood frequency estimates for ungauged tributaries contributing to the Bow, Elbow, and Sheep Rivers were made based on a regional flood frequency analysis. Table 4.4 provides the names, station numbers, drainage areas and relative locations (mountain or foothills) of WSC stations used for regional analysis.

Table 4.4: WSC Stations Used for Regional Analysis

WSC Station Name or Location of Interest	WSC Station ID	Latitude	Longitude	Gross Drainage Area [km^2]
Mountain Region				
Cataract Creek near Forestry Road	05BL022	50° 17' 07"	-114° 35' 19"	165.5
Waiparous Creek near the Mouth	05BG006	51° 16' 58"	-114° 50' 18"	333
Trapp Creek near Longview	05BL027	50° 28' 38"	-114° 25' 35"	137
Highwood River at Diebel's Ranch	05BL019	50° 24' 18"	-114° 30' 03"	774
Elbow River at Bragg Creek	05BJ004	50° 56' 56"	-114° 34' 15"	791
Fish Creek near Priddis	05BK001	50° 53' 08"	-114° 19' 37"	261
Pekisko Creek near Longview	05BL023	50° 28' 27"	-114° 12' 26"	232
Threepoint Creek near Millarville	05BL013	50° 46' 16"	-114° 16' 44"	507
Jumpingpound Creek near the mouth	05BH009	51° 09' 16"	-114° 31' 42"	571
Elbow River at Sarcee Bridge combined with Inflow to Glenmore	05BJ010	50° 59' 41"	-114° 09' 53"	1,189
Sheep River at Black Diamond	05BL014	50° 59' 41"	-114° 09' 53"	592
Stimson Creek near Pekisko	05BL007	50° 25' 48"	-114° 10' 01"	236
Elbow River above Elbow Falls	05BJ006	50° 51' 20"	-114° 47' 37"	437
Sheep River at Okotoks	05BL012	50° 43' 26"	-113° 58' 25"	1,494
Sheep River at Buck Ranch	05BL018	50° 37' 20"	-114° 25' 40"	454
Highwood River below Picklejar Creek	05BL021	50° 29' 55"	-114° 49' 02"	132
Willow Creek above Chain Lakes	05AB028	50° 11' 47"	-114° 12' 46"	162
Foothills Region				
West Arrowwood Creek near Arrowwood	05BM014	50° 45' 51"	-113° 14' 11"	777
Rosebude River below Carstairs Creek	05CE006	51° 24' 57"	-113° 43' 40"	753
Trout Creek near Granum	05AB005	49° 58' 39"	-113° 41' 10"	441
Meadow Creek near the mouth	05AB029	49° 57' 15"	-113° 39' 49"	130
Prairie Blood Coulee near Lethbridge	05AD035	49° 57' 15"	-113° 39' 49"	224
Ray Creek near Innisfail	05CE010	52° 00' 04"	-113° 35' 59"	44

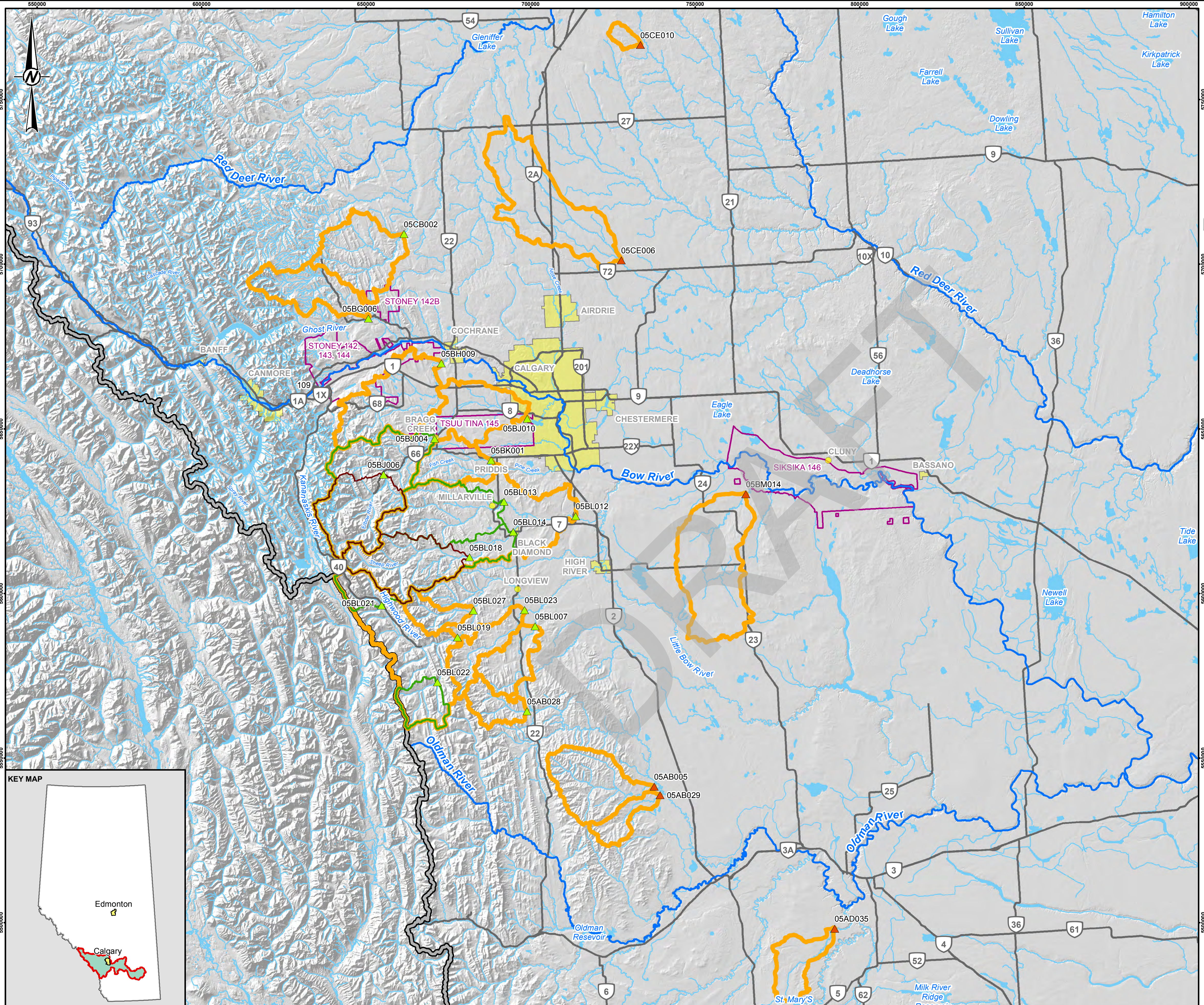
km^2 = square kilometre.

Empirical relationships between drainage area and flood frequency estimates were established for return periods ranging from the 2-year to the 1,000-year flood. The relationships were then used to derive flood frequency estimates for ungauged tributaries.

The flood frequency estimates for the ungauged tributaries were obtained as follows:

- Drainage areas at WSC stations were provided by WSC. Gross drainage areas at ungauged tributary locations were estimated through GIS analysis (see Figure 4.1).
- Flood frequency estimates for the WSC stations (see Appendix C.3) were made based on the natural annual maximum instantaneous flow series.
- Regional relationships between drainage area and peak discharge for a range of return periods (2-year to 1,000-year flood) were developed for two regions - mountains and foothills, as shown in Figures 4.2 and 4.3.
- The resulting regional relationships were then used to estimate the flood peak discharges at the select ungauged locations for the various return periods, as summarized below:
  - The flood frequency estimates for Forty Mile Creek at the Mouth were obtained based on flood frequency estimates for Forty Mile Creek near Banff and the drainage area power factor established for mountain region.
  - The flood frequency estimates for Cougar Creek at the Mouth, Policeman's Creek at Canmore, Stoneworks Creek at Highway 1, Exshaw Creek at Exshaw, Bragg Creek at the Mouth, Threepoint Creek above Ware Creek, and Ware Creek at the Mouth were obtained based on the regional relationships established using data from gauged watersheds within the mountain region.
  - The flood frequency estimates for Bighill Creek at Cochrane, Pine Creek at the Mouth, and Lott Creek at the Mouth were obtained based on the regional relationships established using data from gauged watersheds within the foothills region.
  - The flood frequency estimates for Jumpingpound Creek at Township Road No. 252 and Jumpingpound Creek at the Mouth were obtained based on flood frequency estimates for Jumpingpound Creek near the Mouth and the drainage area power factor established for the foothills region.
  - The flood frequency estimates for West Nose Creek at WSC Station, West Nose Creek at the Mouth, Nose Creek near the Mouth, and Nose Creek above Airdrie were obtained based on flood frequency estimates for Nose Creek at Calgary and the drainage area power factor established for the foothills region.
- The resulting flood frequency estimates at the ungauged locations are provided in Table 4.5.

The alternative method reflects more realistic regulated flood flows downstream of Glenmore Reservoir since it considers the physical limitation of the reservoir to attenuate flood flows. The routing of the flows through the reservoir was completed based on flood operating procedure prior to completion of the upgraded gates.



LEGEND

WATER SURVEY OF CANADA STATIONS

- STATION IN MOUNTAIN REGION
- STATION IN FOOTHILL REGION

WATERSHED SCALES

- DELINEATED SUB-WATERSHED[5]
- DELINEATED SUB-BASIN[5]
- DELINEATED BASIN[5]
- MAJOR RIVER
- WATERCOURSE
- PRIMARY HIGHWAY
- FIRST NATION LAND
- POPULATED PLACE
- PROVINCIAL BOUNDARY
- WATERBODY

0 25 50

1:1,175,000 KILOMETRES

REFERENCE(S)

1. HYDROMETRIC STATIONS, BASIN DATA OBTAINED FROM AGRICULTURE AND AGRI-FOOD CANADA (AAFC).
2. HILLSHADE AND HIGHWAYS OBTAINED FROM GEOGRATIS, © DEPARTMENT OF NATURAL RESOURCES CANADA. ALL RIGHTS RESERVED.
3. HYDROLOGY AND PROVINCIAL BOUNDARY OBTAINED FROM IHS ENERGY INC.
4.POPULATED PLACES AND INDIAN RESERVES OBTAINED FROM ALTALIS © GOVERNMENT OF ALBERTA 2015. ALL RIGHTS RESERVED.
5.SUB-BASINS WERE DELINEATED BASED ON 10 m OR 20 m INTERVAL CONTOURS GENERATED FROM SHUTTLE RADAR TOPOGRAPHY MISSION (SRTM).

DATUM: NAD83 PROJECTION: UTM ZONE 11

CLIENT

ALBERTA ENVIRONMENT AND PARKS

PROJECT

HYDROLOGY ASSESSMENT - BOW, ELBOW, HIGHWOOD AND SHEEP RIVER

TITLE

LOCATION OF THE WATER SURVEY OF CANADA STATIONS USED FOR REGIONAL ANALYSIS

CONSULTANT

Golder Associates

YYYY-MM-DD	2017-02-07
DESIGNED	NG
PREPARED	SK
REVIEWED	GB
APPROVED	GB

PROJECT NO. 1532956 REV. 1 FIGURE **4.1**

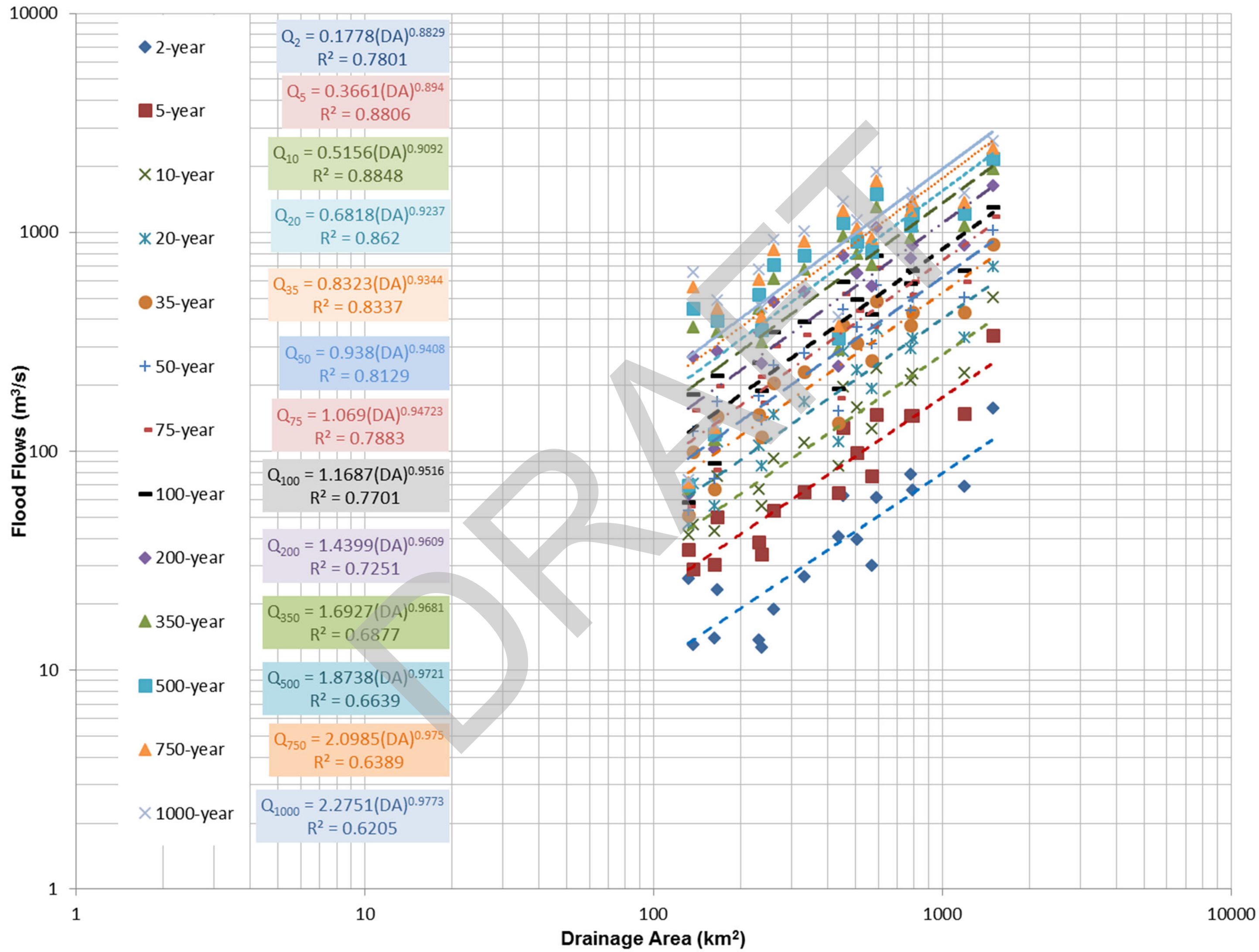


Figure 4.2: Empirical Relationships – Mountains Region in the Bow River Basin

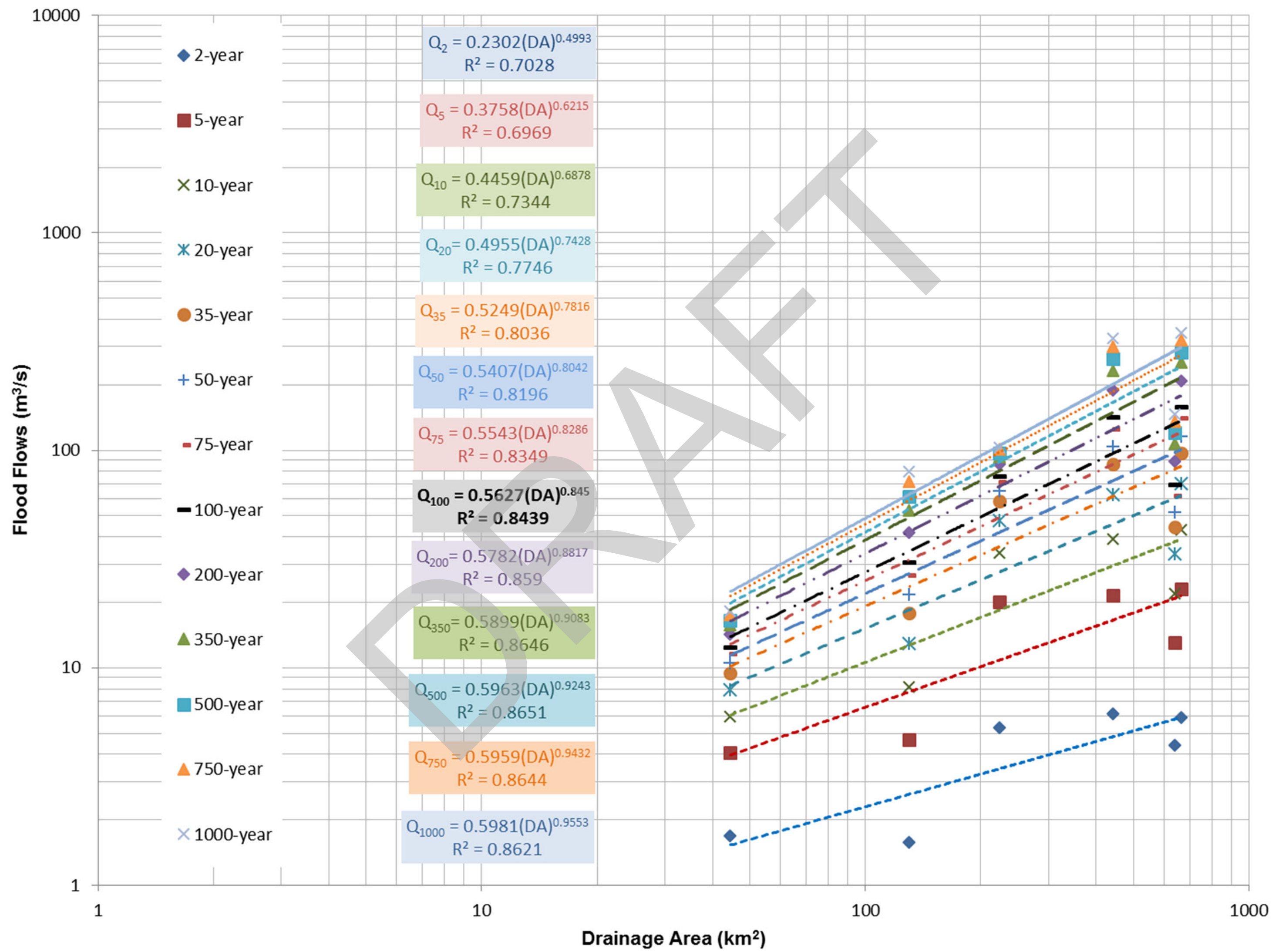


Figure 4.3: Empirical Relationships – Foothills Region in the Bow River Basin

Table 4.5: Results of Regional Flood Frequency and Single Station Transfer Analysis

WSC Station Name / Location of Interest	Regional Analysis (RA) / Single Station Transfer (SST) Approach[1]	Latitude	Longitude	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Computed Instantaneous Flood Flows (m³/s)[1]												
						1000-year	750-year	500-year	350-year	200-year	100-year	75-year	50-year	35-year	20-year	10-year	5-year	2-year
Forty Mile Creek near Banff[2]	SST using Redearth Creek near the Mouth	51° 12' 25"	-115° 35' 06"	133	133	57.3	55.9	53.8	51.9	49.0	45.2	43.7	41.4	39.4	36.2	32.1	27.6	20.8
Forty Mile Creek at the Mouth	SST Using Forty Mile Creek near Banff - Mountain Region Power	51° 10' 35"	-115° 35' 15"	148	148	60.2	58.7	56.6	54.7	51.7	47.9	46.3	44.1	42.1	38.8	34.6	30.1	22.9
Cougar Creek at the Mouth	Mountain Region (RA)	51° 04' 45"	-115° 20' 11"	42.6	42.6	89.0	81.4	71.9	64.0	53.0	41.5	37.4	32.0	27.7	21.8	15.6	10.5	4.88
Bragg Creek at the Mouth	Mountain Region (RA)	51° 56' 58"	-114° 34' 23"	49.7	49.7	103.0	94.6	83.5	74.3	61.4	48.1	43.2	37.0	32.0	25.2	18.0	12.0	5.59
Policeman's Creek at Canmore	Mountain Region (RA)	50° 05' 09"	-115° 20' 56"	10.4	10.4	22.4	20.5	18.2	16.3	13.6	10.8	9.8	8.47	7.41	5.92	4.32	2.96	1.40
Stoneworks Creek at Hwy. 1	Mountain Region (RA)	51° 06' 07"	-115° 21' 27"	6.17	6.17	13.5	12.4	11.0	9.9	8.3	6.60	5.99	5.20	4.56	3.66	2.70	1.86	0.886
Exshaw Creek at Exshaw	Mountain Region (RA)	51° 03' 30"	-115° 09' 39"	32.3	32.3	67.9	62.1	54.9	48.9	40.6	31.9	28.7	24.7	21.4	16.9	12.1	8.18	3.82
Jumpingpound Creek Near the Mouth	Recorded	51° 09' 16"	-114° 31' 42"	571	571	1035	936	815	711	568	425	374	310	260	193	127	76.8	30.0
Jumpingpound Creek at Township Road No.252	SST using Jumpingpound Creek near the Mouth - Foothills Region Power	51° 07' 41.9"	-114° 34' 03"	474	474	866	785	686	600	482	363	321	267	225	168	112	68.4	27.3
Jumpingpound Creek at the Mouth	SST using Jumpingpound Creek near the Mouth - Foothills Region Power	51° 11' 19"	-114° 30' 05"	601	601	1087	982	855	744	594	444	390	323	270	200	132	79.3	30.8
Bighill Creek at the Mouth	Regional Analysis using Foothills Relationship	51° 10' 53"	-114° 28' 50"	177	99	48.4	45.6	41.8	38.4	33.3	27.4	25.0	21.8	19.1	15.1	10.5	6.55	2.29
West Nose Creek at WSC Station	SST using Nose Creek at Calgary - Foothills Region Power	51° 07' 49"	-114° 02' 54"	275	163	81.4	72.2	61.0	52.5	41.6	31.3	27.6	23.2	20.0	15.6	11.3	7.97	4.17
West Nose Creek at the Mouth	SST using Nose Creek at Calgary - Foothills Region Power	51° 07' 49"	-114° 02' 54"	324	212	104.5	92.4	77.7	66.6	52.4	39.0	34.3	28.7	24.5	19.0	13.6	9.37	4.76
Nose Creek above Airdrie	SST using Nose Creek at Calgary - Foothills Region Power	51° 18' 46"	-114° 01' 37"	247	178	88.4	78.3	66.2	56.8	44.9	33.6	29.7	24.9	21.4	16.6	12.0	8.41	4.36
Nose Creek at Calgary	Recorded	51° 07' 20"	-114° 02' 52"	893	746	348	303	249	209	159	113	97.3	79.0	65.5	48.3	32.3	20.5	8.92
Nose Creek at the Mouth	SST using Nose Creek at Calgary - Foothills Region Power	51° 03' 00"	-114° 01' 00"	986	878	407	353	289	242	184	130	111	90.1	74.4	54.5	36.1	22.7	9.68
Fish Creek at the Mouth	SST based on Threepoint Creek near Millarville and Fish Creek near Priddis	50° 54' 15"	-114° 00' 38"	440	440	1041	943	823	719	577	434	383	318	267	199	132	80.4	31.7
Pine Creek at the Mouth	Foothills Region (RA)	50° 50' 30"	-113° 57' 11"	217	212	99.7	93.1	84.2	76.4	65.0	51.9	46.9	40.1	34.5	26.5	17.7	10.5	3.34
Lott Creek at the Mouth	Foothills Region (RA)	51° 00' 17"	-144° 13' 21"	114	114	55.2	52.0	47.5	43.6	37.7	30.8	28.1	24.4	21.3	16.7	11.6	7.14	2.45
Ware Creek at the Mouth	Mountain Region (RA)	50° 42' 54"	-114° 27' 36"	129	129	263	240	211	187	154	119	107	90.7	78.0	60.7	42.8	28.2	13.0
Threepoint Creek above Ware Creek	Mountain Region (RA)	50° 42' 56"	-114° 27' 34"	136	136	276	252	222	196	161	125	112	95.2	81.8	63.6	44.8	29.5	13.6
Threepoint Creek near Millarville	Recorded	50° 46' 15"	-114° 16' 44"	507	507	1140	1040	914	803	650	495	439	368	312	235	156	96.2	39.8
Threepoint Creek at the Mouth	SST using Threepoint Creek near Millarville - Mountain Region Power	50° 41' 07"	-114° 11' 59"	638	638	1430	1300	1140	1000	810	616	545	457	387	290	192	118	48.7

1. Where the "Regional Analysis Approach" listed as Mountain and Foothills, instantaneous flood flows were derived using regression formulae presented in the Mountains and Foothills figures
2. Instantaneous flood flows were estimated by applying ratio between effective drainage areas at Redearth Creek and Forty Mile Creek

4.3 Consideration of Historic Flood Information

Bow and Elbow Rivers

In hydrologic assessment terms, historic floods are defined as documented floods which occurred prior to the start of systematic flow monitoring. Historic floods along the Bow River at Calgary are documented to have occurred in 1879, 1897, and 1902. Newspaper reports and local residents indicated that the 1879 flood that was observed on the Bow River was as severe as the flood of 1897. These historic floods have been considered in several previous assessments and studies (including: AENV 1983; Golder 2010; Golder 2014a) and are also being considered in the current study. Including this documented historic flood information improves flood frequency analysis results for the Bow River at Calgary, and the knowledge gained on the impact of the historic flooding can be applied for other locations along the Bow and Elbow Rivers, as detailed below.

The historic flood peak discharges for the Bow River at Calgary, upstream of the Elbow River, have been estimated as 2,265 m^3/s for both 1879 and 1897, and 1,557 m^3/s for 1902 (AENV 1983). The largest flood after commencement of systematic monitoring in 1911 occurred in June 2013. WSC estimated the 2013 flood peak discharge for the Bow River at Calgary to be 1,840 m^3/s.

Precipitation and air temperature data recorded at three Environment Canada climate stations (i.e., Calgary Airport, Banff, and Kneehill) were examined to assess the validity that the historic floods on the Bow River which occurred in 1897 and 1902 are associated with significant amounts of precipitation in the basin. Plots of the precipitation and air temperature data recorded in 1897 and 1902 are provided in Appendix C.5. The 1897 flood was documented to have occurred on June 18, 1897, and the 1902 flood on July 4, 1902.

The recorded precipitation data are examined as follows:

- The annual total precipitation recorded in 1902 is the highest amount (more than 870 mm at Calgary and more than 770 mm at Banff) on record since 1885.
- The total precipitation over a period of three months (May to July) in 1902 (approximately 580 mm at Calgary, approximately 400 mm at Banff, and approximately 360 mm at Kneehill) is much higher than the 1897 precipitation over the same three month period.
- Large amounts of precipitation (approximately 100 mm) were recorded at the Calgary Airport and Kneehill stations for the four-day period June 14 to 18, 1897, when the historic flood occurred. The total precipitation at the Banff station over the same period was 63 mm.
- During the 1902 flood event, a large amount of precipitation was recorded at the Calgary Airport, while the precipitation recorded at Banff and Kneehill was not as high as Calgary. This indicates that there was noticeable areal variation in precipitation in the upper watershed of the Bow River.
- The 1897 and 1902 floods were likely caused mainly by large rainfalls, because the recorded air temperatures at all stations were higher than the freezing point for more than one month in 1879 and for more than two months in 1902 before the floods.

Analyses of the historic precipitation and air temperature data indicate that the magnitudes of the historic floods observed in Calgary were influenced by the areal distribution and magnitude of precipitation in the upstream watershed. There is some uncertainty with the estimated magnitudes of the historic floods, but it is clear that the

1897 and 1902 floods were caused by large rainfall events (over the majority of the upstream watershed in 1897 and mainly over the watershed area downstream of Banff in 1902).

In this and previous Golder studies (Golder 2010, 2014), the historic Bow River floods were included in the assessment along with the systematically recorded flow data for flood frequency analysis through Calgary. Inclusion of historic flood information is thought to increase the reliability of the flood frequency estimates (particularly for low-probability events) by extending the period of record and capturing more extreme flood events. The statistical method used to incorporate the historical information is outlined in the relatively new United States Geological Survey Bulletin 17C (USGS 2015). This methodology improves and replaces that of the previous Bulletin 17B (USGS 1982) methodology, and allows for a more sophisticated and statistically robust inclusion of pre-systematic, historic flood information described by perception thresholds and flow intervals.

To incorporate knowledge of historic floods at Calgary, flood frequency estimates at select location locations along the Bow and Elbow Rivers were calculated using available systematic flow records and adjusted to account for the relative impact of the historic floods. For the Bow River at Calgary, the flood frequency estimates are based on results from the Bulletin 17C methodology directly (see Figure C.1.15 in Appendix C).

Adjustments for the Elbow River were made based on ratios between the flood frequency estimates calculated for the Bow River at Calgary with and without historic flood information (Table 4.6), which were then applied to the previously-calculated, best-fit distribution flood frequency estimates for the Elbow River using recorded data. Historic flood information was considered for natural/naturalized and regulated estimates for (1) the Bow River between Ghost Dam and Bow River below Elbow confluence and (2) the Elbow River below Bragg Creek.

It is reasonable to assume that the historic floods documented for Bow River at Calgary would have also occurred along both the Bow and Elbow Rivers around and through Calgary but not for Bow River upstream of Ghost Dam due to spatial variation of precipitation within the Bow River basin. For example, the June 2013 flood is roughly considered a 5-year flood at Lake Louise but a 25-year flood at Ghost Reservoir. It is also not realistic to assume that the relative impact of the historic floods extends much farther downstream of Calgary, as significant flood attenuation is expected for the lower Bow River and the effects of historical floods on estimated flood frequency are expected to be small.

Table 4.6: Historical Flood Adjustment Ratios Used for Flood Frequency Estimates

Return Period [years]	Adjustment Ratios for the Bow and the Elbow Rivers	Adjustment Ratios for the Highwood River
2	1.01	1.00
5	1.06	1.01
10	1.10	1.02
20	1.15	1.02
35	1.18	1.03
50	1.21	1.03
75	1.23	1.03
100	1.25	1.04
200	1.30	1.04
350	1.34	1.05
500	1.37	1.05
750	1.40	1.06
1,000	1.43	1.06

Highwood River

Anecdotal evidence suggests that High River was flooded by the Highwood River in the 1880s, prior to the construction of the CPR line in 1894 (NHC 1974). However, a reliable flow estimate is not available. The only documentation is that “a resident recounted a story told by her mother about flooding in High River during the 1880s.” NHC noted that “an area extending from the high ridge one mile south of 12th Avenue to two or three miles north of town was covered with water” and “that this early report is the indication of widespread flooding through and to the south of the present High River town site due to overbank flow out of the Highwood River into the Little Bow basin."

Fortunately, the USGS Bulletin 17C methodology allows for inclusion of historic flood events with uncertain flows using observation thresholds and estimated flow intervals over an ungauged period in which a flood has been documented to have occurred.

Based on the rather limited information available about the 1880s flood, it is reasonable to assume that it was more severe than any other flood the resident, her mother, or others had observed at the time of the interview in 1974. If a larger flood had occurred, it is reasonable to assume that it would have been observed and noted. This is not the case and NHC notes that the flood of 1923 “appears to be the first one since the 1880s that placed water within town boundaries,” with an estimated unrecorded peak in excess of approximately 650 m^3/s. Considering the 1923 estimate upstream of High River and the largest flow recorded at Aldersyde until 1974 (708 m^3/s in 1942), it is reasonable to assume that the historical flood was at least approximately 710 m^3/s at Aldersyde.

This estimate is also supported by the fact that the historical flood flow causes flooding south of 12th Avenue. Using preliminary hydraulic modelling, Golder determined that a flow upstream of High River between 400 to 500 m^3/s would have been required to trigger flooding south of 12th Avenue, similar to the 520 m^3/s flow threshold flow needed to cause overflow into the Little Bow River basin by NHC.

Similar to how historic data was considered for the Bow River at Calgary using the Bulletin 17C methodology, frequency analysis was performed using the Highwood River below Little Bow Canal flood peak data series, with and without including the 1880 to 1890 pre-systematic period. Appropriate perception thresholds and flow intervals were assigned for one “flood” year and nine “non-flood” years, using the 710 m^3/s threshold determined above.

Flood frequency estimate ratios (see Figure C.1.72 in Appendix C and Table 4.6) calculated at High River, with and without historic flood and pre-systematic flow monitoring period data, were then used to adjust the previously-calculated, best-fit distribution flood frequency estimates at High River below Little Bow Canal and at the mouth.

4.4 Analysis of the Regulated Flood Flow Series

The regulated daily flow series for the Bow River and its tributaries with flow regulation (i.e., Cascade, Spray, Kananaskis and Elbow Rivers) were generated for the period 1930 to 2015 by routing the naturalized daily flow series through the major storage facilities based on the current reservoir operation rules.

The annual maximum daily regulated flow series were converted to the annual maximum instantaneous regulated flow series using the relationships described in Section 3.3. Table A2 in Appendix A provides a summary of the factors used in the conversion.

Table 4.7 presents the resulting flood frequency estimates and the corresponding upper and lower confidence intervals for the regulated flows. The annual maximum instantaneous regulated flow series used in the flood frequency analyses are provided in Appendix C.

It is important to note that limitations of the base analysis methodology do not support the use of regulated flood frequency estimates for flows higher than experienced in the historical record. While reported, regulated flood frequency estimates above the 100-year flood are not recommended for use for design purposes, as they do not consider the capacity of existing reservoirs and over-estimate the ability of regulation to reduce flood peaks.

An alternative method was used to generate improved regulated flood frequency estimates for the Elbow River below Glenmore Dam. The alternate method routed a series of synthetic flood inflow hydrographs through Glenmore Reservoir. The hydrographs were developed with peaks corresponding to the hydrologically-derived, naturalized 2-year to 1,000-year maximum instantaneous flood flows calculated as part of this study. The shape and characteristics of the hydrographs were determined using a methodology developed by Golder as part of study completed for the City of Calgary (Golder 2016b). It is summarized as follows.

1) Derive the flood volume corresponding to the hydrographs that contain the naturalized annual maximum instantaneous flood series for Elbow River at Sarcee Bridge (assumed the same as Glenmore Reservoir inflow) for the duration of flood events.

2) Establish relationship between flood volumes derived in Step 1 and corresponding naturalized annual maximum instantaneous flood series. For the Elbow River, the flood events in 1915, 1923, 1929, 1932, 1995, 2005, 2008, 2011 and 2013 were considered to establish the relationships (Golder 2016b).

3) Estimate total volumes corresponding to the magnitudes of flood frequency estimates derived for the naturalized 2-year to 1000-year maximum instantaneous flood flows.

4) Identify a typical hourly inflow flood hydrograph that is representative of the response of the catchment based on the historical records. For the Elbow River, the typical shape of the hourly inflow hydrograph was derived by using flood events of 1995, 2005, 2008, and 2011 (Golder 2016b).

5) Establish time from the start of the rise of the flood hydrograph to when flood peak (i.e., time to peak) based on the naturalized annual maximum instantaneous flood series and representative durations of flood events.

6) Derive synthetic inflow flood hydrographs considering the total volumes, magnitudes of flood peaks, time to peak for various return periods, and the typical hourly inflow flood hydrograph shape identified in Step 4.

The resulting inflow and outflow hydrographs are provided in Figures C.3.1 to C.3.13 in Appendix C.

Table 4.7: Flood Frequency Flow Estimates Calculated Using Various Methods - Recorded and Regulated Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type¹	Distribution / Method	1000-yr*		750-yr*		500-yr*		350-yr*		200-yr*		100-yr*		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
BOW RIVER																															
Node 105	Bow River below Spray Confluence	2993	2993	R	EV2	621	951 / 438	601	893 / 432	574	820 / 423	550	764 / 415	513	677 / 401	468	587 / 383	450	551 / 374	425	504 / 361	402	468 / 348	368	414 / 326	326	355 / 296	282	303 / 261	220	235 / 206
Node 107	Bow River below Cascade Confluence	3727	3727	R	3P(MLH)	708	989 / 516	684	942 / 506	652	881 / 492	622	825 / 478	577	740 / 456	524	647 / 428	502	610 / 416	472	562 / 400	446	522 / 384	406	461 / 359	357	392 / 324	308	331 / 285	237	255 / 222
Node 108	Bow River at Canmore	3870	3870	R	*Prorated²*	735	1030 / 536	710	978 / 525	677	915 / 511	646	857 / 496	599	768 / 473	544	672 / 444	521	633 / 432	490	584 / 415	463	542 / 399	422	479 / 373	371	407 / 336	320	344 / 296	246	265 / 231
05BE004 / Node 111	Bow River near Seebe	5170	5170	RR	EV2	1400	2030 / 831	1320	1880 / 812	1220	1690 / 783	1140	1540 / 757	1020	1330 / 717	887	1110 / 664	835	1030 / 641	767	924 / 610	710	840 / 580	626	726 / 532	532	602 / 470	444	494 / 404	330	360 / 308
				R	LP3(MLH)	1020	1750 / 658	984	1640 / 650	937	1490 / 637	897	1370 / 626	836	1210 / 608	762	1040 / 581	732	967 / 571	691	881 / 556	655	809 / 540	599	707 / 512	530	598 / 472	460	501 / 425	358	381 / 335
Node 318	Bow River above Ghost Reservoir	5475	5473	R	LP3(MLH)	991	1710 / 641	958	1600 / 633	912	1450 / 621	873	1340 / 609	814	1180 / 592	742	1010 / 566	713	941 / 556	673	858 / 541	638	788 / 526	583	688 / 498	516	582 / 460	448	487 / 414	348	371 / 326
05BE006 / Node 58	Bow River below Ghost Dam (Ghost Reservoir Outflow)	6550	6550	RR	Weibull	730	826 / 607	718	809 / 599	700	785 / 588	684	764 / 579	658	730 / 561	623	686 / 537	608	669 / 527	586	642 / 512	565	618 / 497	531	579 / 472	483	527 / 436	427	467 / 389	329	363 / 300
				R	LP3(MLH)	1160	2070 / 703	1120	1940 / 693	1060	1770 / 681	1010	1620 / 669	937	1410 / 650	847	1190 / 623	811	1110 / 611	761	1000 / 591	718	914 / 574	652	786 / 543	571	654 / 502	490	539 / 447	373	399 / 349
	Bow River below Ghost Dam (Ghost Reservoir Outflow), historic			R	*Historical adjustment ratio applied to LP3(MLH)³*	1650	*2950 / 1000*	1570	*2720 / 972*	1450	*2430 / 933*	1360	*2180 / 899*	1220	*1840 / 846*	1060	*1490 / 780*	999	*1370 / 753*	917	*1200 / 712*	848	*1080 / 678*	747	*900 / 622*	630	*721 / 554*	521	*573 / 475*	378	*405 / 354*
05BH005 / Node 114	Bow River near Cochrane	7412	7383	R	LP3(MLH)	1230	2240 / 720	1180	2090 / 711	1120	1890 / 698	1070	1730 / 684	983	1500 / 662	885	1260 / 635	845	1180 / 624	791	1050 / 605	744	958 / 588	673	823 / 556	587	677 / 511	500	553 / 455	377	404 / 352
	Bow River near Cochrane, historic			R	*Historical adjustment ratio applied to LP3(MLH)³*	1750	*3190 / 1030*	1650	*2930 / 997*	1530	*2590 / 956*	1440	*2320 / 919*	1280	*1950 / 862*	1110	*1580 / 795*	1040	*1450 / 769*	953	*1260 / 729*	879	*1130 / 694*	771	*943 / 637*	647	*747 / 564*	531	*588 / 484*	382	*410 / 357*
Node 302	Bearspaw Reservoir Inflow	7712	7672	R	LP3(MLH)	1230	2290 / 710	1180	2130 / 701	1110	1910 / 686	1060	1750 / 672	972	1510 / 652	872	1260 / 621	832	1170 / 609	778	1040 / 589	731	943 / 571	659	810 / 542	573	665 / 497	487	539 / 441	367	392 / 342
	Bearspaw Reservoir Inflow, historic			R	*Historical adjustment ratio applied to LP3(MLH)³*	1750	*3260 / 1010*	1650	*2990 / 983*	1520	*2620 / 940*	1420	*2350 / 903*	1270	*1970 / 849*	1090	*1580 / 777*	1030	*1440 / 750*	937	*1250 / 710*	863	*1110 / 674*	755	*928 / 621*	632	*733 / 548*	518	*573 / 469*	372	*398 / 347*

Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)

Table 4.7: Flood Frequency Flow Estimates Calculated Using Various Methods - Recorded and Regulated Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m³/s)																																										
						1000-yr*			750-yr*			500-yr*			350-yr*			200-yr*			100-yr*			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
						Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
05BH008	Bow River below Bearspaw Dam	7770	7730	RR	EV2	5090	9770	911	4430	8330	870	3650	6640	823	3070	5470	785	2350	4020	721	1700	2780	639	1480	2400	610	1230	1930	570	1040	1610	535	808	1210	479	593	843	412	436	591	345	286	347	252
05BH008	Bow River below Bearspaw Dam, extended using Bow River at Calgary - all flows	7770	7730	RR	EV2	2820	5030	1250	2590	4460	1200	2290	3760	1140	2060	3280	1080	1740	2600	998	1410	1960	899	1290	1750	858	1140	1490	801	1020	1300	749	849	1030	674	675	785	575	528	592	478	359	392	336
05BH008	Bow River below Bearspaw Dam, extended using Bow River at Calgary - all flows, historic	7770	7730	RR	*Historical adjustment ratio applied to EV2³*	4020	*7170*	*1780*	3630	*6250*	*1680*	3140	*5150*	*1560*	2770	*4410*	*1450*	2260	*3380*	*1300*	1770	*2450*	*1130*	1590	*2160*	*1060*	1370	*1790*	*965*	1200	*1540*	*885*	972	*1180*	*772*	744	*866*	*634*	561	*629*	*508*	364	*398*	*341*
05BH008	Bow River below Bearspaw Dam, extended using Bow River at Calgary - post 1932 flows	7770	7730	RR	EV2	1830	4320	740	1710	3830	728	1560	3260	710	1430	2800	695	1250	2230	671	1060	1690	633	986	1510	616	891	1280	594	813	1120	573	701	896	535	578	686	484	469	525	420	333	367	308
Node 59	Bearspaw Reservoir Outflow (assigned same flows as Bow River at Calgary)	7770	7730	R	LP3(MLH)	1360	2670	755	1300	2460	744	1220	2210	726	1150	1990	712	1050	1690	685	935	1400	651	888	1290	636	825	1140	614	772	1020	592	690	867	559	594	698	508	500	557	449	370	395	343
Node 59	Bearspaw Reservoir Outflow (assigned same flows as Bow River at Calgary), historic	7770	7730	R	*Historical adjustment ratio applied to LP3(MLH)³*	1940	*3800*	*1080*	1820	*3450*	*1040*	1670	*3030*	*995*	1540	*2670*	*956*	1370	*2200*	*892*	1170	*1750*	*815*	1090	*1590*	*784*	994	*1370*	*740*	912	*1200*	*699*	790	*993*	*640*	655	*770*	*560*	531	*592*	*477*	375	*401*	*348*
05BH004	Bow River at Calgary	7868	7736	RR	EV2	2750	4950	1180	2530	4390	1140	2240	3720	1090	2010	3210	1040	1700	2570	965	1370	1940	869	1260	1730	829	1110	1470	774	990	1270	729	828	1010	655	659	769	563	517	580	468	353	385	330
05BH004	Bow River at Calgary, historic	7868	7736	RR	*Historical adjustment ratio applied to EV2³*	3920	*7050*	*1680*	3550	*6150*	*1600*	3070	*5100*	*1490*	2700	*4310*	*1400*	2210	*3340*	*1260*	1720	*2430*	*1090*	1550	*2130*	*1020*	1340	*1770*	*932*	1170	*1500*	*861*	948	*1160*	*750*	727	*848*	*621*	549	*616*	*497*	358	*391*	*335*

Table 4.7: Flood Frequency Flow Estimates Calculated Using Various Methods - Recorded and Regulated Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Flow Type[1]	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																																						
						1000-yr*			750-yr*			500-yr*			350-yr*			200-yr*			100-yr*			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
						Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
Node 176	Bow River below Elbow River	9128	8995	R	LP3(MLH)	1740	3880	894	1650	3510	878	1540	3070	854	1450	2740	837	1310	2290	804	1150	1830	761	1080	1660	743	998	1440	714	926	1280	689	819	1050	645	694	828	582	574	647	509	414	445	381
	Bow River below Elbow River, historic			R	*Historical adjustment ratio applied to LP3(MLH)*[3]	2480	*5530*	*1270*	2310	*4920*	*1230*	2110	*4210*	*1170*	1950	*3680*	*1120*	1700	*2980*	*1050*	1440	*2290*	*953*	1330	*2050*	*915*	1200	*1730*	*860*	1090	*1510*	*814*	938	*1200*	*739*	765	*913*	*642*	610	*688*	*541*	420	*451*	*386*
Node 158	Bow River below Nose Creek	10114	9656	R	LP3(MLH)	1660	3480	988	1580	3160	960	1460	2770	924	1370	2460	893	1230	2070	842	1080	1640	777	1020	1490	750	935	1310	712	866	1160	676	763	959	620	643	756	549	530	596	471	380	409	349
	Bow River below Nose Creek, historic			R	*Historical adjustment ratio applied to LP3(MLH)*[3]	2370	*4960*	*1410*	2220	*4430*	*1350*	2000	*3800*	*1270*	1840	*3300*	*1200*	1600	*2690*	*1100*	1350	*2050*	*973*	1260	*1840*	*924*	1130	*1580*	*858*	1020	*1370*	*798*	874	*1100*	*710*	709	*834*	*605*	563	*633*	*501*	385	*415*	*354*
Node 164	Bow River below Fish Creek Confluence	10640	10182	R	LP3(MLH)	1690	3660	979	1600	3330	955	1490	2910	922	1390	2620	891	1250	2140	841	1090	1690	774	1030	1530	749	947	1340	712	877	1180	680	772	977	625	651	768	555	535	602	475	383	412	351
	Bow River below Fish Creek Confluence, historic			R	*Historical adjustment ratio applied to LP3(MLH)*[3]	2410	*5220*	*1400*	2240	*4670*	*1340*	2040	*3990*	*1260*	1870	*3520*	*1200*	1630	*2790*	*1090*	1360	*2120*	*969*	1270	*1890*	*923*	1140	*1610*	*858*	1040	*1390*	*803*	884	*1120*	*716*	718	*847*	*612*	569	*640*	*505*	389	*418*	*356*
Node 177	Bow River below Pine Creek	10887	10397	R	LP3(MLH)	1680	3680	979	1600	3380	956	1480	2960	923	1390	2610	891	1250	2130	839	1090	1690	773	1030	1530	749	945	1330	711	875	1180	678	770	974	624	649	766	553	534	600	474	382	411	350
	Bow River below Pine Creek, historic[3]			R	*Historical adjustment ratio applied to LP3(MLH)*[3]	2390	*5240*	*1400*	2240	*4740*	*1340*	2030	*4060*	*1260*	1870	*3510*	*1200*	1630	*2770*	*1090*	1360	*2120*	*968*	1270	*1890*	*923*	1140	*1600*	*857*	1030	*1390*	*801*	882	*1120*	*715*	716	*845*	*610*	568	*638*	*504*	388	*417*	*355*
Node 331	Bow River above Highwood River	11258	10532	R	LP3(MLH)	1690	3730	987	1610	3400	963	1490	2960	928	1400	2620	897	1260	2150	845	1100	1700	779	1030	1530	755	949	1340	719	878	1190	683	773	979	628	651	769	556	536	603	476	383	413	351
	Bow River above Highwood River, historic			R	*Historical adjustment ratio applied to LP3(MLH)*[3]	2410	*5320*	*1410*	2260	*4770*	*1350*	2040	*4060*	*1270*	1880	*3520*	*1200*	1640	*2800*	*1100*	1380	*2130*	*975*	1270	*1890*	*930*	1140	*1610*	*866*	1040	*1410*	*807*	885	*1120*	*719*	718	*848*	*613*	570	*641*	*506*	389	*419*	*356*
Node 165	Bow River below Highwood River	15342	14497	R	EV2	5330	11600	1800	4780	9960	1730	4100	8030	1630	3590	6660	1540	2910	4960	1410	2250	3500	1260	2020	3000	1200	1740	2450	1120	1520	2060	1040	1240	1570	927	954	1140	785	732	837	646	497	548	458
05BM002 / Node 178	Bow River below Carseland Dam	15665	14696	RR	EV2	6120	11300	2360	5550	9950	2250	4820	8250	2100	4260	6980	1980	3500	5450	1790	2730	3990	1570	2460	3510	1470	2120	2940	1340	1860	2490	1250	1500	1930	1080	1130	1410	889	831	997	692	498	589	434
				R	3P(MLH)	3790	6830	2190	3550	6270	2090	3240	5570	1960	2970	4950	1840	2570	4090	1650	2150	3220	1460	1980	2900	1380	1770	2480	1260	1590	2160	1170	1330	1720	1030	1050	1270	864	808	931	698	525	578	475
Node 180	Bow River at Hwy. 547	17443	15920	R	3P(MLH)	3540	6390	2010	3320	5870	1920	3040	5180	1810	2780	4610	1710	2410	3840	1550	2020	3020	1370	1860	2730	1300	1660	2340	1200	1500	2040	1100	1260	1620	973	997	1210	822	767	882	666	502	552	454
Node 181	Bow River at Hyw. 842	18028	16344	R	3P(MLH)	3320	6050	1900	3120	5530	1820	2860	4910	1720	2620	4370	1630	2280	3640	1480	1910	2850	1310	1770	2590	1240	1580	2220	1140	1430	1950	1060	1210	1550	941	959	1150	796	741	850	645	487	537	442
Node 189	Bow River below Crowfoot Creek	20169	17672	R	3P(MLH)	3490	6350	1990	3270	5800	1900	3000	5150	1800	2750	4590	1700	2390	3820	1550	2000	3000	1370	1850	2710	1300	1660	2330	1190	1490	2030	1110	1260	1620	982	1000	1200	830	773	886	673	508	560	460

Table 4.7: Flood Frequency Flow Estimates Calculated Using Various Methods - Recorded and Regulated Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m³/s)																																						
						1000-yr*			750-yr*			500-yr*			350-yr*			200-yr*			100-yr*			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
						Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
05BM004 / Node 182	Bow River below Bassano Dam	20253	17751	RR	EV2	7280	11000	3610	6620	9760	3410	5780	8290	3140	5130	7160	2880	4240	5720	2530	3330	4330	2140	3010	3880	1990	2600	3310	1800	2270	2870	1640	1830	2280	1390	1380	1690	1110	1000	1220	836	580	695	503
	Bow River below Bassano Dam, extended			R	EV2	5210	9870	2100	4740	8670	2020	4150	7260	1890	3690	6160	1800	3060	4780	1650	2430	3500	1480	2200	3090	1400	1920	2580	1300	1700	2220	1210	1400	1730	1070	1090	1290	897	836	965	727	552	580	500
Node 184	Bow River at Hwy. 539	20915	18186	R	EV2	4870	9420	1930	4440	8290	1850	3890	6920	1750	3470	5880	1680	2890	4590	1550	2310	3350	1390	2100	2970	1320	1830	2480	1230	1630	2130	1150	1340	1660	1020	1050	1250	869	811	932	710	541	568	492
Node 185	Bow River at Hwy. 36	21423	18544	R	EV2	4160	7930	1690	3800	6990	1640	3340	5890	1550	2990	5010	1480	2500	3940	1370	2010	2900	1230	1830	2570	1180	1600	2150	1090	1430	1860	1020	1180	1460	908	932	1100	773	722	826	633	484	508	441
Node 186	Bow River at Hwy. 875	22307	18878	R	EV2	3840	7230	1640	3530	6430	1590	3120	5410	1510	2800	4640	1440	2370	3680	1330	1910	2730	1210	1750	2430	1150	1540	2050	1070	1380	1780	1000	1150	1410	893	912	1070	762	712	812	625	481	505	438
05BN012 / Node 187	Bow River near the Mouth	25280	19160	RR	EV2	5820	12000	1910	5310	10600	1860	4660	8770	1790	4150	7480	1730	3450	5860	1600	2730	4280	1440	2470	3760	1370	2140	3150	1270	1880	2690	1180	1520	2070	1040	1150	1490	860	833	1040	669	473	592	394
				R	EV2	5000	9740	2010	4540	8510	1910	3950	7000	1790	3500	5950	1690	2890	4590	1550	2280	3340	1370	2060	2910	1300	1790	2430	1200	1580	2070	1110	1300	1620	981	1000	1200	827	768	889	668	506	532	459
Node 188	Bow River at the Mouth	25612	19306	R	EV2	4650	8880	1900	4230	7810	1830	3710	6500	1730	3300	5590	1630	2740	4330	1500	2170	3160	1330	1970	2760	1260	1720	2320	1160	1520	1980	1080	1260	1570	959	981	1170	812	754	871	658	501	527	455
BOW RIVER TRIBUTARIES																																												
05BD002 / Node 154	Cascade River near Banff	664	664	R	LP3(moment)	63.3	78.1	59.1	62.5	75.3	58.9	61.4	71.8	58.7	60.5	69.1	58.5	59.4	65.5	58.1	58.4	62.2	57.6	58.1	61.5	57.4	57.8	60.9	57.1	57.6	60.7	56.8	57.4	60.4	56.4	57.4	59.8	56	57.3	58.9	55.8	54.8	55.7	52.9
05BD003 / Node 207	Lake Minnewanka near Banff, End of Day Elevations[7] (m)	647	647	R	LP3(moment)	1475.53	1475.81	1475.42	1475.53	1475.80	1475.42	1475.53	1475.79	1475.41	1475.53	1475.78	1475.41	1475.52	1475.76	1475.40	1475.52	1475.73	1475.39	1475.52	1475.71	1475.39	1475.51	1475.68	1475.39	1475.51	1475.65	1475.39	1475.48	1475.60	1475.38	1475.44	1475.50	1475.37	1475.34	1475.39	1475.27	1474.99	1475.12	1474.82
Node 41	Outflows from Spray Lake	#N/A	#N/A	R	EV3	127	148	111	126	144	110	123	140	109	121	135	108	117	128	106	111	119	102	109	115	100	105	110	97.3	101	104	93.8	93.7	96.8	87	83.6	88.1	76.2	71.2	77.8	63.3	47.8	55.6	40.8
Node 43	Transalta's Diversion from Spray River to Bow River at Canmore	#N/A	#N/A	R	EV3	66.3	72.5	62.8	66.2	72.3	62.8	66.1	71.9	62.8	66	71.6	62.8	65.8	70.8	62.7	65.4	69.6	62.6	65.1	68.9	62.5	64.7	67.8	62.3	64.2	66.7	62.1	63	64.5	61.6	60.8	61.3	59.6	56.9	58.4	53.9	45.2	49.9	39.9
05BC006 / Node 201	Spray Reservoir at Three Sisters Dam, End of Day Elevations[7] (m)	481	481	R	LP3(moment)	1698.94	1699.72	1698.34	1698.93	1699.68	1698.34	1698.91	1699.61	1698.34	1698.89	1699.55	1698.34	1698.86	1699.45	1698.34	1698.79	1699.28	1698.32	1698.75	1699.20	1698.31	1698.69	1699.08	1698.29	1698.63	1698.96	1698.27	1698.49	1698.74	1698.20	1698.25	1698.42	1698.05	1697.88	1698.03	1697.65	1696.83	1697.20	1696.39
05BC002 / Node 51	Spray River near Spray Lake, reduced simulated watershed	362	362	R	3P(MLH)	692	1230	183	616	1080	175	526	899	165	450	752	155	348	563	140	250	392	122	217	333	113	176	262	102	144	210	90.4	104	146	70.0	66.1	88.6	47.8	39.5	56.1	30.5	17.2	26.7	14.8
05BC001	Spray River at Banff, after 1951	751	751	RR	EV2	382	788	62.2	327	653	58.9	262	505	54.8	216	407	51.6	160	286	47.0	110	186	40.6	94.7	156	38.2	76.4	122	34.9	63.2	97.2	32.6	47.0	68.8	28.4	32.6	45.3	23.4	22.6	29.3	18.5	13.4	15.9	12

Table 4.7: Flood Frequency Flow Estimates Calculated Using Various Methods - Recorded and Regulated Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km^2)	Effective Drainage Area (km^2)	Flow Type[1]	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																																						
						1000-yr*			750-yr*			500-yr*			350-yr*			200-yr*			100-yr*			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
						Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
Node 61	Kananaskis River Outflow from Upper Kananaskis Lake	#N/A	#N/A	R	3P(MLH)	106	145	78.9	102	137	76.2	95.5	127	72.7	89.9	118	69.3	81.6	104	64.1	72.1	89.7	58.3	68.3	83.8	56.1	63.2	76.3	52.6	58.9	70	49.7	52.3	60.8	45.3	44.7	50.5	39.8	37.4	41.3	34.1	27.8	30	24.9
Node 62	Kananaskis River Outflow from Pocaterra	#N/A	#N/A	R	Weibull	169	193	128	164	186	124	156	177	120	149	169	115	138	157	108	124	142	99.7	118	135	95.6	110	126	90.3	103	119	85.3	92.3	106	77.9	78.6	89.8	68	65	73.6	58.1	46.9	51.3	43.9
Node 63	Kananaskis River Outflow from Barrier Dam	#N/A	#N/A	R	EV2	1060	2820	300	950	2380	291	817	1890	277	715	1540	265	580	1120	249	447	772	227	401	661	217	344	531	203	300	438	190	242	324	171	184	226	146	138	158	120	88.3	99.7	79.6
05BF001	Kananaskis River near Seebe, after 1946	933	933	RR	EV2	835	1530	309	728	1300	287	600	1030	256	507	837	235	389	615	198	281	426	161	246	367	147	204	299	130	173	249	116	134	187	97	98.4	132	76.3	72.0	92.5	58.9	46.6	55.8	41.8
05BG010	Ghost River above Waiparous Creek	485	485	RR	EV2	1870	3060	201	1560	2550	188	1210	1990	169	966	1610	154	678	1140	134	437	755	111	363	636	103	280	497	88.9	222	397	80.2	154	279	66.8	95.7	176	51.0	57.6	104	35.3	25.3	40.5	18.7
05BG001	Ghost River near Cochrane	911	911	RR	3P(MLH)	1050	3230	529	957	2830	489	844	2360	442	744	1970	401	607	1470	343	466	1010	276	415	857	251	350	678	219	298	543	191	228	379	155	157	233	113	100	135	75.9	44.5	55.0	34.3
ELBOW RIVER																																												
05BJ001 / Node 161	Elbow River below Glenmore Dam	1236	1236	RR	EV2	895	*2080*	*311*	810	*1800*	*298*	703	*1460*	*284*	620	*1220*	*268*	507	*916*	*244*	394	*646*	*217*	354	*558*	*206*	304	*457*	*190*	265	*379*	*174*	212	*285*	*151*	158	*199*	*122*	113	*136*	*93.4*	64	*77*	*55*
				R	3P(MLH)	810	*1590*	*433*	748	*1430*	*408*	672	*1250*	*377*	604	*1090*	*348*	507	*872*	*305*	405	*656*	*255*	367	*580*	*237*	318	*486*	*212*	277	*409*	*190*	221	*307*	*159*	161	*210*	*123*	111	*136*	*88.7*	57	*66.1*	*48*
	Elbow River below Glenmore Dam, historic			R	*Historical adjustment ratio applied to 3P(MLH)*[3]	1150	*2270*	*617*	1050	*2000*	*572*	921	*1710*	*517*	811	*1460*	*467*	660	*1130*	*397*	507	*821*	*319*	452	*715*	*292*	383	*585*	*255*	327	*483*	*224*	253	*352*	*182*	178	*232*	*136*	118	*145*	*94.3*	57.6	*67.1*	*48.7*
	Elbow River below Glenmore Dam			R	Alternative method[8]	1974	*n/a*	*n/a*	1747	*n/a*	*n/a*	1522	*n/a*	*n/a*	1266	*n/a*	*n/a*	1003	*n/a*	*n/a*	669	*n/a*	*n/a*	494	*n/a*	*n/a*	357	*n/a*	*n/a*	242	*n/a*	*n/a*	160	*n/a*	*n/a*	160	*n/a*	*n/a*	157	*n/a*	*n/a*	70	*n/a*	*n/a*
Node 213	Glenmore Reservoir, End of Day Elevations[7] (m)	1224	1224	R	3P(MLH)	1076.47	1080.60	1075.60	1076.42	1080.17	1075.57	1076.37	1079.62	1075.54	1076.31	1079.14	1075.49	1076.21	1078.44	1075.40	1076.09	1077.71	1075.31	1076.04	1077.42	1075.28	1075.96	1077.06	1075.24	1075.88	1076.76	1075.18	1075.76	1076.34	1075.08	1075.58	1075.95	1075.00	1075.36	1075.63	1074.92	1074.95	1075.05	1074.78
HIGHWOOD RIVER																																												
05BL004	Highwood River below Little Bow Canal	1953	1953	RR	3P(MLH)	6190	15400	1280	5470	13200	1210	4610	10800	1120	3900	8780	1010	2960	6310	854	2080	4110	707	1780	3400	649	1410	2580	560	1140	1990	490	799	1310	396	487	748	283	274	425	183	106	170	81.8
	Highwood River below Little Bow Canal, extended			RR	EV2	2650	*3860*	*1460*	2350	*3370*	*1330*	1980	*2780*	*1170*	1700	*2360*	*1030*	1340	*1810*	*848*	992	*1310*	*663*	873	*1140*	*602*	728	*941*	*518*	619	*791*	*450*	476	*598*	*360*	336	*419*	*263*	229	*282*	*185*	118	*142*	*100*
	Highwood River below Little Bow Canal, extended, historic			RR	*Historical adjustment ratio applied to EV2*[4]	2810	*4090*	*1550*	2480	*3560*	*1400*	2080	*2920*	*1230*	1780	*2470*	*1080*	1400	*1890*	*885*	1030	*1360*	*687*	903	*1180*	*623*	750	*970*	*534*	636	*813*	*462*	486	*611*	*368*	341	*426*	*267*	231	*285*	*187*	118	*142*	*100*

Table 4.7: Flood Frequency Flow Estimates Calculated Using Various Methods - Recorded and Regulated Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Gross Drainage Area (km²)	Effective Drainage Area (km²)	Flow Type[1]	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																									
						1000-yr*		750-yr*		500-yr*		350-yr*		200-yr*		100-yr*		75-yr		50-yr		35-yr		20-yr		10-yr		5-yr		2-yr	
						Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower	Flood Est.	Upper / Lower
05BL024	Highwood River near the Mouth	3952	3941	RR	3P(MLH)	4700	*14000*	4300	*12400*	3800	*10400*	3360	*8810*	2750	*6730*	2130	*4670*	1900	*3970*	1610	*3130*	1370	*2520*	1050	*1780*	728	*1100*	467	*644*	205	263
							1900		*1780*		*1610*		*1470*		*1270*		*1050*		*960*		*852*		*763*		*624*		*467*		*326*		
	Highwood River near the Mouth, extended			RR	EV2	4880	*7720*	4320	*6660*	3630	*5430*	3110	*4520*	2440	*3440*	1790	*2440*	1580	*2110*	1310	*1730*	1110	*1440*	853	*1080*	602	*748*	409	*505*	211	*253*
							2640		*2400*		*2110*		*1870*		*1550*		*1210*		*1090*		*932*		*806*		*642*		*471*		*330*		*180*
	Highwood River near the Mouth, extended, historic			RR	*Historical adjustment ratio applied to EV2*[4]	5170	*8170*	4560	*7030*	3820	*5710*	3260	*4740*	2550	*3590*	1860	*2530*	1630	*2180*	1350	*1780*	1140	*1480*	872	*1100*	612	*760*	413	*510*	212	*254*
							2790		*2530*		*2220*		*1960*		*1620*		*1250*		*1130*		*960*		*828*		*656*		*479*		*333*		*180*
Node 172	Highwood River at the Mouth	3991	3964	RR	Prorated[5]	4930	*7800*	4360	*6720*	3670	*5480*	3140	*4560*	2460	*3470*	1810	*2460*	1600	*2130*	1320	*1750*	1120	*1450*	861	*1090*	608	*755*	413	*510*	213	255
							2670		*2420*		*2130*		*1890*		*1570*		*1220*		*1100*		*941*		*814*		*648*		*476*		*333*		182
	Highwood River at the Mouth, historic			RR	Prorated[5]	5220	*8260*	4600	*7090*	3860	*5760*	3290	*4780*	2570	*3620*	1880	*2550*	1650	*2200*	1360	*1800*	1150	*1490*	880	*1110*	618	*767*	417	*515*	214	*256*
							2830		*2560*		*2240*		*1980*		*1640*		*1270*		*1140*		*970*		*836*		*662*		*484*		*336*		*182*
05BL015	Little Bow Canal at High River	N/A[6]	N/A[6]	Canal	3P(MLH)	23.8	*42*	22.1	*38.1*	19.9	*33.6*	18.0	*29.7*	15.2	*24.3*	12.2	*18.6*	11.1	*16.6*	9.62	*13.9*	8.42	*11.9*	6.72	*9.11*	4.89	*6.28*	3.33	*4.06*	1.6	*1.89*
							12.6		*12*		*11*		*10.2*		*9.06*		*7.64*		*7.11*		*6.38*		*5.74*		*4.84*		*3.75*		*2.72*		*1.33*
05AC930	Little Bow River at Highway No. 533	792	312	RR	EV2	1040	*1520*	832	*1250*	609	*952*	463	*754*	301	*568*	176	*397*	141	*341*	103	*275*	77.8	*225*	50	*163*	28.6	*105*	15.9	*62.5*	6.39	*21.3*
							15.2		*15.1*		*14.5*		*14.1*		*13.7*		*12.9*		*12.4*		*11.7*		*11*		*9.73*		*8.05*		*6.34*		*4.2*

* Regulated flood frequency estimates above the 75-year flood are not recommended for use for design purposes, as they do not consider the capacity of existing reservoirs and over-estimate the ability of regulation to reduce flood peaks

1. Series Type: RR: Recorded Regulated Flows; R: Regulated Flows
2. Prorated: Instantaneous flood flows and confidence bounds were estimated by applying ratio between effective drainage areas at Node 108 and Node 107
3. Historical Adjustment Ratio Applied: Instantaneous flood flows and confidence bounds including historical floods were derived based on scaling the frequency analysis for Bow River at Calgary with and without historic floods (by applying a percentage multiplier to each return period)
4. Historical Adjustment Ratio Applied: Instantaneous flood flows and confidence bounds including historical floods were derived based on scaling the frequency analysis for Highwood River below Little Bow with and without historic floods (by applying a percentage multiplier to each return period)
5. Prorated: Instantaneous flood flows and confidence bounds were estimated by applying ratio between effective drainage areas at Node 172 and WSC station 05BL024
6. Drainage areas for point of diversion cannot be defined
7. Lake Level in metres above sea level
8. Alternative Method: Inflow Design Floods generated based on historically adjusted flood for Elbow at Sarcee were routed through Glenmore Reservoir based on Operation rules provided by the City of Calgary

5.0 COMMENTARY ON THE EFFECTS OF CLIMATE CHANGE

Recent studies on the effect of climate change (e.g., Martz et al. 2007; Valeo et al. 2007) indicate that climate change could result in increased air temperature, more frequent drought and water shortages, increased precipitation in some areas, and increased flooding. As a result of climate change and variability, many regions of Canada, including the Prairies, could experience warmer air temperatures and changes in stream flow magnitude and timing (e.g., higher winter stream flows and lower summer stream flows).

Prediction of future scenarios depends on the climate model used for the prediction. Precipitation is projected to increase in Alberta, with less precipitation falling as snow and more rainfall-on-snow events (Valeo et al. 2007). Such changes in precipitation patterns could increase the frequency and intensity of extreme events (i.e., flood, drought, hail, and windstorms). For the Bow River watershed, it is predicted that if rain-on-snow events occur more frequently and the snowpack begins to melt earlier, then flood events could occur earlier in the spring than in the past.

Using the predictions from the Canadian Regional Climate Model, Valeo et al. (2007) showed that May precipitation could increase by more than 35 percent under a $2xCO_2$ scenario. The resulting increases in precipitation in May could nearly double spring peak flows.

Islam and Gan (2015) used a physically-based land surface scheme, the Modified Soil Biosphere Atmosphere (MISBA), to assess the future stream flows in the South Saskatchewan River Basin of Alberta, which includes the Bow River and its tributaries, under the combined impacts of climate change and El Nino Southern Oscillation (ENSO). Under climate change projections alone or under a combined impact of climate change and ENSO, the annual mean flows for the Bow River Bow River and its tributaries (Elbow, Highwood and Sheep Rivers) are projected to decrease. However, the mean spring (March to May) flow in the Bow River at Calgary is projected to increase by 6%, 16%, and 23% in 2020s, 2050s, and 2080s, respectively. In contrast, the mean summer (June to August) flows in the Bow River and its tributaries (Elbow, Highwood and Sheep Rivers) are projected to decrease by 25%, 26%, and 28% in 2020s, 2050s, and 2080s, respectively.

The 2013 floods in the Bow and Elbow River basins have been the largest floods since 1932, as illustrated in Figure 5.1. Based on the recorded flow data for the past 103 years (i.e., 1911 to 2013), the annual peak flows do not appear to be trending upward in the Bow River or Elbow River. The trend in the Bow River appears to be a decreasing one, likely due to flow regulation at TransAlta's hydropower reservoirs on the Bow River and its tributaries. There is no trend in the annual peak flows in the Elbow River. Any trend shown in Figure 5.1 is not statistically significant.

About 80 percent of the recorded annual peak flows in the Bow and Elbow Rivers occurred between the ends of May and June (see Table 5.1 and Figure 5.2). The frequency of annual peak flows occurring outside this time window (earlier or later) does not appear to be changing with time. The recent patterns in the timing of these peak flows are similar to what were observed at the beginning of the century. There is no clear evidence that the patterns in magnitude or timing of annual peak flows have changed significantly over the past hundred years.

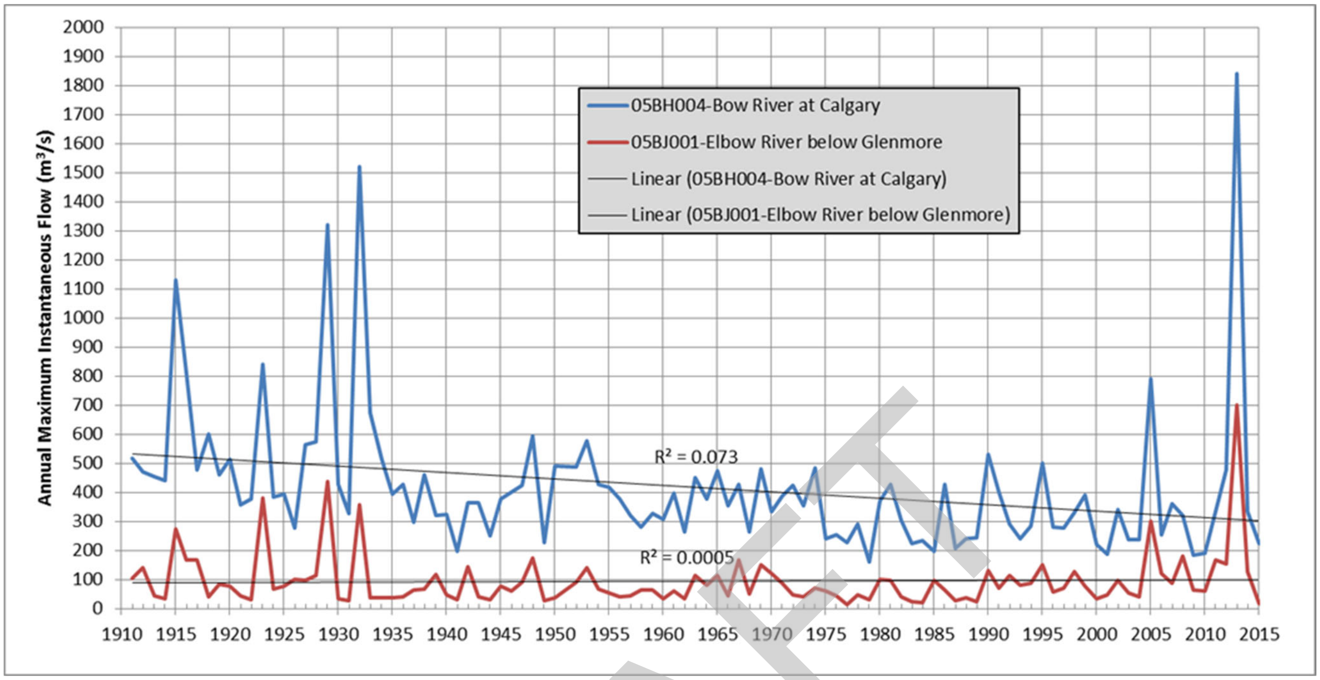


Figure 5.1: Annual Flood Peak Flows in the Bow and Elbow Rivers in Calgary

Table 5.1: Timings of Annual Maximum Daily Flows in the Bow and Elbow Rivers

Month	Bow River - Occurrences of Annual Maximum Daily Flows Since 1911		Elbow River - Occurrences of Annual Maximum Daily Flows Since 1911	
	Number	%	Number	%
April	-	-	4	4
May	9	9	25	24
June	75	72	59	57
July	16	15	7	7
August	3	3	8	8
September	1	1	4	4

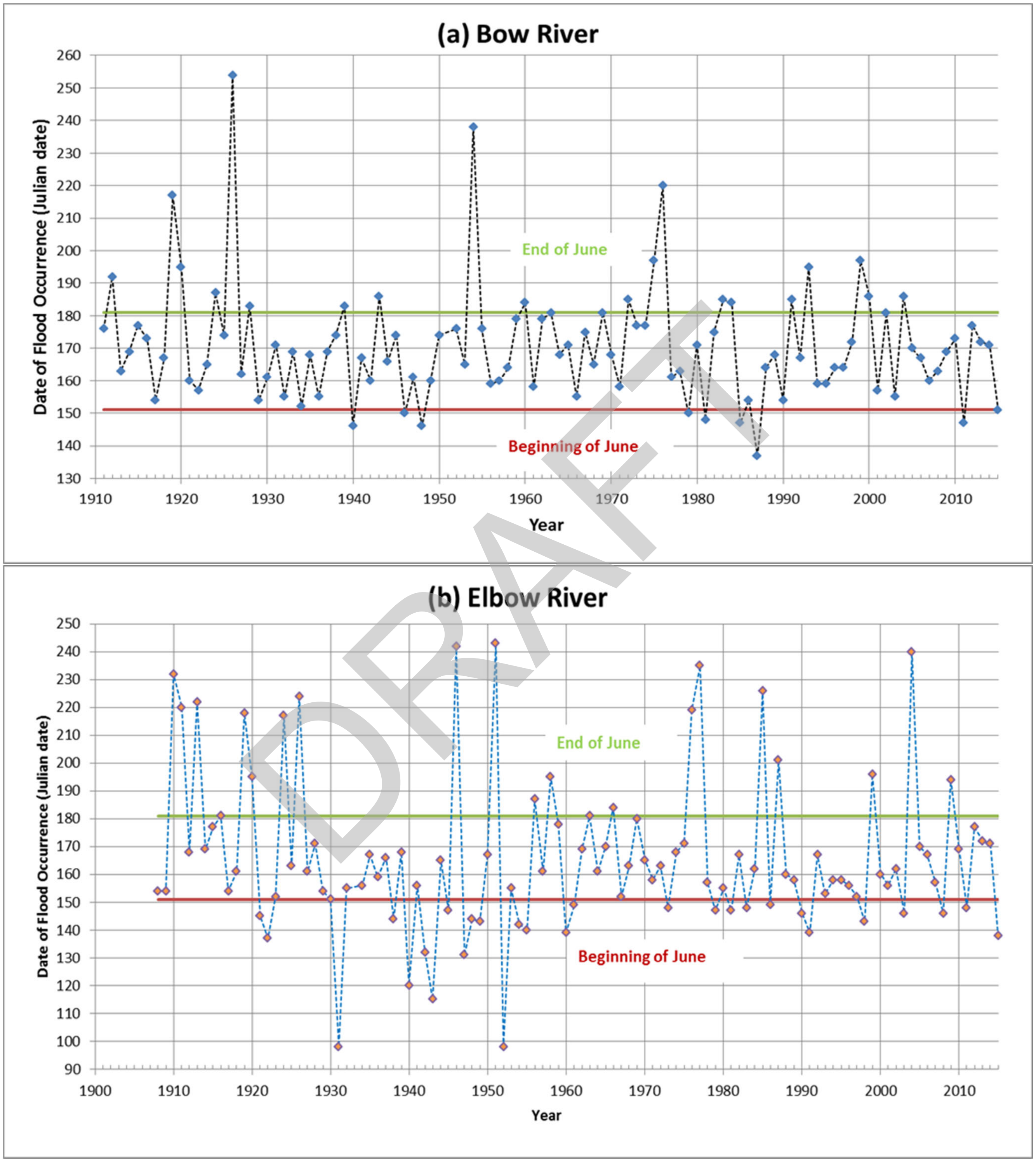


Figure 5.2: Timings of Past Annual Peak Flows in the Bow and Elbow Rivers

6.0 CONCLUSIONS

The results of this study support the following conclusions:

- The flood frequency estimates obtained in this study are the most up-to-date for the various locations along the Bow, Elbow, Highwood, and Sheep Rivers and their tributaries. These estimates provide the updated flood hydrology information as input to the River Hazard Studies being completed under the Provincial Flood Hazard Identification Program, as well as flood mitigation and other projects.
- This study includes June 2013 flood flow data for the Bow River Basin and other river basins along the eastern mountain slopes in southern Alberta. It also includes preliminary estimates of the annual maximum flows in 2013, 2014 and 2015. Inclusion of additional flow information, particularly for the large 2013 floods, increases the sample sizes for flood frequency analyses, and the reliability of resulting flood frequency estimates.
- Consideration of historic flood information (i.e., 1879, 1897 and 1902 floods) for updating the flood frequency estimates for the Elbow River increases the reliability of results for the Elbow River.
- The reliability of the Highwood River flood frequency estimates is increased by including in the analysis the anecdotal evidence about a historic flood of the 1880's.
- Application of the RBAT and WRMM models, including use of the SSARR channel routing procedures, provides an accurate basis to simulate and account for the storage effects of the various reservoirs in the Bow River basin. The resulting natural/naturalized and regulated flood flow series provide good data sets for the flood frequency analyses.

Table 6.1 summarizes the recommended estimates of instantaneous flood peak discharges for return periods ranging from the 2-year flood to the 1,000-year flood for natural/naturalized flow conditions. The 95% upper and lower confidence intervals are provided where applicable.

The maximum recorded length available and used in the flood frequency are less than 100 years, except the two locations on Bow River (Bow at Banff and Bow at Calgary). Hence, there are significant uncertainties (i.e., the confidence intervals are very large) with flood frequency estimates for return periods greater than the 100-year.

Table 6.1: Final Flood Frequency Flow Estimates – Natural and Naturalized Flows

Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Effective Drainage Area (km^2)	Distribution / Method	1000-yr Flood Est.	1000-yr Upper	1000-yr Lower	750-yr Flood Est.	750-yr Upper	750-yr Lower	500-yr Flood Est.	500-yr Upper	500-yr Lower	350-yr Flood Est.	350-yr Upper	350-yr Lower	200-yr Flood Est.	200-yr Upper	200-yr Lower	100-yr Flood Est.	100-yr Upper	100-yr Lower
BOW RIVER																					
05BA001	Bow River at Lake Louise	422	EV2	182	304	95.8	172	279	94.2	159	247	92.3	149	222	90.1	135	191	86.7	118	156	81.9
05BB001	Bow River at Banff	2210	EV2	554	754	425	538	715	418	517	667	410	498	630	401	468	576	389	431	509	369
Node 105	Bow River below Spray River	2993	3P(MLH)	844	1230	593	811	1160	578	769	1070	560	729	997	542	670	883	514	602	763	479
Node 107	Bow River below Cascade River	3727	3P(MLH)	1050	1590	725	1010	1490	707	956	1380	682	905	1270	659	829	1130	621	742	966	577
Node 108	Bow River at Canmore	3870	*Prorated*[1]	1090	1650	753	1050	1550	734	993	1430	708	940	1320	684	861	1170	645	770	1000	599
Node 109	Bow River above Kananaskis	4199	*Interpolated*[2]	1270	2220	773	1210	2040	755	1130	1810	731	1060	1640	708	957	1400	670	843	1140	624
Node 110	Bow River below Kananaskis	5139	EV2	1770	3850	831	1660	3430	817	1510	2910	795	1400	2540	776	1230	2050	742	1050	1550	694
05BE004 / Node 111	Bow River near Seebe	5170	EV2	1760	3520	903	1650	3160	883	1510	2720	858	1400	2390	837	1240	1940	794	1060	1510	743
Node 318	Bow River above Ghost Reservoir	5473	*Prorated*[1]	1860	3730	956	1750	3340	935	1600	2880	908	1480	2530	886	1310	2050	840	1120	1600	786
05BE006 / Node 58	Bow River below Ghost Dam (Ghost Reservoir Outflow), historic	6550	*Historical adjustment ratio applied to LP3(MLH)*[3]	2390	4730	1450	2230	4280	1380	2030	3690	1300	1850	3210	1220	1610	2590	1120	1350	1980	994
05BH005 / Node 114	Bow River near Cochrane, historic	7383	*Interpolated*[2]	3270	*6650*	*1890*	3020	*5890*	*1780*	2690	*5000*	*1650*	2420	*4300*	*1540*	2060	*3410*	*1370*	1680	*2540*	*1190*
Node 302	Bearspaw Reservoir Inflow, historic	7672	*Assigned the same flows as Bow River at Calgary*	3580	*7320*	*2040*	3290	*6450*	*1920*	2920	*5460*	*1770*	2620	*4680*	*1650*	2220	*3700*	*1460*	1790	*2730*	*1260*
05BH004 / Node 59	Bow River at Calgary, historic	7736	*Historical adjustment ratio applied to LP3(MLH)*[3]	4880	*9970*	*2780*	4400	*8630*	*2570*	3790	*7080*	*2300*	3330	*5940*	*2100*	2710	*4510*	*1790*	2090	*3190*	*1480*
Node 176	Bow River below Elbow River	8995	*Concurrent*[8]	5310	*7930*	*4230*	4820	*7080*	*3840*	4190	*6040*	*3350*	3710	*5240*	*2990*	3050	*4180*	*2470*	2390	*3140*	*1970*
Node 158	Bow River below Nose Creek	9656	*Coincident*[4]	5370	*10500*	*3270*	4880	*9110*	*3050*	4240	*7530*	*2750*	3760	*6370*	*2530*	3090	*4890*	*2170*	2420	*3520*	*1810*
Node 164	Bow River below Fish Creek	10182	*Coincident*[4]	6100	*8720*	*5020*	5480	*7740*	*4500*	4700	*6550*	*3860*	4120	*5650*	*3400*	3340	*4470*	*2760*	2580	*3330*	*2160*
Node 177	Bow River below Pine Creek	10397	*Coincident*[4]	6180	*11300*	*4080*	5560	*9790*	*3730*	4770	*8060*	*3280*	4180	*6790*	*2950*	3390	*5190*	*2470*	2620	*3720*	*2010*
Node 331	Bow River above Highwood River	10532	*Prorated*[1]	6260	*8880*	*5180*	5630	*7890*	*4650*	4830	*6680*	*3990*	4240	*5770*	*3520*	3440	*4570*	*2860*	2660	*3410*	*2240*
Node 165	Bow River below Highwood River	14497	EV2	7180	*16300*	*2250*	6390	*13800*	*2150*	5420	*11000*	*2000*	4690	*8980*	*1900*	3750	*6620*	*1740*	2840	*4520*	*1530*
05BM002 / Node 178	Bow River below Carseland Dam	14696	EV2	6770	15100	2380	6080	12900	2280	5240	10500	2130	4590	8670	2010	3730	6500	1830	2880	4580	1620
Node 180	Bow River at Hwy. 547	15920	*Interpolated*[2]	7090	13000	2860	6370	11300	2720	5480	9480	2510	4790	8010	2340	3890	6460	2070	2990	4580	1800
Node 181	Bow River at Hwy. 842	16344	*Interpolated*[2]	7210	12300	3030	6470	10800	2870	5560	9120	2650	4870	7770	2450	3950	6450	2160	3030	4580	1860
Node 189	Bow River below Crowfoot Creek	17672	*Interpolated*[2]	7560	10000	3550	6790	9130	3340	5820	8020	3070	5090	7050	2810	4120	6400	2420	3150	4580	2060
05BM004 / Node 182	Bow River below Bassano Dam, extended	17751	LP3(MLH)	7580	9900	3580	6810	9030	3370	5840	7950	3090	5100	7010	2830	4130	6400	2440	3160	4580	2070
Node 184	Bow River at Hwy. 539	18186	*Interpolated*[2]	6660	9490	3270	6030	8660	3090	5240	7640	2840	4620	6740	2610	3790	5960	2280	2950	4350	1940

WSC Station ID / Node ID	75-yr Flood Est.	75-yr Upper	75-yr Lower	50-yr Flood Est.	50-yr Upper	50-yr Lower	35-yr Flood Est.	35-yr Upper	35-yr Lower	20-yr Flood Est.	20-yr Upper	20-yr Lower	10-yr Flood Est.	10-yr Upper	10-yr Lower	5-yr Flood Est.	5-yr Upper	5-yr Lower	2-yr Flood Est.	2-yr Upper	2-yr Lower
BOW RIVER																					
05BA001	111	145	80	102	129	77	95.1	117	74.3	84.6	101	70	72.7	83.3	63.9	61.9	68.7	56.7	48.2	51.9	45.4
05BB001	416	483	360	394	450	346	375	422	333	346	380	313	308	333	285	269	288	253	211	225	200
Node 105	574	716	464	537	653	443	505	598	425	456	524	395	398	440	358	341	368	315	264	283	248
Node 107	707	902	559	659	821	533	618	752	509	556	652	474	481	542	426	409	445	374	311	331	291
Node 108	734	937	580	684	852	553	642	781	529	577	677	492	499	563	442	425	462	388	323	344	302
Node 109	798	1060	605	738	942	578	689	853	554	614	726	515	527	595	464	446	485	407	338	360	317
Node 110	983	1400	678	894	1200	649	822	1060	624	719	868	582	606	687	526	505	551	462	380	407	358
05BE004 / Node 111	994	1370	718	906	1190	687	834	1050	657	731	878	607	616	703	541	513	562	470	384	414	360
Node 318	1050	1450	760	959	1260	727	883	1110	695	774	929	643	652	744	573	543	595	498	406	438	381
05BE006 / Node 58	1260	1770	945	1130	1530	875	1030	1330	817	878	1080	728	718	830	624	577	640	521	408	437	379
05BH005 / Node 114	1540	*2240*	*1120*	1360	*1890*	*1030*	1220	*1930*	*946*	1010	*1280*	*822*	800	*955*	*683*	619	*696*	*554*	413	*445*	*383*
Node 302	1630	*2400*	*1180*	1440	*2020*	*1080*	1280	*1730*	*991*	1060	*1350*	*854*	829	*998*	*703*	634	*716*	*566*	415	*448*	*385*
05BH004 / Node 59	1880	*2770*	*1360*	1610	*2260*	*1210*	1400	*1890*	*1080*	1120	*1430*	*902*	845	*1020*	*717*	627	*708*	*560*	401	*433*	*372*
Node 176	2150	*2780*	*1780*	1860	*2340*	*1560*	1630	*2010*	*1390*	1310	*1560*	*1130*	996	*1150*	*882*	739	*816*	*675*	464	*497*	*434*
Node 158	2180	*3070*	*1660*	1890	*2540*	*1490*	1650	*2140*	*1330*	1330	*1640*	*1110*	1010	*1180*	*882*	746	*827*	*679*	465	*497*	*436*
Node 164	2310	*2940*	*1940*	1980	*2460*	*1680*	1730	*2110*	*1490*	1380	*1630*	*1200*	1040	*1190*	*926*	762	*839*	*698*	469	*502*	*439*
Node 177	2350	*3240*	*1830*	2020	*2670*	*1620*	1760	*2250*	*1440*	1400	*1710*	*1180*	1050	*1220*	*922*	770	*851*	*703*	472	*504*	*443*
Node 331	2380	*3010*	*2010*	2040	*2520*	*1740*	1780	*2160*	*1540*	1420	*1670*	*1240*	1070	*1220*	*956*	780	*857*	*716*	478	*511*	*448*
Node 165	2530	*3860*	*1450*	2150	*3100*	*1330*	1870	*2590*	*1240*	1500	*1950*	*1100*	1140	*1380*	*931*	867	*1000*	*762*	582	*644*	*538*
05BM002 / Node 178	2590	3960	1540	2230	3220	1420	1950	2690	1320	1580	2020	1170	1210	1460	983	917	1050	797	604	677	550
Node 180	2690	3970	1700	2310	3240	1540	2010	2720	1420	1620	2060	1230	1230	1480	1010	923	1060	805	599	669	548
Node 181	2720	3970	1750	2330	3250	1580	2030	2730	1450	1630	2070	1250	1240	1490	1020	925	1070	807	597	667	547
Node 189	2820	3980	1920	2420	3280	1710	2100	2770	1550	1680	2120	1320	1260	1520	1050	932	1080	816	591	658	545
05BM004 / Node 182	2830	3980	1930	2420	3280	1720	2100	2770	1560	1680	2120	1320	1260	1520	1050	932	1080	816	591	658	545
Node 184	2660	3810	1820	2300	3170	1630	2010	2690	1480	1620	2070	1260	1230	1490	1020	913	1060	795	581	645	533

Table 6.1: Final Flood Frequency Flow Estimates – Natural and Naturalized Flows

Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Effective Drainage Area (km^2)	Distribution / Method	1000-yr			750-yr			500-yr			350-yr			200-yr			100-yr			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
				Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
Node 185	Bow River at Hwy. 36	18544	*Interpolated*[2]	5910	9160	3020	5390	8360	2850	4740	7390	2640	4220	6510	2430	3510	5590	2140	2780	4160	1840	2520	3680	1720	2190	3080	1560	1930	2630	1420	1570	2040	1220	1200	1470	989	898	1050	778	573	635	524
Node 186	Bow River at Hwy. 875	18878	*Interpolated*[2]	5200	8840	2780	4790	8080	2630	4280	7150	2450	3850	6300	2260	3250	5260	2020	2620	3990	1740	2390	3550	1630	2100	3000	1490	1860	2570	1360	1530	2000	1180	1180	1450	964	884	1030	762	565	625	515
05BN012 / Node 187	Bow River near the Mouth	19160	3P(MLH)	4610	8580	2580	4290	7840	2450	3890	6950	2290	3540	6120	2120	3030	4970	1910	2490	3840	1660	2280	3440	1560	2020	2930	1430	1800	2520	1310	1490	1970	1140	1160	1430	942	872	1020	749	559	617	507
Node 188	Bow River at the Mouth	19306	*Assigned the same flows as 05BN012*[6]	4610	8580	2580	4290	7840	2450	3890	6950	2290	3540	6120	2120	3030	4970	1910	2490	3840	1660	2280	3440	1560	2020	2930	1430	1800	2520	1310	1490	1970	1140	1160	1430	942	872	1020	749	559	617	507
BOW RIVER TRIBUTARIES																																										
05BB003 / Node 305	Forty Mile Creek near Banff	133	*Transferred using Redearth Creek based on ratio of drainage area*	57.3	n/a	n/a	55.9	n/a	n/a	53.8	n/a	n/a	51.9	n/a	n/a	49	n/a	n/a	45.2	n/a	n/a	43.7	n/a	n/a	41.4	n/a	n/a	39.4	n/a	n/a	36.2	n/a	n/a	32.1	n/a	n/a	27.6	n/a	n/a	20.8	n/a	n/a
Node 306	Forty Mile Creek at the Mouth	148	*Transferred using Redearth Creek based on ratio of drainage area*	57.3	n/a	n/a	55.9	n/a	n/a	53.8	n/a	n/a	51.9	n/a	n/a	49	n/a	n/a	45.2	n/a	n/a	43.7	n/a	n/a	41.4	n/a	n/a	39.4	n/a	n/a	36.2	n/a	n/a	32.1	n/a	n/a	27.6	n/a	n/a	20.8	n/a	n/a
05BC001 / Node 106	Spray River at Banff	751	EV2	432	802	218	402	720	210	363	613	200	332	536	191	287	434	179	240	336	163	222	303	156	199	262	145	180	229	137	154	187	123	125	145	106	99.2	111	88.1	68.2	75.1	62.8
05BD002 / Node 154	Cascade River near Banff	664	EV2	423	938	187	390	824	181	348	686	172	314	583	165	268	453	154	219	336	140	201	296	133	178	248	124	159	214	116	134	169	104	106	125	88.2	82.7	94.4	72.6	54.9	61.6	49.9
Node 307	Cougar Creek at the Mouth	43	*Regionalization*[5]	89	n/a	n/a	81.4	n/a	n/a	71.9	n/a	n/a	64.0	n/a	n/a	53.0	n/a	n/a	41.5	n/a	n/a	37.4	n/a	n/a	32.0	n/a	n/a	27.7	n/a	n/a	21.8	n/a	n/a	15.6	n/a	n/a	10.5	n/a	n/a	4.88	n/a	n/a
Node 308	Policeman's Creek at Canmore	10	*Regionalization*[5]	22.4	n/a	n/a	20.5	n/a	n/a	18.2	n/a	n/a	16.3	n/a	n/a	13.6	n/a	n/a	10.8	n/a	n/a	9.80	n/a	n/a	8.47	n/a	n/a	7.41	n/a	n/a	5.92	n/a	n/a	4.32	n/a	n/a	2.96	n/a	n/a	1.4	n/a	n/a
Node 309	Stoneworks Creek at Hwy. 1	6	*Regionalization*[5]	13.5	n/a	n/a	12.4	n/a	n/a	11.0	n/a	n/a	9.9	n/a	n/a	8.3	n/a	n/a	6.6	n/a	n/a	5.99	n/a	n/a	5.2	n/a	n/a	4.56	n/a	n/a	3.66	n/a	n/a	2.7	n/a	n/a	1.86	n/a	n/a	0.886	n/a	n/a
Node 310	Exshaw Creek at Exshaw	32	*Regionalization*[5]	67.9	n/a	n/a	62.1	n/a	n/a	54.9	n/a	n/a	48.9	n/a	n/a	40.6	n/a	n/a	31.9	n/a	n/a	28.7	n/a	n/a	24.7	n/a	n/a	21.4	n/a	n/a	16.9	n/a	n/a	12.1	n/a	n/a	8.18	n/a	n/a	3.82	n/a	n/a
05BF025 / Node 56	Kananaskis River below Barrier Dam	899	EV2	691	1510	231	623	1290	222	537	1040	210	472	865	200	386	648	184	300	457	166	270	396	159	234	326	148	205	275	139	168	213	125	130	157	106	100	114	88.3	68	74.8	62.8
05BG010	Ghost River above Waiparous Creek, extended with diversion added	485	EV2	1160	1930	450	990	1610	404	790	1250	343	648	1010	297	474	718	238	320	474	179	272	398	157	216	311	131	175	250	111	126	177	85.2	82.2	114	60	51.7	70.1	40.2	24	30.5	20
05BG006	Waiparous Creek near the Mouth, extended	333	3P(MLH)	692	1200	410	630	1080	378	553	925	339	487	794	303	395	623	253	301	455	200	267	397	181	224	325	155	190	268	135	144	196	105	97.9	127	74.3	61.6	76.4	48.8	26.3	32	21.3
05BG001 / Node 316	Ghost River near Cochrane, extended with diversion added	911	LP3(MLH)	1960	8410	741	1710	6670	680	1420	4860	596	1190	3670	536	909	2420	451	642	1440	352	553	1150	317	446	843	271	367	639	234	267	410	184	174	239	129	108	137	85.3	48.6	59	39.4
Node 317	Ghost River at the Mouth	940	*Assigned the same flows as 05BG001*	1960	8410	741	1710	6670	680	1420	4860	596	1190	3670	536	909	2420	451	642	1440	352	553	1150	317	446	843	271	367	639	234	267	410	184	174	239	129	108	137	85.3	48.6	59	39.4
05BH015	Jumpingpound Creek at Township Road No. 252, extended	474	*Transferred using Jumpingpound Creek near the Mouth - Foothills Region Power*	866	n/a	n/a	785	n/a	n/a	686	n/a	n/a	600	n/a	n/a	482	n/a	n/a	363	n/a	n/a	321	n/a	n/a	267	n/a	n/a	225	n/a	n/a	168	n/a	n/a	112	n/a	n/a	68.4	n/a	n/a	27.3	n/a	n/a
05BH009	Jumpingpound Creek near the Mouth, extended	571	3P(MLH)	1030	2250	488	936	2000	448	815	1670	404	711	1410	363	568	1070	306	425	747	241	374	638	217	310	505	186	260	407	160	193	287	125	127	177	87.5	76.8	102	56.5	30	39.7	22.3
Node 174	Jumpingpound Creek at the Mouth	601	*Transferred using Jumpingpound Creek near the Mouth - Foothills Region Power*	1087	n/a	n/a	982	n/a	n/a	855	n/a	n/a	744	n/a	n/a	594	n/a	n/a	444	n/a	n/a	390	n/a	n/a	323	n/a	n/a	270	n/a	n/a	200	n/a	n/a	132	n/a	n/a	79.3	n/a	n/a	30.8	n/a	n/a
Node 322	Bighill Creek at the Mouth	99	*Regionalization*[5]	48.4	n/a	n/a	45.6	n/a	n/a	41.8	n/a	n/a	38.4	n/a	n/a	33.3	n/a	n/a	27.4	n/a	n/a	25	n/a	n/a	21.8	n/a	n/a	19.1	n/a	n/a	15.1	n/a	n/a	10.5	n/a	n/a	6.55	n/a	n/a	2.29	n/a	n/a

Table 6.1: Final Flood Frequency Flow Estimates – Natural and Naturalized Flows

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Effective Drainage Area (km^2)	Distribution / Method	Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)																																			
				1000-yr			750-yr			500-yr			350-yr			200-yr			100-yr			75-yr			50-yr			35-yr			20-yr			10-yr			5-yr			2-yr		
				Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower	Flood Est.	Upper	Lower
05BH016	West Nose Creek at the Mouth	212	*Transferred using Nose Creek at Calgary - Foothills Region Power*	104.5	n/a	n/a	92.4	n/a	n/a	77.7	n/a	n/a	66.6	n/a	n/a	52.4	n/a	n/a	39	n/a	n/a	34.3	n/a	n/a	28.7	n/a	n/a	24.5	n/a	n/a	19	n/a	n/a	13.6	n/a	n/a	9.37	n/a	n/a	4.76	n/a	n/a
05BH014	Nose Creek above Airdrie	178	*Transferred using Nose Creek at Calgary - Foothills Region Power*	88.4	n/a	n/a	78.3	n/a	n/a	66.2	n/a	n/a	56.8	n/a	n/a	44.9	n/a	n/a	33.6	n/a	n/a	29.7	n/a	n/a	24.9	n/a	n/a	21.4	n/a	n/a	16.6	n/a	n/a	12	n/a	n/a	8.41	n/a	n/a	4.36	n/a	n/a
05BH003 / Node 175	Nose Creek at Calgary, extended	746	EV2	348	495	101	303	426	91.9	249	347	80.9	209	288	72.2	159	219	58.8	113	158	46.5	97.3	138	42.2	79	115	36.2	65.5	98.1	31.3	48.3	75.4	24.5	32.3	53.3	17.7	20.5	35.6	12	8.92	15.6	5.71
05BH901	Nose Creek at the Mouth	878	*Transferred using Nose Creek at Calgary - Foothills Region Power*	407	n/a	n/a	353	n/a	n/a	289	n/a	n/a	242	n/a	n/a	184	n/a	n/a	130	n/a	n/a	111	n/a	n/a	90.1	n/a	n/a	74.4	n/a	n/a	54.5	n/a	n/a	36.1	n/a	n/a	22.7	n/a	n/a	9.68	n/a	n/a
05BK001	Fish Creek near Priddis	261	3P(MLH)	926	3500	465	829	3010	422	713	2440	373	614	1990	328	481	1430	264	350	921	203	305	761	182	248	574	152	204	445	128	148	290	95.5	93.3	160	63.8	53.7	83.9	38.7	19.1	25.7	13.9
Node 163	Fish Creek at the Mouth	440	*Based on Threepoint Creek near Millarville and Fish Creek near Priddis*	1041	n/a	n/a	943	n/a	n/a	823	n/a	n/a	719	n/a	n/a	577	n/a	n/a	434	n/a	n/a	383	n/a	n/a	318	n/a	n/a	267	n/a	n/a	199	n/a	n/a	132	n/a	n/a	80.4	n/a	n/a	31.7	n/a	n/a
Node 330	Pine Creek at the Mouth	212	*Regionalization*[5]	99.7	n/a	n/a	93.1	n/a	n/a	84.2	n/a	n/a	76.4	n/a	n/a	65	n/a	n/a	51.9	n/a	n/a	46.9	n/a	n/a	40.1	n/a	n/a	34.5	n/a	n/a	26.5	n/a	n/a	17.7	n/a	n/a	10.5	n/a	n/a	3.34	n/a	n/a
05BM008	Crowfoot Creek near Cluny	950	3P(MLH)	797	1980	193	701	1700	182	589	1380	170	495	1120	159	373	794	141	259	514	117	220	428	108	174	323	93.8	139	249	79.5	95.5	160	58	56.6	87.7	36.3	30.4	45.1	20.3	10.1	16.3	7.34
05BN006	New West Coulee near the Mouth	102	EV3	11.7	16.8	7.88	11.4	16.1	7.82	11.1	15.2	7.75	10.7	14.4	7.65	10.2	13.2	7.48	9.49	11.8	7.23	9.18	11.2	7.11	8.73	10.4	6.93	8.32	9.79	6.77	7.65	8.8	6.45	6.76	7.58	5.92	5.78	6.36	5.18	4.17	4.61	3.73
05BN002	Twelve Mile Creek near Cecil	124	3P(MLH)	26.9	48.9	16.8	25.5	44.9	16.3	23.6	40	15.7	22	35.7	15.1	19.5	29.8	14.2	16.7	23.7	12.8	15.6	21.5	12.3	14.2	18.6	11.5	12.9	16.3	10.7	11.1	13.1	9.53	9.05	9.99	7.88	7.11	7.93	6.16	4.68	5.54	3.94
Node 179	Arrowwood Creek above Hwy. 547	718	LP3(moment)	298	977		273	824		239	677		212	552		172	398		129	263		113	217		93	165		76.9	128		55	86.5		33.4	50.6		17.4	27.1		4.4	7.9	
ELBOW RIVER AND TRIBUTARIES																																							
05BJ004	Elbow River at Bragg Creek, extended using relationship established with Elbow at Sarcee Bridge based on Instantaneous floods, historic	791	*Historical adjustment ratio applied to 3P(MLH)*[3]	2150	4000	1260	1930	3520	1150	1660	2980	1010	1440	2520	891	1140	1930	727	840	1340	557	736	1150	497	607	916	420	508	745	359	377	527	277	250	331	191	155	195	125	67.5	79.6	57.4
05BJ010	Elbow River at Sarcee Bridge, combined data from 05BJ001, 05BJ005, 05BJ010 with estimated instantaneous flows from the 1983 AENV floodplain study, historic	1189	*Historical adjustment ratio applied to 3P(MLH)*[3]	2150	4000	1170	1930	3520	1070	1660	2950	941	1440	2500	834	1140	1900	685	841	1340	531	738	1150	474	610	918	404	509	749	347	379	535	271	253	335	191	157	199	128	70.4	83.1	60.3
Node 161	Elbow River below Glenmore Dam, historic	1236	*Assigned the same flows as 05BJ010*	2150	4000	1170	1930	3520	1070	1660	2950	941	1440	2500	834	1140	1900	685	841	1340	531	738	1150	474	610	918	404	509	749	347	379	535	271	253	335	191	157	199	128	70.4	83.1	60.3
Node 340	Bragg Creek at the Mouth	50	*Regionalization*[5]	103	n/a	n/a	94.6	n/a	n/a	83.5	n/a	n/a	74.3	n/a	n/a	61.4	n/a	n/a	48.1	n/a	n/a	43.2	n/a	n/a	37	n/a	n/a	32	n/a	n/a	25.2	n/a	n/a	18	n/a	n/a	12	n/a	n/a	5.59	n/a	n/a
Node 335	Lott Creek at the Mouth	114	*Regionalization*[5]	55.2	n/a	n/a	52	n/a	n/a	47.5	n/a	n/a	43.6	n/a	n/a	37.7	n/a	n/a	30.8	n/a	n/a	28.1	n/a	n/a	24.4	n/a	n/a	21.3	n/a	n/a	16.7	n/a	n/a	11.6	n/a	n/a	7.14	n/a	n/a	2.45	n/a	n/a
SHEEP RIVER AND TRIBUTARIES																																							
05BL014	Sheep River at Black Diamond	592	3P(MLH)	1900	5010	910	1720	4390	837	1500	3680	751	1310	3100	672	1050	2310	561	787	1600	445	693	1360	401	576	1080	345	484	872	301	361	601	235	240	360	165	148	206	107	61.5	79.6	47.1
05BL012	Sheep River at Okotoks, extended	1494	3P(MLH)	2620	4650	1520	2420	4220	1430	2180	3670	1310	1950	3210	1190	1640	2580	1030	1300	1950	852	1180	1730	784	1020	1460	694	886	1240	616	701	939	507	504	646	377	338	417	261	158	196	127
Node 344	Sheep River at the Mouth, extended	1570	*Prorated*[1]	2750	4890	1600	2540	4440	1500	2290	3860	1380	2050	3370	1250	1720	2710	1080	1370	2050	896	1240	1820	824	1070	1530	730	931	1300	648	737	987	533	530	679	396	355	438	274	166	206	134

Table 6.1: Final Flood Frequency Flow Estimates – Natural and Naturalized Flows

Computed Instantaneous Flood Flows with 95% Confidence Bounds (m^3/s)

WSC Station ID / Node ID	WSC Station Name / Location of Interest	Effective Drainage Area (km^2)	Distribution / Method	1000-yr Flood Est.	1000-yr Upper	1000-yr Lower	750-yr Flood Est.	750-yr Upper	750-yr Lower	500-yr Flood Est.	500-yr Upper	500-yr Lower	350-yr Flood Est.	350-yr Upper	350-yr Lower	200-yr Flood Est.	200-yr Upper	200-yr Lower
Node 338	Ware Creek at the Mouth	129	*Regionalization*[5]	265	*n/a*	*n/a*	242	*n/a*	*n/a*	213	*n/a*	*n/a*	188	*n/a*	*n/a*	155	*n/a*	*n/a*
Node 339	Threepoint Creek above Ware Creek	136	*Regionalization*[5]	278	*n/a*	*n/a*	254	*n/a*	*n/a*	223	*n/a*	*n/a*	198	*n/a*	*n/a*	162	*n/a*	*n/a*
05BL013	Threepoint Creek near Millarville	507	3P(MLH)	1140	2690	542	1040	2380	501	914	2010	455	803	1710	410	650	1310	345
Node 341	Threepoint Creek at the Mouth	638	*Transferred using Threepoint Creek near Millarville (Mountain Region Power)*	1430	*n/a*	*n/a*	1300	*n/a*	*n/a*	1140	*n/a*	*n/a*	1000	*n/a*	*n/a*	810	*n/a*	*n/a*
HIGHWOOD RIVER AND TRIBUTARIES																		
05BL019	Highwood River at Diebel's Ranch	774	LP3(MLH)	1390	7030	469	1250	5750	446	1080	4370	417	945	3400	390	765	2290	350
05BL004	Highwood River below Little Bow Canal, extended, historic	1953	*Historical adjustment ratio applied to EV2*[7]	2830	4100	1560	2490	3570	1410	2090	2950	1240	1790	2490	1090	1400	1900	889
05BL024	Highwood River near the Mouth, extended, historic	3941	*Historical adjustment ratio applied to EV2*[7]	5200	8190	2820	4580	7050	2560	3830	5720	2230	3270	4760	1970	2550	3600	1630
Node 172	Highwood River at the Mouth, historic	3964	*Prorated*[1]	5230	8240	2840	4600	7090	2570	3850	5750	2240	3290	4790	1980	2560	3620	1640
05BL022	Cataract Creek near Forestry Road	166	EV2	1280	2770	128	1070	2280	122	834	1730	114	670	1350	106	475	934	96.6
05BL023	Pekisko Creek near Longview	232	3P(MLH)	680	1770	284	608	1540	262	522	1260	233	449	1040	207	350	764	172
05BL007	Stimson Creek near Pekisko	236	3P(MLH)	456	943	227	413	835	209	360	708	188	314	600	169	252	458	141
05BL027	Trapp Creek near Longview	137	3P(MLH)	819	2020	82.4	719	1740	79.5	602	1410	75.4	505	1150	71.6	379	822	65.5

WSC Station ID / Node ID	100-yr Flood Est.	100-yr Upper	100-yr Lower	75-yr Flood Est.	75-yr Upper	75-yr Lower	50-yr Flood Est.	50-yr Upper	50-yr Lower	35-yr Flood Est.	35-yr Upper	35-yr Lower	20-yr Flood Est.	20-yr Upper	20-yr Lower	10-yr Flood Est.	10-yr Upper	10-yr Lower	5-yr Flood Est.	5-yr Upper	5-yr Lower	2-yr Flood Est.	2-yr Upper	2-yr Lower
Node 338	120	*n/a*	*n/a*	108	*n/a*	*n/a*	91.5	*n/a*	*n/a*	78.7	*n/a*	*n/a*	61.2	*n/a*	*n/a*	43.1	*n/a*	*n/a*	28.4	*n/a*	*n/a*	13.1	*n/a*	*n/a*
Node 339	126	*n/a*	*n/a*	113	*n/a*	*n/a*	95.9	*n/a*	*n/a*	82.5	*n/a*	*n/a*	64.1	*n/a*	*n/a*	45.1	*n/a*	*n/a*	29.7	*n/a*	*n/a*	13.7	*n/a*	*n/a*
05BL013	495	941	275	439	806	249	368	648	216	312	521	187	235	371	149	158	232	106	98.2	134	69.8	39.8	52	29.4
Node 341	616	*n/a*	*n/a*	545	*n/a*	*n/a*	457	*n/a*	*n/a*	387	*n/a*	*n/a*	290	*n/a*	*n/a*	192	*n/a*	*n/a*	118	*n/a*	*n/a*	48.7	*n/a*	*n/a*
HIGHWOOD RIVER AND TRIBUTARIES																								
05BL019	583	1430	300	519	1170	282	439	887	254	378	693	231	295	477	195	212	301	155	146	186	115	78.8	92.8	66.6
05BL004	1030	1360	692	905	1180	624	752	972	535	637	814	463	486	611	369	342	426	268	231	286	188	118	142	101
05BL024	1870	2530	1270	1630	2180	1130	1350	1780	961	1140	1480	829	872	1100	656	612	761	479	413	510	334	213	255	181
Node 172	1880	2540	1280	1640	2190	1140	1360	1790	967	1150	1490	834	877	1110	660	615	765	482	415	513	336	214	256	182
05BL022	309	581	83.6	259	478	78.5	201	363	71.7	161	284	65.2	113	193	55.9	72.4	117	45.4	45.4	67.9	33.9	22.2	29.2	18.4
05BL023	254	511	134	221	428	119	180	332	100	148	262	85.5	106	176	63.9	66.9	102	43.7	38.4	55.5	26.7	13.7	19.9	9.65
05BL007	189	322	112	167	277	102	138	221	86.9	116	179	74.9	86.2	127	58.8	56.6	77.5	40.9	34	44	25.9	12.7	16.6	9.58
05BL027	261	532	57.9	222	438	55.1	175	331	50.3	139	257	46.6	95.8	178	40.7	56.9	119	31.2	31	72.7	20.2	11.3	18.3	7.99

1. Prorated: Instantaneous flood flows were estimated by applying ratio between effective drainage areas at the node in interest and node upstream or downstream of the node in interest using an exponent of 1
2. Interpolated: Instantaneous flood flows were estimated based on interpolation between frequency analysis for upstream and downstream stations
3. Historical Adjustment Ratio Applied: Instantaneous flood flows including historical floods were derived by applying a percentage multiplier to each return period based on ratios of Bow River at Calgary results with and without historic floods
4. Historical Assessment using Bulletin 17C Methodology: Instantaneous flood frequency flow estimates for Bow River at Calgary were derived using the updated Bulletin 17C methodology to incorporate historical floods
5. Regionalization: Instantaneous flood flows were derived based on regional analysis
6. Instantaneous flood flows at Node 188 (Bow River at the Mouth) were assigned the same as 05BN012 (Bow River near the Mouth)
7. Historical Adjustment Ratio Applied: Instantaneous flood flows and confidence bounds including historical floods were derived based on scaling the frequency analysis for Highwood River below Little Bow with and without historic floods (by applying a percentage multiplier to each return period)
8. Concurrent: Instantaneous flood flows were generated based on an examination of the concurrent data records

7.0 CLOSURE

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

GOLDER ASSOCIATES LTD.

APEGA PERMIT TO PRACTICE 05122

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Reviewed by:

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Principal, Senior Water Resources Engineer

GB/DL

https://golderassociates.sharepoint.com/sites/121016/project files/5 technical work/04 report revisions/1_hydrology/hydrology report rev1_final/1532956_bow elbow highwood sheep hydrology_sept 2020.docx

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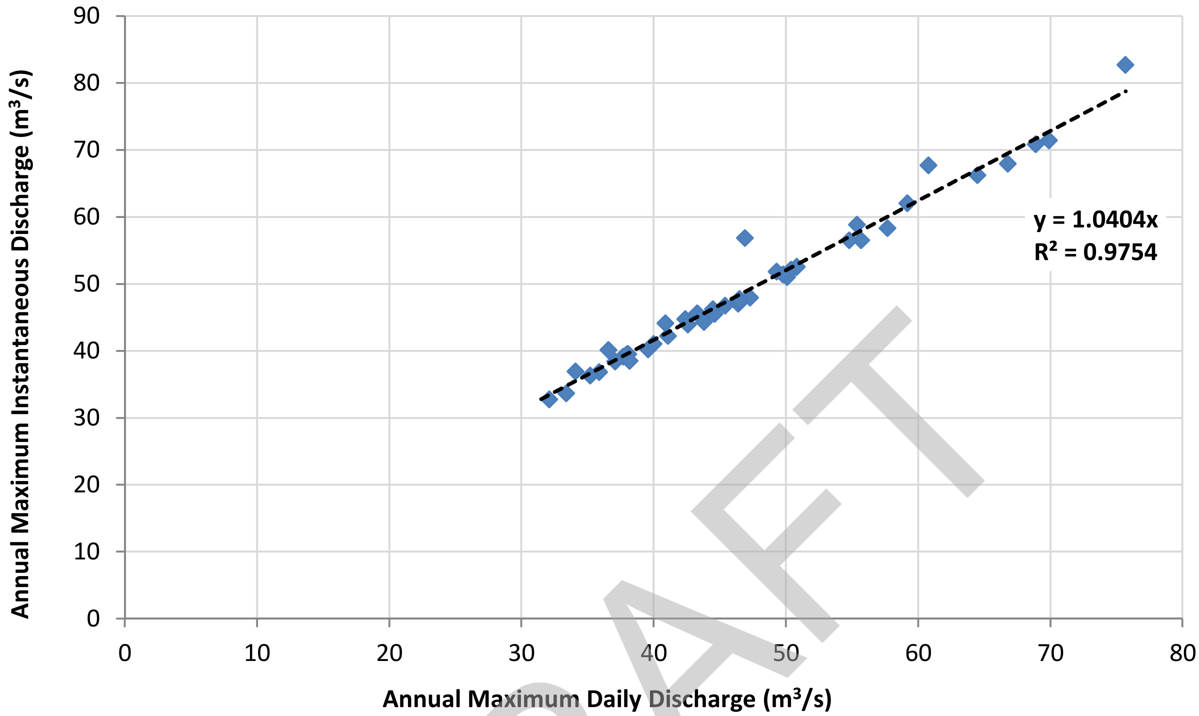
APPENDIX A

Data Used in this Study

Figure A-1: Bow River at Lake Louise (05BA001)



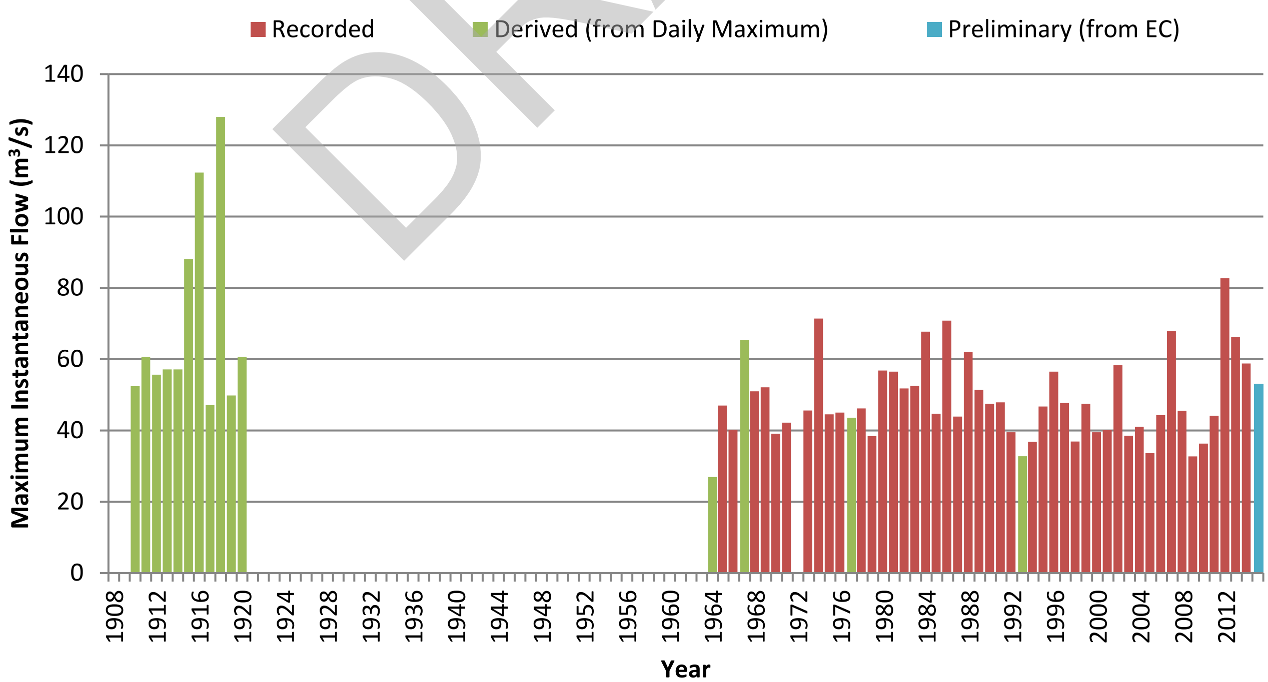
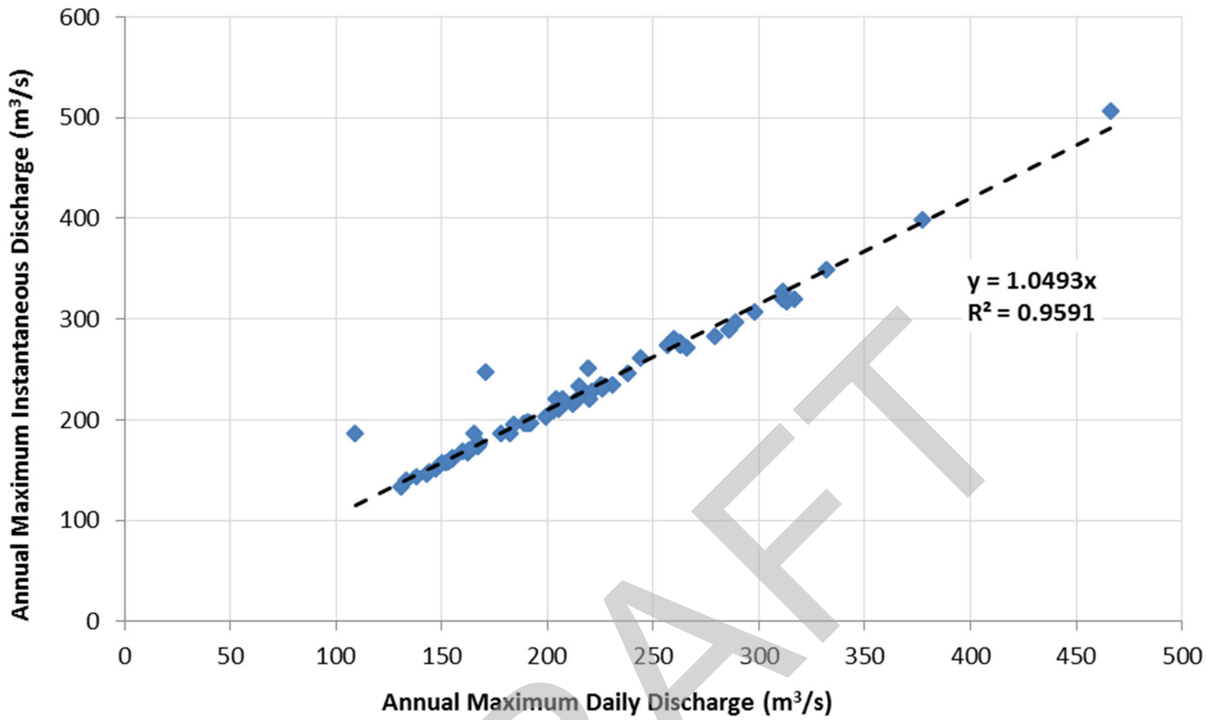


Figure A-2: Bow River at Banff (05BB001)



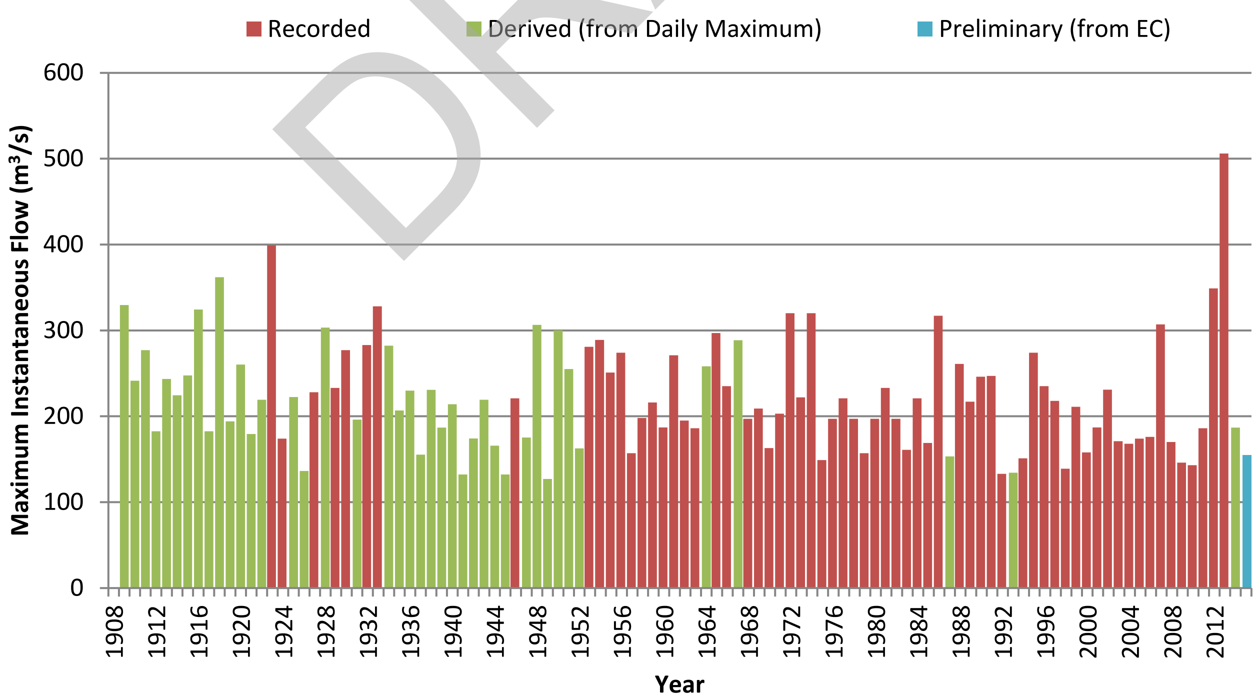
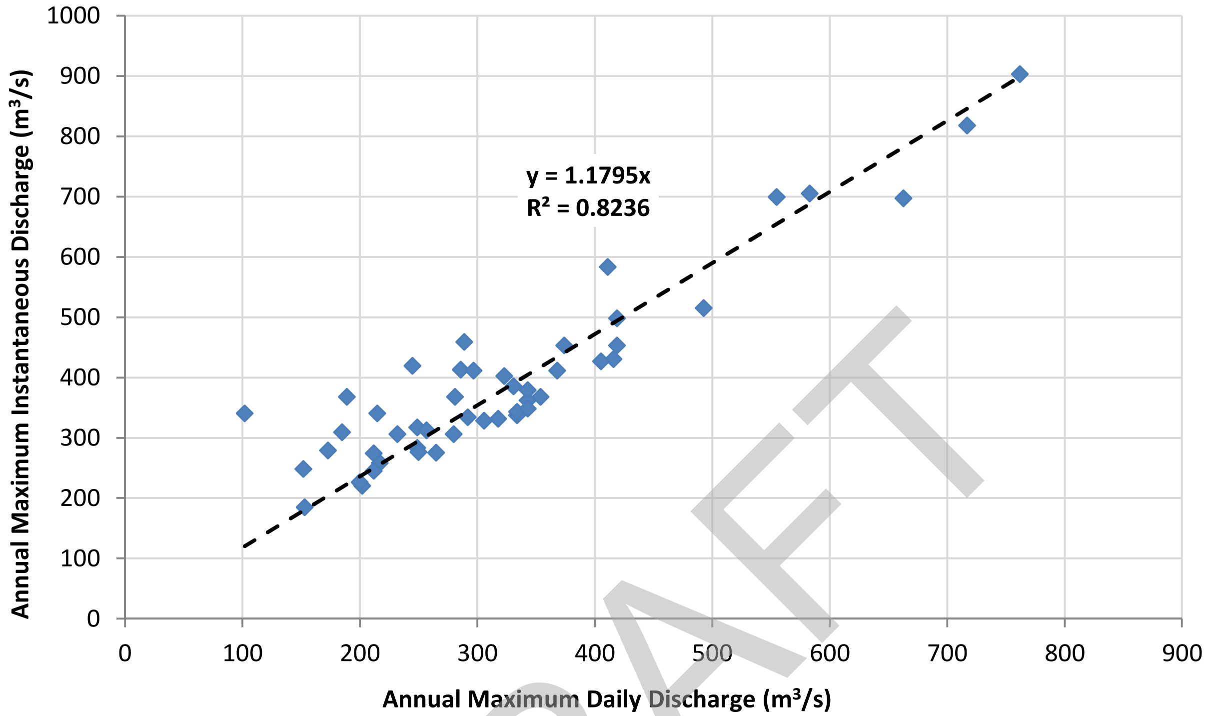


Figure A-3: Bow River near Seebe (05BE004)



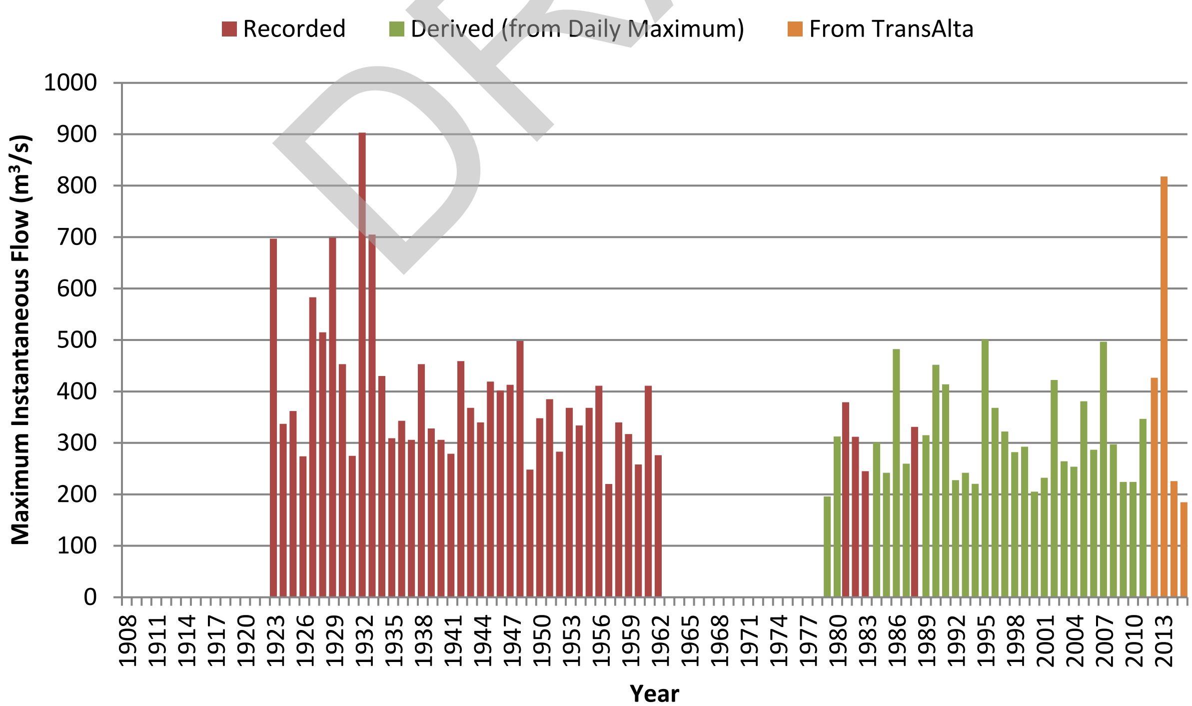
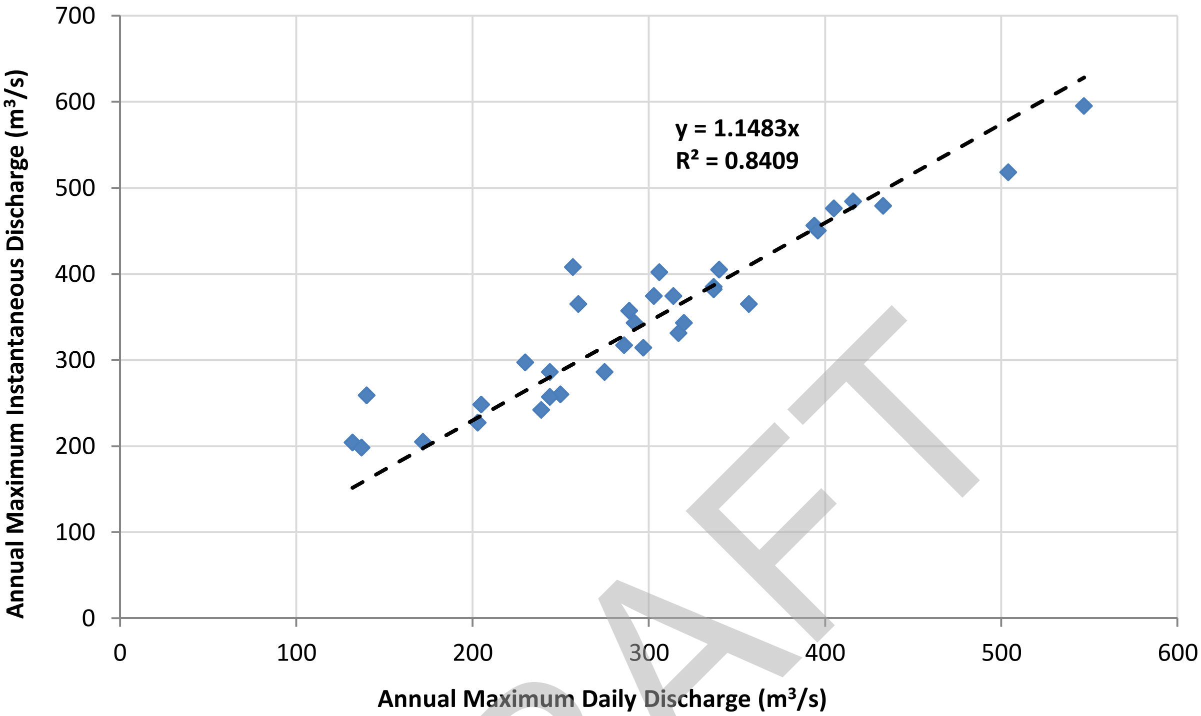


Figure A-4: Bow River below Ghost Dam (Ghost Reservoir Outflow) (05BE006)



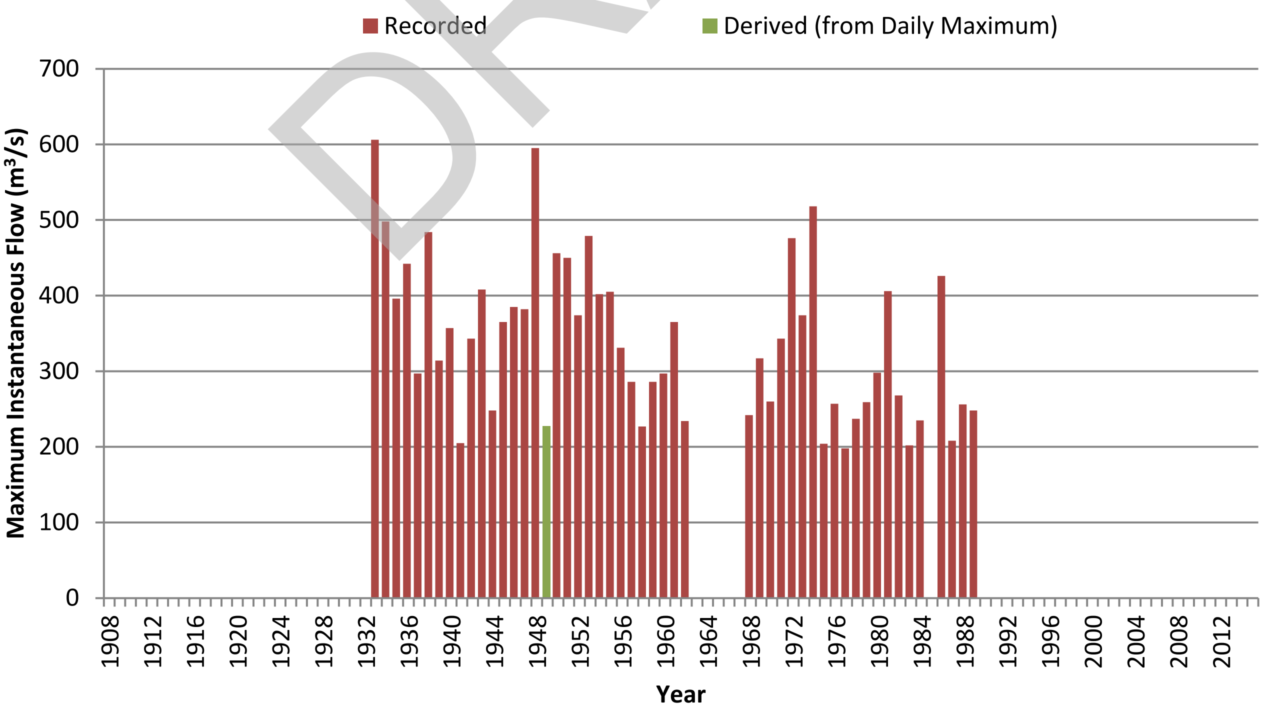
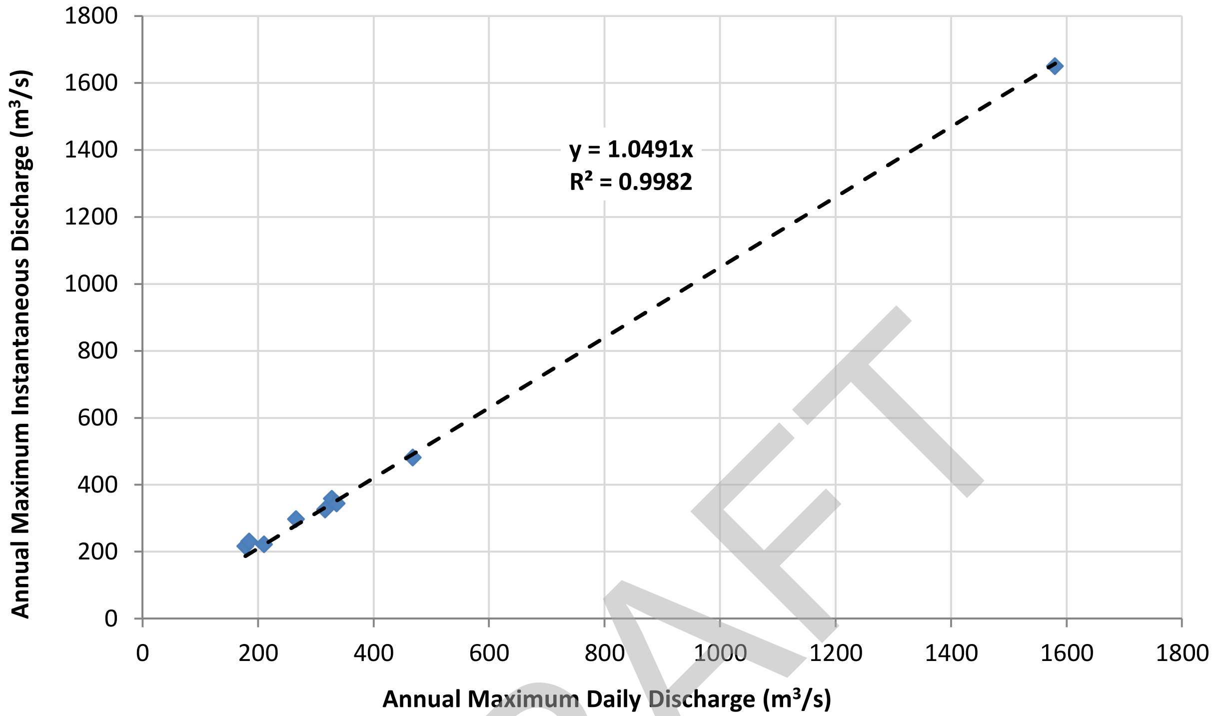


Figure A-5: Bow River near Cochrane (05BH005)



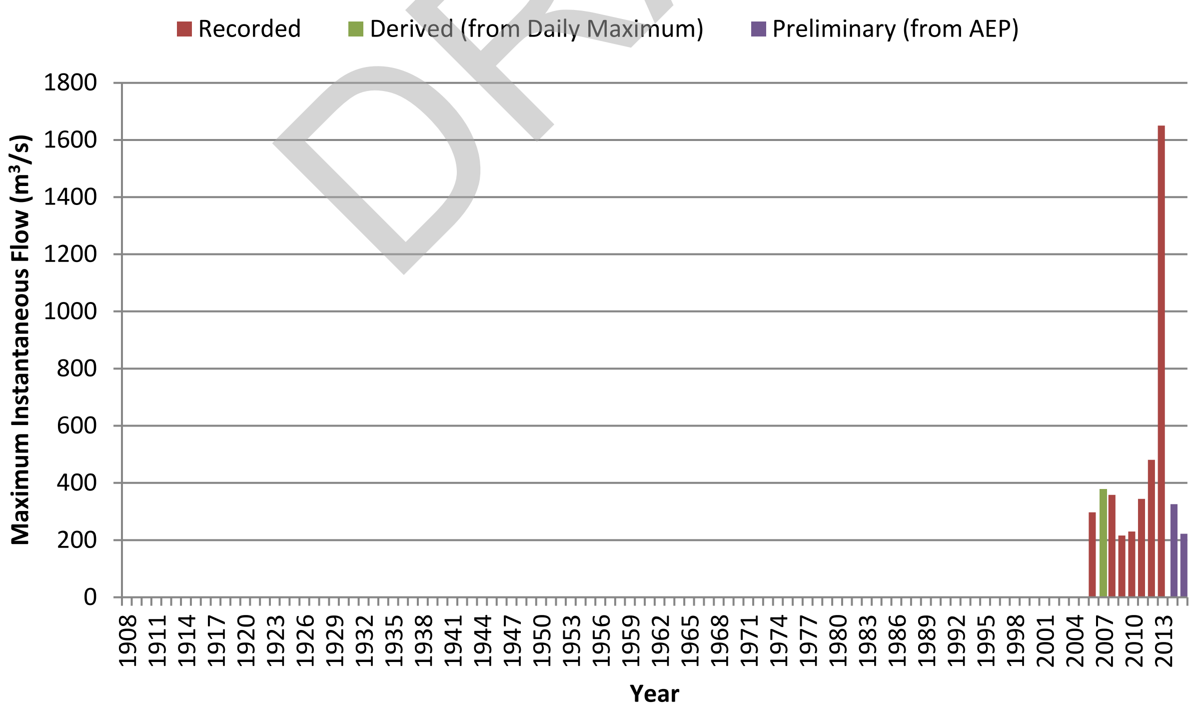
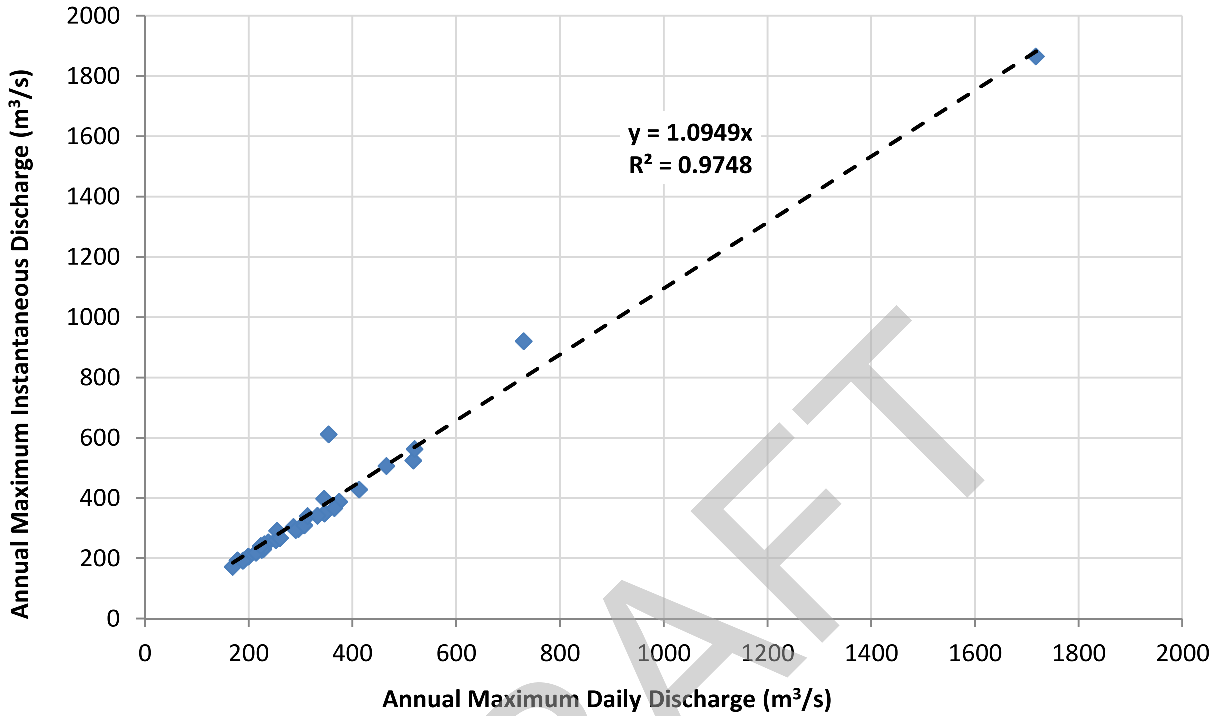


Figure A-6: Bow River below Bearspaw Dam (Bearspaw Reservoir Outflow) (05BH008)



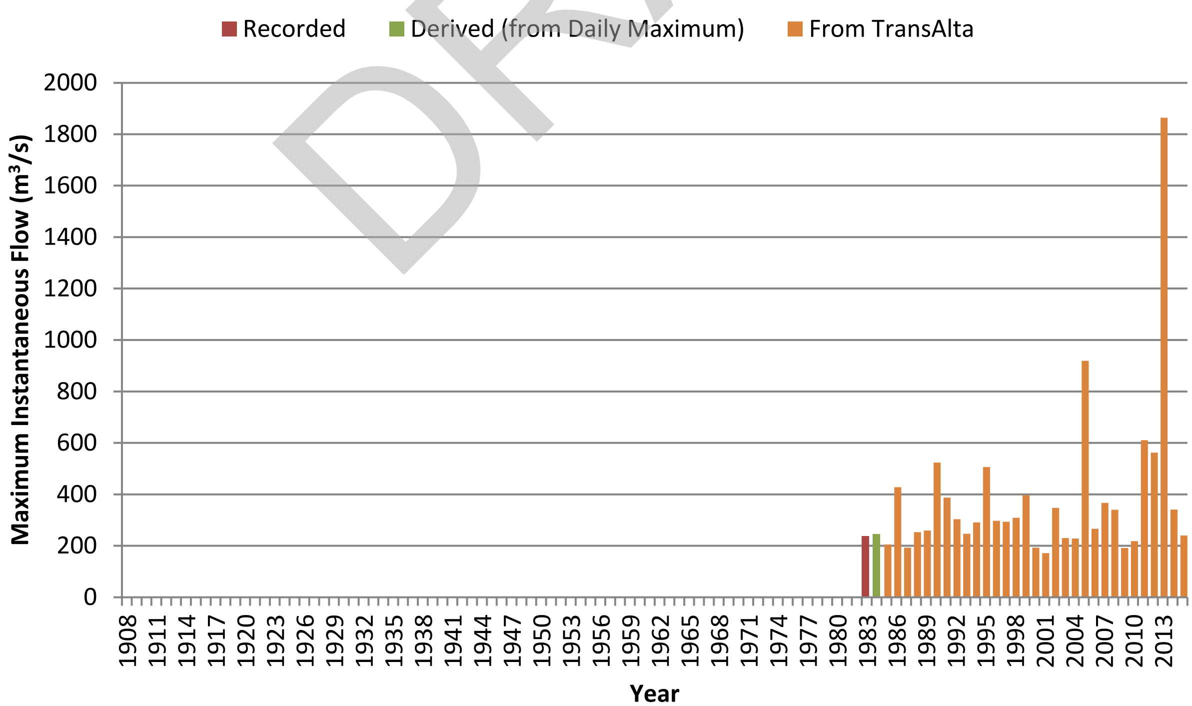
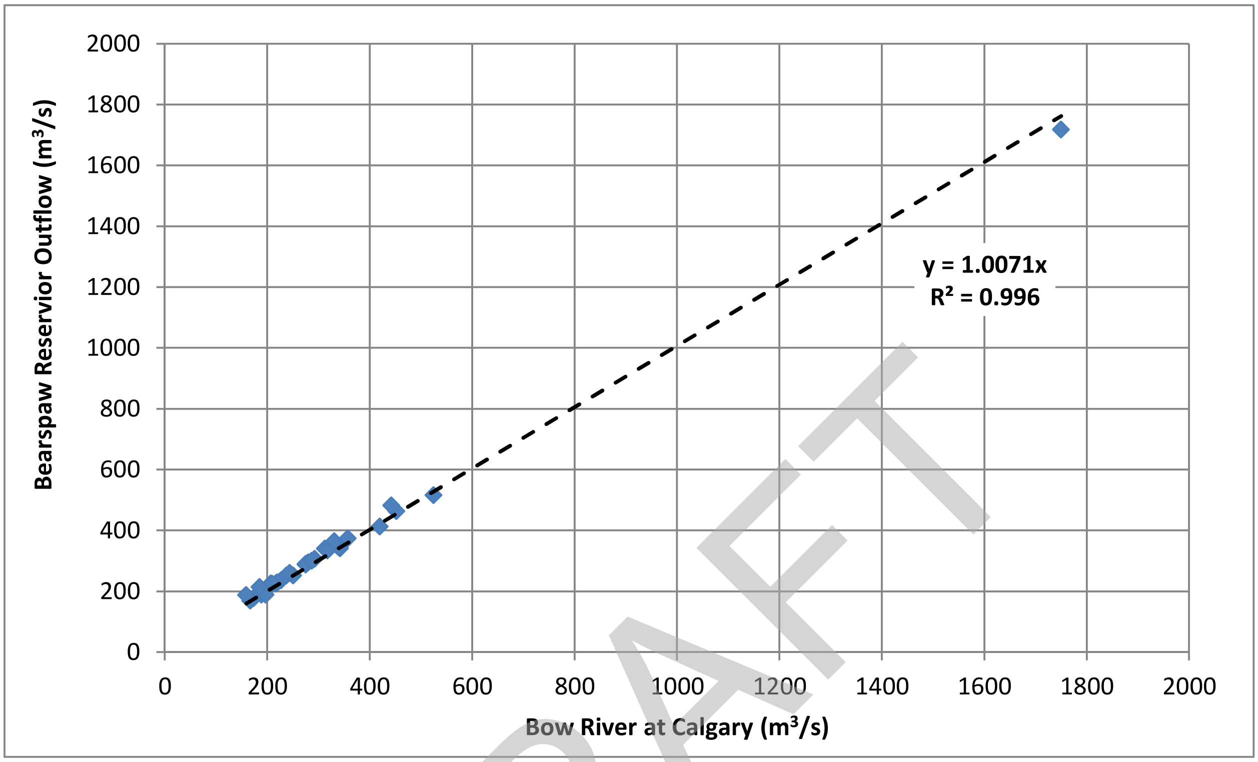


Figure A-7: Bow River below Bearspaw Dam (Bearspaw Reservoir Outflow) extended using Bow River at Calgary



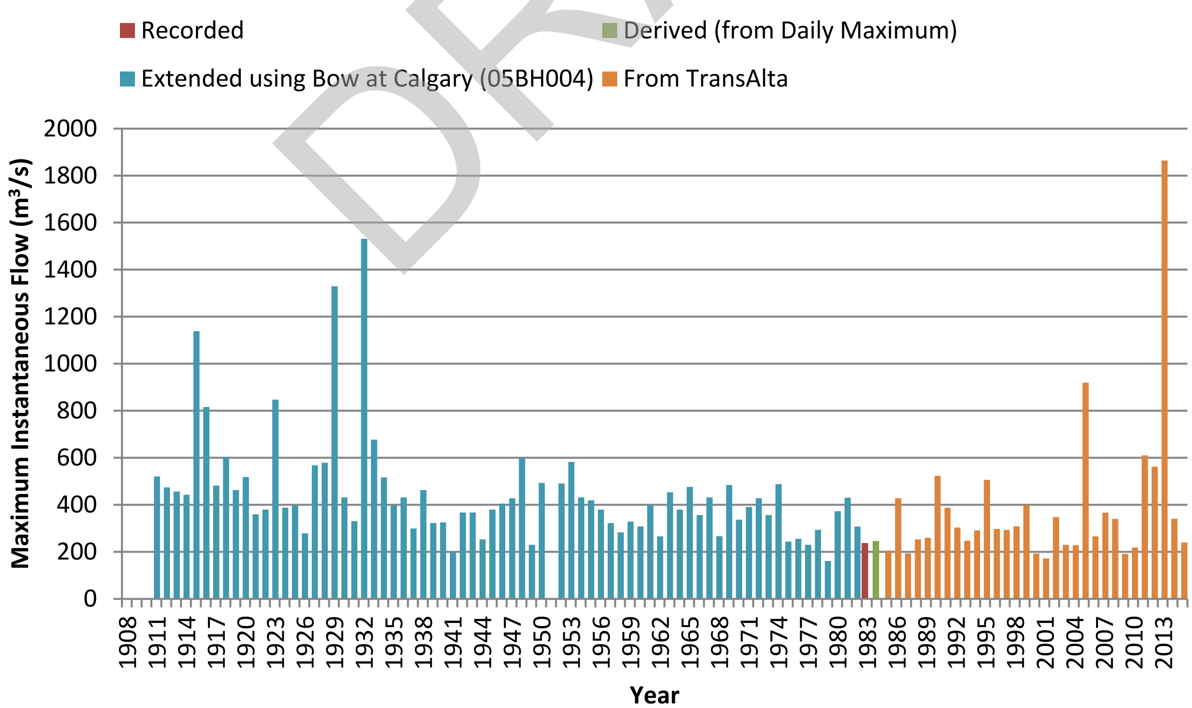
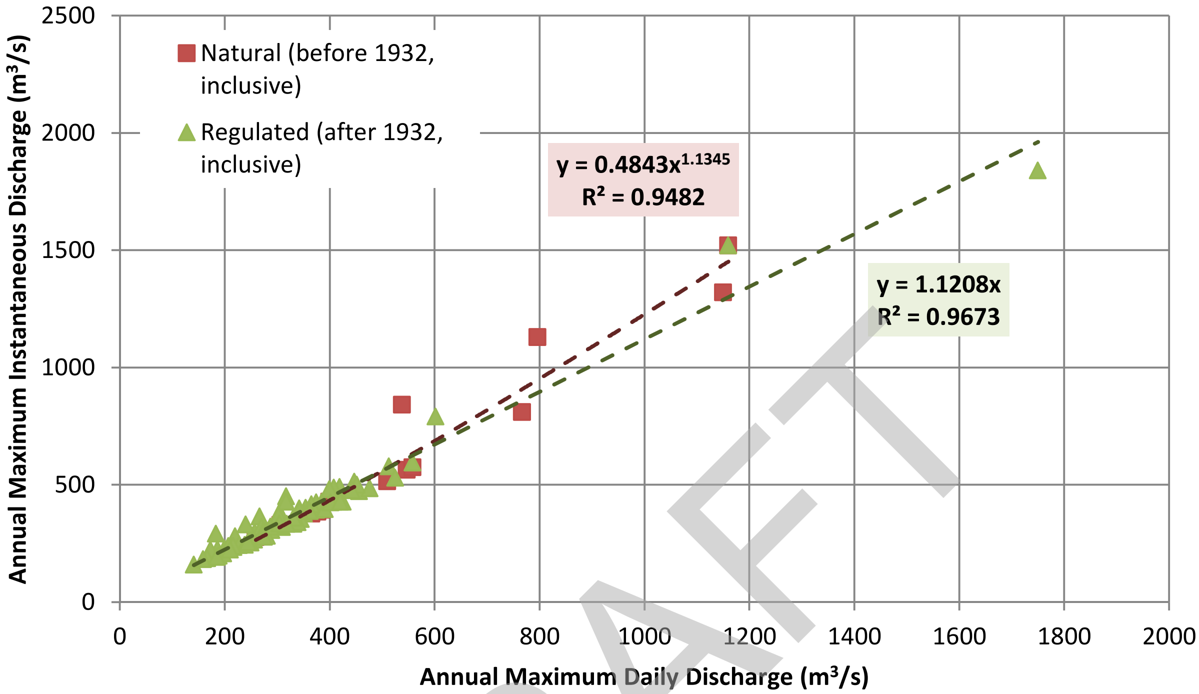


Figure A-8: Bow River at Calgary (05BH004)



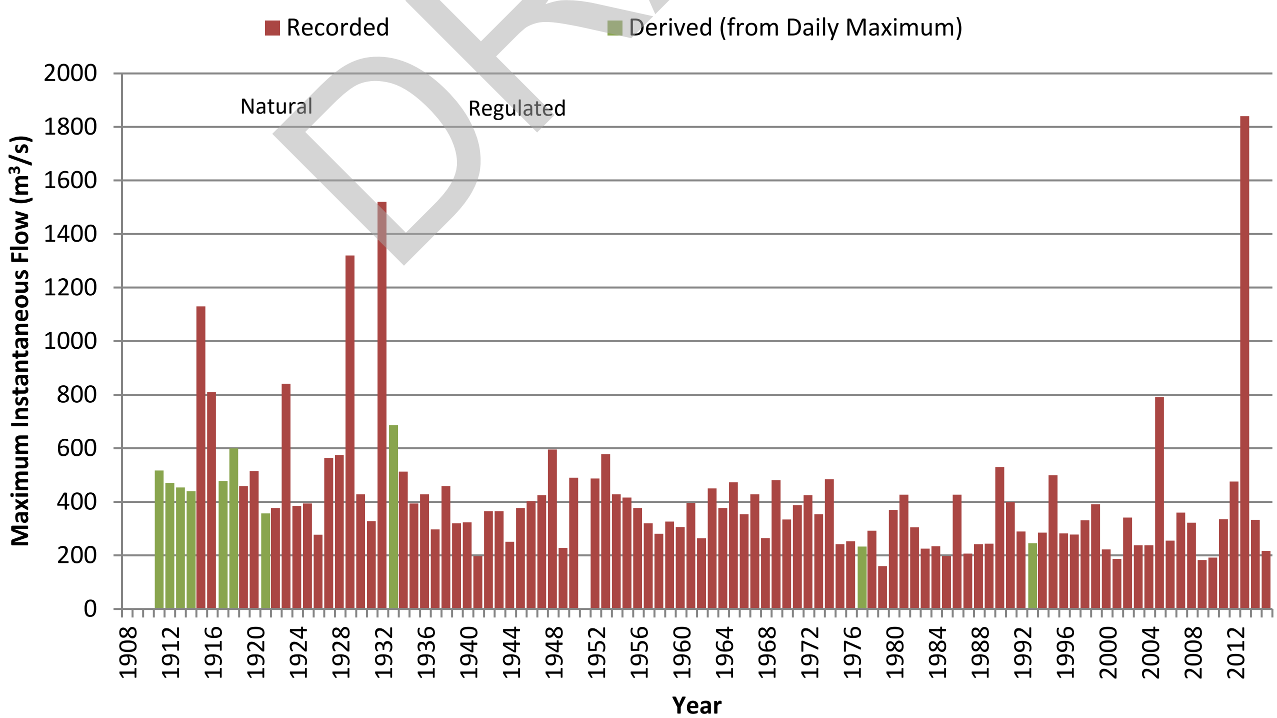
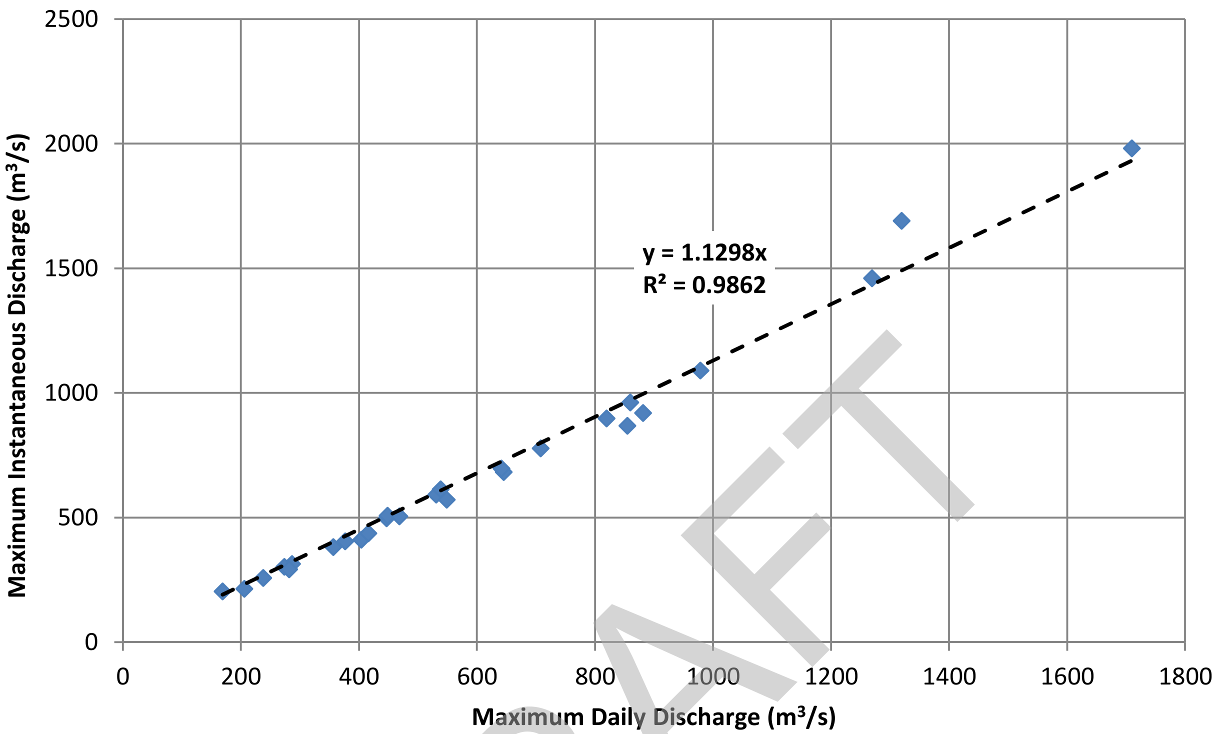


Figure A-9: Bow River below Carseland Dam (05BM002)



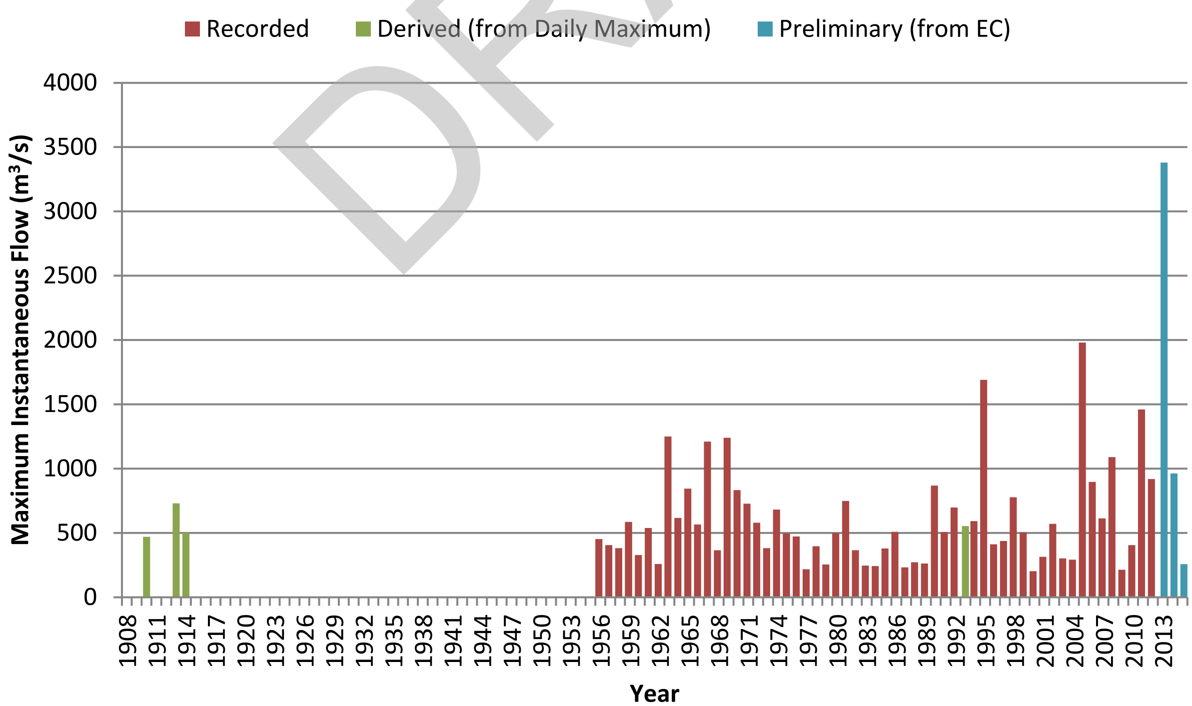
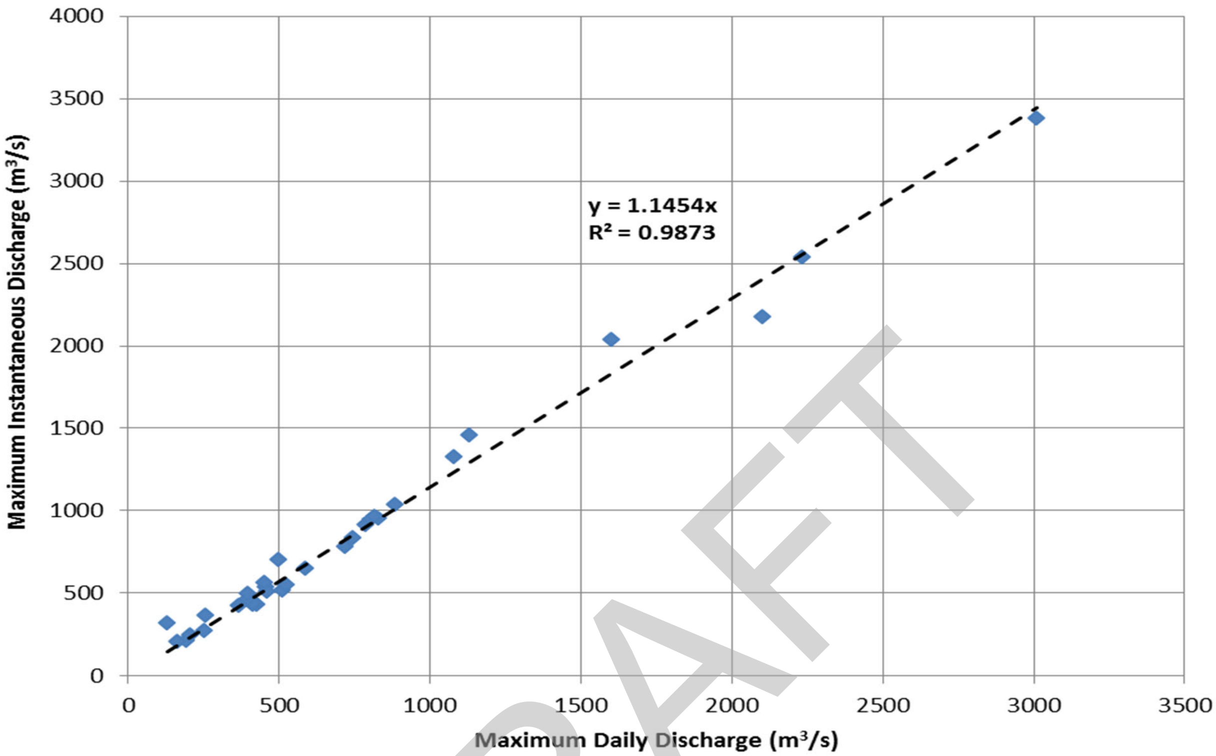


Figure A-10: Bow River below Bassano Dam (05BM004)



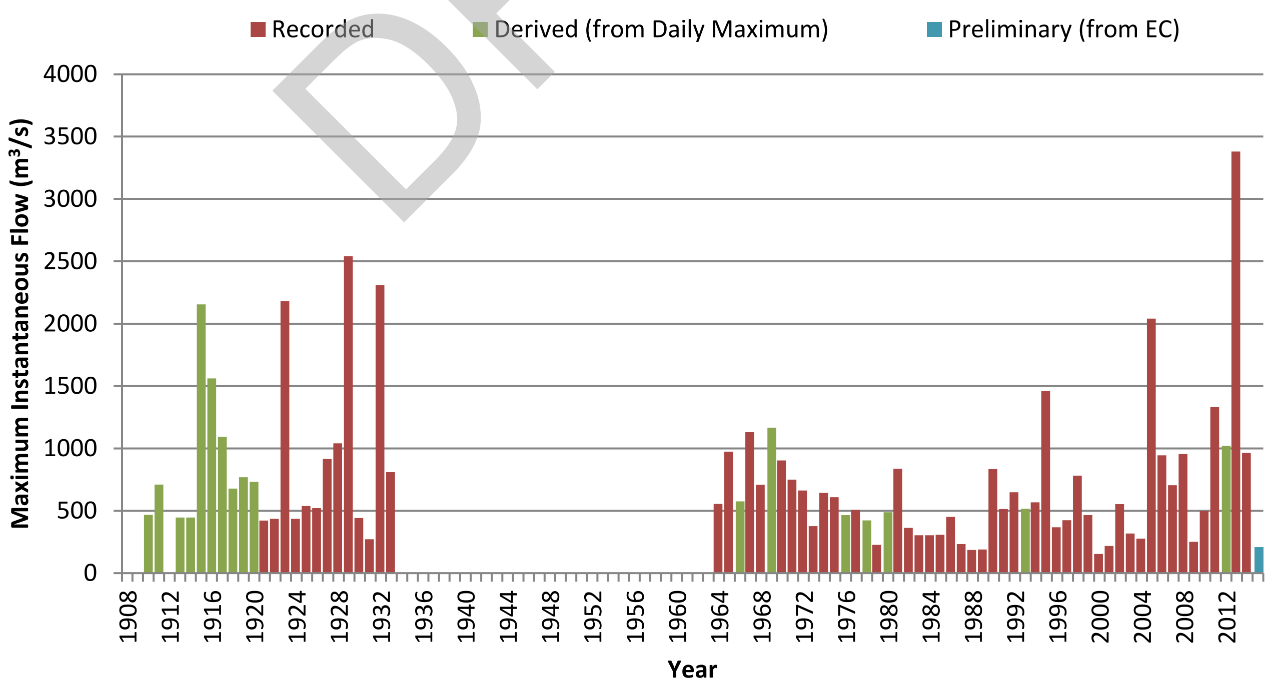
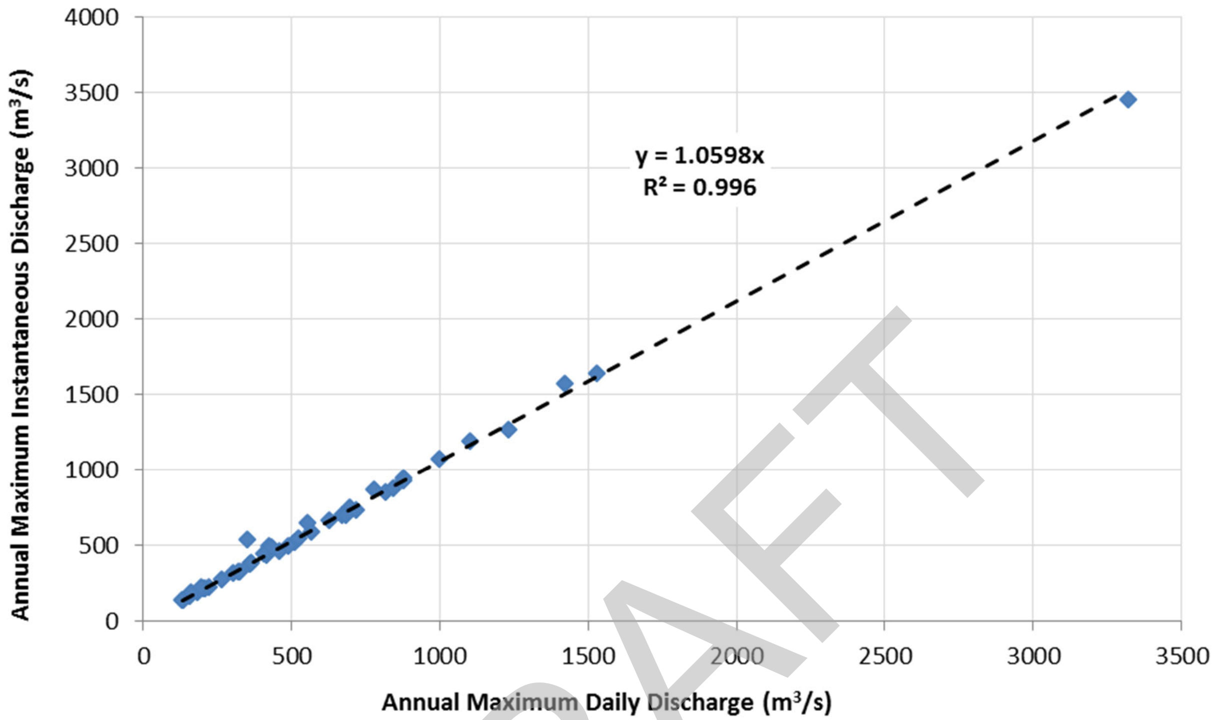


Figure A-11: Bow River near the Mouth - Highway 524 (05BN012)



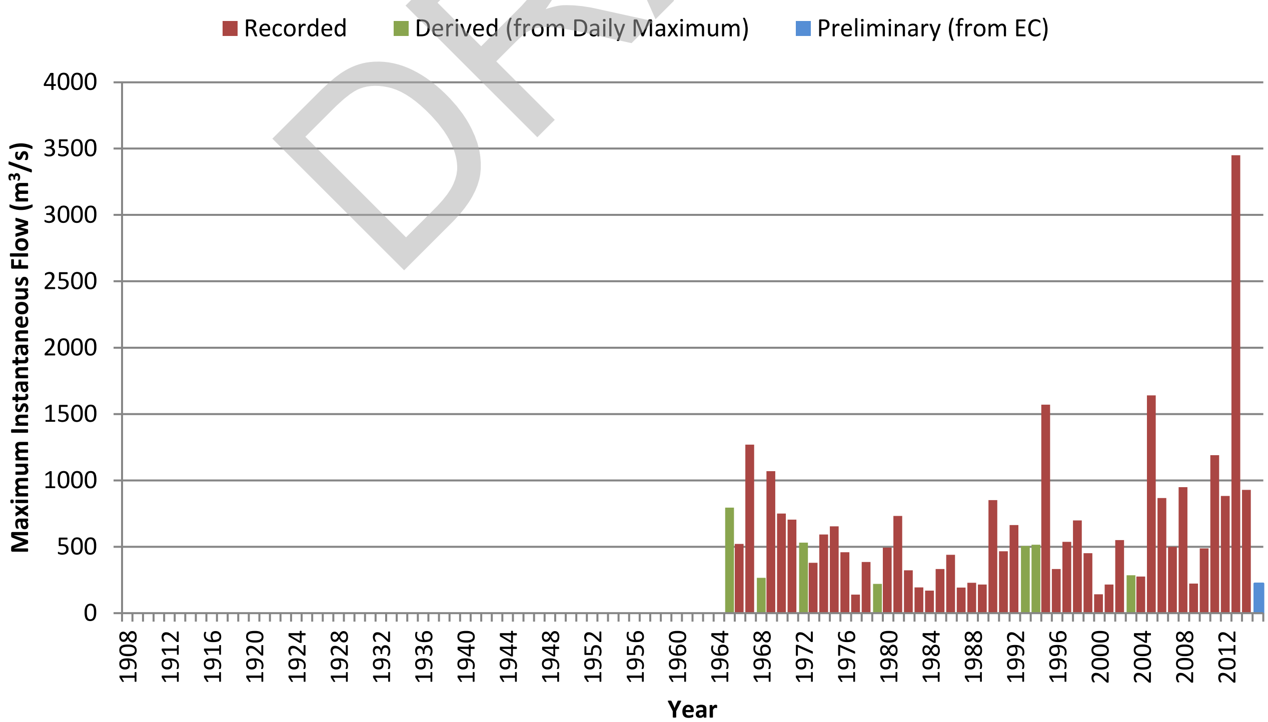
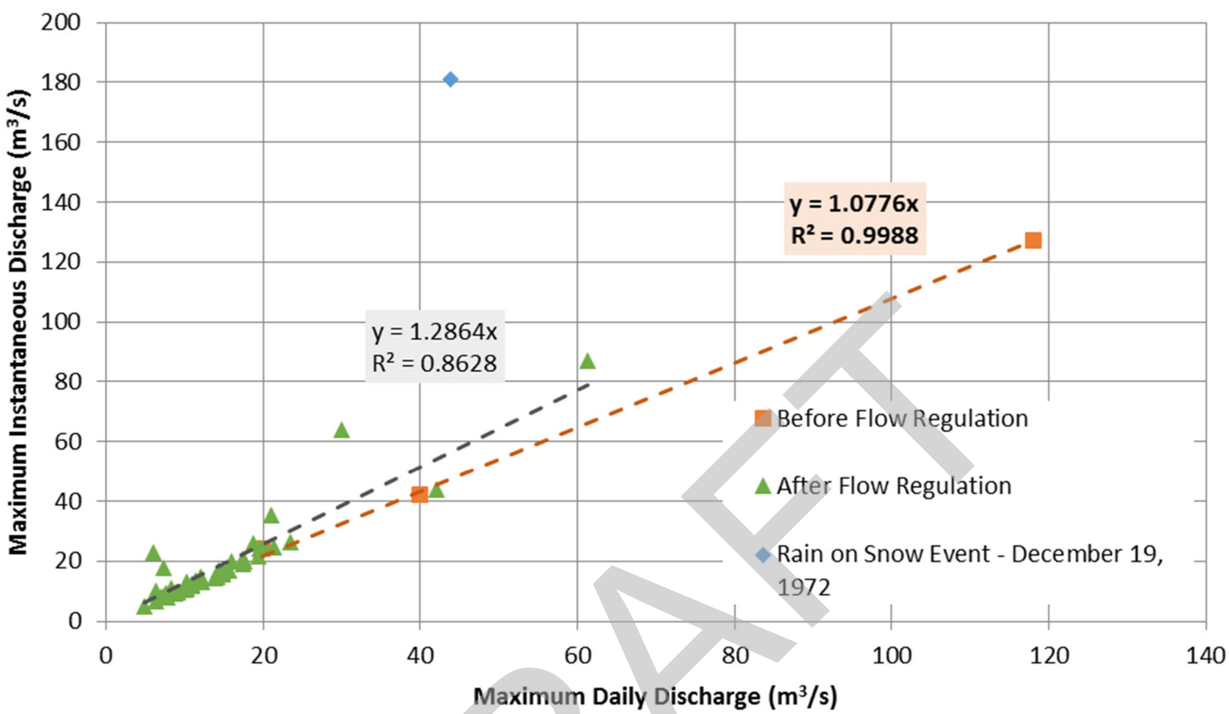


Figure A-12: Spray River at Banff (05BC001)



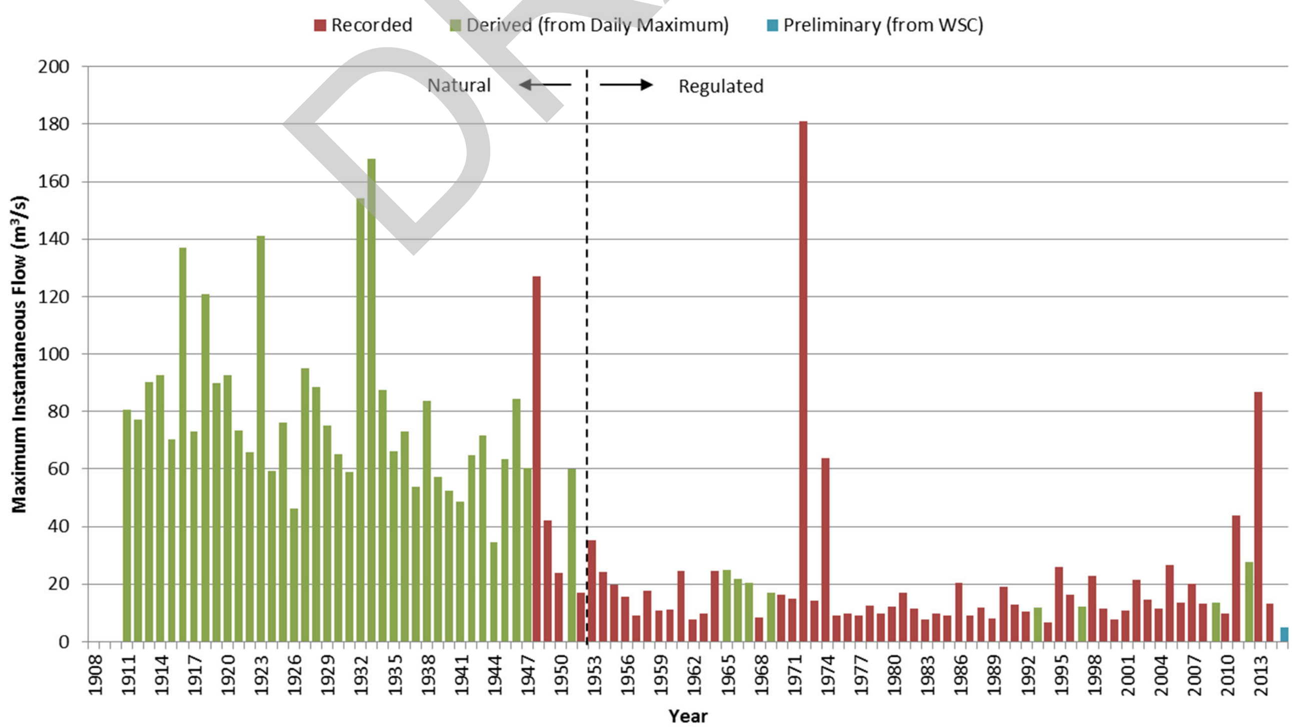


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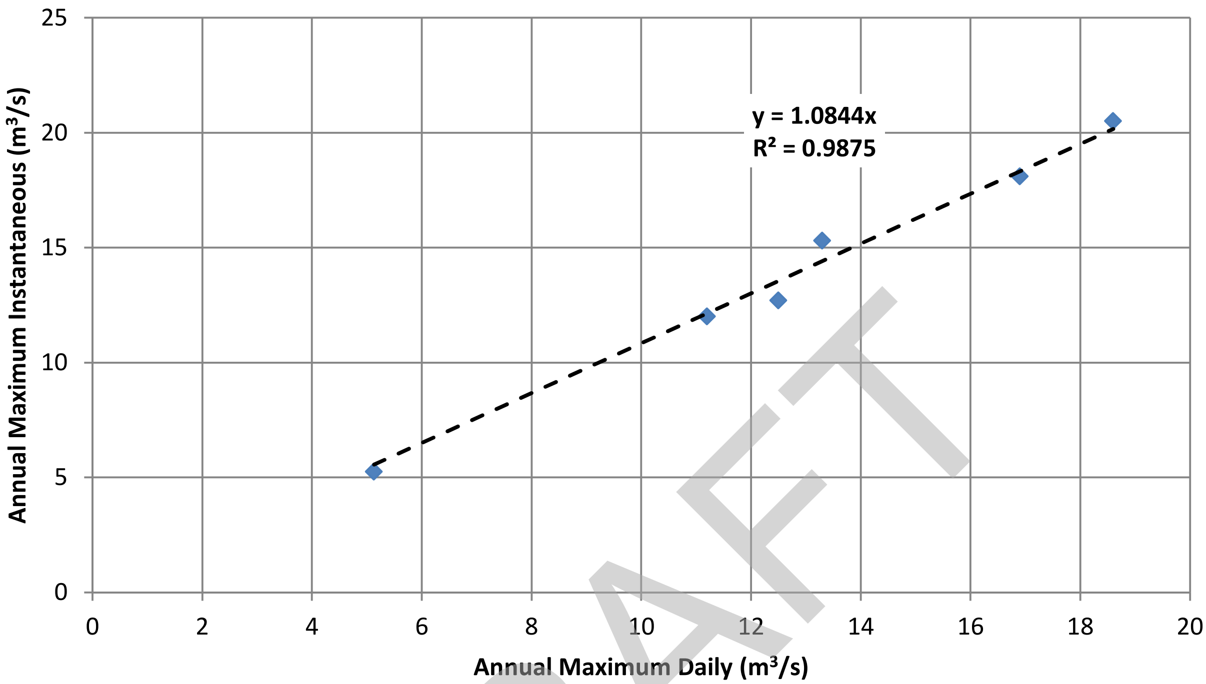
Figure A-13: Forty Mile Creek near Banff (05BB003)



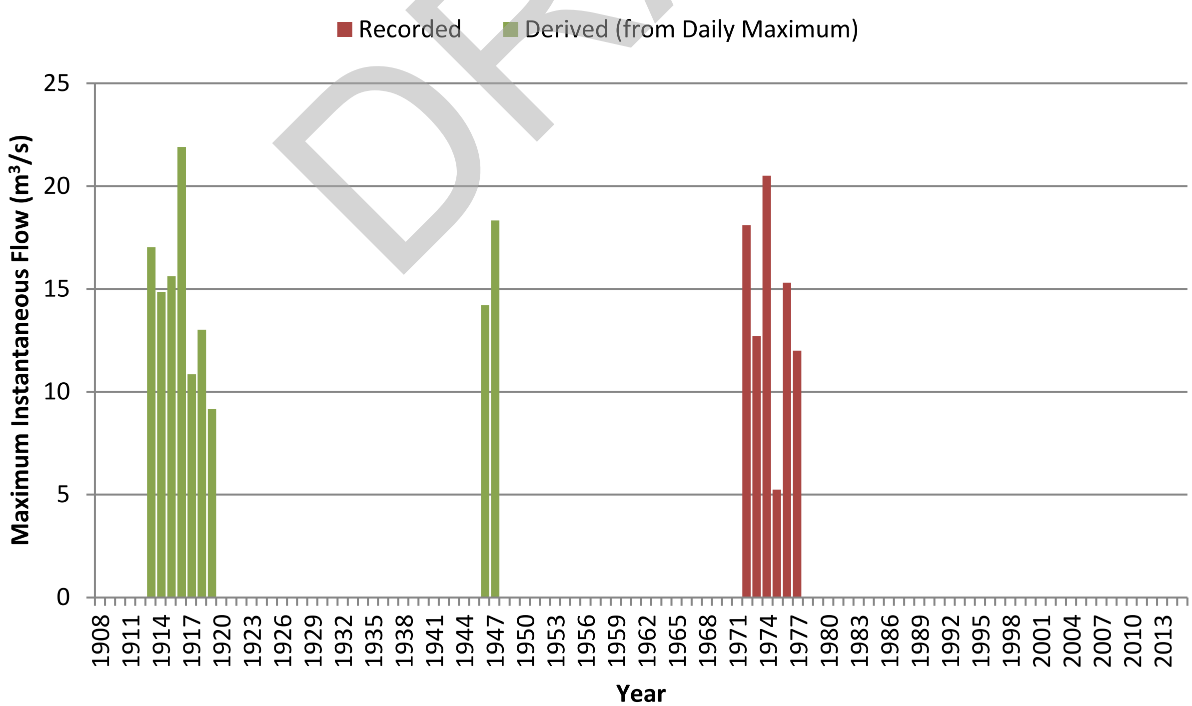
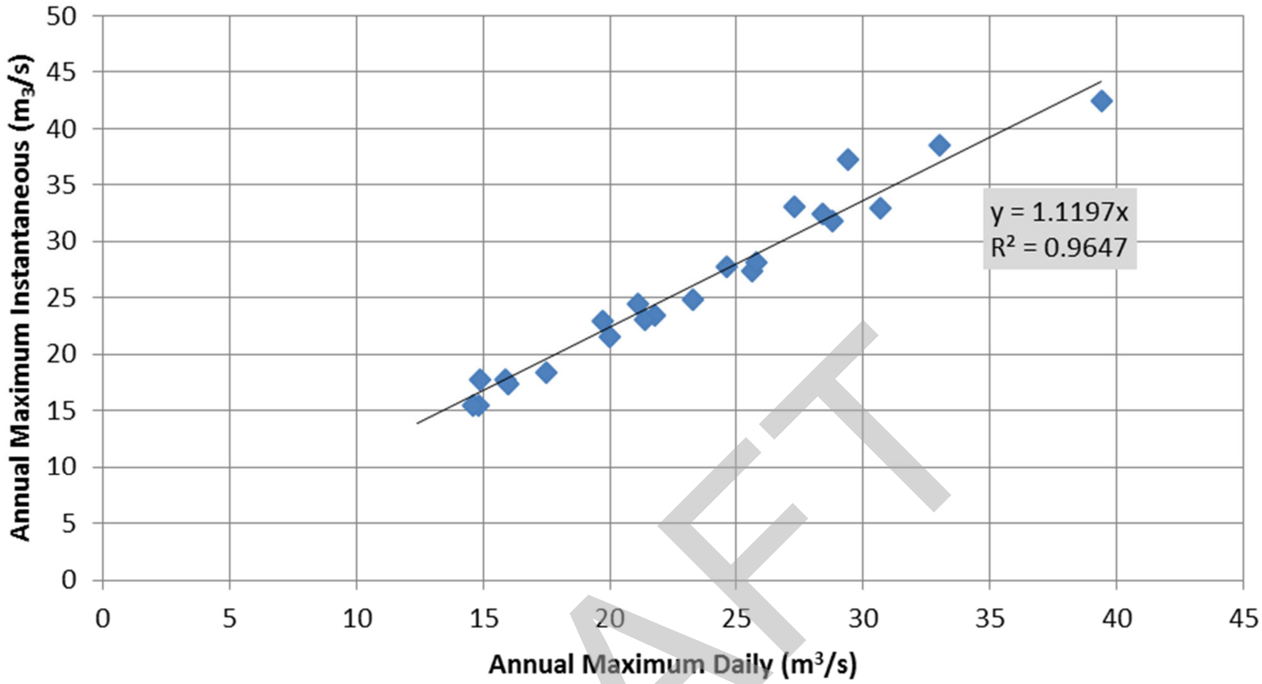
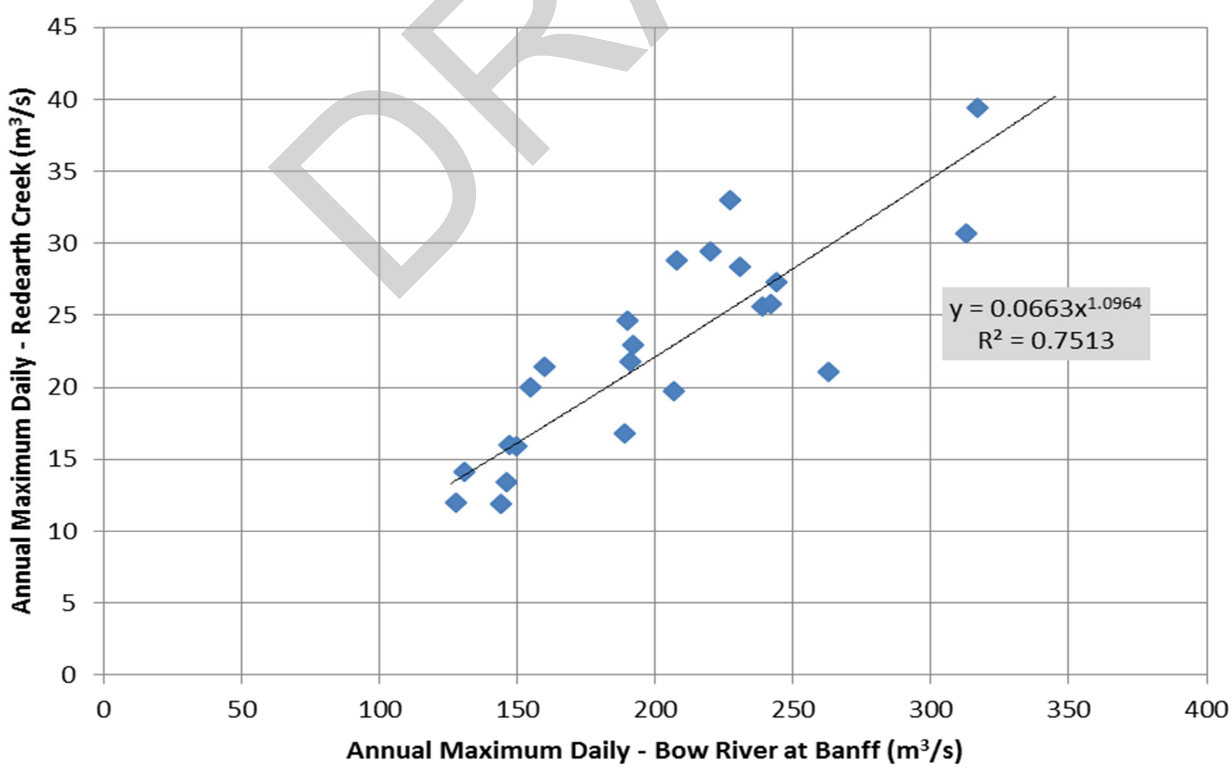


Figure A-14: Redearth Creek near the Mouth (05BB005)





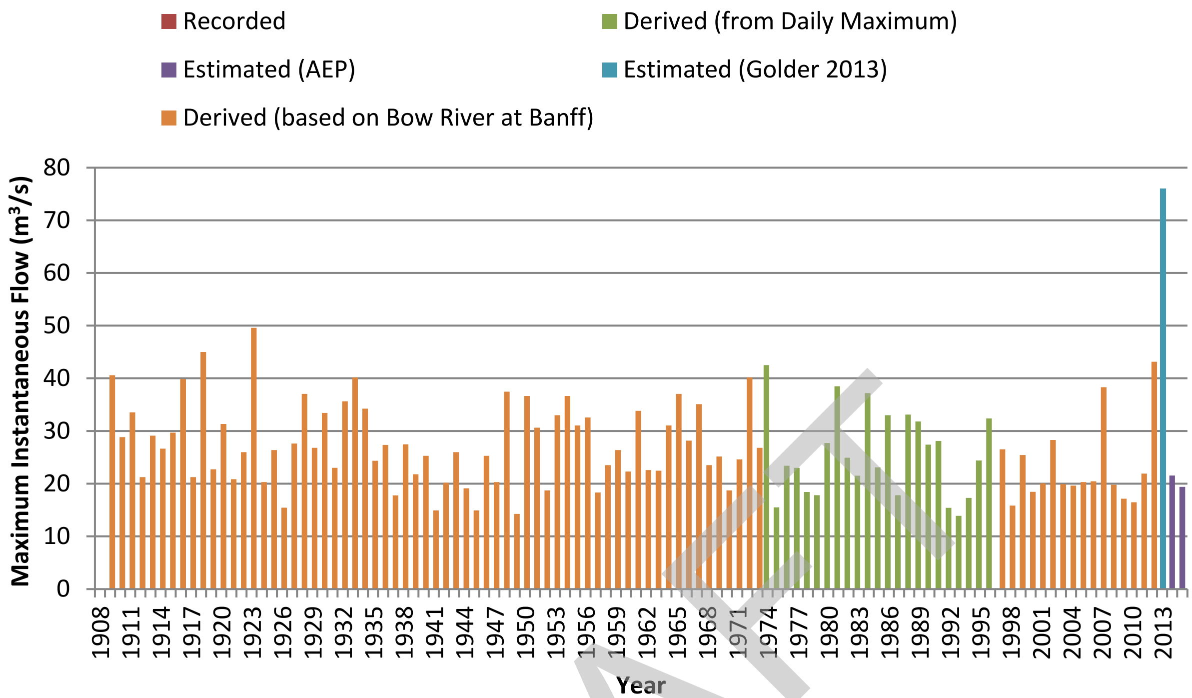
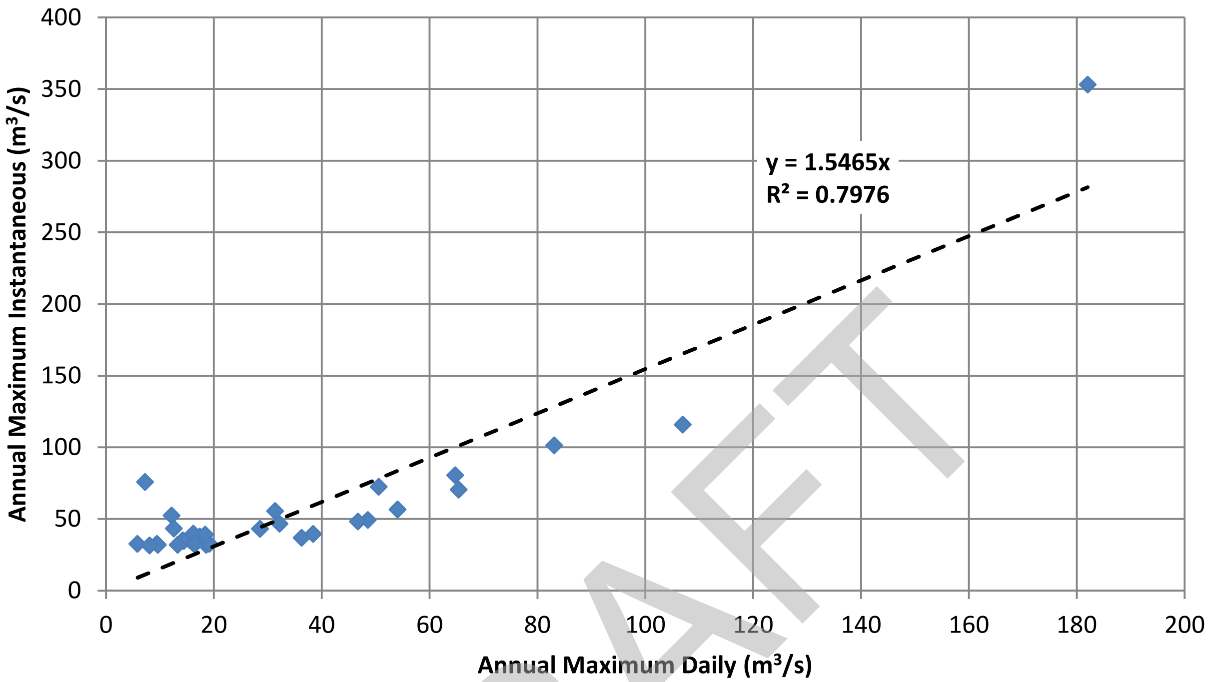

Recorded
Derived (from Daily Maximum)
Estimated (AEP)
Estimated (Golder 2013)
Derived (based on Bow River at Banff)
Maximum Instantaneous Flow (m³/s)
0
10
20
30
40
50
60
70
80
1908
1911
1914
1917
1920
1923
1926
1929
1932
1935
1938
1941
1944
1947
1950
1953
1956
1959
1962
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
2013
Year

Figure A-15: Kananaskis River below Barrier Dam (05BF025)



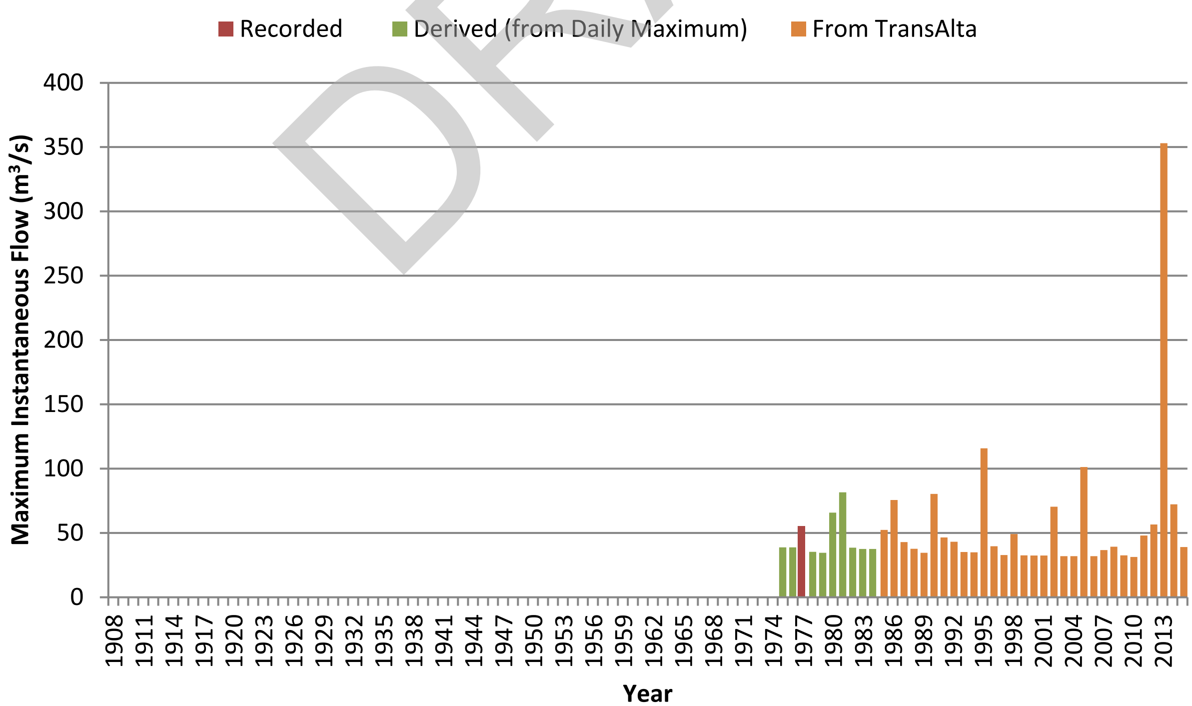
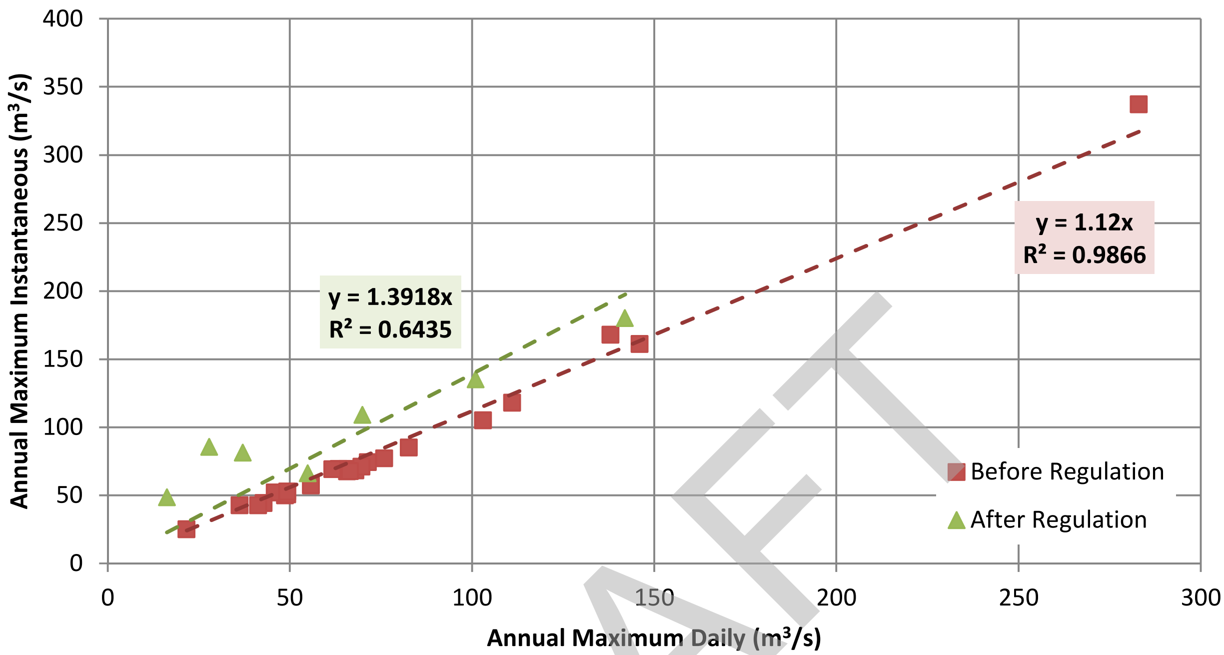


Figure A-16: Kananaskis River near Seebe (05BF001)



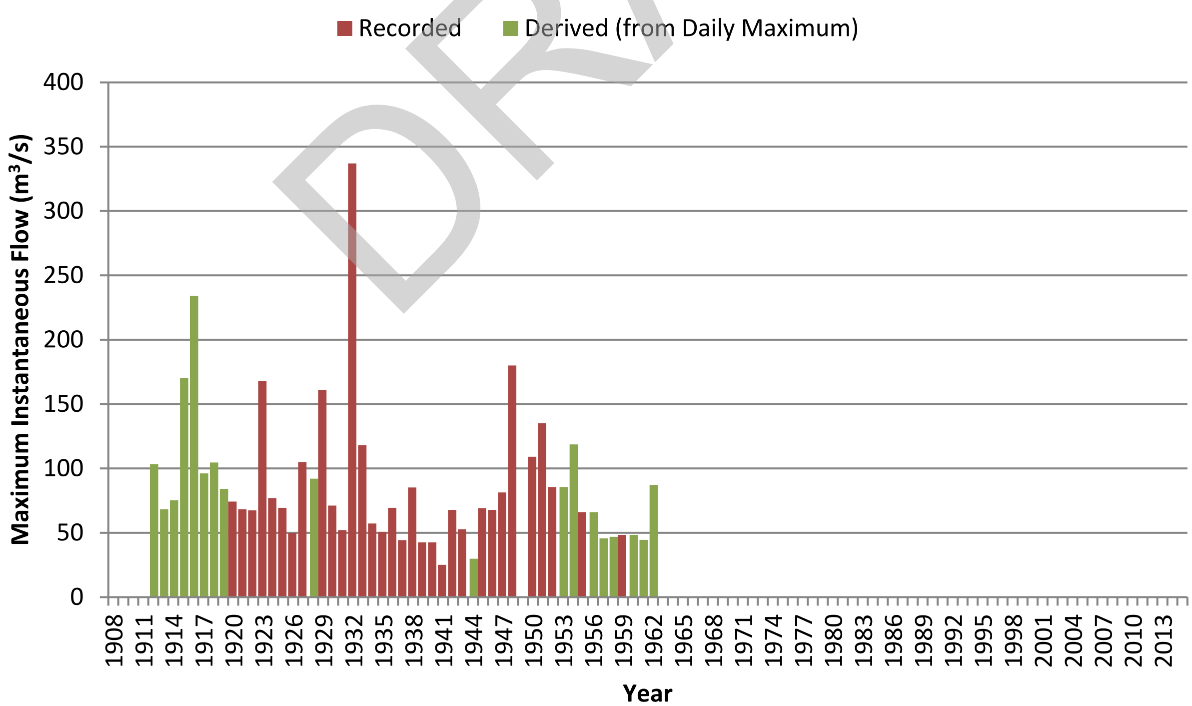
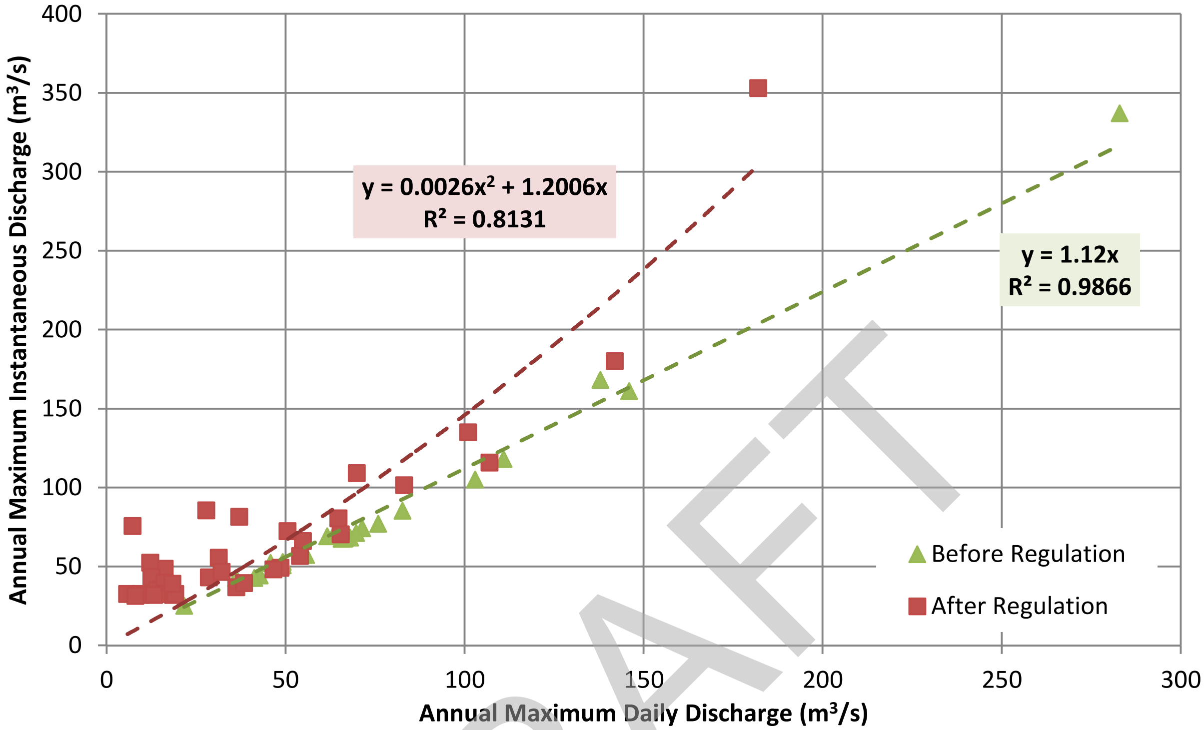


Figure A-17: Kananaskis River near Seebe (05BF001) extended using Kananaskis River below Barrier Dam (05BF025)



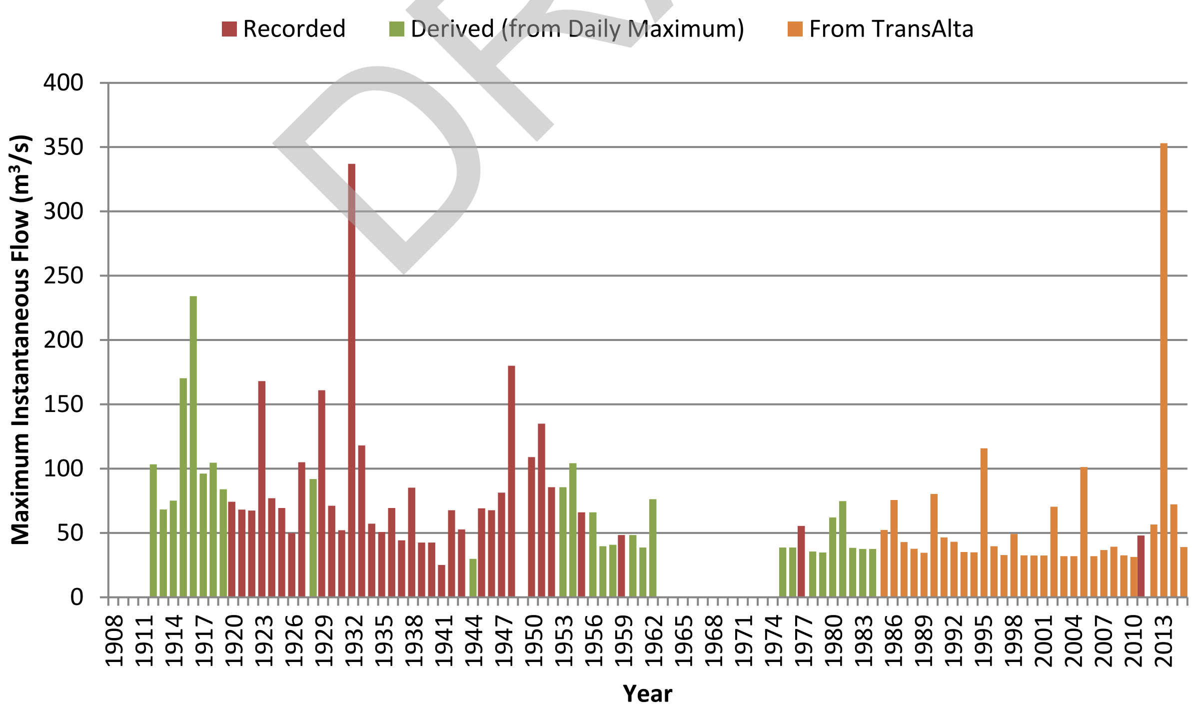
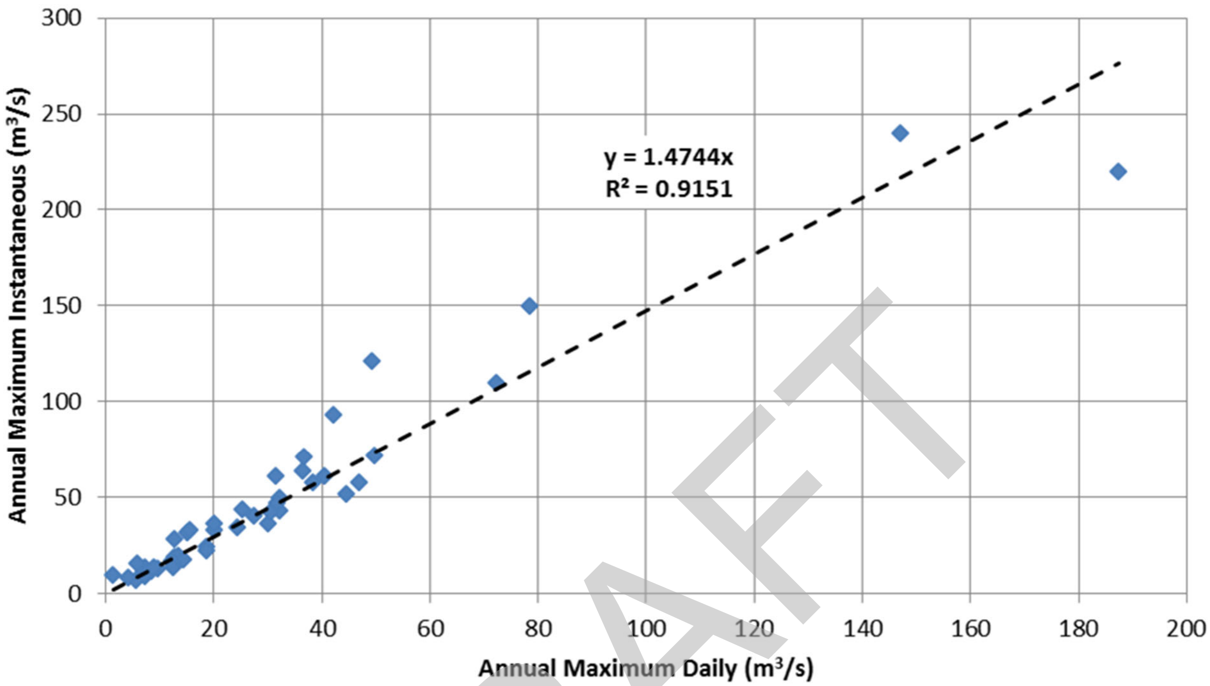


Figure A-18: Waiparous Creek near the Mouth (05BG006)



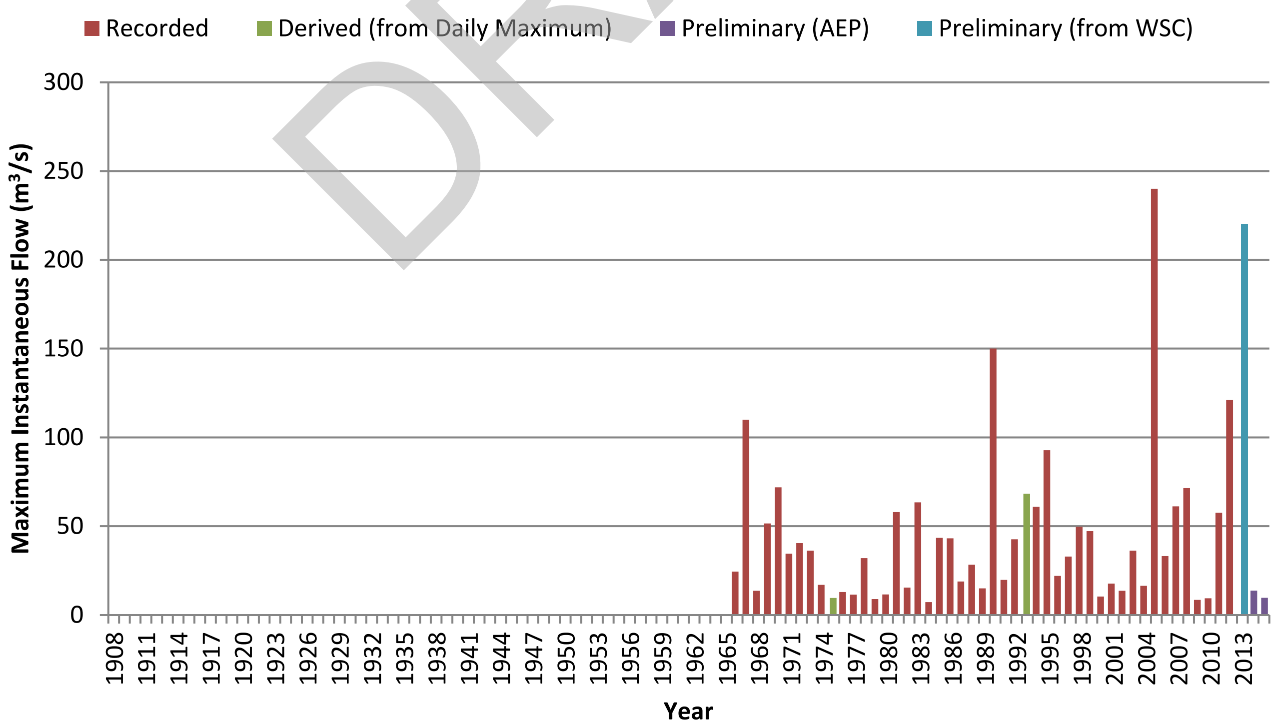
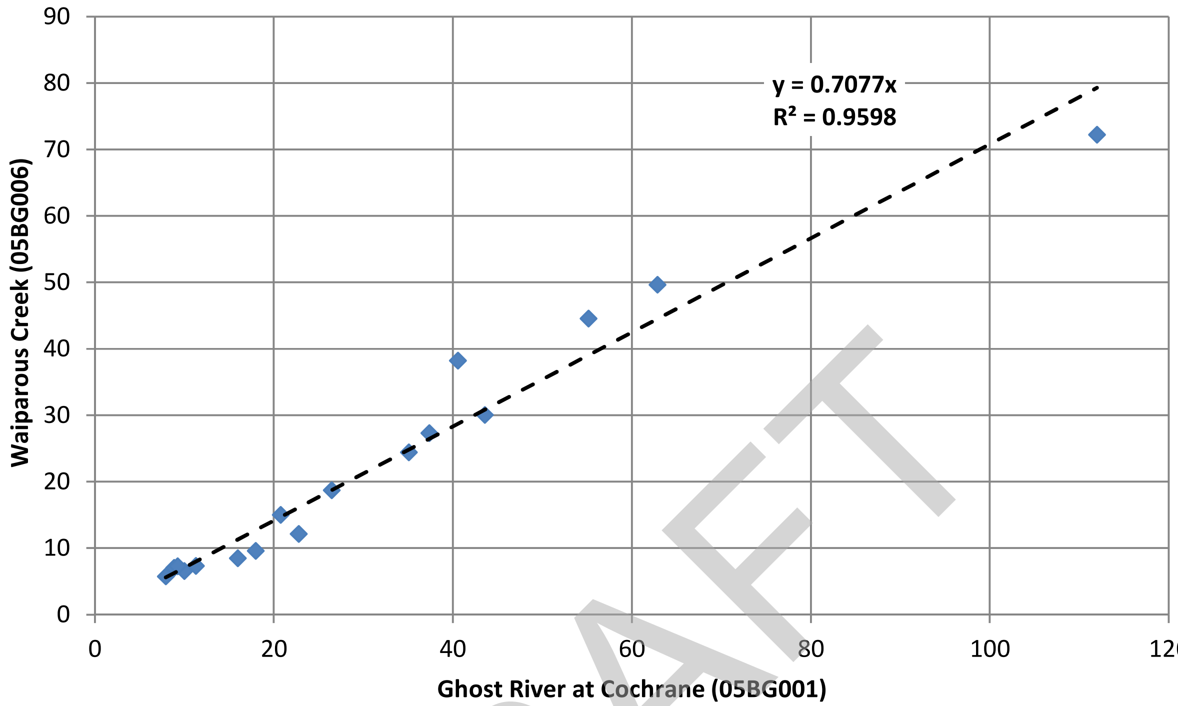
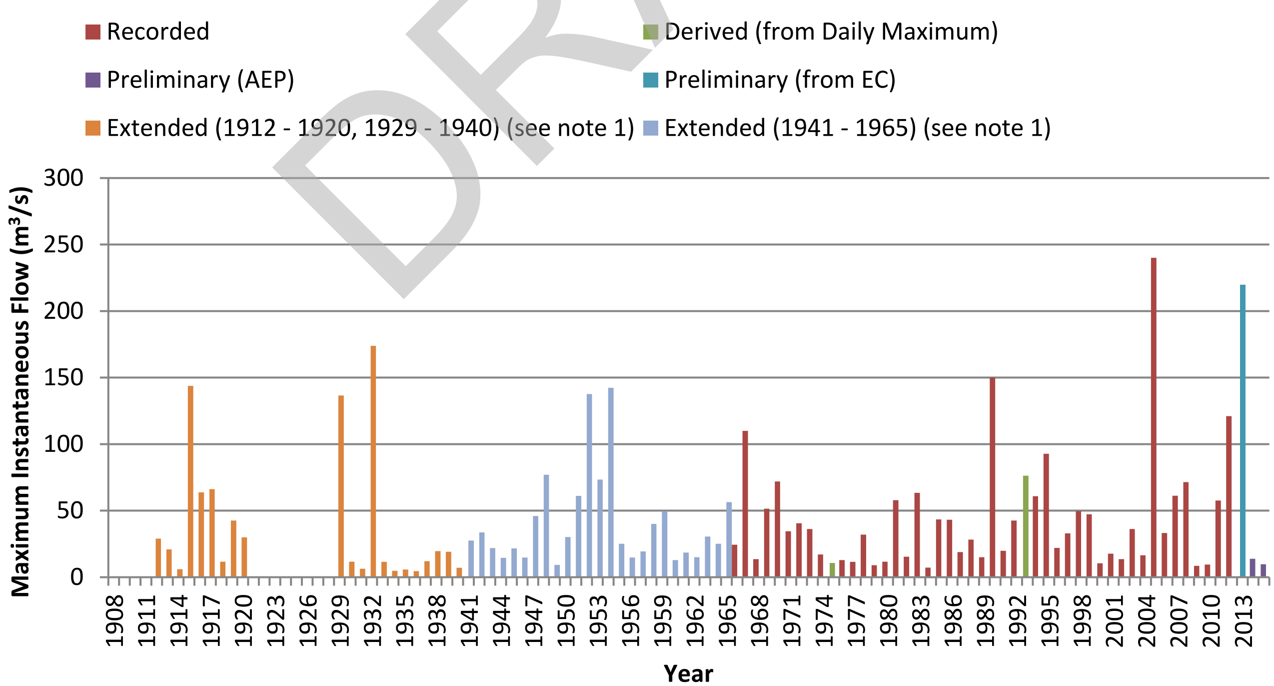


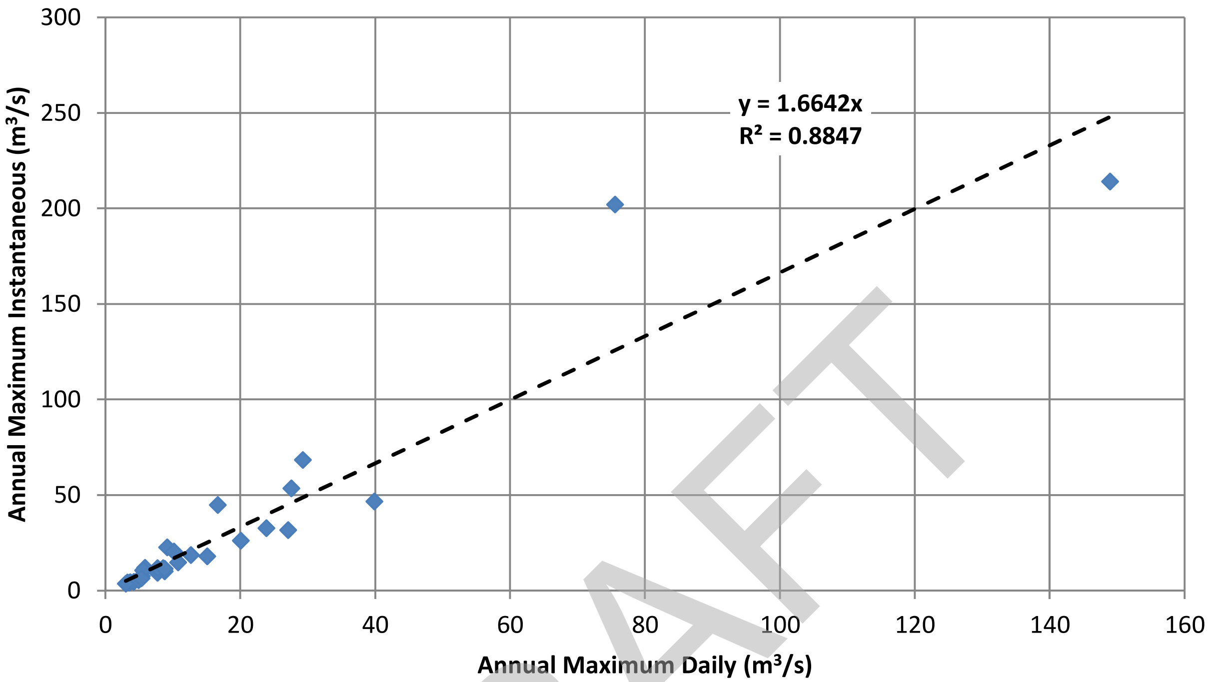
Figure A-19: Waiparous Creek near the Mouth (05BG006) (extended)





Note 1: extended using 05BG001 based on proportion of drainage area (no Ghost Diversion)
Note 2: Extended using 05BG001 based on flow relationship (Ghost Diversion is active during this period)

Figure A-20: Ghost River above Waiparous Creek (05BG010)



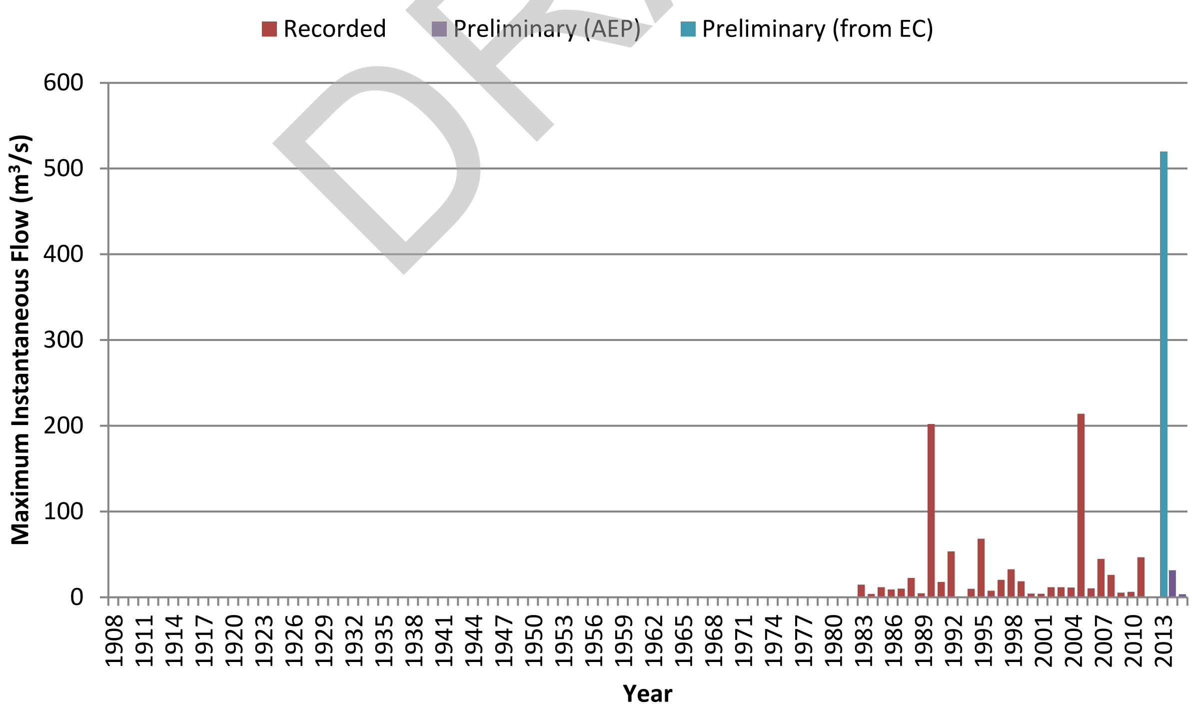


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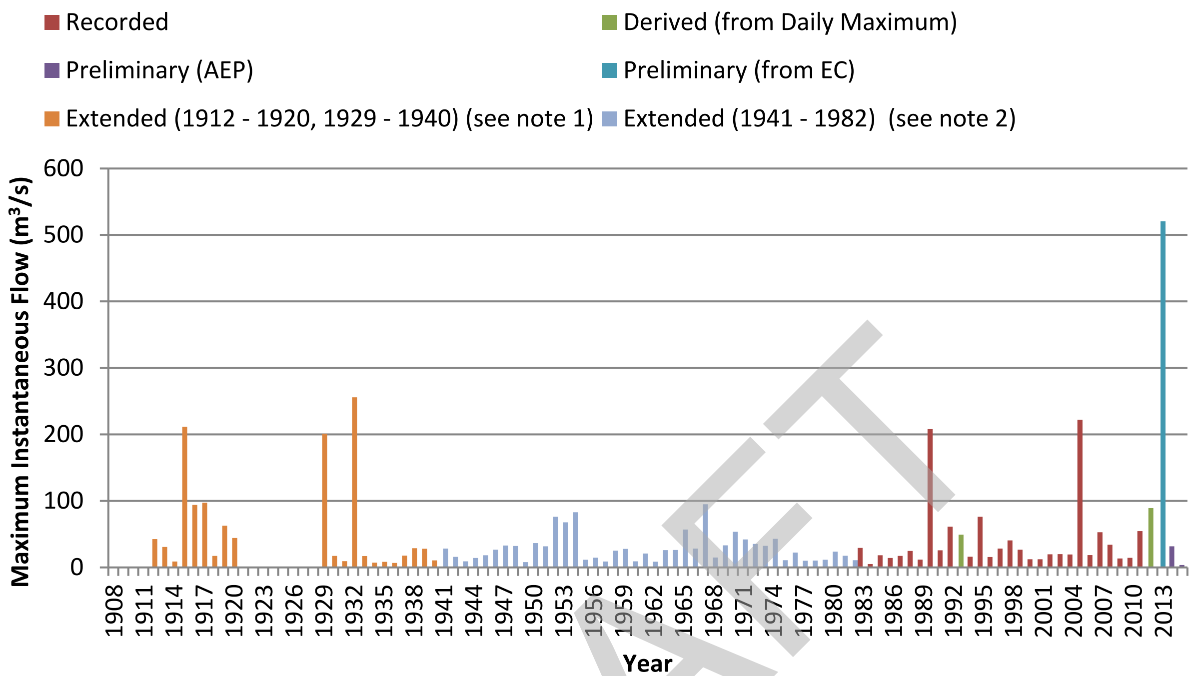
Figure A-21: Ghost River above Waiparous Creek with diversion added (extended)



Note 1: extended using 05BG001 based on proportion of drainage area
Note 2: extended using 05BG001 based on post-diversion flows

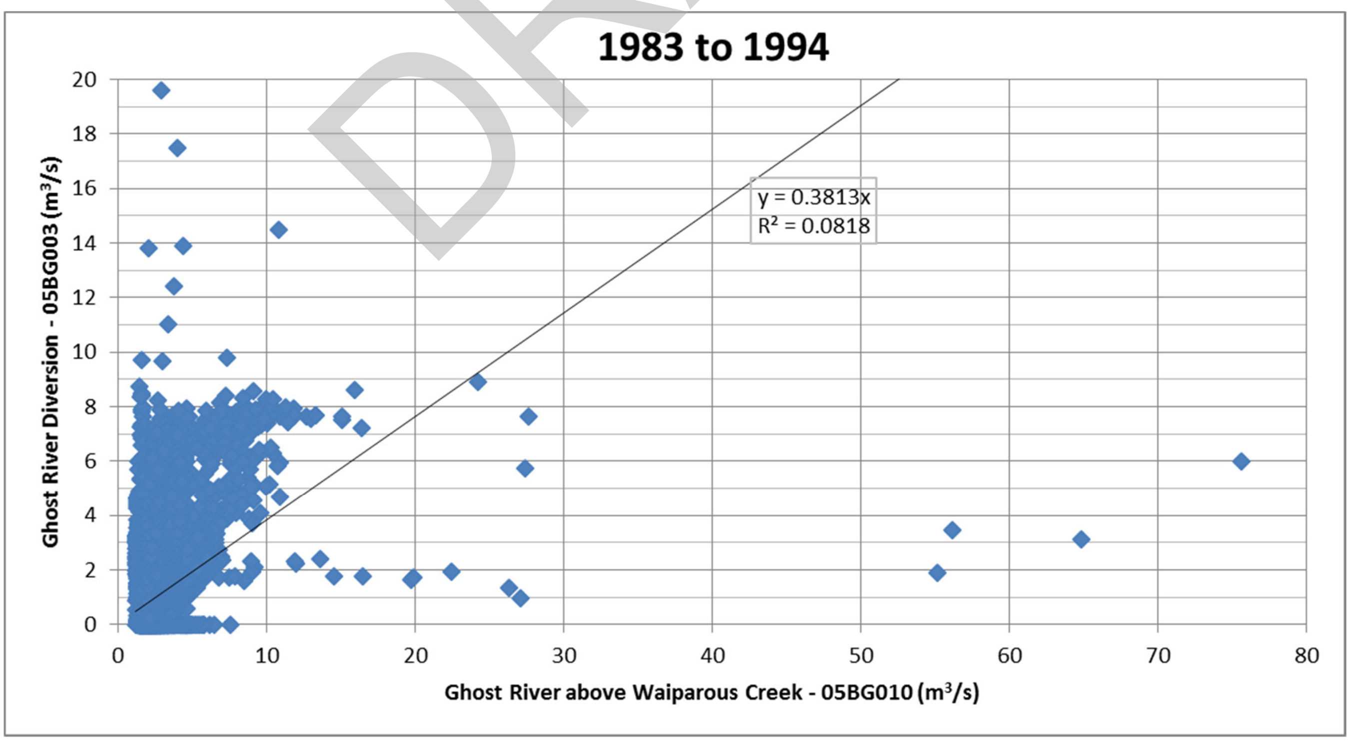
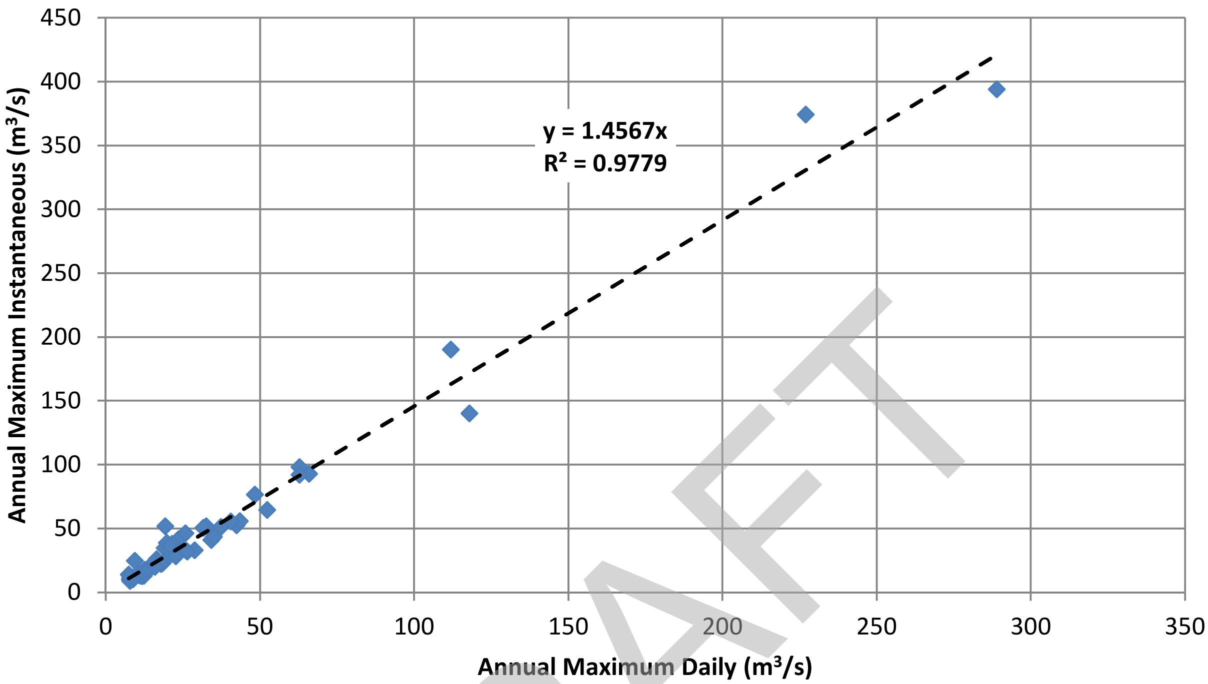


Figure A-22: Ghost River near Cochrane (05BG001)



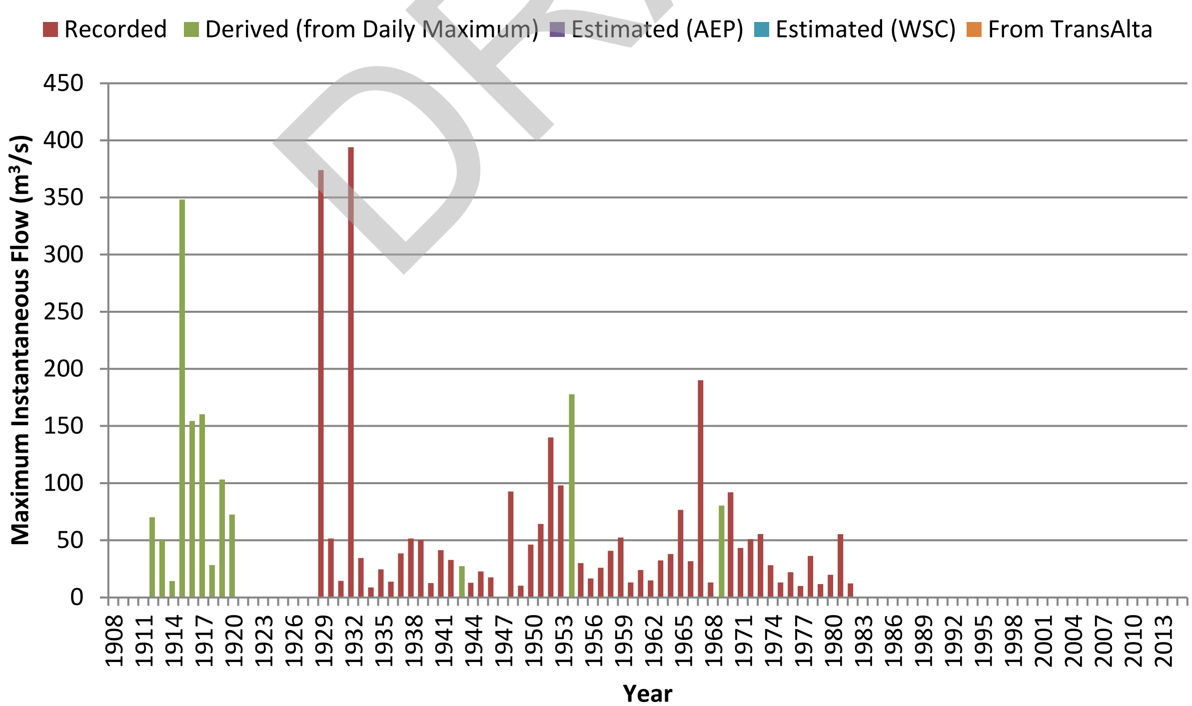
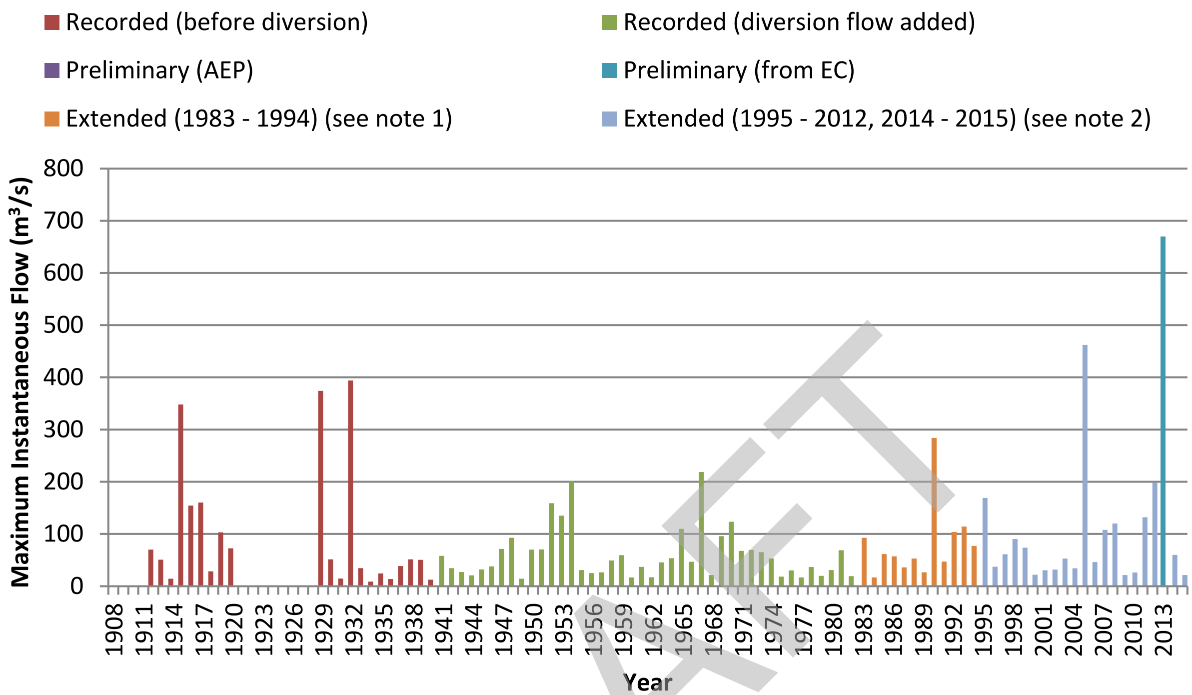


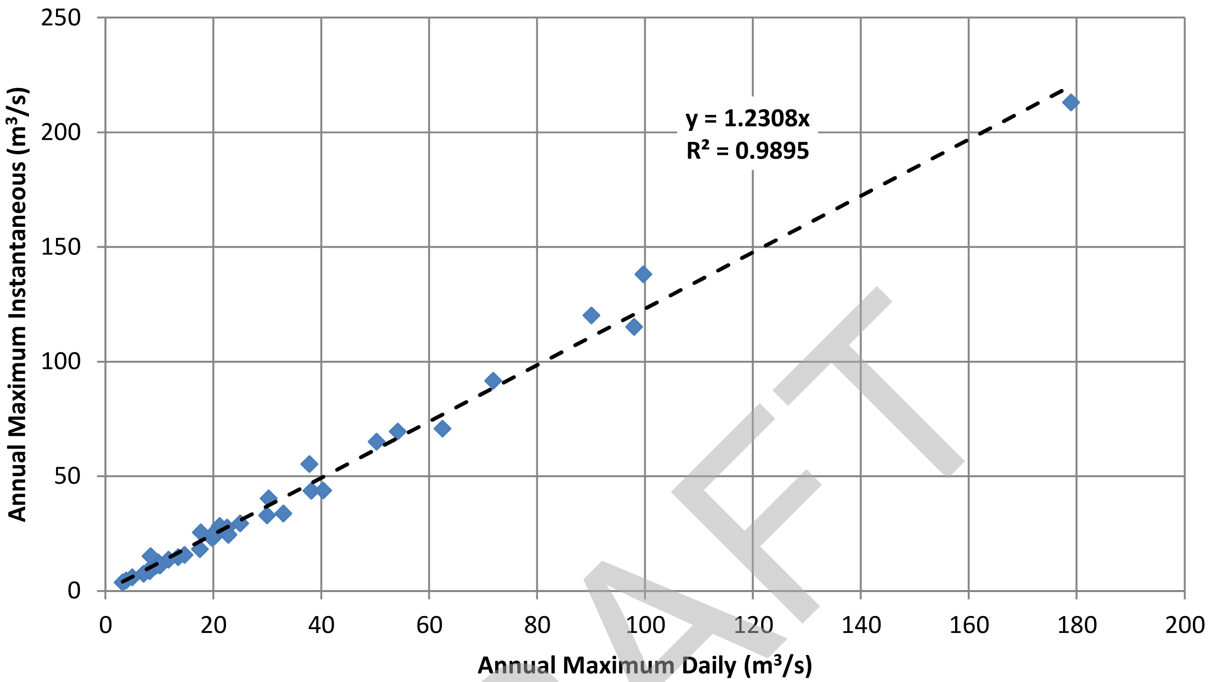
Figure A-23: Ghost River near Cochrane (05BG001) (extended)



Note 1: Extended using Waiparous Creek near the Mouth (05BG006), Ghost River Diversion to Lake Minnewanka (05BG003) and Ghost River above Waiparous Creek (05BG010) flows

Note 2: Extended using Waiparous Creek near the Mouth (05BG006), Ghost River above Waiparous Creek (05BG010) and assumed Ghost Diversion flows of 8 m³/s. for the sensitivity test, diversion flows of 30 m³/s were assumed for this period.

Figure A-24: Jumpingpound Creek near the Mouth (05BH009)



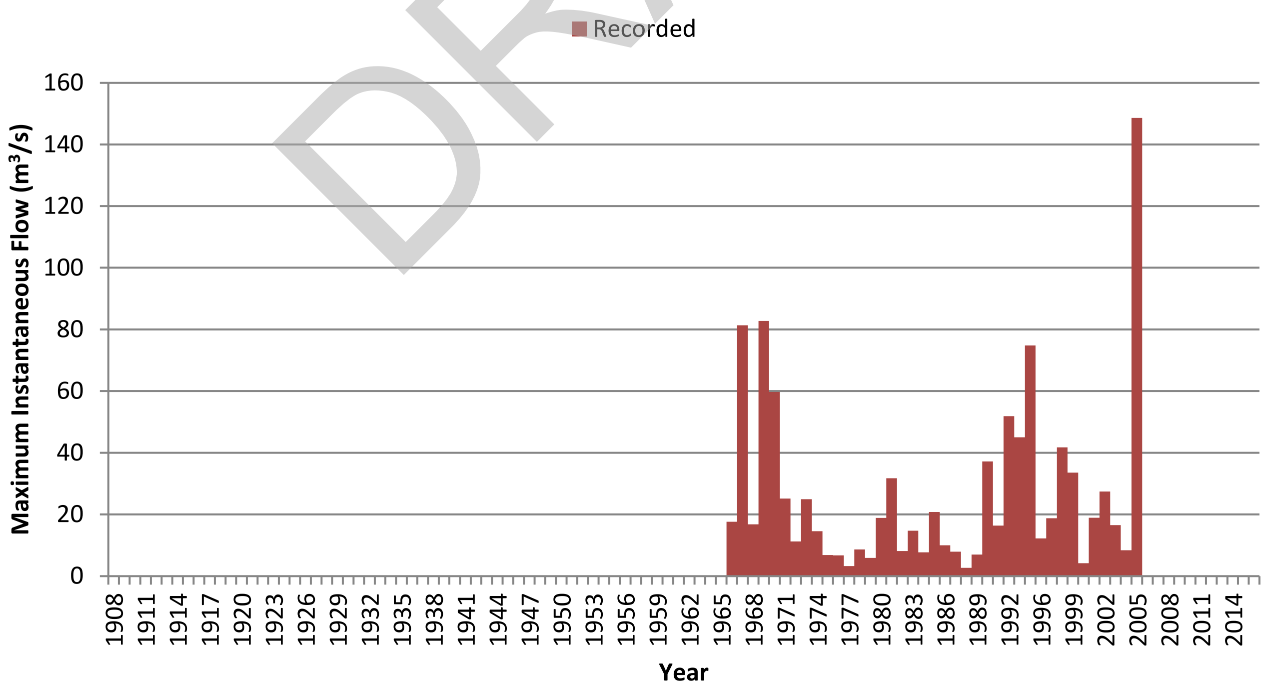
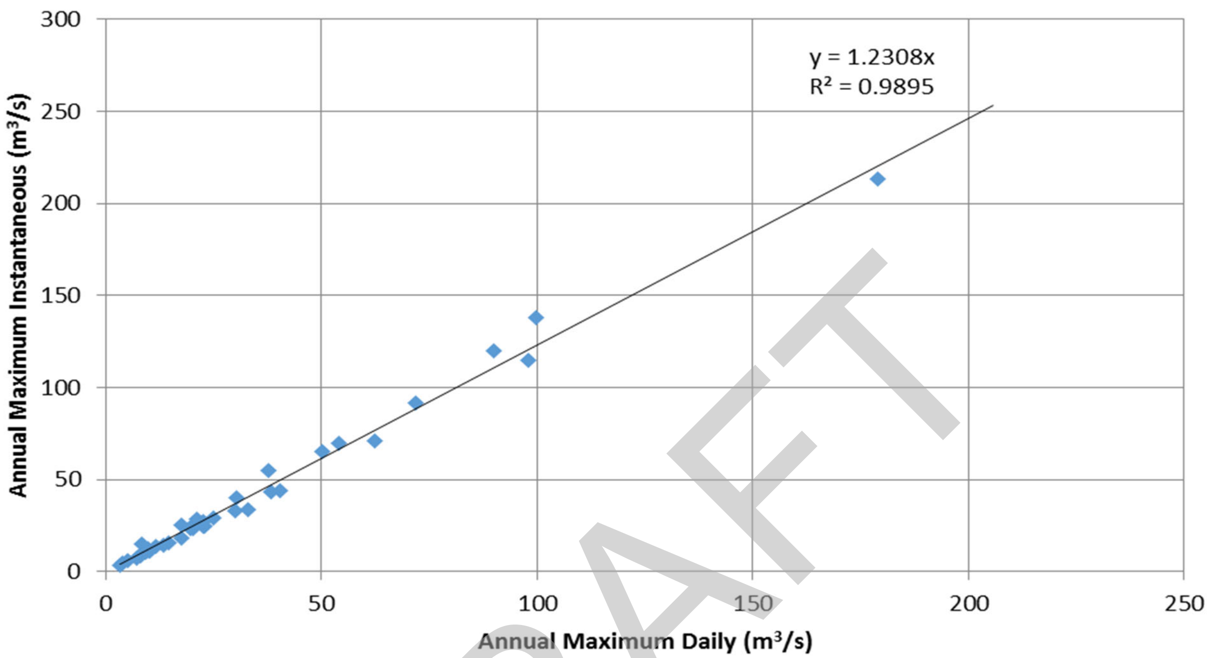


Figure A-25: Jumpingpound Creek near the Mouth (05BH009) (extended) –using flows at Jumpingpound Creek near Jumpingpound (05BH006) from 1908 to 1933, and Jumpingpound Creek at Township Road No. 252 (05BH015) from 2006 to 2015



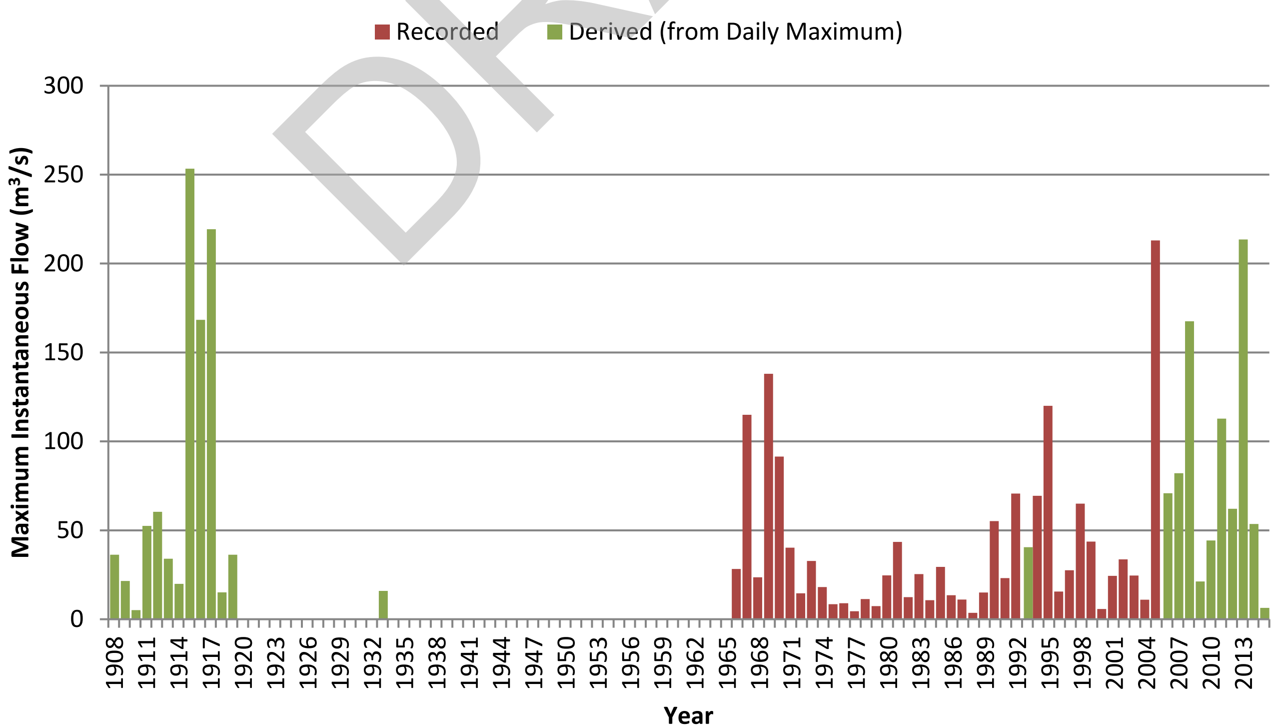
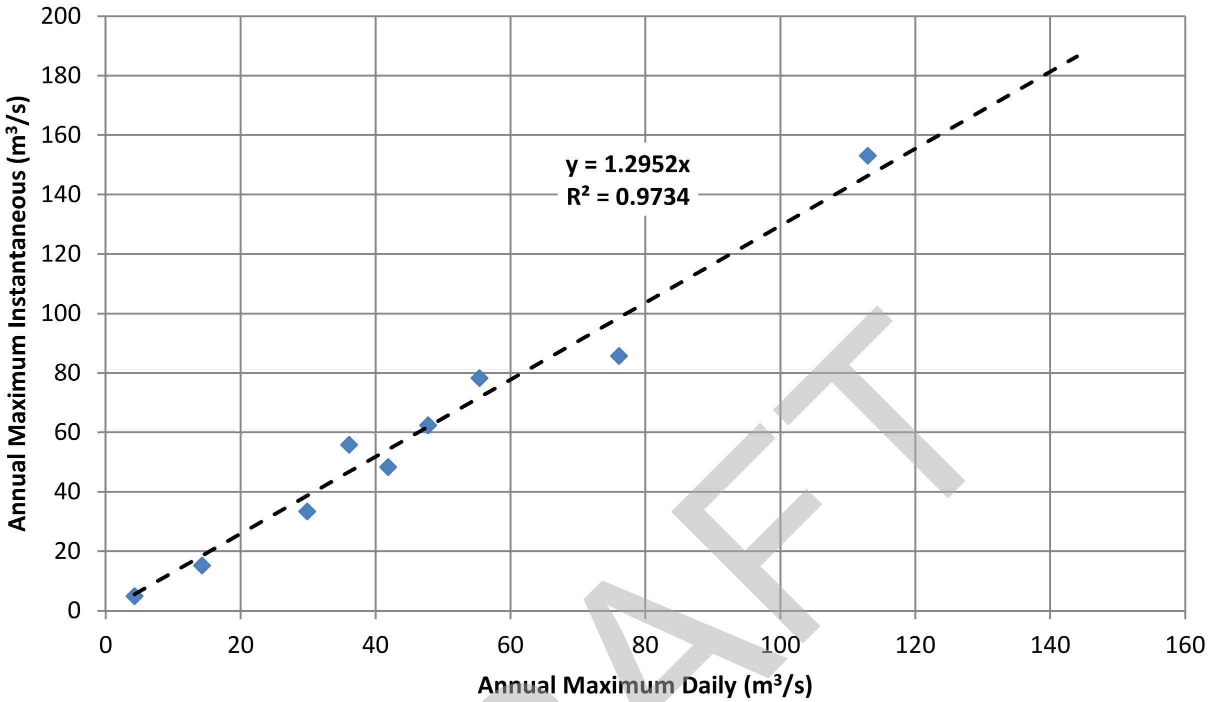


Figure A-26: Jumpingpound Creek at Township Road No. 252 (05BH015)



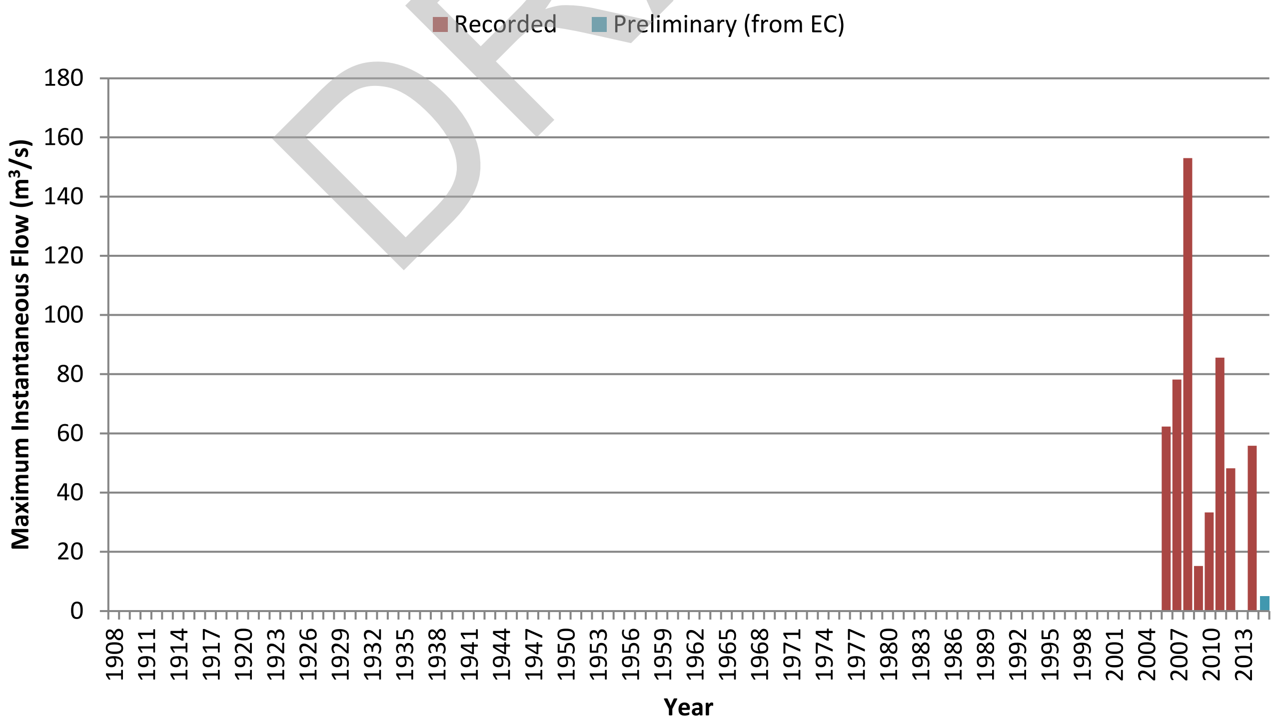
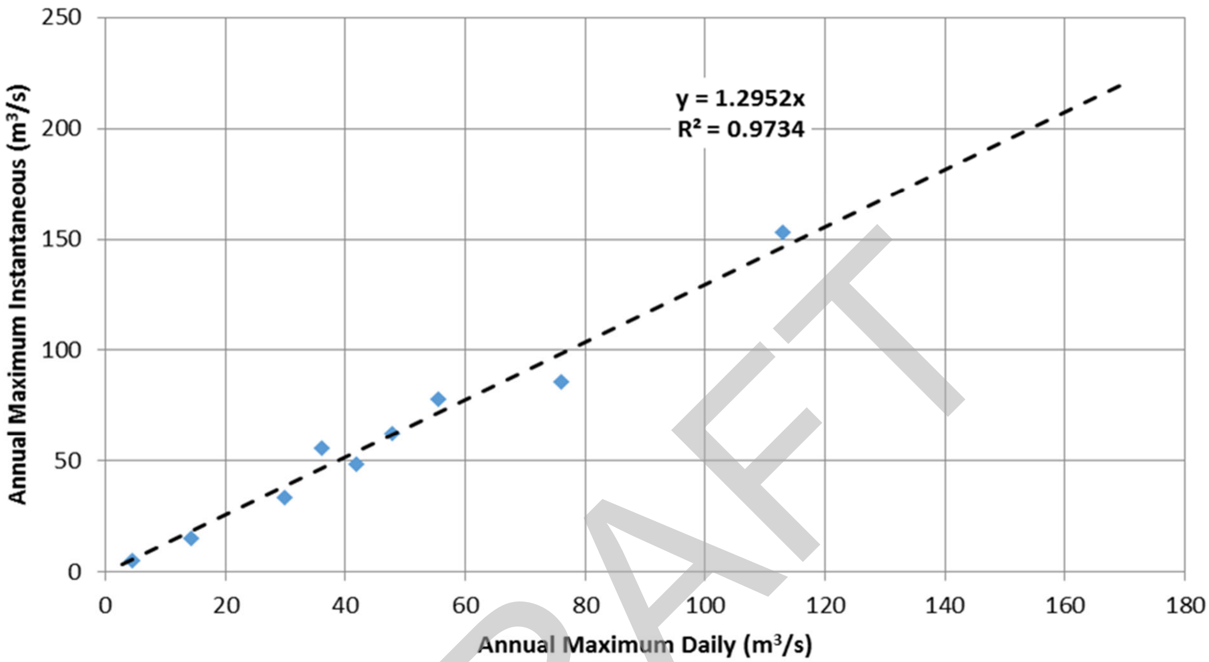


Figure A-27: Jumpingpound Creek at Township Road No. 252 (05BH015) (extended) - using flows at Jumpingpound Creek near Jumpingpound (05BH006) from 1908 to 1933, and Jumpingpound Creek near the Mouth (05BH009) from 1966 to 2005



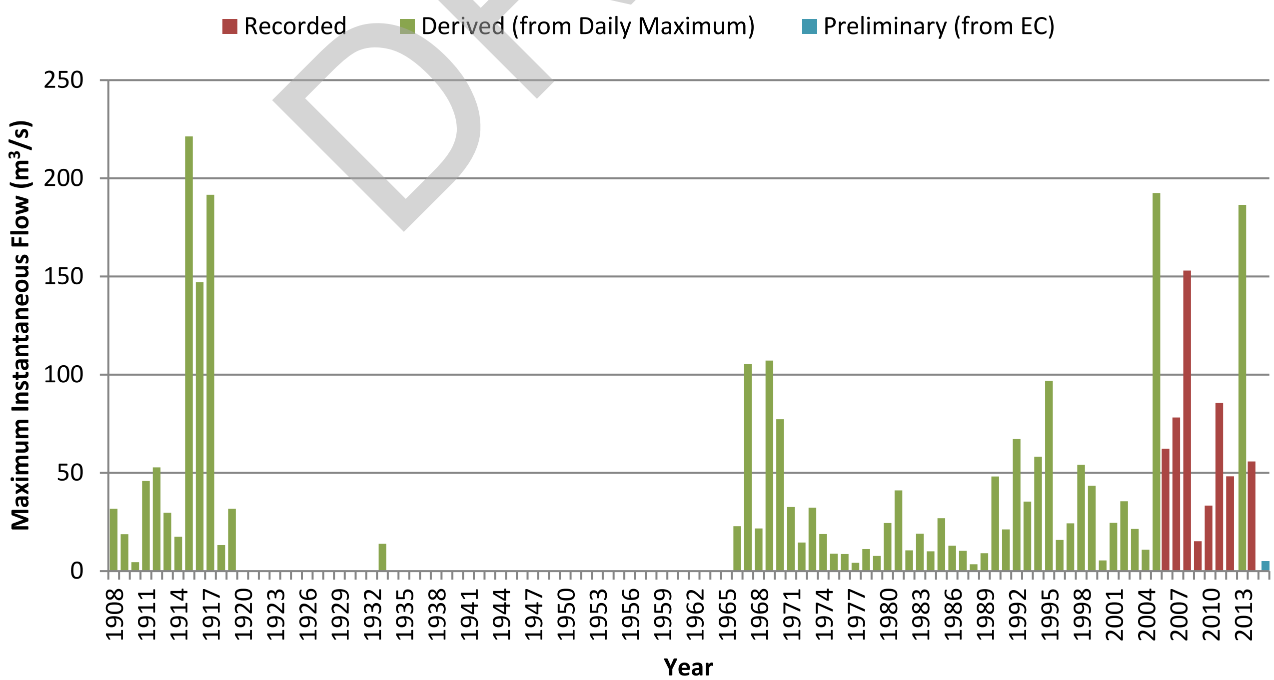
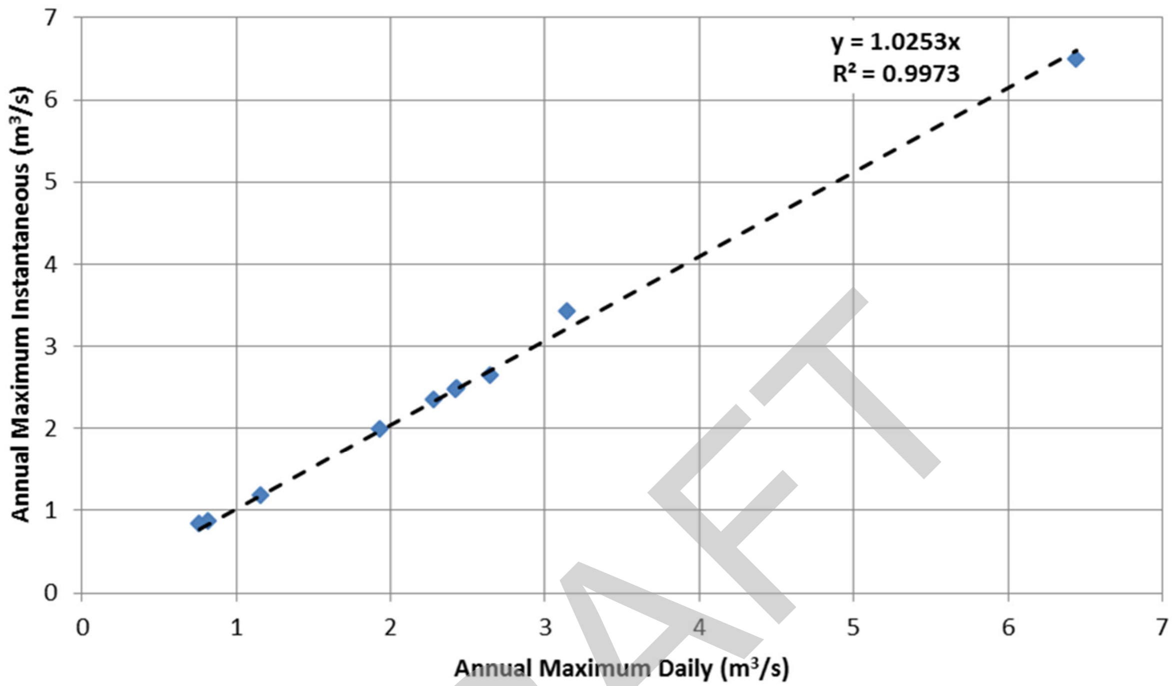


Figure A-28: Nose Creek above Airdrie (05BH014)



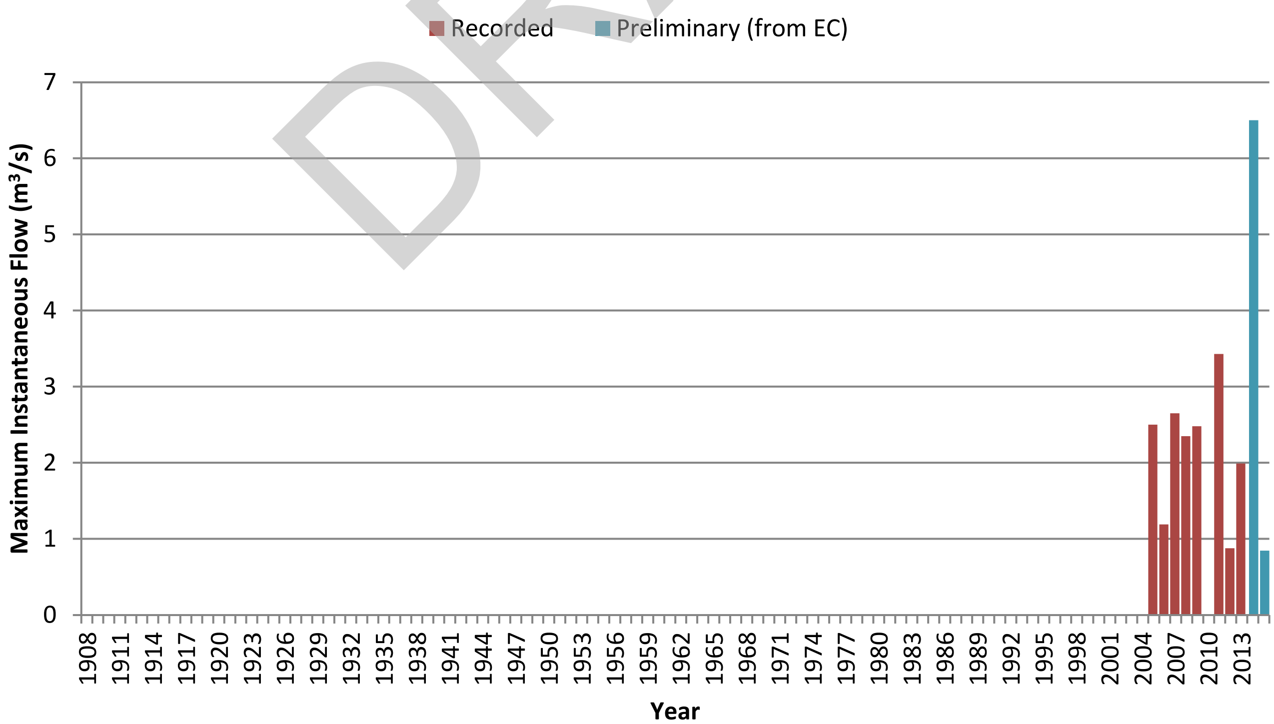
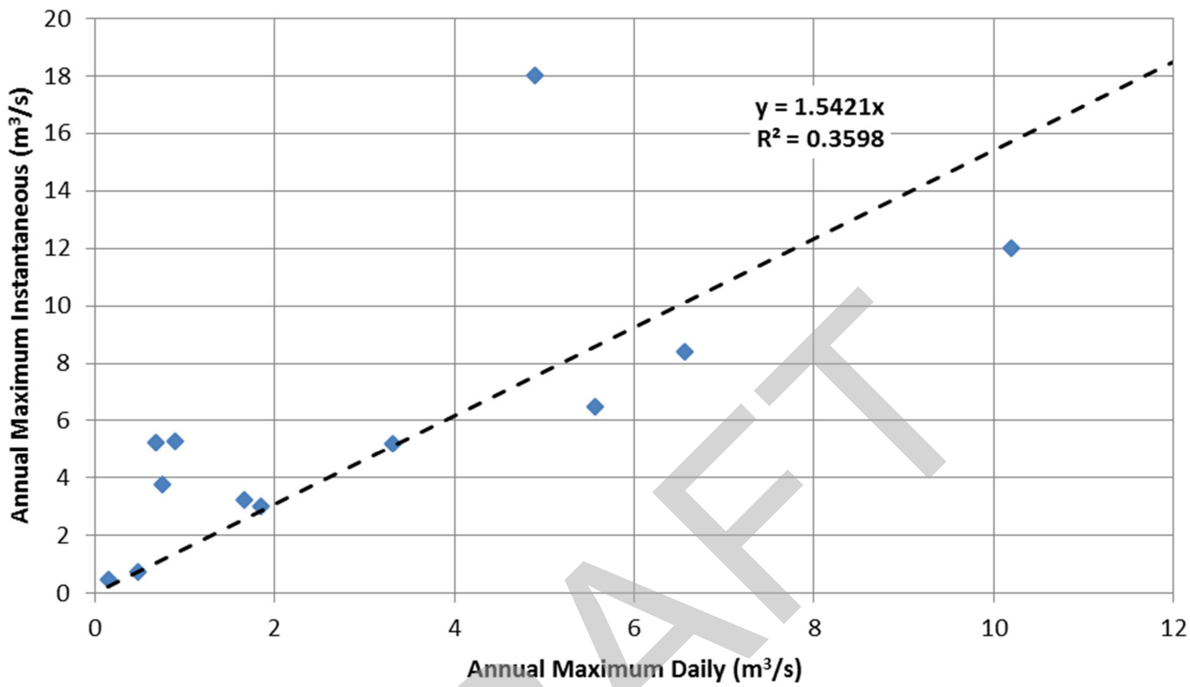
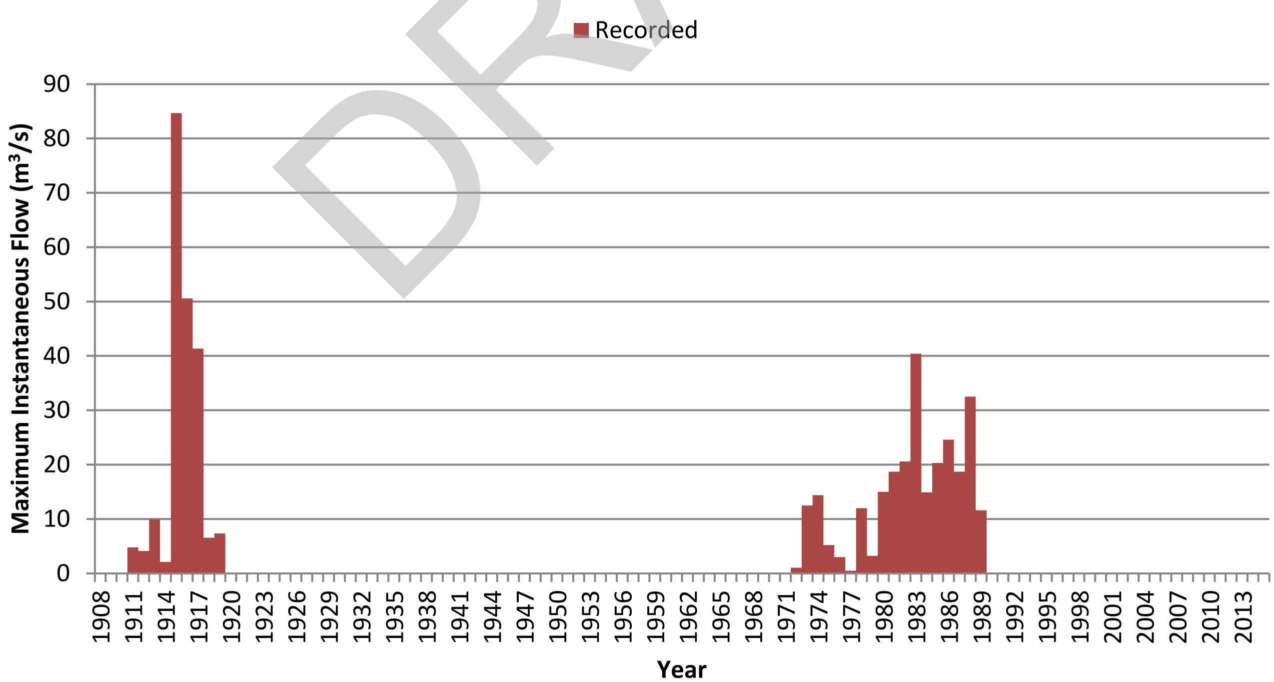


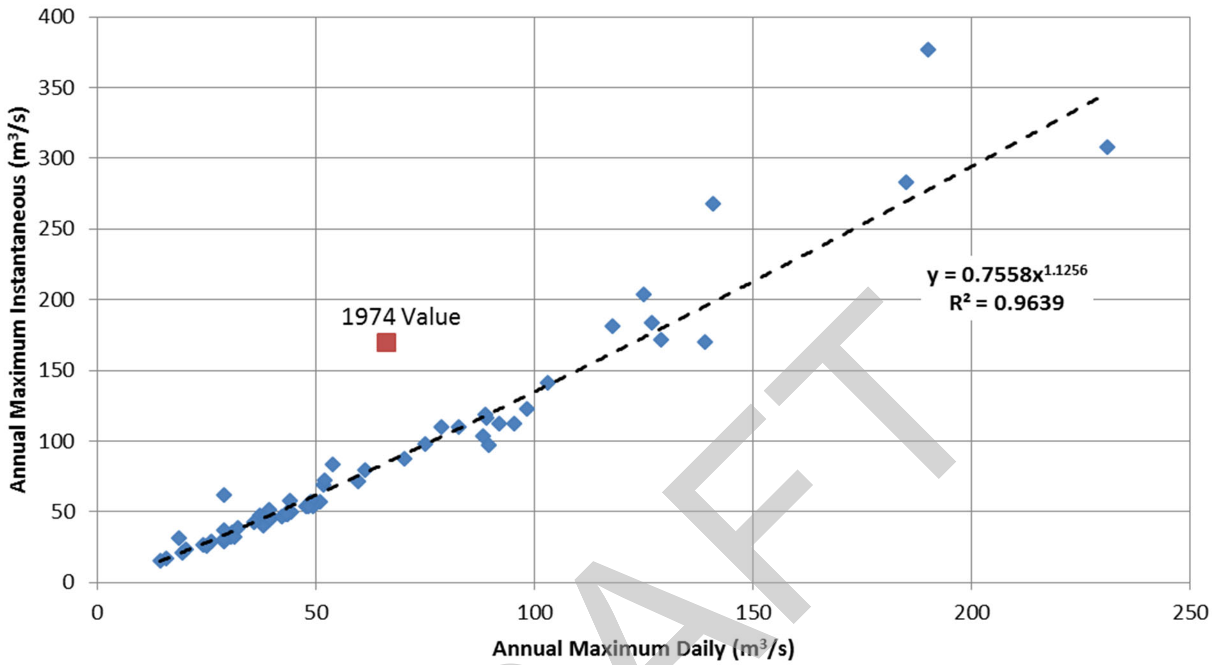
Figure A-29: Nose Creek at Calgary and at Mouth (Combined 05BH003 and 05BH901)

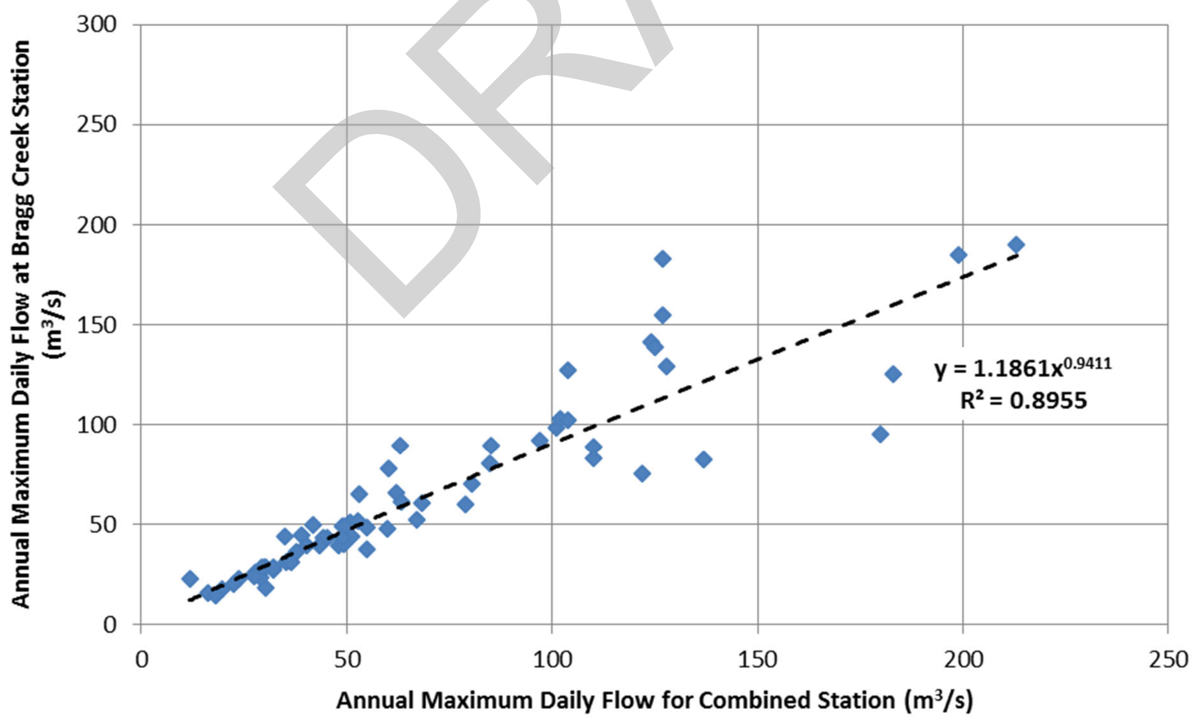


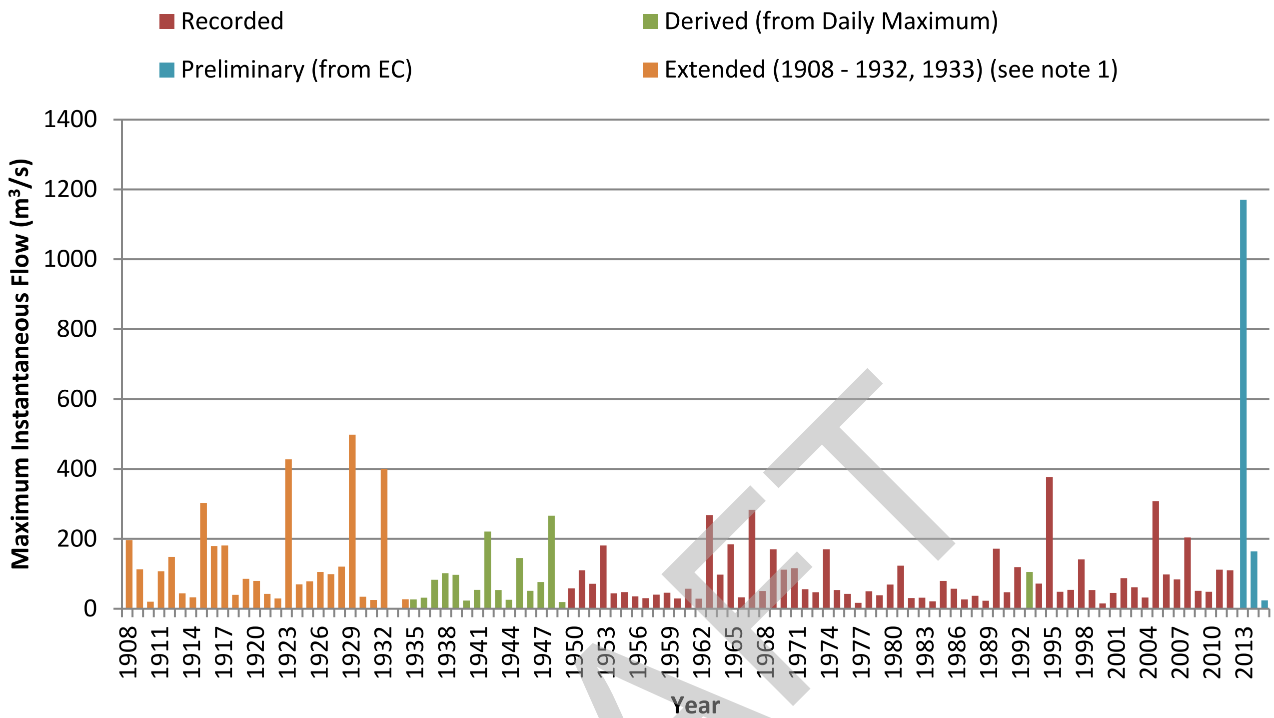


Note: Poor relationship between daily maximum and instantaneous maximum flows. The relationship was not used to extend dataset for instantaneous maximum flows.

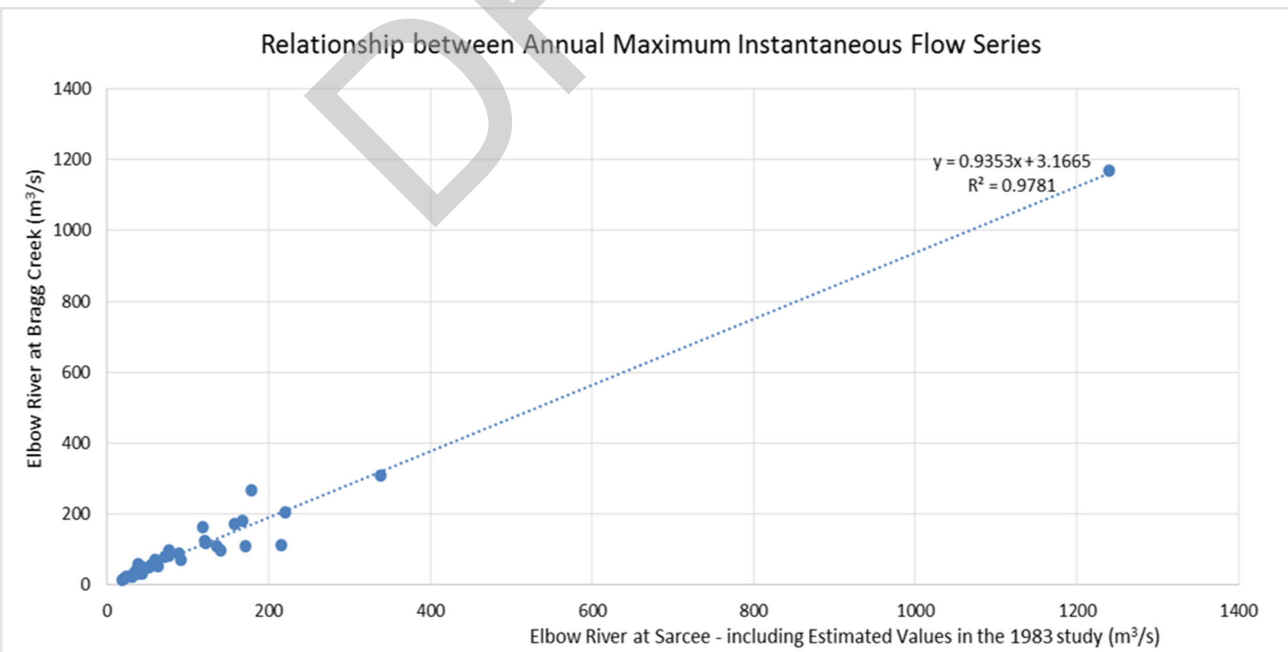
Figure A-30: Elbow River at Bragg Creek (05BJ004) (extended)

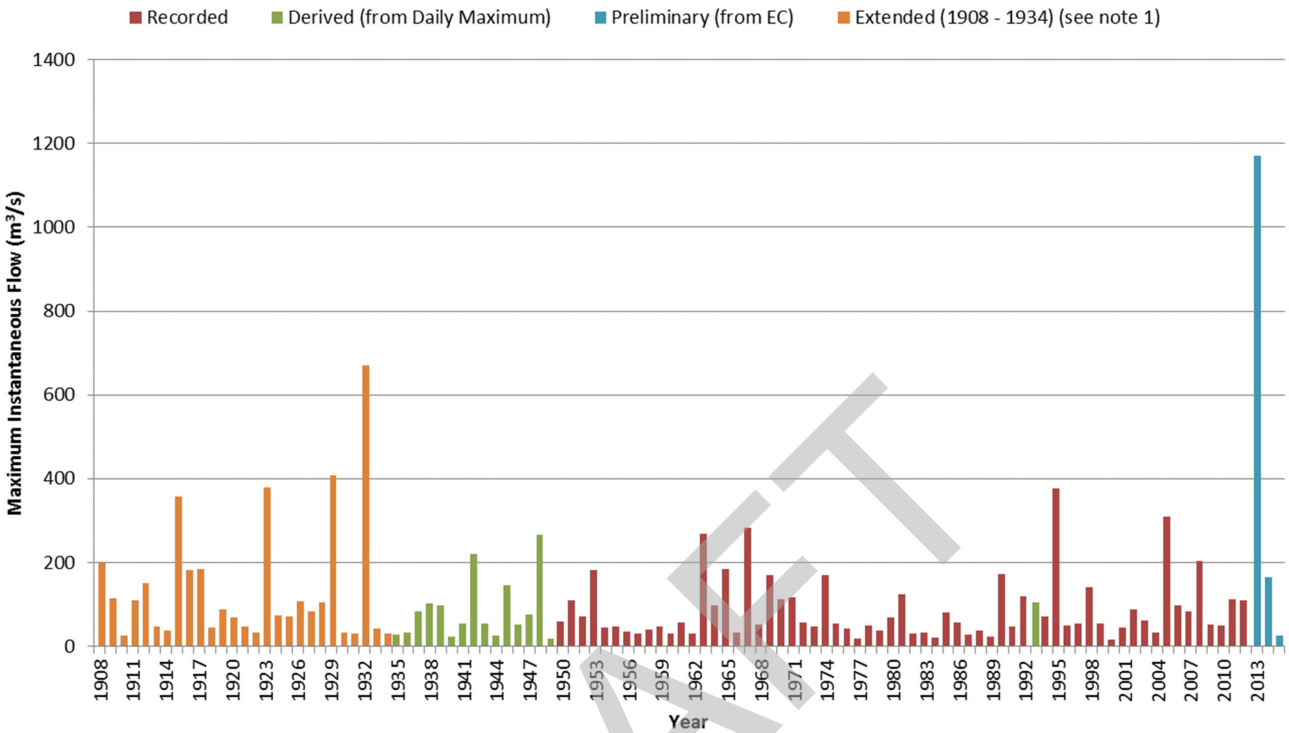






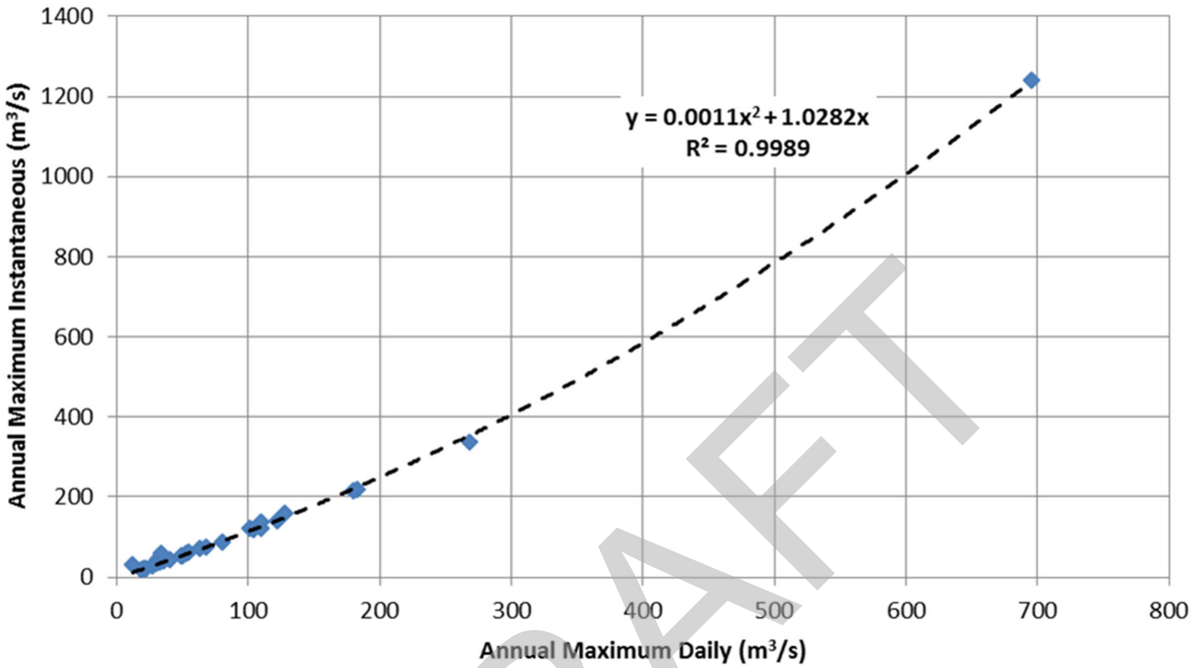
Note 1: Extending using Elbow River combined flows, Elbow River below Glenmore (05BJ001), Elbow River Upstream of Glenmore Reservoir (05BJ005), and Elbow River at Sarcee Bridge (05BJ010).

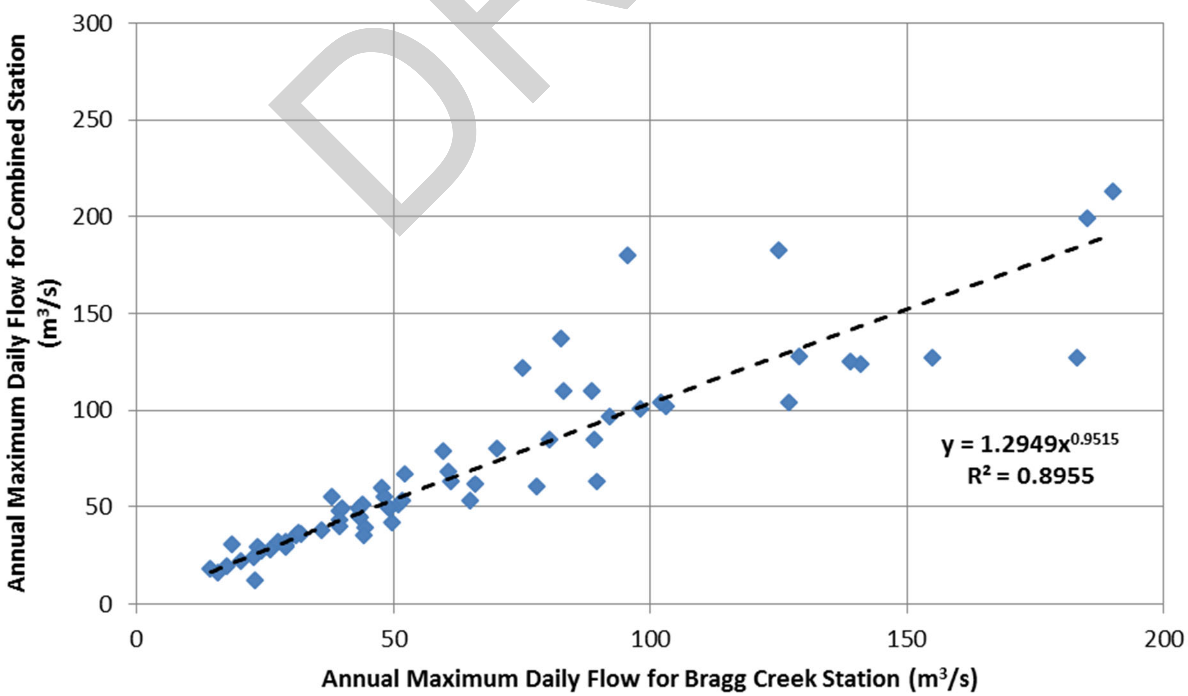


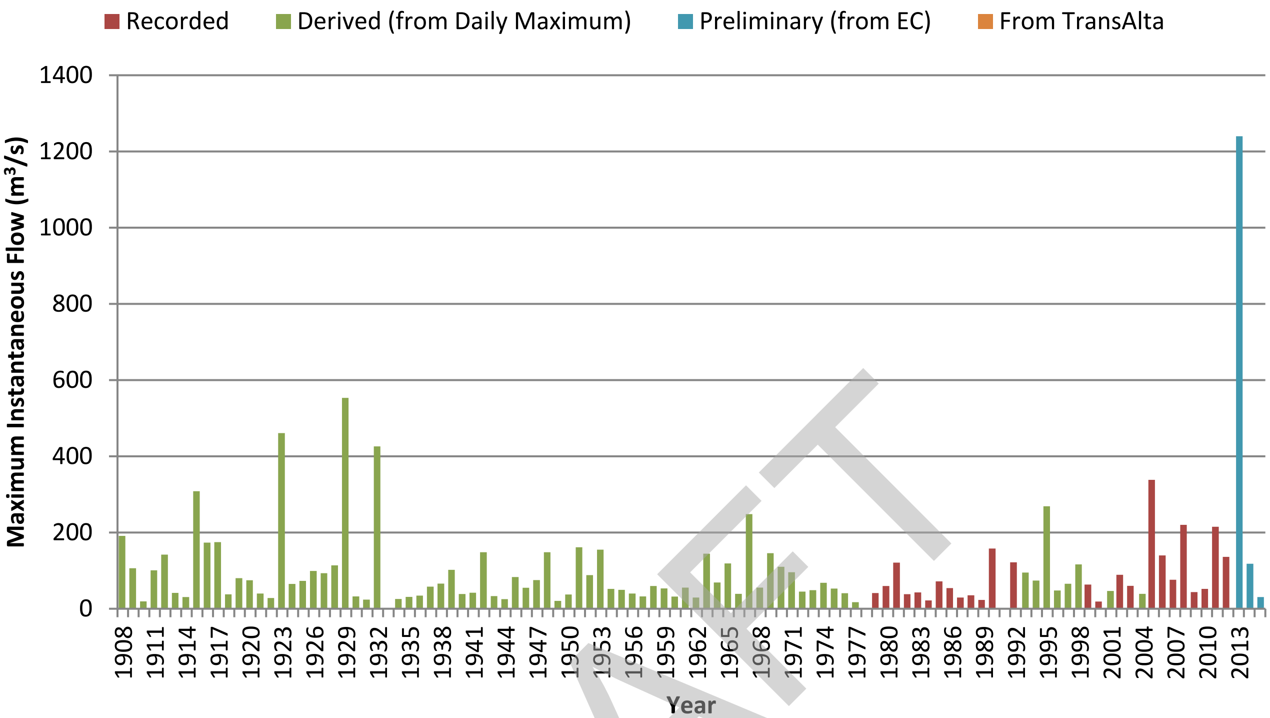


Note 1: Extending using relationship established with annual maximum instantaneous flow series for Elbow River at Sarcee Bridge (05BJ0010 including estimate values from the 1983 study)

Figure A-31: Elbow River at Sarcee Combined – using Elbow River below Glenmore (05BJ001), Elbow River Upstream of Glenmore Reservoir (05BJ005), and Elbow River at Sarcee Bridge (05BJ010)

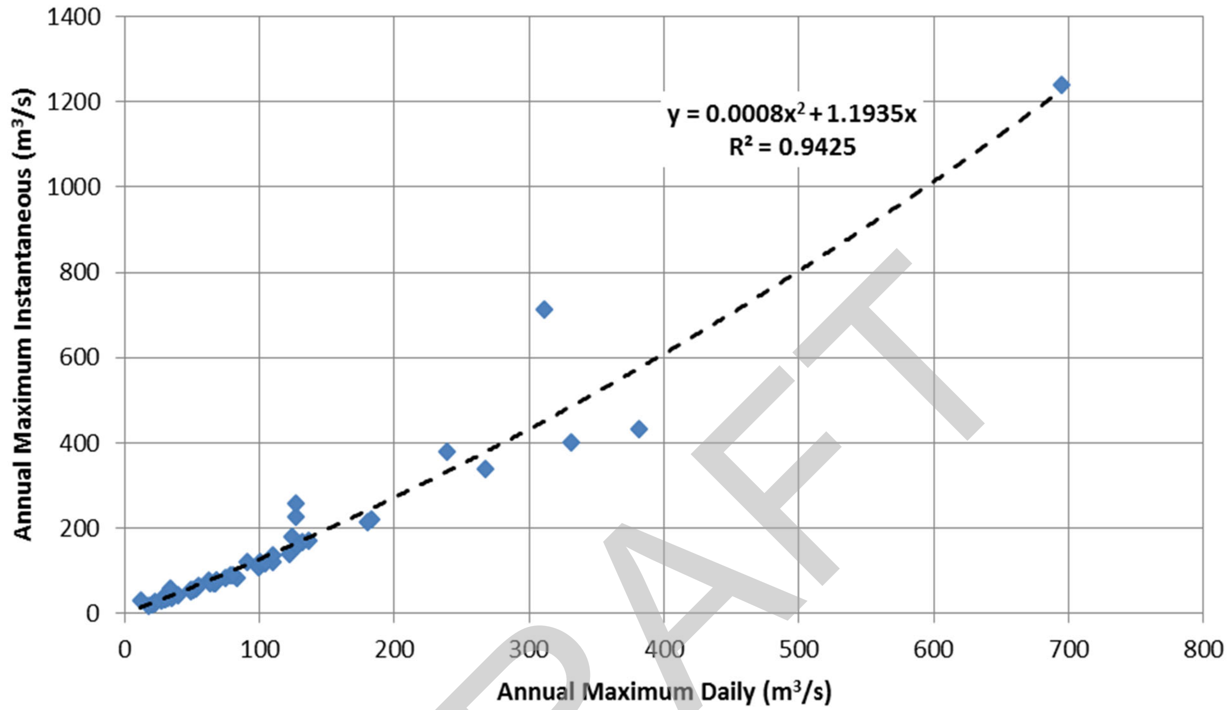






Note: Using flows at Elbow River below Glenmore (05BJ001) from 1908 to 1932; Elbow River Upstream of Glenmore Reservoir (05BJ005) from 1934 to 1978; and Elbow River at Sarcee Bridge (05BJ010) from 1979 to 2015.

Figure A-32: Elbow River at Sarcee combined Using 1983 Report Values – using flows at Elbow River below Glenmore (05BJ001), Elbow River Upstream of Glenmore Reservoir (05BJ005), and Elbow River at Sarcee Bridge (05BJ010)



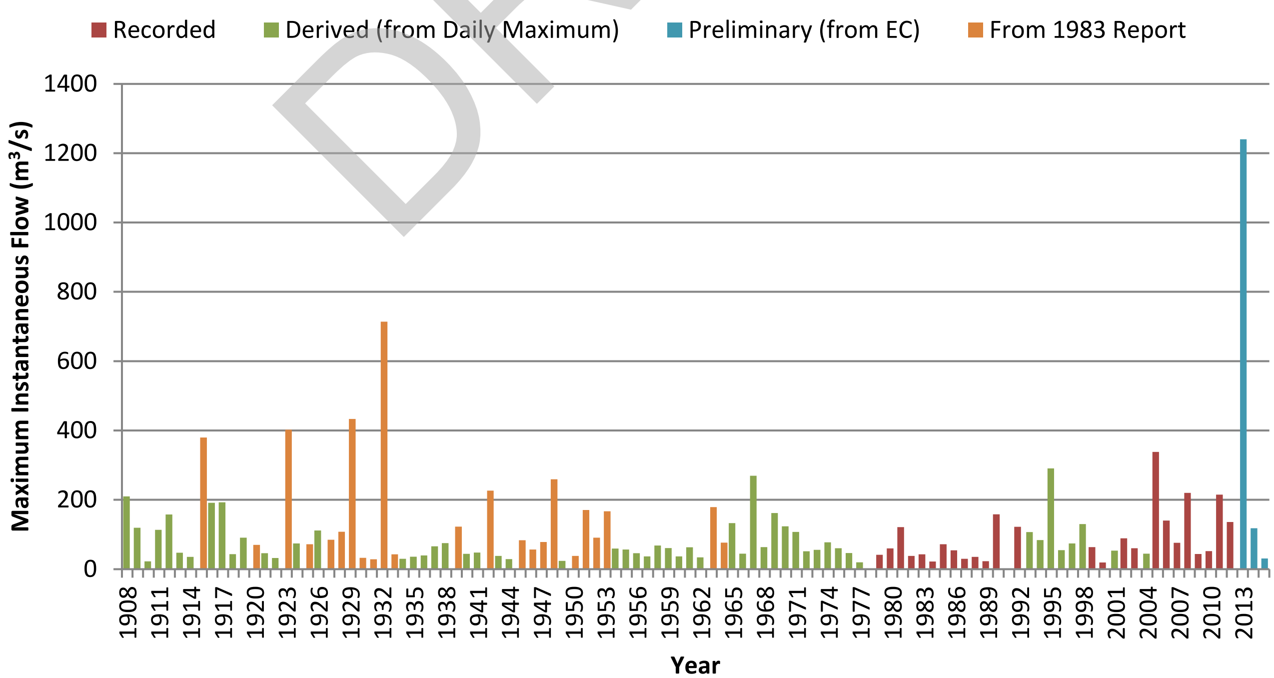
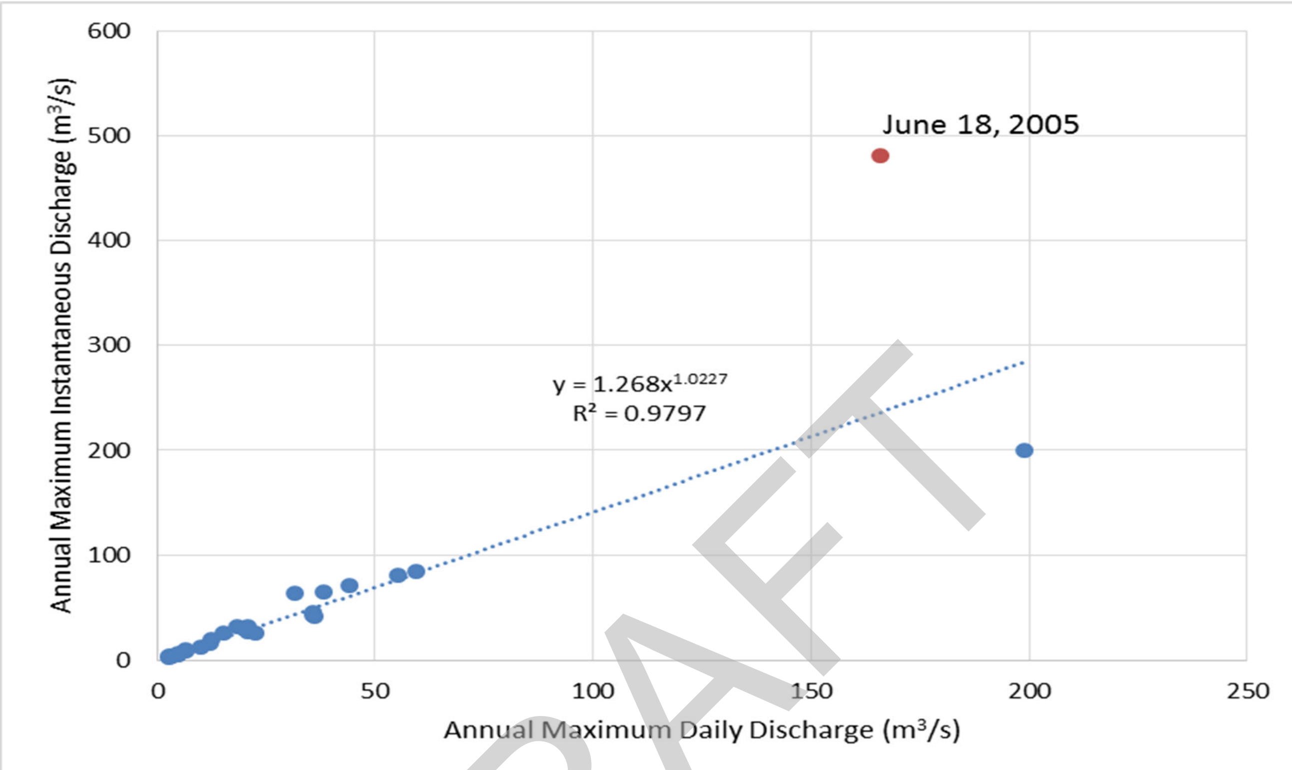


Figure A-33: Fish Creek at Priddis



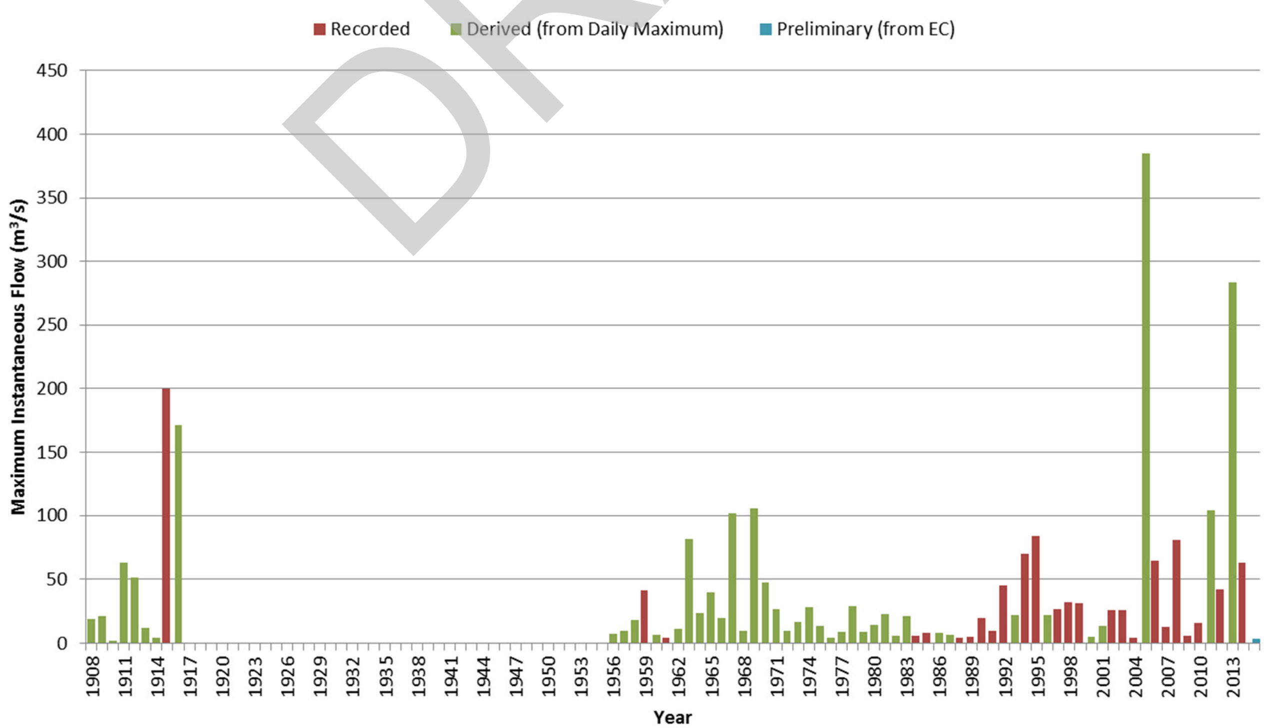
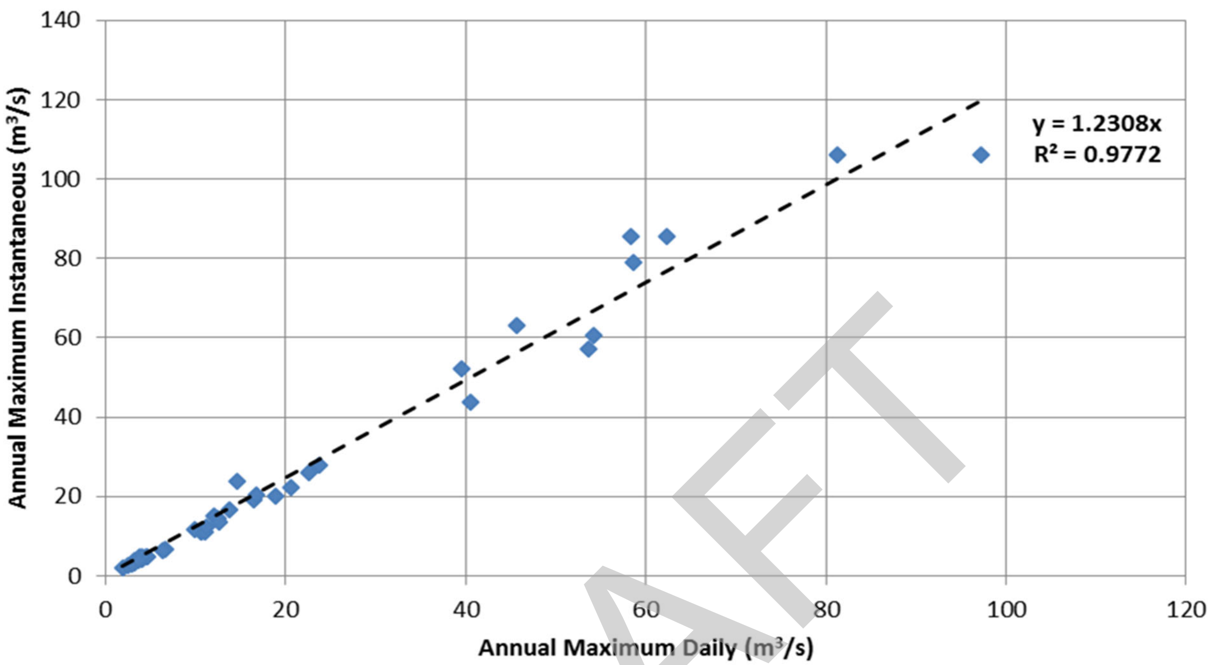


Figure A-34: Crowfoot Creek near Cluny (05BM008)



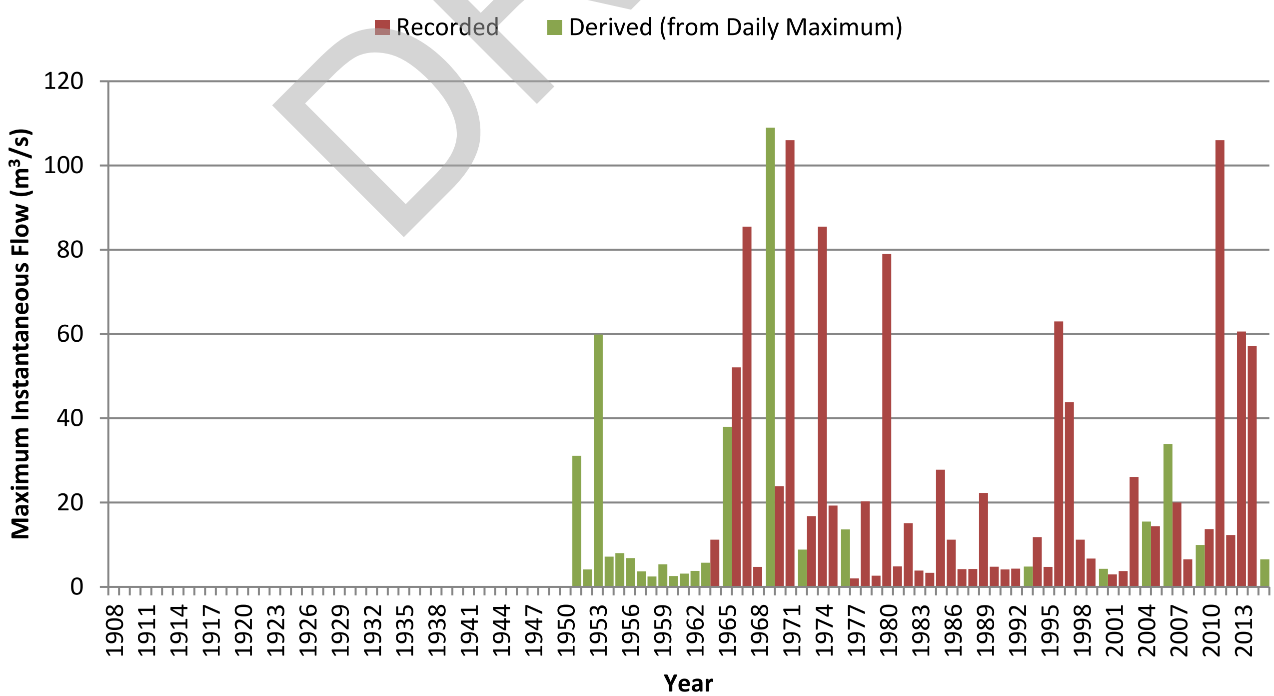
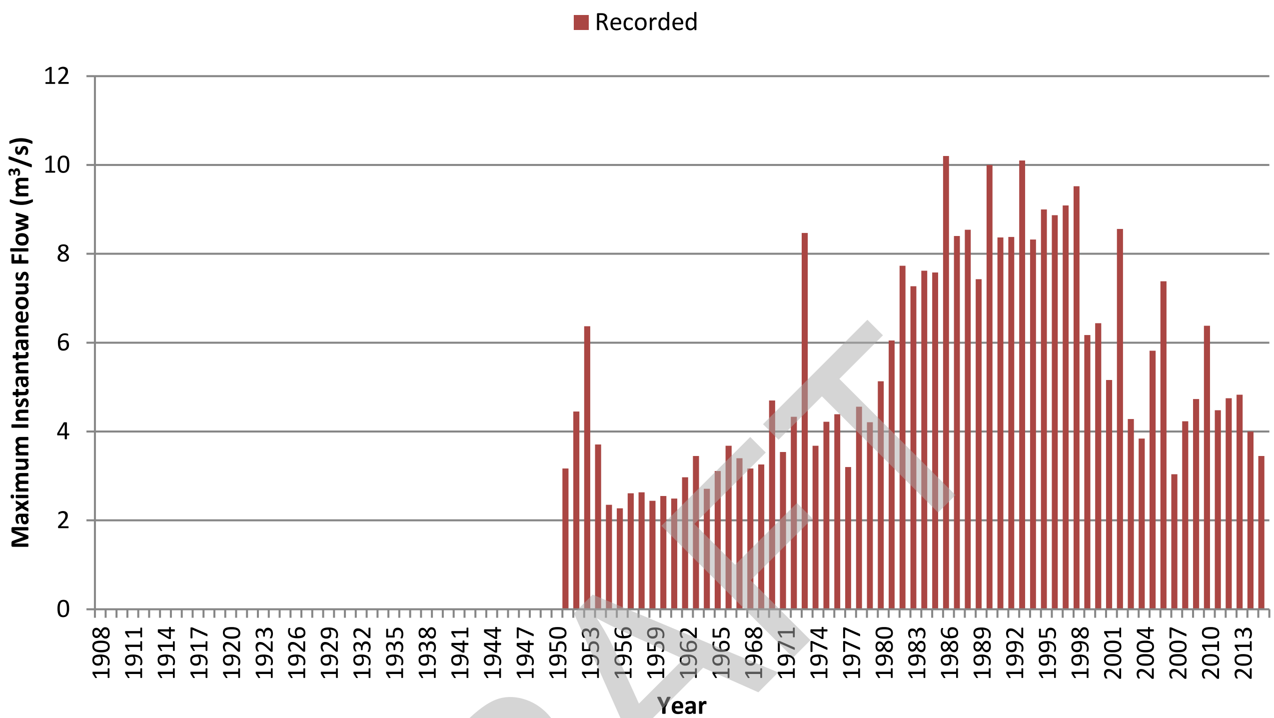
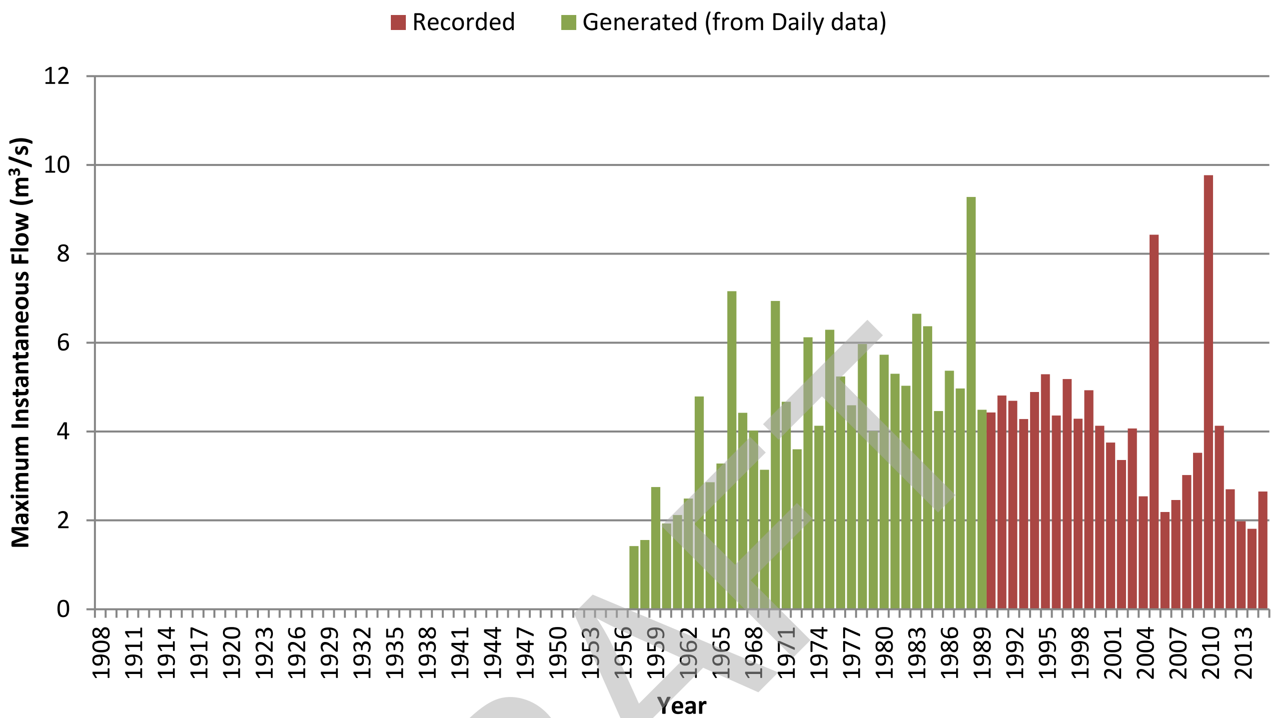


Figure A-35: Twelve Mile Creek near Cecil (05BN002)



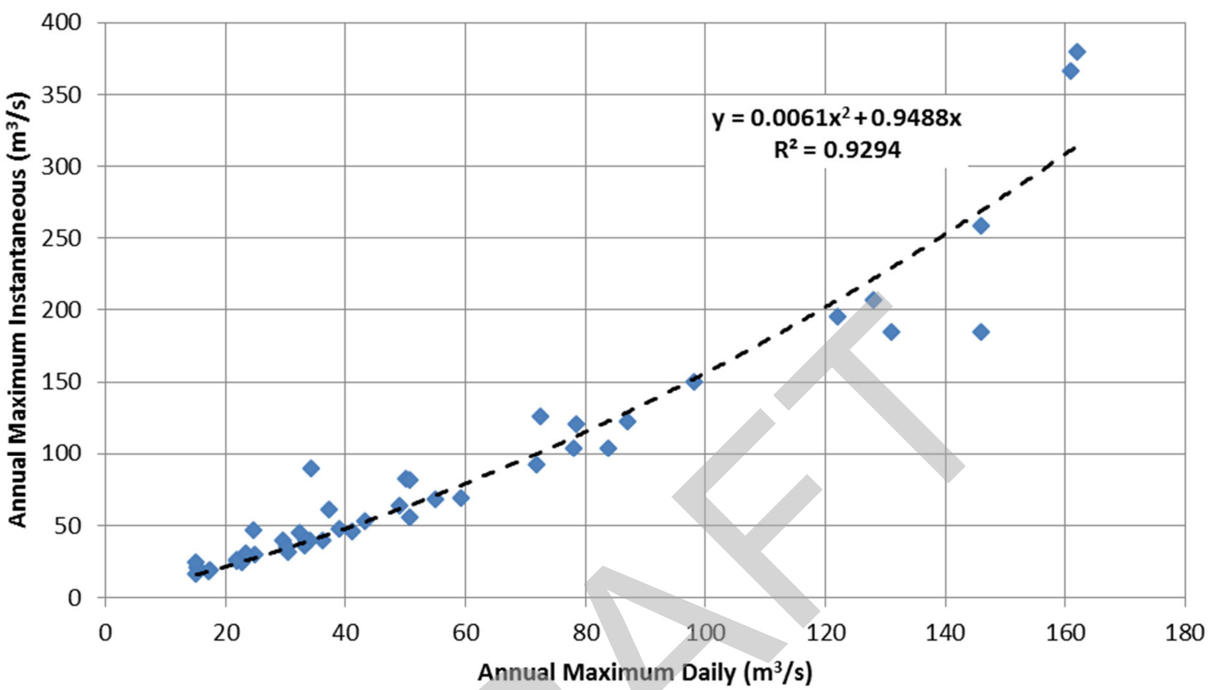
Note: Presented data are the daily maximum flows. No instantaneous maximum flow data available to derived relationship between daily maximum and instantaneous maximum flows. Frequency analysis was completed using daily maximum flows.

Figure A-36: New West Coulee near the Mouth (05BN006)



Note: Presented data are the daily maximum flows. No instantaneous maximum flow data available to derived relationship between daily maximum and instantaneous maximum flows. Frequency analysis was completed using daily maximum flows.

Figure A-37: Sheep River at Black Diamond (05BL014)



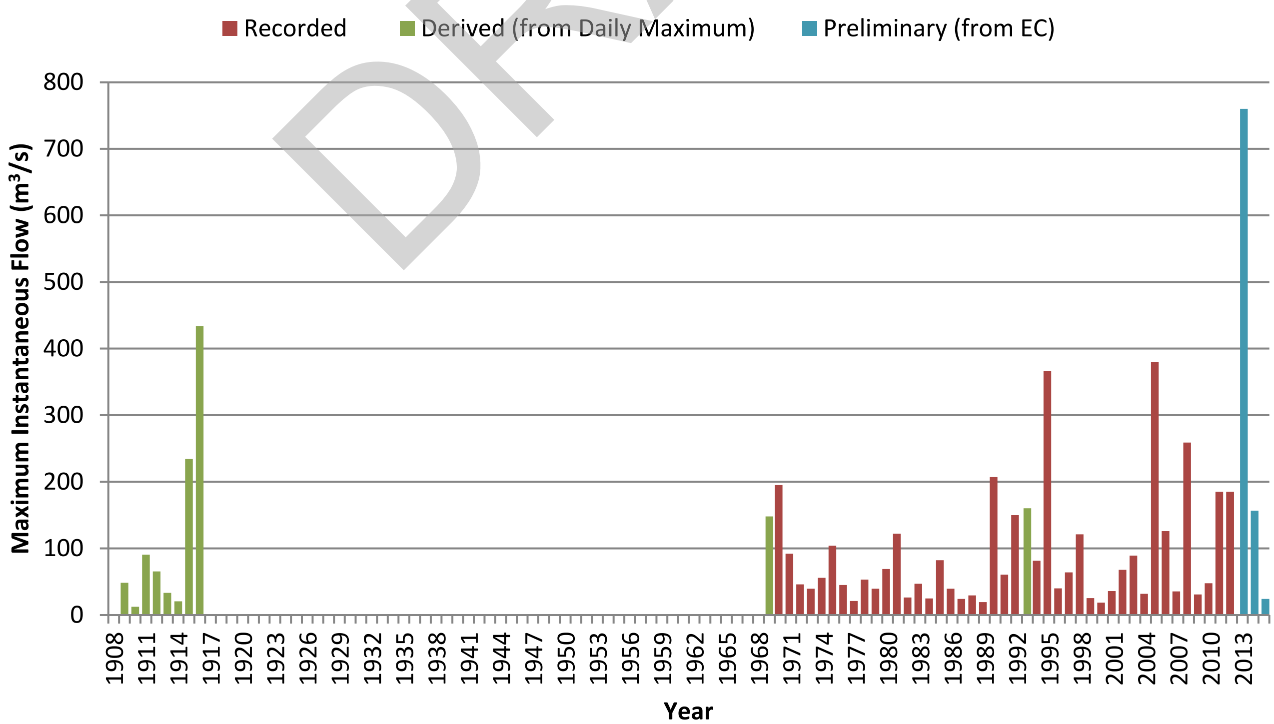
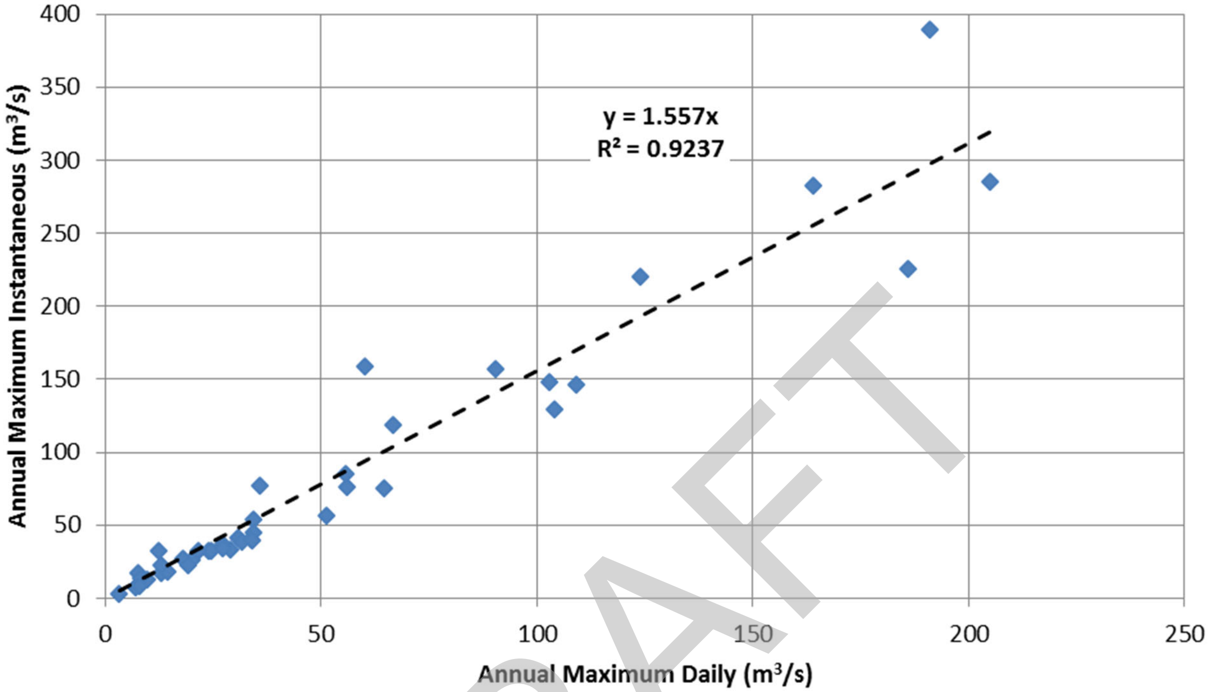


Figure A-38: Threepoint Creek at Millarville (05BL013)



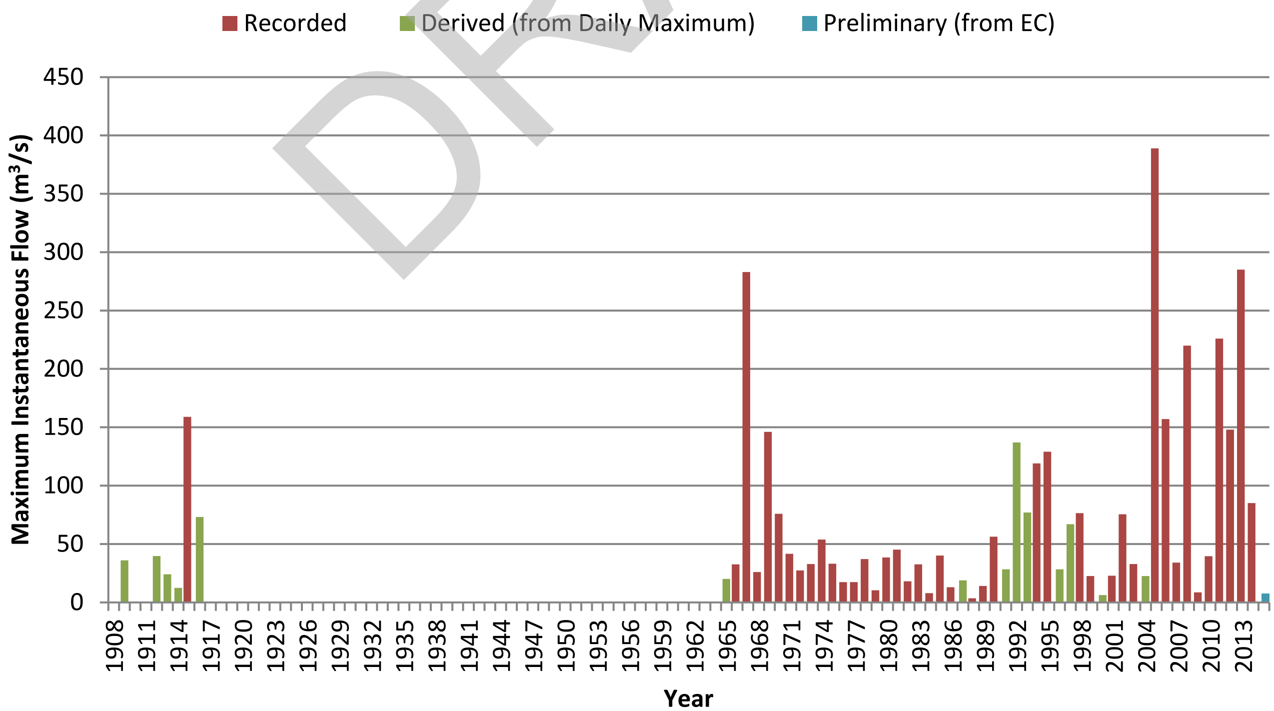
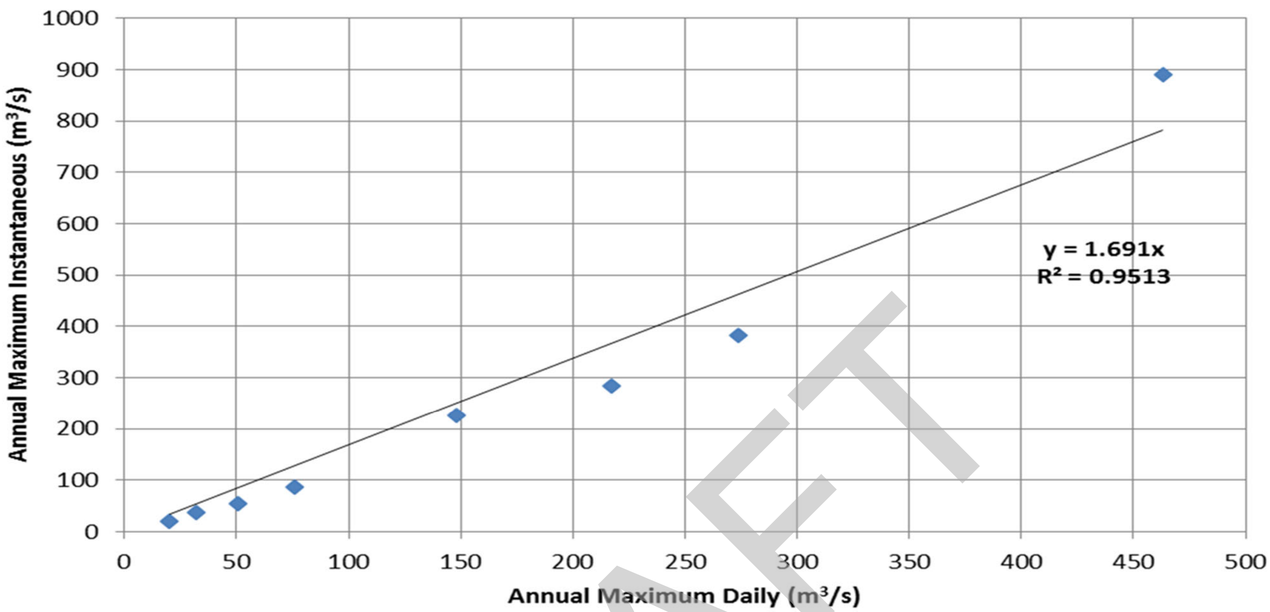


Figure A-39: Sheep River at Okotoks (05BL012)



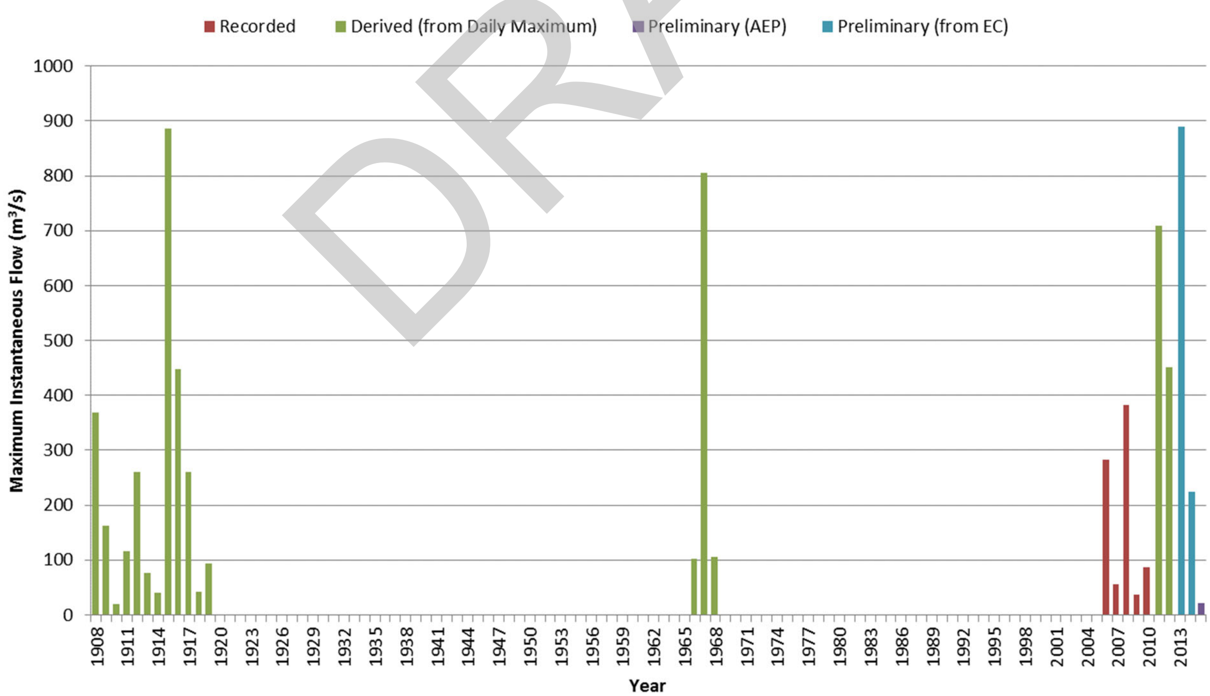
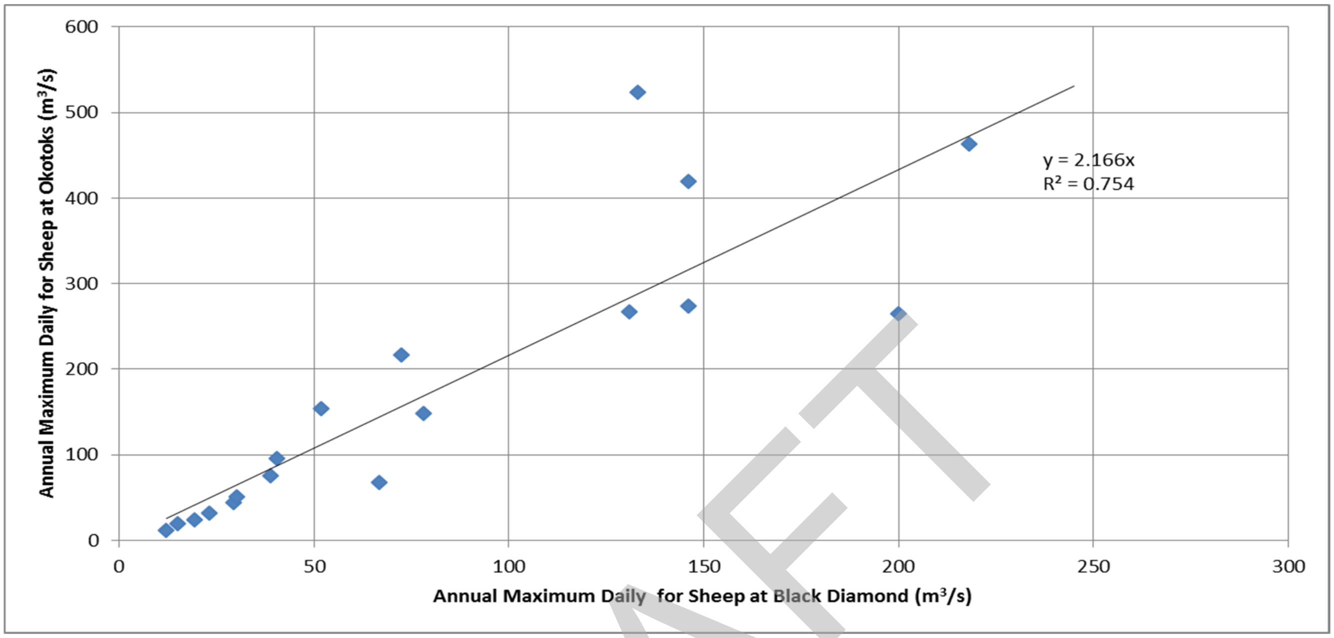


Figure A-40: Sheep River at Okotoks (05BL012) (extended) – using flows at Sheep River near Aldersyde (05BL020) from 1958 to 1965 and Sheep River at Black Diamond (05BL014) from 1969 to 2005



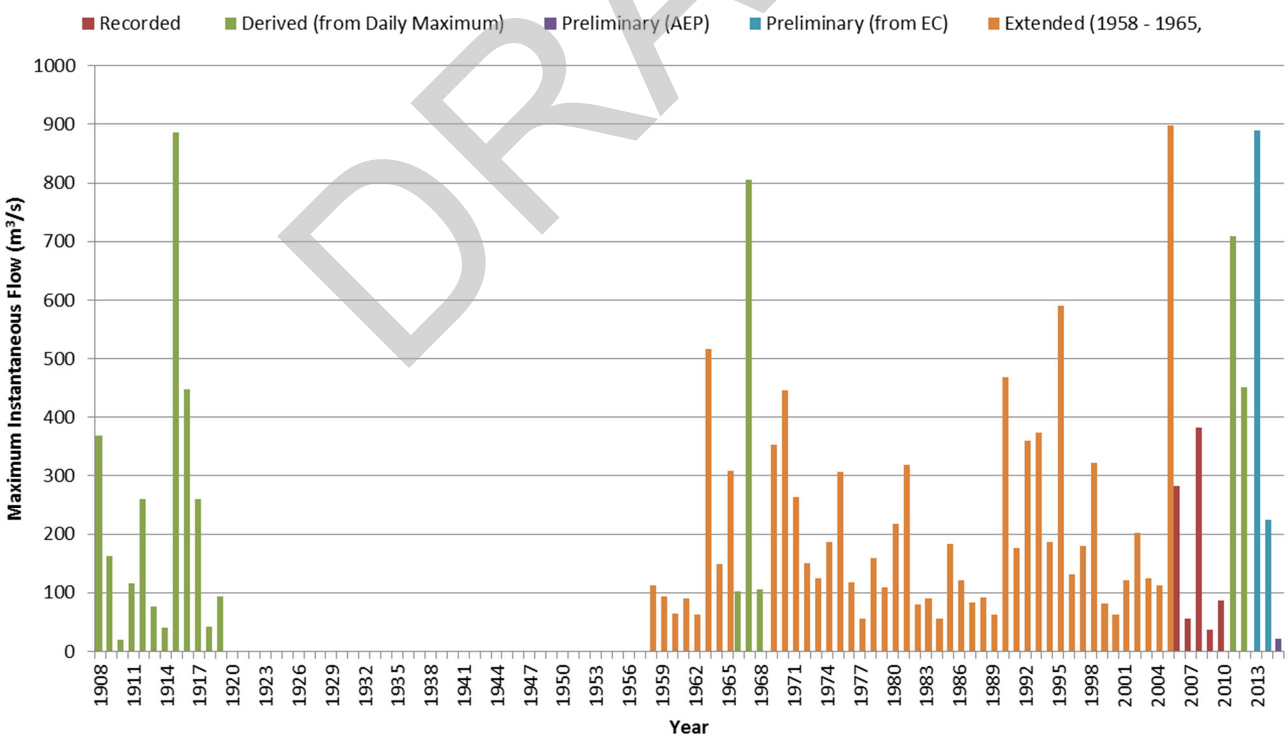
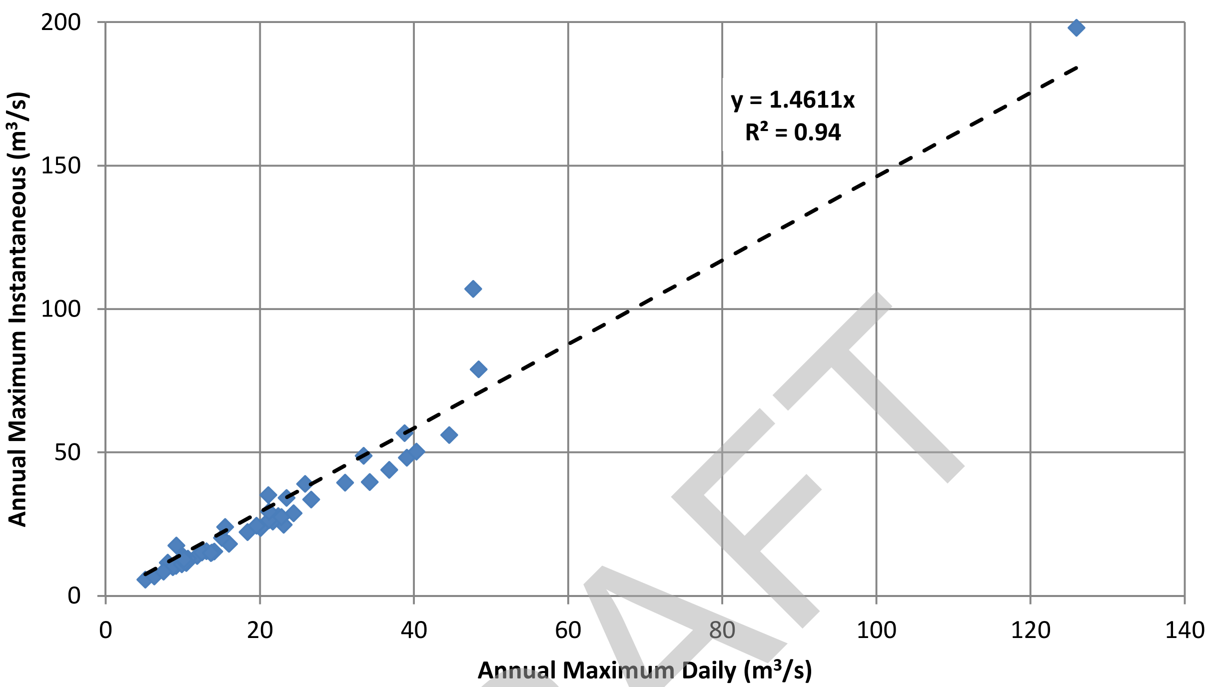


Figure A-41: Cataract Creek near Forestry Road (05BL022)



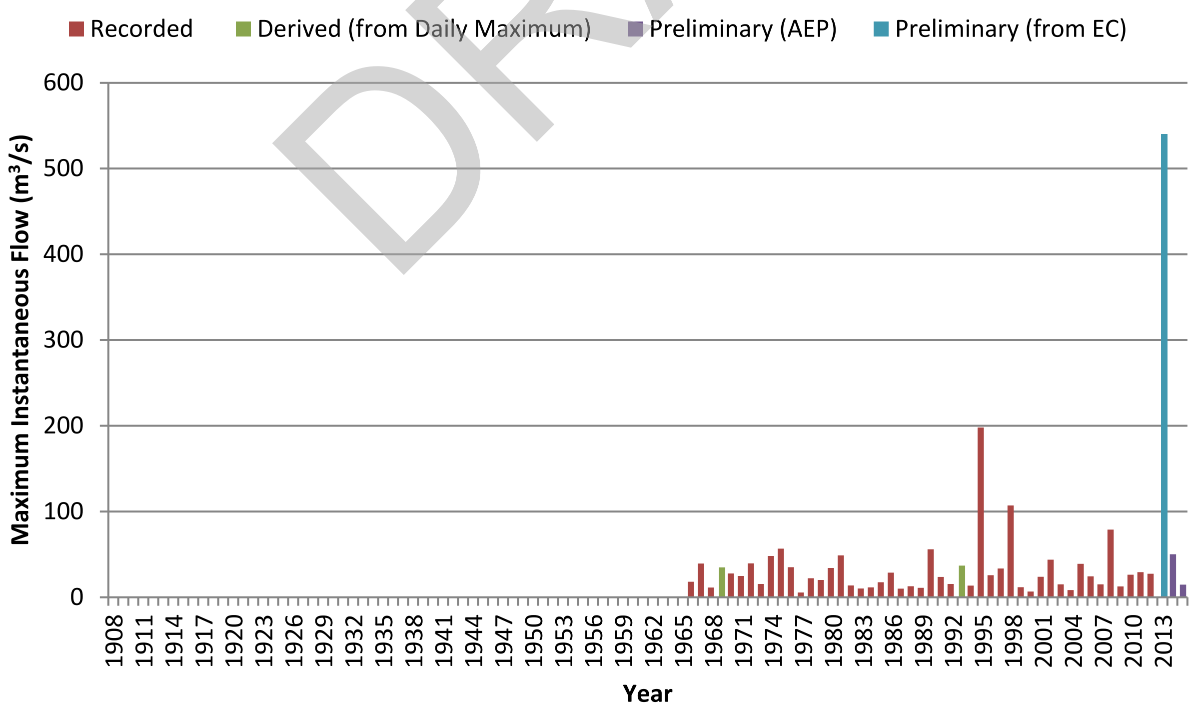


Figure A-42: Highwood River near Diebel's Ranch (05BL019)

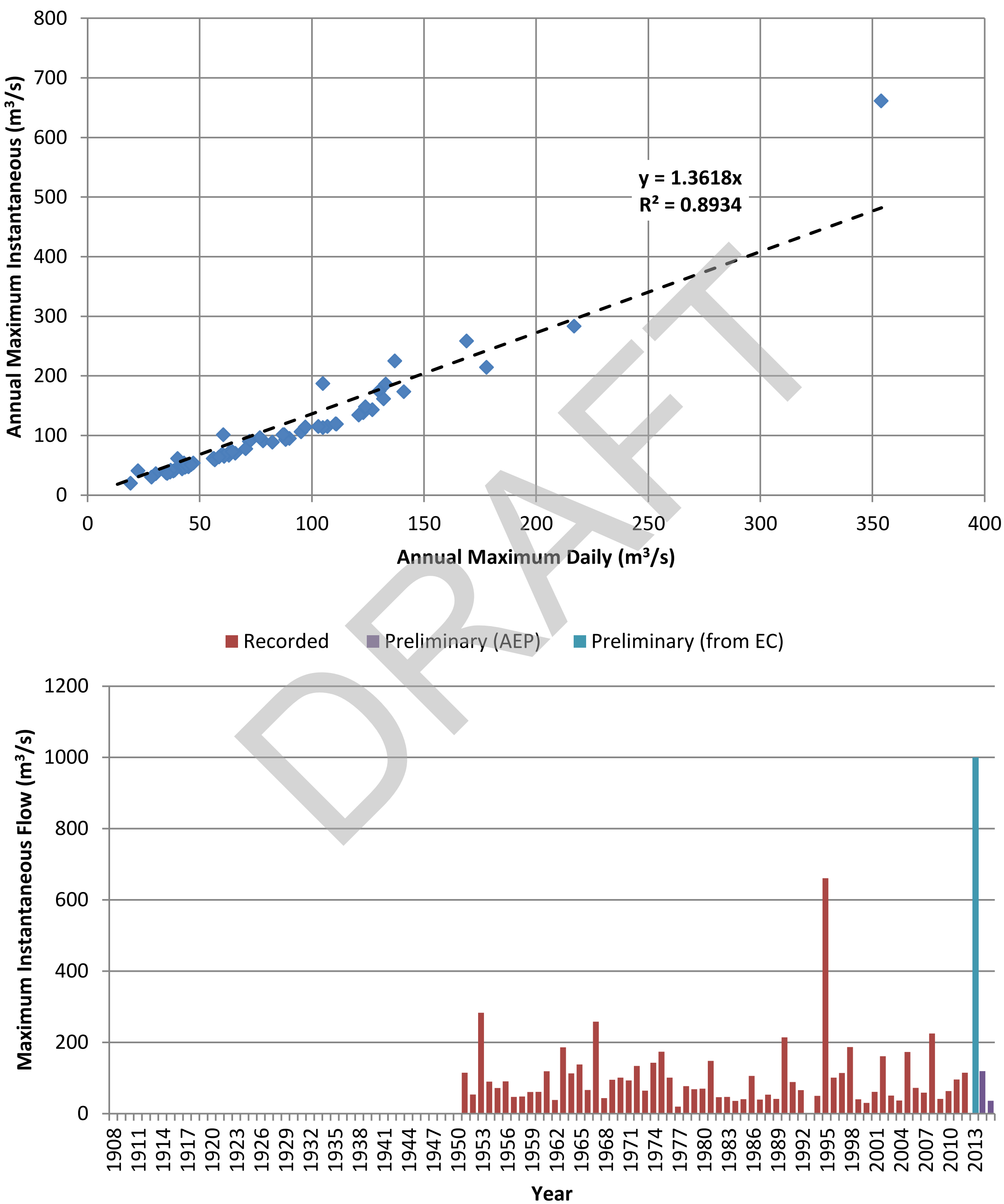
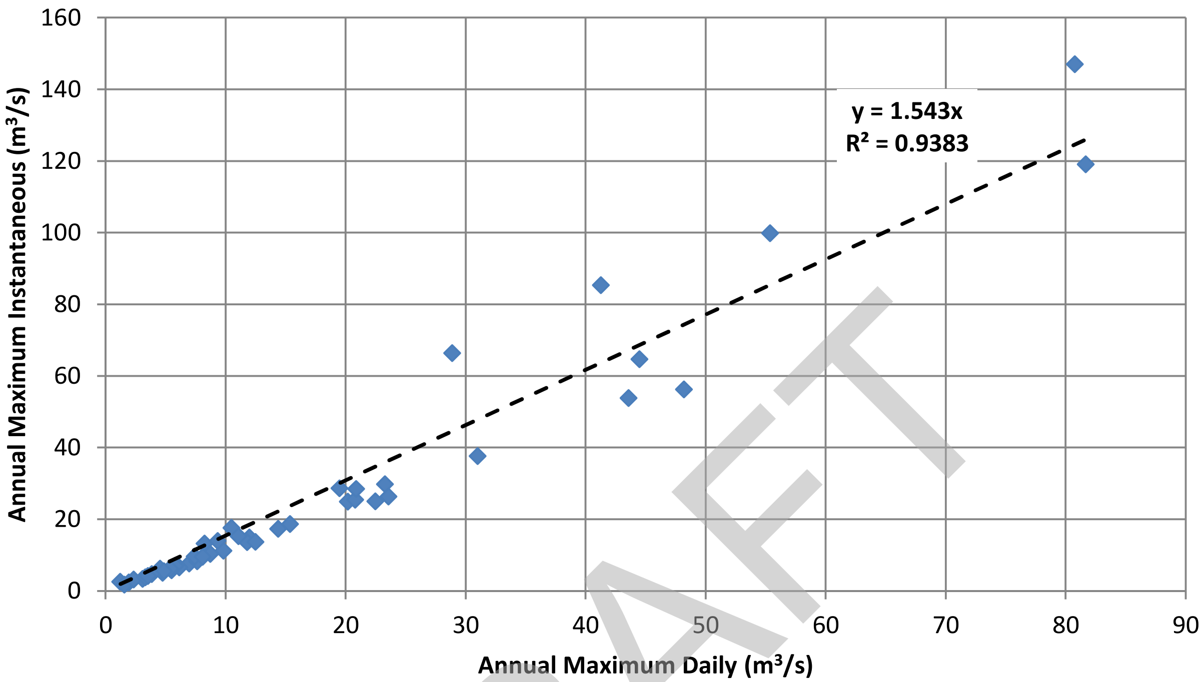


Figure A-43: Pekisko Creek near Longview (05BL023)



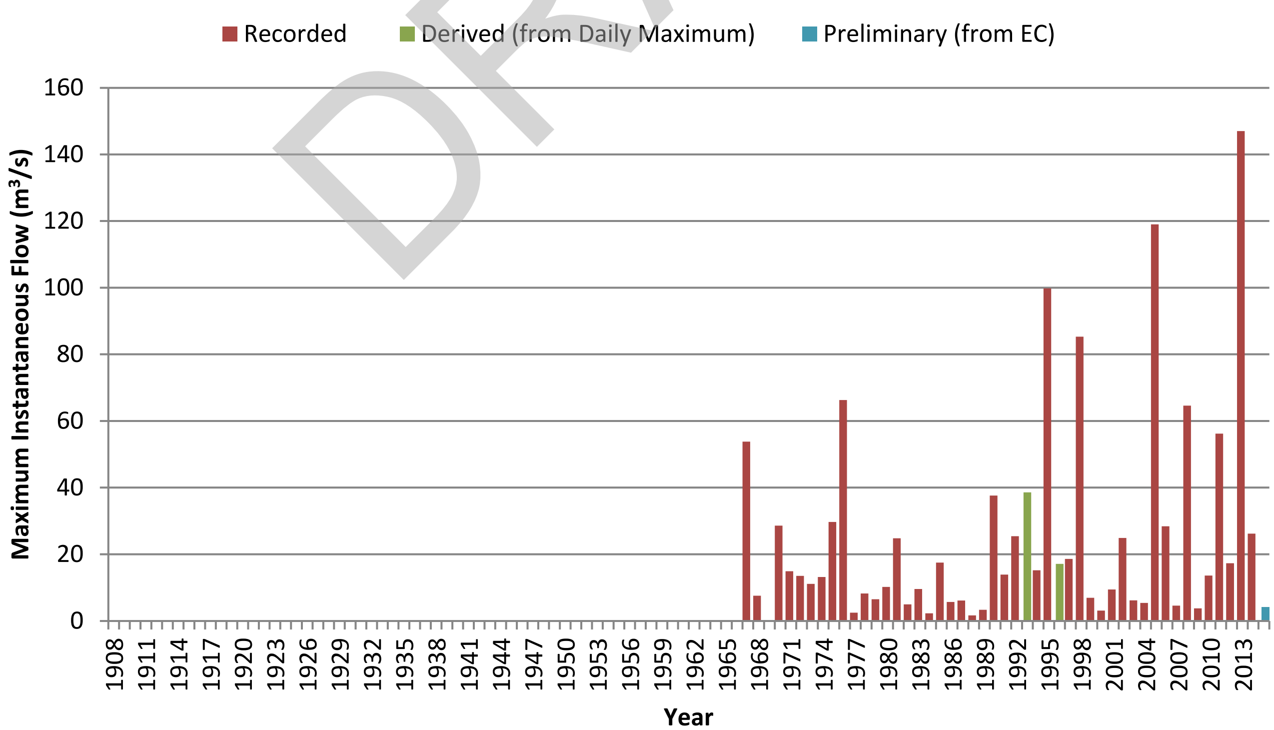
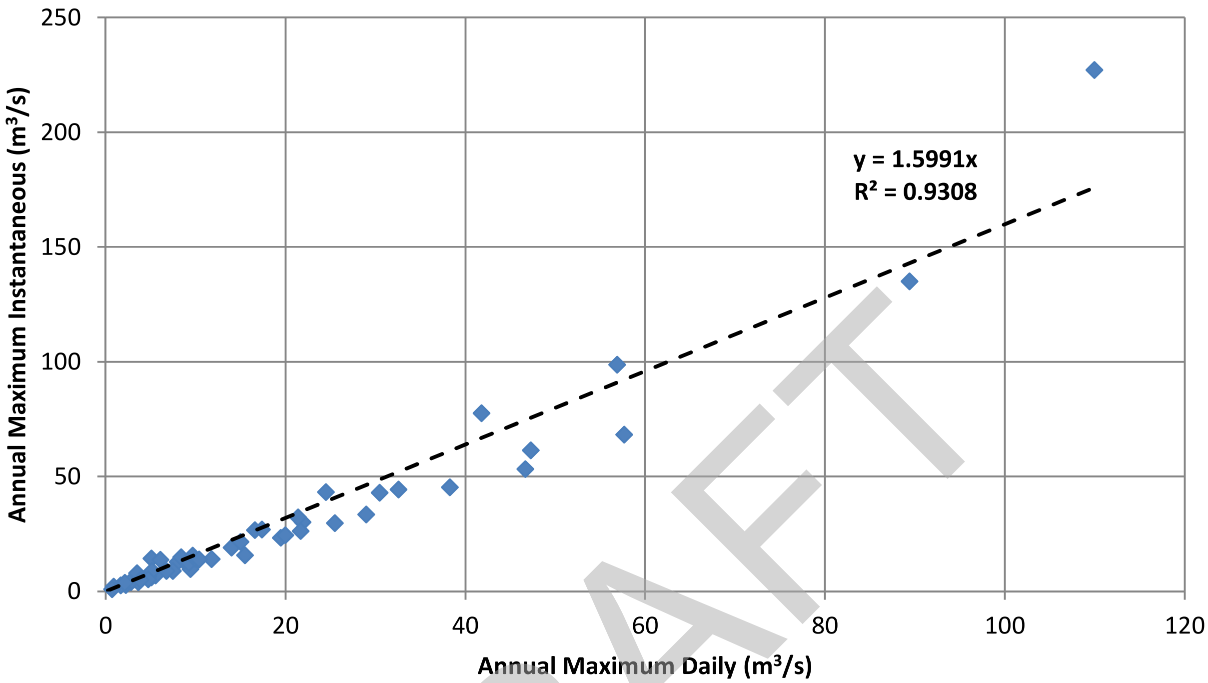


Figure A-44: Stimson Creek near Pekisko (05BL007)



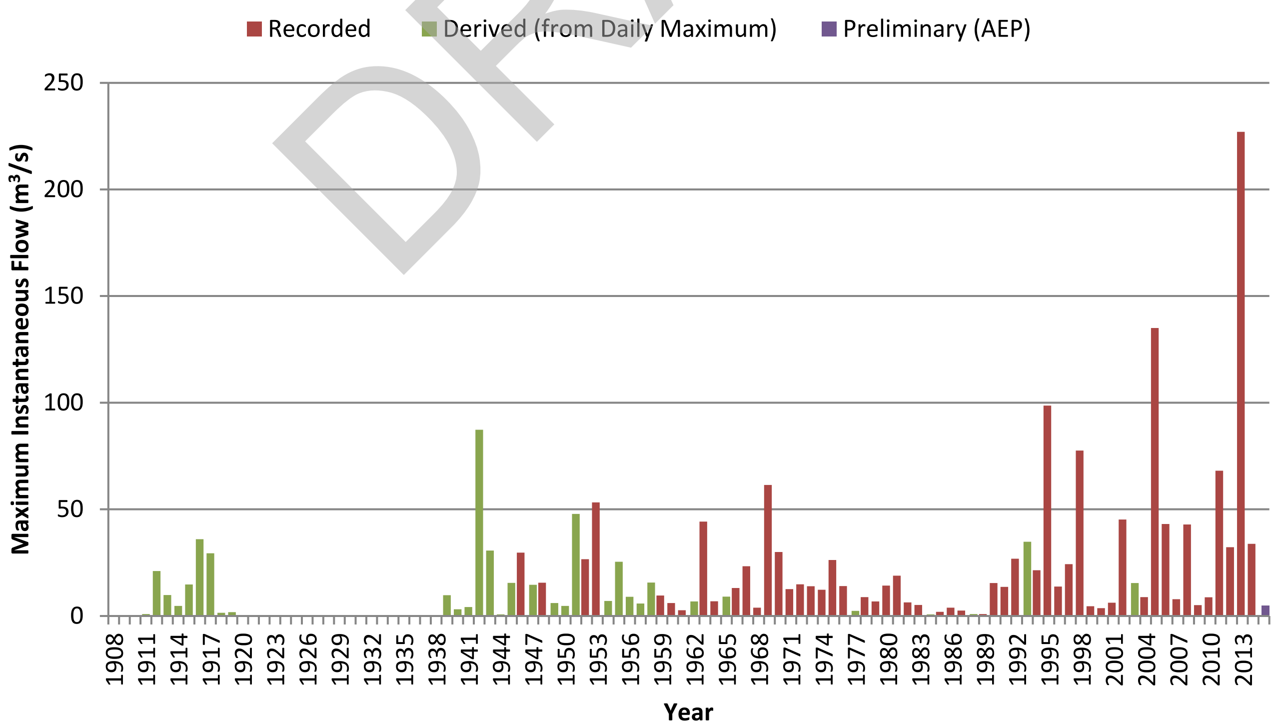
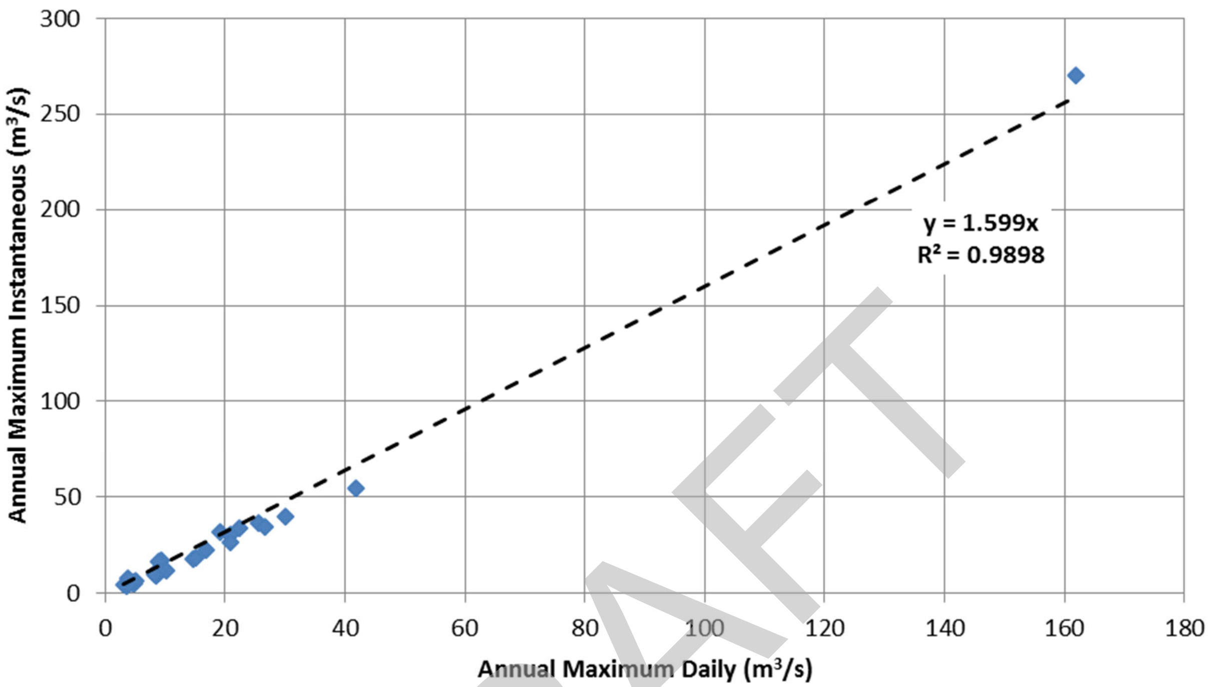


Figure A-45: Trap Creek near Longview (05BL027)



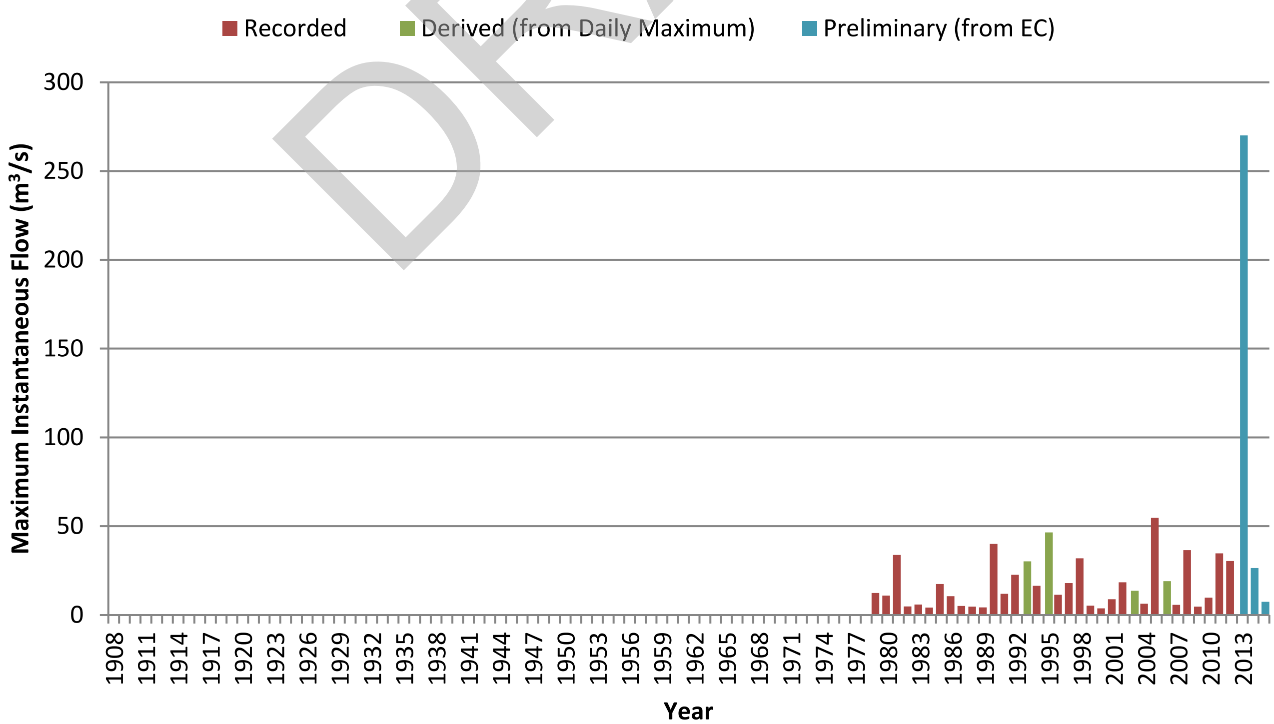
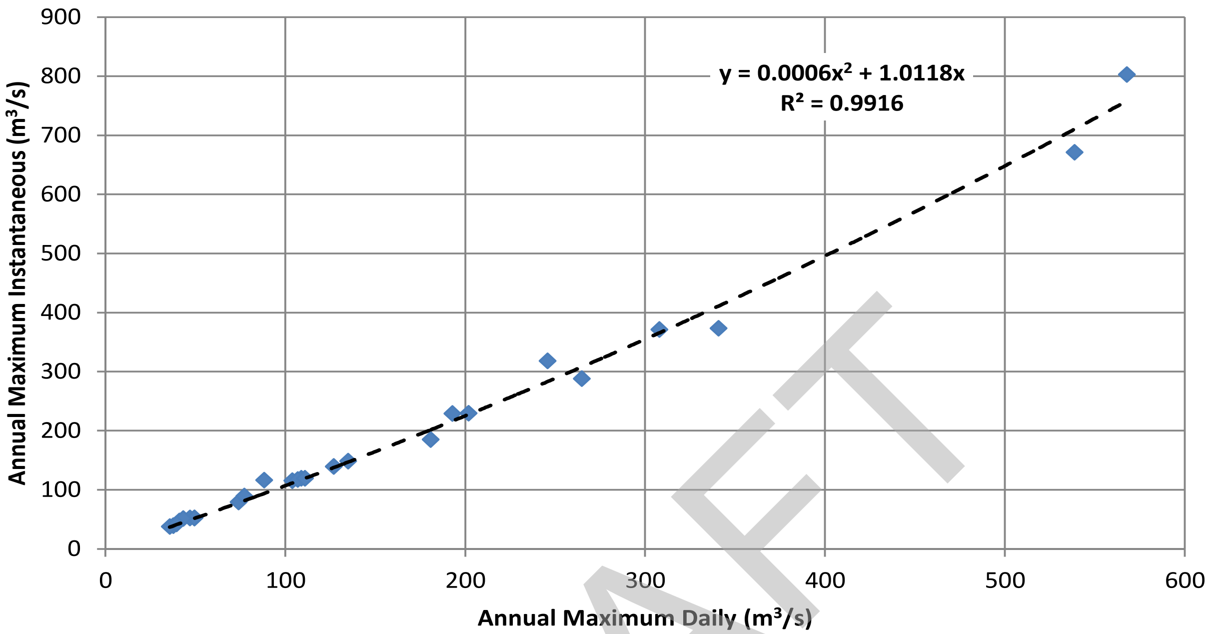
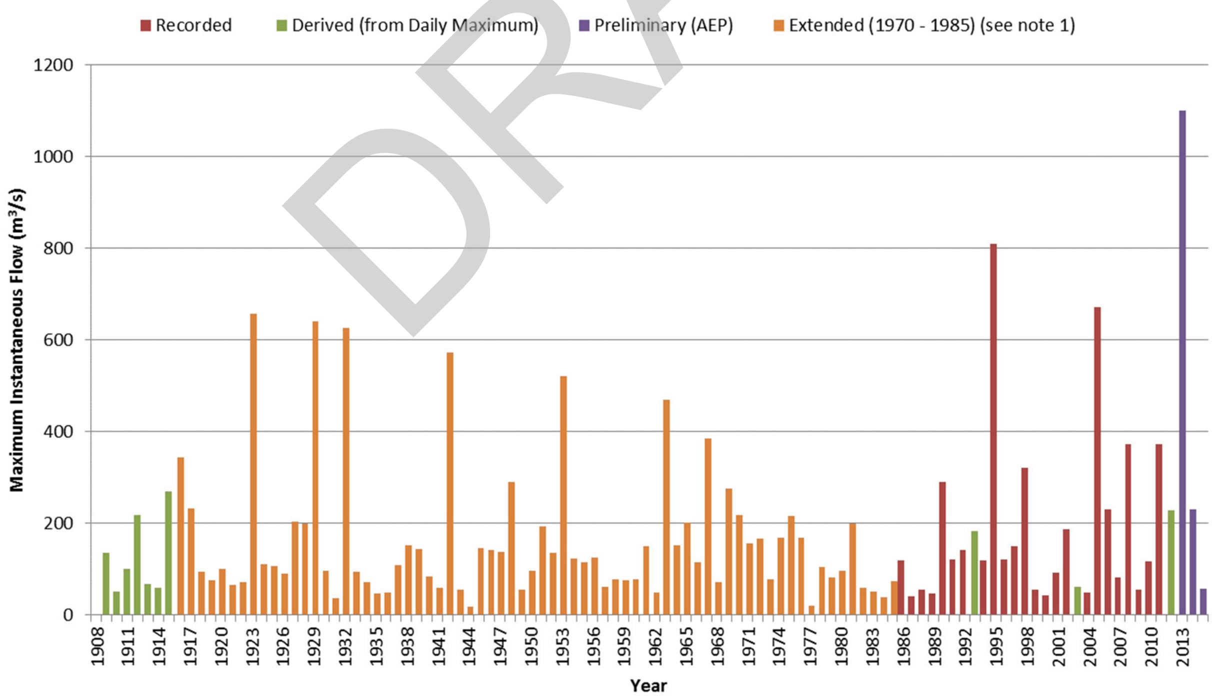


Figure A-46: Highwood River below the Little Bow Canal (05BL004)





Note 1: Extended using maximum daily flows at Highwood River near Aldersyde (05BL009).

Figure A-47: Relationship between Highwood River near the mouth (05BL024) and Highwood River below the Little Bow Canal

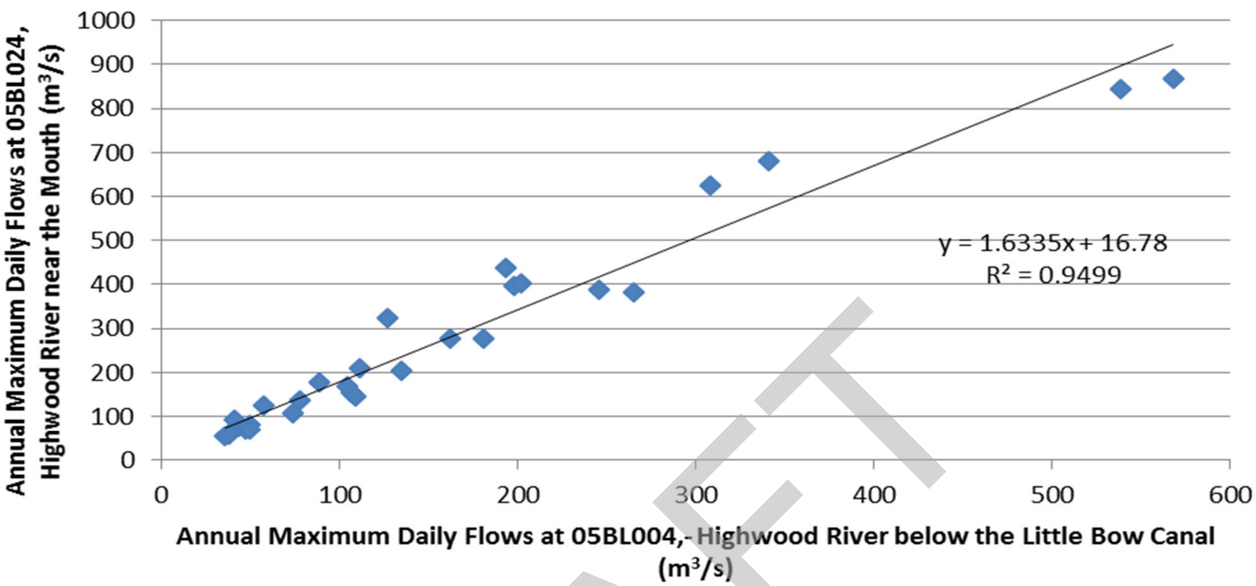


Figure A-48: Relationship between Highwood River near the mouth (05BL024), Highwood River near Aldersyde and Highwood River below the Little Bow Canal

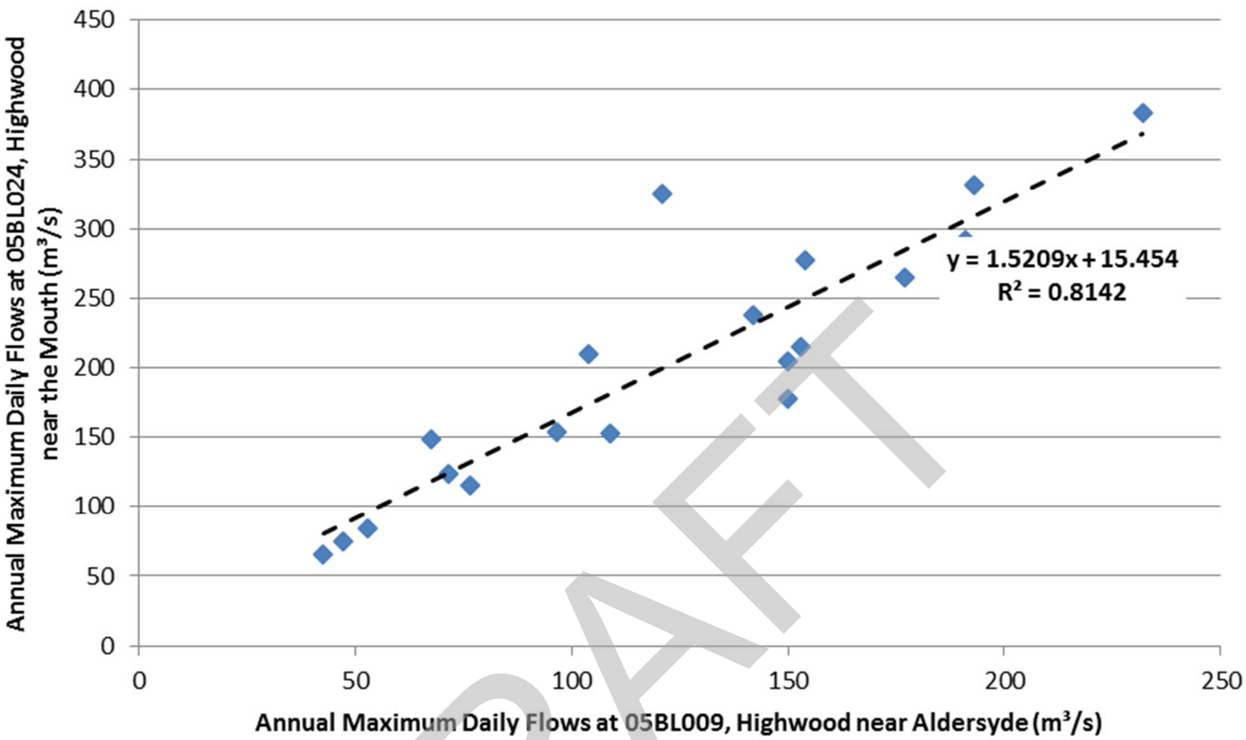
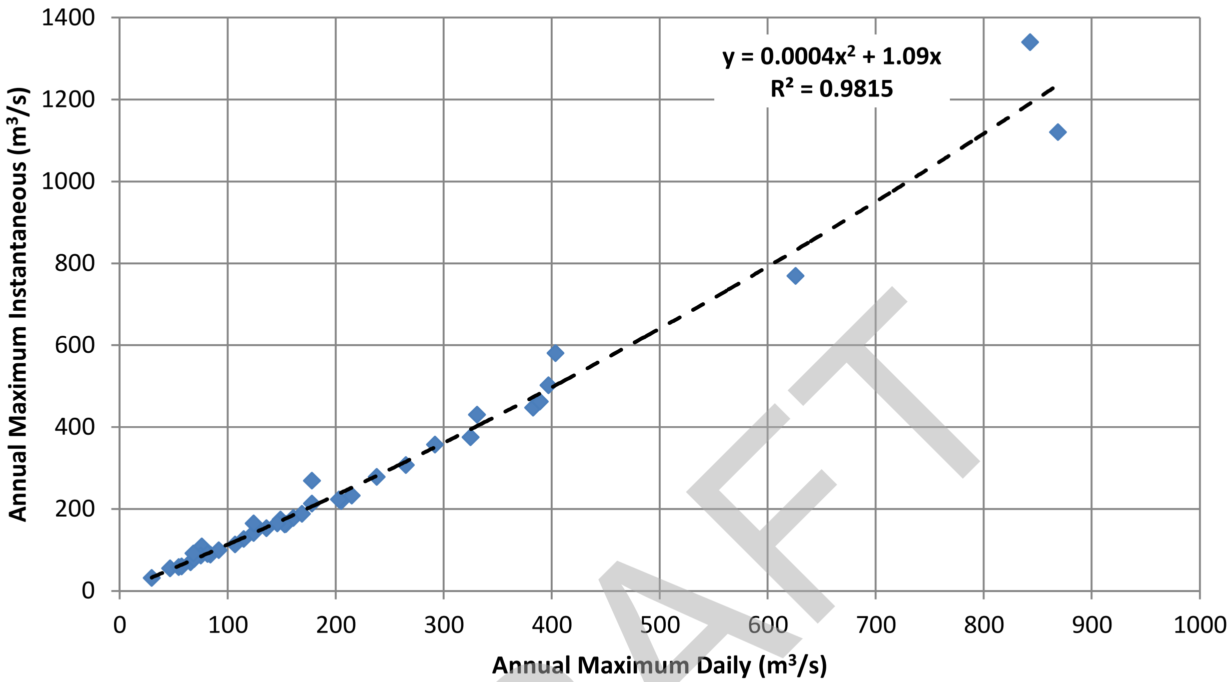
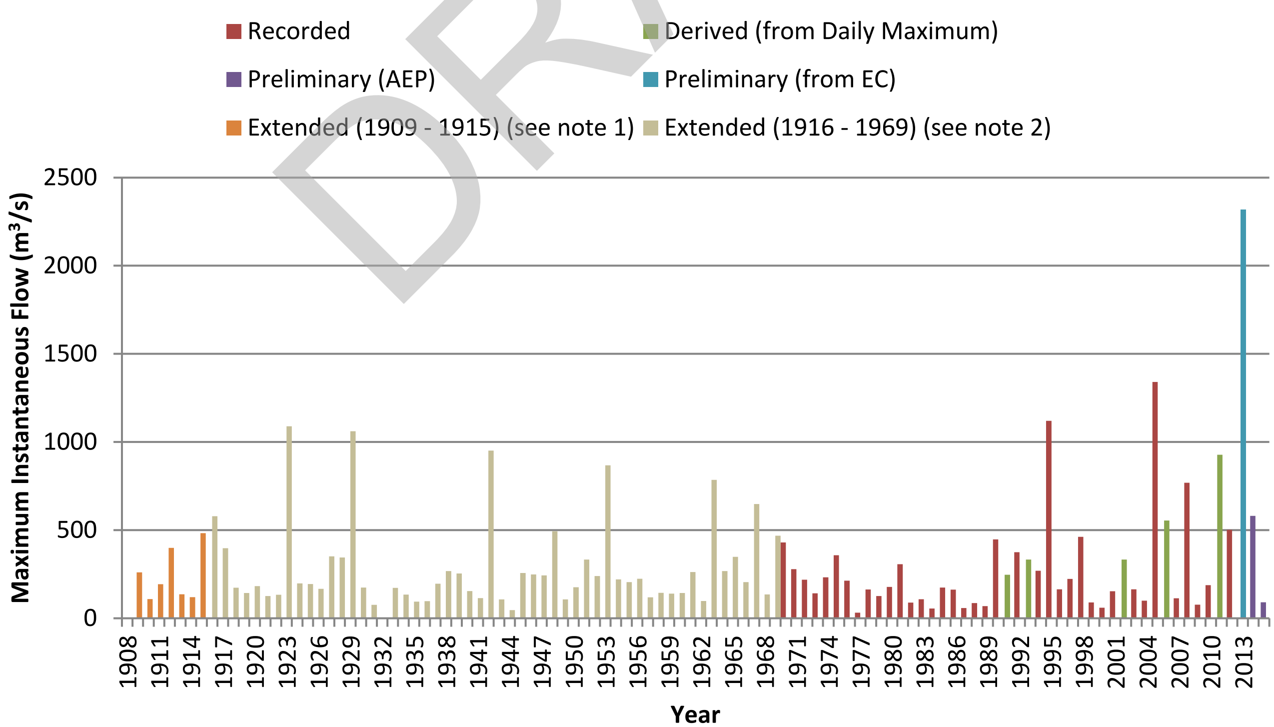


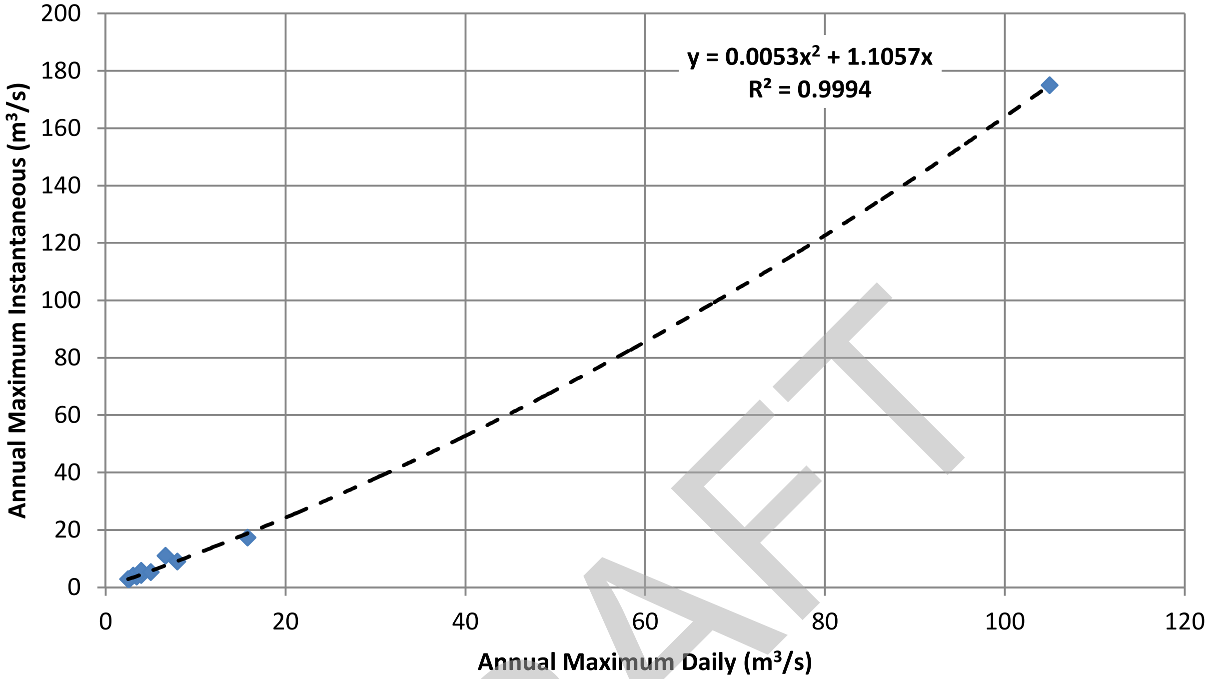
Figure A-49: Highwood River near the mouth (05BL024)





Note 1: Extended using flows at Highwood River below the Little Bow Canal (05BL004).
Note 2: Extended using flows at Highwood River near Aldersyde (05BL009).

Figure A-50: Little Bow River at Hwy 553 (05AC930)



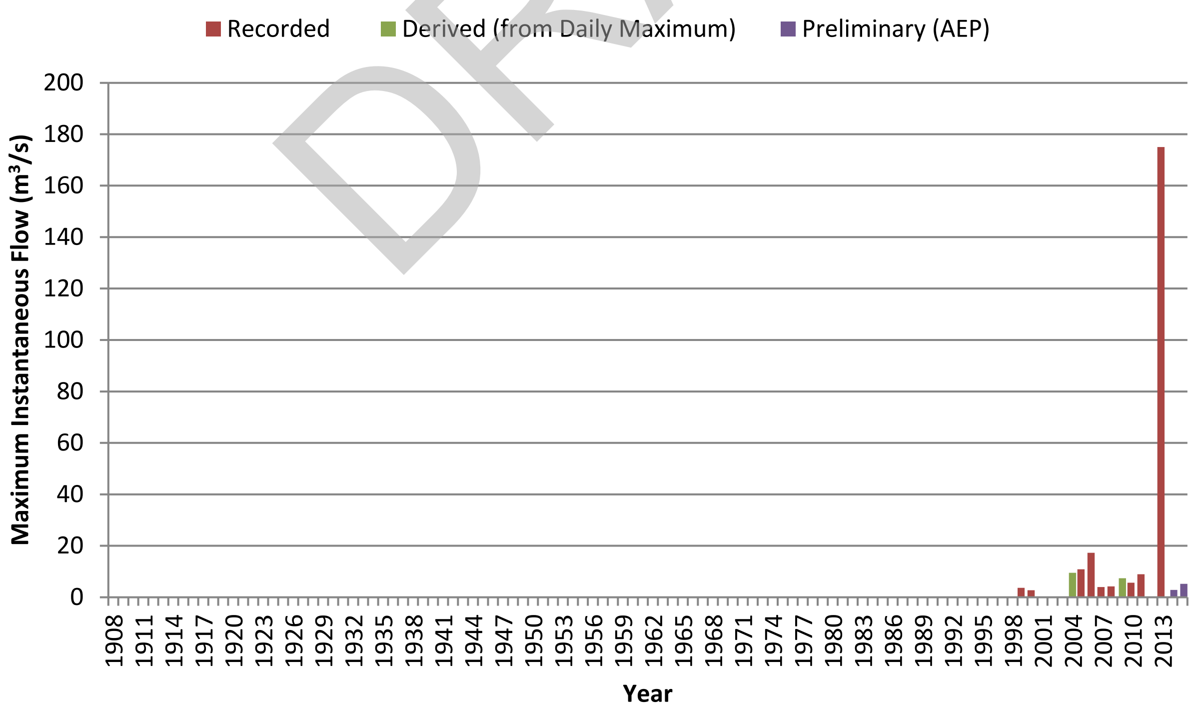


Table A-1: Relationship between Daily Maximum and Instantaneous Maximum Flood Flows - Naturalized Flows

	Multiplication Factor	Source of Multiplication Factor
Bow River Naturalized Flow Station		
Bow River above Spray Confluence (05BB001) - Node 116	1.0493	Bow at Banff
Bow below Spray Confluence - Node 105	1.0493	Bow at Banff
Bow below Cascade Confluence - Node 107	1.0493	Bow at Banff
Bow River at Canmore - Node 108	1.0493	Bow at Banff
Bow River above Kananaskis - Node 109	1.1795	Bow near Seebe
Bow River below Kananaskis - Node 110	1.1795	Bow near Seebe
Bow River at Seebe - Node 111	1.1795	Bow near Seebe
Ghost Reservoir Inflow	1.1483	Ghost outflow
Ghost Reservoir Outflow (05BE006) - Node 58	1.1483	Ghost outflow
Bow Cochrane (05BH005) - Node 114	1.1483	Ghost outflow
Bearspaw Reservoir Inflow	$0.4843x^{1.1345}$	Calgary pre 1932
SSRB / R Bearspaw Reservoir Outflow (same as Bow River at Calgary) - Node 59	$0.4843x^{1.1345}$	Calgary pre 1932
Bow at Calgary d/s of Elbow Confluence - Node 176	$0.4843x^{1.1345}$	Calgary pre 1932
Bow River at Nose Creek Confluence - Node 158	$0.4843x^{1.1345}$	Calgary pre 1932
Bow River at Fish Creek Confluence - Node 164	$0.4843x^{1.1345}$	Calgary pre 1932
UB Bow River at Pine Creek - Node 172	$0.4843x^{1.1345}$	Calgary pre 1932
Bow River above Highwood Confluence	1.1298	Carseland
Bow River at Highwood Confluence - Node 165	1.1298	Carseland
Bow River at Carseland Weir - Node 178	1.1298	Carseland
Bow River at Hwy 547 - Node 180	1.1298	Carseland
Bow River at Hwy 842 - Node 181	1.1298	Carseland
Bow River at Crowfoot Confluence - Node 189	1.0995	Bassano
Bow River at Bassano - Node 182	1.0995	Bassano
LB Bow River between Bassano and Hwy 539 - Node 190	1.0995	Bassano
Bow River at Hwy 539 - Node 184	1.0995	Bassano
Bow River at Hwy 36 - Node 185	1.0598	near mouth
Bow River at Hwy 875 - Node 186	1.0598	near mouth
Bow River at the Gauge 05BN012 - Node 187	1.0598	near mouth
Bow River at the Mouth - Node 188	1.0598	near mouth
Tributaries Naturalized Flow Station		
Spray River at Mouth (05BC001) - Node 106	1.0776	Spray pre 1951
Cascade River at Lake Minewanka - Node 154	1.0776	Spray pre 1951
Kananaskis River at Barrier Lake - Node 56	1.12	pre 1946
Jumpingpound Creek - Node 174	1.2086	near mouth
Nose Creek at Calgary - Node 175	1.5421	
Fish Creek above confluence with Bow - Node 163	$1.268x^{1.0227}$	near Priddis
Glenmore Dam Node - Node 161	$0.0011x^2 + 1.0282x$	upstream of Glenmore/Sarcee bridge
Highwood River at High River - Node 171	$0.0006x^2 +1.0118x$	below Little Bow canal
Highwood River at the Mouth - Node 172	$0.0004x^2 + 1.09x$	near mouth
Arrowood Creek above Hwy 547 - Node 179	1	
Crowfoot Creek above confluence with Bow River - Node 183	1.2308	near Cluny
New West Coulee Tributary - Node 192	1	no recorded inst. Max data
Twelve Mile Creek Tributary - Node 191	1	no recorded inst. Max data

Table A-2: Relationship between Daily Maximum and Instantaneous Maximum Flood Flows - Regulated Flows

	Multiplication Factor	Source of Multiplication Factor
Bow River Regulated Flow Station		
Bow River below Spray Confluence - Node 105	1.0493	Bow at Banff
Bow below Cascade Confluence - Node 107	1.0493	Bow at Banff
Bow River at Canmore - Node 108	1.0493	Bow at Banff
Bow River at Seebe - Node 111	1.1795	Bow near Seebe
Ghost Reservoir Inflow	1.1483	Ghost outflow
Ghost Reservoir Outflow (05BE006) - Node 58	1.1483	Ghost outflow
Bow Cochrane (05BH005) - Node 114	1.1483	Ghost outflow
Bearspaw Reservoir Inflow	1.1208	Calgary after 1932
SSRB / R Bearspaw Reservoir Outflow (same as Bow River at Calgary) - Node 59	1.1208	Calgary after 1932
Bow at Calgary d/s of Elbow Confluence - Node 176	1.1208	Calgary after 1932
Bow River at Nose Creek Confluence - Node 158	1.1208	Calgary after 1932
Bow River at Fish Creek Confluence - Node 164	1.1208	Calgary after 1932
UB Bow River at Pine Creek - Node 177	1.1208	Calgary after 1932
Bow River above Highwood Confluence	1.1298	Carseland
Bow River at Highwood Confluence - Node 165	1.1298	Carseland
Bow River at Carseland Weir - Node 178	1.1298	Carseland
Bow River at Hwy 547 - Node 180	1.1298	Carseland
Bow River at Hwy 842 - Node 181	1.1298	Carseland
Bow River at Crowfoot Confluence - Node 189	1.1738	Bassano
Bow River at Bassano - Node 182	1.1738	Bassano
Bow River between Bassano and Hwy 539 - Node 190	1.1738	Bassano
Bow River at Hwy 539 - Node 184	1.1738	Bassano
Bow River at Hwy 36 - Node 185	1.0604	Bow near the mouth
Bow River at Hwy 875 - Node 186	1.0604	Bow near the mouth
Bow River at the Gauge 05BN012 - Node 187	1.0604	Bow near the mouth
Bow River at the Mouth - Node 188	1.0604	Bow near the mouth
Tributaries Regulated Flow Station		
Cascade River at Lake Minewanka - Node 154	1.2864	Spray after 1951
Outflows from Spray Lake	1.2864	Spray after 1951
TransAlta's Diversion from Spray River to Bow River at Canmore	1.2864	Spray after 1951
Spray River below Spray Lake (reduced simulated watershed)	1.2864	Spray after 1951
Kananaskis River Outflow from Upper Kananaskis Lake	1.2864	Spray after 1951
Kananaskis River Outflow from Pocaterra	1.2864	Spray after 1951
Kananaskis River Outflow from Barrier Dam	$0.0026x^2 + 1.2006x$	Kananaskis near Seebe, extended below Barrier
Glenmore Dam Node - Node 161	1.1349	Glenmore Dam downstream
Highwood River at High River - Node 171	$0.0006x^2 +1.0118x$	below the Little Blow Canal
Highwood River at the Mouth - Node 172	$0.0004x^2 + 1.09x$	Highwood near the mouth
Spray Lake End of Day Elevations	1	no factor for water level
Upper Kananaskis Lake End of Day Elevations	1	no factor for water level
Pocaterra End of Day Elevations	1	no factor for water level
Barrier Lake End of Day Elevations	1	no factor for water level
Lake Minnewanka End of Day Elevations	1	no factor for water level
Ghost Lake End of Day Elevations	1	no factor for water level
Bearspaw Lake End of Day Elevations	1	no factor for water level
Glenmore Reervoir End of Day Elevations	1	no factor for water level
Spray Lake Spills to Spray River	1	no factor for spill way

Table A-2: Relationship between Daily Maximum and Instantaneous Maximum Flood Flows - Regulated Flows

	Multiplication Factor	Source of Multiplication Factor
Bow River Regulated Flow Station		
Rundle Plant Spills	1	no factor for spill way

Table A.3: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Natural and Naturalized Flows

WSC Station ID / Node ID	BOW RIVER													
	05BA001	05BB001	Node 105	Node 107	Node 108	Node 109	Node 110	05BE004 / Node 111	Node 318	05BE006 / Node 58	05BH005 / Node 114		Node 302	
WSC Station Name or Location of Interest	Bow River at Lake Louise	Bow River at Banff	Bow River below Spray River	Bow River below Cascade River	Bow River at Canmore	Bow River above Kananaskis	Bow River below Kananaskis	Bow River near Seebe	Bow River above Ghost Reservoir	Bow River below Ghost Dam (Ghost Reservoir Outflow), historic	Bow River near Cochrane	Bow River near Cochrane, historic[1]	Bearspaw Reservoir Inflow	Bearspaw Reservoir Inflow, historic[1]
Anderson-Darling statistic, A^2 = - N -S														
3 Parameter Log-normal	0.578	0.239	0.324	0.235	0.240	0.234	0.457	0.388	0.482	0.467	0.479	n/a	0.521	n/a
Extreme Value	0.466	0.216	0.335	0.247	0.251	0.243	0.330	0.268	0.345	0.460	0.505	n/a	0.552	n/a
Log_Pearson III	0.489	0.354	0.569	0.852	0.864	0.874	0.439	0.386	0.469	0.425	0.443	n/a	0.490	n/a
Weilbull	4.439	2.433	9.4	46.7	36.4	26.4	67.8	68.5	74.3	67.0	82.3	n/a	508.2	n/a
Serial correlation coefficient test for independence														
S_1	0.232	0.014	-0.004	0.021	0.013	0.002	0.037	0.065	0.034	0.020	0.079	n/a	0.089	n/a
t	1.815	0.142	-0.040	0.190	0.118	0.014	0.339	0.620	0.313	0.185	0.726	n/a	0.813	n/a
t(α=0.05)	1.672	1.660	-1.663	1.663	1.663	1.663	1.663	1.662	1.663	1.663	1.663	n/a	1.663	n/a
t(α=0.01)	2.392	2.363	-2.372	2.372	2.372	2.372	2.372	2.368	2.372	2.372	2.372	n/a	2.372	n/a
Spearman rank order correlation coefficient test for no-trend														
r_s	0.258	0.252	0.040	0.062	0.058	0.052	0.086	0.139	0.087	0.011	-0.042	n/a	-0.028	n/a
t	2.048	2.672	0.367	0.573	0.535	0.477	0.791	1.334	0.801	0.101	-0.389	n/a	-0.254	n/a
t(α=0.05)	2.001	1.983	1.989	1.989	1.989	1.989	1.989	1.986	1.989	1.989	-1.989	n/a	-1.989	n/a
t(α=0.01)	2.662	2.623	2.636	2.636	2.636	2.636	2.636	2.631	2.636	2.636	-2.636	n/a	-2.636	n/a
Mann-Whitney split sample test for homogeneity														
Size of earlier sample	31	54	43	43	43	43	43	47	43	43	43	n/a	43	n/a
z	-1.767	-1.751	-0.203	-0.695	-0.661	-0.661	-0.851	-0.937	-0.903	-0.376	-0.151	n/a	-0.272	n/a
z(α=0.05)	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	n/a	-1.645	n/a
z(α=0.01)	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	n/a	-2.326	n/a
Test of general randomness (Runs for above or below the median)														
Median	47.5	216	267	319	318	346	376	377	370	405	412	n/a	382	n/a
N1(for Q>=Median)	32	54	43	43	43	43	43	47	43	43	43	n/a	43	n/a
N2(for Q<Median)	29	53	43	43	43	43	43	46	43	43	43	n/a	43	n/a
Run_ab	23	56	44	46	46	42	46	48	46	40	38	n/a	38	n/a
z	2.181	0.292	0.000	0.434	0.434	0.434	0.434	0.105	0.434	0.868	1.302	n/a	1.302	n/a
z(a=0.05)	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	n/a	1.960	n/a
z(a=0.01)	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	n/a	2.576	n/a

NOTES:

n/a, statistical test is either not applicable or not available

1. Historic floods were calculated based on ratio between recorded flows and historic flows, therefore, statistical test is not applicable
2. Flood estimates were calculated using prorating based on drainage area
3. Selected distribution based on best statistical fit 0.475
4. Criteria for the respective statistical tests were not met 1.960

Table A.3: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Natural and Naturalized Flows

WSC Station ID / Node ID	BOW RIVER															
	05BH004 / Node 59			Node 176		Node 158		Node 164		Node 177		Node 331		Node 165	05BM002 / Node 178	Node 180
WSC Station Name or Location of Interest	Bearspaw Reservoir Outflow (same as Bow River at Calgary)	Bow River at Calgary, extended	Bow River at Calgary, historic	Bow River below Elbow River	Bow River below Elbow River, historic[1]	Bow River below Nose Creek	Bow River below Nose Creek, historic[1]	Bow River below Fish Creek	Bow River below Fish Creek, historic[1]	Bow River below Pine Creek	Bow River below Pine Creek, historic[1]	Bow River above Highwood River	Bow River above Highwood River, historic[1]	Bow River below Highwood River	Bow River below Carseland Dam	Bow River at Hwy. 547
Anderson-Darling statistic, $A^2 = -N - S$																
3 Parameter Log-normal	0.644	0.760	n/a	0.592	n/a	0.584	n/a	0.550	n/a	0.554	n/a	0.555	n/a	0.540	0.295	0.301
Extreme Value	0.599	0.665	n/a	0.561	n/a	0.552	n/a	0.534	n/a	0.539	n/a	0.539	n/a	0.358	0.113	0.145
Log_Pearson III	0.544	0.652	n/a	0.504	n/a	0.497	n/a	0.479	n/a	0.484	n/a	0.487	n/a	0.397	0.239	0.258
Weilbull	60.9	80.5	n/a	508	n/a	508	n/a	508	n/a	508	n/a	508	n/a	508	66	60
Serial correlation coefficient test for independence																
S_1	0.065	0.145	n/a	0.080	n/a	0.082	n/a	0.087	n/a	0.089	n/a	0.091	n/a	0.219	0.137	0.137
t	0.594	1.478	n/a	0.733	n/a	0.746	n/a	0.799	n/a	0.812	n/a	0.829	n/a	2.042	1.259	1.259
t(α=0.05)	1.663	1.660	n/a	1.663	n/a	1.663	n/a	1.663	n/a	1.663	n/a	1.663	n/a	1.663	1.663	1.663
t(α=0.01)	2.372	2.363	n/a	2.372	n/a	2.372	n/a	2.372	n/a	2.372	n/a	2.372	n/a	2.372	2.372	2.372
Spearman rank order correlation coefficient test for no-trend																
r_s	0.014	0.184	n/a	-0.052	n/a	-0.049	n/a	-0.063	n/a	-0.064	n/a	-0.065	n/a	-0.164	-0.116	-0.116
t	0.126	1.899	n/a	-0.480	n/a	-0.447	n/a	-0.582	n/a	-0.588	n/a	-0.596	n/a	-1.525	-1.069	-1.069
t(α=0.05)	1.989	1.983	n/a	-1.989	n/a	-1.989	n/a	-1.989	n/a	-1.989	n/a	-1.989	n/a	-1.989	-1.989	-1.989
t(α=0.01)	2.636	2.624	n/a	-2.636	n/a	-2.636	n/a	-2.636	n/a	-2.636	n/a	-2.636	n/a	-2.636	-2.636	-2.636
Mann-Whitney split sample test for homogeneity																
Size of earlier sample	43	52	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	43	43
z	-0.773	-1.346	n/a	-0.540	n/a	-0.574	n/a	-0.540	n/a	-0.531	n/a	-0.531	n/a	-0.626	-0.229	-0.229
z(α=0.05)	-1.645	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	-1.645	-1.645
z(α=0.01)	-2.326	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	-2.326	-2.326
Test of general randomness (Runs for above or below the median)																
Median	403	430	n/a	455	n/a	455	n/a	465	n/a	464	n/a	464	n/a	589	604	604
N1(for Q>=Median)	43	53	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	43	43
N2(for Q<Median)	43	52	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	43	43
Run_ab	42	42	n/a	36	n/a	36	n/a	36	n/a	36	n/a	36	n/a	34	34	34
z	0.434	2.255	n/a	1.736	n/a	1.736	n/a	1.736	n/a	1.736	n/a	1.736	n/a	2.169	2.169	2.169
z(a=0.05)	1.960	1.960	n/a	1.960	n/a	1.960	n/a	1.960	n/a	1.960	n/a	1.960	n/a	1.960	1.960	1.960
z(a=0.01)	2.576	2.576	n/a	2.576	n/a	2.576	n/a	2.576	n/a	2.576	n/a	2.576	n/a	2.576	2.576	2.576

Table A.3: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Natural and Naturalized Flows

WSC Station ID / Node ID	BOW RIVER								BOW RIVER TRIBUTARIES					
	Node 181	Node 189	05BM004 / Node 182	Node 184	Node 185	Node 186	05BN012 / Node 187	Node 188	05BC001 / Node 106		Node 154	05BF001	05BF025 / Node 56	05BG010
WSC Station Name or Location of Interest	Bow River at Hwy. 842	Bow River below Crowfoot Creek	Bow River below Bassano Dam, extended	Bow River at Hwy. 539	Bow River at Hwy. 36	Bow River at Hwy. 875	Bow River near the Mouth	Bow River at the Mouth	Spray River at Banff, before 1951	Spray River at Banff	Cascade River near Banff	Kananaskis River near Seebe, before 1946	Kananaskis River below Barrier Dam	Ghost River above Waiparous Creek, extended
Anderson-Darling statistic, $A^2 = -N - S$														
3 Parameter Log-normal	0.283	0.289	0.221	0.213	0.230	0.254	0.193	0.181	0.486	0.853	0.481	0.492	1.229	0.719
Extreme Value	0.170	0.176	0.278	0.283	0.292	0.315	0.223	0.219	0.683	0.794	0.392	0.395	1.044	0.354
Log_Pearson III	0.278	0.283	0.388	0.389	0.416	0.455	0.358	0.358	0.840	0.957	0.850	0.832	1.378	0.801
Weilbull	508	508	18.166	21.7	22.4	41.0	41.2	46.8	1.917	18.638	46.808	2.391	22.816	6.302
Serial correlation coefficient test for independence														
S_1	0.141	0.141	0.171	0.189	0.150	0.136	0.168	0.155	0.152	0.196	0.151	0.358	0.192	0.190
t	1.300	1.296	1.579	1.945	1.385	1.253	1.549	1.426	0.947	1.824	1.394	2.135	1.783	1.869
t(α=0.05)	1.663	1.663	1.663	1.660	1.663	1.663	1.663	1.663	1.686	1.663	1.663	1.696	1.663	1.661
t(α=0.01)	2.372	2.372	2.372	2.363	2.372	2.372	2.372	2.372	2.429	2.372	2.372	2.453	2.372	2.367
Spearman rank order correlation coefficient test for no-trend														
r_s	-0.071	-0.073	-0.177	-0.026	-0.152	-0.148	-0.207	-0.196	0.487	-0.278	0.061	0.558	-0.194	-0.010
t	-0.652	-0.675	-1.647	-0.264	-1.406	-1.371	-1.940	-1.834	3.478	-2.656	0.559	3.803	-1.810	-0.100
t(α=0.05)	-1.989	-1.989	-1.989	-1.983	-1.989	-1.989	-1.989	-1.989	2.023	-1.989	1.989	2.037	-1.989	-1.986
t(α=0.01)	-2.636	-2.636	-2.636	-2.624	-2.636	-2.636	-2.636	-2.636	2.708	-2.636	2.636	2.738	-2.636	-2.629
Mann-Whitney split sample test for homogeneity														
Size of earlier sample	43	43	43	53	43	43	43	43	22	43	43	17	43	48
z	-0.643	-0.626	-0.523	-1.384	-0.246	-0.229	-0.954	-0.816	-2.575	-3.386	-1.533	-2.446	-1.499	-0.029
z(α=0.05)	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645		-1.645	-1.645
z(α=0.01)	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326		-2.326	-2.326
Test of general randomness (Runs for above or below the median)														
Median	572	556	568	576	544	539	556	548	73.0	68.7	54.5	70.3	69.8	25.4
N1(for Q>=Median)	43	43	43	53	43	43	43	43	22	43	43	17	43	48
N2(for Q<Median)	43	43	43	52	43	43	43	43	19	43	43	17	43	48
Run_ab	36	36	32	39	32	36	30	34	20	41	34	12	42	36
z	1.736	1.736	2.603	2.843	2.603	1.736	3.037	2.169	0.442	0.651	2.169	2.090	0.434	2.668
z(a=0.05)	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960		1.960	1.960
z(a=0.01)	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576		2.576	2.576

Table A.3: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Natural and Naturalized Flows

WSC Station ID / Node ID	BOW RIVER TRIBUTARIES														
	05BG006		05BG001		05BH015	05BH009		05BH003 / Node 175		Node 163	05BK001	05BM008	05BN006	05BN002	Node 179
WSC Station Name or Location of Interest	Waiparous Creek near the Mouth	Waiparous Creek near the Mouth, extended	Ghost River near Cochrane, extended	Ghost River near Cochrane, sensitivity analysis	Jumpingpound Creek at Township Road No. 252, extended	Jumpingpound Creek near the Mouth	Jumpingpound Creek near the Mouth, extended	Nose Creek at Calgary, Extended	Nose Creek at Calgary	Fish Creek at the Mouth	Fish Creek near Priddis	Crowfoot Creek near Cluny	New West Coulee near the Mouth	Twelve Mile Creek near Cecil	Arrowwood Creek above Hwy. 547
Anderson-Darling statistic, A² = - N -S															
3 Parameter Log-normal	0.341	0.183	0.333	0.465	0.167	0.128	0.162	0.265	0.327	0.192	0.167	0.458	0.410	0.879	0.741
Extreme Value	0.593	0.779	0.347	0.280	0.498	0.555	0.332	0.248	0.859	0.619	0.537	2.000	0.394	1.191	0.914
Log_Pearson III	0.846	0.449	0.318	0.485	0.207	0.192	0.203	0.912	0.502	0.358	0.434	0.762	0.461	1.039	0.375
Weilbull	1.003	2.092	2.967	1.975	2.207	1.879	1.125	1.460	1.300	3.332	1.997	4.032	0.737	1.319	1.969
Serial correlation coefficient test for independence															
S_1	0.066	0.142	0.137	0.226	0.338	0.259	0.329	0.013	0.046	0.184	0.180	0.209	0.353	0.761	0.192
t	0.450	1.380	1.337	2.234	2.712	1.610	2.700	0.062	0.399	1.412	1.345	1.681	2.825	9.229	1.342
t(α=0.05)	1.678	1.661	1.661	1.661	1.672	1.688	1.671	1.711	1.666	1.672	1.674	1.670	1.673	1.670	1.678
t(α=0.01)	2.408	2.367	2.367	2.367	2.394	2.434	2.390	2.492	2.378	2.394	2.397	2.388	2.395	2.388	2.408
Spearman rank order correlation coefficient test for no-trend															
r_s	-0.071	-0.124	-0.089	-0.221	-0.067	-0.047	-0.101	-0.113	-0.184	-0.133	-0.167	-0.136	0.022	-0.523	0.209
t	-0.494	-1.214	-0.863	-2.197	-0.509	-0.285	-0.791	-0.568	-1.622	-1.024	-1.252	-1.091	0.167	-4.870	1.484
t(α=0.05)	-2.011	-1.986	-1.986	-1.986	-2.002	-2.026	-2.000	-2.060	-1.992	-2.002	-2.004	-1.998	2.002	-1.998	2.011
t(α=0.01)	-2.682	-2.629	-2.629	-2.629	-2.663	-2.715	-2.659	-2.787	-2.643	-2.663	-2.668	-2.656	2.665	-2.656	2.682
Mann-Whitney split sample test for homogeneity															
Size of earlier sample	25	48	49	48	32	20	32	14	38	30	35	30.0	30	33	25
z	-0.999	-0.667	-0.887	-1.638	-1.467	-0.674	-1.086	-0.776	-1.676	-0.798	-1.762	-0.813	-0.743	-4.993	-0.728
z(α=0.05)	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645		-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645
z(α=0.01)	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326		-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326
Test of general randomness (Runs for above or below the median)															
Median	33.1	27.9	51.5	53.6	28.3	24.6	29.4	8.59	5.66	15.9	32.0	19.527	4.36	4.56	3.98
N1(for Q>=Median)	25	48	49	48	30	20	32	14	39	30	29	30.0	30	33	25
N2(for Q<Median)	25	48	47	48	30	19	31	13	38	30	28	30.0	29	32	25
Run_ab	23	46	46	36	26	21	30	13	37	25	27	25.0	21	17	20
z	0.857	0.616	0.612	2.668	1.302	0.167	0.633	0.582	0.572	1.562	0.666	1.562	2.494	4.125	1.715
z(a=0.05)	1.960	1.960	1.960	1.960	1.960	1.960	1.960		1.960	1.960	1.960	1.960	1.960	1.960	1.960
z(a=0.01)	2.576	2.576	2.576	2.576	2.576	2.576	2.576		2.576	2.576	2.576	2.576	2.576	2.576	2.576

Table A.3: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Natural and Naturalized Flows

WSC Station ID / Node ID	ELBOW RIVER								SHEEP RIVER AND TRIBUTARIES					
	05BJ004			05BJ010			Node 161		05BL014	05BL012		Node 344		05BL013
WSC Station Name or Location of Interest	Elbow River at Bragg Creek	Elbow River at Bragg Creek, extended	Elbow River at Bragg Creek, historic[1]	Elbow River at Sarcee Bridge, same as Glenmore Reservoir Inflow - combined 05BJ001, 05BJ005, 05BJ010	Elbow River at Sarcee Bridge, same as Glenmore Reservoir Inflow - combined 05BJ001, 05BJ005, 05BJ010 with 1983 values	Elbow River at Sarcee Bridge, same as Glenmore Reservoir Inflow - historic[1]	Elbow River below Glenmore Dam	Elbow River below Glenmore Dam, historic[1]	Sheep River at Black Diamond	Sheep River at Okotoks	Sheep River at Okotoks, extended	Sheep River at the Mouth[2]	Sheep River at the Mouth, extended[2]	Threepoint Creek near Millarville
Anderson-Darling statistic, $A^2 = -N - S$														
3 Parameter Log-normal	0.241	0.356	n/a	0.156	0.212	n/a	0.497	n/a	0.100	0.314	0.281	n/a	n/a	0.335
Extreme Value	0.356	0.567	n/a	0.271	0.312	n/a	0.362	n/a	0.466	0.739	0.650	n/a	n/a	0.703
Log_Pearson III	0.421	0.716	n/a	0.302	0.666	n/a	0.345	n/a	0.377	0.339	1.030	n/a	n/a	0.558
Weilbull	479	17.1	n/a	620	15.2	n/a	9.681	n/a	1.320	0.989	1.312	n/a	n/a	2.240
Serial correlation coefficient test for independence														
S_1	0.049	0.037	n/a	0.075	0.101	n/a	0.102	n/a	0.165	0.075	0.105	n/a	n/a	0.169
t	0.436	0.385	n/a	0.762	1.028	n/a	1.049	n/a	1.208	0.354	0.866	n/a	n/a	1.258
t(α=0.05)	1.665	1.659	n/a	1.660	1.660	n/a	1.659	n/a	1.675	1.717	1.668	n/a	n/a	1.674
t(α=0.01)	2.375	2.362	n/a	2.363	2.363	n/a	2.362	n/a	2.400	2.508	2.383	n/a	n/a	2.397
Spearman rank order correlation coefficient test for no-trend														
r_s	-0.117	0.034	n/a	-0.020	0.001	n/a	0.035	n/a	-0.110	-0.187	-0.104	n/a	n/a	-0.157
t	-1.050	0.349	n/a	-0.203	0.006	n/a	0.364	n/a	-0.802	-0.911	-0.861	n/a	n/a	-1.177
t(α=0.05)	-1.990	1.983	n/a	-1.983	1.983	n/a	1.983	n/a	-2.006	-2.069	-1.995	n/a	n/a	-2.004
t(α=0.01)	-2.640	2.623	n/a	-2.624	2.624	n/a	2.623	n/a	-2.672	-2.807	-2.650	n/a	n/a	-2.668
Mann-Whitney split sample test for homogeneity														
Size of earlier sample	41	54	n/a	53	53	n/a	54	n/a	28	13	35	n/a	n/a	28
z	-0.241	-0.221	n/a	-0.455	-0.256	n/a	-0.147	n/a	-1.355	-1.251	-0.341	n/a	n/a	-1.285
z(α=0.05)	-1.645	-1.645	n/a	-1.645	-1.645	n/a	-1.645	n/a	-1.645		-1.645	n/a	n/a	-1.645
z(α=0.01)	-2.326	-2.326	n/a	-2.326	-2.326	n/a	-2.326	n/a	-2.326		-2.326	n/a	n/a	-2.326
Test of general randomness (Runs for above or below the median)														
Median	56.1	59.8	n/a	63.4	66.8	n/a	59.7	n/a	60.7	124	149	n/a	n/a	36.0
N1(for Q>=Median)	41	54	n/a	53	53	n/a	54	n/a	28	13	35	n/a	n/a	29
N2(for Q<Median)	40	54	n/a	52	53	n/a	54	n/a	27	12	35	n/a	n/a	28
Run_ab	37	46	n/a	44	46	n/a	48	n/a	23	14	34	n/a	n/a	30
z	1.005	1.740	n/a	1.862	1.562	n/a	1.353	n/a	1.495	0.213	0.482	n/a	n/a	0.136
z(a=0.05)	1.960	1.960	n/a	1.960	1.960	n/a	1.960	n/a	1.960		1.960	n/a	n/a	1.960
z(a=0.01)	2.576	2.576	n/a	2.576	2.576	n/a	2.576	n/a	2.576		2.576	n/a	n/a	2.576

Table A.3: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Natural and Naturalized Flows

WSC Station ID / Node ID	HIGHWOOD RIVER AND TRIBUTARIES									
	05BL019	05BL004		05BL024		Node 172	05BL022	05BL023	05BL007	05BL027
WSC Station Name or Location of Interest	Highwood River at Diebel's Ranch	Highwood River below Little Bow Canal	Highwood River below Little Bow Canal, extended	Highwood River near the Mouth	Highwood River near the Mouth, extended	Highwood River at the Mouth[6]	Cataract Creek near Forestry Road	Pekisko Creek near Longview	Stimson Creek near Pekisko	Trapp Creek near Longview
Anderson-Darling statistic, A² = - N -S										
3 Parameter Log-normal	0.588	0.327	0.575	0.130	0.538	n/a	0.461	0.114	0.227	0.464
Extreme Value	0.466	0.446	0.389	0.179	0.244	n/a	0.296	0.499	0.432	0.524
Log_Pearson III	0.450	0.880	0.719	0.381	0.702	n/a	0.573	0.176	0.407	1.021
Weilbull	2.970	2.006	2.767	1.344	5.887	n/a	295	1.994	8.815	219
Serial correlation coefficient test for independence										
S_1	-0.060	0.055	0.091	0.233	0.154	n/a	-0.041	0.066	0.242	0.102
t	-0.470	0.319	0.928	1.571	1.577	n/a	-0.280	0.450	2.284	0.598
t(α=0.05)	-1.670	1.691	1.660	1.681	1.660	n/a	-1.678	1.679	1.663	1.691
t(α=0.01)	-2.388	2.441	2.363	2.416	2.363	n/a	-2.408	2.410	2.372	2.441
Spearman rank order correlation coefficient test for no-trend										
r_s	0.032	-0.245	-0.057	-0.236	-0.039	n/a	-0.045	-0.051	-0.109	-0.261
t	0.255	-1.493	-0.584	-1.610	-0.397	n/a	-0.309	-0.347	-1.016	-1.602
t(α=0.05)	1.998	-2.030	-1.983	-2.015	-1.983	n/a	-2.011	-2.012	-1.988	-2.030
t(α=0.01)	2.656	-2.724	-2.623	-2.692	-2.624	n/a	-2.682	-2.685	-2.635	-2.724
Mann-Whitney split sample test for homogeneity										
Size of earlier sample	33	19	27	23	53	n/a	25	24	44	19
z	-0.650	-0.608	-0.186	-1.922	-0.654	n/a	-0.689	-1.480	-0.093	-0.714
z(α=0.05)	-1.645		-1.645	-1.645	-1.645	n/a	-1.645	-1.645	-1.645	
z(α=0.01)	-2.326		-2.326	-2.326	-2.326	n/a	-2.326	-2.326	-2.326	
Test of general randomness (Runs for above or below the median)										
Median	77.3	121	117	203	197	n/a	24.6	13.9	13.6	12.4
N1(for Q>=Median)	33	19	54	23	53	n/a	25	25	44	19
N2(for Q<Median)	32	18	53	23	53	n/a	25	24	43	18
Run_ab	36	18	46	18	40	n/a	25	20	37	20
z	0.627	0.496	1.650	1.789	2.733	n/a	0.286	1.586	1.617	0.171
z(a=0.05)	1.960		1.960	1.960	1.960	n/a	1.960	1.960	1.960	
z(a=0.01)	2.576		2.576	2.576	2.576	n/a	2.576	2.576	2.576	

Table A.4: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Regulated Flows

WSC Station ID / Node ID	BOW RIVER															
	Node 105	Node 107	Node 108	05BE004 / Node 111		318	05BE006 / Node 58		05BH005 / Node 114		302		05BH008			
WSC Station Name or Location of Interest	Bow River below Spray River	Bow River below Cascade River	Bow River at Canmore[2]	Bow River near Seebe, recorded	Bow River near Seebe, regulated	Bow River above Ghost Reservoir	Bow River below Ghost Dam (Ghost Reservoir Outflow), recorded	Bow River below Ghost Dam (Ghost Reservoir Outflow), regulated	Bow River near Cochrane	Bow River near Cochrane, historic[1]	Bearspaw Reservoir Inflow	Bearspaw Reservoir Inflow, historic[1]	Bearspaw Reservoir Outflow	Bearspaw Reservoir Outflow, extended using Bow River at Calgary - all flows	Bearspaw Reservoir Outflow, extended using Bow River at Calgary - all flows, historic	Bearspaw Reservoir Outflow, extended using Bow River at Calgary - post 1932 flows
Anderson-Darling statistic, A^2 = - N -S																
3 Parameter Log-normal	0.396	0.358	0.323	0.185	0.454	0.455	0.553	0.503	0.527	*n/a*	0.563	*n/a*	0.202	0.687	*n/a*	0.419
Extreme Value	0.375	0.360	0.303	0.169	0.473	0.474	0.446	0.511	0.542	*n/a*	0.574	*n/a*	0.143	0.549	*n/a*	0.412
Log_Pearson III	0.526	0.584	0.533	0.373	0.437	0.437	0.645	0.444	0.467	*n/a*	0.482	*n/a*	0.549	1.094	*n/a*	1.045
Weilbull	4.537	4.746	11.8	2.041	54.3	54.3	0.379	67.9	62.1	*n/a*	56.0	*n/a*	1.709	26.5	*n/a*	79.9
Serial correlation coefficient test for independence																
S_1	0.013	0.055	0.053	0.129	0.112	0.112	0.232	0.030	0.004	*n/a*	0.020	*n/a*	0.098	0.307	*n/a*	0.168
t	0.114	0.506	0.485	1.117	1.026	1.026	1.651	0.276	0.039	*n/a*	0.185	*n/a*	0.541	3.243	*n/a*	1.514
t(α=0.05)	1.663	1.663	1.663	1.666	1.663	1.663	1.677	1.663	1.663	*n/a*	1.663	*n/a*	1.697	1.660	*n/a*	1.664
t(α=0.01)	2.372	2.372	2.372	2.378	2.372	2.372	2.407	2.372	2.372	*n/a*	2.372	*n/a*	2.457	2.364	*n/a*	2.374
Spearman rank order correlation coefficient test for no-trend																
r_s	0.152	0.143	0.053	0.370	-0.154	-0.154	0.454	-0.072	-0.109	*n/a*	-0.099	*n/a*	-0.198	0.443	*n/a*	0.263
t	1.407	1.321	0.487	3.451	-1.425	-1.425	3.568	-0.666	-1.007	*n/a*	-0.915	*n/a*	-1.124	4.991	*n/a*	2.435
t(α=0.05)	1.989	1.989	1.989	1.992	-1.989	-1.989	2.010	-1.989	-1.989	*n/a*	-1.989	*n/a*	-2.040	1.983	*n/a*	1.990
t(α=0.01)	2.636	2.636	2.636	2.643	-2.636	-2.636	2.680	-2.636	-2.636	*n/a*	-2.636	*n/a*	-2.744	2.625	*n/a*	2.639
Mann-Whitney split sample test for homogeneity																
Size of earlier sample	43	43	43	39	43	43	26	43	43	*n/a*	43	*n/a*	17	54	*n/a*	41
z	-1.542	-1.611	-0.531	-3.077	-1.490	-1.490	-2.921	-0.540	-0.721	*n/a*	-0.618	*n/a*	-0.144	-4.132	*n/a*	-3.381
z(α=0.05)	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	*n/a*	-1.645	*n/a*		-1.645	*n/a*	-1.645
z(α=0.01)	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	*n/a*	-2.326	*n/a*		-2.326	*n/a*	-2.326
Test of general randomness (Runs for above or below the median)																
Median	218	238	264	334	358	349	331	376	382	*n/a*	370	*n/a*	293	380	*n/a*	344
N1(for Q>=Median)	43	43	43	39	43	43	26	43	43	*n/a*	43	*n/a*	17	53	*n/a*	41
N2(for Q<Median)	43	43	43	38	43	43	25	43	43	*n/a*	43	*n/a*	16	51	*n/a*	41
Run_ab	50	46	46	36	40	40	20	42	44	*n/a*	46	*n/a*	15	40	*n/a*	36
z	1.302	0.434	0.434	0.802	0.868	0.868	1.837	0.434	0.000	*n/a*	0.434	*n/a*	0.880	2.559	*n/a*	1.333
z(a=0.05)	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	*n/a*	1.960	*n/a*		1.960	*n/a*	1.960
z(a=0.01)	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	*n/a*	2.576	*n/a*		2.576	*n/a*	2.576

NOTES:

n/a, statistical test is either not applicable or not available

1. Historic floods were calculated based on ratio between recorded flows and historic flows, therefore, statistical test is not applicable
2. Flood estimates were calculated using prorating based on drainage area
3. Selected distribution based on best statistical fit 0.360
4. Criteria for the respective statistical tests were not met -2.326

Table A.4: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Regulated Flows

WSC Station ID / Node ID	BOW RIVER																
	Node 59		05BH004		Node 176		Node 158		Node 164		Node 177		Node 331		Node 165	05BM002 / Node 178	
WSC Station Name or Location of Interest	Bearspaw Reservoir Outflow (same as Bow River at Calgary)	Bearspaw Reservoir Outflow (same as Bow River at Calgary), historic	Bow River at Calgary	Bow River at Calgary, historic	Bow River below Elbow River	Bow River below Elbow River, historic[1]	Bow River below Nose Creek	Bow River below Nose Creek, historic[1]	Bow River below Fish Creek	Bow River below Fish Creek, historic[1]	Bow River below Pine Creek	Bow River below Pine Creek, historic[1]	Bow River above Highwood River	Bow River above Highwood River, historic[1]	Bow River below Highwood River	Bow River below Carseland Dam, recorded	Bow River below Carseland Dam, regulated
Anderson-Darling statistic, A^2 = - N -S																	
3 Parameter Log-normal	0.705	n/a	0.867	n/a	0.732	n/a	0.498	n/a	0.506	n/a	0.498	n/a	0.487	n/a	0.200	0.299	0.165
Extreme Value	0.634	n/a	0.642	n/a	0.682	n/a	0.352	n/a	0.407	n/a	0.399	n/a	0.388	n/a	0.141	0.213	0.176
Log_Pearson III	0.558	n/a	0.804	n/a	0.574	n/a	0.350	n/a	0.372	n/a	0.364	n/a	0.354	n/a	0.750	0.400	0.790
Weilbull	54.5	n/a	27.4	n/a	508	n/a	47.1	n/a	60.2	n/a	54.9	n/a	60.2	n/a	46.8	24.7	41.1
Serial correlation coefficient test for independence																	
S_1	0.042	n/a	0.323	n/a	0.053	n/a	0.053	n/a	0.045	n/a	0.038	n/a	0.036	n/a	0.176	0.196	0.068
t	0.386	n/a	3.427	n/a	0.487	n/a	0.485	n/a	0.410	n/a	0.345	n/a	0.329	n/a	1.625	1.548	0.618
t(α=0.05)	1.663	n/a	1.660	n/a	1.663	n/a	1.663	n/a	1.663	n/a	1.663	n/a	1.663	n/a	1.663	1.671	1.663
t(α=0.01)	2.372	n/a	2.364	n/a	2.372	n/a	2.372	n/a	2.372	n/a	2.372	n/a	2.372	n/a	2.372	2.390	2.372
Spearman rank order correlation coefficient test for no-trend																	
r_s	-0.094	n/a	0.486	n/a	-0.137	n/a	-0.081	n/a	-0.103	n/a	-0.100	n/a	-0.100	n/a	-0.181	-0.070	-0.156
t	-0.862	n/a	5.613	n/a	-1.268	n/a	-0.741	n/a	-0.952	n/a	-0.923	n/a	-0.920	n/a	-1.689	-0.547	-1.444
t(α=0.05)	-1.989	n/a	1.983	n/a	-1.989	n/a	-1.989	n/a	-1.989	n/a	-1.989	n/a	-1.989	n/a	-1.989	-2.000	-1.989
t(α=0.01)	-2.636	n/a	2.625	n/a	-2.636	n/a	-2.636	n/a	-2.636	n/a	-2.636	n/a	-2.636	n/a	-2.636	-2.659	-2.636
Mann-Whitney split sample test for homogeneity																	
Size of earlier sample	43	n/a	53	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	32	43
z	-0.402	n/a	-4.230	n/a	-0.428	n/a	-0.341	n/a	-0.402	n/a	-0.384	n/a	-0.384	n/a	-1.274	-0.543	-0.376
z(α=0.05)	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	n/a	-1.645	-1.645	-1.645
z(α=0.01)	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	n/a	-2.326	-2.326	-2.326
Test of general randomness (Runs for above or below the median)																	
Median	377	n/a	374	n/a	419	n/a	383	n/a	393	n/a	392	n/a	393	n/a	515	504	531
N1(for Q>=Median)	43	n/a	52	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	32	43
N2(for Q<Median)	43	n/a	52	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	n/a	43	31	43
Run_ab	42	n/a	40	n/a	38	n/a	42	n/a	40	n/a	40	n/a	44	n/a	42	27	40
z	0.434	n/a	2.562	n/a	1.302	n/a	0.434	n/a	0.868	n/a	0.868	n/a	0.000	n/a	0.434	1.396	0.868
z(a=0.05)	1.960	n/a	1.960	n/a	1.960	n/a	1.960	n/a	1.960	n/a	1.960	n/a	1.960	n/a	1.960	1.960	1.960
z(a=0.01)	2.576	n/a	2.576	n/a	2.576	n/a	2.576	n/a	2.576	n/a	2.576	n/a	2.576	n/a	2.576	2.576	2.576

Table A.4: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Regulated Flows

WSC Station ID / Node ID	BOW RIVER											BOW RIVER TRIBUTARIES			
	Node 180	Node 181	Node 189	05BM004 / Node 182		Node 184	Node 185	Node 186	05BN012 / Node 187		Node 188	Node 154	Node 207	Node 201	Node 51
WSC Station Name or Location of Interest	Bow River at Hwy. 547	Bow River at Hyw. 842	Bow River below Crowfoot Creek	Bow River below Bassano Dam, recorded	Bow River below Bassano Dam, regulated	Bow River at Hwy. 539	Bow River at Hwy. 36	Bow River at Hwy. 875	Bow River near the Mouth, recorded	Bow River near the Mouth, regulated	Bow River at the Mouth	Cascade River at Lake Minnewanka	Lake Minnewanka End of Day Elevations7	Spray Lake End of Day Elevations7	Spray River below Spray Lake, reduced simulated watershed
Anderson-Darling statistic, A^2 = - N -S															
3 Parameter Log-normal	0.171	0.148	0.157	0.299	0.248	0.262	0.247	0.241	0.372	0.250	0.251	11.517	11.062	7.081	1.558
Extreme Value	0.194	0.182	0.190	0.227	0.205	0.213	0.202	0.198	0.316	0.149	0.158	190.0	30.662	25.924	4.031
Log_Pearson III	0.802	0.788	0.802	0.486	0.424	0.441	0.430	0.444	0.421	0.325	0.330	9.159	9.089	5.089	1.561
Weilbull	53.1	74.0	74.0	2.399	26.0	26.6	26.1	26.0	37.3	21.9	22.0	508	508	508	6.207
Serial correlation coefficient test for independence															
S_1	0.078	0.082	0.075	0.300	0.228	0.207	0.199	0.193	0.240	0.242	0.236	0.267	0.131	0.481	0.231
t	0.714	0.752	0.685	2.664	2.129	1.925	1.851	1.792	1.714	2.272	2.215	2.527	1.201	5.001	2.163
t(α=0.05)	1.663	1.663	1.663	1.666	1.663	1.663	1.663	1.663	1.677	1.663	1.663	1.663	1.663	1.663	1.663
t(α=0.01)	2.372	2.372	2.372	2.379	2.372	2.372	2.372	2.372	2.407	2.372	2.372	2.372	2.372	2.372	2.372
Spearman rank order correlation coefficient test for no-trend															
r_s	-0.128	-0.118	-0.117	0.167	-0.230	-0.211	-0.201	-0.201	-0.081	-0.267	-0.263	0.072	-0.024	-0.300	-0.032
t	-1.181	-1.085	-1.084	1.447	-2.164	-1.976	-1.877	-1.877	-0.571	-2.544	-2.496	0.665	-0.216	-2.880	-0.292
t(α=0.05)	-1.989	-1.989	-1.989	1.993	-1.989	-1.989	-1.989	-1.989	-2.010	-1.989	-1.989	1.989	-1.989	-1.989	-1.989
t(α=0.01)	-2.636	-2.636	-2.636	2.645	-2.636	-2.636	-2.636	-2.636	-2.680	-2.636	-2.636	2.636	-2.636	-2.636	-2.636
Mann-Whitney split sample test for homogeneity															
Size of earlier sample	43	43	43	38	43	43	43	43	26	43	43	43	43	43	43
z	-0.151	-0.022	-0.004	-2.469	-1.231	-1.032	-0.946	-0.911	-1.413	-1.697	-1.637	-1.568	-1.118	-4.268	-0.561
z(α=0.05)	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645	-1.645
z(α=0.01)	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326	-2.326
Test of general randomness (Runs for above or below the median)															
Median	501	497	519	555	531	536	479	478	500	511	502	56.6	1475	1697	15.0
N1(for Q>=Median)	43	43	43	38	43	43	43	43	26	43	43	48	51	44	43
N2(for Q<Median)	43	43	43	37	43	43	43	43	25	43	43	38	35	42	43
Run_ab	40	40	40	27	36	36	36	36	20	37	36	32	38	38	36
z	0.868	0.868	0.868	2.673	1.736	1.736	1.736	1.736	1.837	1.519	1.736	2.512	1.014	1.297	1.736
z(a=0.05)	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960	1.960
z(a=0.01)	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576	2.576

Table A.4: Results of Statistical Tests of Annual Maximum Instantaneous Floods and Goodness-of-Fit of Probability Distribution Functions - Regulated Flows

WSC Station ID / Node ID	BOW RIVER TRIBUTARIES				ELBOW RIVER									
	05BC001	05BF001	05BG010	05BG001	Node 161		Node 213	05BL004		05BL024		Node 172	05BL015	05AC930
WSC Station Name or Location of Interest	Spray River at Banff, after 1951	Kananaskis River near Seebe, after 1946	Ghost River above Waiparous Creek	Ghost River near Cochrane	Elbow River below Glenmore Dam	Elbow River below Glenmore Dam, historic[1]	Glenmore Reservoir End of Day Elevations7	Highwood River below the Little Bow Canal	Highwood River below the Little Bow Canal, extended	Highwood River near the Mouth	Highwood River near the Mouth, extended	Highwood River at the Mouth[5]	Little Bow Canal at High River	Little Bow River at Highway No. 533
Anderson-Darling statistic, $A^2 = -N - S$														
3 Parameter Log-normal	0.899	2.815	0.719	0.333	0.253	*n/a*	26.918	0.347	0.575	0.114	0.518	*n/a*	0.594	2.898
Extreme Value	0.408	1.063	0.354	0.347	0.276	*n/a*	33.184	0.489	0.389	0.168	0.226	*n/a*	0.618	0.444
Log_Pearson III	0.591	2.507	0.801	0.318	0.417	*n/a*	26.959	0.582	0.719	0.378	0.710	*n/a*	1.140	0.858
Weilbull	378	1.317	6.302	2.967	14.6	*n/a*	31.4	1.396	2.767	1.293	5.870	*n/a*	44.6	3.235
Serial correlation coefficient test for independence														
S_1	0.118	0.326	0.190	0.137	0.168	*n/a*	-0.090	0.076	0.091	0.231	0.117	*n/a*	0.527	0.063
t	0.925	2.536	1.869	1.337	1.552	*n/a*	-0.819	0.446	0.928	1.555	1.205	*n/a*	6.197	0.199
t(α=0.05)	1.670	1.674	1.661	1.661	1.663	*n/a*	-1.663	1.691	1.660	1.681	1.660	*n/a*	1.660	1.812
t(α=0.01)	2.389	2.397	2.367	2.367	2.372	*n/a*	-2.372	2.441	2.363	2.416	2.363	*n/a*	2.364	2.764
Spearman rank order correlation coefficient test for no-trend														
r_s	0.062	0.408	-0.010	-0.089	-0.194	*n/a*	-0.211	-0.245	-0.057	-0.238	-0.021	*n/a*	-0.474	-0.126
t	0.487	3.311	-0.100	-0.863	-1.813	*n/a*	-1.976	-1.494	-0.584	-1.625	-0.220	*n/a*	-5.416	-0.423
t(α=0.05)	1.999	2.004	-1.986	-1.986	-1.989	*n/a*	-1.989	-2.030	-1.983	-2.015	-1.983	*n/a*	-1.984	-2.201
t(α=0.01)	2.657	2.668	-2.629	-2.629	-2.636	*n/a*	-2.636	-2.724	-2.623	-2.692	-2.623	*n/a*	-2.625	-3.106
Mann-Whitney split sample test for homogeneity														
Size of earlier sample	32	29	48	49	43	*n/a*	43	19	27	23	27	*n/a*	52	7
z	-0.510	-2.650	-0.029	-0.887	-0.263	*n/a*	-1.184	-0.669	-2.473	-1.944	-0.151	*n/a*	-5.719	-0.429
z(α=0.05)	-1.645	-1.645	-1.645	-1.645	-1.645	*n/a*	-1.645		-1.645	-1.645	-1.645	*n/a*	-1.645	
z(α=0.01)	-2.326	-2.326	-2.326	-2.326	-2.326	*n/a*	-2.326		-2.326	-2.326	-2.326	*n/a*	-2.326	
Test of general randomness (Runs for above or below the median)														
Median	13.3	42.8	25.4	51.5	55.4	*n/a*		119	117	201	198	*n/a*	1.78	5.67
N1(for Q>=Median)	32	29	48	49	43	*n/a*		19	54	23	54	*n/a*	52	7
N2(for Q<Median)	32	28	48	47	43	*n/a*		18	53	23	53	*n/a*	51	6
Run_ab	28	24	36	46	39	*n/a*		18	46	18	42	*n/a*	23	5
z	1.260	1.468	2.668	0.612	1.085	*n/a*		0.496	1.650	1.789	2.428	*n/a*	5.842	1.435
z(a=0.05)	1.960	1.960	1.960	1.960	1.960	*n/a*			1.960	1.960	1.960	*n/a*	1.960	
z(a=0.01)	2.576	2.576	2.576	2.576	2.576	*n/a*			2.576	2.576	2.576	*n/a*	2.576	

APPENDIX B

Naturalized Daily Flows and Flood Routing at Key Locations

B1.0 INTRODUCTION

The work completed in this study involves generation of daily natural flows for all relevant location of interest in the Bow River basin. The locations coincide with the major hydraulic structures in the basin (reservoirs and major water intake structures) and Water Survey of Canada (WSC) flow gauging locations. The principal approach for flow naturalization involved removal of the effects of storage and diversions. Flow naturalization was conducted reach by reach from upstream location (i.e., Bow River at Banff) to the downstream location (Bow River at the Mouth). The approach, known as the Project Depletion Method and was used by AEP in the past, and was built into the River Basin Assessment Tool (RBAT) model. Apart from minor modifications, the following section follows the explanation of the Project Depletion Method that has been laid out in the RBAT User's Manual. The principal update in this study is the use of up to date storage levels and outflows from TransAlta's structures in the period from 1985 to 2015, along with updated information from Environment Canada related to the June 2013 flood data.

B2.0 AVAILABILITY OF INPUT DATA

The process of developing natural flow estimates requires the use of historic records of reservoir levels and outflows from the date each structure started its operation. This appendix describes the methodology for calculating natural flows as well as how this methodology was implemented at each location of interest given the available data. It should be noted that the primary purpose of developing natural flows was to properly assess incoming annual peak flows into all major structures, and for as many years as possible. Naturalized annual peak flows constitute a principal input into the hydrologic frequency analyses. Annual peak flows were assessed for as many years as possible, as further explained in subsequent sections that provide more information about each storage site where natural flow series were developed.

B3.0 PROJECT DEPLETION METHOD

Alberta Environment uses the Project Depletion Method to calculate natural flows on all major rivers in Alberta. The same methodology is employed by the Prairie Provinces Water Board (PPWB). The PPWB consists of representatives from Environment Canada (representing the Federal Government) and the representatives of the three Prairie Provinces. The short summary that explains the project depletion method in this section follows closely the documentation of the Natural Flow Computation Program (NFCP) program used in this study. Technical specifications for NFCP were approved by the PPWB in November of 2008.

Natural flows are river flows that would have been observed at selected locations in a river basin assuming there had been no human intervention by operation of large storage reservoirs or withdrawals. The most common approach to estimate natural flows is the Project Depletion Method, which is essentially aimed at “undoing” the impacts of human intervention in a systematic way, reach by reach, in a downstream progression.

The calculation procedure is explained below for a small example shown in Figure B1 that contains all elements found in complex river basins. There are two river reaches with a reservoir R_1 at their confluence. In this example naturalized flow is calculated at the reservoir site. There is one diversion into the reservoir (D_1) and one return flow (RT_1) into the reservoir, one diversion channel out of the reservoir (D_2), and regulated outflow from the reservoir into natural channel reach C_3. The general approach to calculate naturalized flows at any location is to estimate local runoff which originates between the given location and the closest upstream locations at which natural flows had already been evaluated. Denote the naturalized flow at reservoir as Q_{R1} and the local runoff between natural flows Q_1, Q_2 and the reservoir as LR. The naturalized flow at the reservoir site can then be calculated as:

$Q_{R1} = Q_1 + Q_2 + LR$ (1)

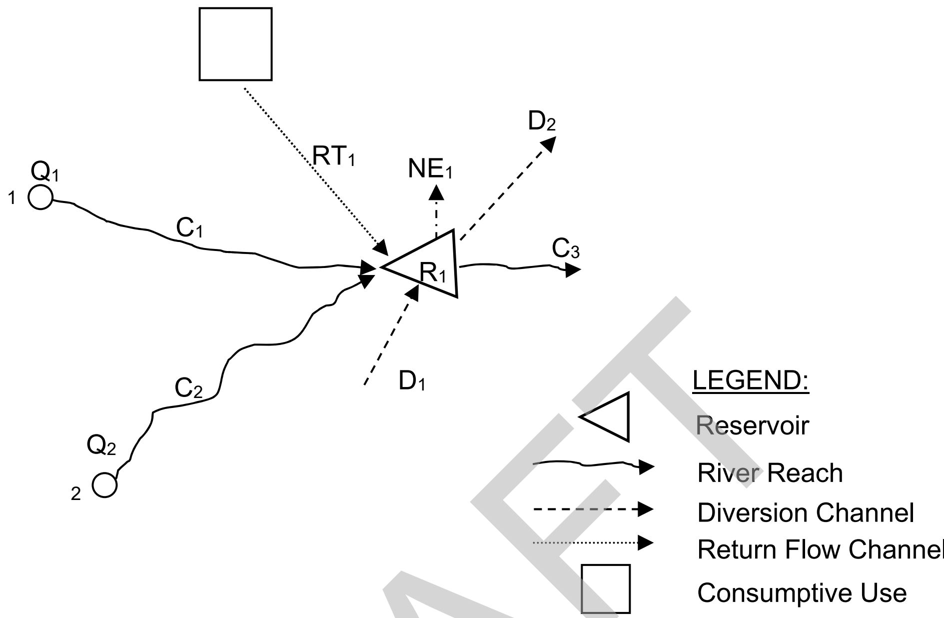


Figure B-1: Sample Schematic for Calculation of Naturalized Flows

Consequently, the principal component of deriving naturalized flows is determination of the local runoff LR. Assuming Qr1 and Qr2 are the recorded flows at locations 1 and 2, LR for the reservoir in Figure B1 can be calculated using the following equation assuming average flow over time step t:

$LR = Q_{C3} + Q_{D2} - Q_{RT1} - Q_{D1} + \Delta V/t - Q_{r1} - Q_{r2}$ (2)

Where:

Q_{C3} The recorded flow in channel C_3

Q_{D1} Flow in diversion channel D_1

Q_{D2} Flow in diversion channel D_2

Q_{RT1} Flow in return flow channel RT_1

$\Delta V/t$ Reservoir storage change over time step t

Reservoir storage change is further evaluated using the starting and ending storage (Vs and Ve) for a time step, along with adjustments for net evaporation (evaporation minus precipitation) for a given time interval *t*. Note that the sign for net evaporation is reversed since the consideration is to remove the effect of net evaporation (i.e. put the evaporation loss back in the river since this loss would not have happened if the reservoir had not been built):

$$\frac{\Delta V}{t} = \frac{Ve - Vs}{t} + \frac{(E - P)[A(Ve) + A(Vs)]}{2t} \qquad (3)$$

Where:

V_e Volume at the end of time step *t* (m^3)

V_s Volume at the start of time step *t* (m^3)

P Total precipitation over time step *t* (m)

E Total evaporation from the reservoir surface over time step *t* (m)

$A(V_e)$ Surface area (m^2) corresponding to the ending volume *Ve*

$A(V_s)$ Surface area (m^2) corresponding to the starting volume *Vs*

To summarize, local runoff LR can in general be assessed by conducting a water balance calculation for a sub-catchment which is delineated by the downstream point for which LR is evaluated and the upstream control points where recorded flow series are available. The general expression is:

$$LR = \sum_{i=1}^{m} Q_i - \sum_{j=1}^{n} Q_j + \sum_{k=1}^{l} \frac{\Delta V_k}{t} \qquad (4)$$

Where:

Q_i Average outflows (i=1, m) from a sub catchment within time step *t*

Q_j Average inflows (i=1, m) into a sub catchment within time step *t*

While the storage change term ∆V/t is summed up over all storage reservoirs in the sub-catchment area under consideration. Inflows and outflows into a sub-catchment include all diversions and return flows into it, as well as diversions out of it. Normally, naturalized flows should be calculated at all on-stream reservoir locations, especially when reservoirs have sizeable live storage.

Equation (1) suggests that naturalized flows be first determined at upstream locations (e.g., locations 1 and 2 in the example in Figure B1). The calculation then proceeds in the above manner for all requested locations in the river basin in a downstream progression. It should be noted that for short (e.g., daily) time steps, the length of river reaches along channels C_1 and C_2 may require the use of channel routing, such that the routed outflow from these channels takes part in the mass balance calculation at the reservoir node, both for calculating local runoff LR, which would require the routing of recorded flows along these channels, and for calculating the naturalized flow, which would require routing of the naturalized flow estimates previously made at nodes 1 and 2.

AEP uses the Wilson's routing equation in the Hydrol model which was borrowed from the Streamflow Synthesis and Reservoir Regulation (SSARR) model. A brief description of Wilson's equation is provided below.

As with the other river routing methods, the governing equation is related to channel storage change over a time step, which is a function of average inflow and outflow:

$$\frac{I_{t-1}+I_t}{2}-\frac{O_{t-1}+O_t}{2}=\frac{\Delta S}{t} \quad (5)$$

By subtracting both sides of the above equation with O_{t-1}, multiplying by $t/(O_t\text{-}O_{t-1})$ and by letting $\Delta S/(O_t\text{-}O_{t-1}) = TS$, the above equation becomes:

$$Ot=\frac{\left[\frac{I_{t-1}+I_t}{2}-O_{t-1}\right]\cdot t}{TS+\frac{t}{2}}+O_{t-1} \quad (6)$$

Where the term *TS* represents the average travel time along a river reach for given flow conditions, evaluated either by reading from the *TS* vs *Q* table or by using a functional form of the travel time vs flow curve as:

$$TS=\frac{Kts}{\left(\frac{O_{t-1}+O_t}{2}\right)^n} \quad (7)$$

The routing coefficients *Kts* and *n* must previously be determined by finding the best fit curve for a given set of the available *(Ts,Q)* coordinates. Usually, *Ts* can be determined for any given flow rate by linear interpolation from a table of *(Ts,Q)* points (these tables were provided by Alberta Environment and used in this project). In the above definition of *Ts*, the base of the denominator shown below represents the average channel flow over a time step as the arithmetic average of the outflows at the beginning and the end of the time step:

$$\frac{O_{t-1}+O_t}{2}$$

Various implementations of the SSARR method may rely on different estimates of the average channel flow during a given time step (which may also include inflows into the channel in some form). The method relies on the established empirical relationship between the travel time and flow for a given channel. Once this relationship is available, the calibration consists of deciding how many sequential phases a given river reach should be divided into, which is conducted using repeated simulation trials until the observed downstream hydrograph closely matches the simulated channel outflow. All work on calibration of the SSARR method in the South Saskatchewan River basin had already been done by AEP. The upper Bow River Basin schematic that was obtained from Alberta already has the channels broken into lengths that work as single phase channels (i.e., no further subdivision is required).

The use of the SSARR channel routing method is optional within RBAT (i.e., naturalized flows can be calculated with or without channel routing), since calculating naturalized flows using sufficiently long (monthly, seasonal or annual) time steps does not require channel routing. In this study, the time step was daily, while the travel time from the most upstream point of interest (Banff) to the mouth is well above one day, indicating that channel routing is required. The use of the SSARR routing method in the calculation of naturalized flows does not change the methodology. Instead, it merely introduces a more realistic account of flow changes in large river systems where the total travel time is greater than the simulation time step. It should also be noted that the SSARR river routing is as accurate as the available input data.

It should be noted that the Wilson's equation deals with the transformation of surface water movement aimed to account for the channel storage change from day to day. However, large channel storage changes may happen in the Bow River during the formation of ice cover in November, and its subsequent melting in April. These transformations of water into ice and back into liquid can also be understood movements of flow into and out of storage, but such channel storage changes are not modelled by the Wilson's equation.

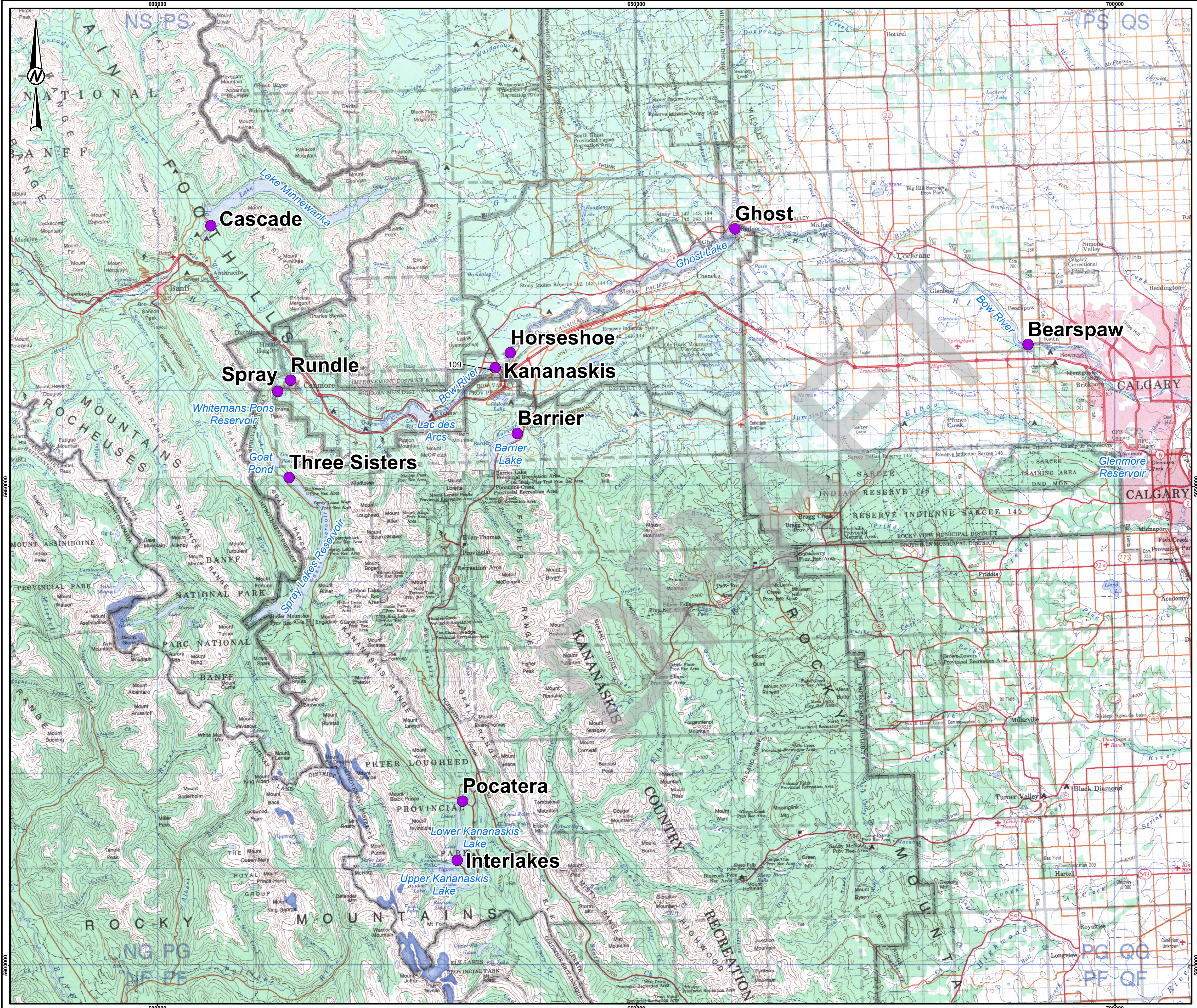
B4.0 GENERATION OF DAILY NATURAL FLOWS AT SPRAY LAKE

Figure B2 shows the Spray Lake and diversion to the three downstream power plants that eventually discharge into the Bow River at Canmore. The Spray River drains in the northerly direction and joins the Bow River at Banff. Flow Monitoring Station 05BC001 is located just upstream of the confluence with Bow River. The Spray Lake is a naturally occurring lake, which was dyked off to divert water through three hydro power plants over a shorter distance and a large drop in elevation. The diversion route is indicated in orange color in Figure B2. The total catchment area of Spray Lake at the mouth is approximately 751 km^2, of which about 520 km^2 drain into Spray Lake. Although the remaining catchment area downstream of the Lake is roughly one third of the total, the upstream runoff into Spray Lake is considerably higher due to higher specific yield, such that roughly 85% of the total annual natural flow of Spray Lake at the mouth (Station 05BC001) originates upstream of the dam.

Proper calculation of natural flows at Spray Lake requires the historic daily lake levels as well as all daily outflows from the lake. The old Spray river channel still collects the runoff downstream of the lake, but after construction of the dam in 1949 it also serves as a potential spillway conduit to evacuate large floods that exceed the capacity of the diversion route. The spillway into the Spray River has historically been used only once in 1974. Due to structural stability issues, the levels at Spray Lake in the last 15 to 20 years have been kept below normal, which prevented any spilling during the June 2013 flood. There are several issues associated with assessing daily natural flows at the dam site that are outlined below.

Between 1918 and 1939 natural inflow into the Spray Lake was based on the recorded flows at Station 05BC002. This station was submerged by the lake once the dam impoundment began. Its original drainage area was 360 km^2, which was increased by a factor of 1.3 to account for additional catchment area into the lake that was created by the dam (520 km^2) less the adjustment for the considerable increase in the lake surface area which is handled by net evaporation directly in the water balance equation.

Construction of the dam and hydro power plant in 1949 has effectively divided the Spray river basin into two sub-basins, one delineated by the Spray Lake which drains its outflow through the Goat Creek as a tributary of the Bow River at Canmore, and the other one which continues to function as natural runoff downstream of the Spray Lake. A non-linear relationship was established between the runoff from drainage area of 391 km^2 and the Spray River flow at the mouth (drainage area 730 km^2) based on data from 1915 to 1939 (see Figure B3). The naturalized daily flows for Spray River at the mouth for the period 1951 to 1975 were estimated based on this relationship. Figure B4 provides the Spray Lake operation rules used for flow naturalization and regulations.



LEGEND

DAM

0 15 30

1:400,000 KILOMETRES

REFERENCE(S)

1. TOPOGRAPHIC MAP DATA FROM SOFTMAP © HER MAJESTY THE QUEEN IN RIGHT OF CANADA. DEPARTMENT OF NATURAL RESOURCES. ALL RIGHT RESERVED.
DATUM: NAD83 PROJECTION: UTM ZONE 11

CLIENT
ALBERTA ENVIRONMENT AND PARKS

PROJECT
HYDROLOGY ASSESSMENT - BOW, ELBOW, HIGHWOOD AND SHEEP RIVER

TITLE
TRANSALTA'S HYDROELECTRIC DEVELOPEMENTS IN THE BOW RIVER BASIN

CONSULTANT

YYYY-MM-DD	2017-01-19
DESIGNED	GB
PREPARED	SK
REVIEWED	GB
APPROVED	GB

Golder Associates

PROJECT NO.	REV.	FIGURE
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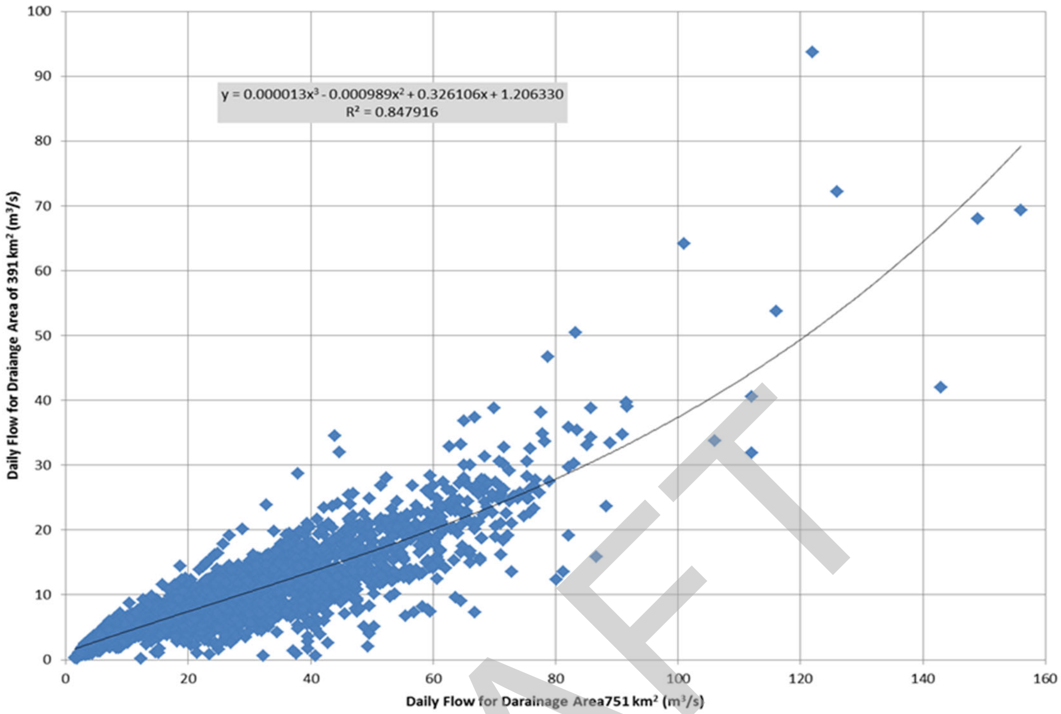


Figure B-3: Relationship between Daily Flows for Spray River

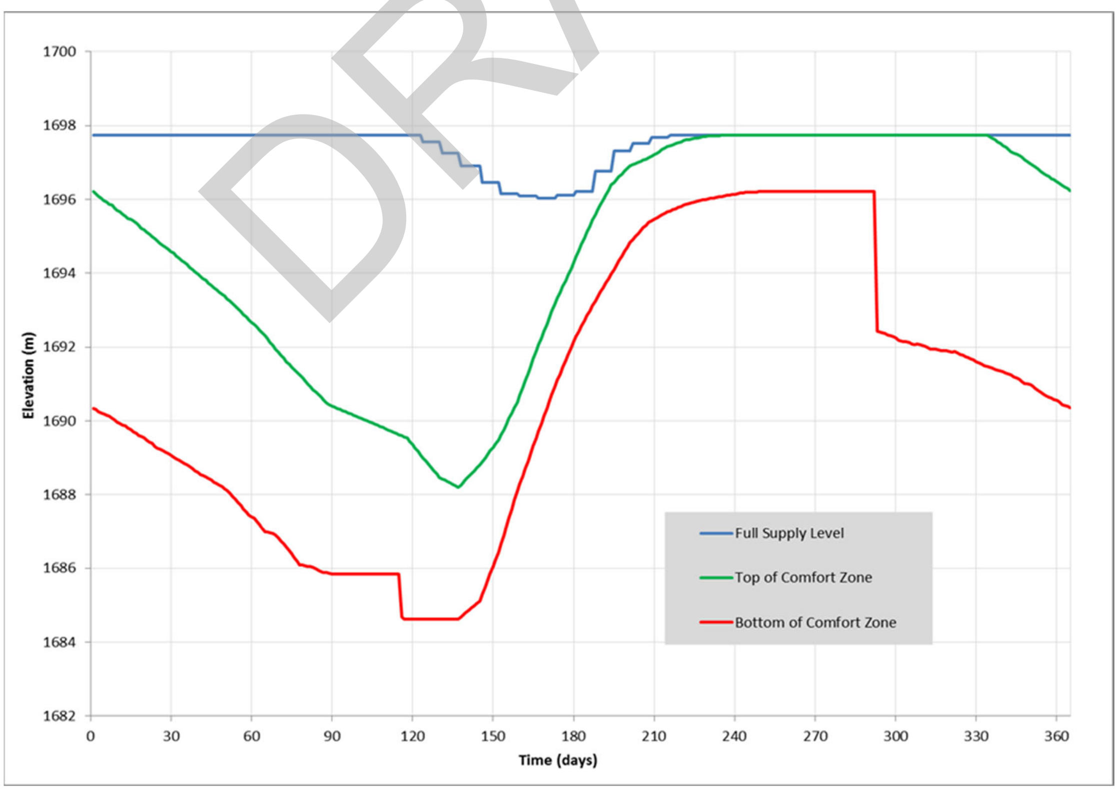


Figure B-4: Spray Lake Operating Rules

B5.0 GENERATION OF DAILY NATURAL FLOWS AT LAKE MINNEWANKA

Lake Minnewanka is a naturally occurring lake that was raised to increase its storage. In addition to this, about 15% of the total runoff into Lake Minnewanka comes from the Ghost River catchment via the Ghost River diversion. This diversion was built in 1941 and a flow monitoring station has operated until 1994. Although the station has been discontinued, this diversion continues to operate, and it would also operate during floods.

In the 2010 study, the Ghost diversion was considered as integral part of the local runoff, since it is a structure that operates permanently without human intervention. Hence, naturalization was previously done with the Ghost Lake diversion implicitly included as part of the runoff into Lake Minnewanka, and this is the way TransAlta naturalizes flows on Lake Minnewanka. Attempts were made to develop relationship between the diverted flows and the flows that remain in the Ghost River downstream of the diversion, but no meaningful relationship could be established (see Figure B5). Here is the plot for ten years (1983 and 1994) of daily data for both stations picked up for the same days:

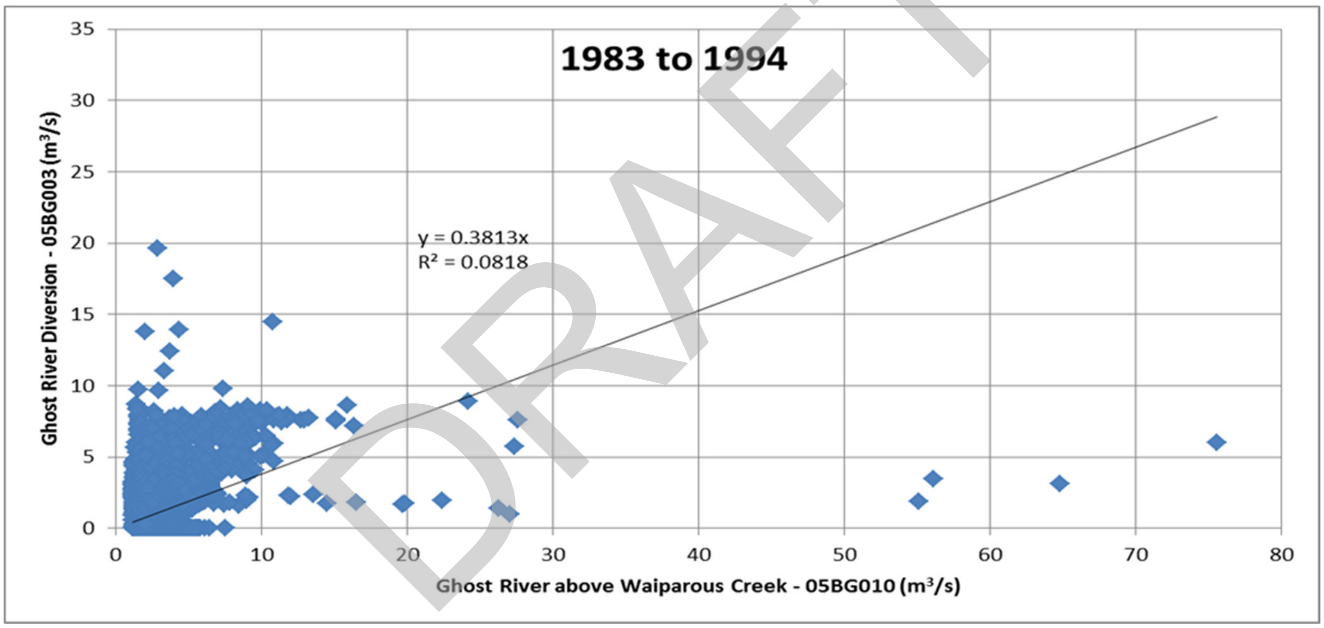


Figure B-5: Relationship between Ghost River Diversion and Ghost River flow above Waiparous Creek

One of the reasons may be the distance of Station 05BG010 from the point of diversion, which enables this station to collect additional highly variable runoff. Discrepancies may also be due to the accuracy of the flow values, which are converted from gauged water levels. Consequently, in this study Ghost diversion was considered as integral part of runoff into Lake Minnewanka for calculation of naturalized flows into the lake.

Naturalized flows into Lake Minnewanka were estimated based on its recorded outflows available from WSC Station 05BD002 until 1941 and from WSC Station 05BD004 from 1942. The Lake elevations (WSC Station 05BD003) are available from 1917. There are many days with missing data prior to 1943, when the continuous daily records began. However, the records between 1917 and 1943 are usually available at least once or twice a week, which allowed the use of linear interpolation as the first approximation for infilling the missing data, particularly since this lake is large and the levels do not vary substantially from day to day. Until 1941, the dam was operated in the range between 1450 and 1455 m, with flow regulation having a relatively small impact on the downstream Bow River flows at Ghost and Bearspaw dams. The mean annual flow of Cascade River at the mouth is 8.4 m^3/s, compared to about 90 m^3/s for the Bow River at Bearspaw dam. Effects of flow regulation are more pronounced after 1942, when the lake levels were raised to operate in the range between 1465 and 1475 m and Ghost diversion started to operate. This study included verification and the previous calculation, smoothing out the noise during the winter months that often resulted in negative inflows into Lake Minnewanka, as well as extension of the natural flow calculation to July 31, 2015.

Figure B6 provides the current operating rules used for Lake Minnewanka by TransAlta.

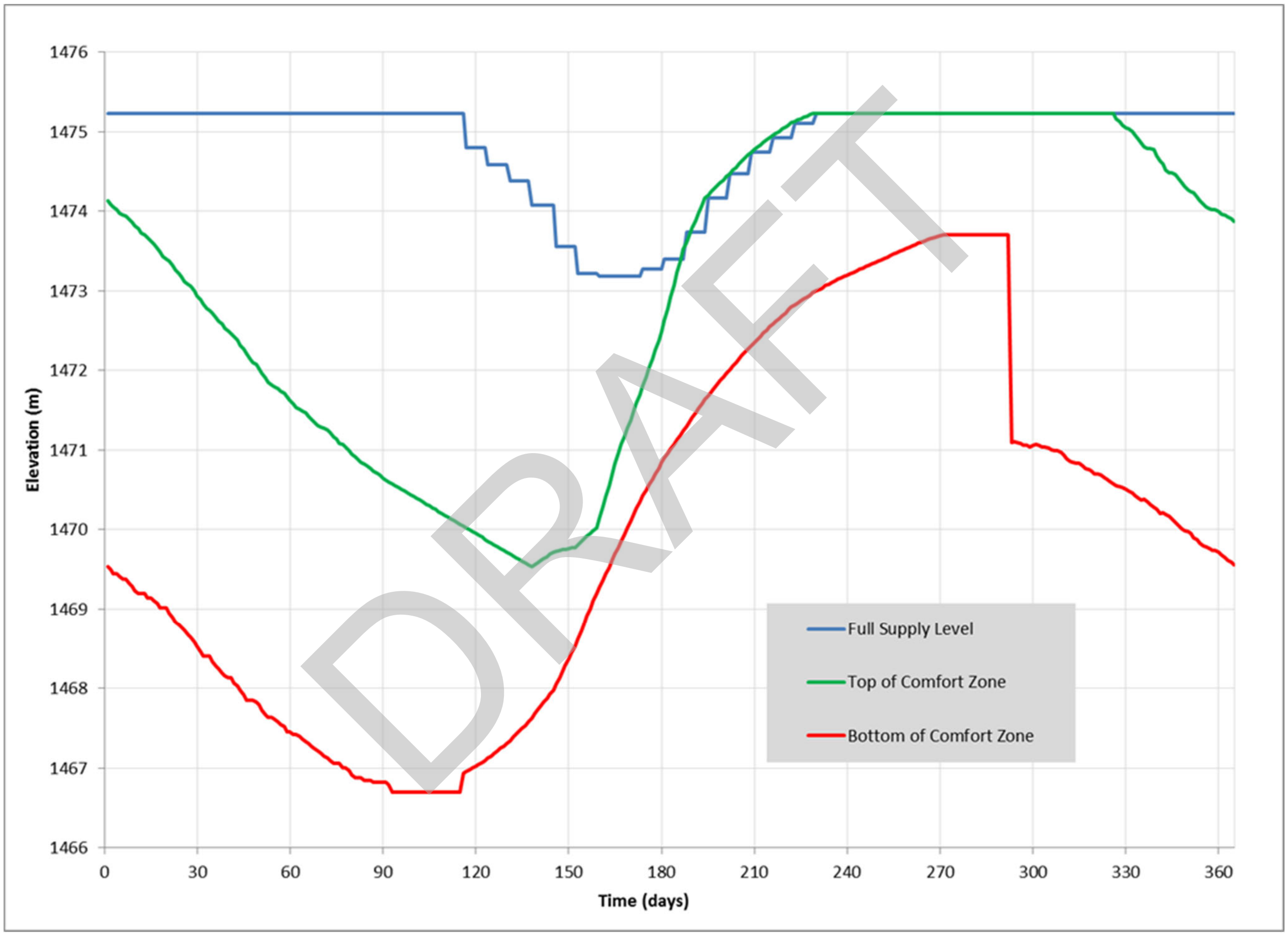


Figure B-6: Lake Minnewanka Operating Rules

B6.0 GENERATION OF DAILY NATURAL FLOWS AT THE UPPER AND LOWER KANANASKIS LAKES

Upper and Lower Kananaskis Lakes are also naturally occurring lakes that were raised to higher elevations to provide more balancing storage and head for hydro power generation. The upper Kananaskis Lake receives runoff from the catchment area of about 150 km^2 and it drains into the lower Kananaskis Lake, which in addition to receiving outflow from the Upper Kananaskis Lake also receives inflow from a local catchment area of roughly the same size (151 km^2), although some of the runoff originating from this area is diverted into the Spray Lakes via the Mud Lake diversion. The Lower Kananaskis Lake eventually drains into the Barrier Lake, located some 50 km downstream of it. The time of travel vs flow values for this river reach was retrieved from Alberta Environment and Parks the Hydrstra model, which enabled the use of the SSARR routing of outflows from the Lower Kananaskis Lake to the Barrier Lake.

The Upper Kananaskis Dam had its normal full supply level raised in 1942 by about 14 m. The Lower Kananaskis Dam was built in 1955 with an increase in full supply elevation by 11 m and allowed annual fluctuation of water levels by 14 m. Prior to 1942, both lakes were functioning as natural water bodies. The hydro power plants associated with these lakes are known as Interlakes and Pocaterra. The following procedure is needed to calculate naturalized inflows into both lakes:

a) Use the Upper Kananaskis storage levels and outflow records to remove the effect of storage and calculate naturalized flows at the Upper Kananaskis Lake; and

b) Use the Lower Kananaskis storage levels, outflows and the outflow from the Upper Kananaskis as a part of the total inflow to assess the net runoff from the local contributing catchment into the Lower Kananaskis Lake.

The data available for full implementation of the above procedure are only available for the 1985 to 2015 for both reservoirs. Water levels at both lakes and the outflows from the Lower Kananaskis Lake are also available for 1975-1985 period, but the turbine flows out of the Upper Kananaskis Lake are missing. It was decided to naturalize flows from 1975 to 1985 for the combined Upper and Lower Kananaskis sub-catchments by using the storage change at both reservoirs and outflows from the Lower Kananaskis Lake, and then subdivide the total runoff into two series based on the size of the drainage areas. This approach provided 10 more years of data (1975-1984) that can provide input into statistical frequency analyses.

Calculation of natural flows for both lakes using lake levels and outflows is only possible after 1985. From 1975 to 1985, the flows between the Upper and Lower Kananaskis Lake are unknown while the storage change at both reservoirs and the outflow from the Lower Kananaskis Lake are still known. This allows the calculation of natural flows at the outflow of the Lower Kananaskis by combining two storage reservoirs (Upper and Lower Kananaskis) into an equivalent single storage. Total inflow into an equivalent (combined) storage was then divided into two inflow series based on the respective size of the catchment areas. Natural flows prior to 1975 cannot be assessed with certainty based on the data that are currently available.

Figures B7 and B8 provide the current operating rules used for Upper and Lower Kananaskis Lake by TransAlta.

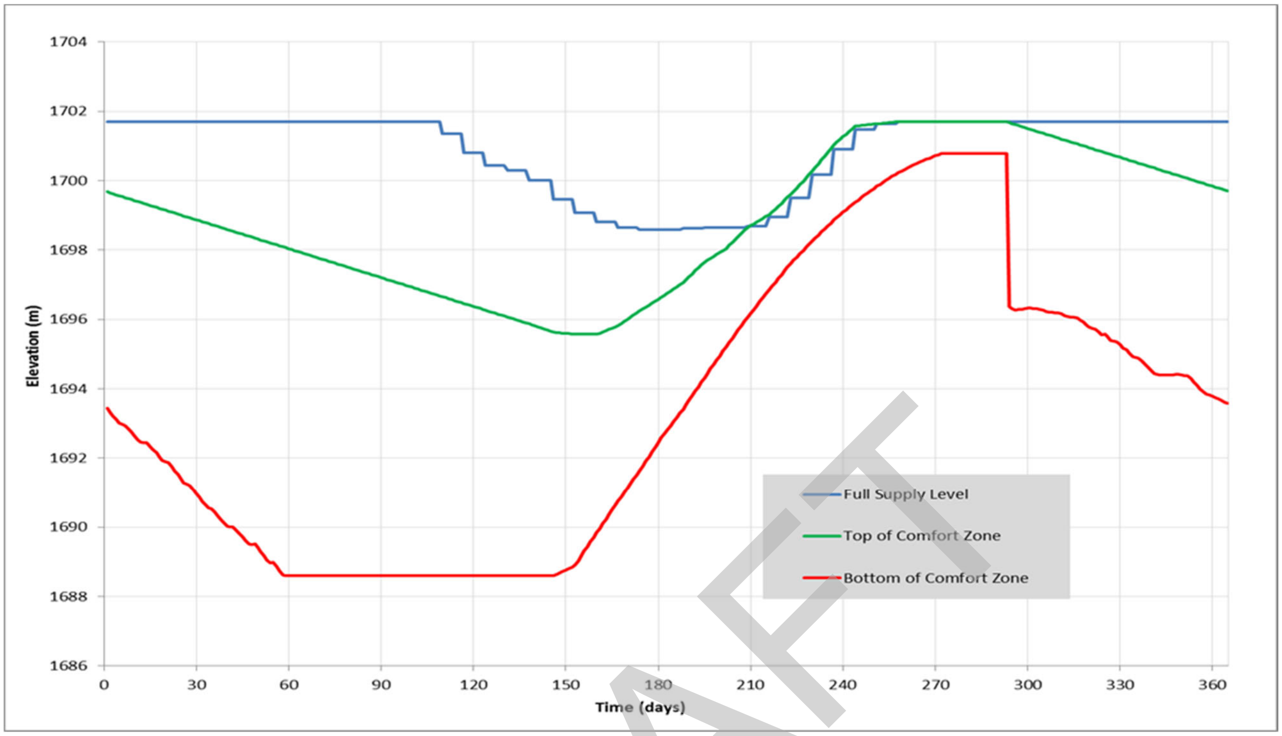


Figure B7: Upper Kananaskis Lake Operating Rules

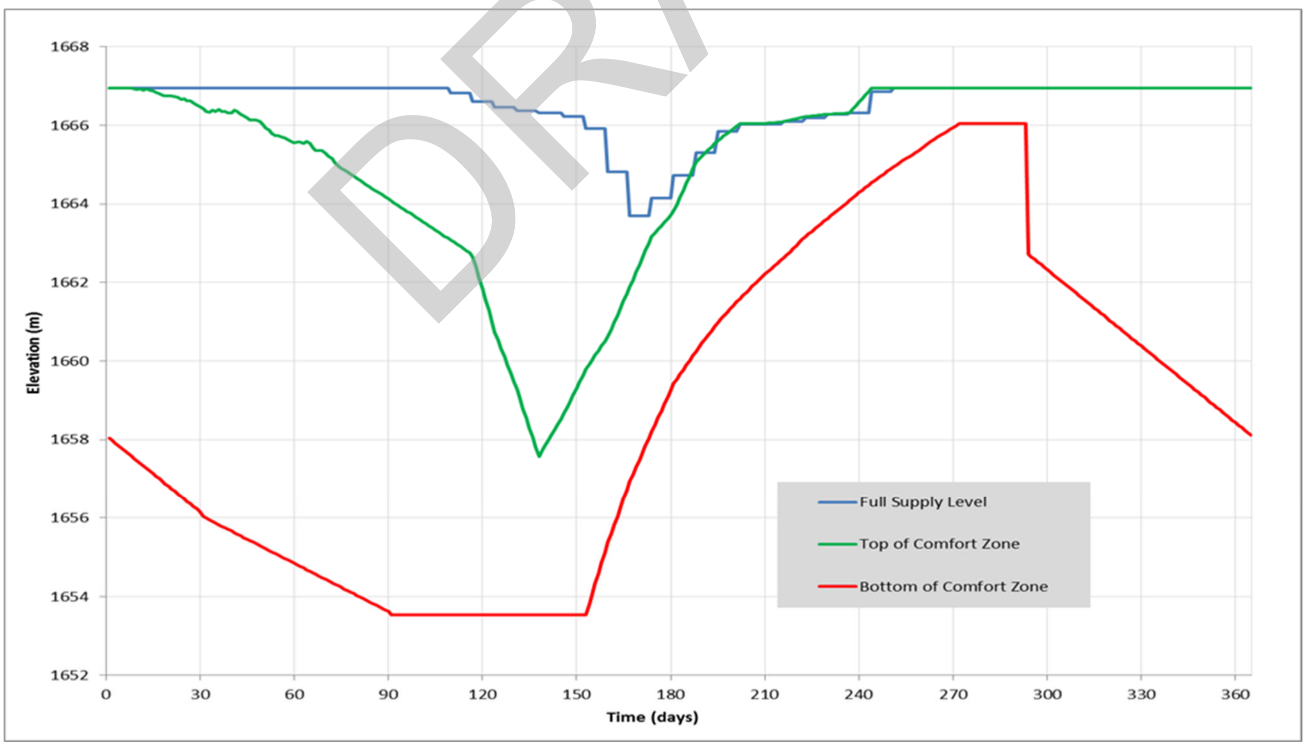


Figure B-8: Lower Kananaskis Lake Operating Rules

B7.0 GENERATION OF DAILY NATURAL FLOWS AT BARRIER LAKE

The following information is required for assessment of natural flows at the Barrier dam:

a) Estimated daily naturalized flows at both the Upper and Lower Kananaskis Lake. This estimate was available for the 1975 – 2015 period.

b) Continuous daily recorded outflows from the Lower Kananaskis Lake (Pocaterra). Some data are available prior to 1955 but mainly as seasonal records, and there is a large section of data completely missing from 1955 to 1975, when the continuous records begin.

c) Travel time vs flow relationship for the 50 km Kananaskis River reach between Pocaterra and Barrier to allow proper channel routing.

d) Historic daily elevations of Barrier Reservoir. These have been made available by AEP from 1948 to 1988, and they are also available from Water Survey of Canada as a continuous record from 1970 to 2015 (Station 05BF024). These two datasets are not always in perfect agreement in the overlapping period from 1970 to 1988.

e) Historic daily outflows from the Barrier Reservoir. Genuine turbine flows should be available from TransAlta, however these are only available from 1985 to 2015. For periods prior to 1985, there are two Water Survey of Canada stations. Station 05BF025 is located immediately downstream of the dam, with a total catchment area of 899 km^2 and a continuous flow record from 1975 to 2015. The update in this study relied heavily on the information received from TransAlta. Station 05BF001 is located further downstream and includes a slightly larger catchment of 933 km^2 due to a small tributary upstream of it. The data record at this station is available from 1911 to 1962, but there were many missing data gaps that required in-filling, including the complete blackout period from 1963 to 1974 inclusive. Alberta Environment maintains a weekly natural flow database, which contains mean weekly outflows from the Barrier dam from 1948 to 2001. The mean weekly recorded flow data were used as a basis for infilling the missing Barrier outflows, using the linear interpolation model the middle of one week to the middle of the subsequent week.

The linear interpolation model used for conversion of weekly to daily flows on the Kananaskis River in the 1963 – 1974 period is not perfect, but it is the only option available to enable continuous simulation of the entire Bow River basin. The missing period of outflow data between 1963 and 1974 was filled by generating daily flow estimates using linear interpolation of weekly outflows from Barrier Dam provided in the SSRB Natural Flow database from AEP. It should also be noted that the effect of Upper and Lower Kananaskis storage change was ignored for years prior to 1975. Figure B9 provides the current operating rules used for Barrier Lake by TransAlta.

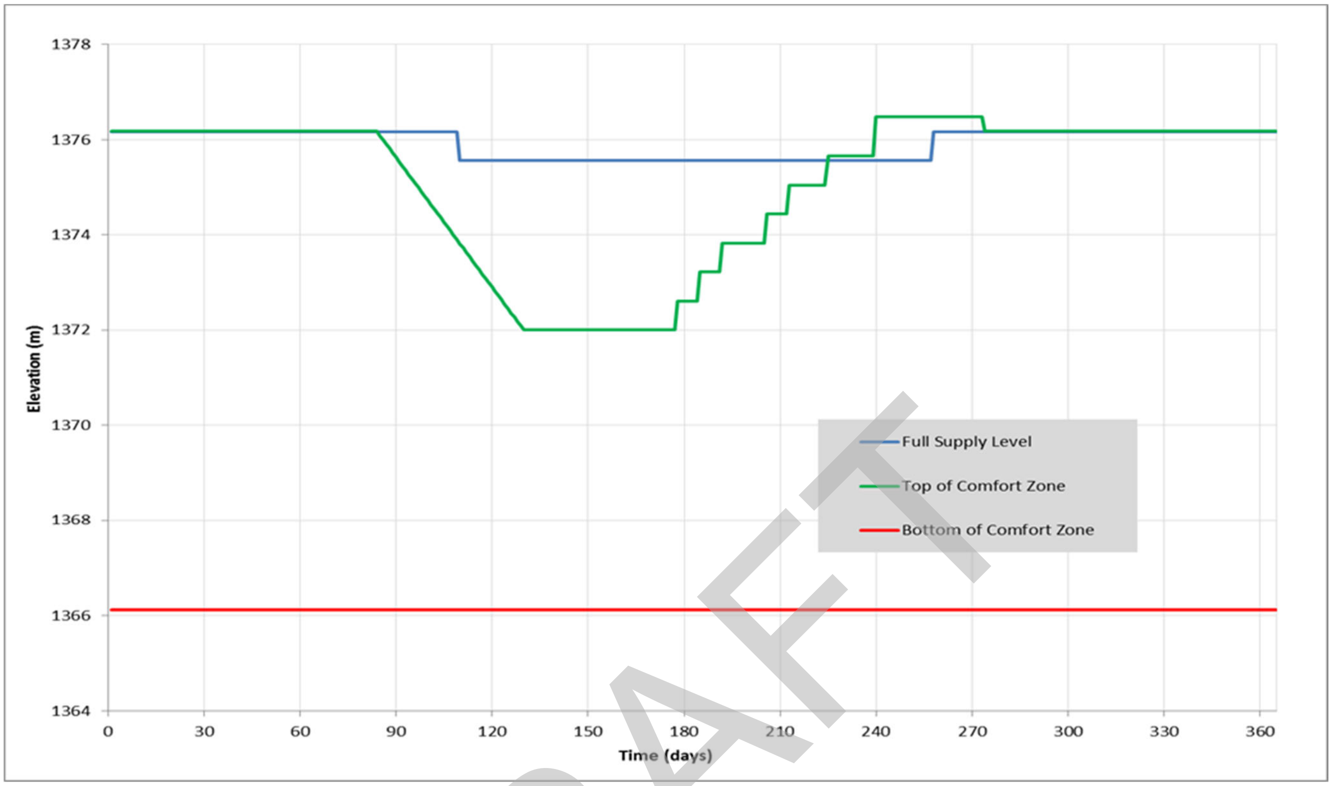


Figure B-9: Barrier Lake Operating Rules

B8.0 GENERATION OF DAILY NATURAL FLOWS BOW RIVER AT SEEBE

Station 05BE004 (Bow River at Seebe) is located roughly half way between Canmore and the Ghost Dam. It is one of the stations for which the development of natural flows has been requested in the RFP. The station data start in 1923, however there is a large data gap between of 18 years and 2 months from October 1962 to December 1978. Genuine natural flows can be developed only for the years when the recorded flows are available at this station. This would give time series of sufficient length for frequency analyses. In-filling of the years with missing data was completed by routing the upstream natural flows from the confluence of Banff and Cascade River.

B9.0 GENERATION OF DAILY NATURAL FLOWS AT GHOST RESERVOIR

Ghost Reservoir started to fill in August of 1929. Prior to 1929, the only possible change to natural flows upstream of Ghost Reservoir would be due to the operation of Lake Minnewanka on Cascade River, which at that time was operating in the lower range between 1450 and 1455 m. Although the Cascade River flows have been adjusted for the effects of Lake Minnewanka storage, the missing link required for estimating natural flows at the Ghost Reservoir site prior to 1929 are the recorded flows in the vicinity of the Ghost Reservoir site.

Station 05BE006 (Bow River below Ghost dam) started operation in 1933. The upstream flow monitoring station at Seebe (05BE004) started operation in 1923. The Ghost River tributary (Station 05BG001) that also contributes significant flows to the Ghost Reservoir storage has missing data between November 1920 and December 1928. The recorded flow data series that represents recorded outflows (or inflows) into the Ghost Reservoir do not exist prior to 1930.

Hence, it was only possible to assess natural flows into Ghost reservoir between 1930 and 2015, following required in-filling of the missing data. When the outflows were missing, the storage change and both inflows (Station 05BE004 at Seebe and the Ghost River Tributary Station 05BG001) were used to generate the outflow estimates. When the storage levels were missing and both outflows and inflows were available, storage levels were estimated by balancing inflows and outflows and by solving for the end of day storage as the only unknown. A regression was also developed between the Bow River below Ghost Reservoir (05BE006) and the Bow River at Calgary (05BH004), and it was used occasionally for in-filing the missing data when there was no other option.

The following information was necessary to estimate daily naturalized flows at the Ghost Reservoir for the period 1930 to 2015:

a) Recorded and naturalized flows of the Bow River downstream of confluence with the Spray River;

b) Recorded and naturalized flows of the Cascade River at Lake Minnewanka;

c) Recorded and naturalized flows of the Kananaskis River at Barrier Reservoir;

d) Time of travel vs flow for all routing reaches of the Bow river between Banff and the Ghost Reservoir as well as on the Kananaskis river below the Barrier dam;

e) End of day Ghost Reservoir elevations;

f) Recorded Ghost Reservoir outflows; and,

g) Precipitation and evaporation on Ghost reservoir.

The RBAT model was run on a daily basis from 1930 to 2015 to obtain estimates of naturalized flows at the Ghost Reservoir. The calculation procedure starts at the most upstream nodes, and evaluates naturalized flows at each node in a downstream progression. This procedure requires separate routing of recorded flows from the three upstream control points, which are the confluence of the Bow and Spray Rivers, Lake Minnewanka and the Barrier Reservoir downstream to the Ghost Reservoir. These routed flows were used to calculate the local inflow into the Ghost Reservoir by subtracting them from the Ghost Reservoir outflow adjusted for storage change. Once the local inflow is calculated in this manner, it is added to the sum of routed natural flows starting from the same three control points and ending at the Ghost Reservoir.

Figure B10 provides the current operating rules used for Ghost Lake by TransAlta.

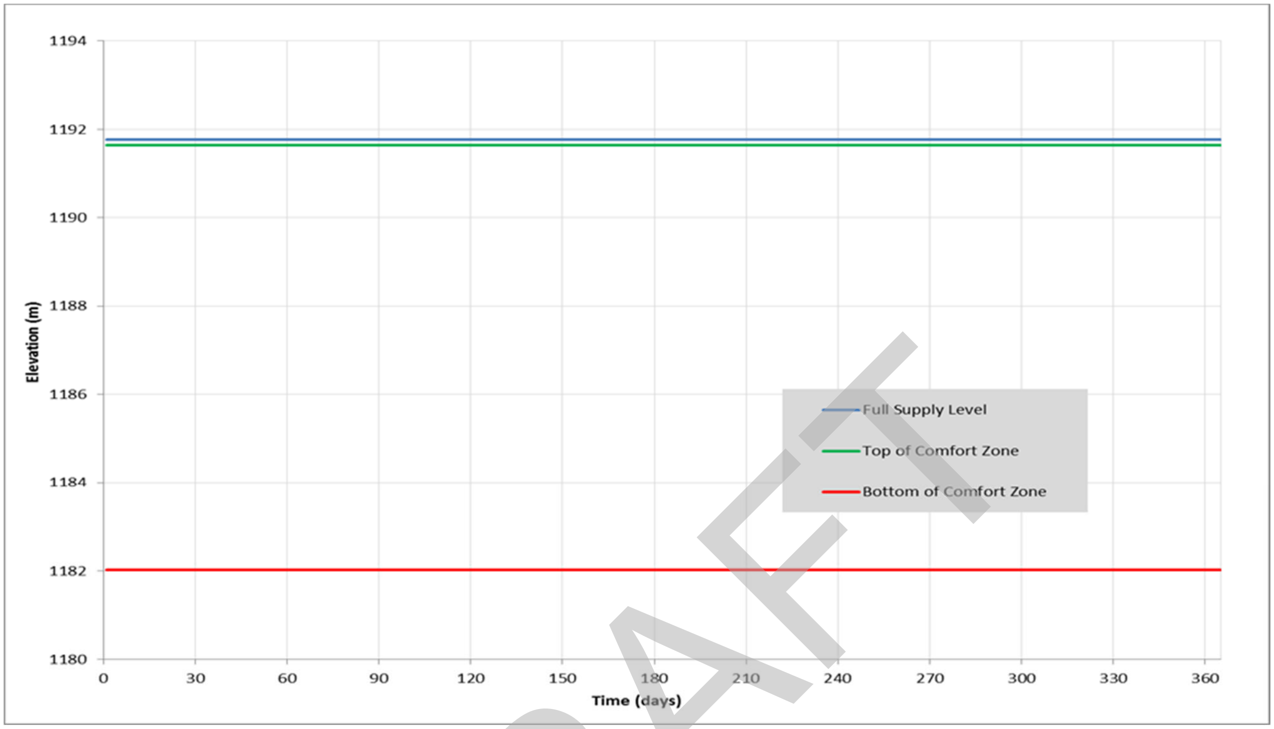


Figure B-10: Ghost Lake Operating Rules

B10.0 GENERATION OF DAILY NATURAL FLOWS AT BEARSPAW RESERVOIR

Naturalized flows at Bearspaw Reservoir were also generated as part of the RBAT run. Updated daily reservoir elevations were received from TransAlta for the 1985 to 2015 period. There are two WSC stations on the Bow River below the Bearspaw dam. Station 05BH008 is close to the dam, but its record begins in 1983 and it is incomplete. The only other long term flow monitoring station in the relative vicinity of the Bearspaw dam is the Bow River at Calgary (05BH004). This station also needed some in-filling of missing data between 1930 and 2015, which was accomplished by developing a relationship with the Bow River below Ghost Dam (05BE006). WSC does not monitor Bearspaw reservoir levels.

Time series of the Bearspaw Reservoir levels provided by Alberta Environment begins in 1955, but this series does not contain the data related to the initial impoundment. Hence, for the period prior to 1955, the levels were kept constant with the evaporation and precipitation set to zero. Natural flow at Bearspaw dam was assessed as the sum of the natural flow at Cochrane (Station 05BH005) and local inflow between Cochrane and Bearspaw dam. Calculation of this local inflow required the following:

a) Recorded flows at Cochrane and downstream of the dam;

b) Storage change at Bearspaw dam (including net evaporation); and

c) Withdrawals from the Bearspaw dam by the City of Calgary.

Figure B11 provides the current operating rules used for Bearspaw Reservoir by TransAlta.

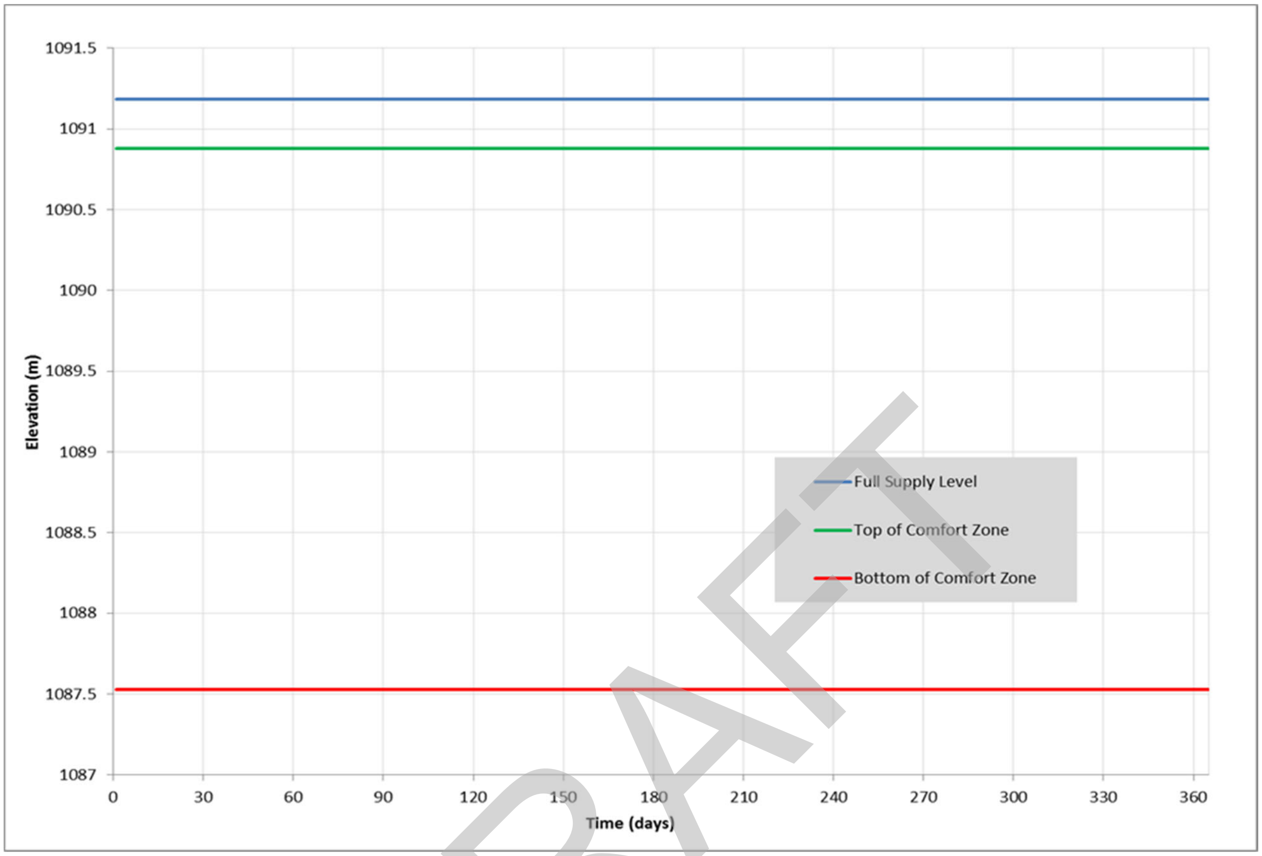


Figure B-11: Bearspaw Reservoir Operating Rules

B11.0 GENERATION OF DAILY NATURAL FLOWS AT GLENMORE RESERVOIR

Glenmore reservoir level data are available from WSC Station 05BJ008, with data records from 1976 to 2015. Additional water level data were obtained from 1933 to 1988 from Alberta Environment in the previous 2010 study. There are two WSC stations downstream of the dam (05BJ005 and 05BJ001) that together provide continuous data coverage for the period from 1912 to 2015. There is also one more flow monitoring station upstream of the dam (WSC Station 05BJ010) with data available after 1979.

The reservoir level data begin abruptly with the reservoir being close to full in 1933, so the actual impoundment of the dam could not be included in the calculation of naturalized flows. Consequently, the reservoir was modelled with fixed elevation (i.e. zero storage change) and zero net evaporation for all years prior to 1933, implying that the recorded flows downstream of the dam was equal to natural flows. Natural flows after 1933 were assessed by using the outflows from the dam adjusted for Glenmore reservoir storage change along with the withdrawals made by The City. The results of the updated 2006 bathymetric survey were used in this study to incorporate the latest estimate of the storage capacity curves. Figure B12 shows comparison of naturalized daily flow series to daily flow recorded at WSC Station 05BJ010.

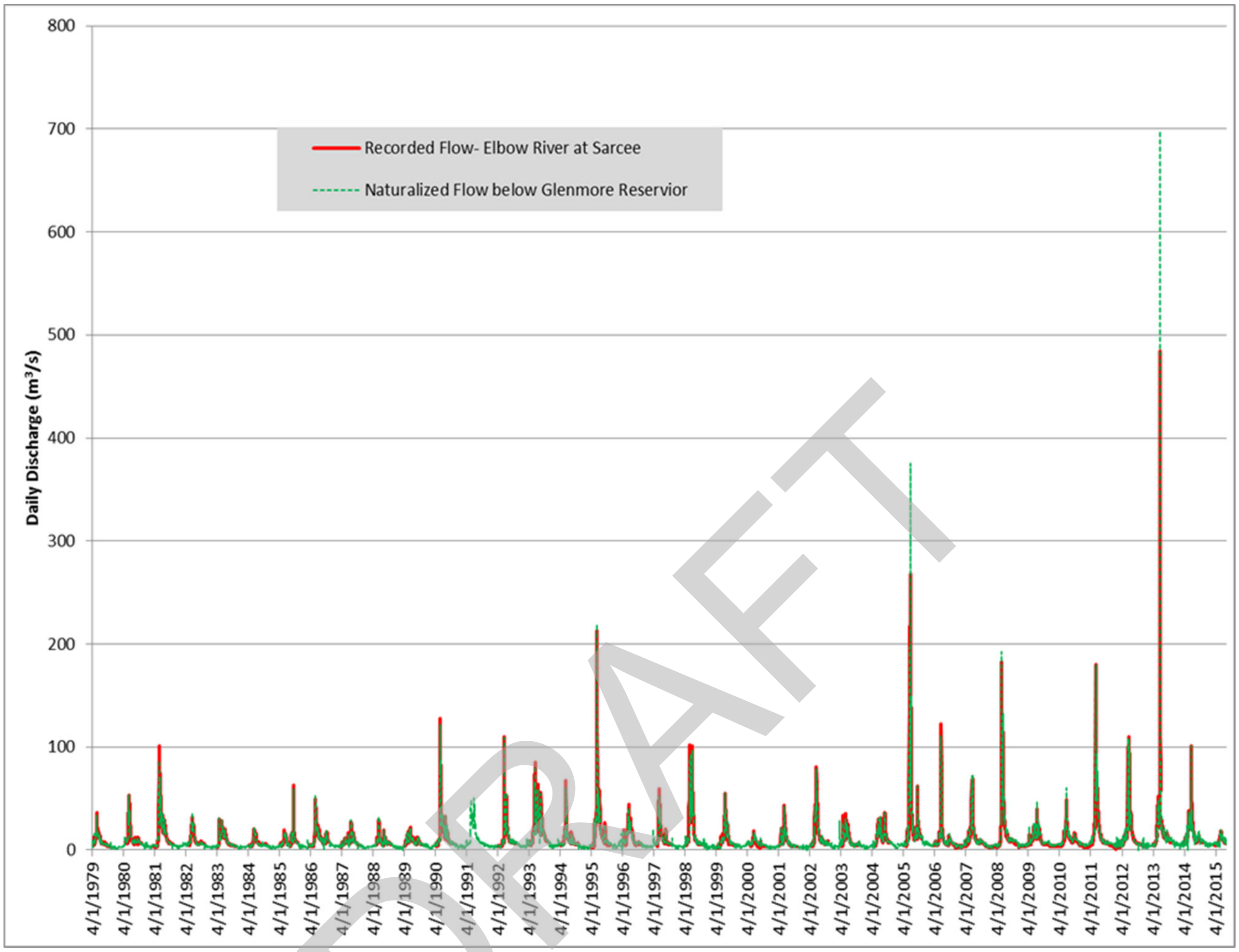


Figure B-12: Comparison of Naturalized and Recorded Flow Data for Elbow River

B12.0 BOW RIVER BASIN FROM CALGARY TO THE MOUTH

The 2010 and 2014 modelling study of the Bow River was completed only up to the end of Bearspaw Dam. The current study includes Glenmore Dam and all other river reaches down to the mouth of the Bow River. The principal tributaries are Fish Creek and the Highwood River, and the major diversion structures are the Carseland and Bassano diversion weirs. Relatively good diversion records were available for Carseland weir, however records of diversions to the Eastern Irrigation District were only available from 1990. Historic annual totals were available for some years prior to 1990 from EID, and these were used to extrapolate the annual water use trend back to 1930, while the weekly demands were obtained by running the WRMM simulation of the entire South Saskatchewan River Basin. Weekly water use data were then interpolated to daily, and a verification of this simulation was conducted to ensure that water use in recent years was equivalent to the recorded diversions.

An assessment of natural flows on the Bow River immediately below confluence with tributaries has been made, such as the Bow River below Fish Creek or below the Highwood River confluence. Assessment of natural flows at these sites can be done by adding the daily tributary inflows to the routed natural flows between Calgary and the tributary confluence. However, the resulting series can be established only for the duration of the available records at the confluence. This reduces the length of record for frequency analyses at the confluence locations.

B13.0 FLOOD ROUTING THROUGH THE BOW SYSTEM

The routing through the storage structures and interconnecting river reaches was conducted based on the existing flood operating guidelines obtained from TransAlta. TransAlta has a licence to store water in their reservoirs. Most reservoirs are expected to be back at their full supply levels by mid-July. For some reservoirs, their maximum allowable storage levels are below the full supply level for some days during the snowmelt period. This maximum allowable storage levels were established by the earlier PMF study that suggested minimum mandatory drawdowns to avoid overtopping the dams in case of catastrophic floods.

There are several constraints that affect the operation of TransAlta reservoirs:

1) Minimum maintenance flow downstream of the Bearspaw dam has been set to 1,200 cfs (34 m^3/s). TransAlta has been in agreement with AEP to maintain this minimum flow at all times.

2) Maximum desirable outflows correspond to the hydro power plant capacities. The use of spillways will only be resorted to in an emergency when it is absolutely necessary.

3) Normally, the reservoir levels are maintained at the top of the operational comfort zone, which is defined separately for each of the reservoirs that have balancing storage. Reservoirs without storage act like large weirs that have two outputs, the hydro power plants (which act as a bottom outlet), and the emergency spillway.

The operating rules for TransAlta can be summarized in the following sequence of decisions which are made as the inflows into a reservoir are increasing from day to day:

a) Outflows are adjusted such that reservoir levels are brought close to the full supply level (if they were not equal to or above them already). In this context the full supply level refers to the top of the comfort zone, which typically varies in terms of the actual elevation throughout the year.

b) If inflows continue to rise, outflow will be increased until it reaches the turbine capacities.

c) Finally, if the turbines are run at full capacity and there is still increase in storage above the full supply levels, the operators will open the spillway gates to a sufficient degree so as to release water over the spillway just enough for storage levels to remain at the top of the comfort zone.

d) When reservoir inflows are too high to maintain the FSL while the outflow equals the full hydro power plant capacity and the available spillway capacity, the storage zone will have to be filled in conjunction with higher outflows via spillway (which are only possible if the storage is allowed to rise).

Table B1 provides the hydro power flow limits caused by the types and number of turbines available at their hydro power plants. Total flow in a channel located downstream of a reservoir is a sum of its spills and its turbine flows.

Table B1: Maximum Flows through Hydro Power Plants

Name of Hydro Power Plant	Maximum Outflow [m^3/s]
Three Sisters	24.6
Spray	45.3
Rundle	62.3
Interlakes	19.8
Pocatera	31.2
Barrier	36.8
Cascade	39.6
Kananaskis	120.7
Horseshoe	104.8
Ghost	243.5
Bearspaw	155.7

Minimum Flows:

While turbine capacities define maximum desirable outflows from TransAlta's storage reservoirs, there are certain operational limits that should also be taken into account. Those are:

a) River maintenance flows. These are defined on the main step of the Bow River study (e.g., 1,200 cfs at the Bearspaw dam), but also on the tributaries. The minimum outflow from Rundle hydro power plant is 7.6 m^3/s all year round, while the Cascade hydro power plant maintains the minimum of 7.2 m^3/s throughout the year except from Julian day 113 to Julian day 239. This is the snowmelt runoff period when TransAlta wants the dam to re-fill as much as possible, and during dry years re-filling may take precedence to power generation in those months, since storage is more valuable later during low flow winter months.

b) Bearspaw Dam withdrawals by the City of Calgary have been modelled for all years at their current level of 4.47 m^3/s. This is a mandatory withdrawal that has to be met all the time. The withdrawal from Glenmore reservoir is also mandatory, however it has a seasonal distribution and it is higher in summer months than in the winter.

The combination of the maintenance flow at Calgary of 34 m^3/s and the mandatory withdrawal at Bearspaw dam of 4.47 m^3/s cause the reservoirs to drop their elevations below the comfort zone level targets in dry years, such as for example in the mid-1930s and early 1940s. However, this is in line with the current operating procedures, since those two flow objective take precedence over the established storage target levels.

The Bow River Basin modelling schematic is illustrated in Figures B13 and B14.

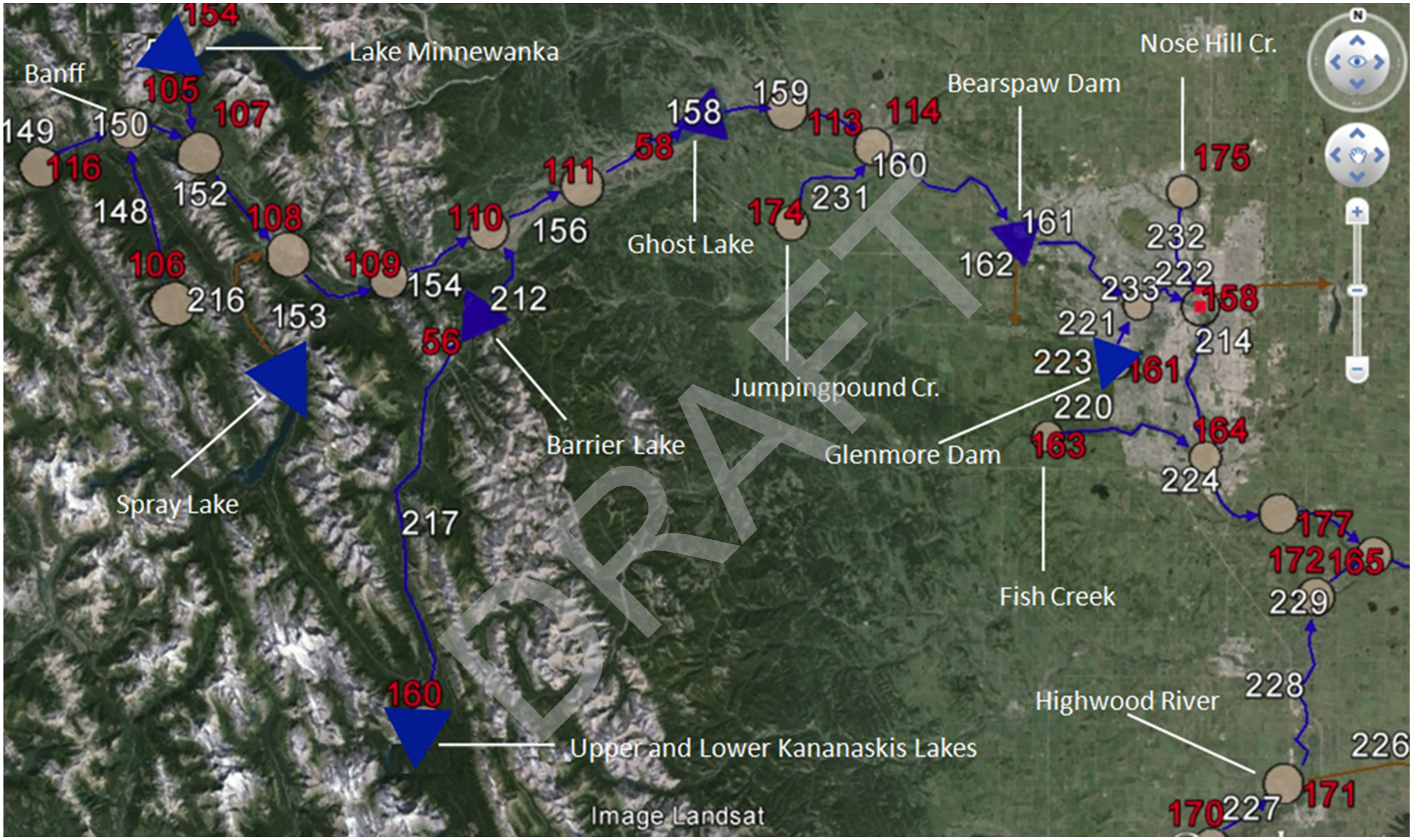


Figure B-13: Modeling Schematic of the Upper Bow River Basin from Banff to Calgary

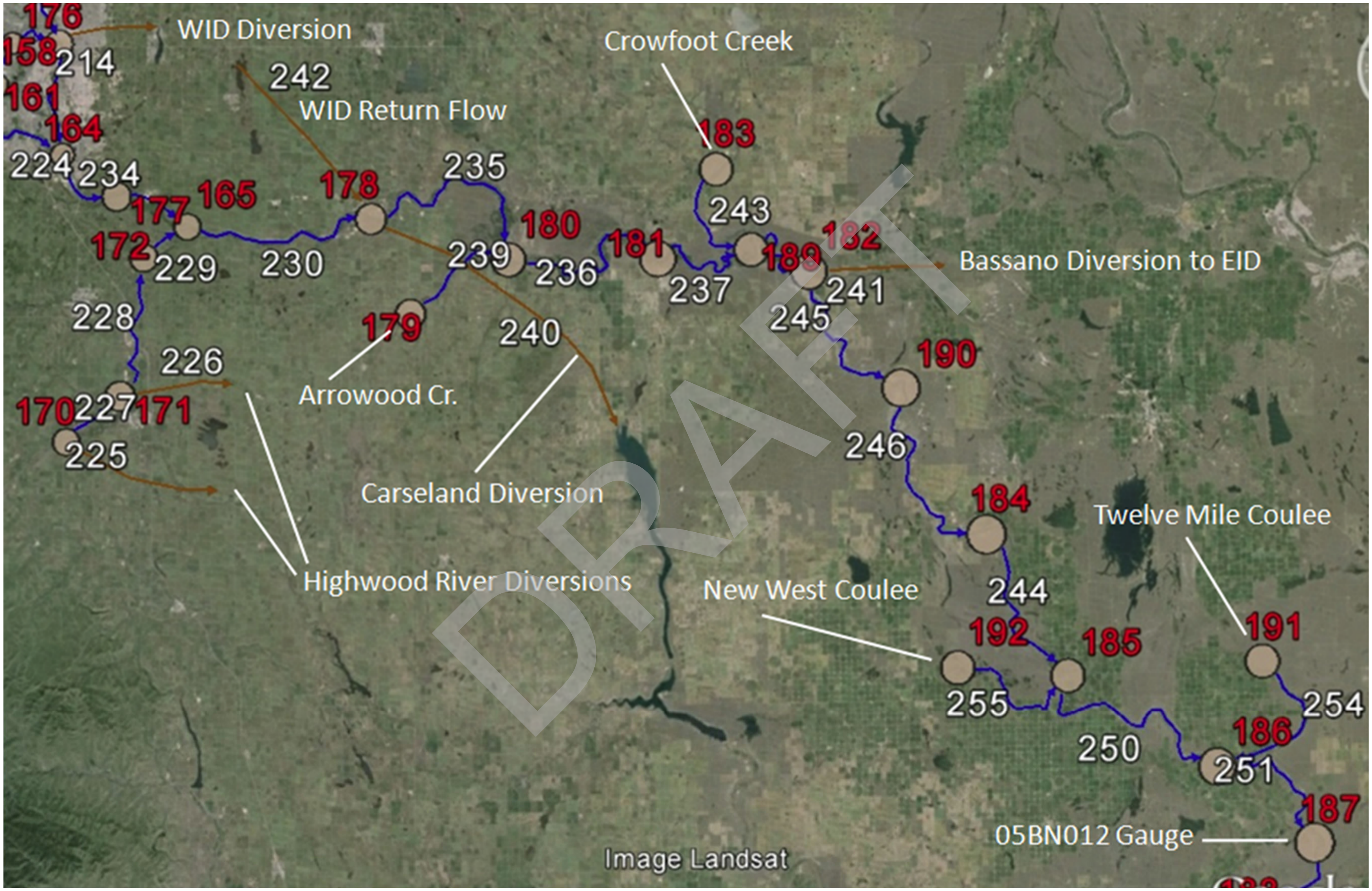


Figure B-14: Modeling Schematic of the Lower Bow River Basin from Calgary to Mouth

APPENDIX C

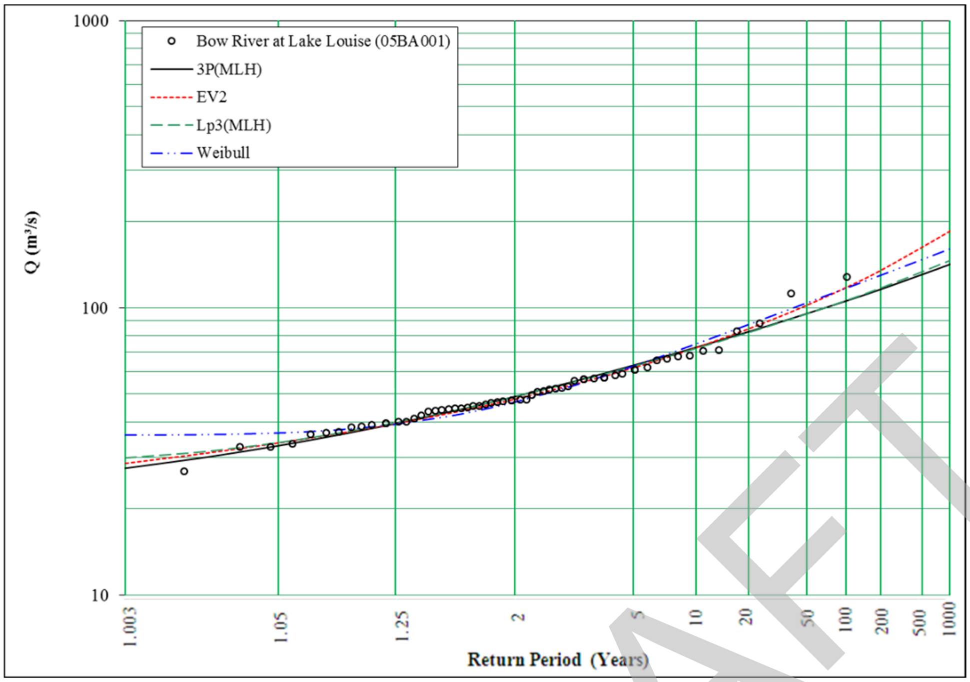
Frequency Analysis - Graphs and Tables

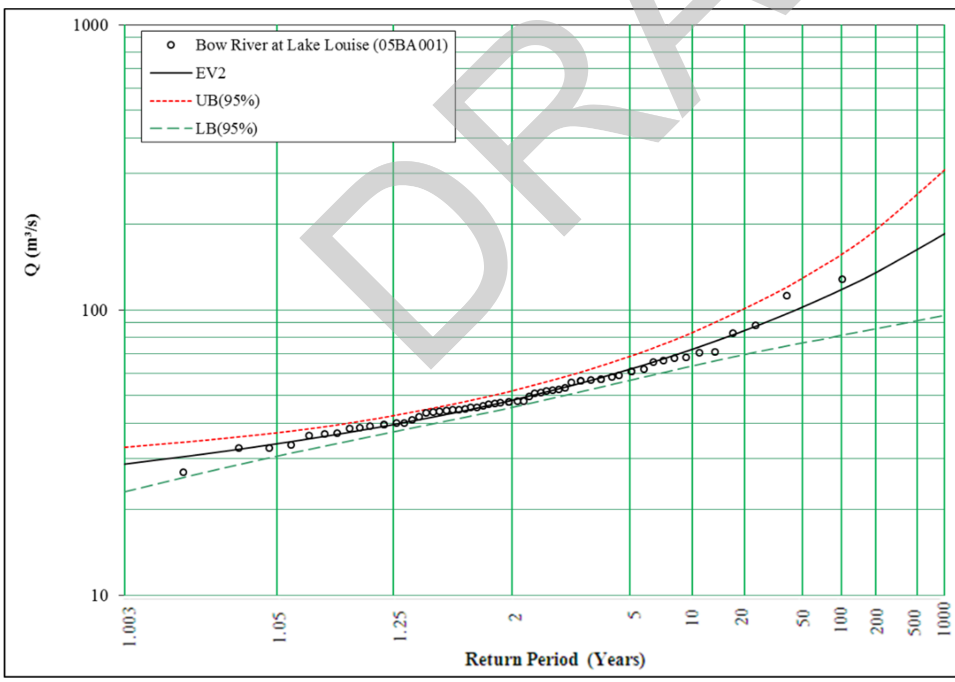
This document has a compilation of graphs and results from frequency analysis of

- **recorded natural or generated naturalized flows at selected assessment nodes, including extended datasets and historic floods, and each station will have the following graphs:**
- **frequency distribution graph - all distributions;**
- **frequency distribution graph - best fit graph with confidence interval; and**
- **flood estimates - all distributions.**

BOW RIVER

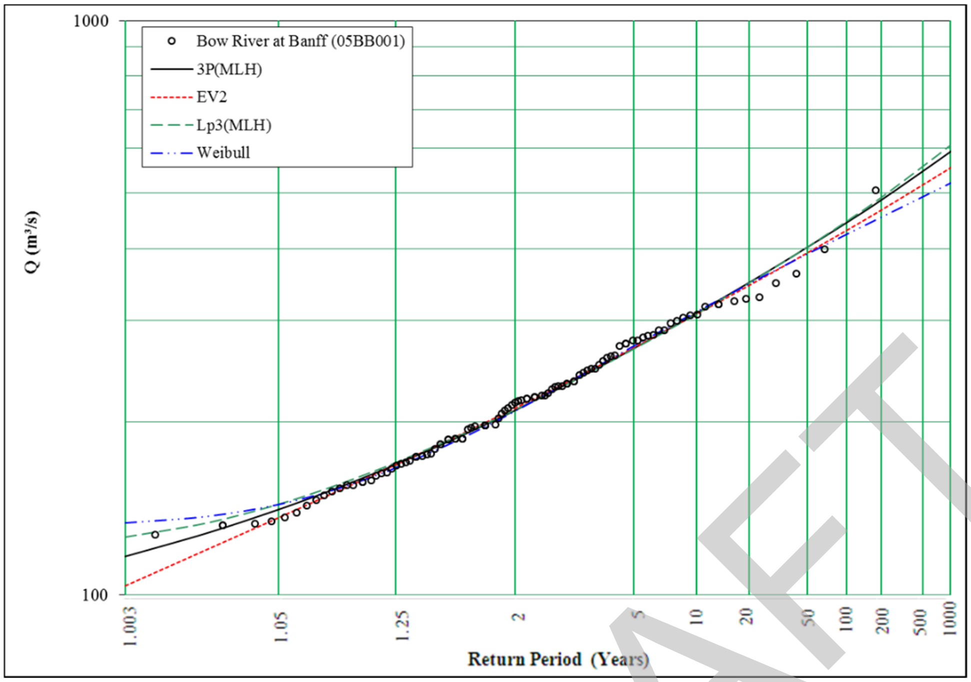
Figure C.1.1: 05BA001, Bow River at Lake Louise

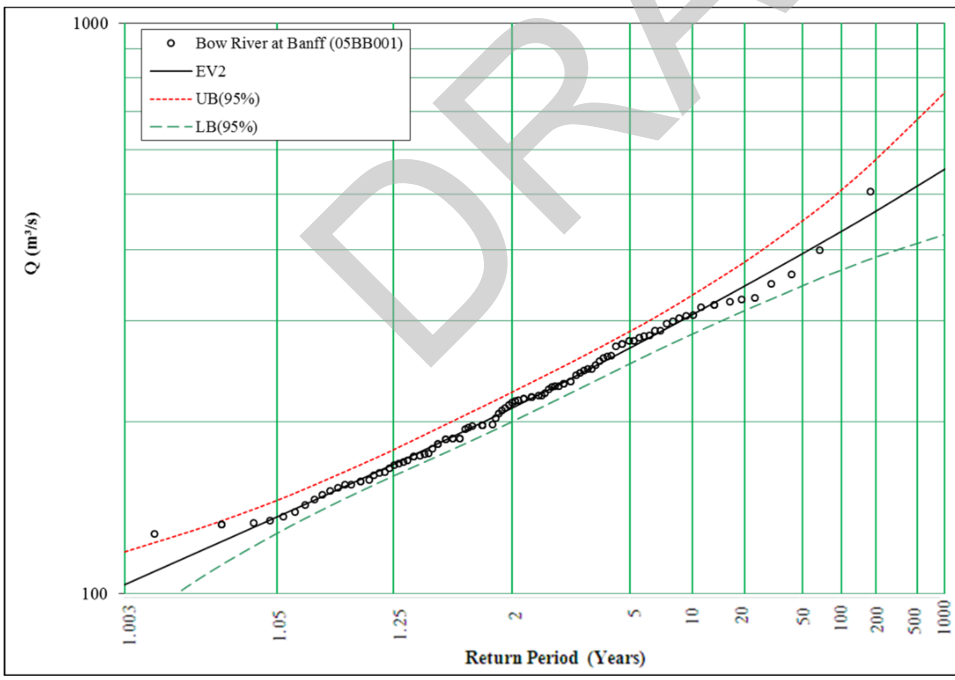




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	49.0	48.2	49.0	46.8
5	63.0	61.9	62.6	62.5
10	72.8	72.7	72.3	74.7
20	82.5	84.6	82.0	87.1
35	90.3	95.1	90.1	97.3
50	95.5	102	95.4	104
75	101	111	102	111
100	106	118	106	117
200	116	135	117	129
350	124	149	126	139
500	129	159	132	146
750	135	172	139	154
1000	140	182	144	159

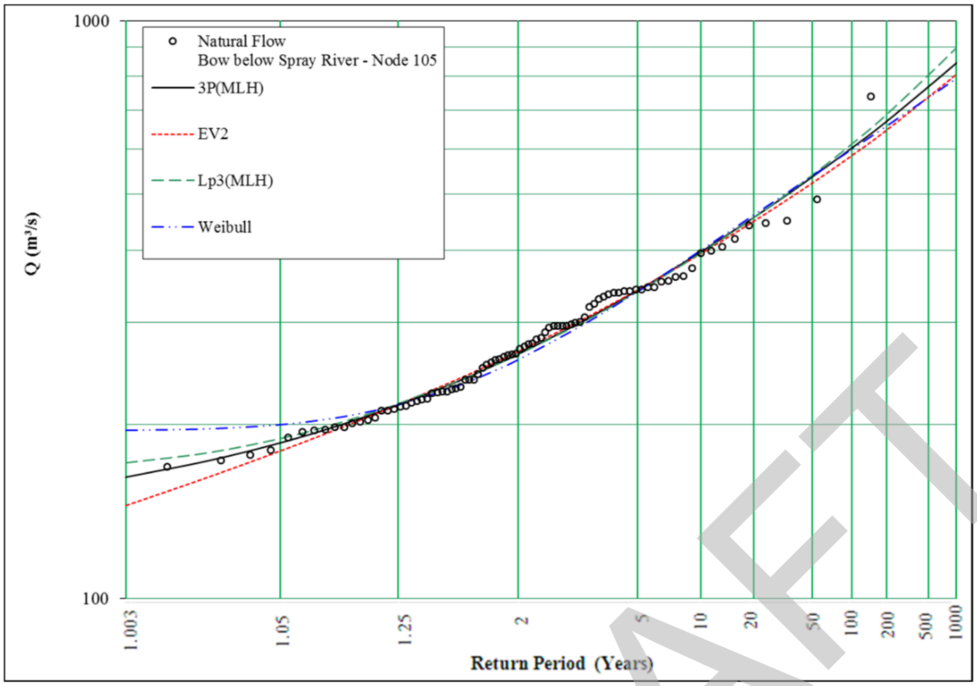
Figure C.1.2: 05BB001, Bow River at Banff

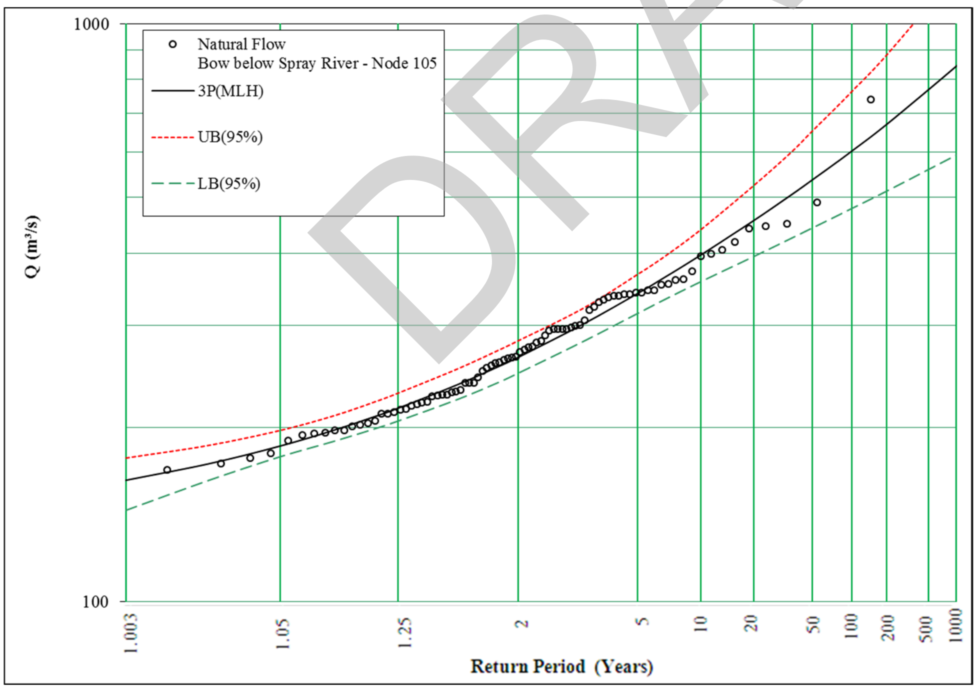




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	209	211	209	209
5	268	269	268	271
10	309	308	308	311
20	349	346	348	348
35	382	375	381	375
50	403	394	403	392
75	427	416	428	411
100	444	431	446	424
200	487	468	491	454
350	523	498	529	478
500	546	517	554	492
750	572	538	584	509
1000	591	554	605	520

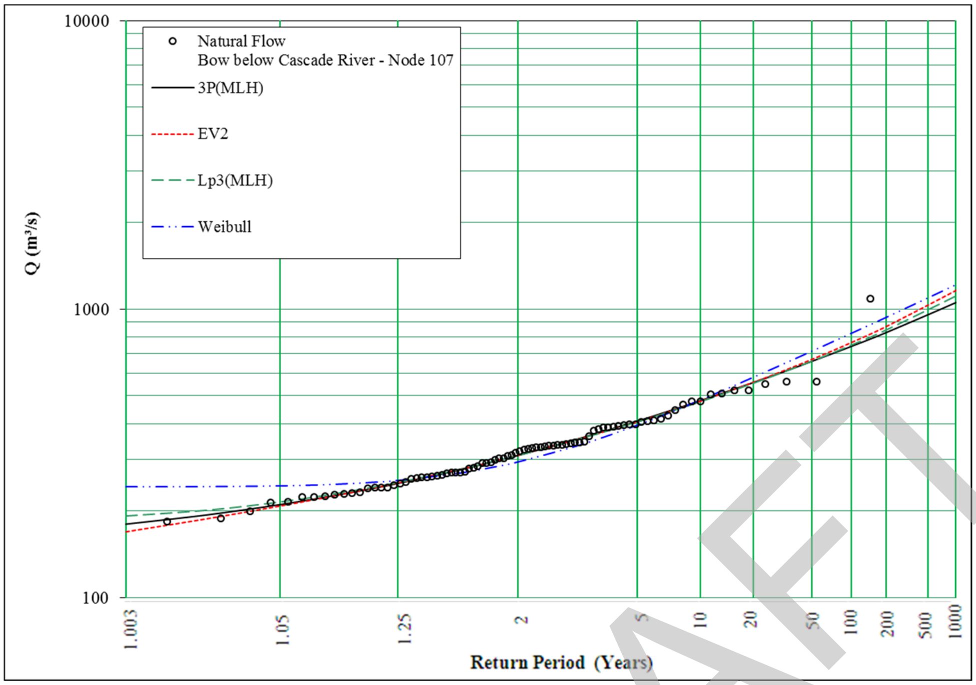
Figure C.1.3: Node 105, Bow River below Spray River

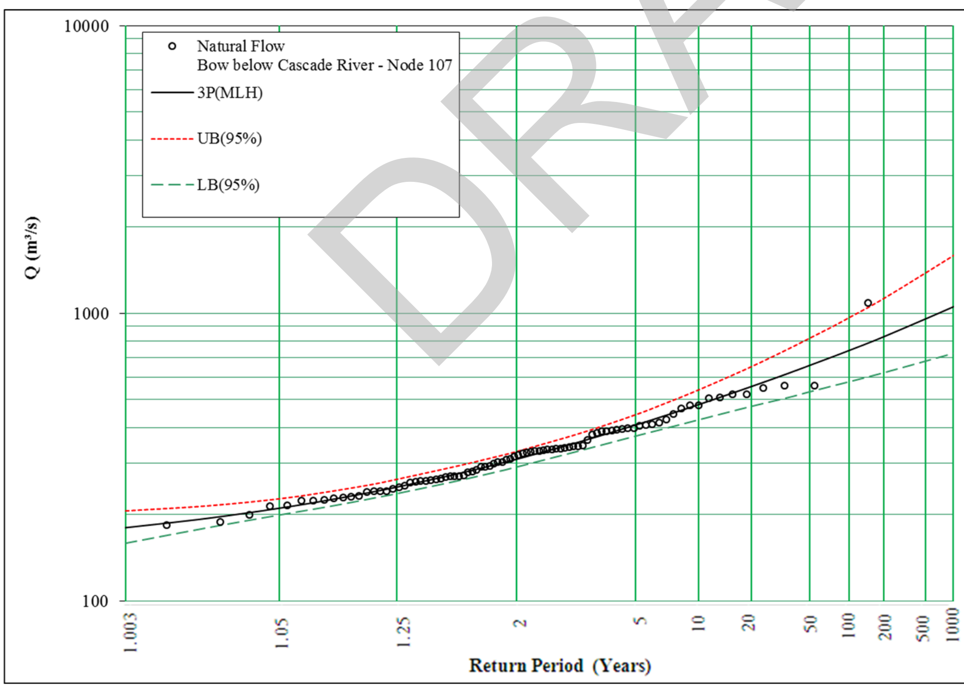




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	264	267	264	259
5	341	342	340	340
10	398	395	396	400
20	456	449	456	460
35	505	494	506	508
50	537	524	541	539
75	574	559	581	573
100	602	584	611	598
200	670	647	688	657
350	729	700	756	704
500	769	736	801	734
750	811	777	856	768
1000	844	807	896	793

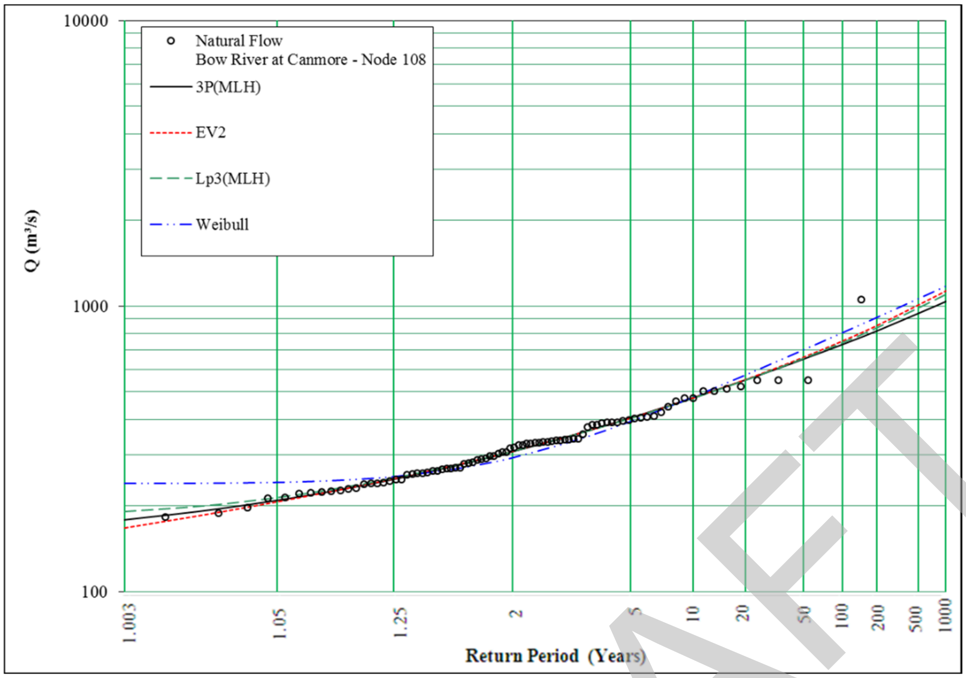
Figure C.1.4: Node 107, Bow River below Cascade River

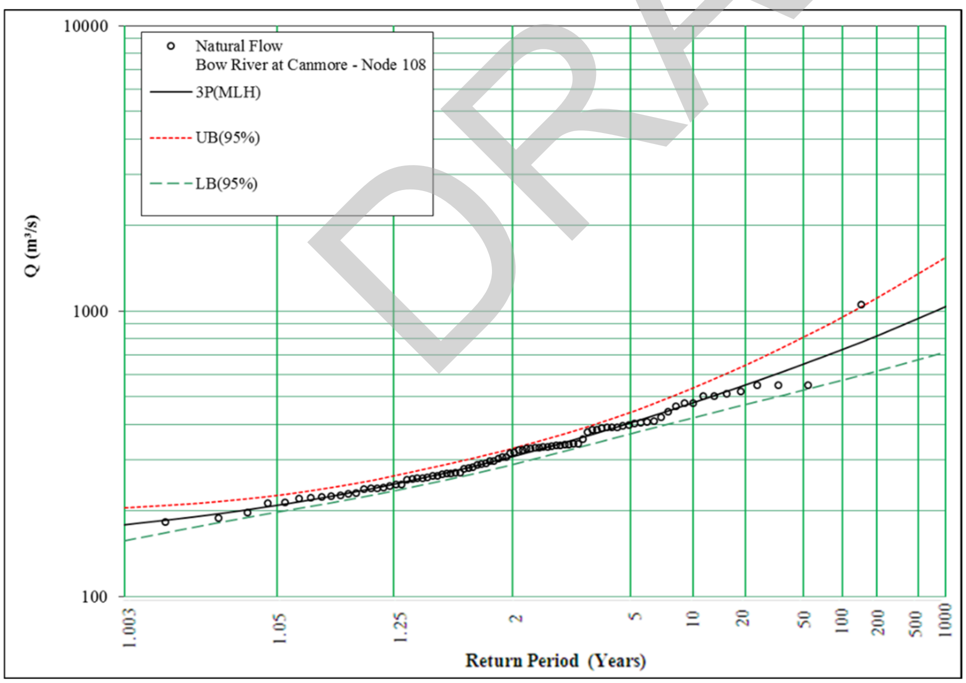




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	311	311	311	295
5	409	407	406	395
10	481	479	478	483
20	556	557	553	579
35	618	625	618	660
50	659	670	661	714
75	707	725	713	777
100	742	766	751	822
200	829	872	848	935
350	905	965	934	1030
500	956	1030	991	1090
750	1010	1100	1060	1160
1000	1050	1160	1110	1210

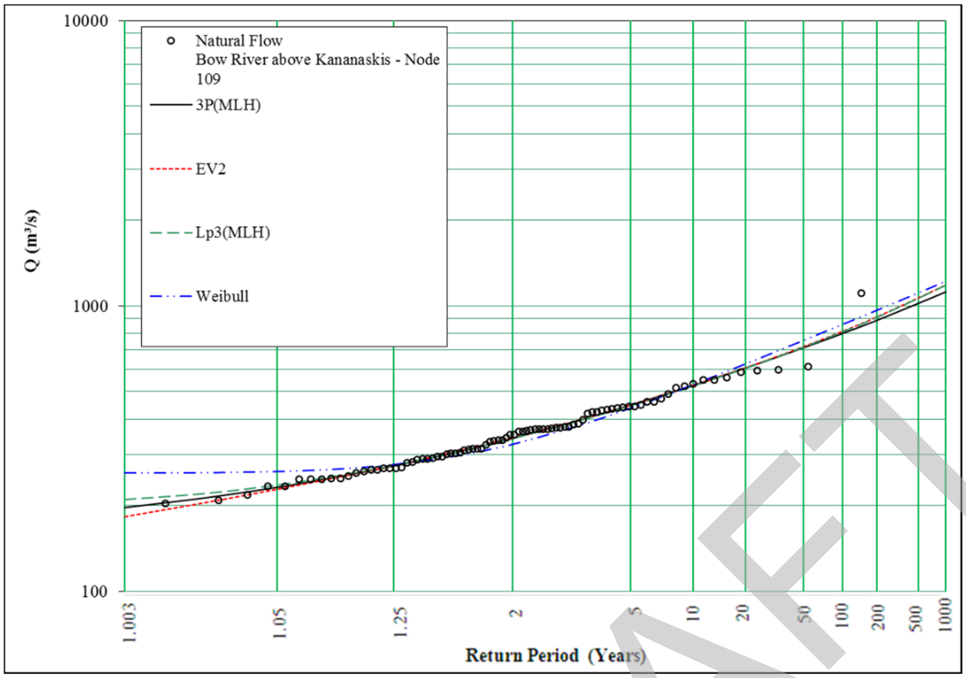
Figure C.1.5: Node 108, Bow River at Canmore

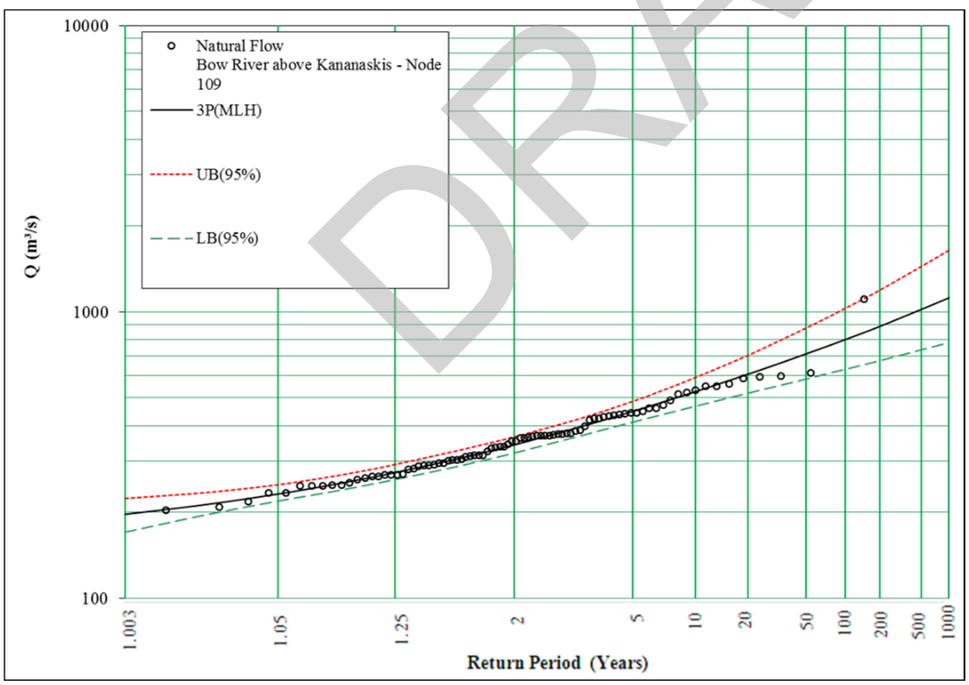




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	309	309	308	293
5	406	404	403	393
10	477	475	474	479
20	550	551	548	571
35	611	616	611	650
50	652	660	654	701
75	698	713	704	761
100	733	752	741	804
200	818	852	837	910
350	892	940	920	999
500	942	1000	976	1060
750	995	1070	1040	1120
1000	1040	1120	1090	1170

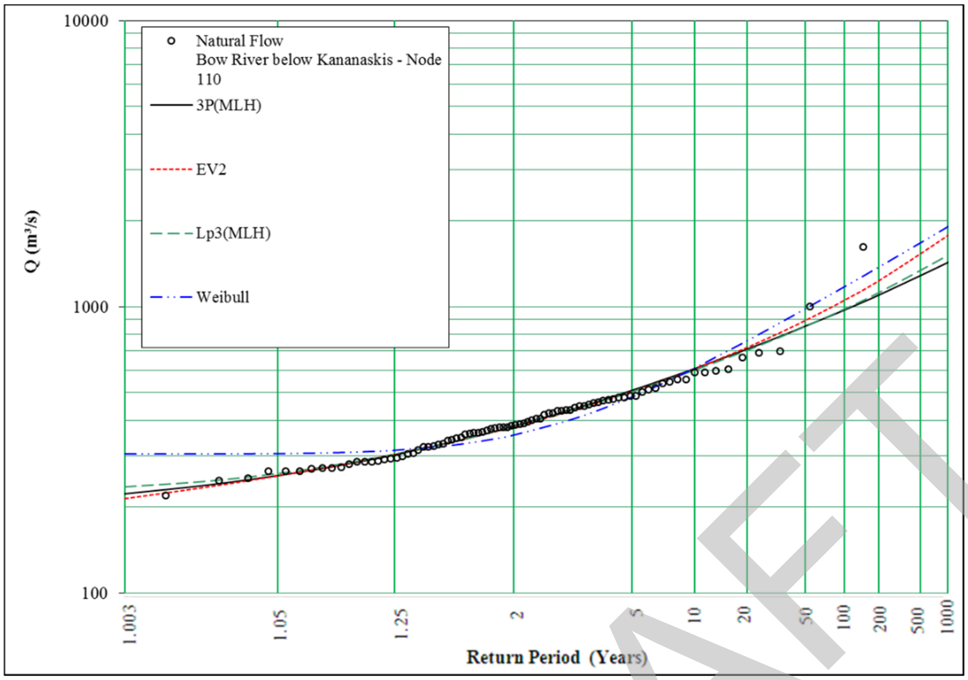
Figure C.1.6: Node 109, Bow River above Kananaskis

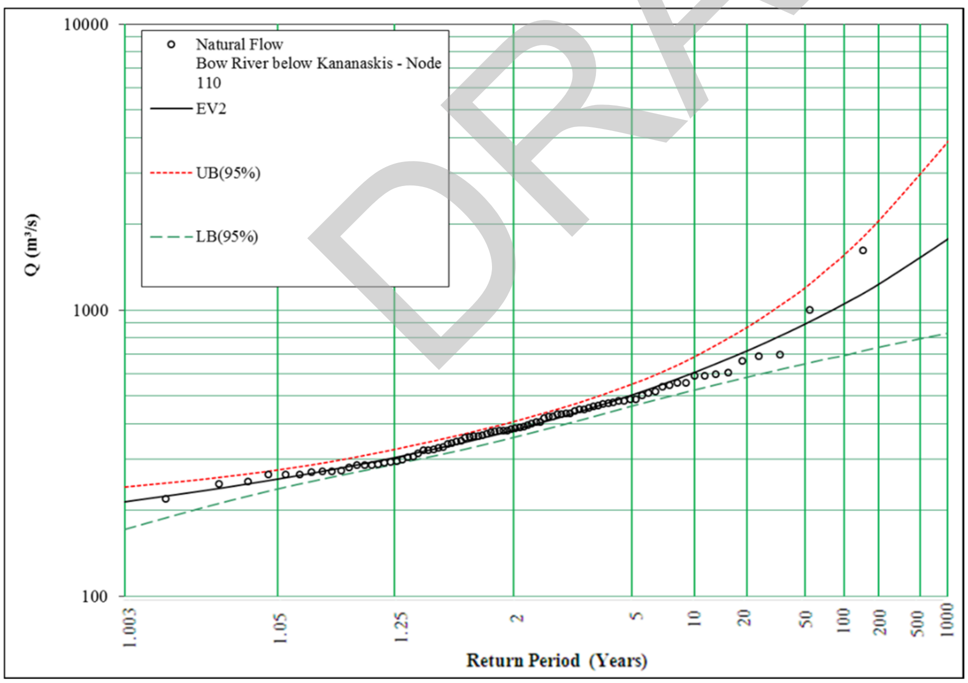




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	343	344	343	328
5	449	448	446	439
10	526	524	523	530
20	605	604	603	625
35	670	672	670	705
50	713	718	716	757
75	763	771	769	816
100	799	811	808	859
200	890	912	909	964
350	968	999	996	1050
500	1020	1060	1050	1110
750	1080	1130	1120	1170
1000	1120	1180	1180	1220

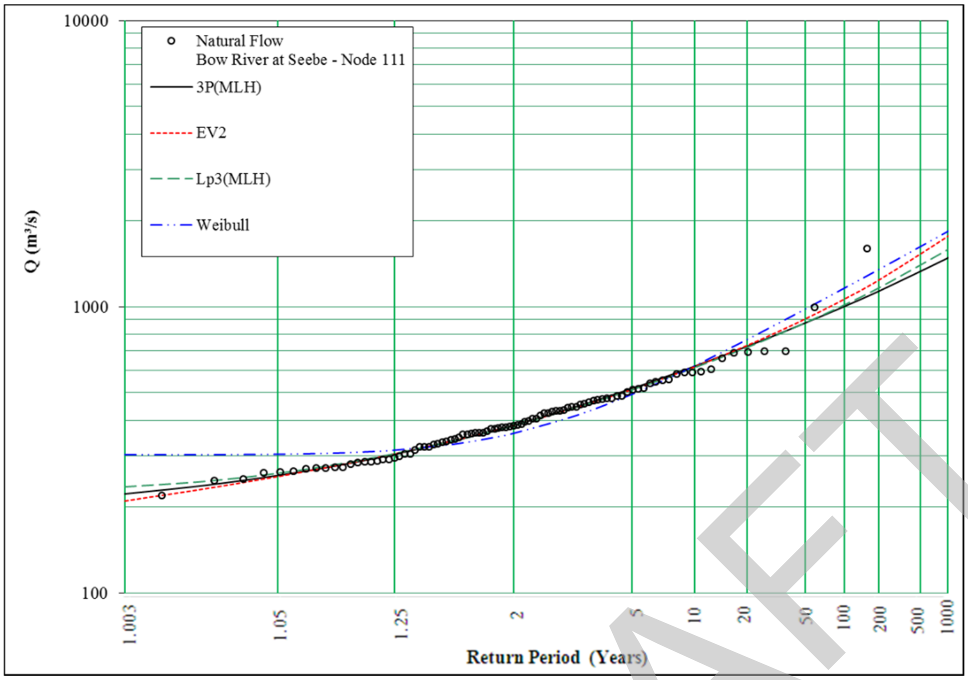
Figure C.1.7: Node 110, Bow River below Kananaskis

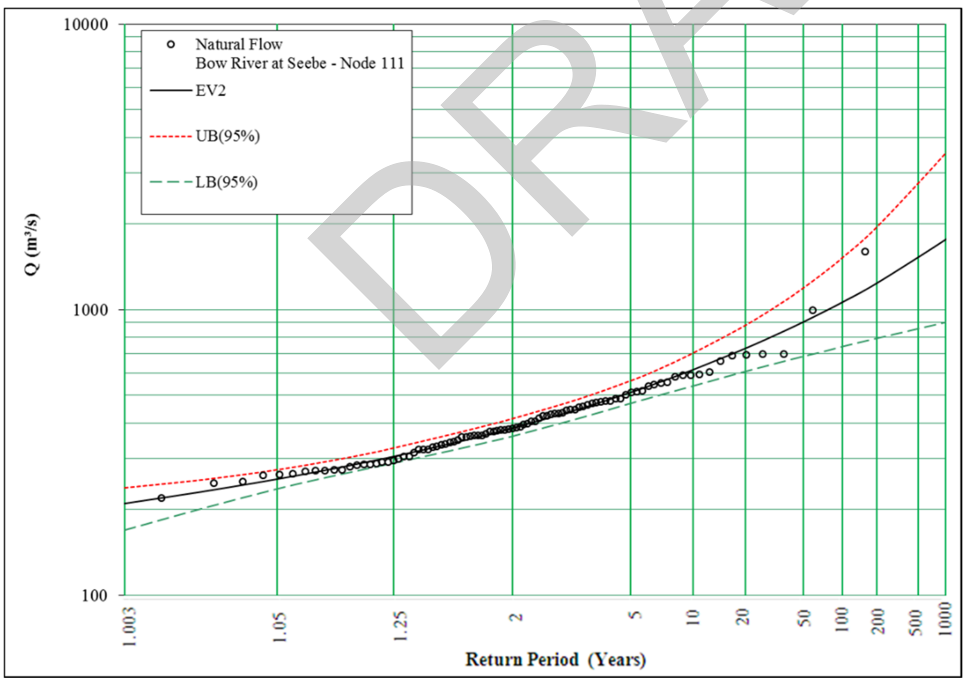




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	381	380	381	355
5	510	505	506	483
10	608	606	602	610
20	710	719	704	759
35	797	822	794	892
50	855	894	855	983
75	923	983	928	1090
100	973	1050	982	1170
200	1100	1230	1120	1370
350	1210	1400	1250	1550
500	1280	1510	1330	1670
750	1360	1660	1440	1800
1000	1430	1770	1510	1900

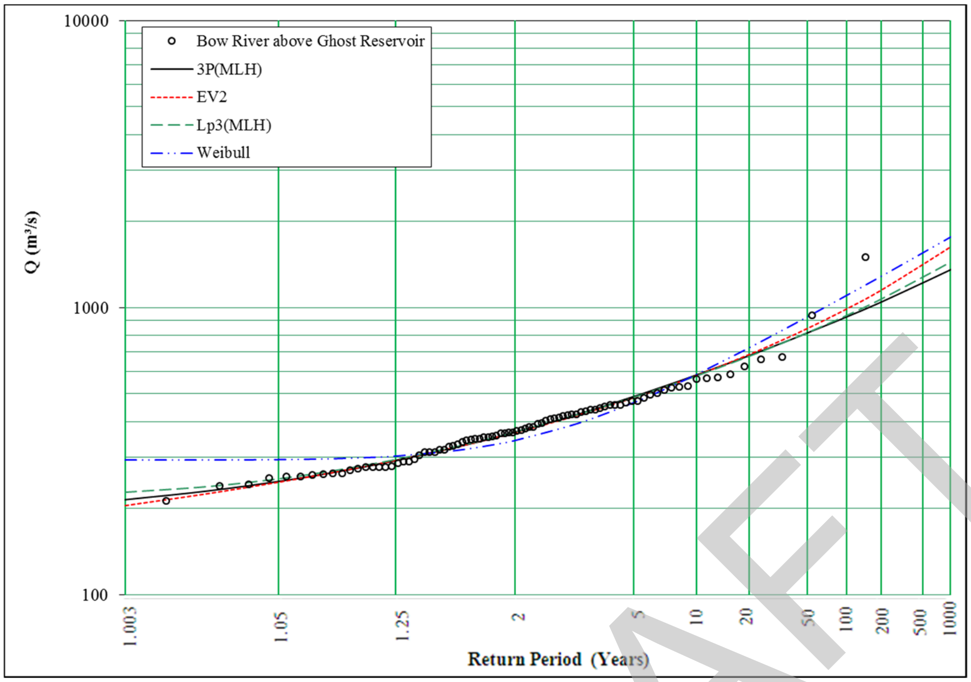
Figure C.1.8: 05BE004 / Node 111, Bow River near Seebe

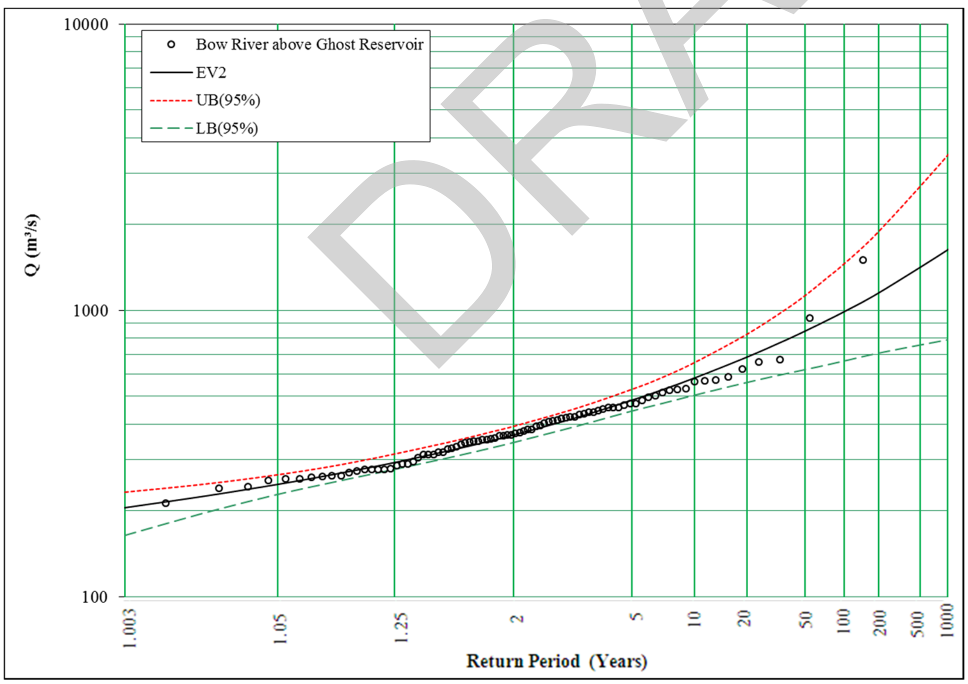




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	385	384	385	361
5	518	513	514	494
10	619	616	614	621
20	726	731	722	766
35	817	834	816	895
50	878	906	881	981
75	949	994	958	1080
100	1000	1060	1020	1160
200	1130	1240	1170	1350
350	1250	1400	1300	1510
500	1330	1510	1390	1620
750	1410	1650	1500	1740
1000	1480	1760	1590	1830

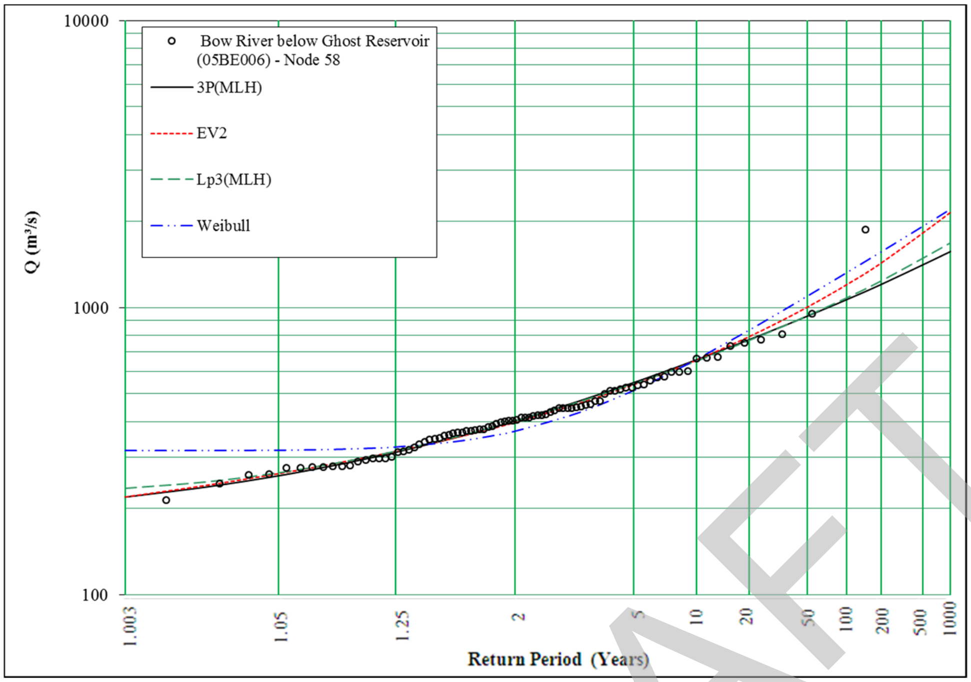
Figure C.1.9: Node 318, Bow River above Ghost Reservoir

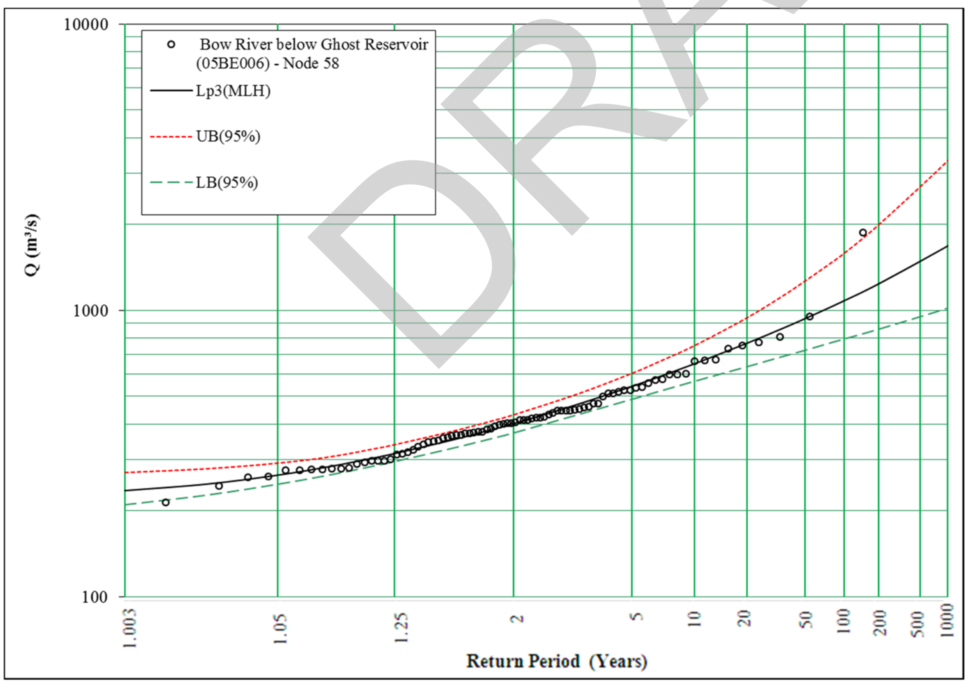




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	367	367	367	343
5	490	486	486	466
10	583	581	577	585
20	679	686	675	722
35	761	781	759	845
50	816	847	817	928
75	880	928	885	1030
100	927	989	937	1100
200	1050	1150	1070	1280
350	1150	1300	1190	1440
500	1220	1400	1270	1550
750	1300	1530	1360	1670
1000	1350	1630	1440	1760

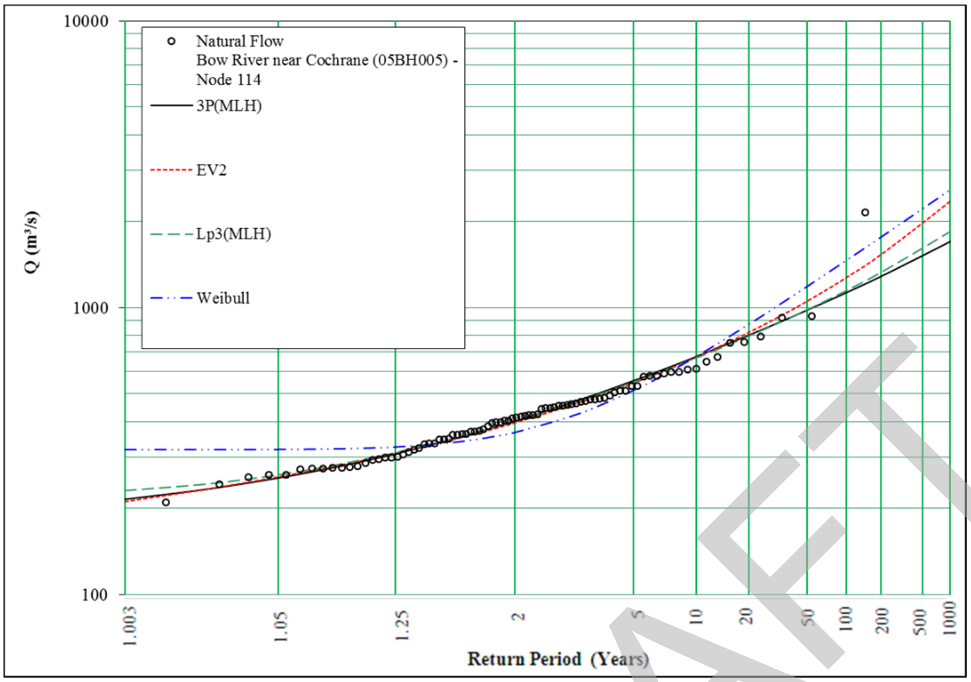
Figure C.1.10: 05BE005 / Node 58, Bow River below Ghost Dam (Ghost Reservoir Outflow)

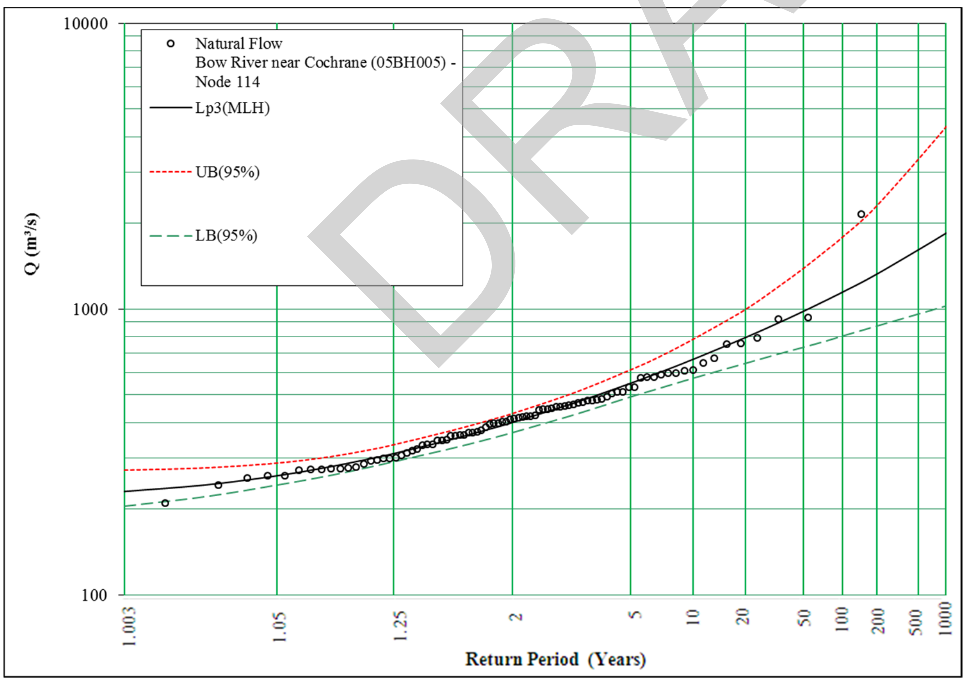




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	402	397	402	371
5	548	538	543	515
10	658	655	651	661
20	772	790	767	834
35	869	915	868	991
50	934	1000	936	1100
75	1010	1110	1020	1230
100	1070	1200	1080	1320
200	1200	1430	1240	1570
350	1330	1650	1380	1780
500	1410	1800	1480	1920
750	1500	1990	1590	2080
1000	1570	2140	1680	2200

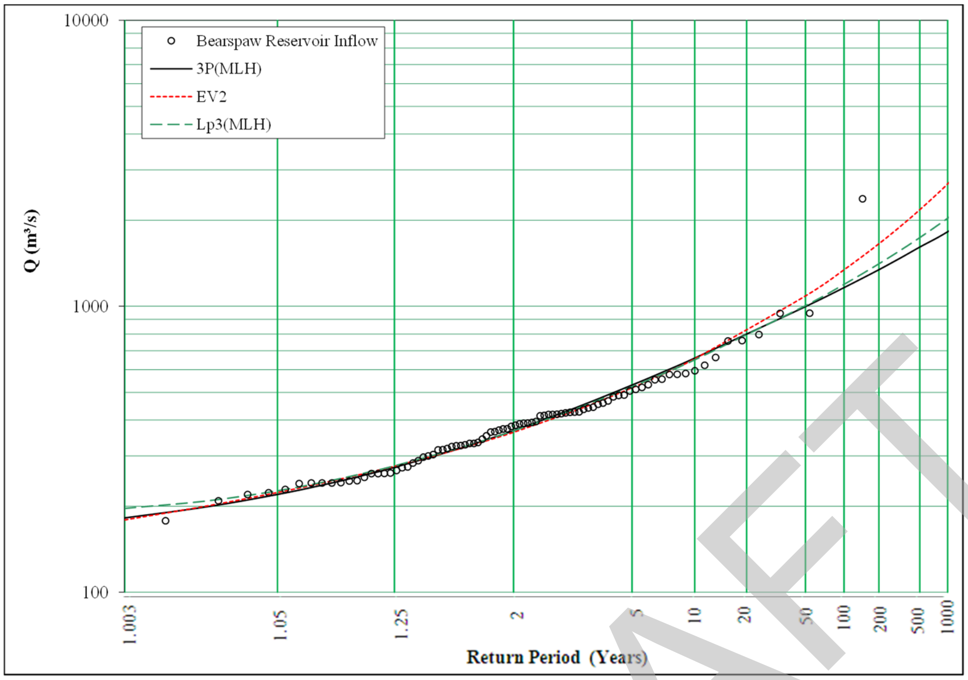
Figure C.1.11: 05BH005 / Node 114, Bow River near Cochrane

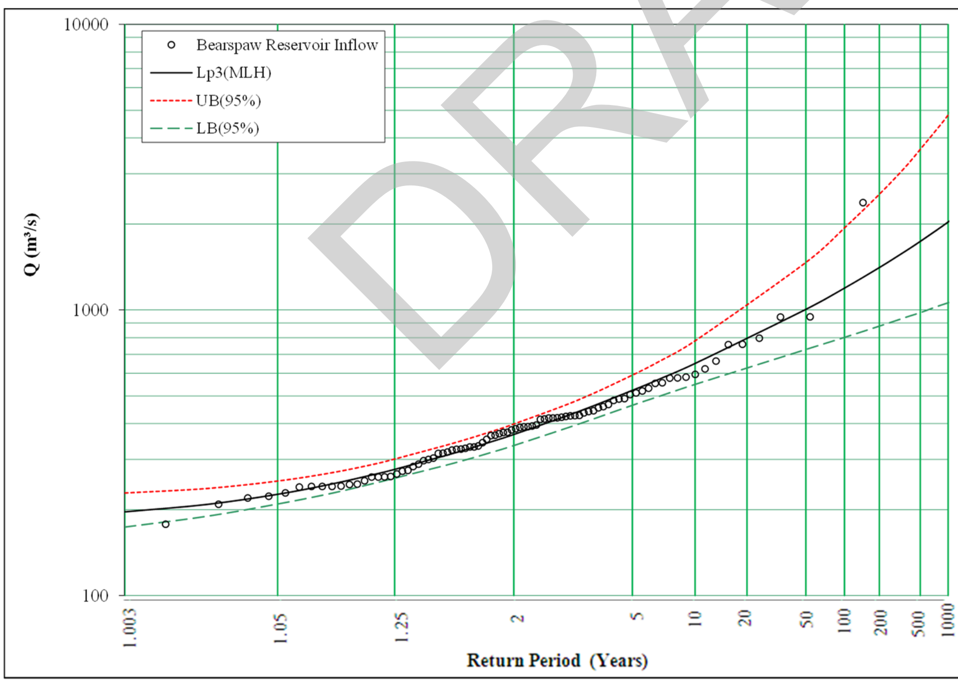




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	401	397	401	367
5	556	547	550	514
10	675	673	667	674
20	801	820	794	872
35	908	957	906	1060
50	980	1050	983	1180
75	1060	1180	1080	1340
100	1130	1270	1140	1460
200	1280	1530	1330	1760
350	1420	1780	1490	2020
500	1520	1950	1600	2200
750	1620	2180	1740	2410
1000	1700	2350	1840	2560

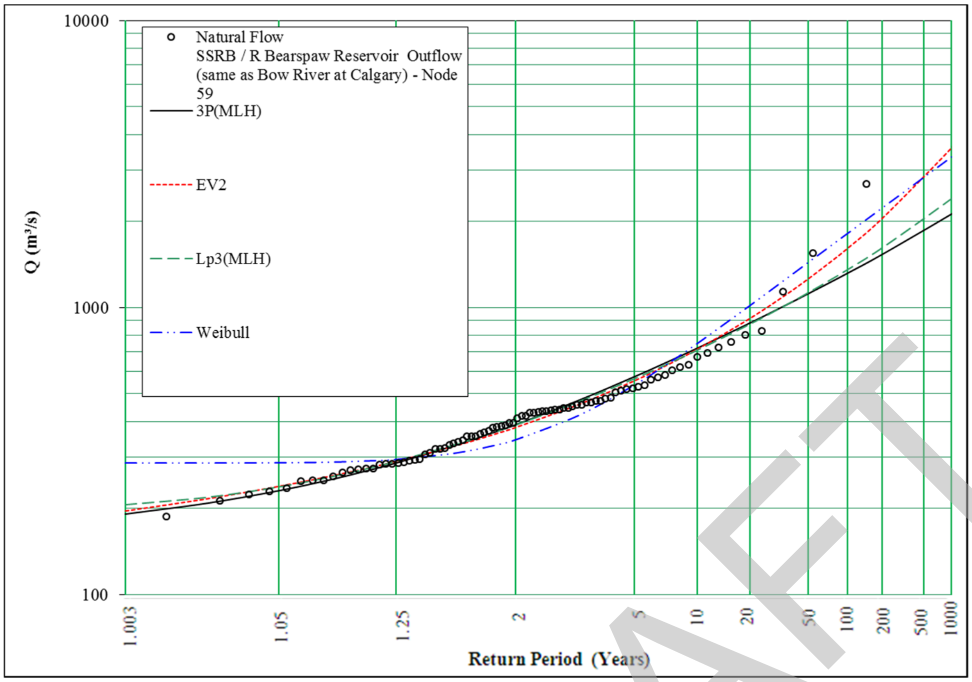
Figure C.1.12: Node 302, Bearspaw Reservoir Inflow

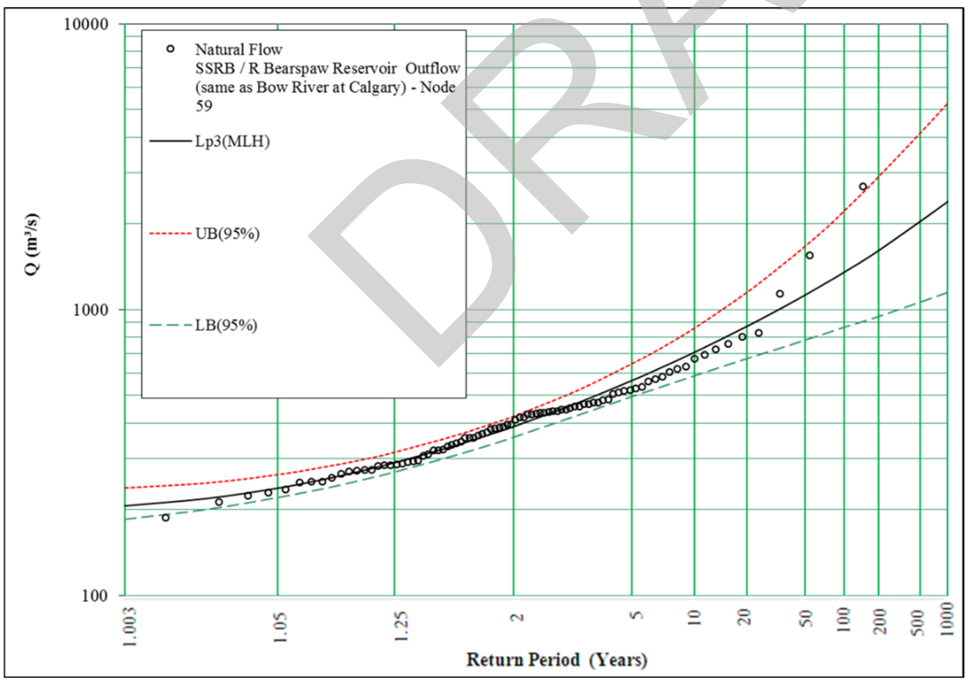




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	367	363	367	
5	531	519	523	
10	659	656	650	
20	797	818	791	
35	916	974	917	
50	997	1090	1010	
75	1090	1230	1110	
100	1160	1340	1190	
200	1340	1660	1410	
350	1500	1960	1600	
500	1610	2180	1740	
750	1730	2460	1910	
1000	1820	2680	2030	

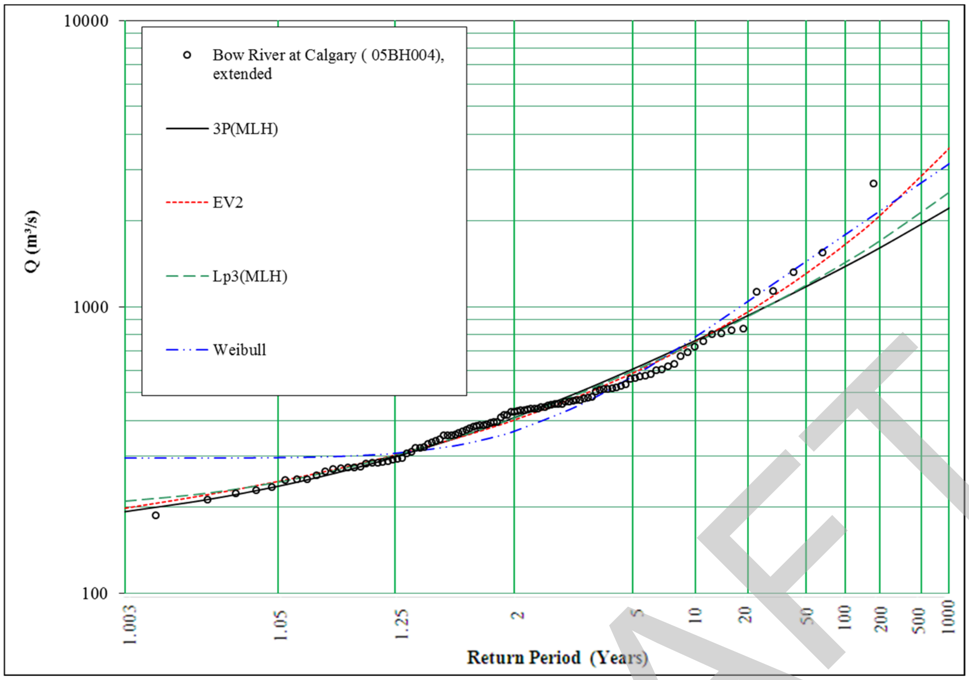
Figure C.1.13: 05BH008 / Node 59, Bearspaw Reservoir Outflow (same as Bow River at Calgary)

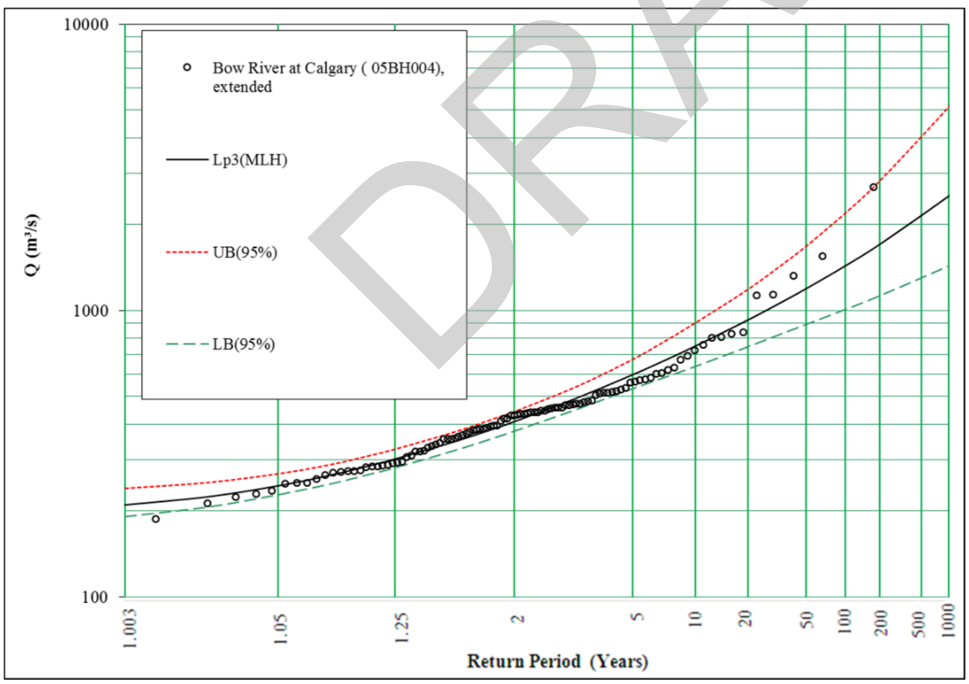




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	390	382	389	346
5	574	556	564	537
10	722	715	709	750
20	882	914	872	1010
35	1020	1110	1020	1260
50	1120	1260	1120	1440
75	1230	1450	1250	1650
100	1320	1600	1350	1810
200	1530	2040	1610	2220
350	1730	2480	1850	2580
500	1860	2810	2020	2830
750	2000	3240	2220	3120
1000	2110	3580	2380	3330

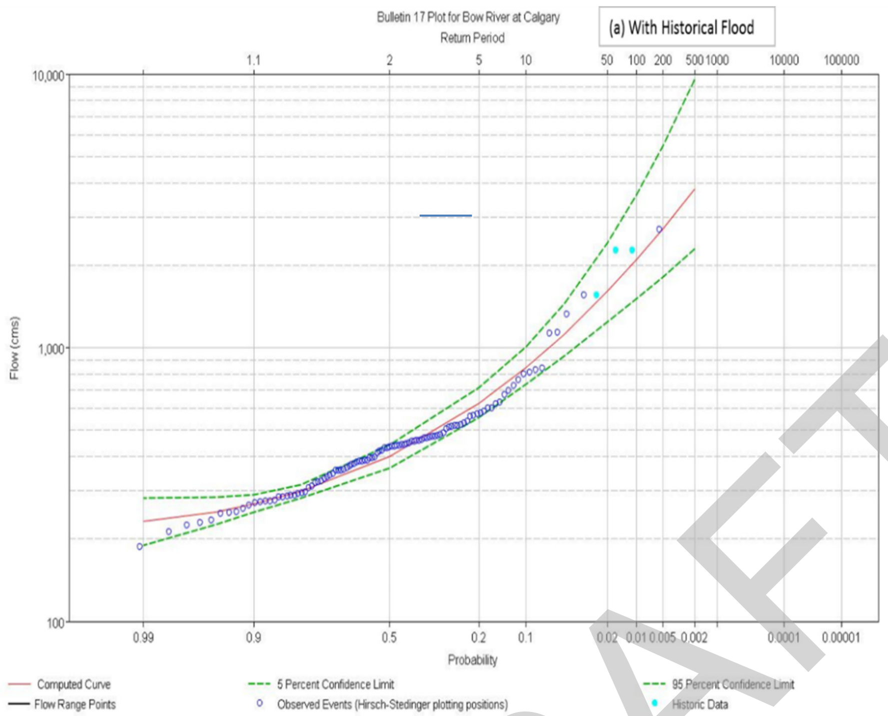
Figure C.1.14: 05BH004 / Node 59, Bow River at Calgary - extended



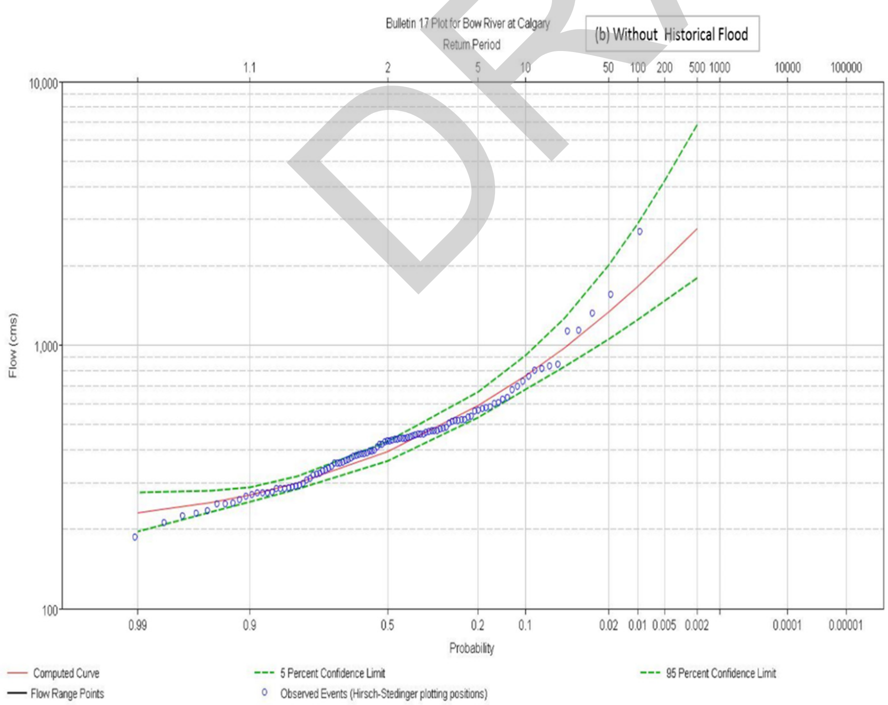


Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	410	402	409	368
5	606	586	597	573
10	762	753	751	787
20	931	957	925	1040
35	1080	1160	1080	1280
50	1180	1310	1190	1440
75	1300	1500	1330	1640
100	1380	1650	1430	1790
200	1610	2080	1700	2160
350	1810	2500	1950	2490
500	1940	2820	2130	2710
750	2090	3230	2350	2970
1000	2210	3550	2510	3160

Figure C.1.15 05BH004 / Node 59, Bow River at Calgary – Using Bulletin 17C Method

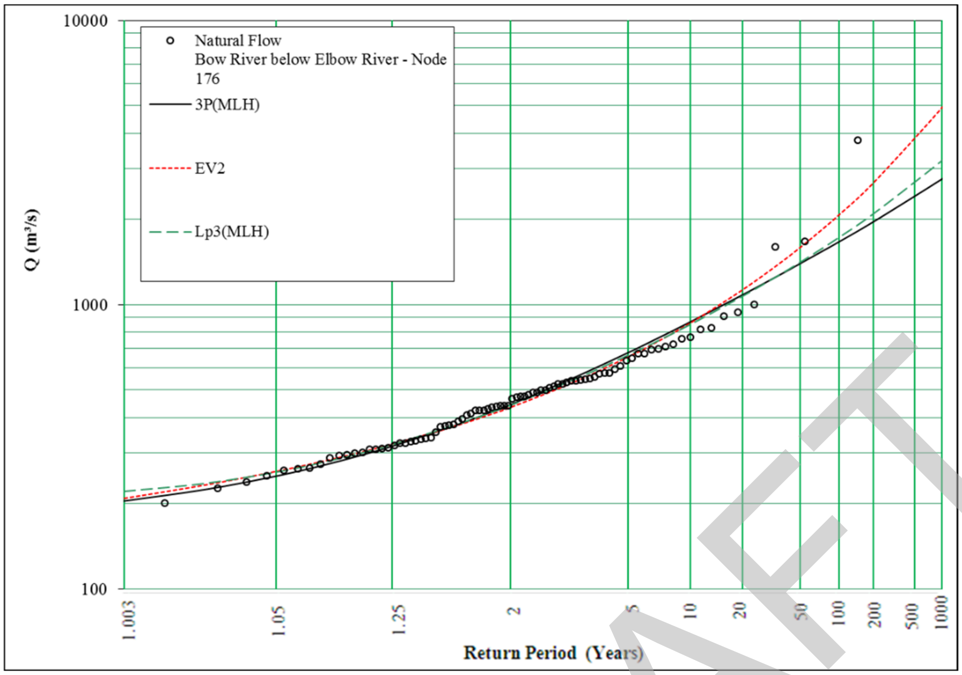


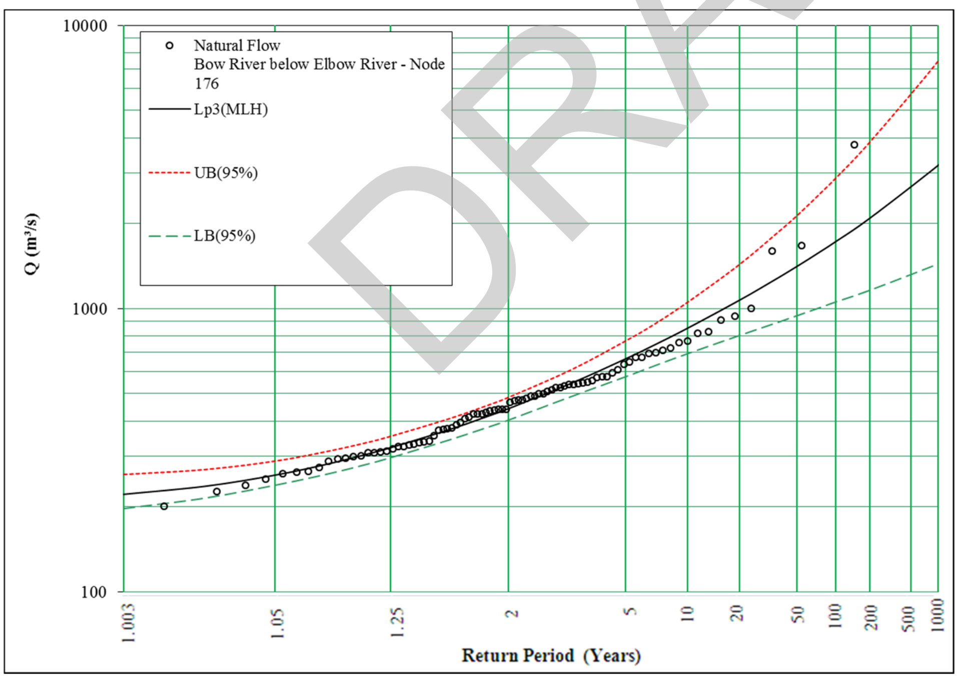
Return Period	Flood Estimates (m^3/s) With Historic Flood	Upper Bound	Lower Bound
2	401	442	364
5	627	714	557
10	845	1009	737
20	1121	1450	936
35	1398	1974	1114
50	1606	2417	1238
75	1875	3056	1391
100	2091	3618	1507
200	2709	5469	1817
350	3330	7676	2103
500	3794	9545	2303
750	4397	12248	2550
1000	4878	14630	2738



Return Period	Flood Estimates (m^3/s) Without Historic Flood	Upper Bound	Lower Bound
2	396	430	363
5	590	665	533
10	766	914	677
20	979	1272	830
35	1184	1682	964
50	1333	2018	1056
75	1522	2491	1167
100	1670	2898	1250
200	2082	4193	1468
350	2480	5672	1663
500	2769	6887	1798
750	3136	8598	1962
1000	3424	10071	2085

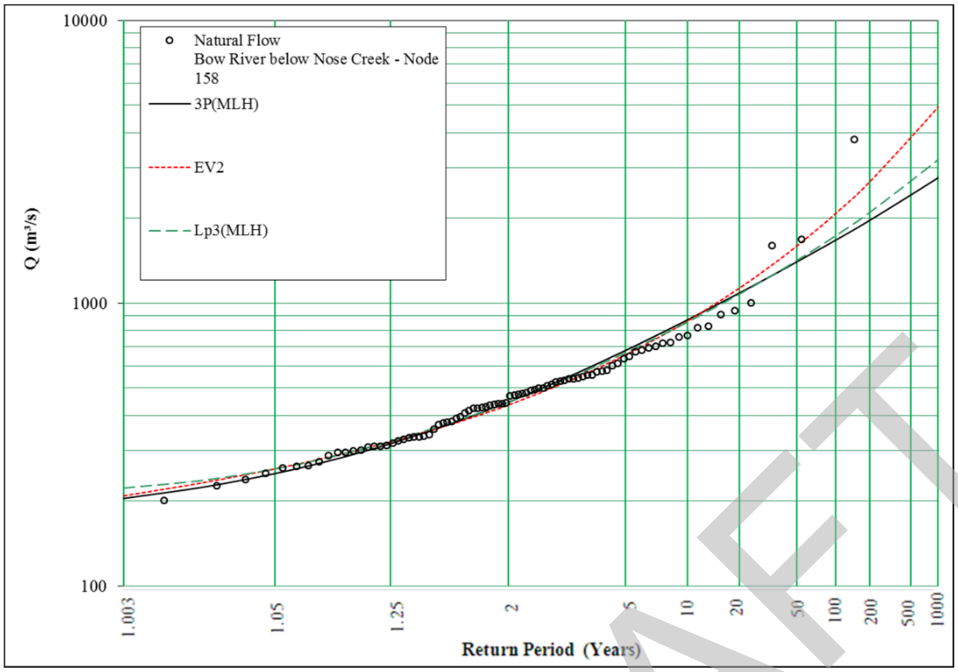
Figure C.1.16: Node 176, Bow River below Elbow River

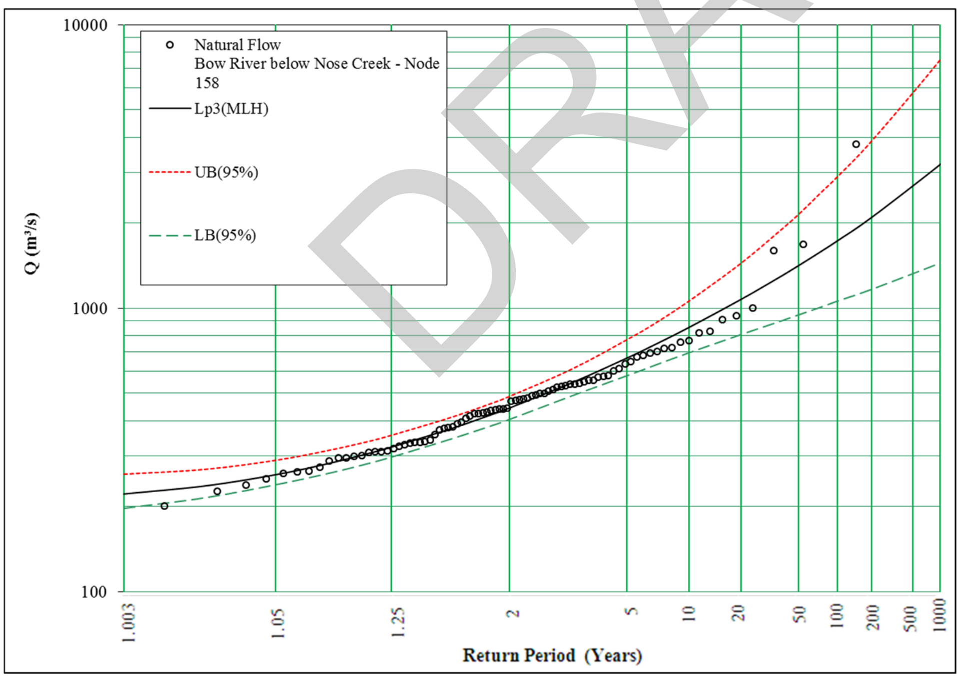




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	445	435	443	
5	678	654	665	
10	870	861	853	
20	1080	1120	1070	
35	1270	1390	1270	
50	1400	1590	1410	
75	1550	1850	1590	
100	1660	2060	1720	
200	1960	2680	2090	
350	2220	3310	2430	
500	2410	3780	2670	
750	2610	4410	2970	
1000	2760	4910	3200	

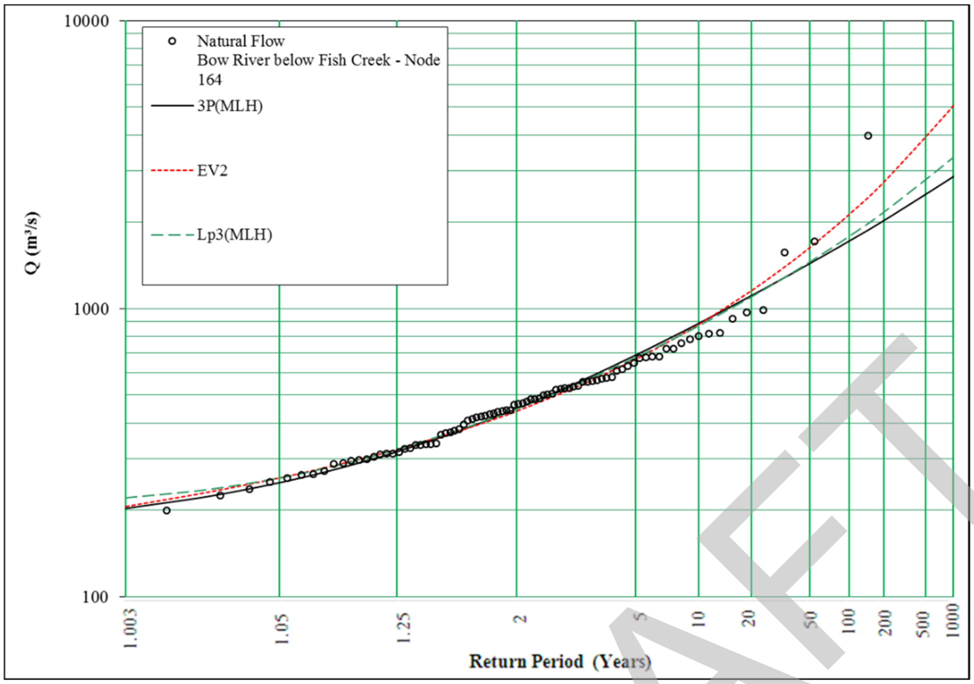
Figure C.1.17: Node 158, Bow River below Nose Creek

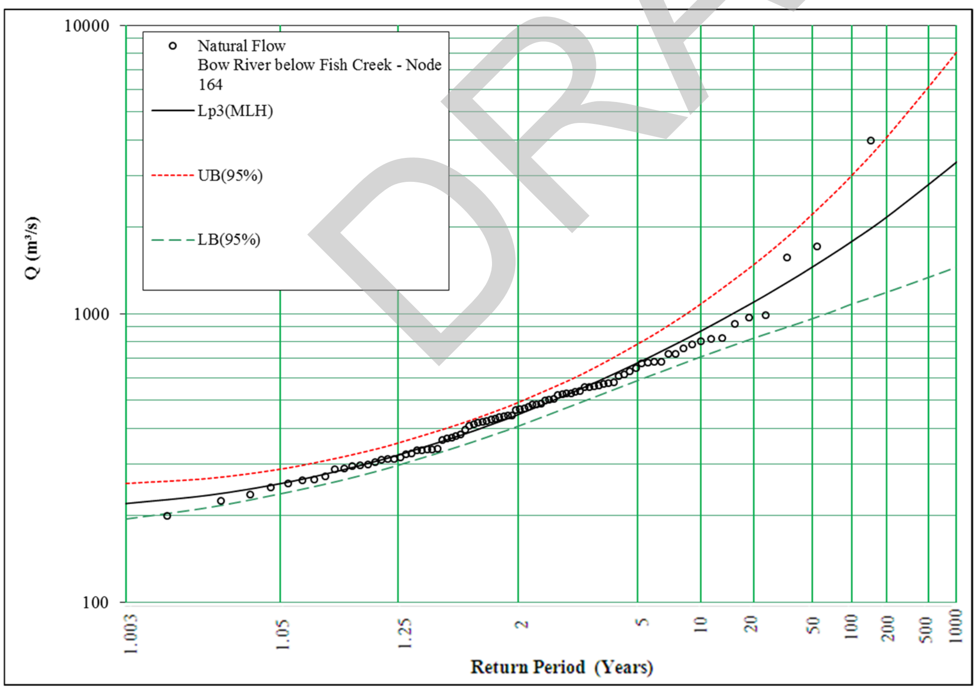




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	446	436	444	
5	680	657	667	
10	872	864	855	
20	1080	1130	1070	
35	1270	1390	1270	
50	1400	1590	1410	
75	1550	1860	1590	
100	1670	2070	1730	
200	1960	2680	2090	
350	2230	3310	2430	
500	2410	3790	2680	
750	2610	4410	2980	
1000	2770	4920	3210	

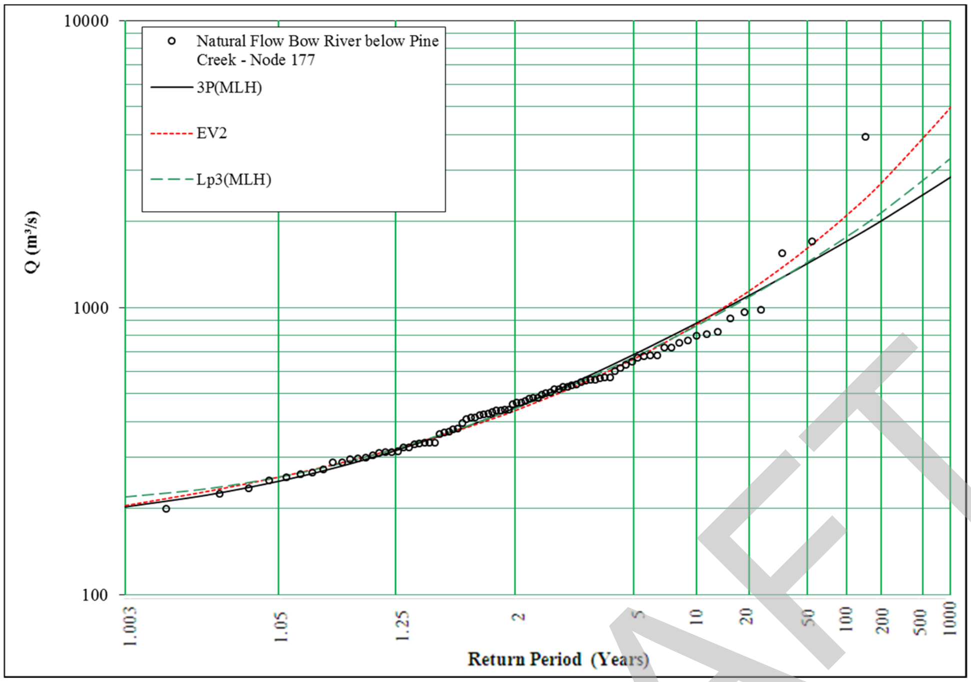
Figure C.1.18: Node 164, Bow River below Fish Creek

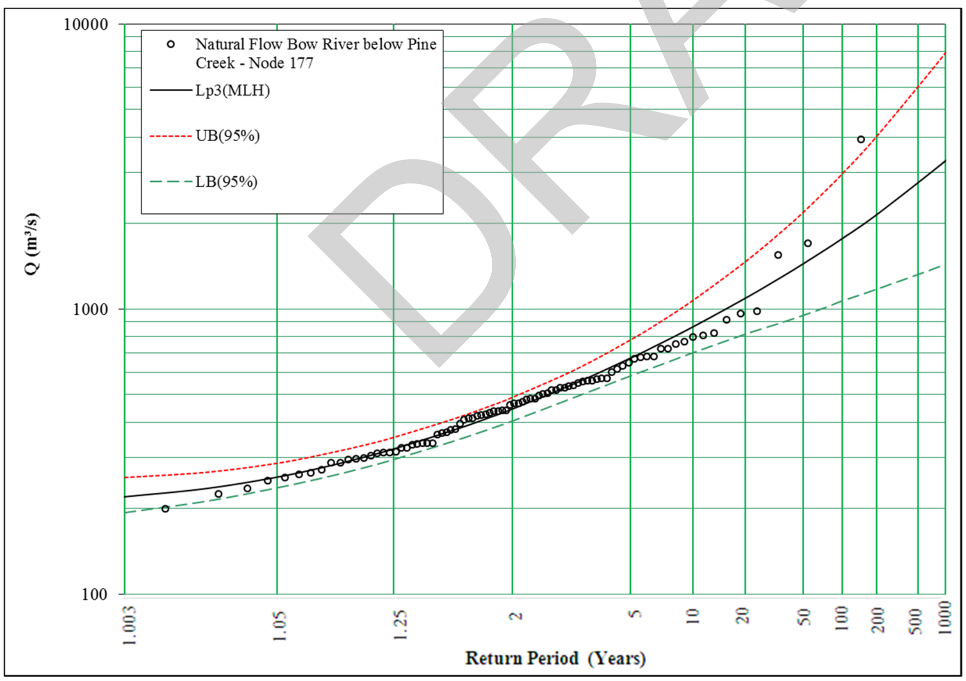




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	449	439	447	
5	690	666	676	
10	888	880	871	
20	1110	1150	1100	
35	1300	1420	1310	
50	1440	1630	1450	
75	1600	1900	1640	
100	1710	2120	1780	
200	2020	2750	2160	
350	2300	3400	2520	
500	2490	3890	2780	
750	2700	4530	3100	
1000	2870	5050	3350	

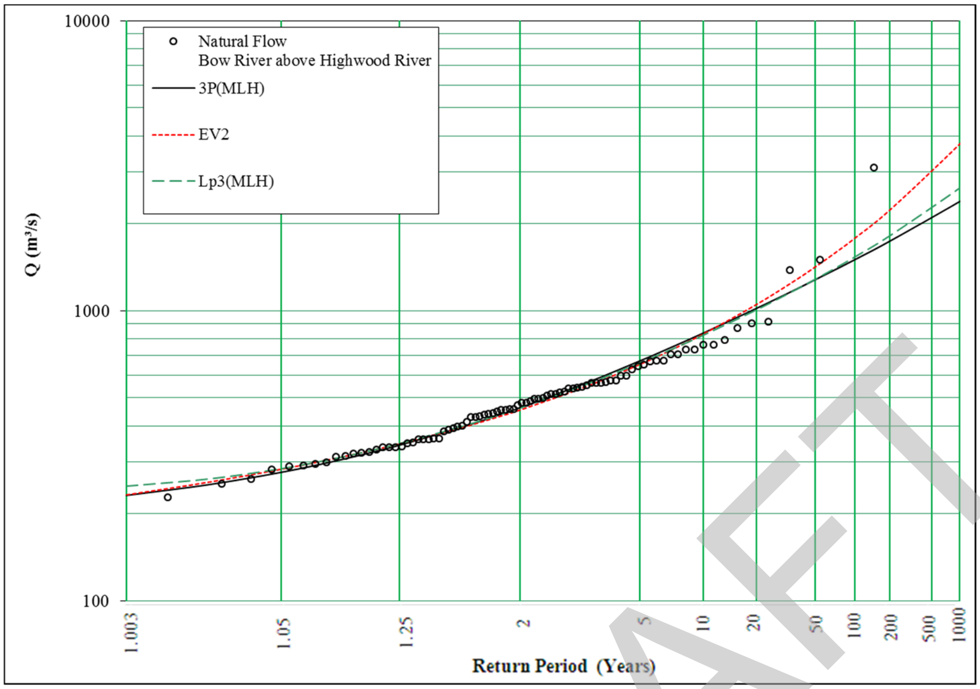
Figure C.1.19: Node 177, Bow River below Pine Creek

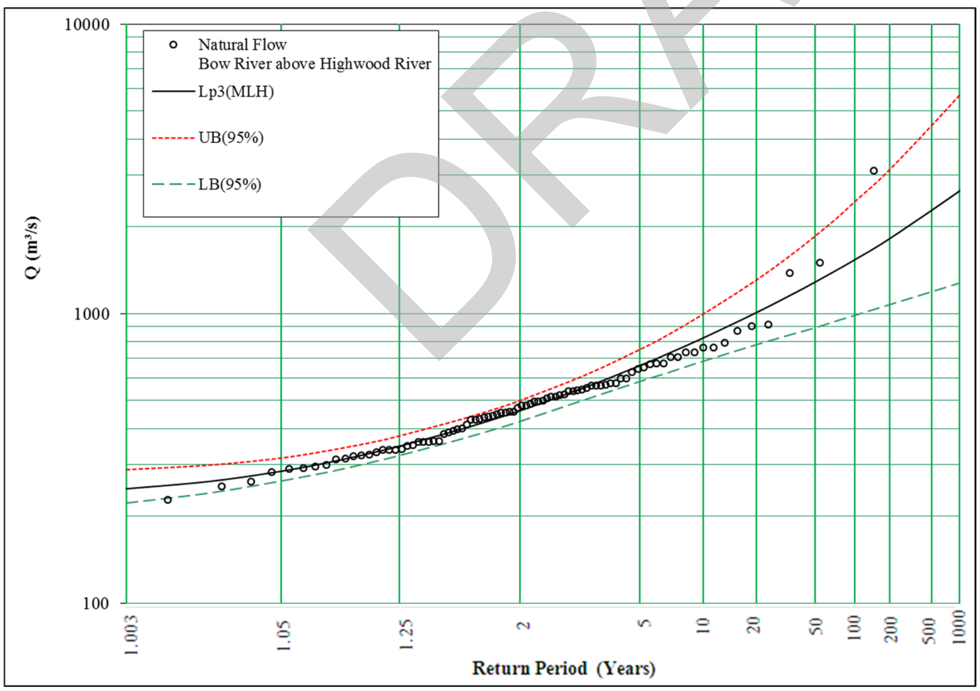




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	447	438	446	
5	686	664	673	
10	883	875	866	
20	1100	1140	1090	
35	1290	1410	1300	
50	1430	1620	1440	
75	1580	1880	1620	
100	1700	2100	1760	
200	2010	2720	2140	
350	2280	3360	2500	
500	2470	3840	2750	
750	2680	4470	3070	
1000	2840	4980	3310	

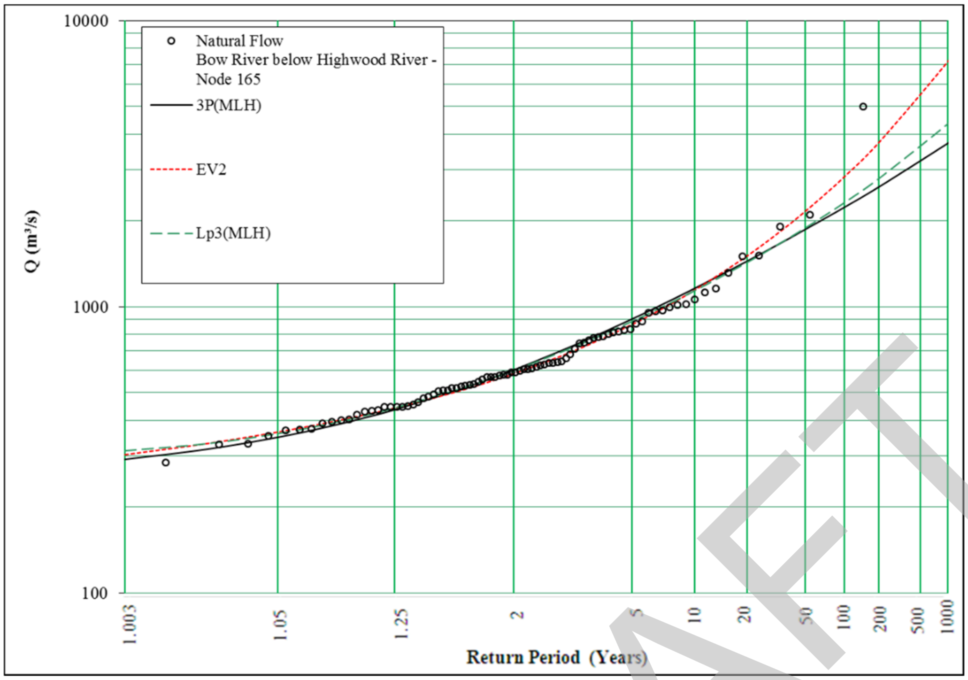
Figure C.1.20: Node 331, Bow River above Highwood River

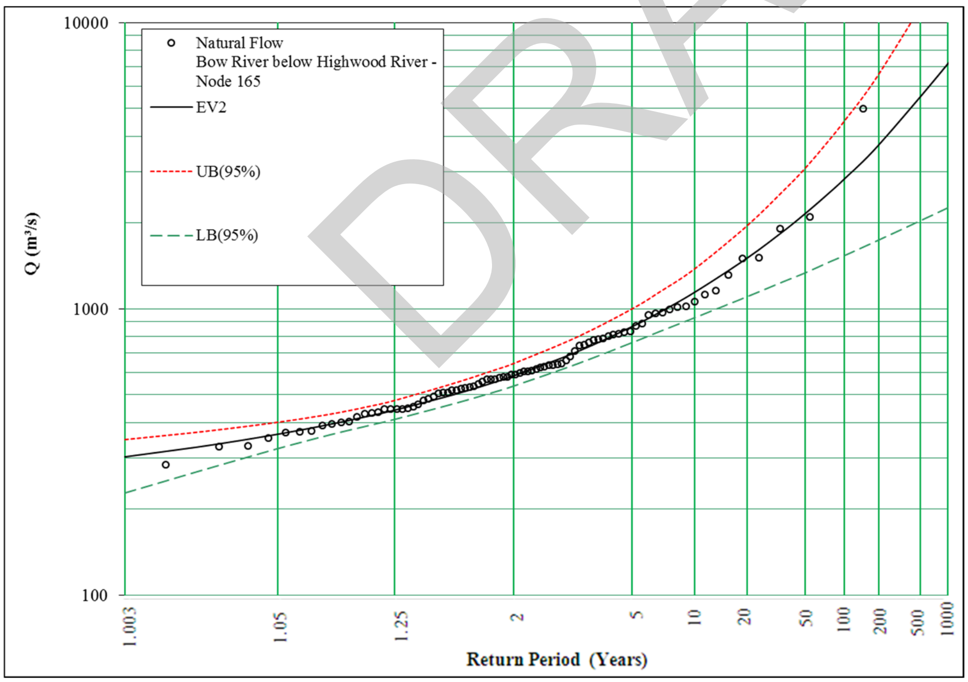




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	462	455	462	
5	671	654	661	
10	838	833	824	
20	1020	1050	1010	
35	1170	1260	1170	
50	1280	1420	1290	
75	1410	1620	1430	
100	1500	1780	1530	
200	1740	2230	1820	
350	1950	2670	2080	
500	2100	3000	2260	
750	2250	3420	2480	
1000	2380	3760	2650	

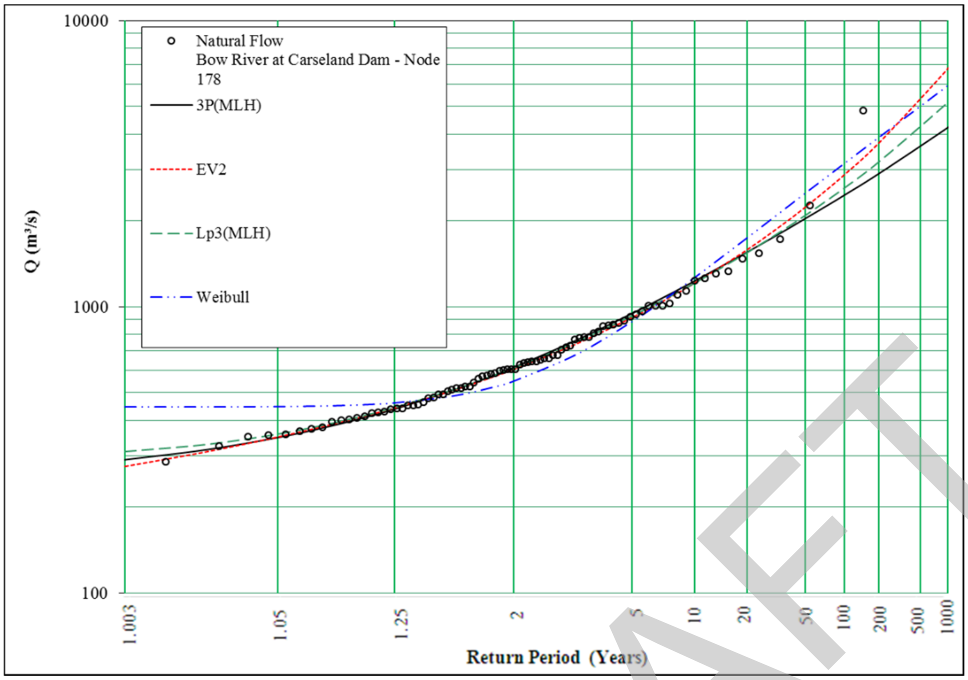
Figure C.1.21: Node 165, Bow River below Highwood River

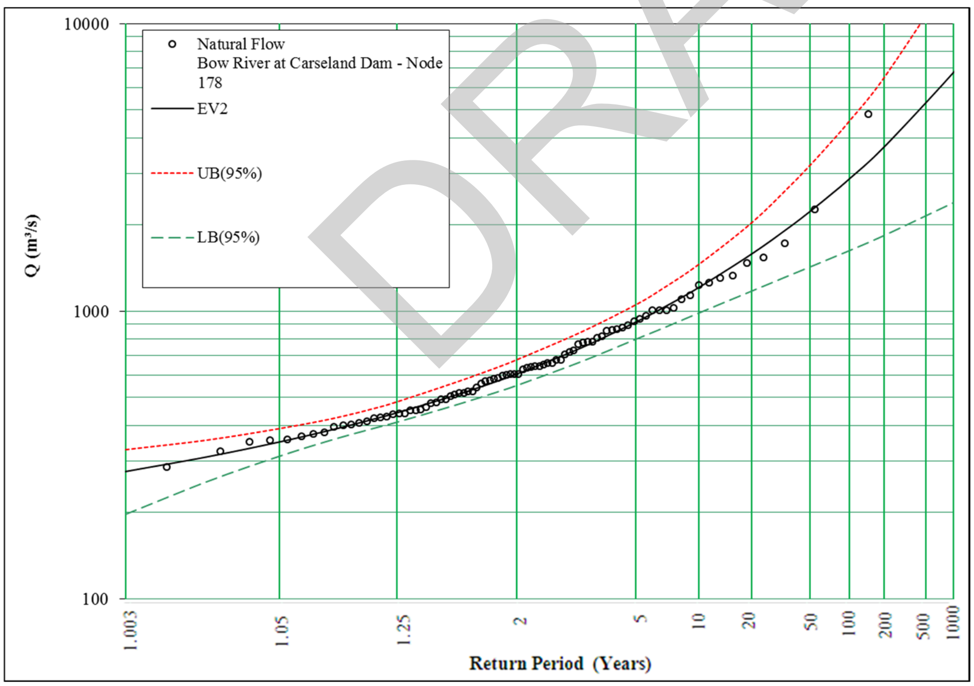




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	600	582	598	
5	906	867	888	
10	1160	1140	1140	
20	1440	1500	1420	
35	1690	1870	1690	
50	1860	2150	1880	
75	2070	2530	2120	
100	2220	2840	2300	
200	2620	3750	2800	
350	2980	4690	3260	
500	3230	5420	3600	
750	3510	6390	4010	
1000	3720	7180	4330	

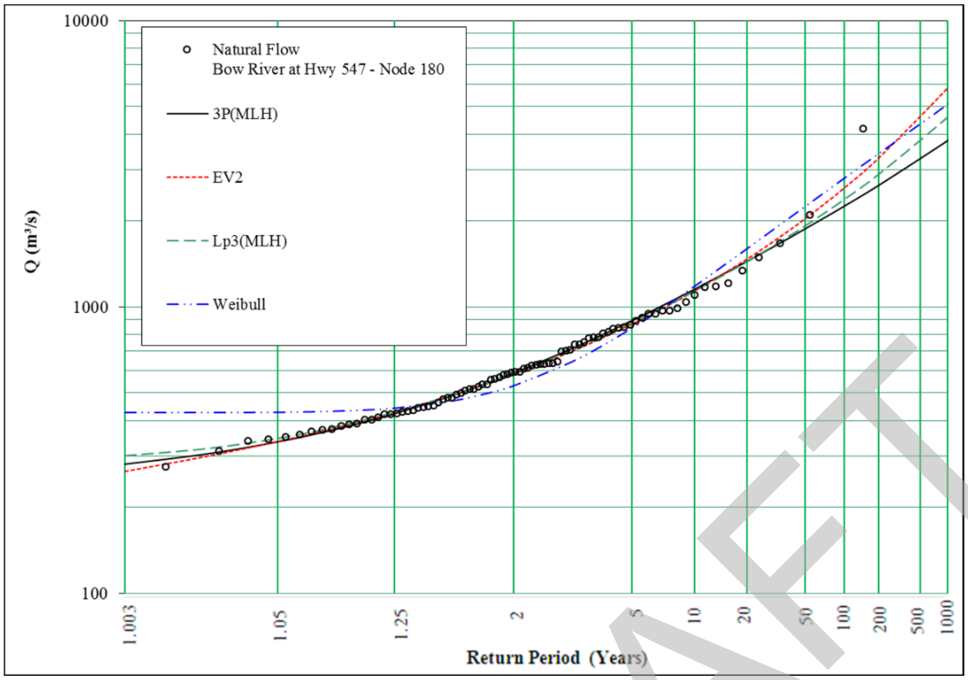
Figure C.1.22: 05BM002 / Node 178, Bow River below Carseland Dam

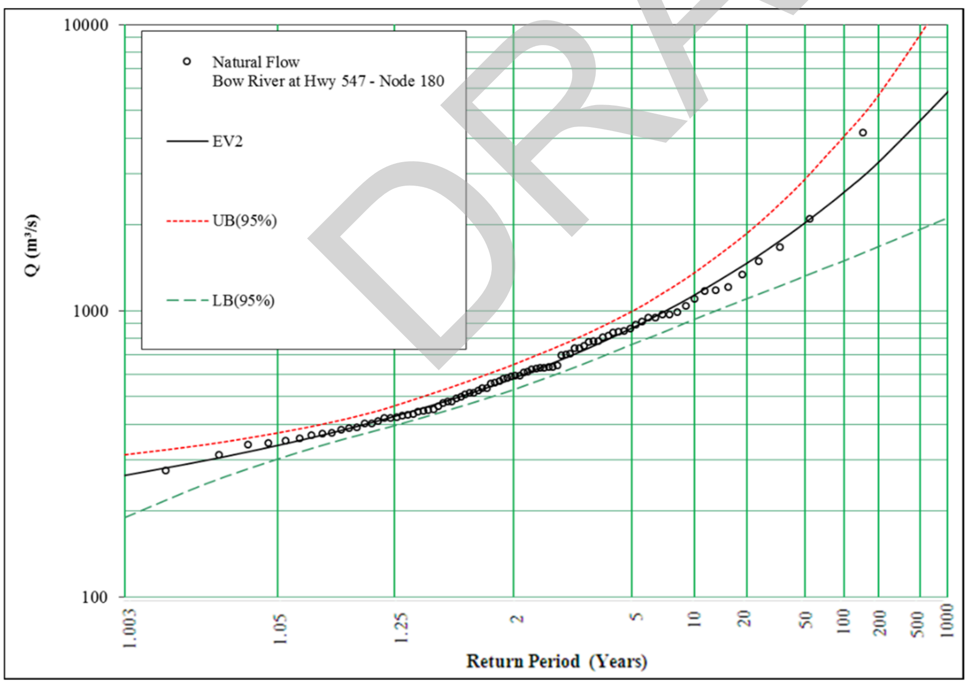




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	613	604	610	548
5	947	917	929	885
10	1230	1210	1210	1260
20	1550	1580	1540	1730
35	1830	1950	1860	2180
50	2030	2230	2080	2490
75	2270	2590	2370	2870
100	2450	2880	2590	3150
200	2920	3730	3200	3890
350	3350	4590	3780	4550
500	3640	5240	4210	4990
750	3970	6080	4740	5510
1000	4220	6770	5150	5900

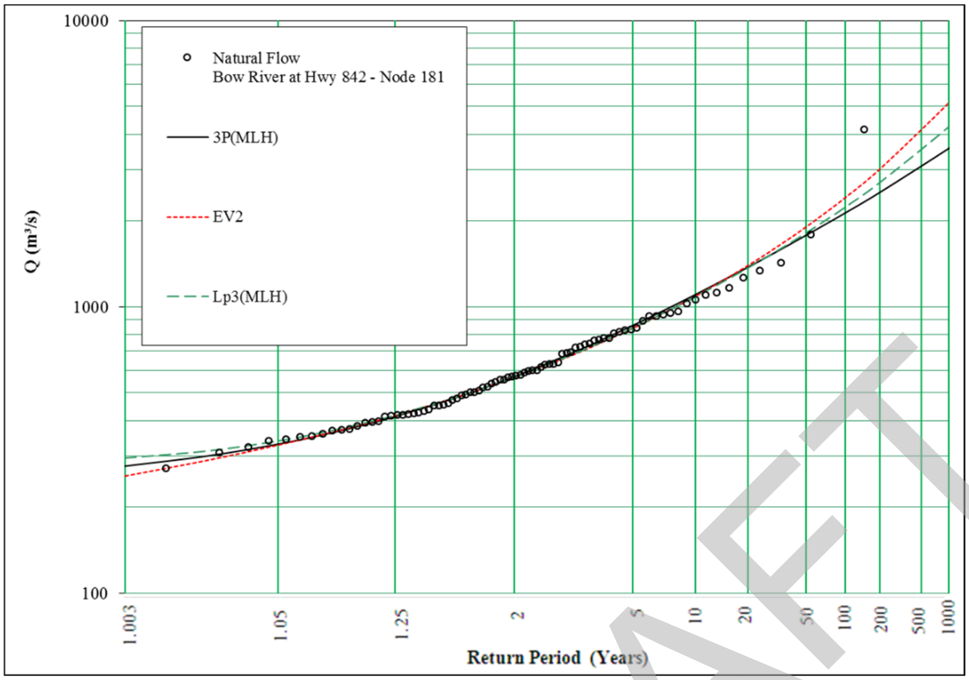
Figure C.1.23: Node 180, Bow River at Hwy. 547

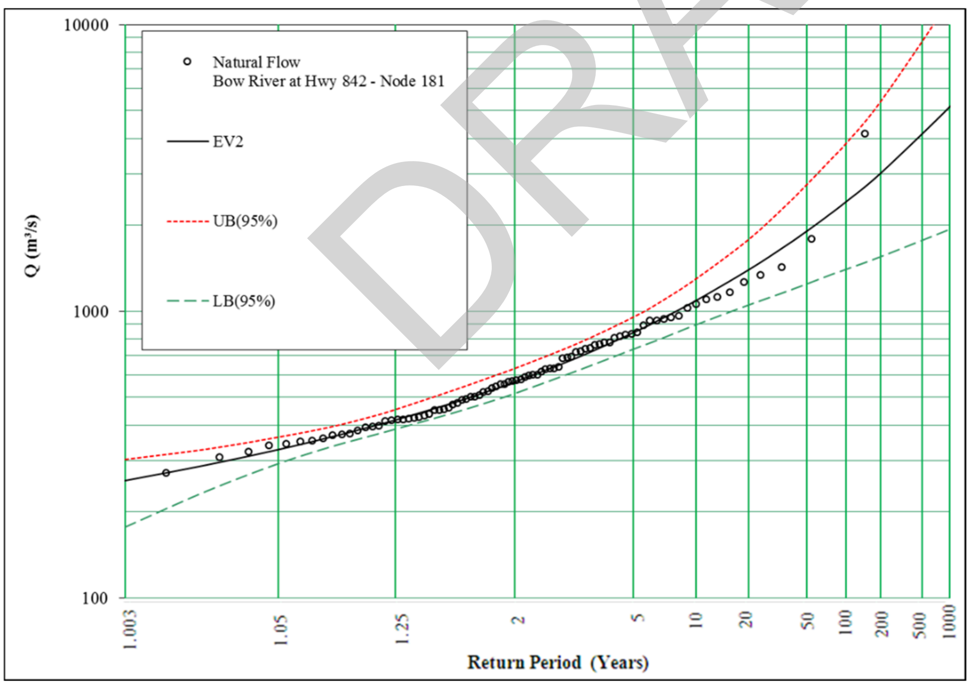




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	587	580	584	529
5	895	870	879	842
10	1150	1140	1130	1180
20	1440	1460	1430	1590
35	1700	1790	1720	1980
50	1870	2030	1920	2240
75	2090	2340	2170	2560
100	2250	2590	2360	2810
200	2660	3310	2900	3430
350	3040	4020	3400	3970
500	3300	4560	3770	4340
750	3580	5250	4220	4770
1000	3810	5800	4580	5090

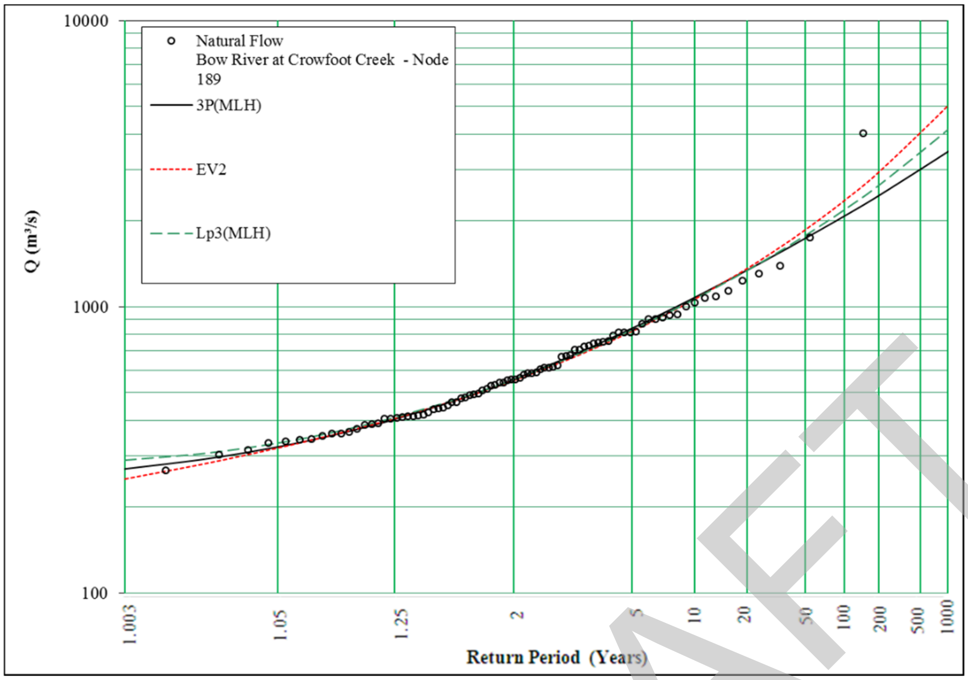
Figure C.1.24: Node 181, Bow River at Hwy. 842

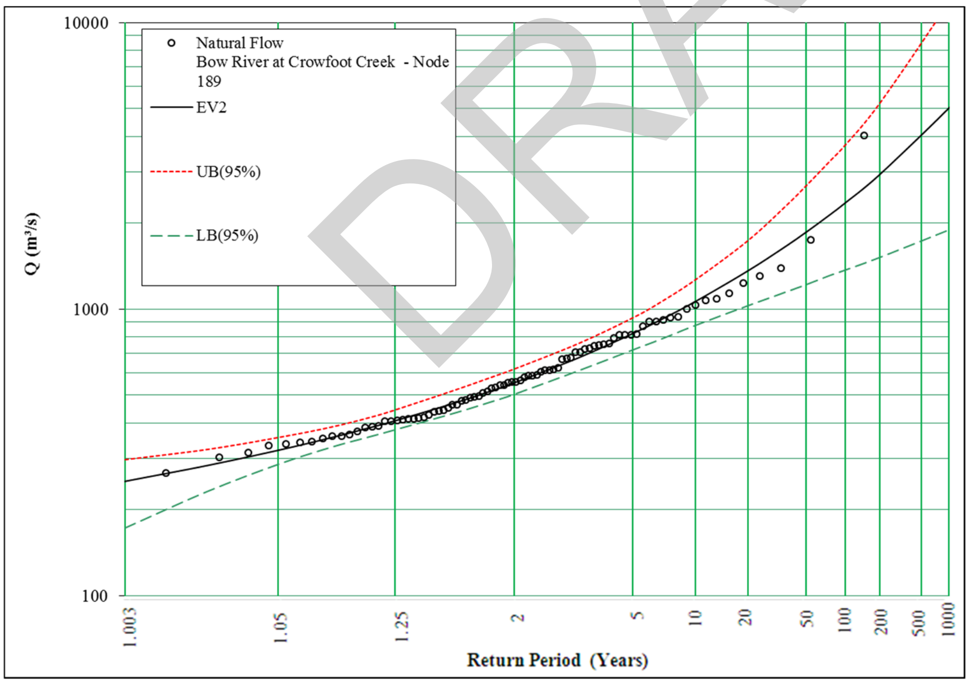




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	569	566	567	
5	861	842	847	
10	1100	1090	1090	
20	1370	1390	1370	
35	1610	1690	1630	
50	1780	1910	1820	
75	1980	2180	2050	
100	2130	2410	2230	
200	2510	3030	2720	
350	2860	3650	3190	
500	3100	4110	3520	
750	3370	4700	3940	
1000	3570	5160	4260	

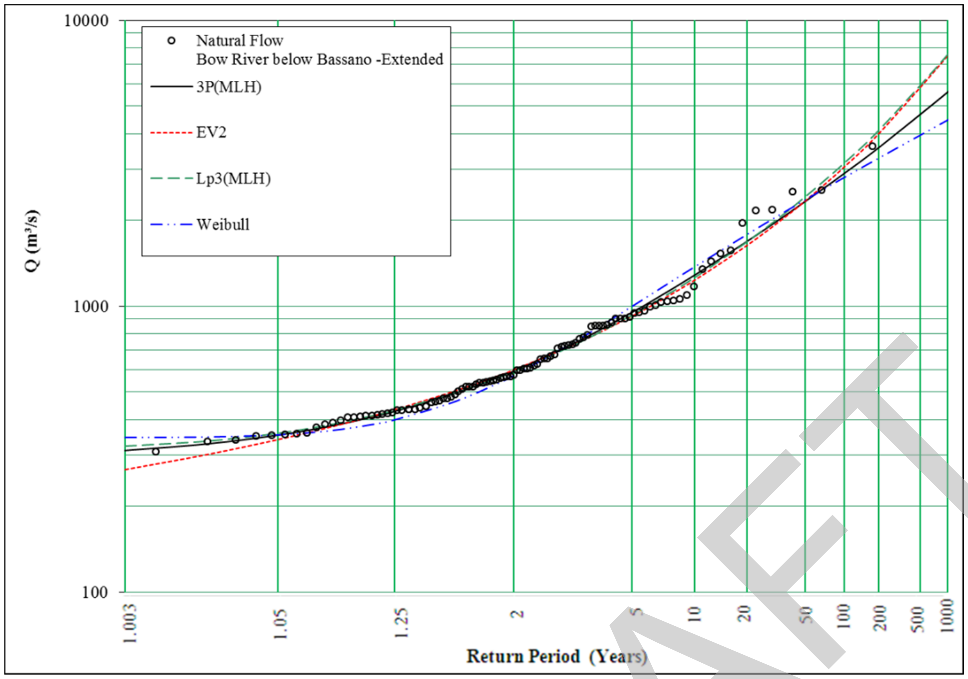
Figure C.1.25: Node 189, Bow River below Crowfoot Creek

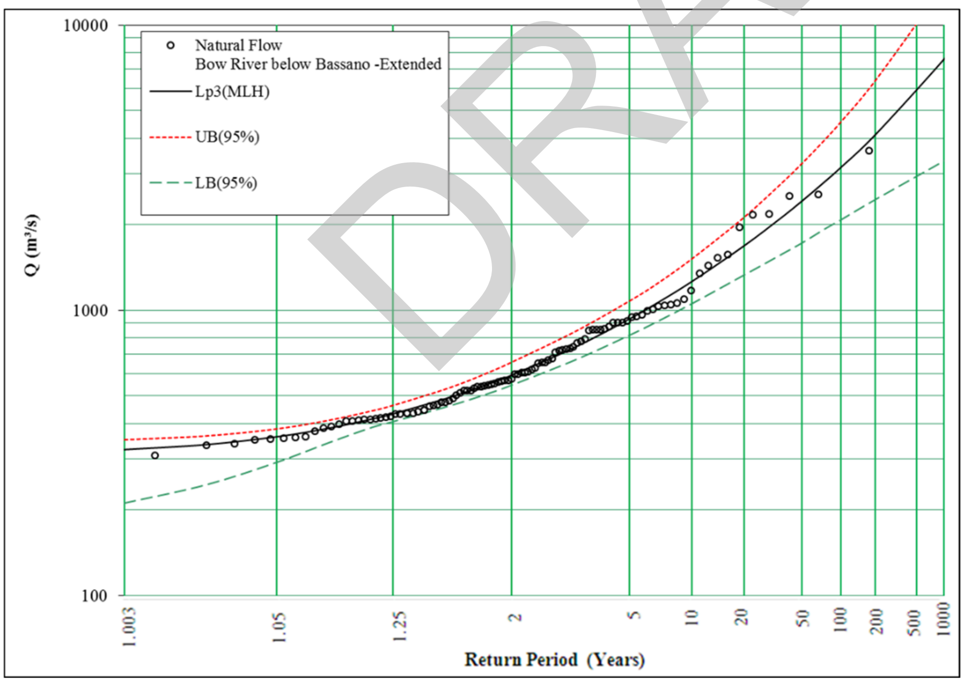




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	556	552	554	
5	840	822	826	
10	1080	1060	1060	
20	1340	1360	1330	
35	1570	1650	1590	
50	1730	1860	1770	
75	1930	2130	2000	
100	2070	2350	2170	
200	2440	2950	2650	
350	2790	3560	3100	
500	3020	4000	3420	
750	3280	4570	3830	
1000	3480	5030	4140	

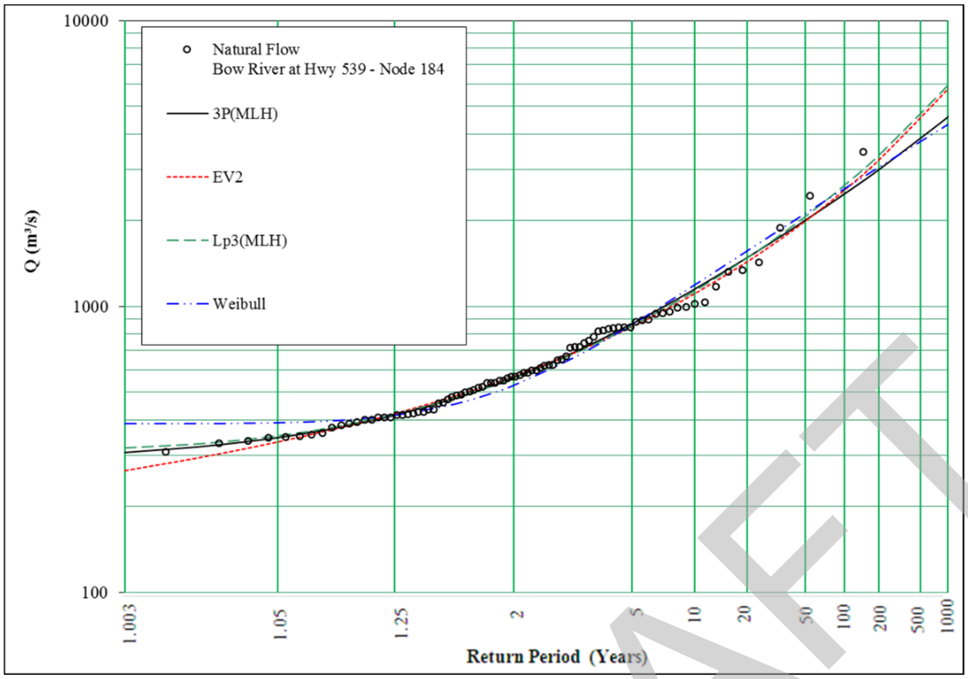
Figure C.1.26: 05BM004 / Node 182, Bow River below Bassano Dam – extended

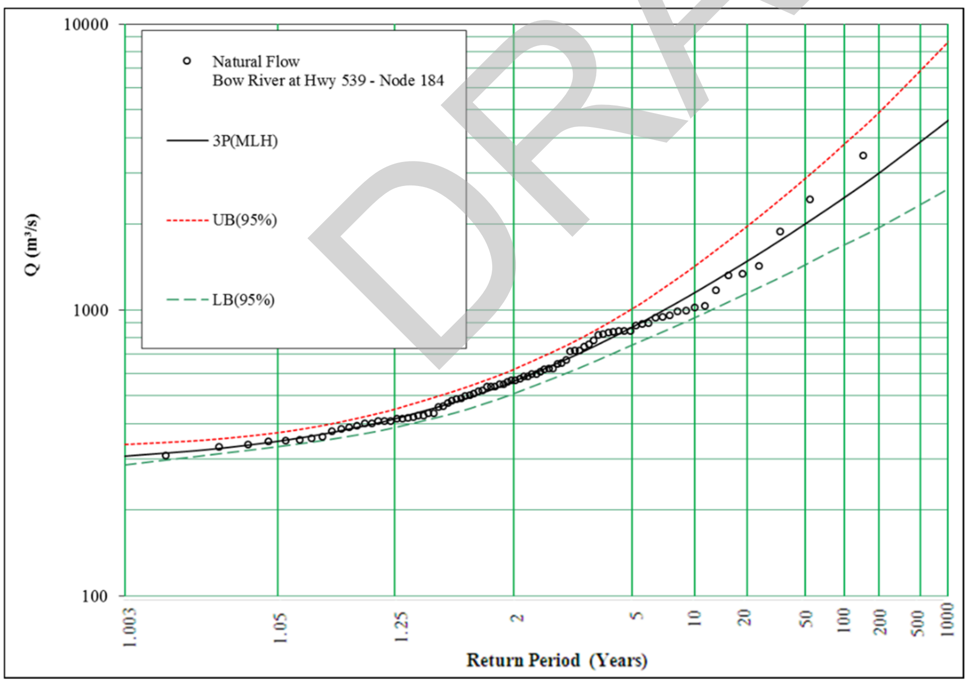




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	592	597	591	571
5	951	922	932	999
10	1280	1230	1260	1370
20	1680	1620	1680	1780
35	2060	2030	2100	2130
50	2330	2330	2420	2360
75	2650	2730	2830	2620
100	2910	3050	3160	2820
200	3590	4000	4130	3300
350	4230	4980	5100	3700
500	4680	5720	5840	3960
750	5190	6690	6810	4260
1000	5600	7480	7580	4470

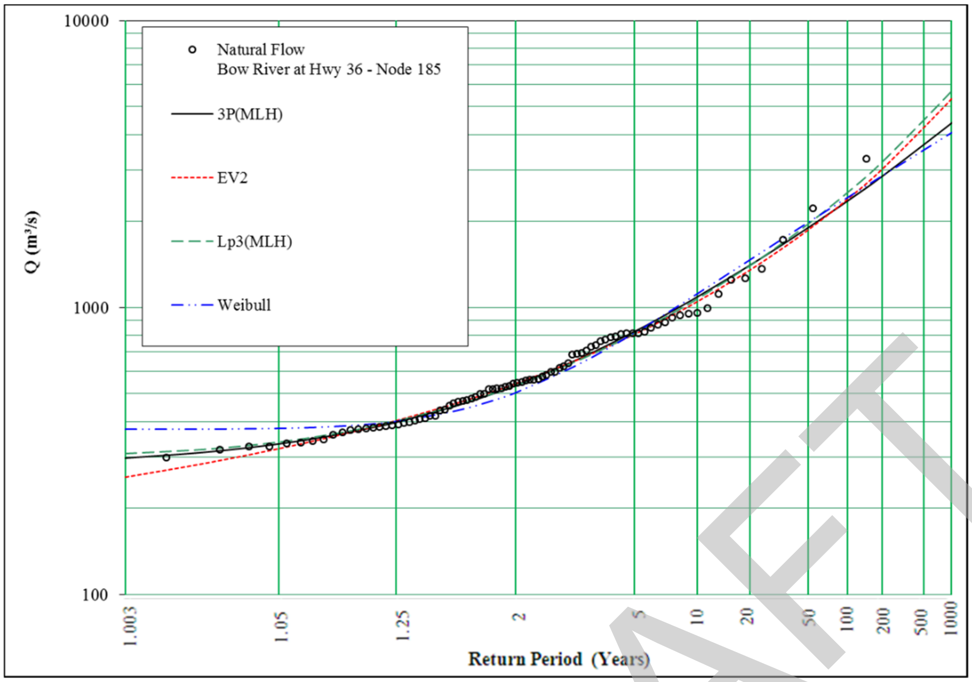
Figure C.1.27: Node 184, Bow River at Hwy. 539

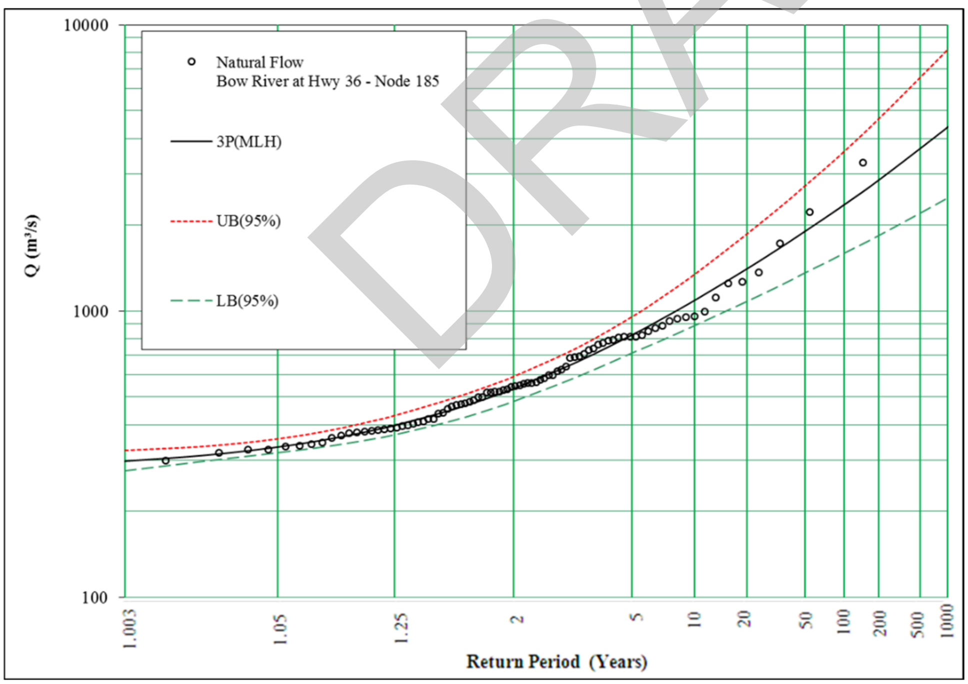




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	562	568	561	529
5	870	849	855	864
10	1150	1110	1130	1190
20	1480	1430	1470	1560
35	1780	1750	1810	1890
50	2000	1990	2060	2110
75	2270	2300	2390	2380
100	2470	2550	2640	2570
200	3010	3260	3380	3060
350	3520	3970	4110	3480
500	3870	4510	4650	3760
750	4270	5210	5350	4080
1000	4590	5760	5910	4320

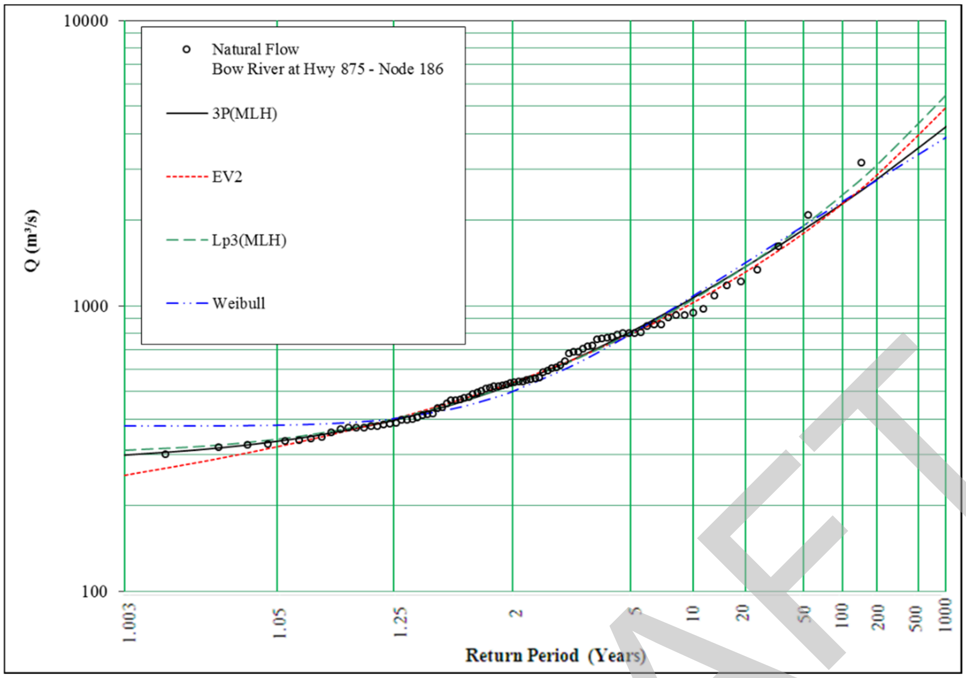
Figure C.1.28: Node 185, Bow River at Hwy. 36

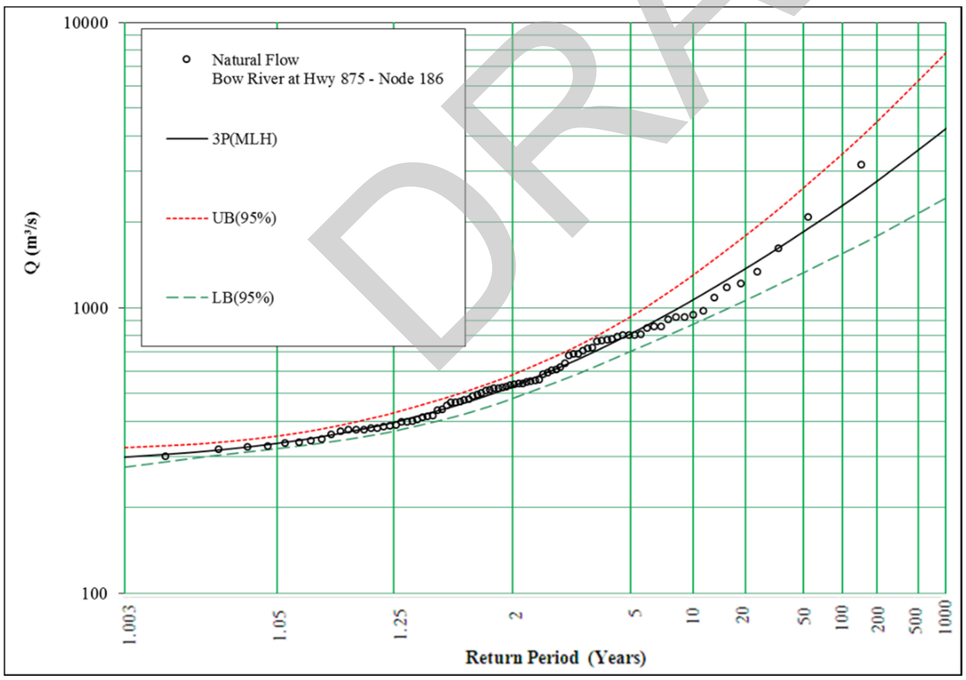




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	534	542	534	505
5	825	806	811	816
10	1090	1050	1070	1120
20	1400	1350	1400	1460
35	1690	1650	1720	1770
50	1900	1870	1960	1980
75	2150	2150	2270	2230
100	2350	2380	2510	2420
200	2870	3030	3220	2880
350	3350	3690	3920	3280
500	3700	4180	4440	3540
750	4080	4810	5120	3840
1000	4380	5320	5660	4060

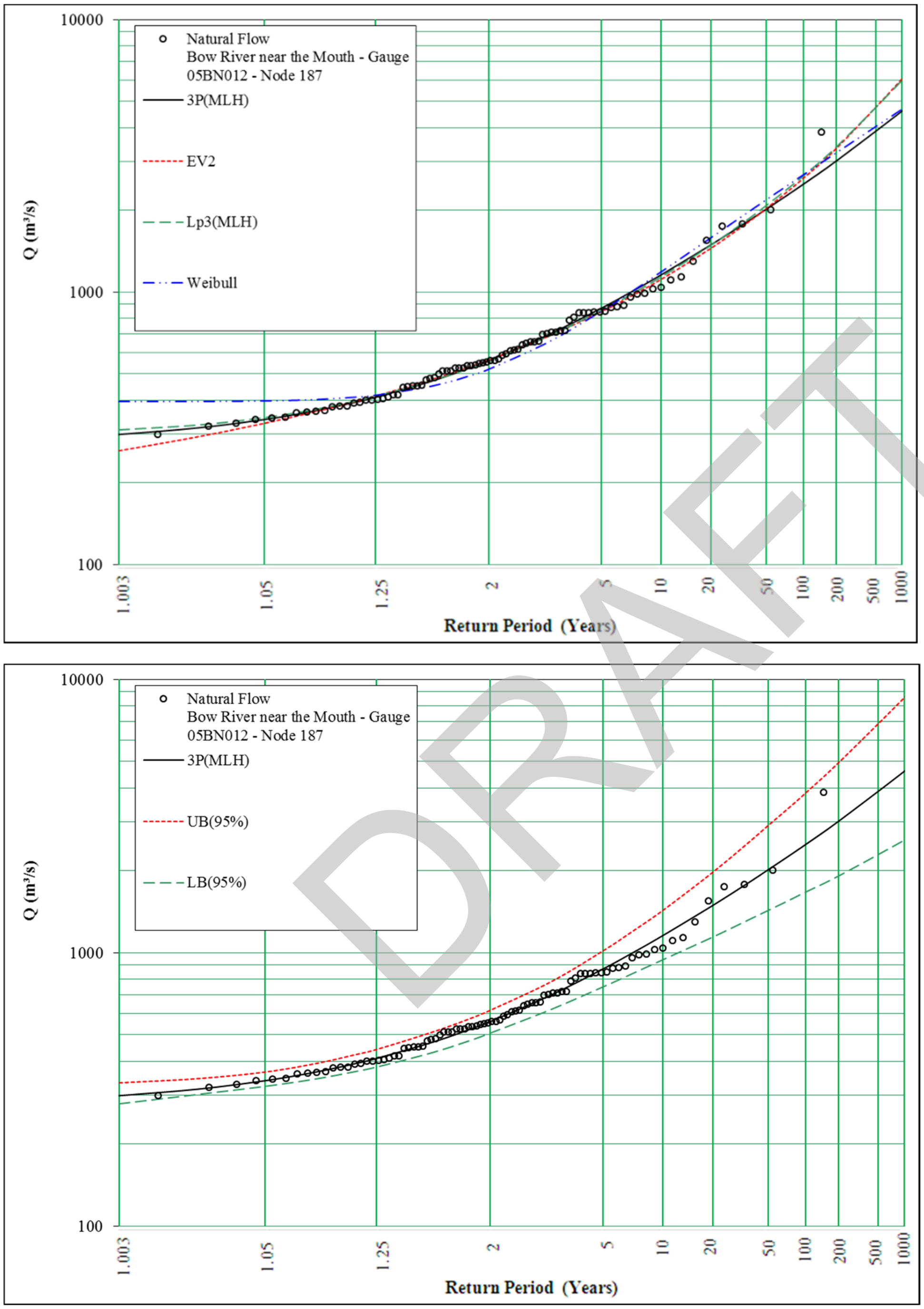
Figure C.1.29: Node 186, Bow River at Hwy. 875





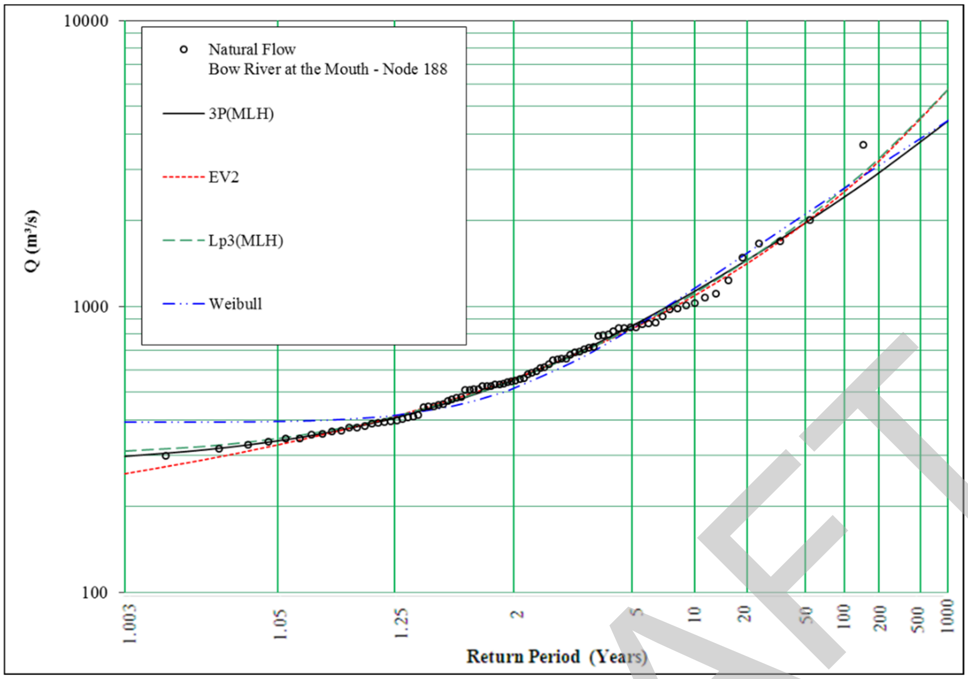
Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	530	539	529	502
5	811	795	799	798
10	1070	1030	1050	1080
20	1370	1310	1370	1420
35	1650	1590	1680	1710
50	1850	1800	1910	1910
75	2090	2060	2200	2150
100	2280	2270	2440	2320
200	2780	2870	3120	2760
350	3250	3460	3790	3140
500	3570	3910	4290	3380
750	3940	4470	4940	3670
1000	4240	4930	5460	3890

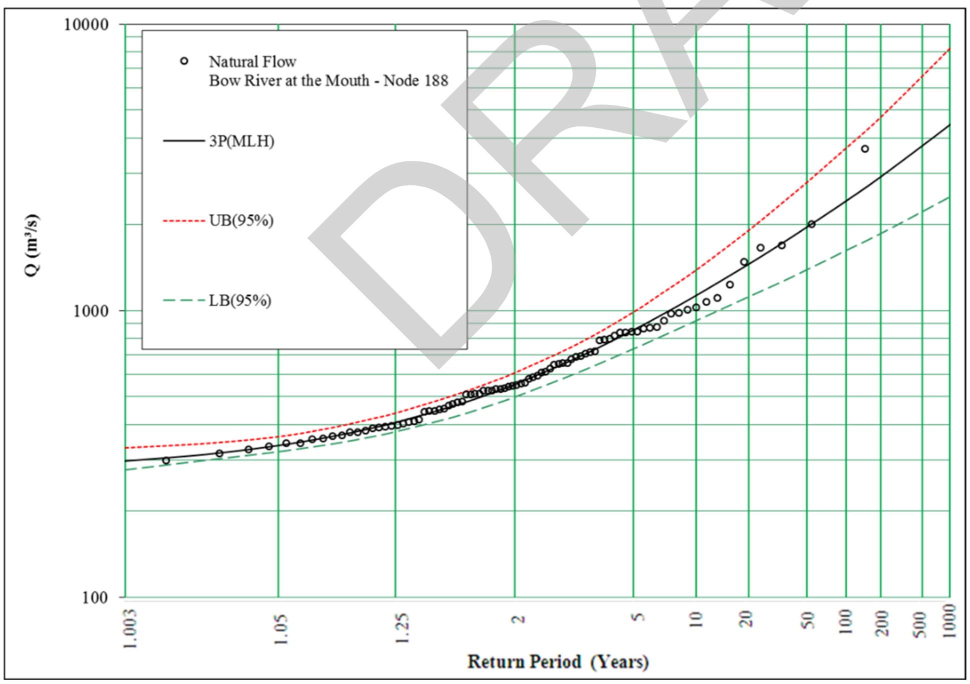
Figure C.1.30: 05BN012 / Node 187, Bow River near the Mouth



Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	559	563	558	521
5	872	849	857	851
10	1160	1110	1140	1190
20	1490	1450	1480	1580
35	1800	1780	1830	1940
50	2020	2030	2080	2180
75	2280	2360	2410	2470
100	2490	2620	2670	2690
200	3030	3370	3410	3240
350	3540	4130	4140	3720
500	3890	4700	4690	4040
750	4290	5450	5400	4410
1000	4610	6050	5970	4680

Figure C.1.31: Node 188, Bow River at the Mouth

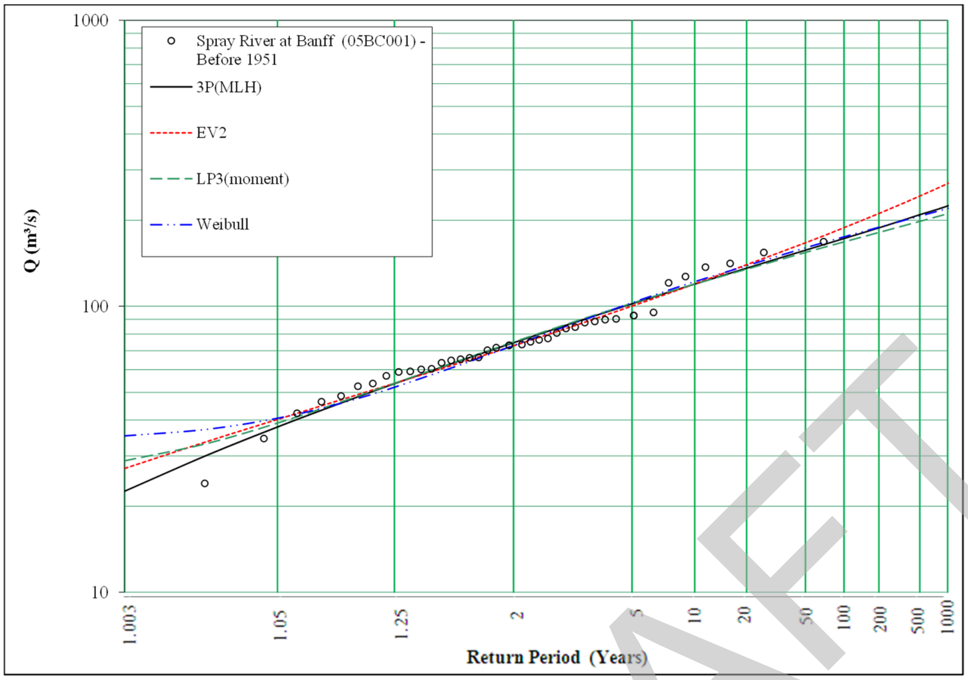


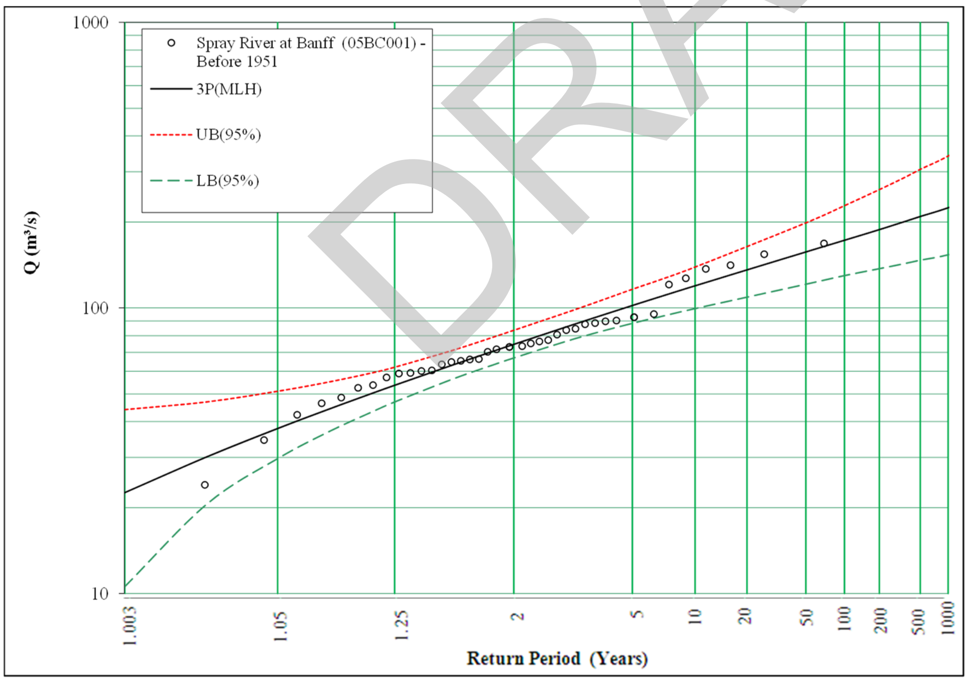


Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	552	557	551	516
5	856	835	841	835
10	1130	1090	1110	1160
20	1450	1410	1450	1530
35	1750	1720	1780	1870
50	1960	1960	2020	2100
75	2220	2270	2340	2380
100	2410	2510	2580	2580
200	2930	3220	3290	3100
350	3420	3920	4000	3550
500	3760	4450	4520	3840
750	4140	5140	5200	4190
1000	4450	5690	5740	4450

BOW RIVER TRIBUTARIES

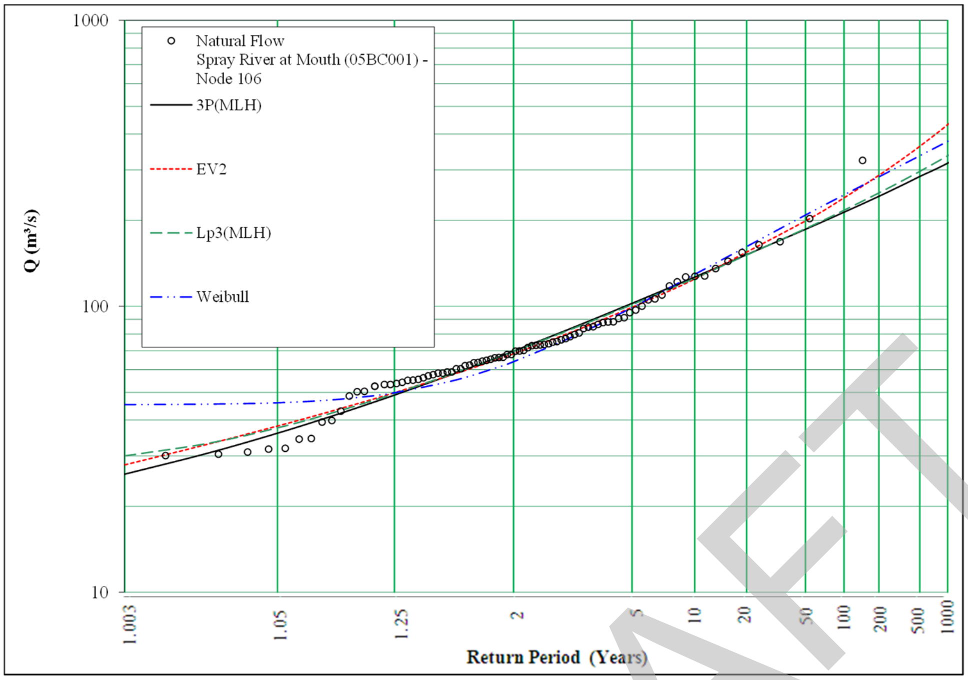
Figure C.1.32: 05BC001 / Node 106, Spray River at Banff - before 1951

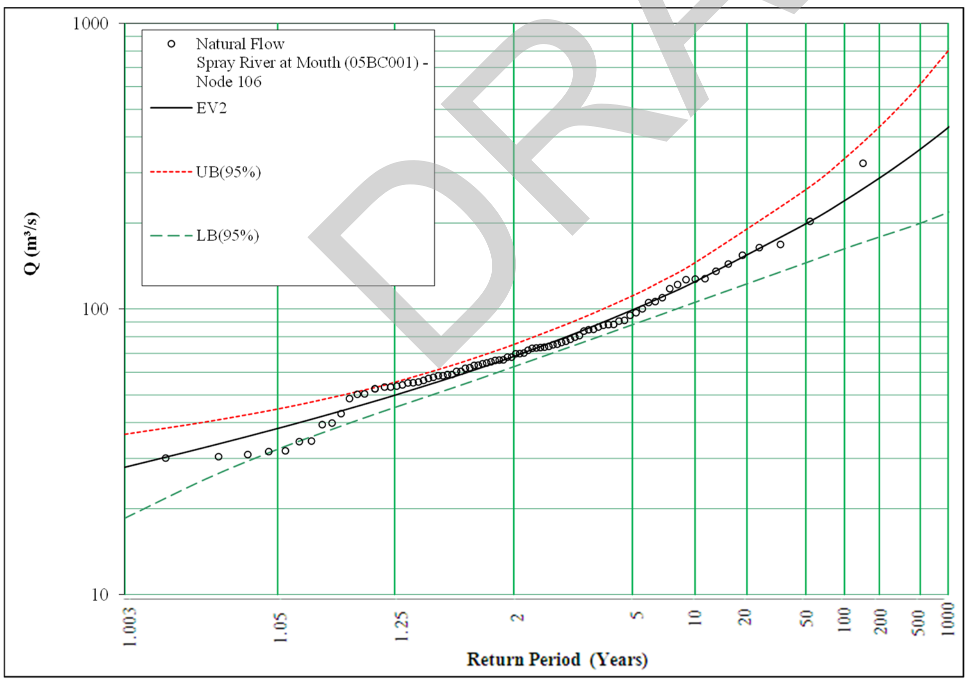




Return Period	3P(MLH)	EV2	LP3 (moment)	Weibull
2	74.6	72.7	75.00	72.9
5	102	100	103	103
10	120	120	120	122
20	136	139	135	139
35	149	156	147	152
50	157	167	154	160
75	166	179	162	169
100	173	188	168	175
200	188	211	181	189
350	201	230	192	200
500	209	243	198	207
750	218	258	205	214
1000	224	269	211	220

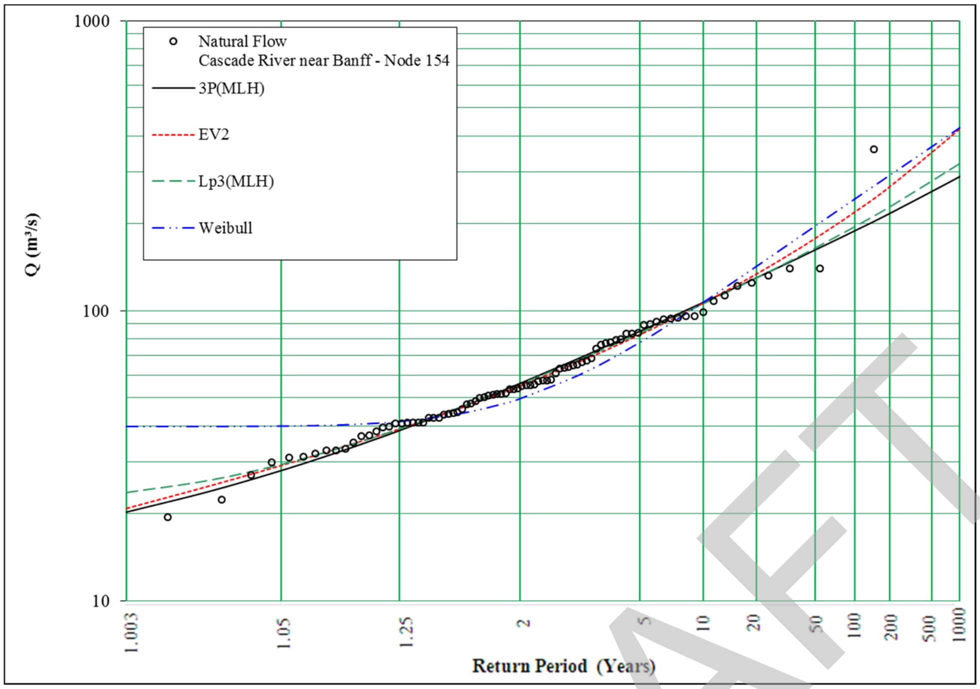
Figure C.1.33: 05BC001 / Node 106, Spray River at Banff

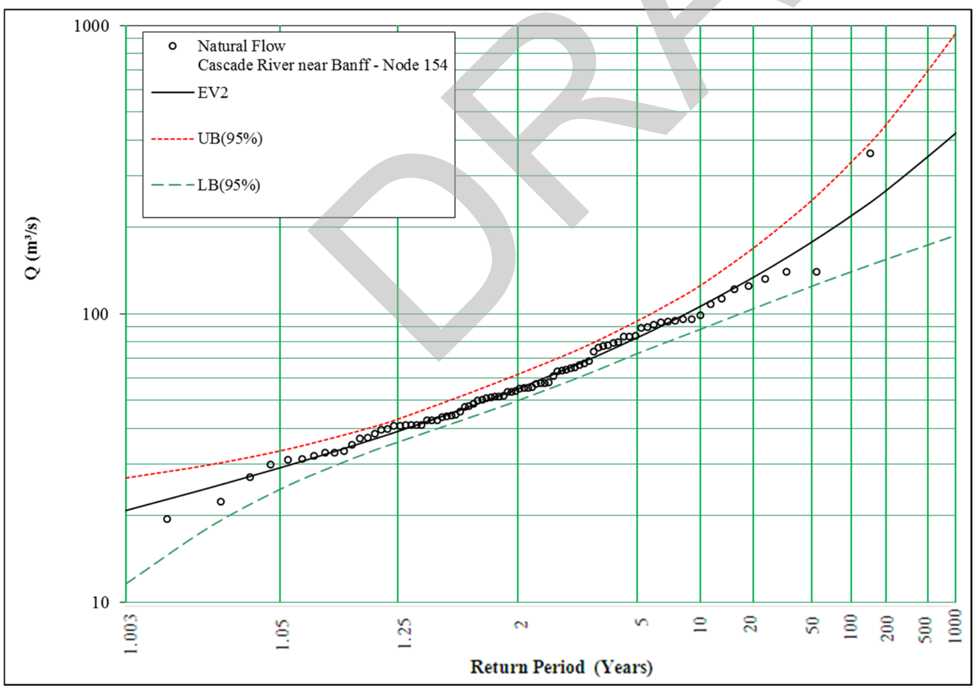




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	69.6	68.2	69.5	64.0
5	102	99.2	101	99.0
10	127	125	125	129
20	151	154	151	162
35	172	180	172	190
50	186	199	187	208
75	202	222	204	230
100	213	240	217	245
200	242	287	249	284
350	268	332	278	316
500	285	363	297	336
750	303	402	320	360
1000	317	432	336	378

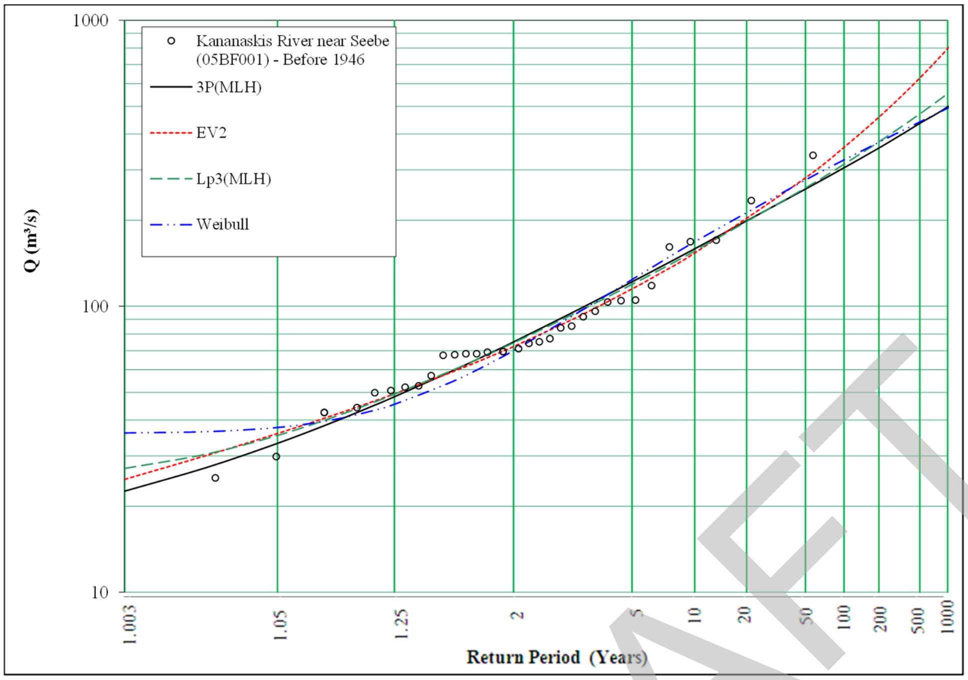
Figure C.1.34: 05BD002 / Node 154, Cascade River near Banff

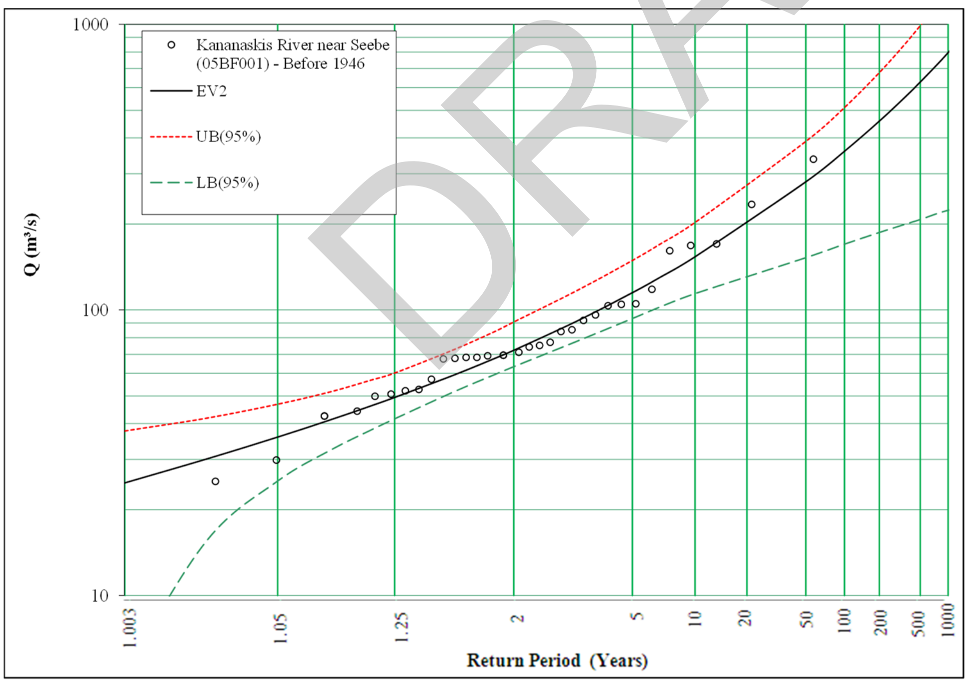




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	56.1	54.9	55.8	49.9
5	85.0	82.7	83.8	77.9
10	107	106	106	107
20	130	134	130	142
35	149	159	151	174
50	162	178	165	196
75	177	201	182	223
100	188	219	195	243
200	217	268	229	294
350	241	314	259	338
500	258	348	279	367
750	276	390	304	402
1000	290	423	322	427

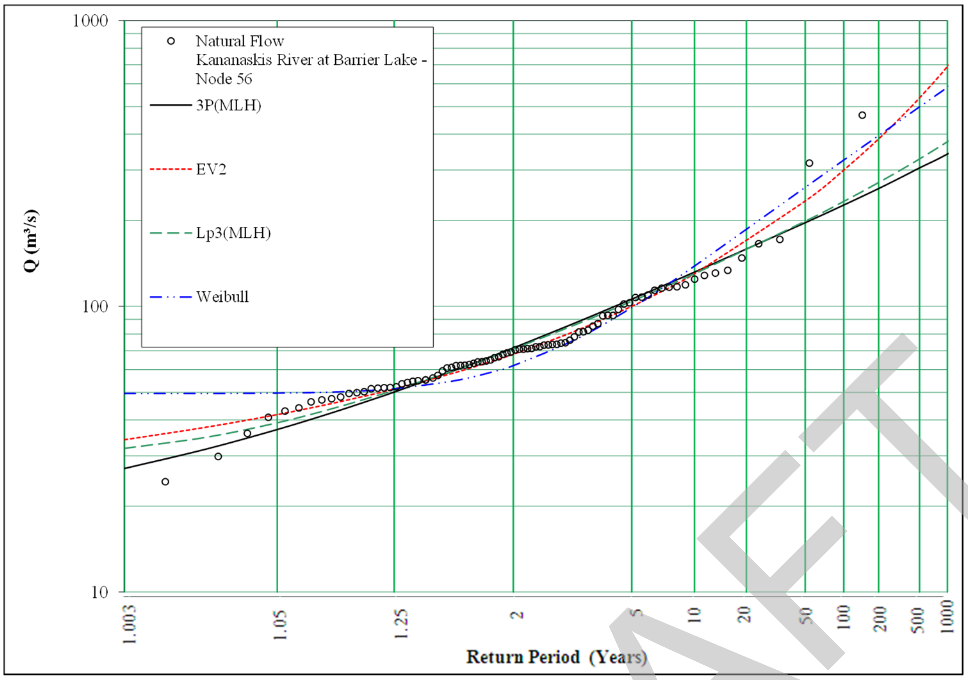
Figure C.1.35: 05BF001, Kananaskis River near Seebe - before 1946

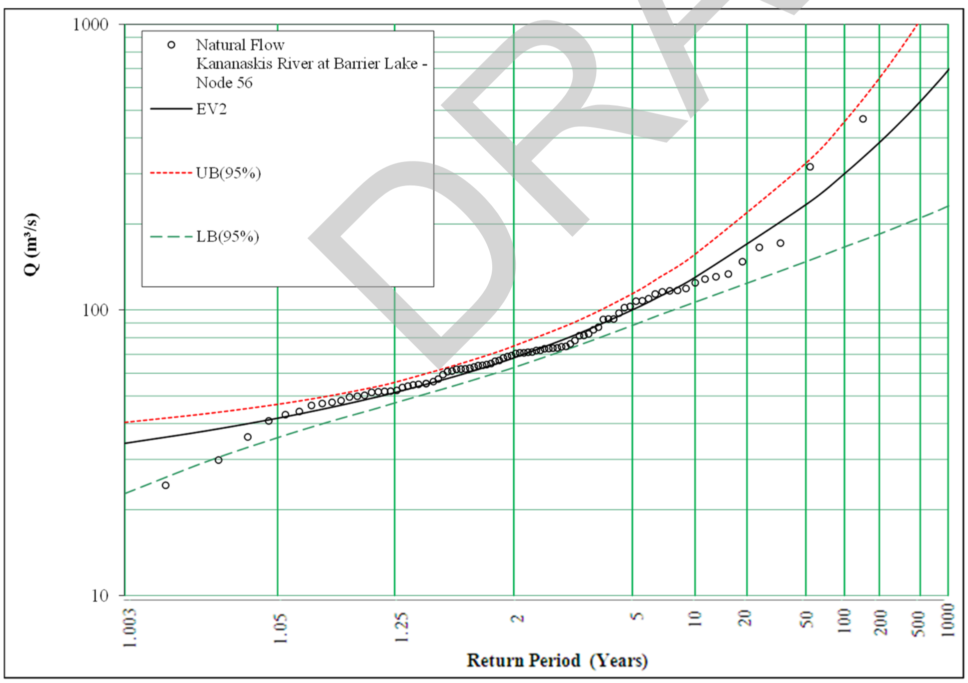




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	75.0	72.3	74.5	70.0
5	122	115	119	124
10	159	154	156	168
20	199	201	197	214
35	233	247	234	252
50	257	281	259	276
75	285	325	290	305
100	305	360	314	325
200	358	458	376	375
350	405	556	432	415
500	437	629	471	442
750	471	722	519	472
1000	498	797	555	493

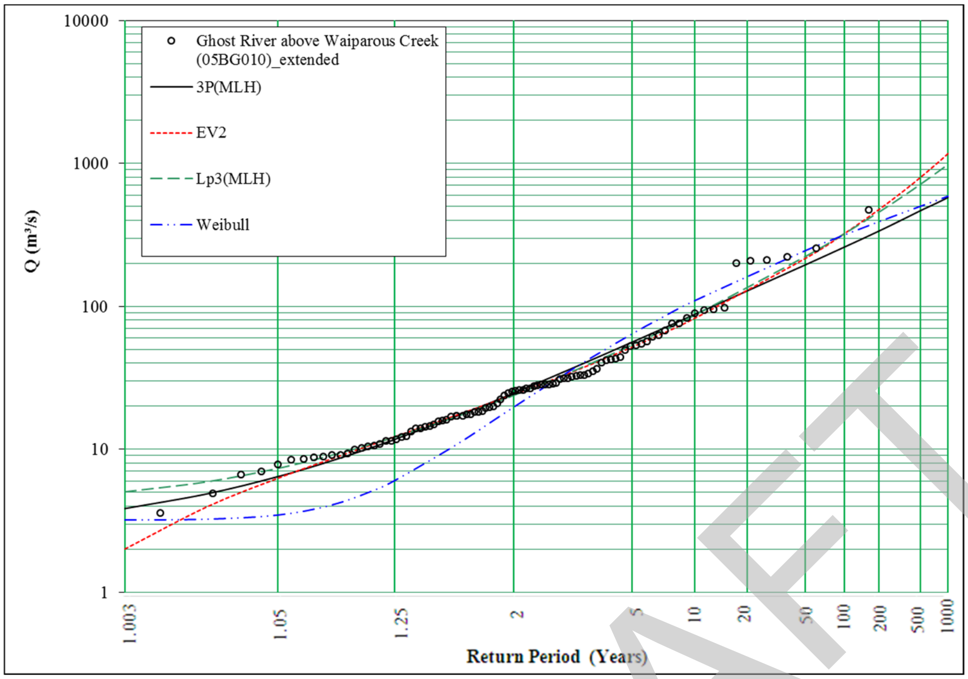
Figure C.1.36: 05BF025 / Node 56, Kananaskis River below Barrier Dam

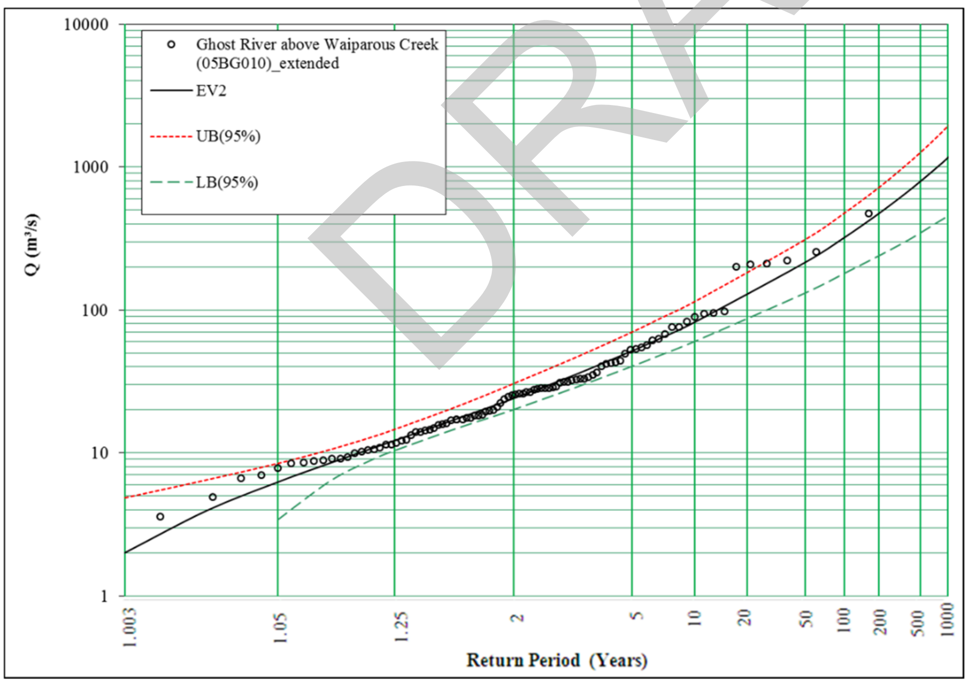




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	71.5	68.0	70.9	62.0
5	106	100	104	99.0
10	132	130	130	138
20	158	168	158	186
35	181	205	182	230
50	196	234	198	261
75	213	270	218	298
100	226	300	233	325
200	258	386	271	396
350	287	472	305	458
500	305	537	328	500
750	326	623	356	549
1000	341	691	377	585

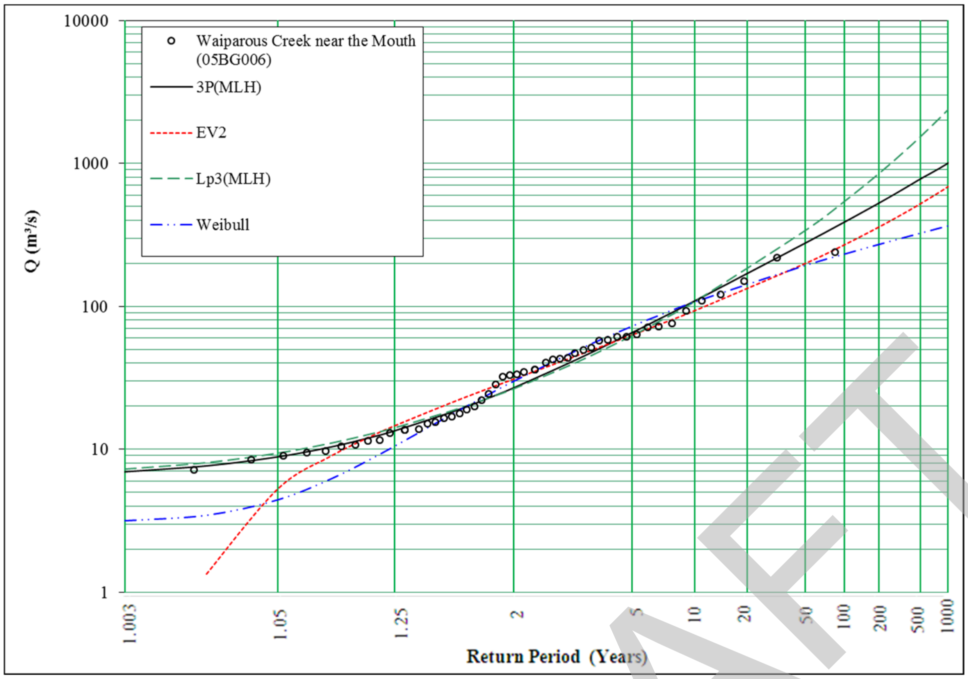
Figure C.1.37: 05BG010, Ghost River above Waiparous Creek - extended with diversion added

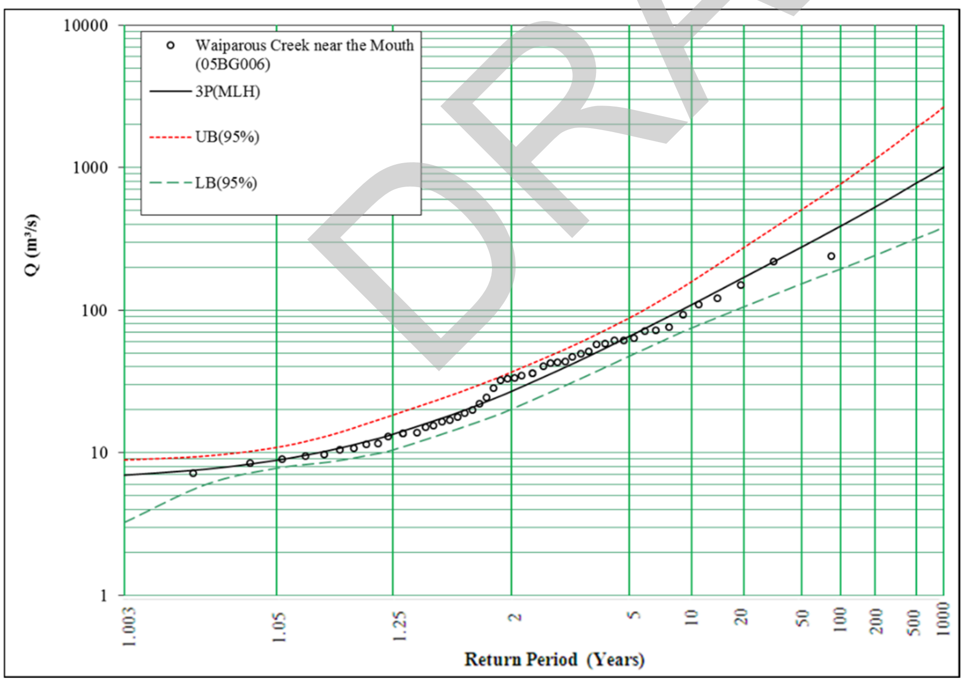




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	24.7	24.0	23.7	19.7
5	56.2	51.7	53.5	64.4
10	87.9	82.2	86.6	110
20	128	126	133	164
35	167	175	183	213
50	195	216	223	246
75	231	272	277	286
100	259	320	321	316
200	337	474	455	392
350	412	648	598	458
500	466	790	709	502
750	528	990	858	553
1000	578	1160	981	591

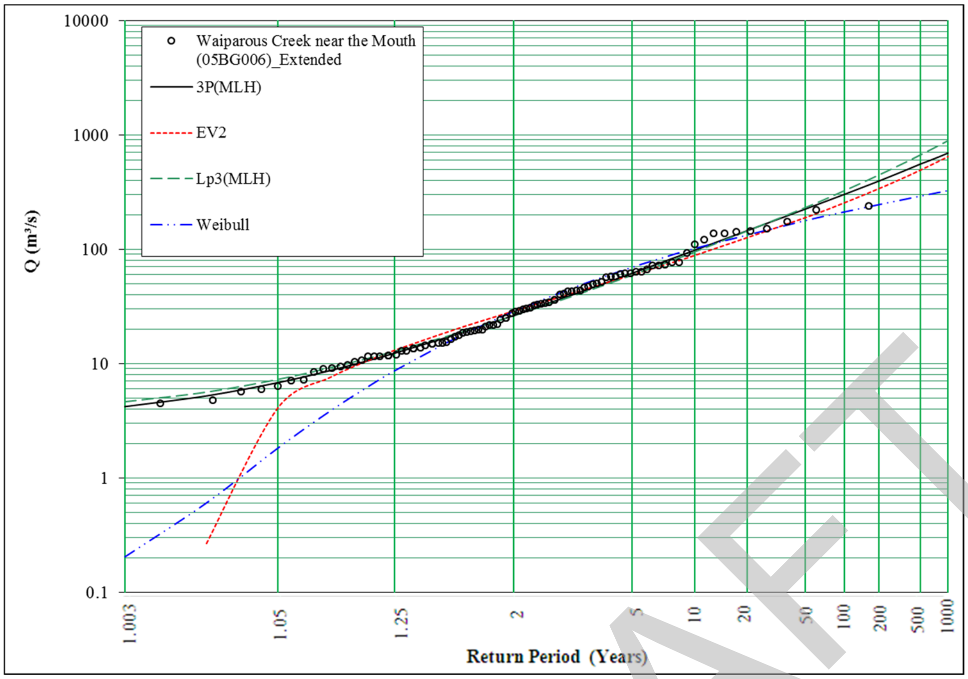
Figure C.1.38: 05BG006, Waiparous Creek near the Mouth

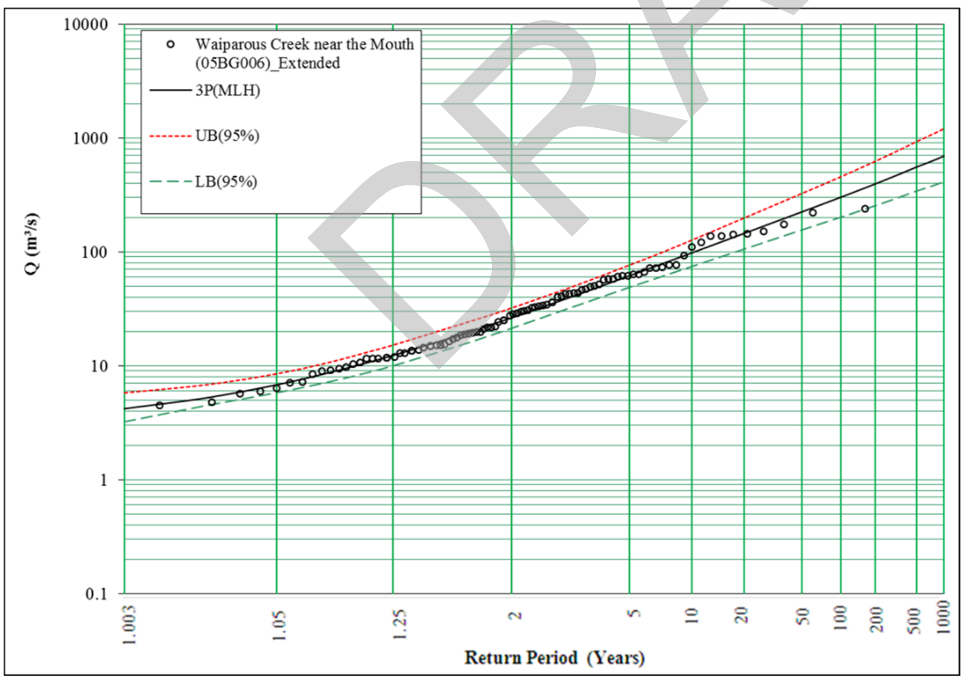




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	26.9	31	26.4	29.9
5	65.5	63.1	62.3	72.7
10	109	93.4	108	108
20	169	132	180	144
35	230	171	266	174
50	278	200	340	194
75	339	238	446	216
100	388	269	540	232
200	528	359	850	272
350	670	451	1220	304
500	776	520	1530	325
750	900	612	1980	349
1000	1000	685	2370	366

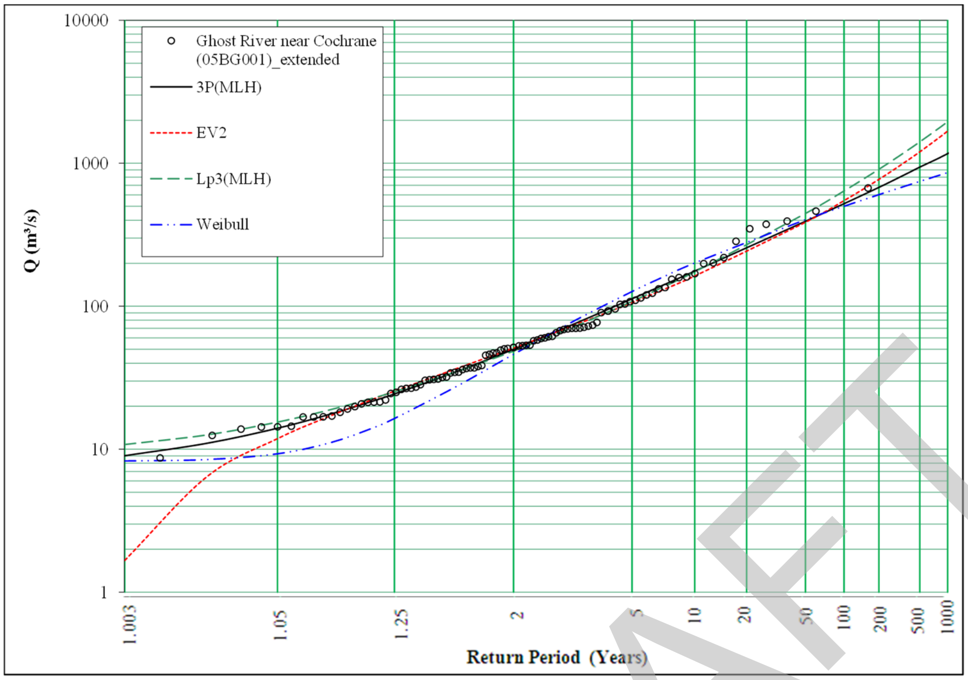
Figure C.1.39: 05BG006, Waiparous Creek near the Mouth – extended

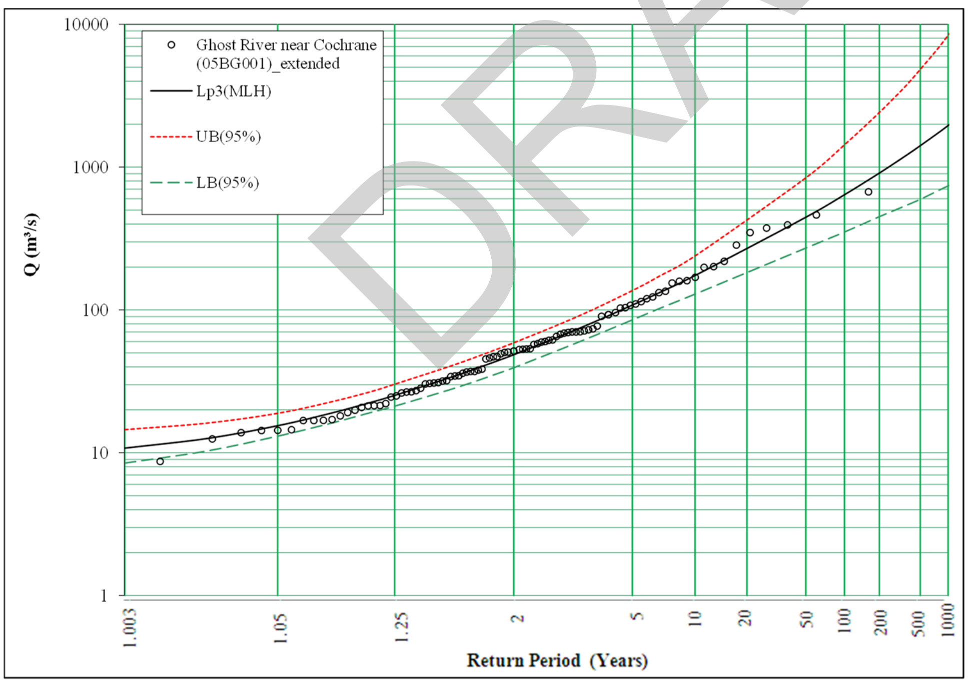




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	26.3	28.8	26.3	28.6
5	61.6	59.6	59.7	69.8
10	97.9	88.4	95.4	102
20	144	125	143	135
35	190	162	194	162
50	224	189	233	179
75	267	225	284	199
100	301	255	326	213
200	395	339	448	247
350	487	425	573	275
500	553	491	668	292
750	630	576	792	313
1000	692	645	892	327

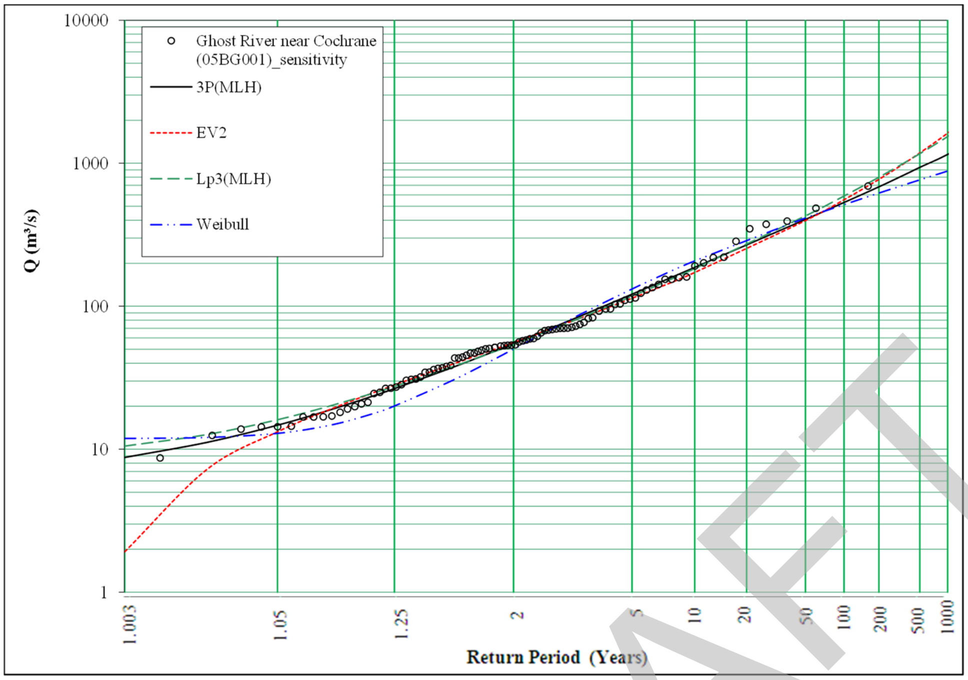
Figure C.1.40: 05BG001, Ghost River near Cochrane - extended with diversion added

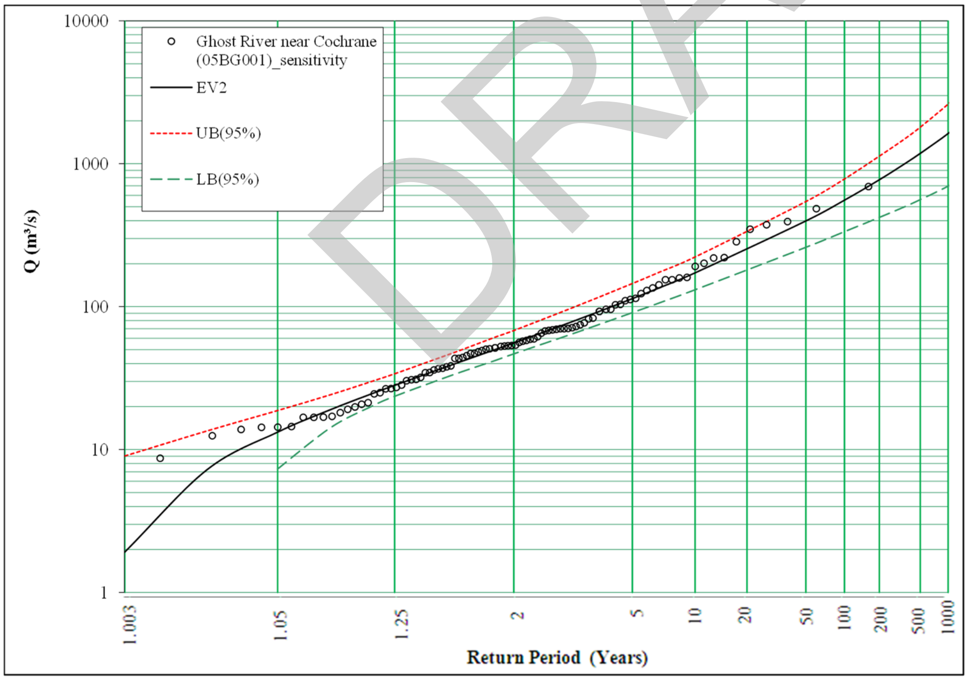




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	50.0	51.1	48.6	46.1
5	113	106	108	127
10	176	163	174	201
20	256	240	267	284
35	335	322	367	356
50	393	387	446	404
75	465	475	553	460
100	522	549	642	501
200	679	773	909	605
350	832	1020	1190	691
500	942	1210	1420	748
750	1070	1470	1710	815
1000	1170	1690	1960	862

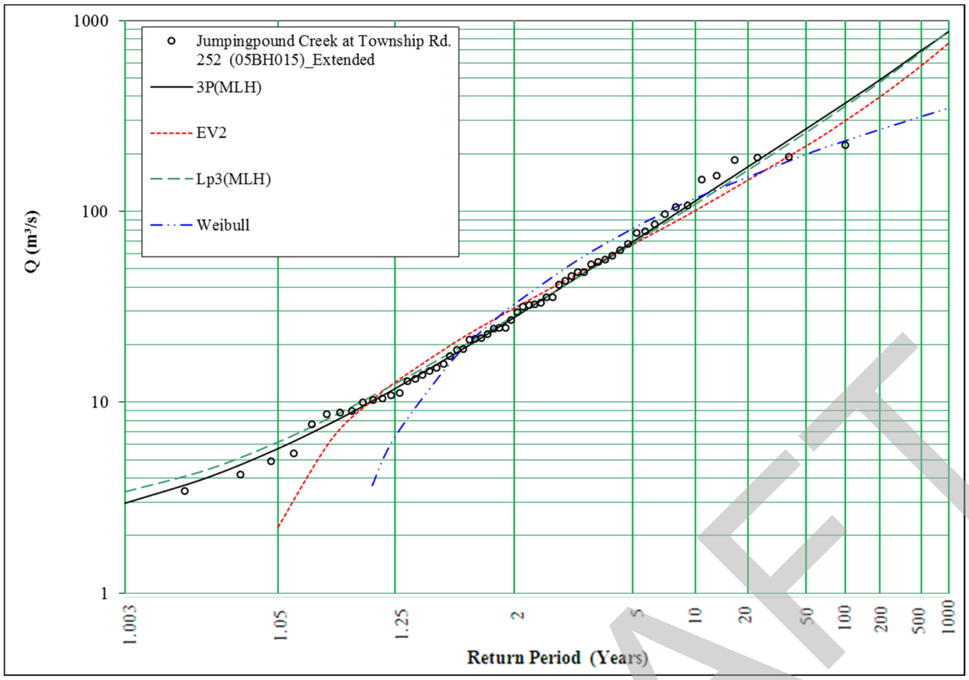
Figure C.1.41: 05BG001, Ghost River near Cochrane - sensitivity analysis

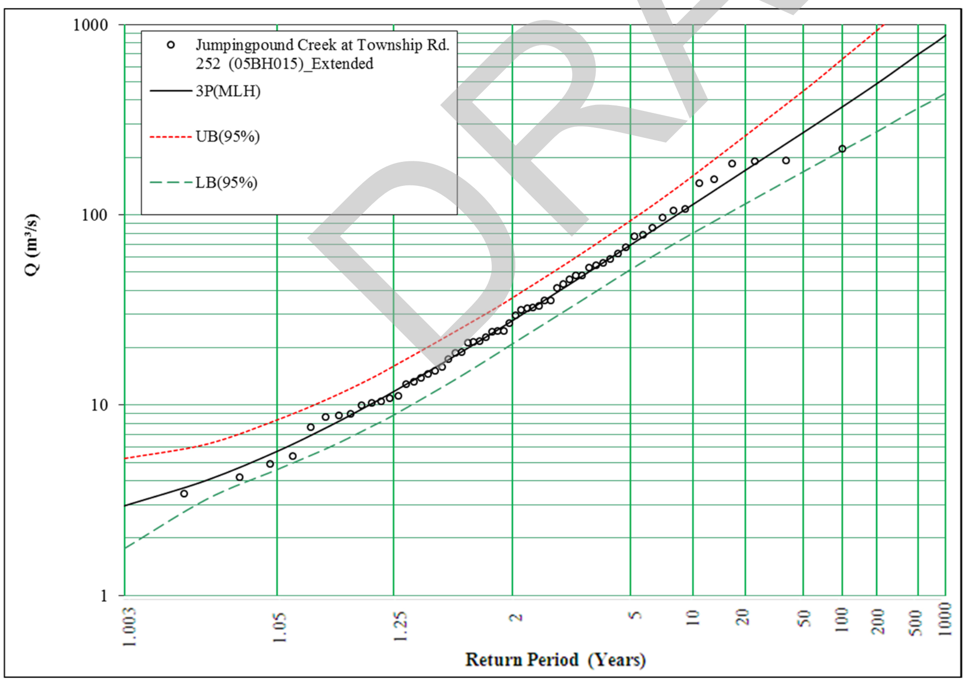




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	54.8	55.8	54.2	50.2
5	122	114	118	132
10	187	173	184	208
20	268	251	271	292
35	347	333	361	366
50	405	398	429	415
75	477	485	518	472
100	532	557	590	515
200	685	773	799	620
350	832	1000	1010	709
500	938	1180	1170	767
750	1060	1430	1370	835
1000	1150	1630	1540	884

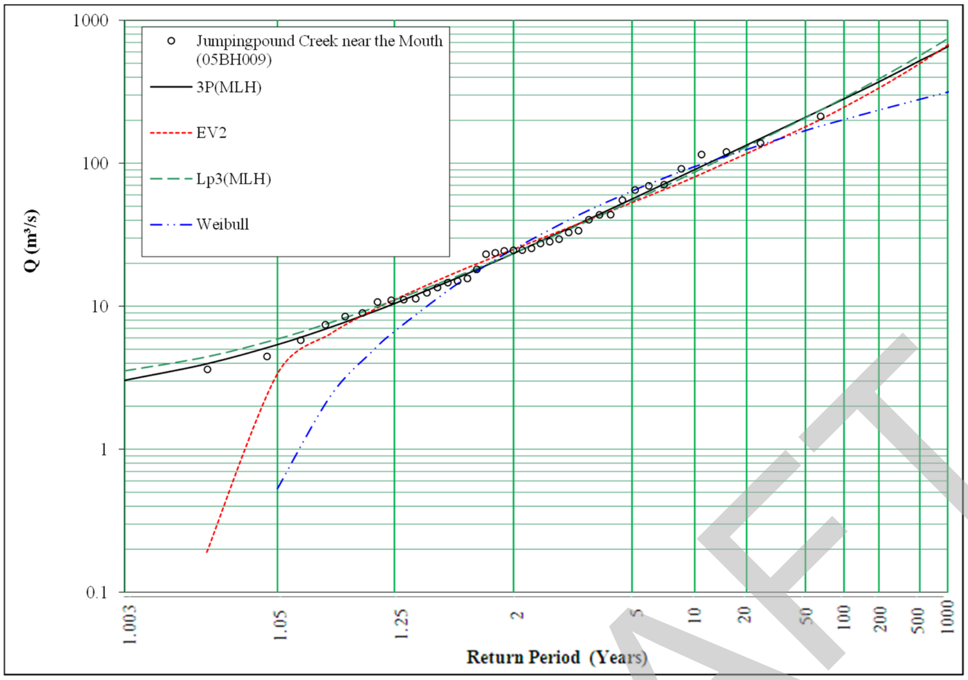
Figure C.1.42: 05BH015, Jumpingpound Creek at Township Road No. 252 – extended

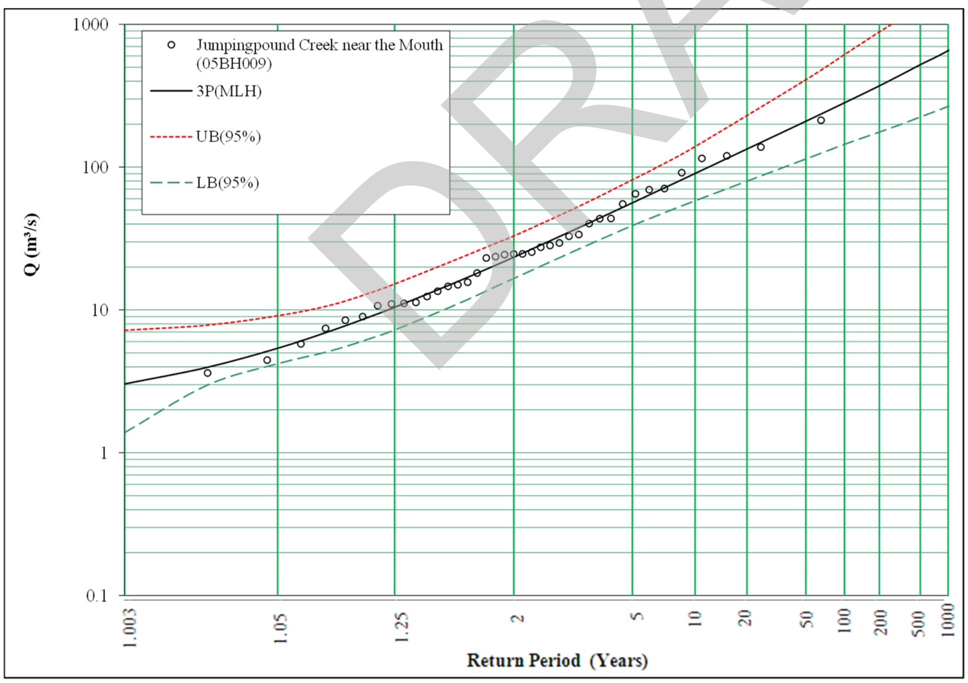




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	27.8	31	28.2	32.6
5	69.5	66.9	67.7	81.1
10	113	101	109	117
20	171	143	163	152
35	228	187	218	181
50	271	219	259	199
75	326	262	312	219
100	369	296	354	233
200	489	396	474	268
350	608	498	592	295
500	695	575	679	313
750	795	677	789	333
1000	878	758	876	347

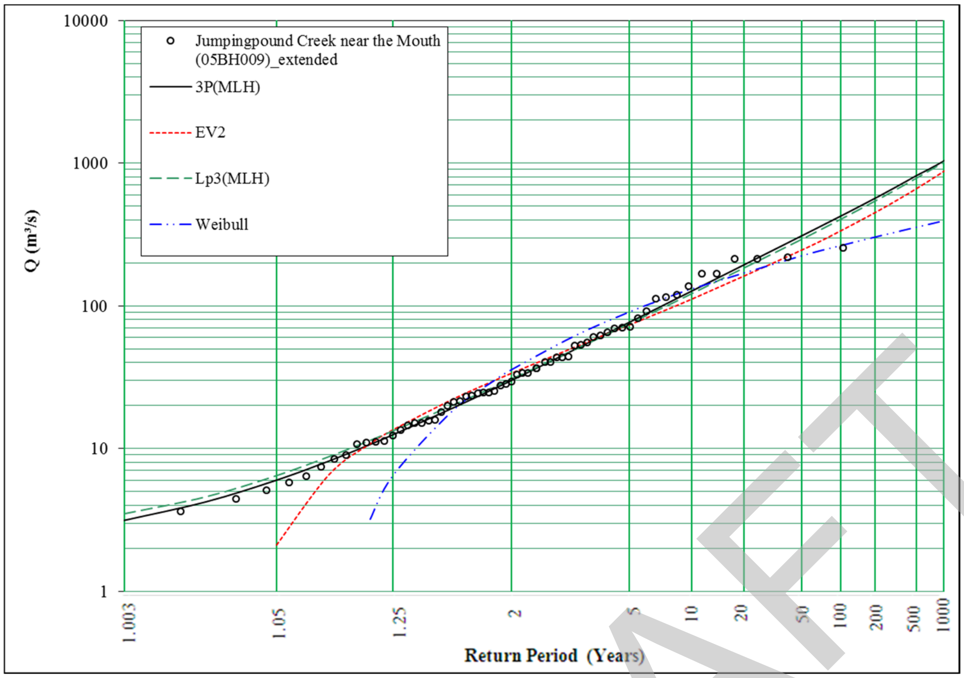
Figure C.1.43: 05BH009, Jumpingpound Creek near the Mouth

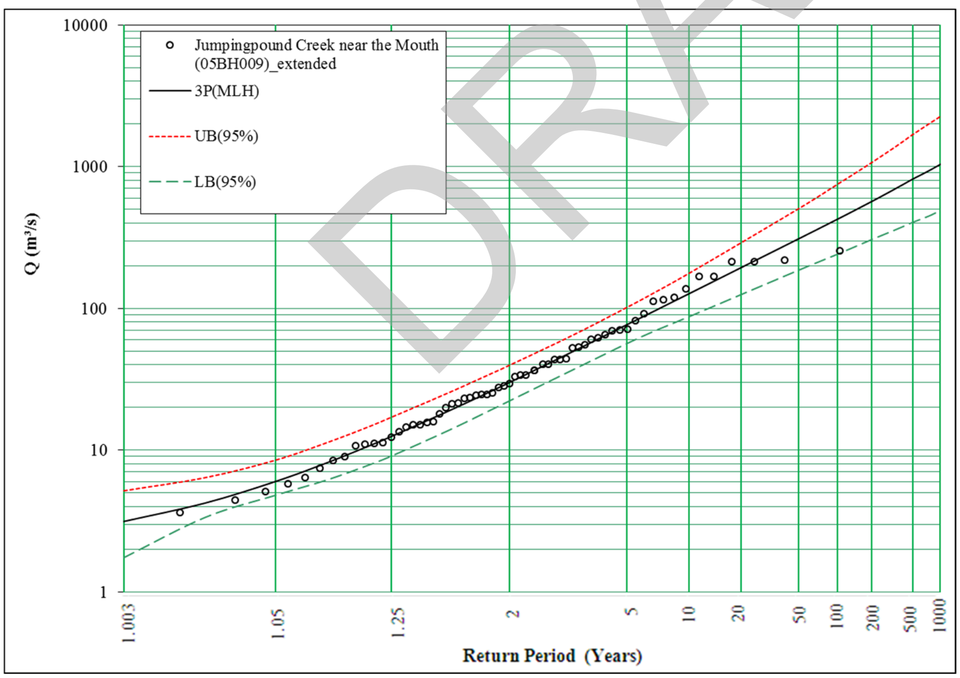




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	23.4	25.0	23.5	25.1
5	56.3	53.1	54.4	64.0
10	90.3	80.4	86.9	94.9
20	134	116	130	127
35	177	152	174	153
50	210	180	208	169
75	250	217	252	189
100	282	247	287	202
200	371	336	389	236
350	459	429	492	263
500	522	500	568	281
750	595	594	667	301
1000	655	672	745	315

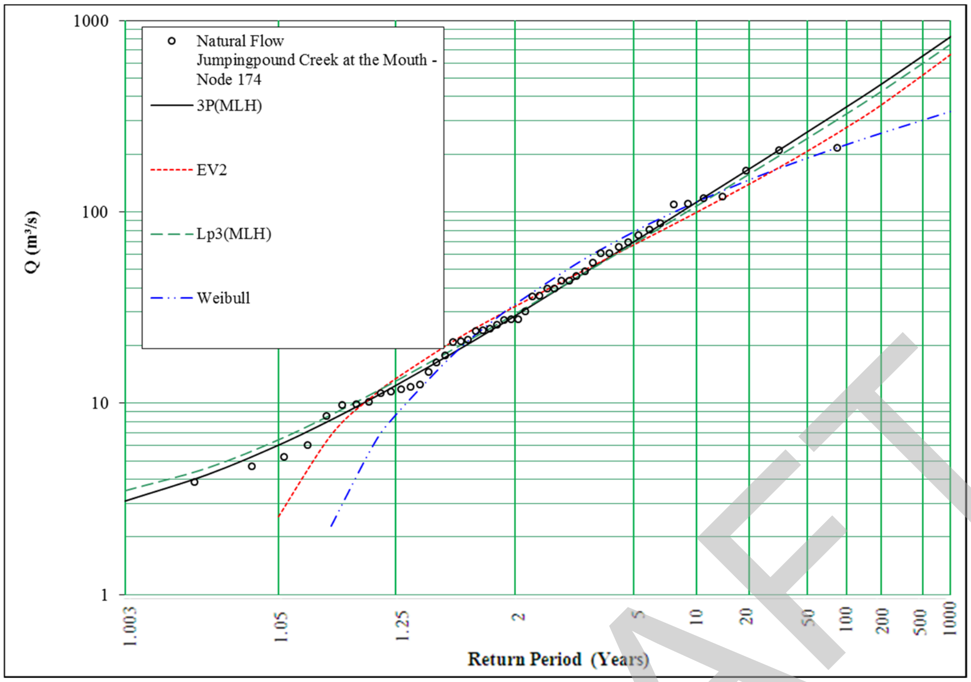
Figure C.1.44: 05BH009, Jumpingpound Creek near the Mouth – extended

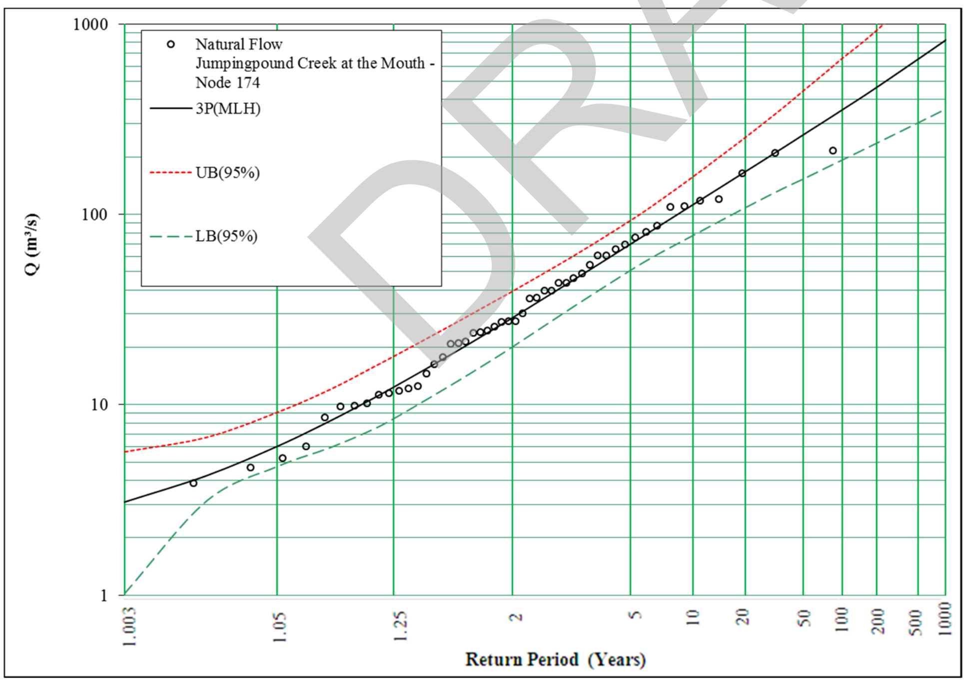




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	30	33.7	30.6	35.6
5	76.8	73.7	74.8	90.3
10	127	112	121	131
20	193	160	183	171
35	260	209	245	203
50	310	246	292	223
75	374	295	353	247
100	425	335	402	263
200	568	451	541	302
350	710	570	678	333
500	815	660	778	353
750	936	779	907	376
1000	1030	875	1010	392

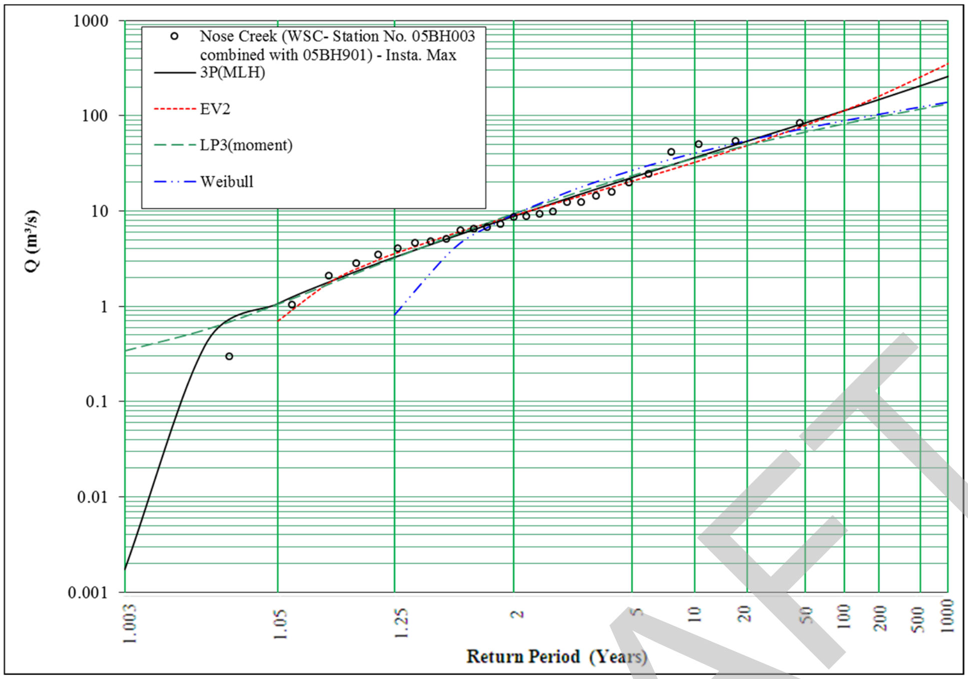
Figure C.1.45: Node 174, Jumpingpound Creek at the Mouth

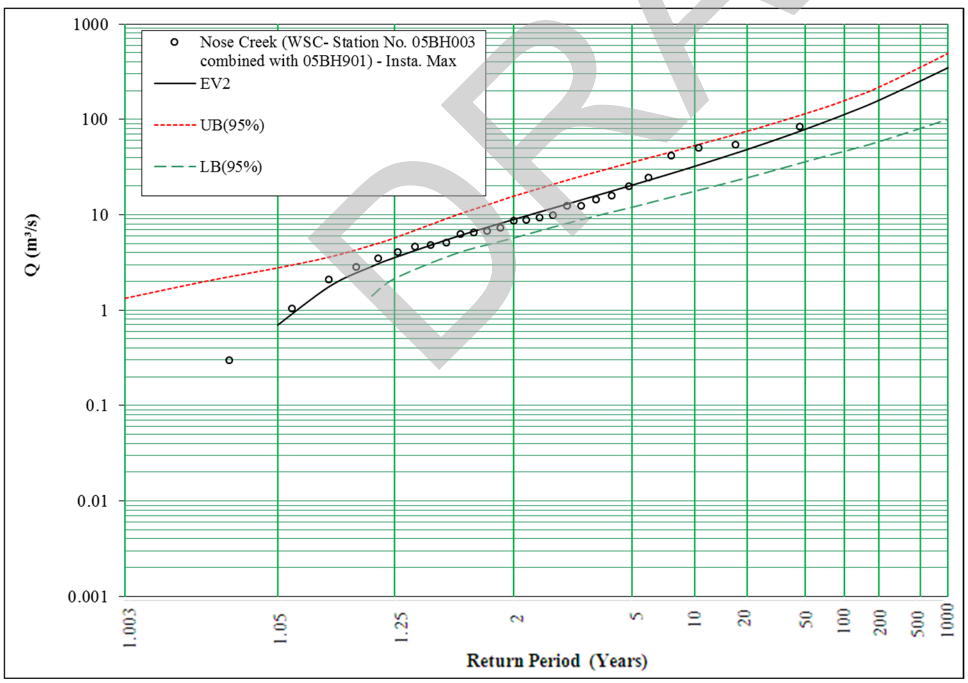




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	28.6	32	29.3	32.8
5	69.8	67.2	68.3	78.5
10	112	99.3	108	112
20	167	139	157	146
35	222	178	206	173
50	262	208	243	190
75	313	245	289	210
100	353	275	325	224
200	465	361	426	257
350	575	447	523	283
500	655	511	593	300
750	746	594	681	319
1000	821	661	750	333

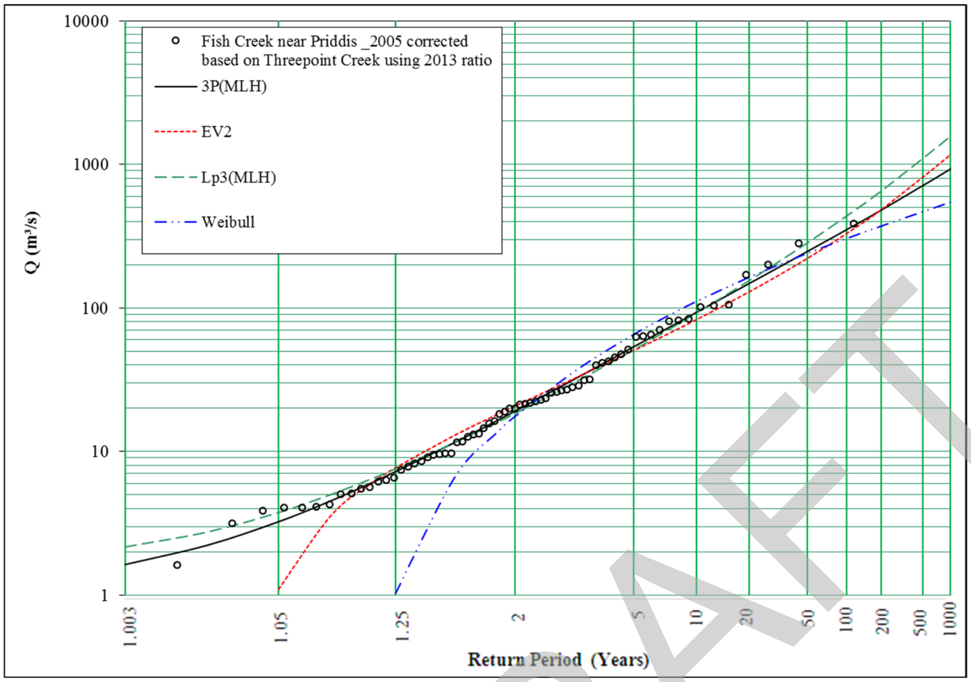
Figure C.1.46: 05BH003 / Node 175, Nose Creek at Calgary – extended

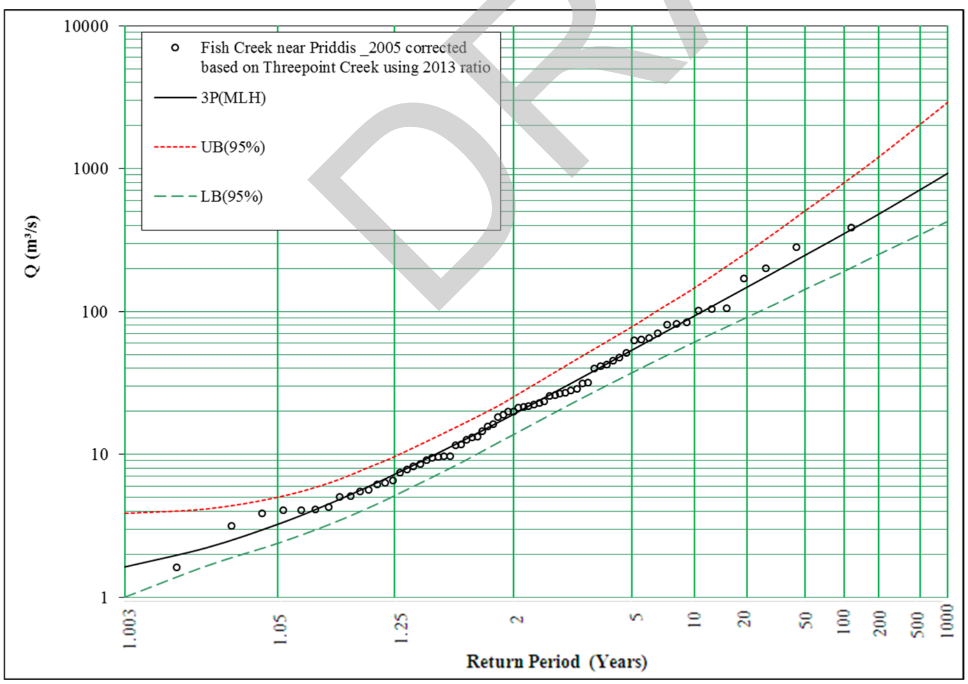




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	8.79	8.92	9.39	9.22
5	22.5	20.5	23.6	26.9
10	36.4	32.3	35.8	40.8
20	54	48.3	49.1	55.10
35	71.4	65.5	60.4	66.9
50	84.2	79	67.9	74.4
75	100	97.3	76.5	83.1
100	113	113	82.7	89.3
200	148	159	97.9	104
350	182	209	110	117
500	207	249	118	124
750	235	303	127	133
1000	258	348	134	140

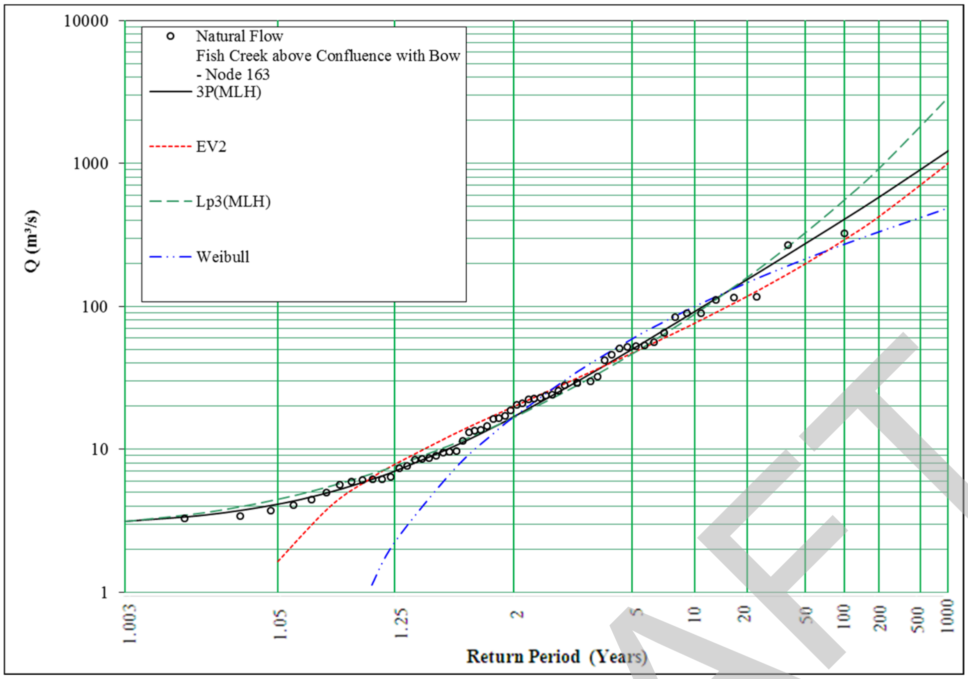
Figure C.1.47: 05BK001, Fish Creek near Priddis

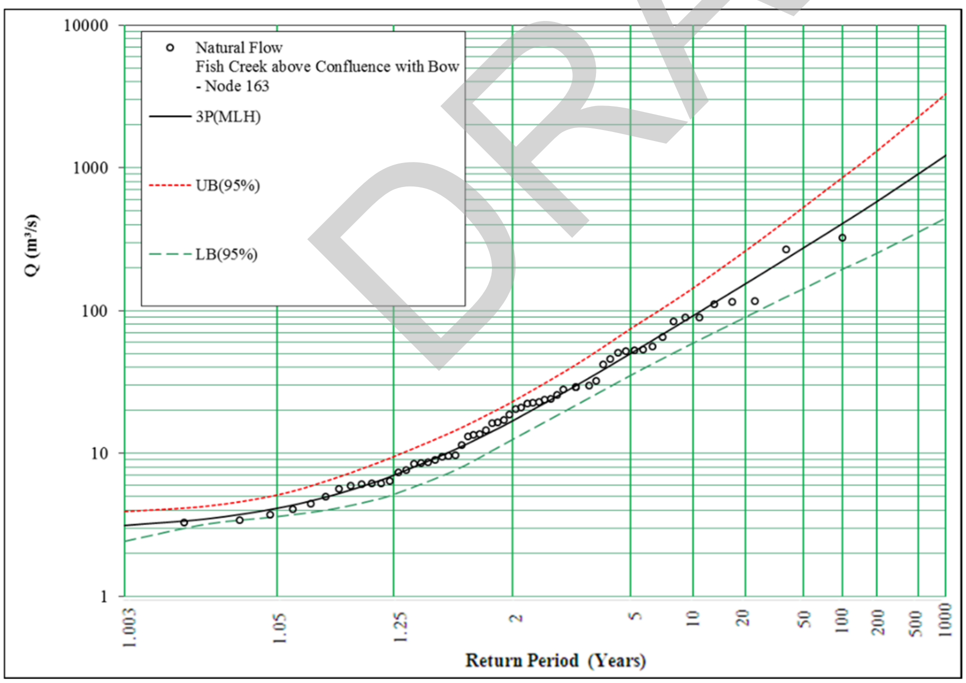




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	19.1	20.7	18.4	17.5
5	53.7	50.5	51.2	65.4
10	93.3	82.8	92.3	111
20	148	129	154	163
35	204	180	226	209
50	248	221	284	239
75	305	279	366	276
100	350	328	435	303
200	481	482	652	370
350	614	655	891	428
500	713	795	1080	466
750	829	991	1340	510
1000	926	1160	1560	542

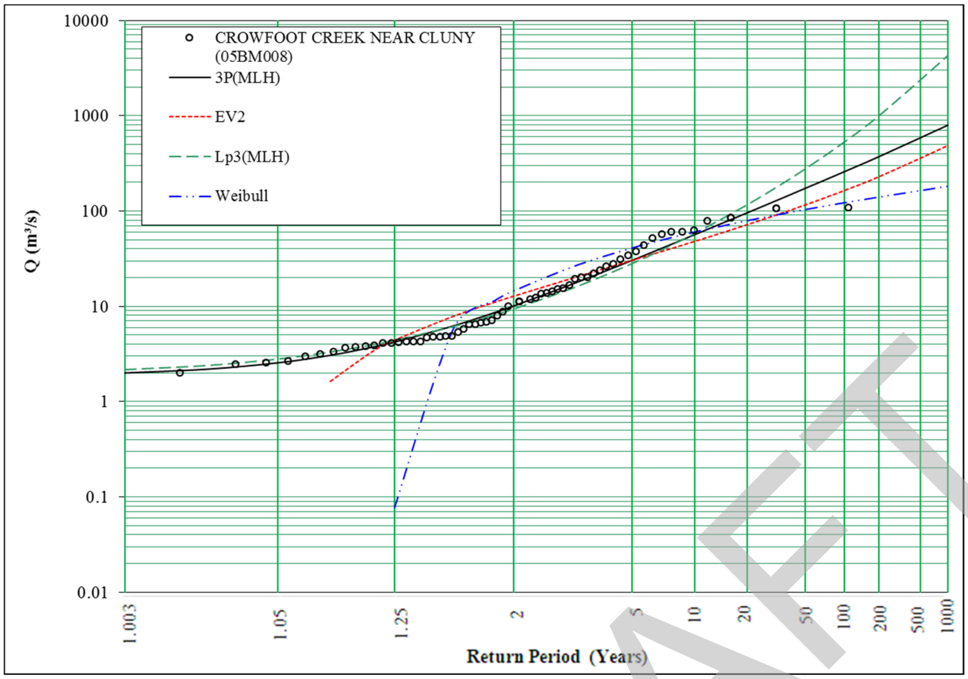
Figure C.1.48: Node 163, Fish Creek at the Mouth

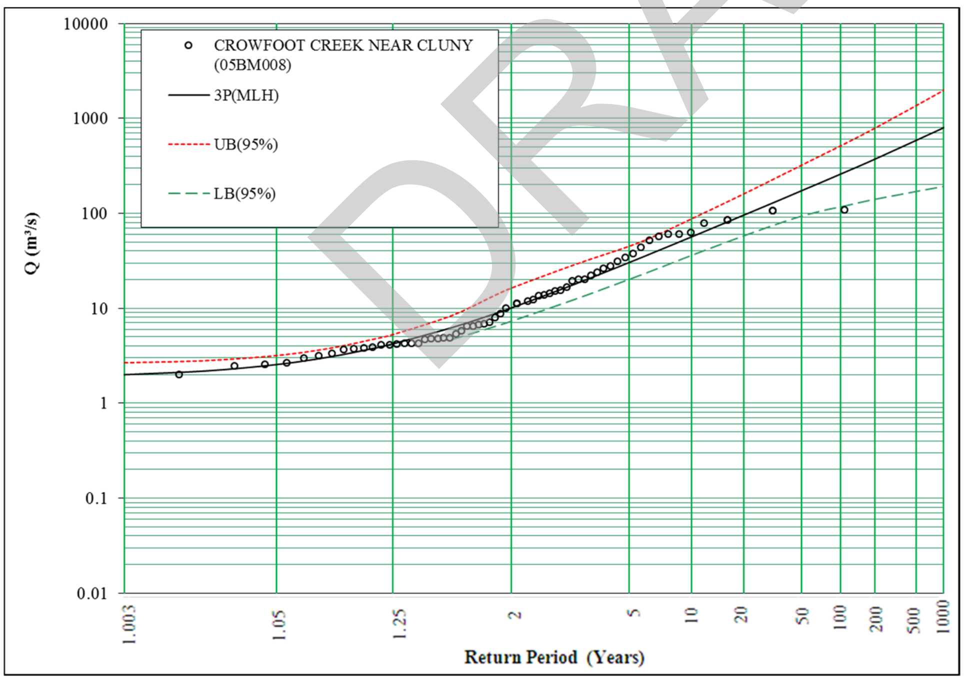




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	16.9	19.8	16.6	16.8
5	50.1	46.9	46.4	59.2
10	92	76	88.1	99.6
20	154	117	158	146
35	221	162	248	186
50	275	198	327	214
75	347	248	445	247
100	406	291	552	270
200	581	423	918	331
350	766	571	1370	382
500	907	690	1770	416
750	1080	855	2350	455
1000	1220	995	2870	484

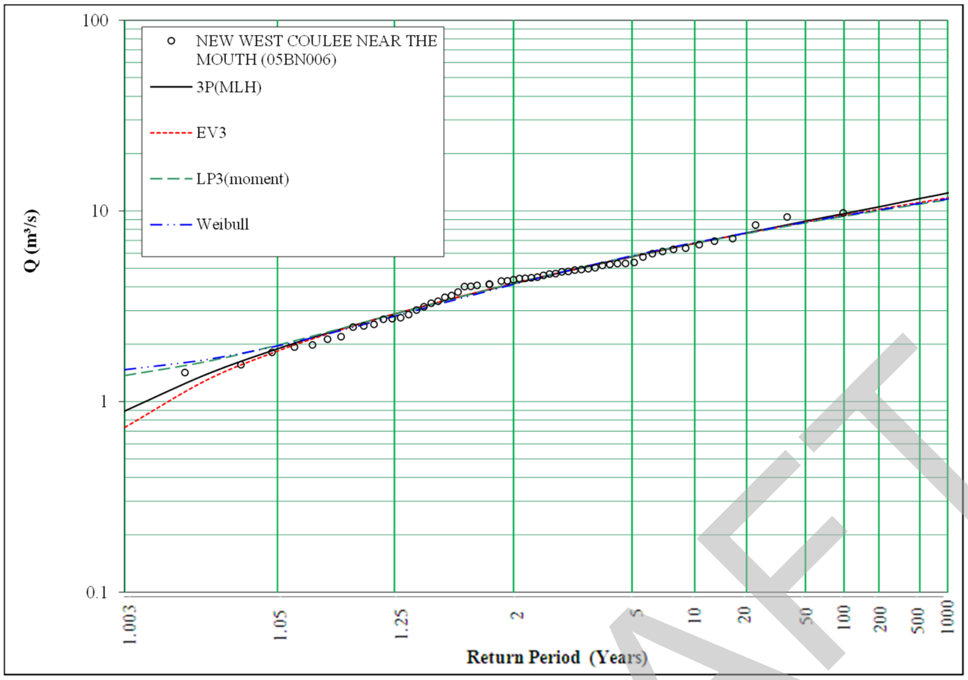
Figure C.1.49: 05BM008, Crowfoot Creek near Cluny

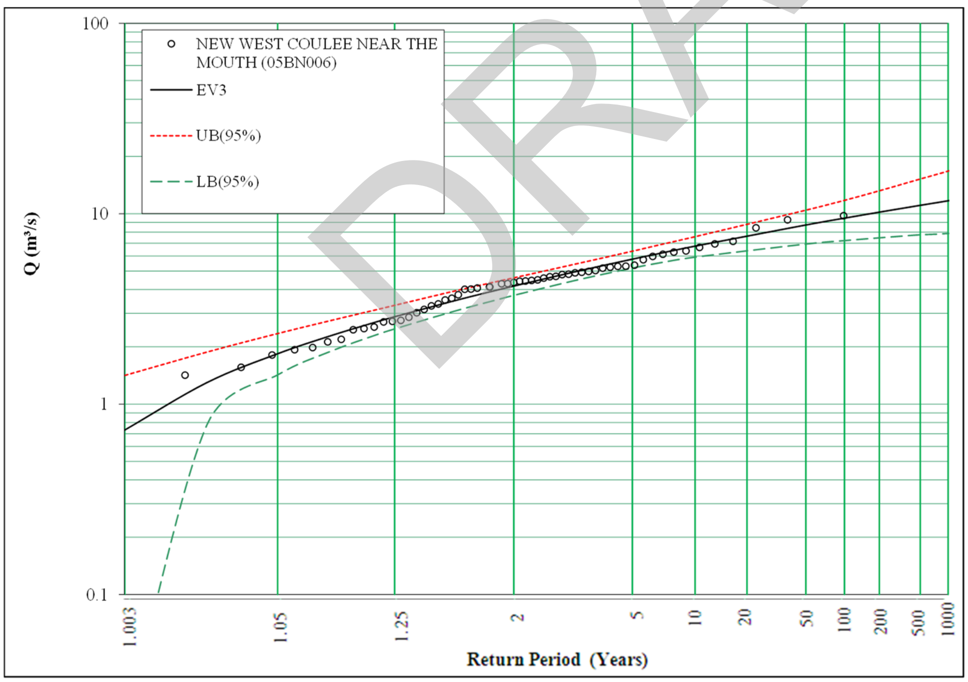




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	10.1	12.8	9.34	14.5
5	30.4	30.5	28.1	40.8
10	56.6	48.3	58.1	60.1
20	95.5	72	116	79.0
35	139	97.1	198	94.0
50	174	117	277	103
75	220	143	405	114
100	259	165	529	122
200	373	230	1000	140
350	495	300	1660	154
500	589	354	2300	164
750	701	428	3310	174
1000	797	489	4290	181

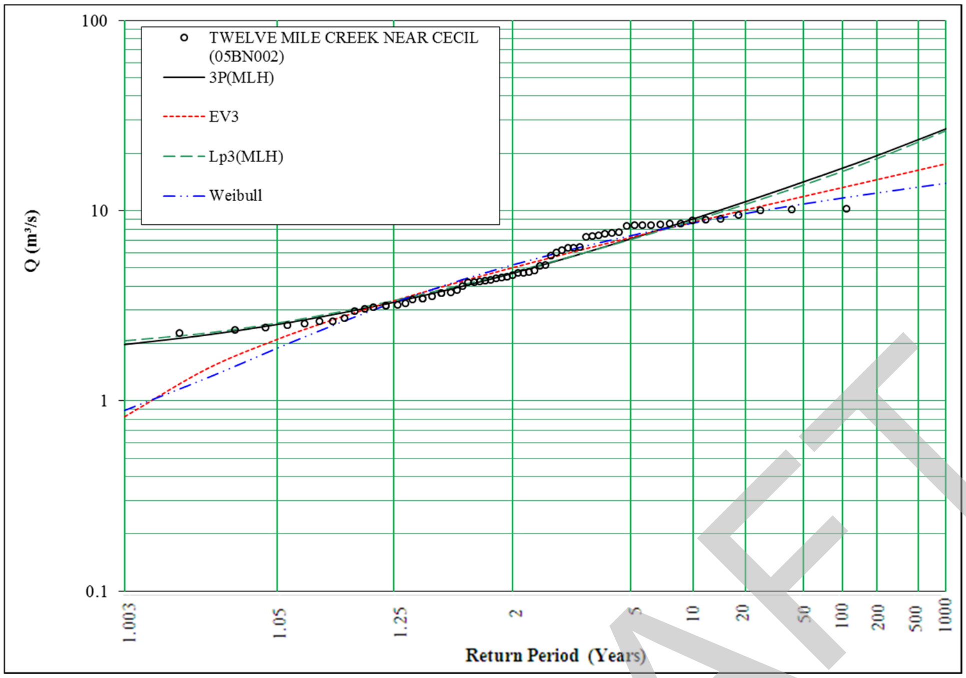
Figure C.1.50: 05BN006, New West Coulee near the Mouth

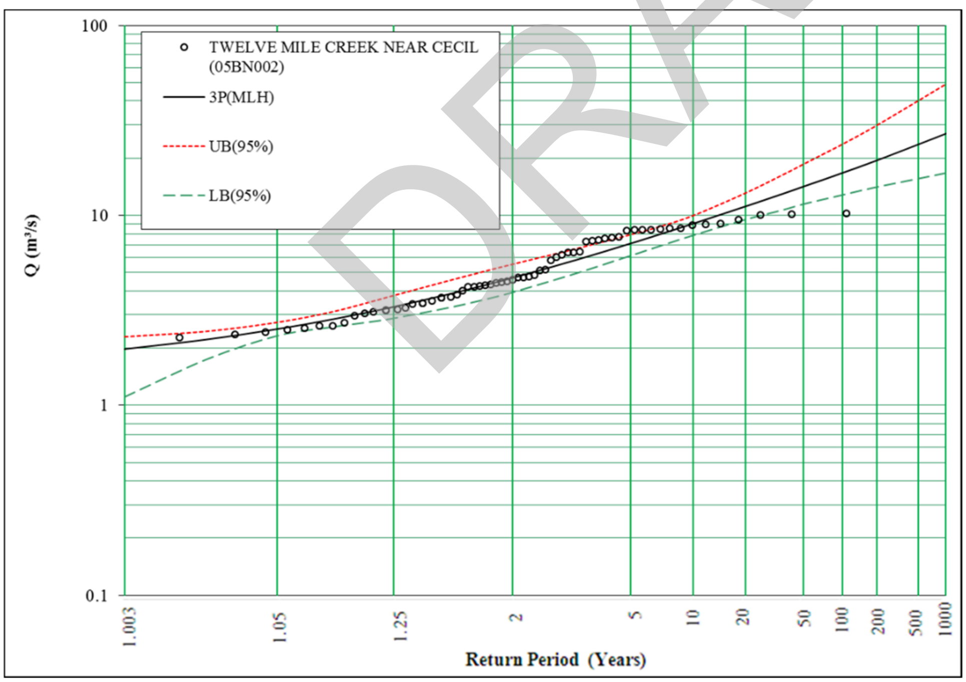




Return Period	3P(MLH)	EV3	LP3 (moment)	Weibull
2	4.15	4.17	4.17	4.12
5	5.76	5.78	5.80	5.82
10	6.76	6.76	6.78	6.83
20	7.68	7.65	7.64	7.71
35	8.39	8.32	8.28	8.36
50	8.84	8.73	8.67	8.75
75	9.33	9.18	9.09	9.18
100	9.68	9.49	9.38	9.47
200	10.5	10.2	10.0	10.1
350	11.2	10.7	10.6	10.7
500	11.6	11.1	10.9	11.0
750	12.1	11.4	11.2	11.3
1000	12.4	11.7	11.5	11.6

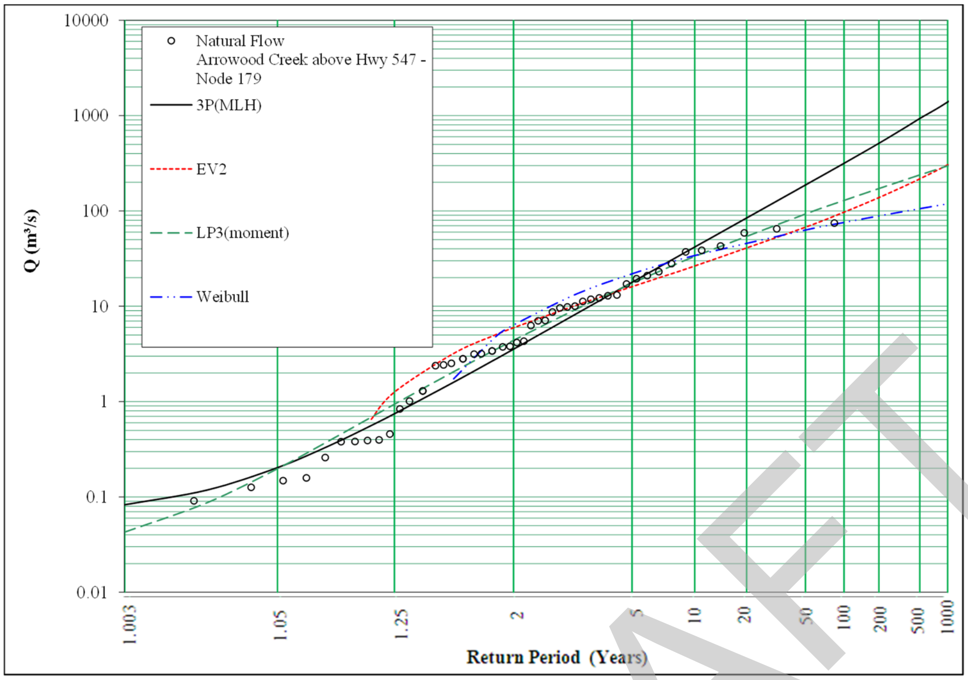
Figure C.1.51: 05BN002, Twelve Mile Creek near Cecil

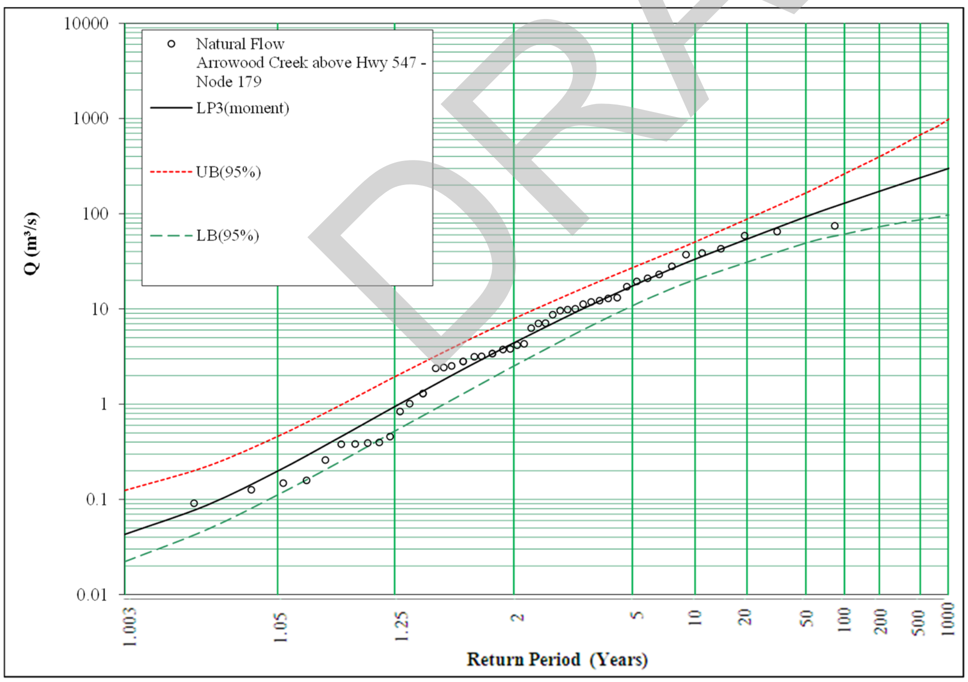




Return Period	3P(MLH)	EV3	Lp3(MLH)	Weibull
2	4.68	5	4.75	5.18
5	7.11	7.21	7.06	7.39
10	9.05	8.66	8.86	8.62
20	11.1	10.1	10.8	9.66
35	12.9	11.2	12.5	10.4
50	14.2	11.8	13.7	10.9
75	15.6	12.6	15.1	11.3
100	16.7	13.2	16.1	11.7
200	19.5	14.5	18.8	12.4
350	22	15.6	21.2	13
500	23.6	16.3	22.9	13.3
750	25.5	17	24.9	13.7
1000	26.9	17.6	26.3	13.9

Figure C.1.52: Node 179, Arrowwood Creek above Hwy. 547

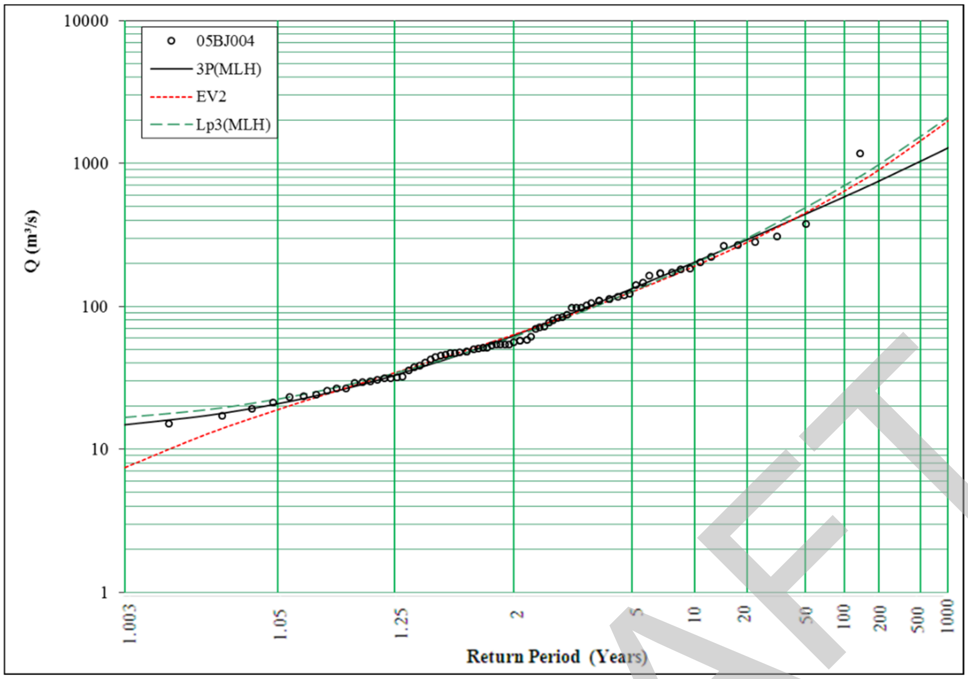


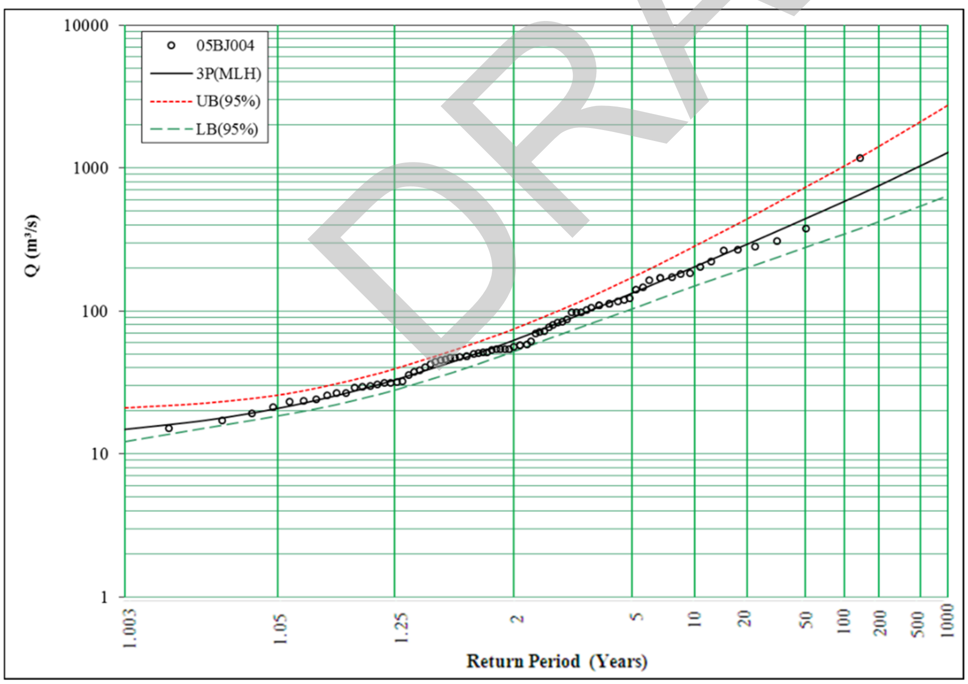


Return Period	3P(MLH)	EV2	LP3 (moment)	Weibull
2	3.55	5.96	4.40	6.34
5	17.9	16.1	17.4	21.9
10	41.8	26.5	33.4	34.1
20	84.5	40.6	55.0	46.4
35	139	55.7	76.9	56.5
50	187	67.6	93.0	63.0
75	256	83.8	113	70.5
100	316	97.3	129	75.8
200	513	138	172	88.6
350	745	183	212	99.0
500	936	218	239	106
750	1180	266	273	113
1000	1390	306	298	119

ELBOW RIVER

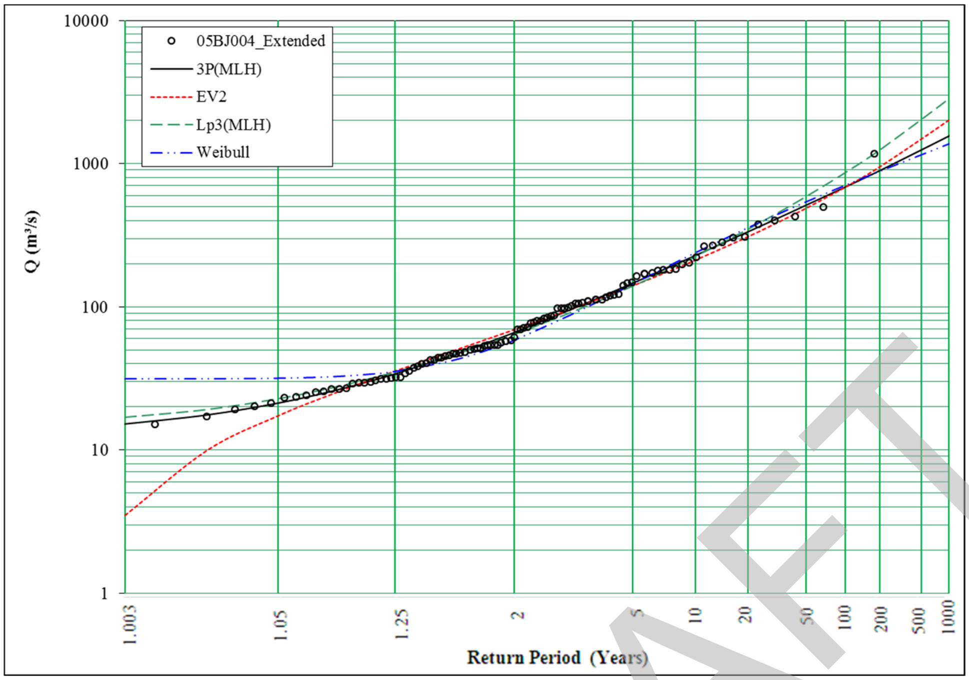
Figure C.1.53: 05BJ004, Elbow River at Bragg Creek

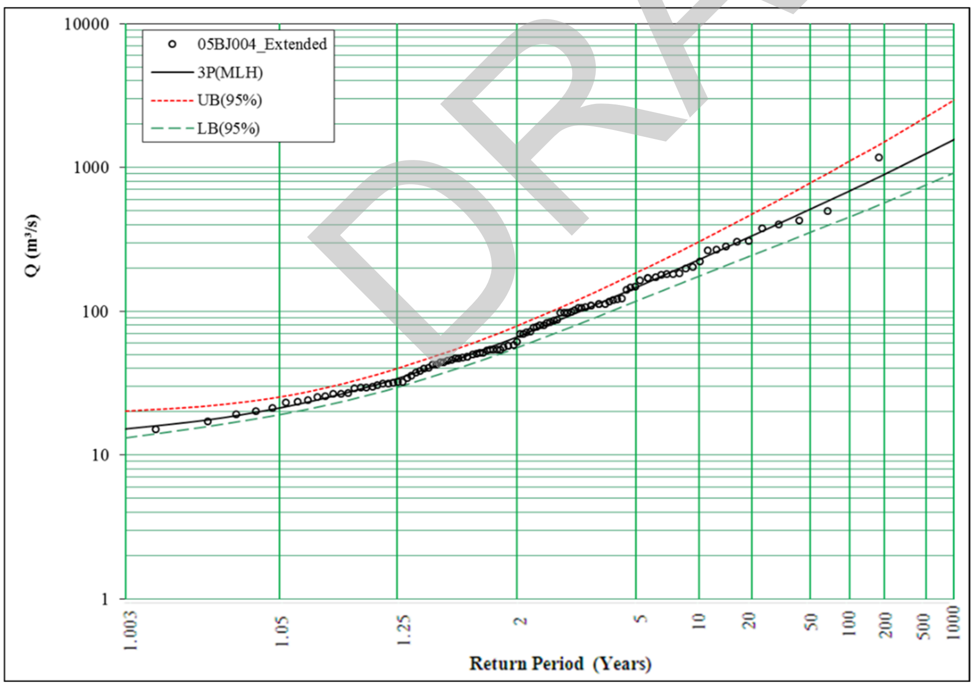




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	62.3	63.1	61	
5	133	126	127	
10	204	191	200	
20	292	280	299	
35	379	375	407	
50	442	451	491	
75	521	554	605	
100	583	639	700	
200	753	902	985	
350	918	1190	1290	
500	1040	1410	1520	
750	1170	1720	1840	
1000	1280	1980	2100	

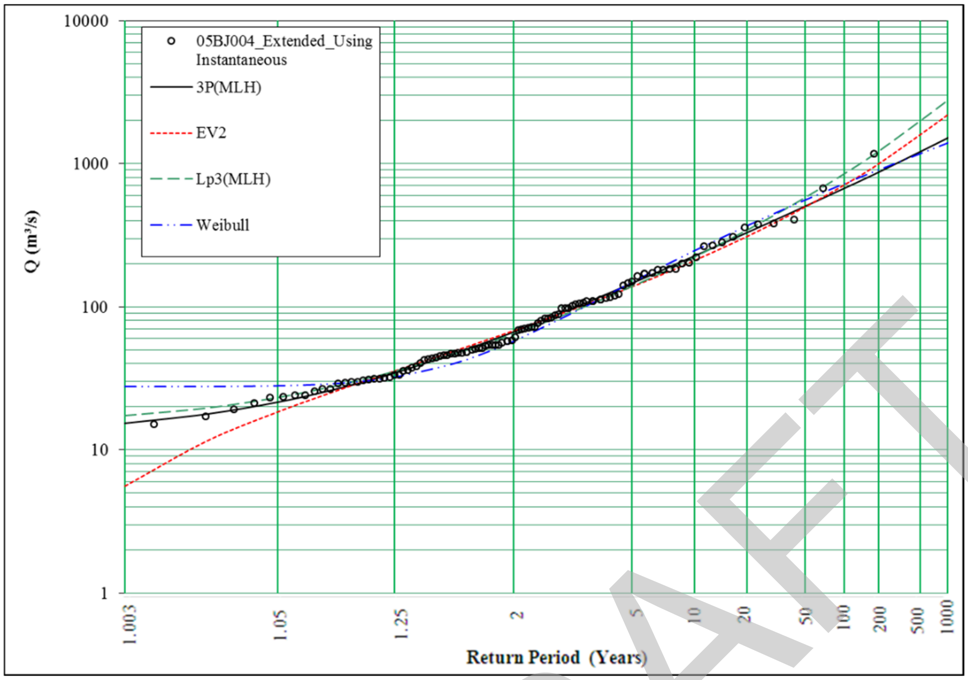
Figure C.1.54: 05BJ004, Elbow River at Bragg Creek – extended Using Annual Maximum Daily Series

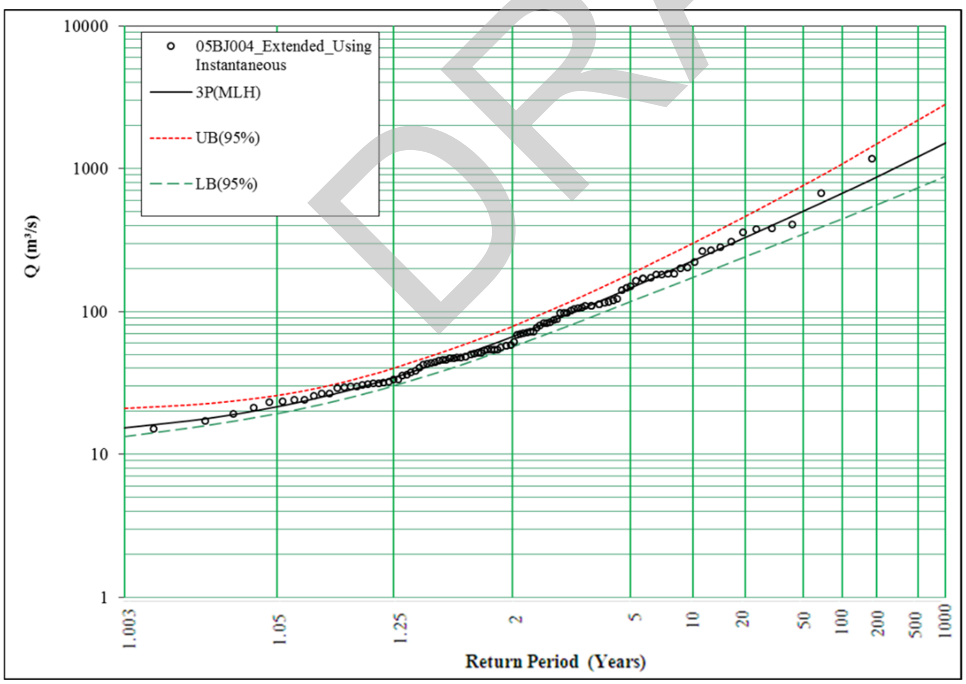




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	66.1	69	64.5	58.3
5	146	140	140	144
10	229	212	226	238
20	333	307	348	354
35	437	409	483	463
50	514	488	592	539
75	610	595	741	632
100	686	683	866	701
200	895	949	1250	881
350	1100	1230	1670	1040
500	1250	1460	2000	1150
750	1420	1760	2460	1270
1000	1560	2010	2840	1360

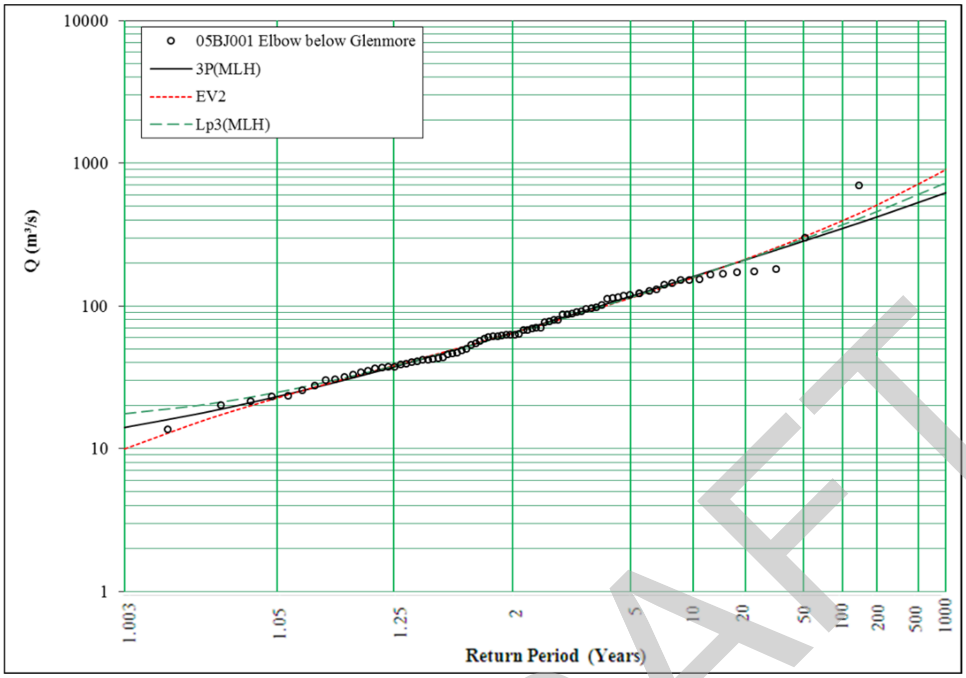
Figure C.1.55: 05BJ004, Elbow River at Bragg Creek – extended Using Annual Maximum Instantaneous Series

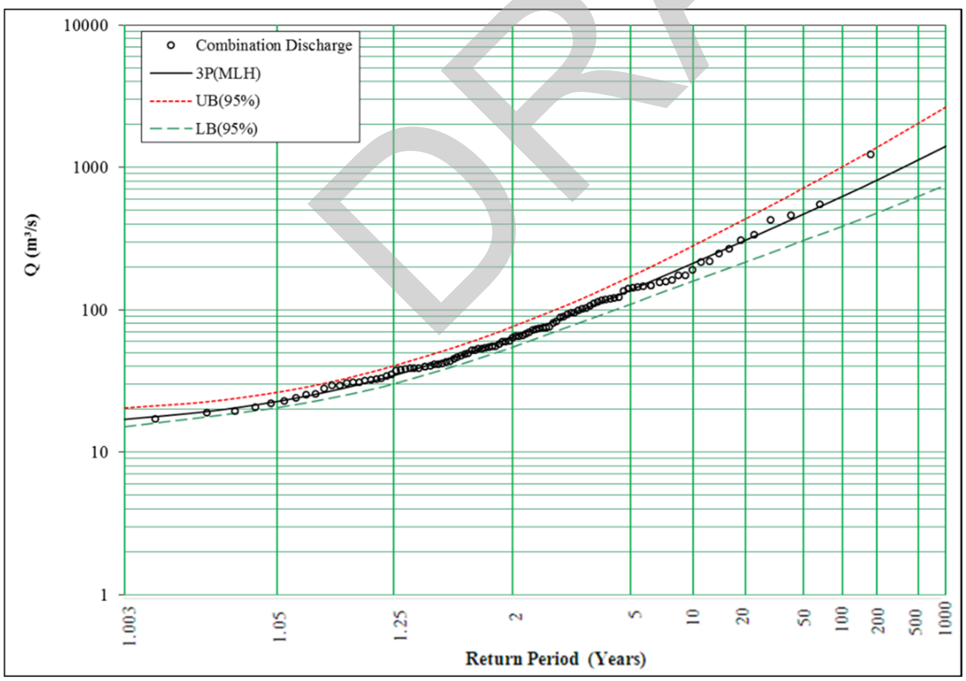




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	66.5	68.1	64.7	57.5
5	146	139	140	148
10	227	211	224	247
20	329	310	344	367
35	430	417	477	479
50	504	501	583	557
75	597	615	729	651
100	671	711	852	721
200	873	1000	1230	904
350	1070	1320	1640	1060
500	1210	1570	1960	1170
750	1380	1910	2410	1300
1000	1510	2200	2780	1390

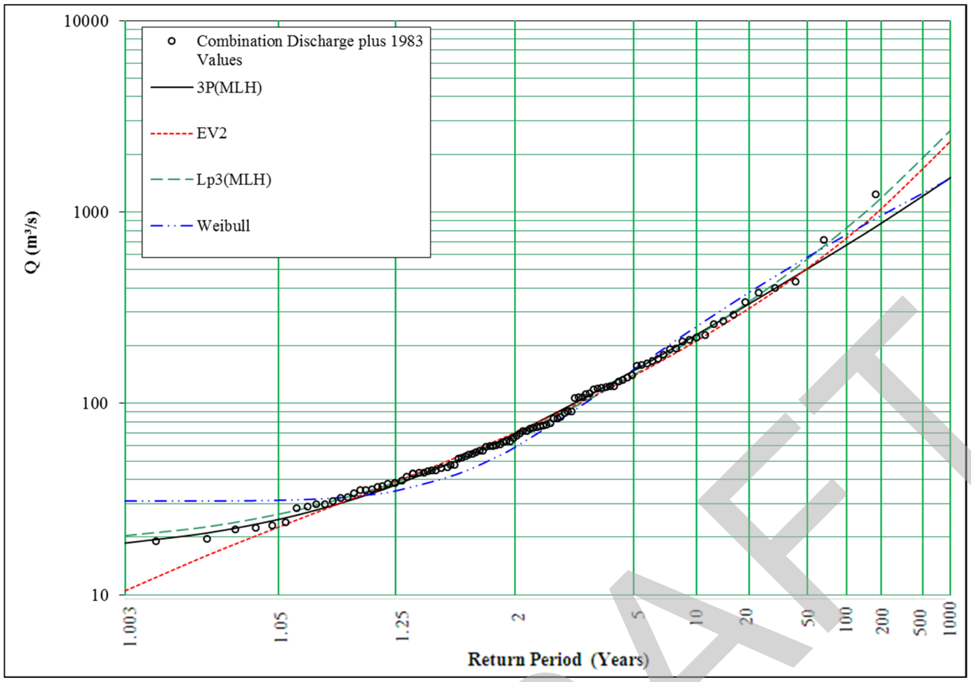
Figure C.1.56: 05BJ010, Elbow River at Sarcee Bridge, same as Glenmore Reservoir Inflow - combined 05BJ001, 05BJ005, 05BJ010

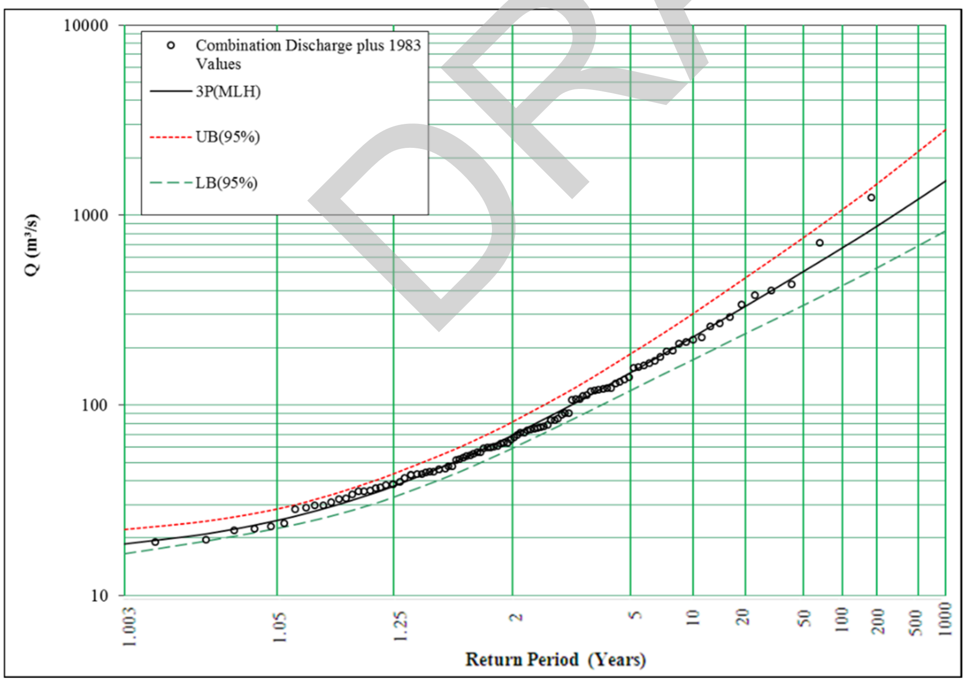




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	64.2	65.1	62.9	
5	138	130	131	
10	212	197	208	
20	307	291	316	
35	401	393	435	
50	470	474	531	
75	556	585	661	
100	625	679	771	
200	813	967	1110	
350	997	1280	1470	
500	1130	1540	1760	
750	1280	1880	2160	
1000	1410	2180	2490	

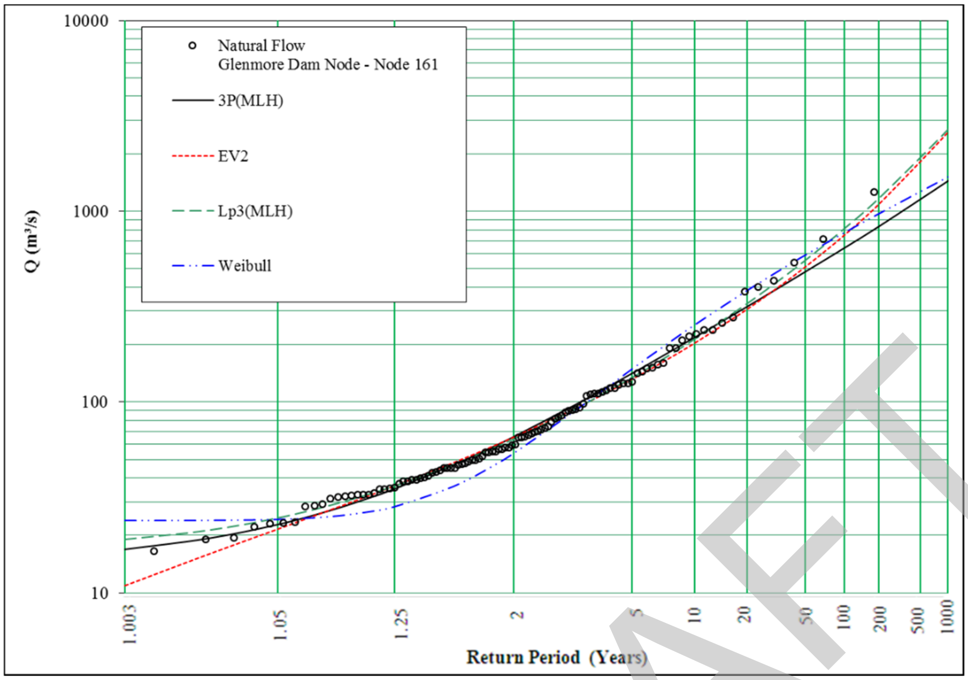
Figure C.1.57: 05BJ010, Elbow River at Sarcee Bridge, same as Glenmore Reservoir Inflow - combined 05BJ001, 05BJ005, 05BJ010 with 1983 values

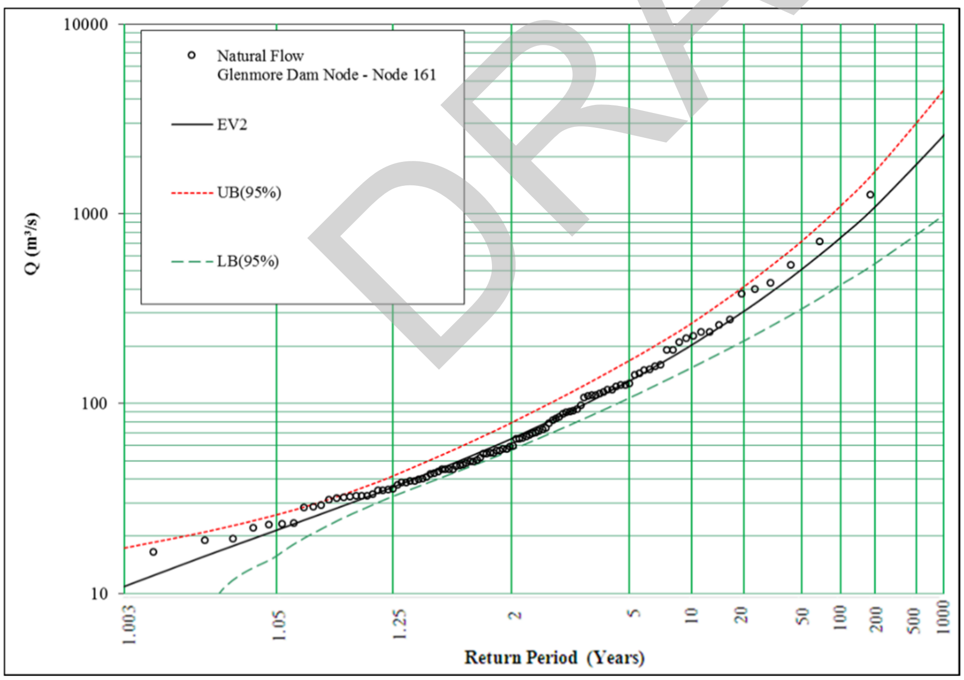




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	69.4	70.3	68	58.8
5	148	140	142	150
10	229	212	224	251
20	331	313	340	377
35	431	422	468	496
50	506	509	569	579
75	599	628	709	680
100	672	729	826	756
200	874	1040	1190	954
350	1070	1380	1580	1130
500	1210	1650	1890	1240
750	1380	2020	2310	1380
1000	1510	2340	2670	1490

Figure C.1.58: 05BJ001 / Node 161, Elbow River below Glenmore Dam

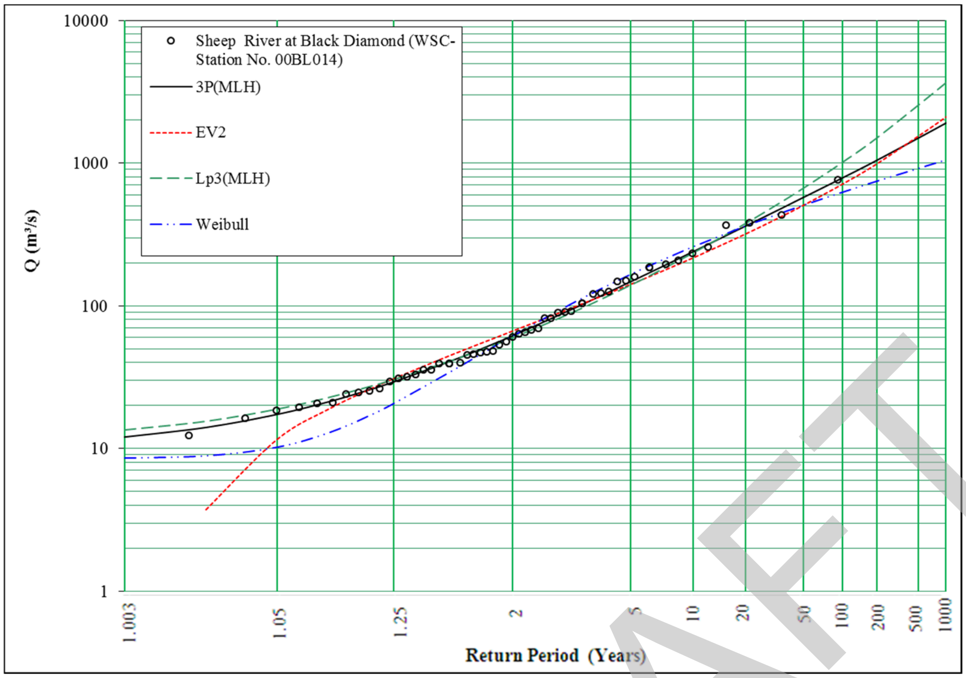


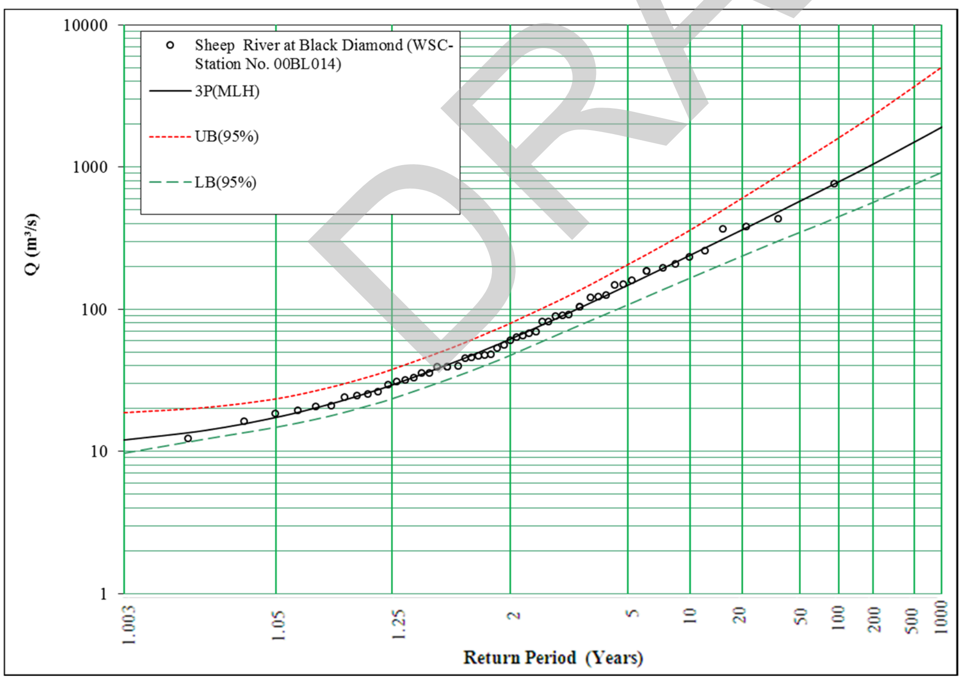


Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	65.7	65.2	63.9	53.9
5	141	132	134	149
10	218	204	214	254
20	316	306	327	383
35	412	419	452	505
50	482	511	553	589
75	571	639	691	692
100	641	748	808	770
200	833	1090	1170	970
350	1020	1470	1560	1150
500	1160	1780	1880	1260
750	1310	2220	2310	1400
1000	1440	2590	2670	1510

SHEEP RIVER AND TRIBUTARIES

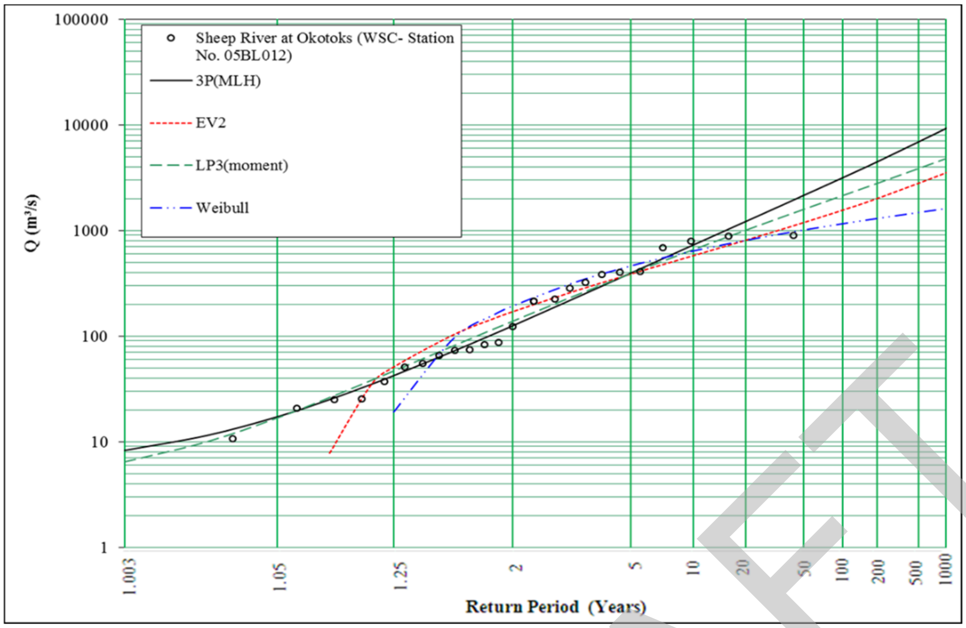
Figure C.1.59: 05BL014, Sheep River at Black Diamond

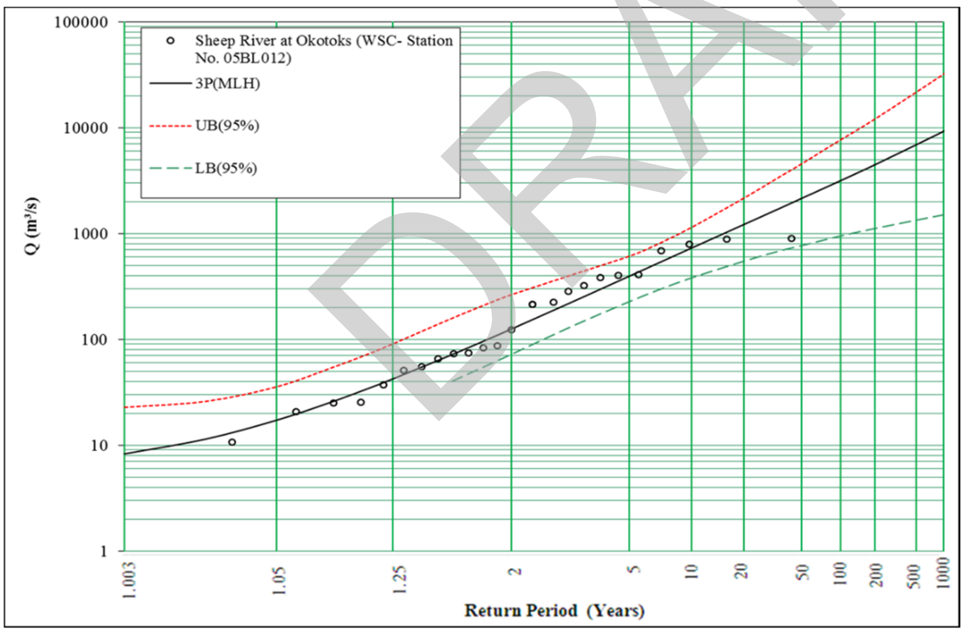




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	61.5	65.9	59.8	61.3
5	148	141	140	166
10	240	215	236	259
20	361	316	378	361
35	484	421	540	449
50	576	504	672	507
75	693	615	857	575
100	787	707	1020	625
200	1050	984	1510	747
350	1310	1280	2070	850
500	1500	1510	2520	917
750	1720	1820	3140	995
1000	1900	2080	3660	1050

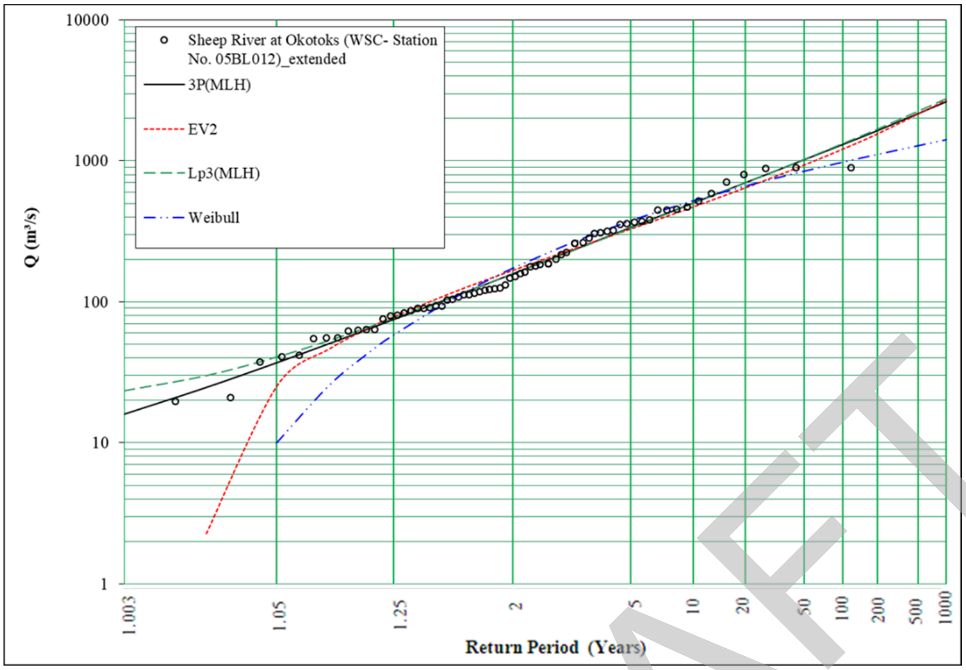
Figure C.1.60: 05BL012, Sheep River at Okotoks

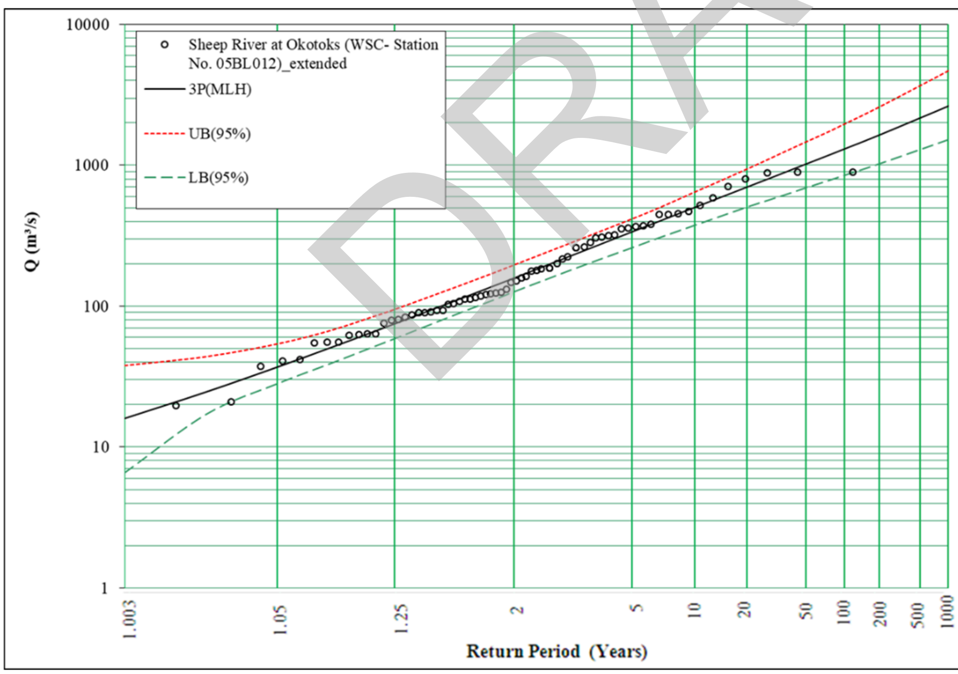




Return Period	3P(MLH)	EV2	LP3 (moment)	Weibull
2	125	169	138	193
5	395	385	392	461
10	729	575	659	638
20	1210	804	1000	802
35	1740	1020	1340	928
50	2150	1180	1590	1010
75	2700	1390	1900	1090
100	3150	1550	2140	1150
200	4470	2000	2790	1290
350	5860	2440	3410	1400
500	6910	2760	3840	1470
750	8160	3170	4380	1550
1000	9220	3490	4780	1600

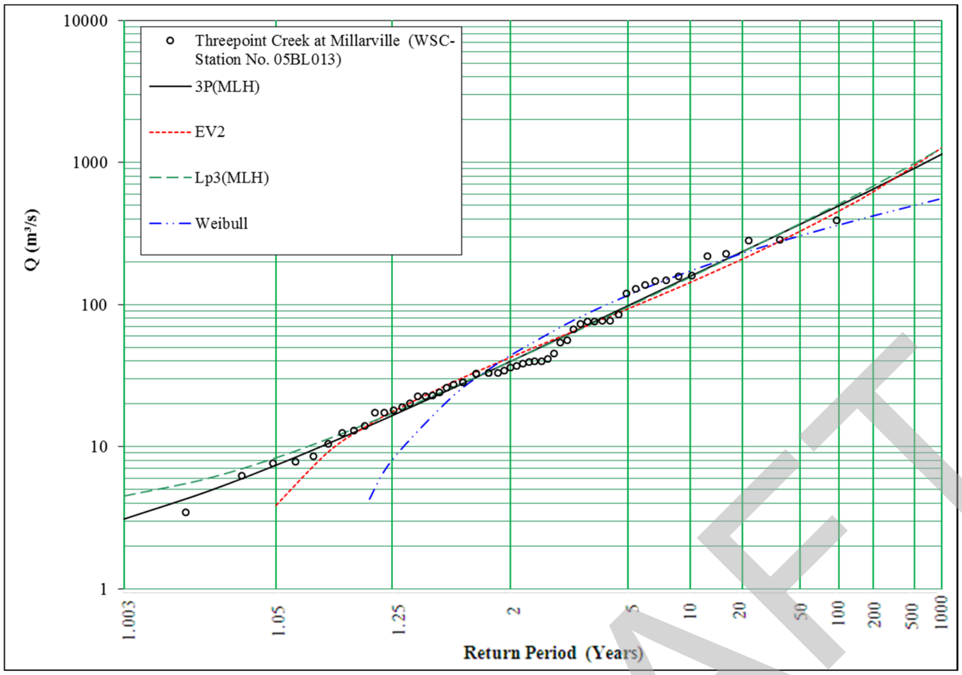
Figure C.1.61: 05BL012, Sheep River at Okotoks – extended

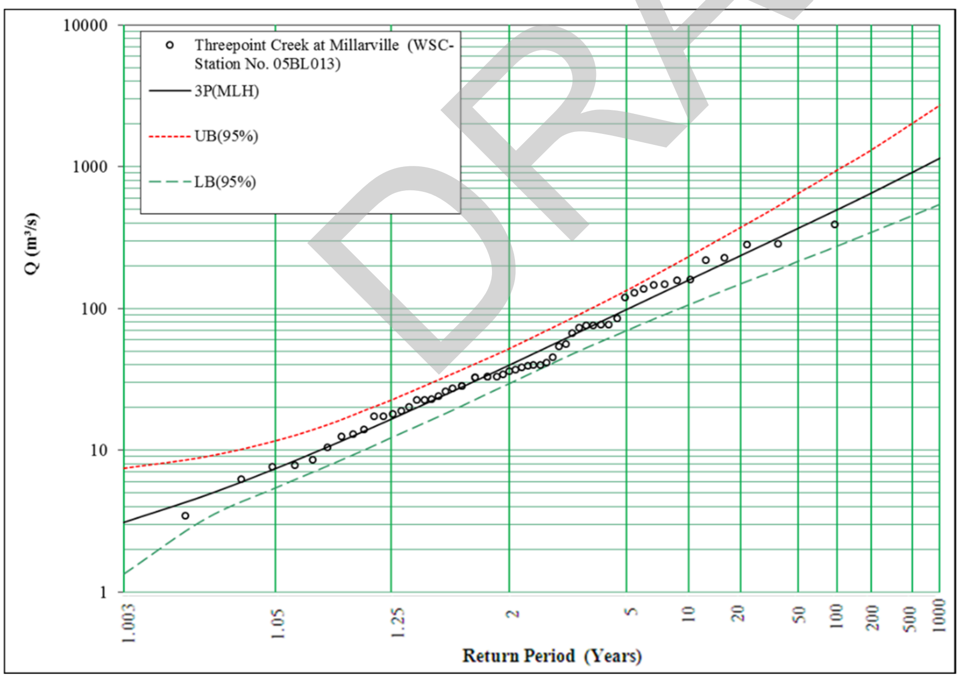




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	158	166	158	172
5	338	328	334	375
10	504	470	499	520
20	701	642	698	661
35	886	808	887	773
50	1020	929	1020	843
75	1180	1080	1190	921
100	1300	1210	1320	977
200	1640	1550	1680	1110
350	1950	1880	2010	1210
500	2180	2130	2240	1280
750	2420	2440	2530	1360
1000	2620	2690	2750	1410

Figure C.1.62: 05BL013, Threepoint Creek near Millarville

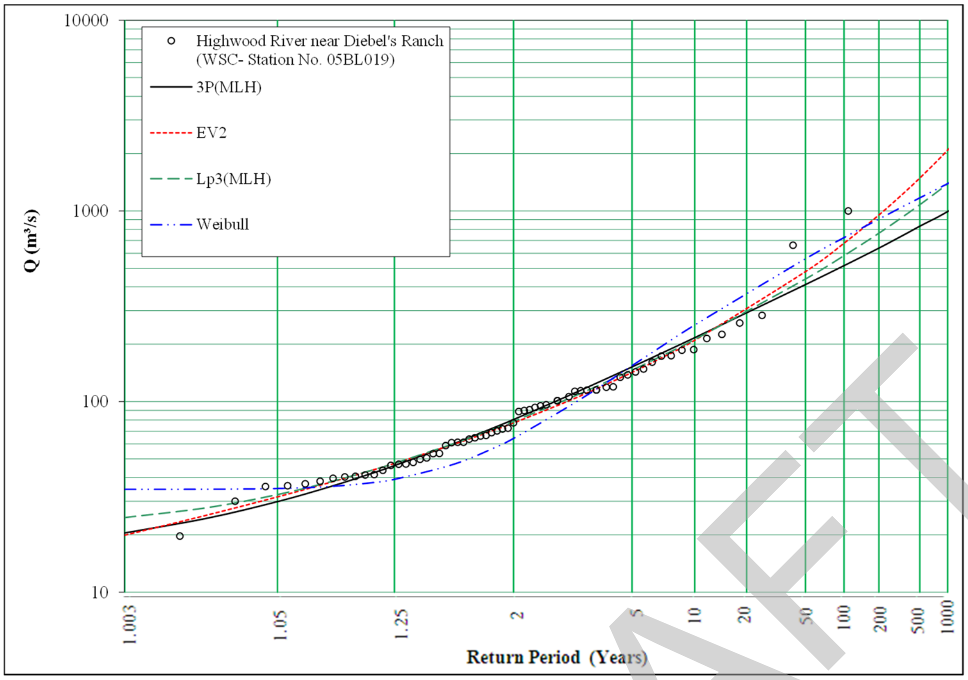


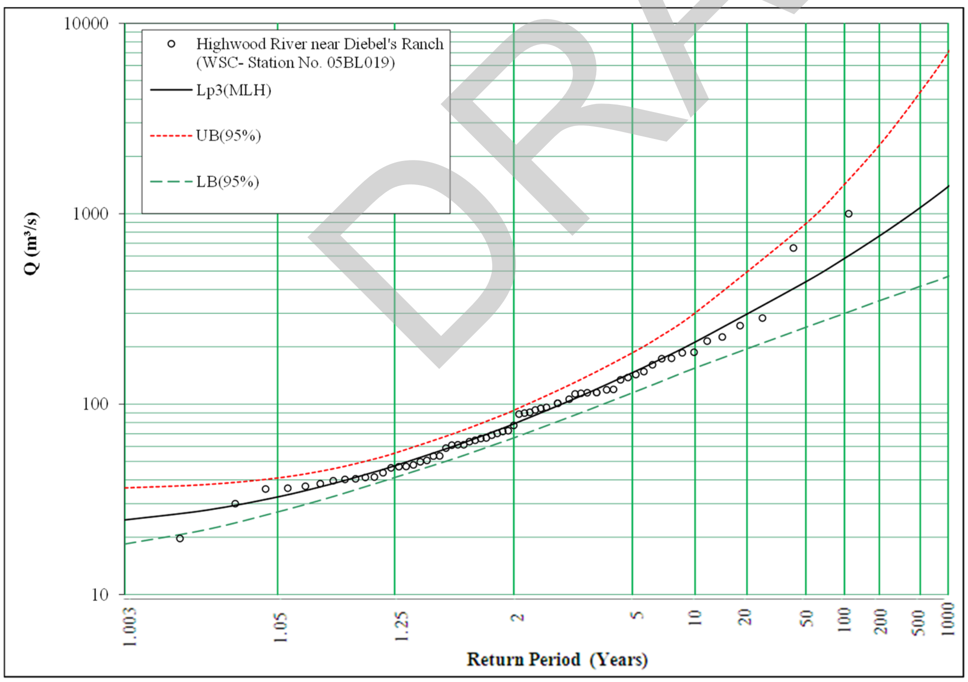


Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	39.8	42.5	39.5	43.7
5	98.2	93.3	96.2	116
10	158	143	156	172
20	235	208	233	228
35	312	276	312	274
50	368	327	371	304
75	439	396	448	337
100	495	453	509	361
200	650	621	682	419
350	803	797	852	466
500	914	932	976	496
750	1040	1110	1140	531
1000	1140	1260	1260	555

HIGHWOOD RIVER AND TRIBUTARIES

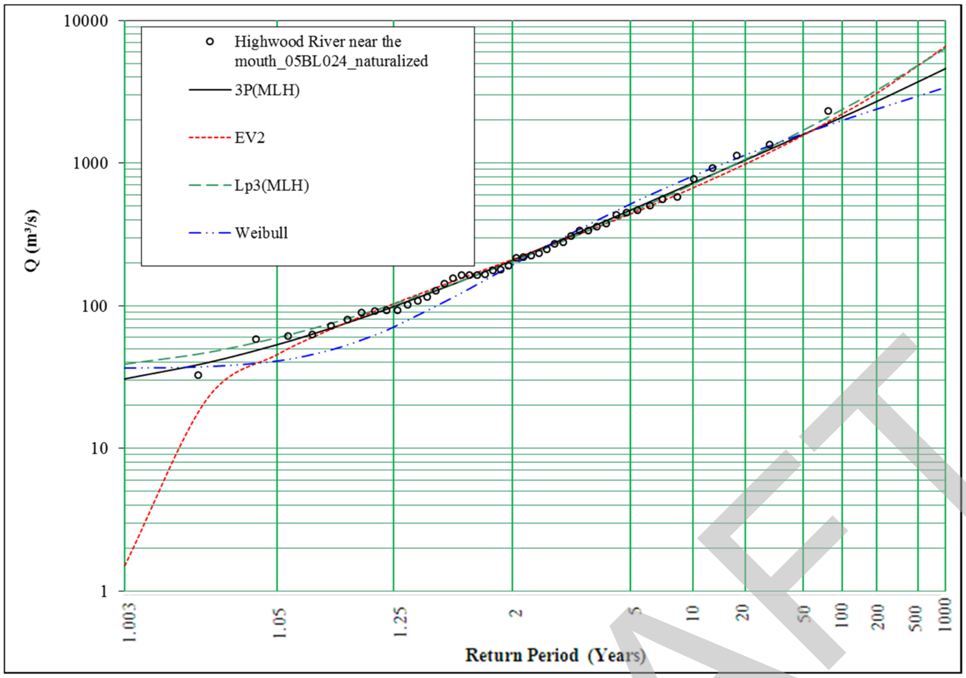
Figure C.1.63: 05BL019, Highwood River at Diebel's Ranch

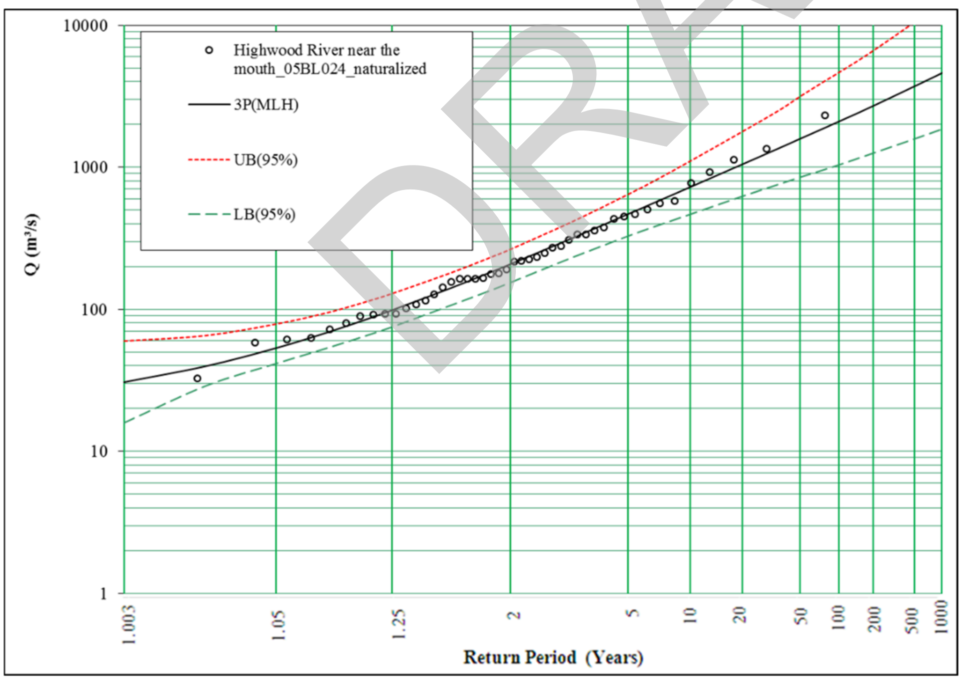




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	80.5	77.3	78.8	64.1
5	152	142	146	155
10	217	210	212	252
20	292	302	295	372
35	362	402	378	484
50	411	480	439	561
75	471	588	519	655
100	517	678	583	726
200	639	953	765	908
350	753	1250	945	1070
500	833	1490	1080	1170
750	922	1820	1250	1300
1000	993	2090	1390	1390

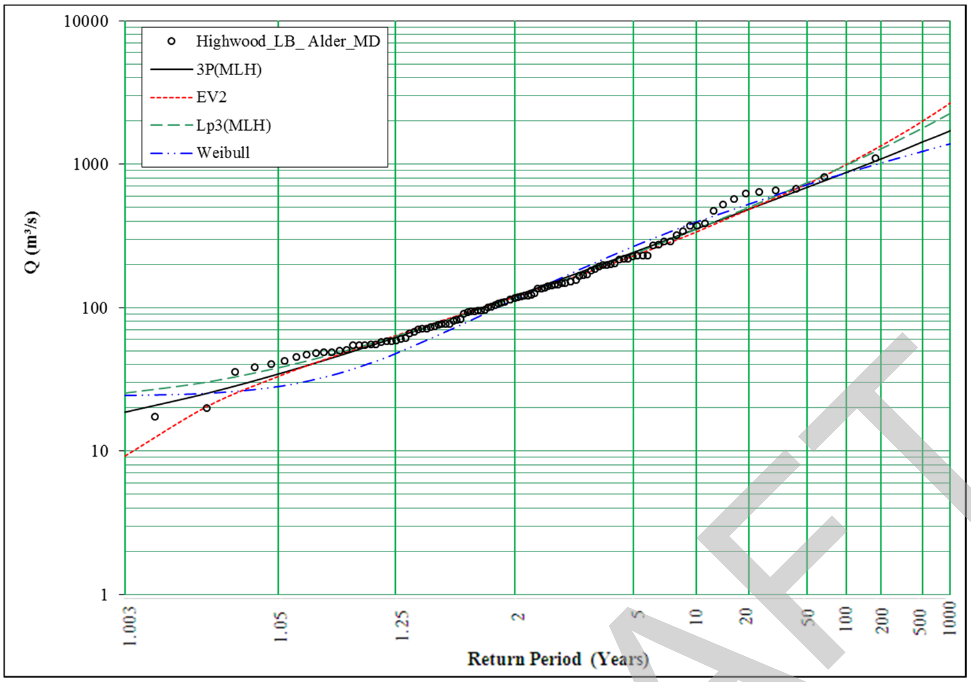
Figure C.1.64: 05BL004, Highwood River below Little Bow Canal

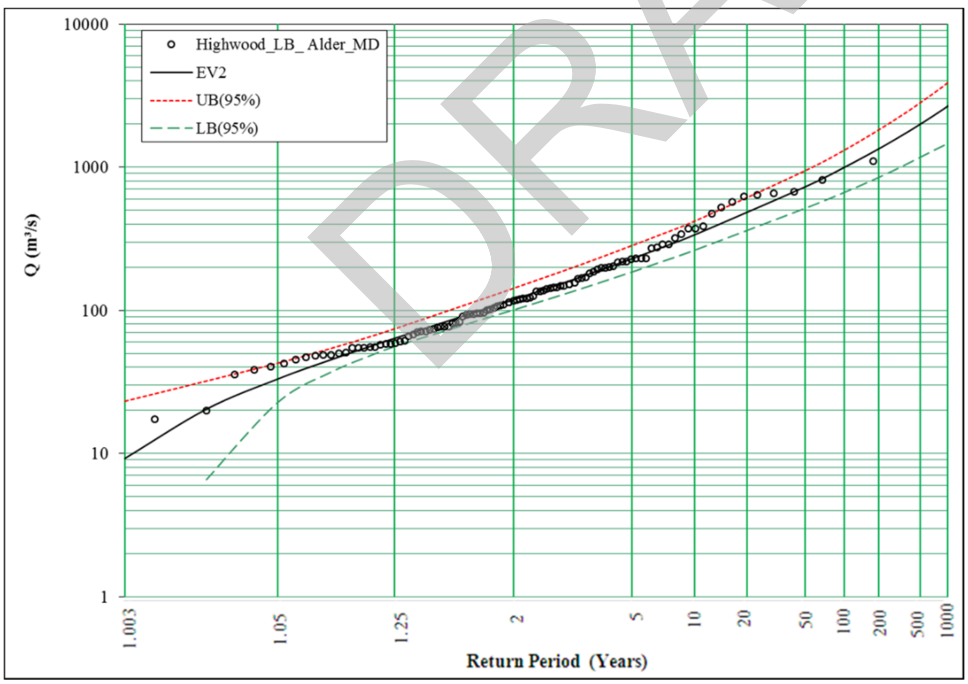




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	208	210	203	192
5	468	437	450	515
10	726	667	711	807
20	1050	976	1060	1130
35	1360	1300	1420	1410
50	1590	1560	1700	1600
75	1870	1910	2070	1820
100	2100	2190	2370	1980
200	2700	3060	3240	2380
350	3300	3990	4130	2710
500	3720	4720	4800	2930
750	4200	5710	5680	3190
1000	4590	6530	6380	3370

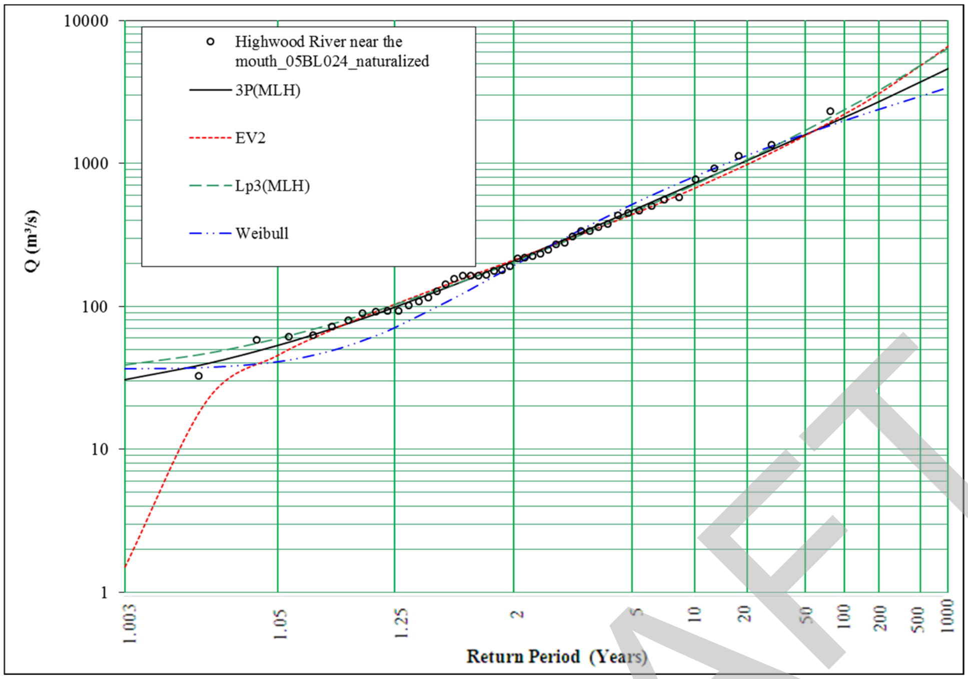
Figure C.1.65: 05BL004, Highwood River below Little Bow Canal – extended

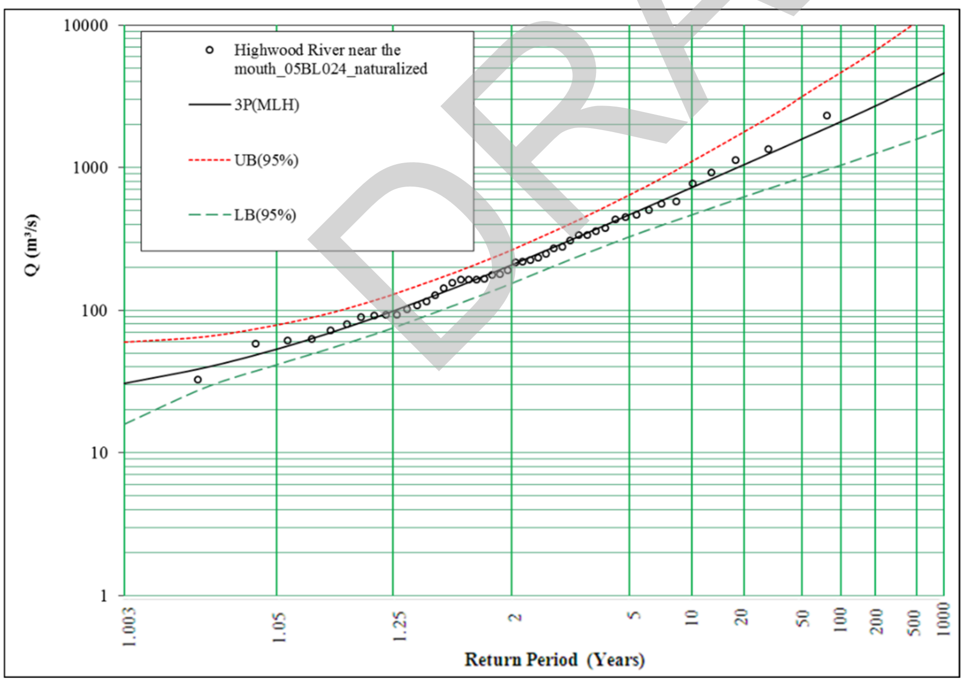




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	120	118	117	114
5	243	229	237	267
10	354	337	352	395
20	484	476	496	530
35	605	620	638	643
50	691	730	742	718
75	795	875	876	803
100	875	994	982	865
200	1090	1340	1280	1020
350	1290	1710	1560	1140
500	1430	1990	1770	1220
750	1580	2360	2040	1320
1000	1710	2670	2250	1380

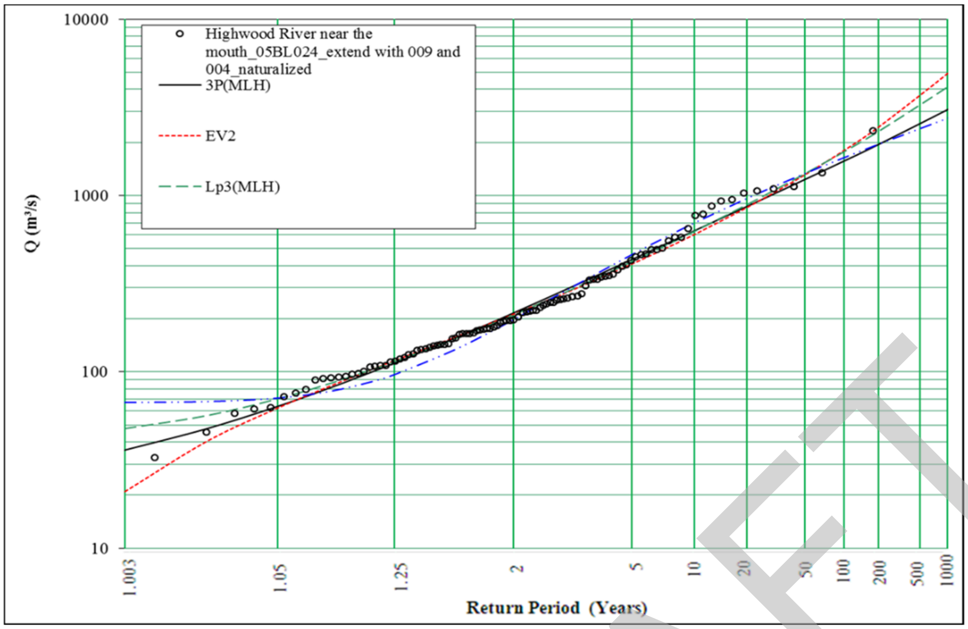
Figure C.1.66: 05BL024, Highwood River near the Mouth

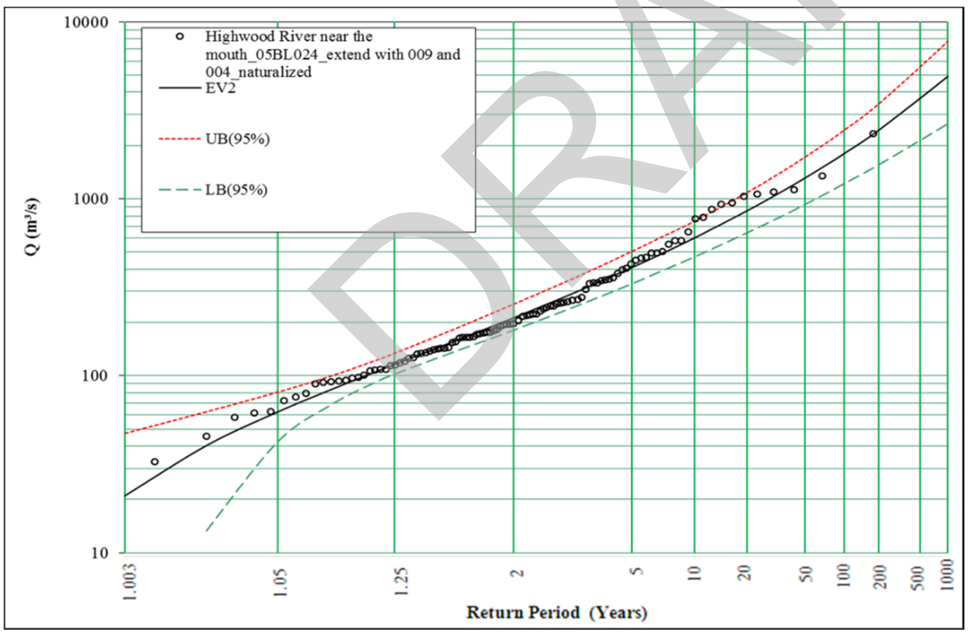




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	208	210	203	192
5	468	437	450	515
10	726	667	711	807
20	1050	976	1060	1130
35	1360	1300	1420	1410
50	1590	1560	1700	1600
75	1870	1910	2070	1820
100	2100	2190	2370	1980
200	2700	3060	3240	2380
350	3300	3990	4130	2710
500	3720	4720	4800	2930
750	4200	5710	5680	3190
1000	4590	6530	6380	3370

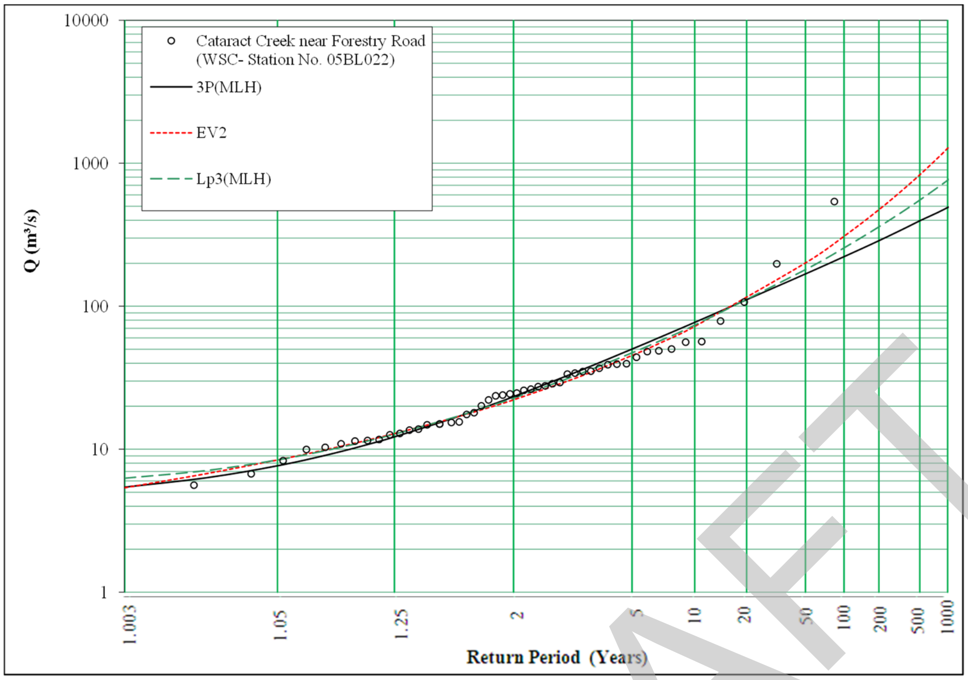
Figure C.1.67: 05BL024, Highwood River near the Mouth – extended

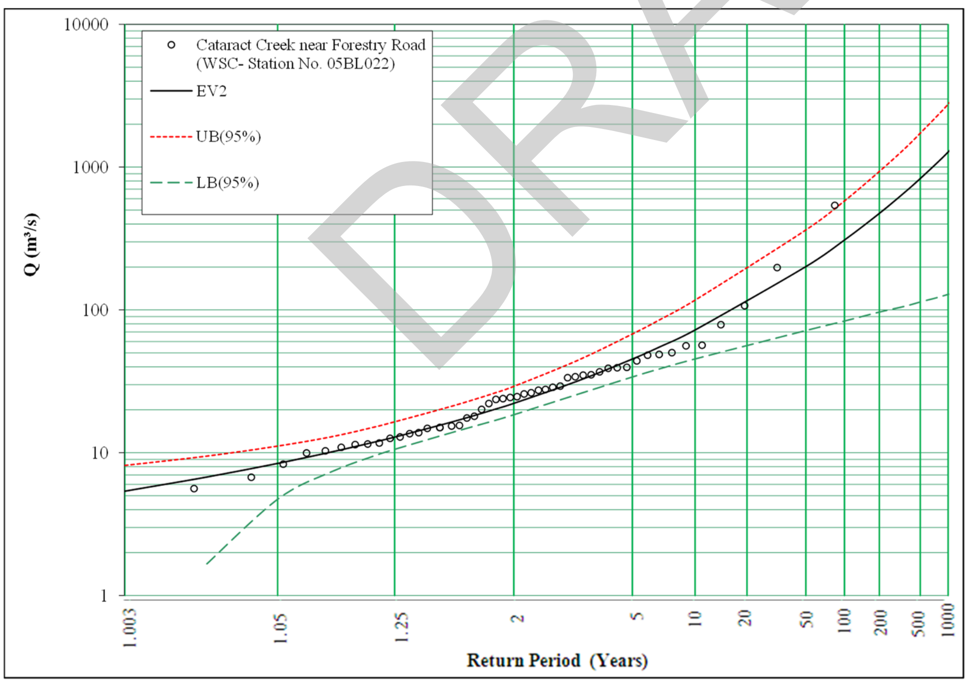




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	216	212	211	197
5	434	409	423	461
10	632	602	628	697
20	865	853	887	957
35	1080	1110	1140	1180
50	1240	1310	1330	1330
75	1420	1580	1580	1500
100	1570	1800	1770	1630
200	1950	2440	2310	1950
350	2310	3120	2850	2210
500	2560	3640	3240	2380
750	2840	4340	3730	2590
1000	3070	4910	4120	2730

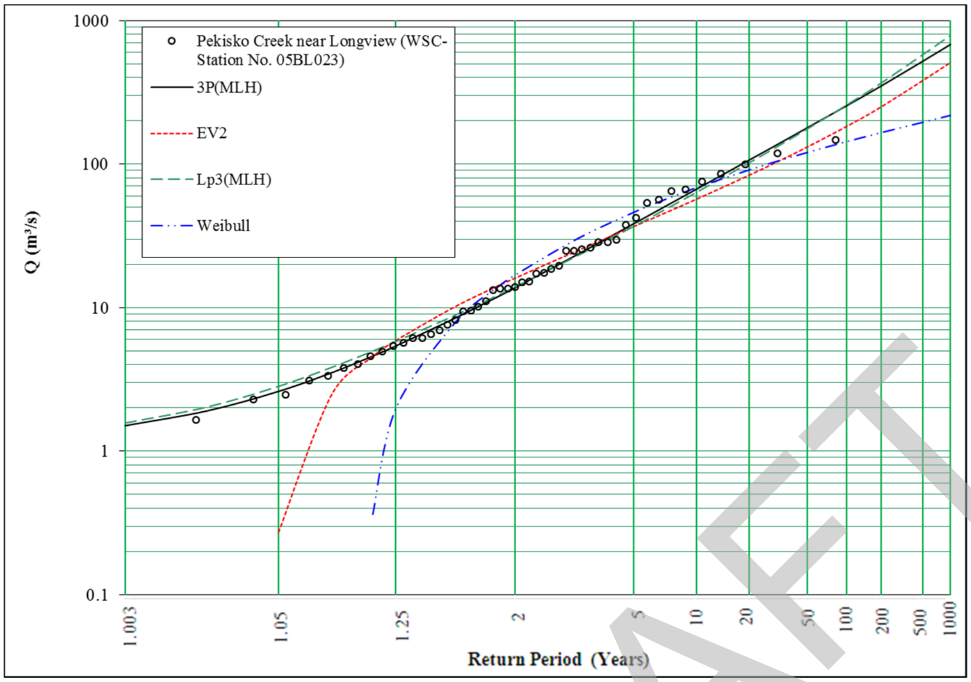
Figure C.1.68: 05BL022, Cataract Creek near Forestry Road

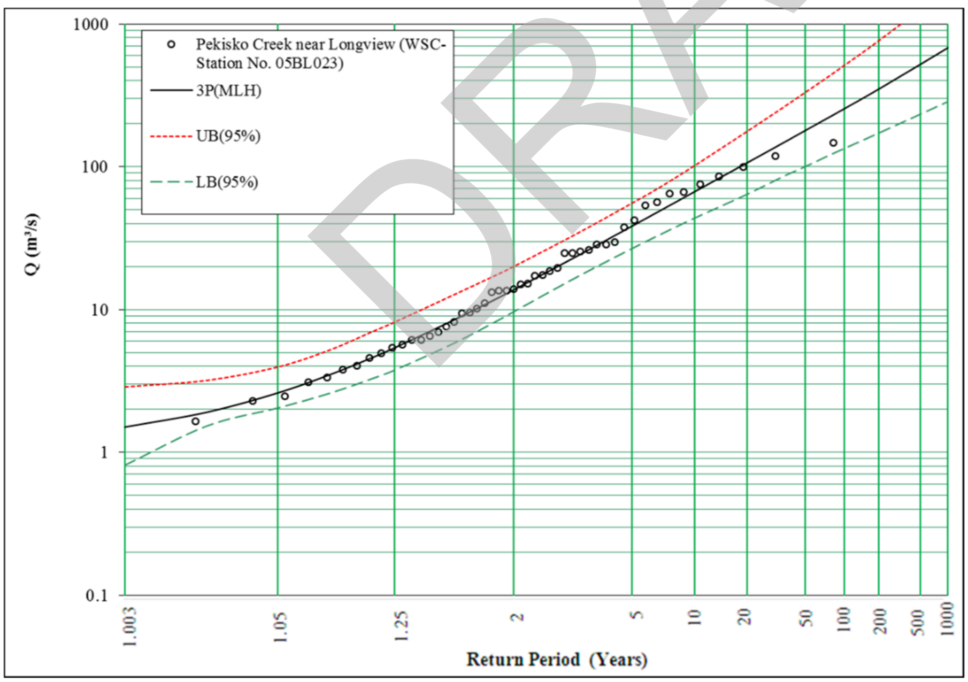




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	23.3	22.2	22.8	
5	50.2	45.4	47.3	
10	77.2	72.4	73.9	
20	111	113	110	
35	144	161	150	
50	168	201	180	
75	199	259	222	
100	222	309	256	
200	288	475	359	
350	351	670	469	
500	397	834	554	
750	449	1070	668	
1000	491	1280	762	

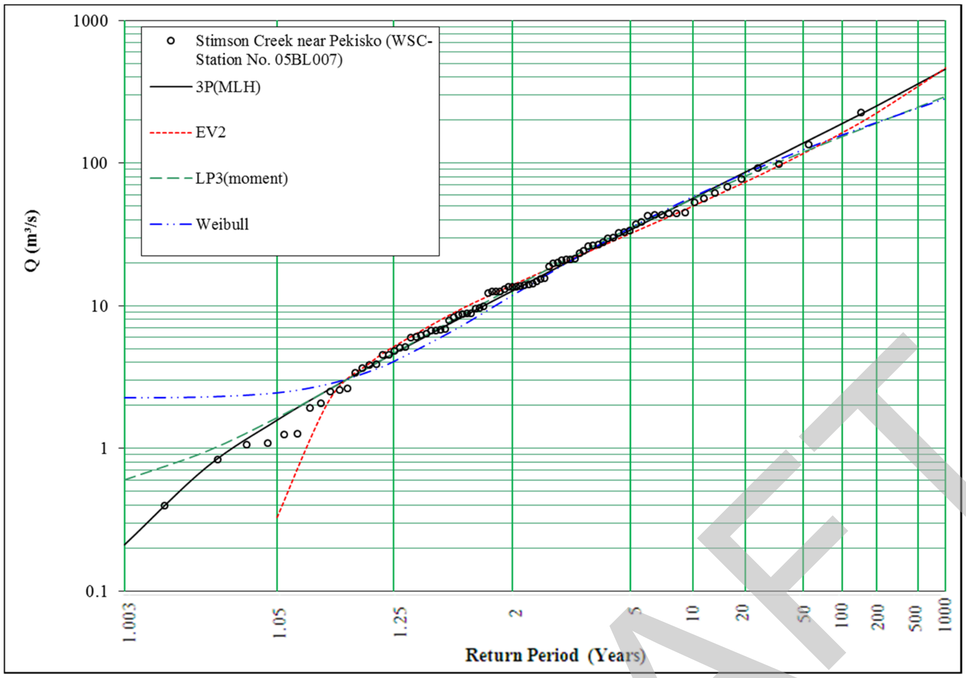
Figure C.1.69: 05BL023, Pekisko Creek near Longview

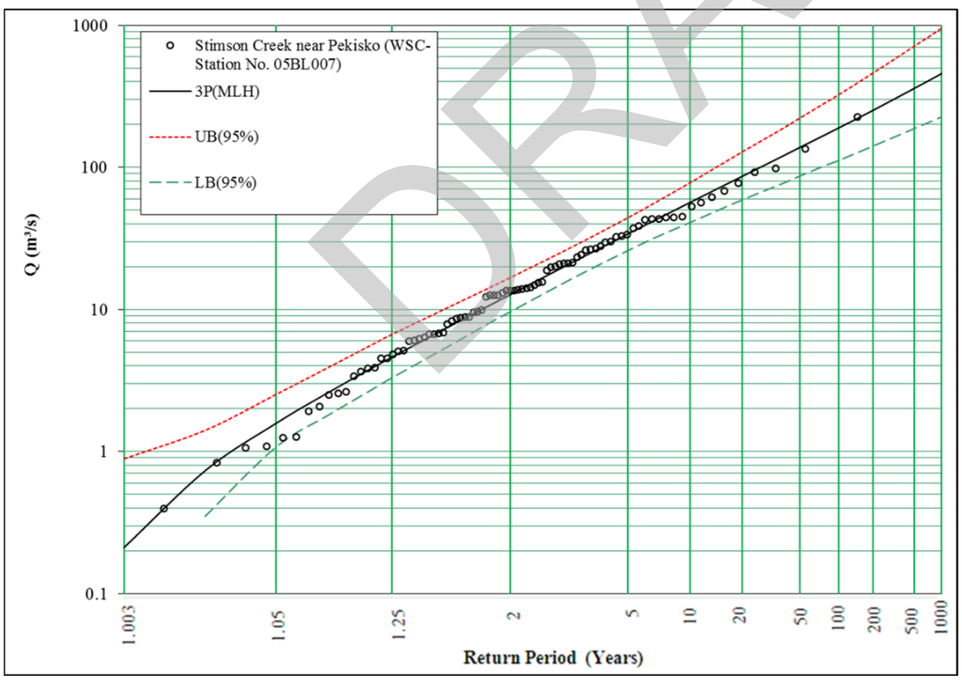




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	13.7	16.1	13.9	16.9
5	38.4	36.8	36.8	46.3
10	66.9	57.1	63.5	68.6
20	106	83.5	102	91
35	148	111	143	109
50	180	132	176	121
75	221	160	220	134
100	254	183	257	143
200	350	251	366	166
350	449	322	481	184
500	522	376	570	196
750	608	449	687	209
1000	680	509	783	218

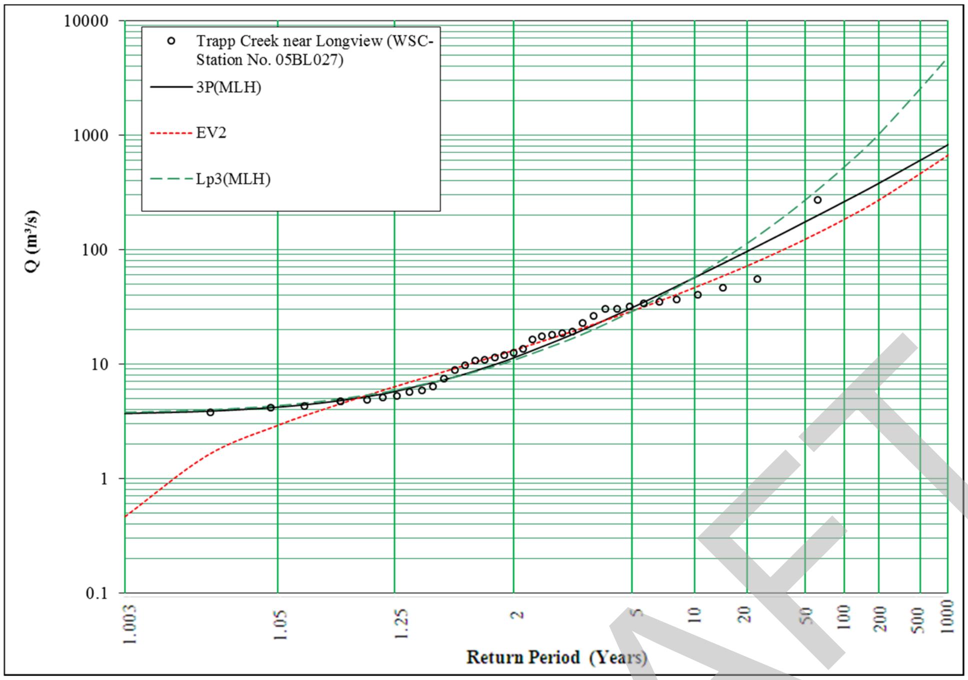
Figure C.1.70: 05BL007, Stimson Creek near Pekisko

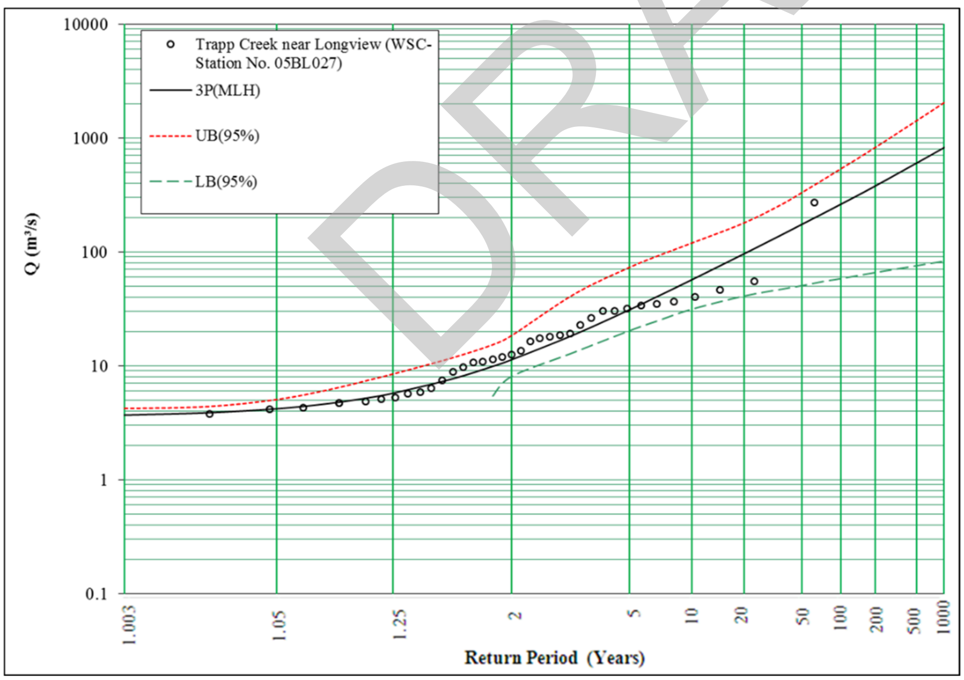




Return Period	3P(MLH)	EV2	LP3(moment)	Weibull
2	12.7	14	13.3	11.8
5	34	32.2	34.9	35.3
10	56.6	50.1	55.7	58.3
20	86.2	73.7	80.3	84.8
35	116	98.3	103	108
50	138	117	119	124
75	167	143	138	144
100	189	163	152	158
200	252	225	189	193
350	314	291	222	224
500	360	341	245	244
750	413	409	271	267
1000	456	464	291	284

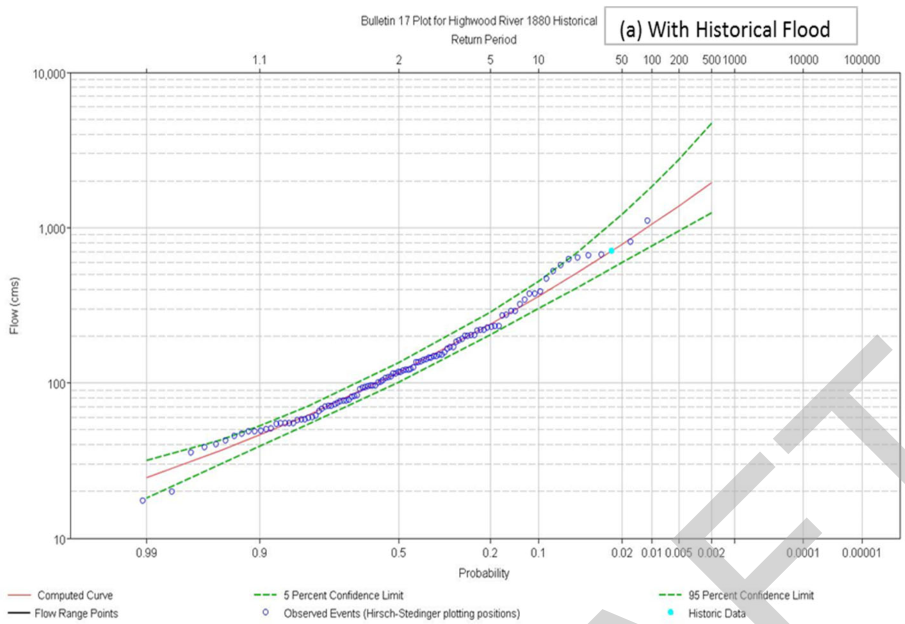
Figure C.1.71: 05BL027, Trapp Creek near Longview

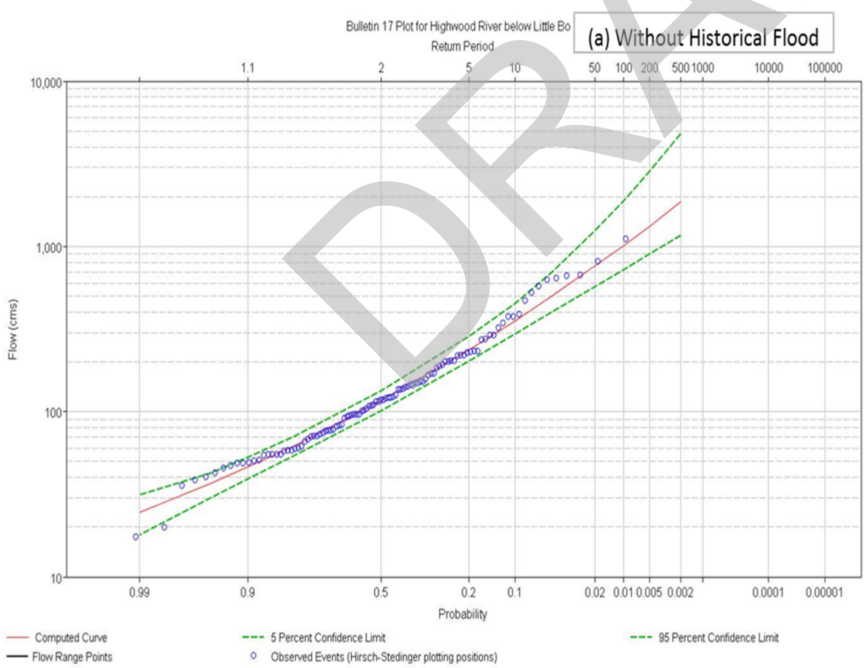




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	11.3	13.1	10.8	
5	31	29	28.8	
10	56.9	46.5	57.3	
20	95.8	71.6	112	
35	139	99.8	192	
50	175	123	270	
75	222	155	397	
100	261	183	522	
200	379	270	1010	
350	505	369	1720	
500	602	450	2420	
750	719	564	3570	
1000	819	661	4710	

Figure C.1.72: Highwood River below Little Bow Canal – Using Bulletin 17C Method





Return	Flood Flow Estimates (m^3/s)		
Period	With Historical Flood	Without Historical Flood	Ratio
2	117	117	1.00
5	240	238	1.01
10	361	355	1.02
20	515	504	1.02
35	669	651	1.03
50	784	761	1.03
75	932	901	1.03
100	1050	1012	1.04
200	1383	1326	1.04
350	1712	1633	1.05
500	1954	1857	1.05
750	2263	2144	1.06
1000	2507	2369	1.06

APPENDIX C.2

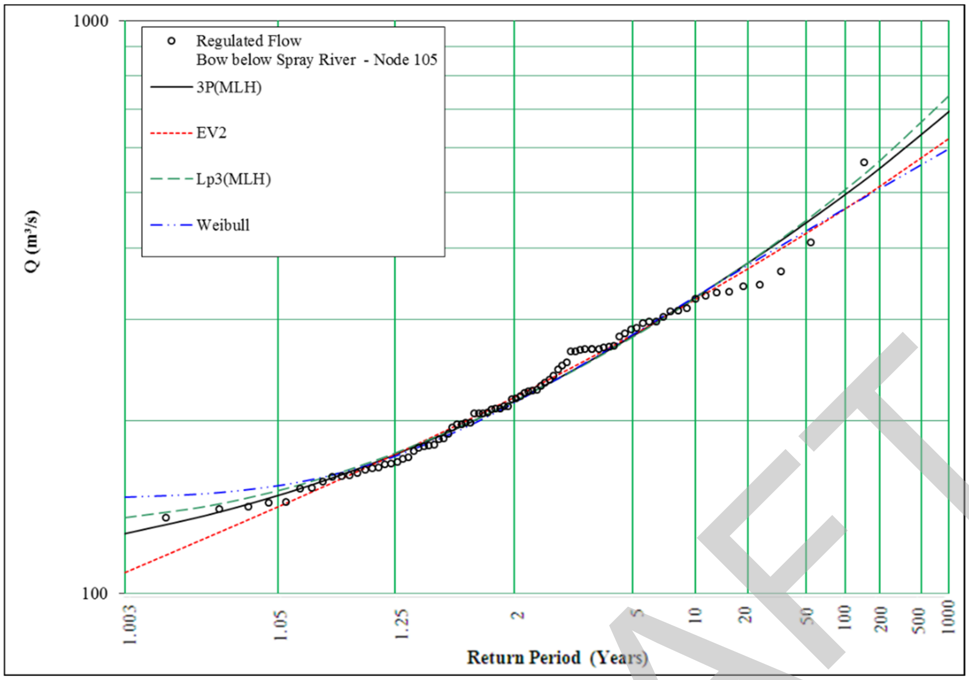
Frequency Distribution Plots - Recorded and Regulated Flows

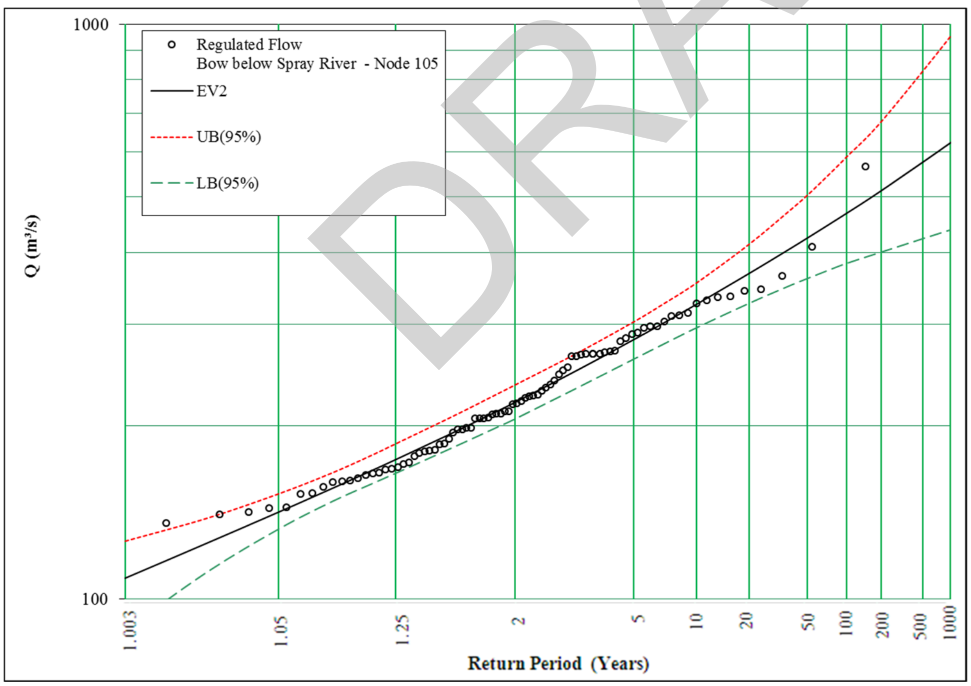
This document has a compilation of graphs and results from frequency analysis of

- **recorded and regulated flows at selected assessment nodes, including extended datasets and historic floods, and each station will have the following graphs:**
- **frequency distribution graph - all distributions;**
- **frequency distribution graph - best fit graph with confidence interval; and**
- **flood estimates - all distributions.**

BOW RIVER

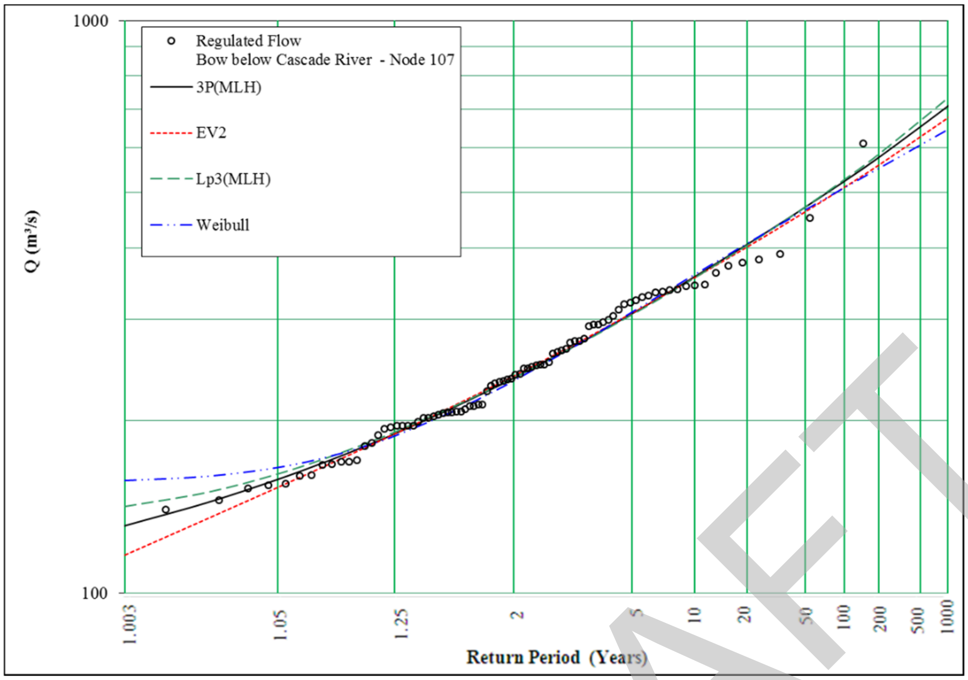
Figure C.2.1: Node 105, Bow River below Spray River

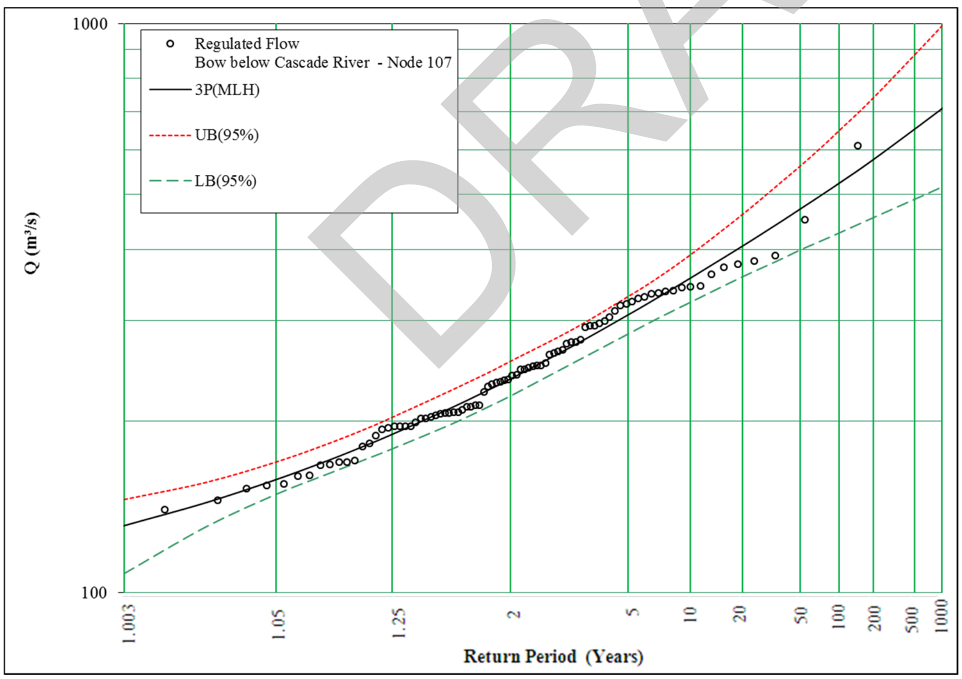




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	216	220	216	215
5	281	282	280	283
10	329	326	327	329
20	377	368	377	373
35	417	402	419	407
50	444	425	447	429
75	474	450	481	452
100	496	468	505	469
200	552	513	569	508
350	600	550	623	539
500	632	574	661	559
750	667	601	705	581
1000	693	621	738	596

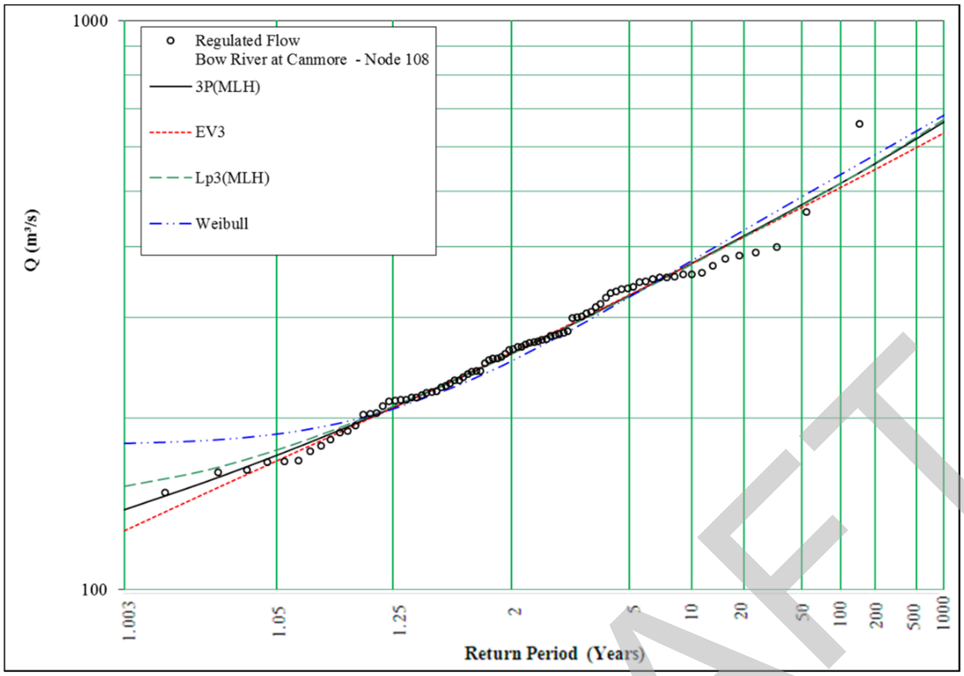
Figure C.2.2: Node 107, Bow River below Cascade River

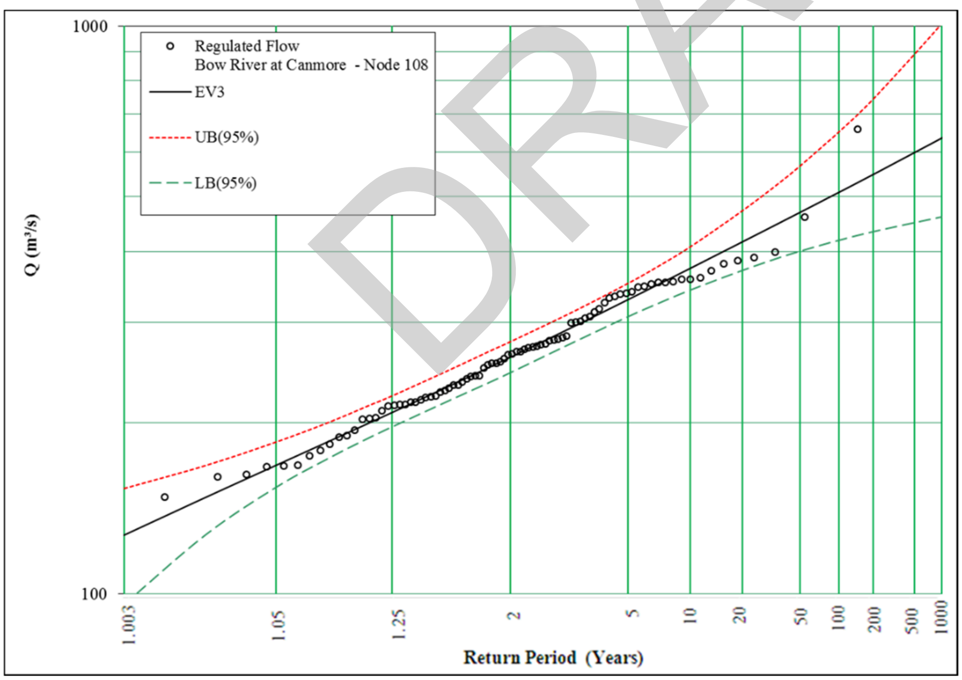




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	237	239	237	234
5	308	308	306	309
10	357	355	355	360
20	406	402	405	407
35	446	439	446	443
50	472	463	473	466
75	502	491	504	492
100	524	511	527	509
200	577	559	584	551
350	622	599	633	584
500	652	625	666	604
750	684	654	704	627
1000	708	675	732	644

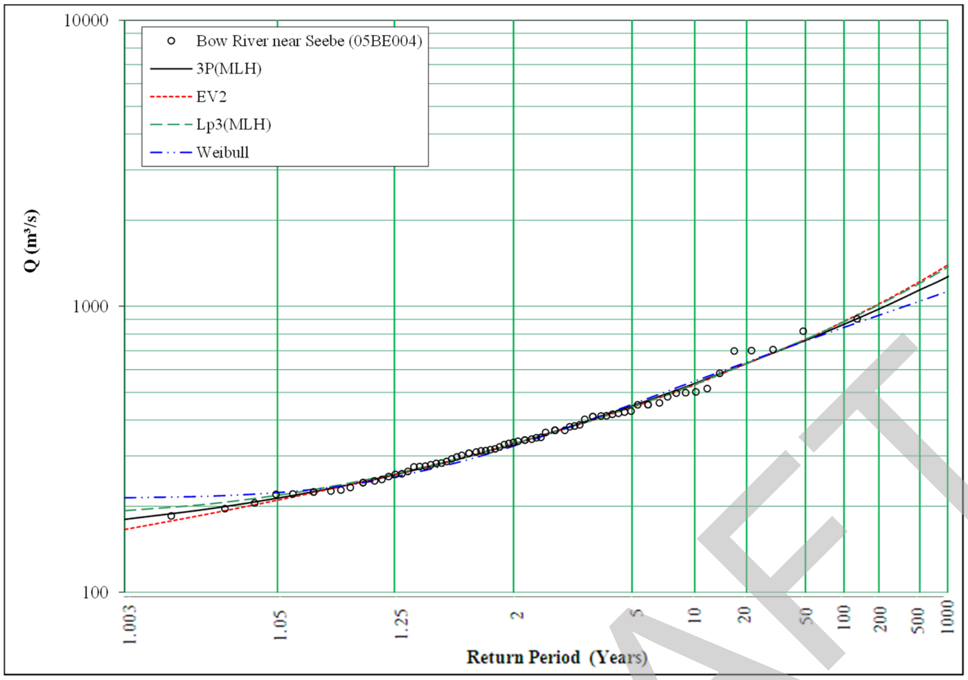
Figure C.2.3: Node 108, Bow River at Canmore – regulated

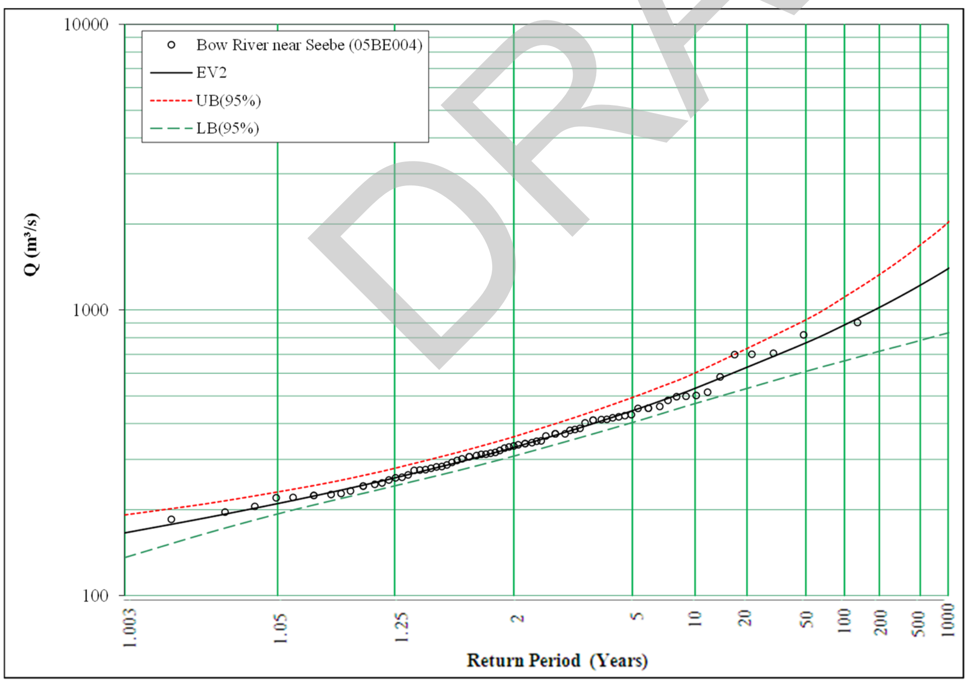




Return Period	3P(MLH)	EV3	Lp3(MLH)	Weibull
2	259	261	259	252
5	329	330	327	327
10	374	374	373	378
20	418	416	416	428
35	452	449	451	466
50	475	470	473	490
75	499	493	499	517
100	517	509	517	536
200	560	548	561	580
350	596	578	598	616
500	620	597	622	638
750	644	619	649	663
1000	663	634	669	681

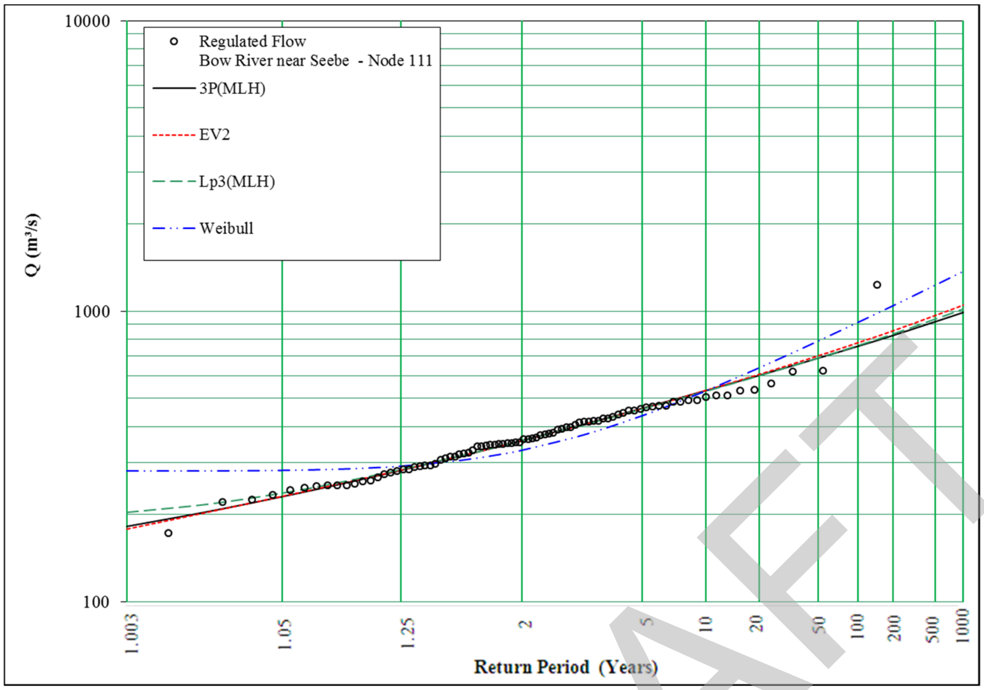
Figure C.2.4: 05BE004 / Node 111, Bow River near Seebe – recorded regulated

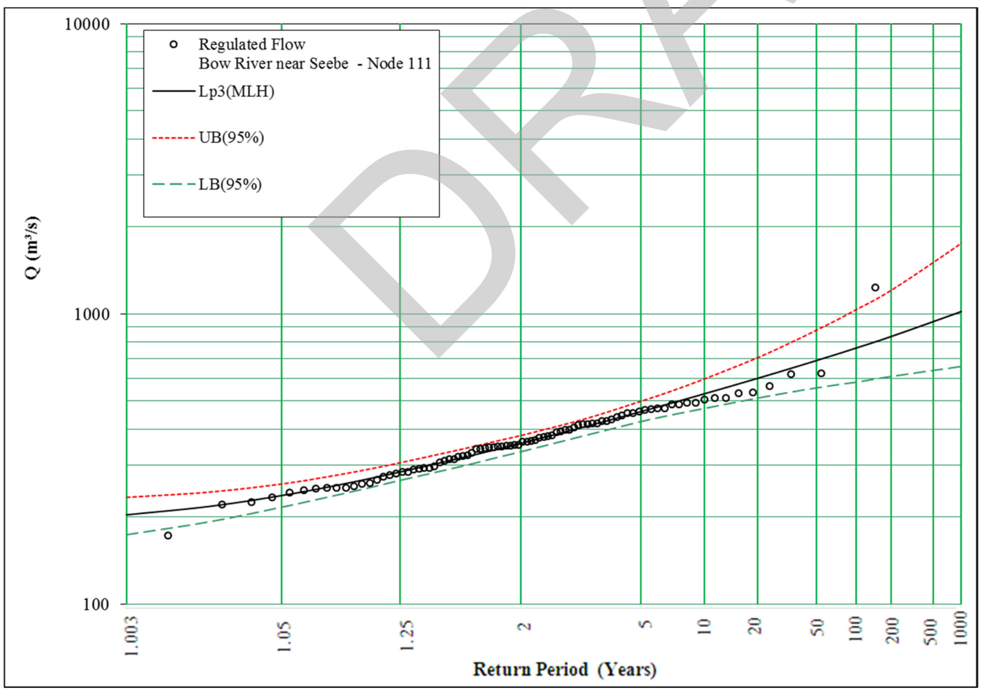




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	330	330	330	324
5	448	444	445	454
10	537	532	533	547
20	630	626	628	638
35	708	710	710	711
50	760	767	766	756
75	821	835	833	807
100	866	887	883	844
200	978	1020	1010	930
350	1080	1140	1130	999
500	1140	1220	1210	1040
750	1210	1320	1300	1090
1000	1270	1400	1370	1130

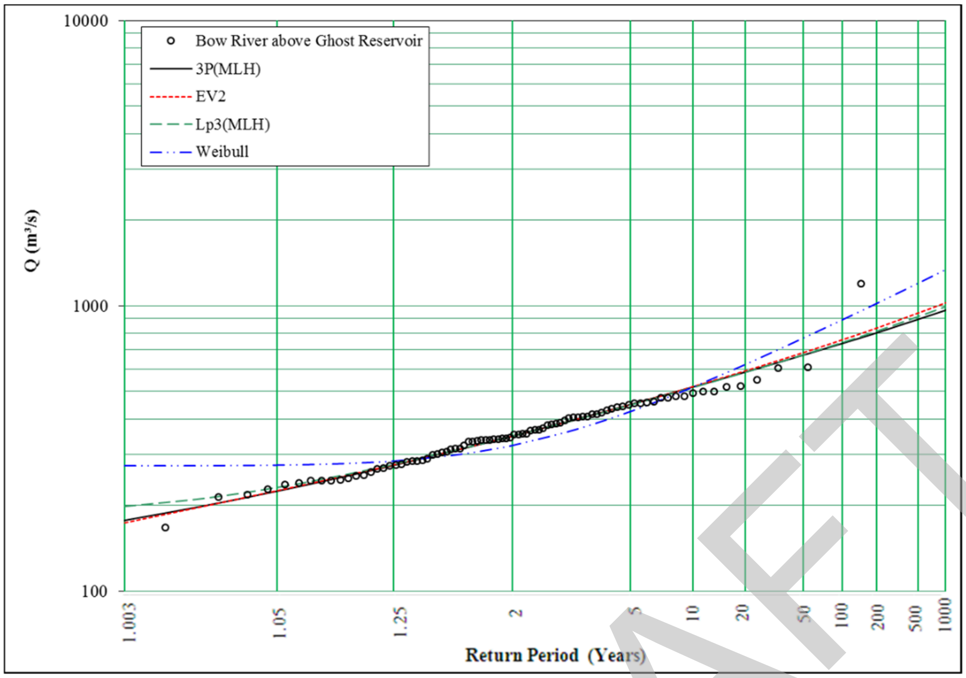
Figure C.2.5: 05BE004 / Node 111, Bow River near Seebe – regulated

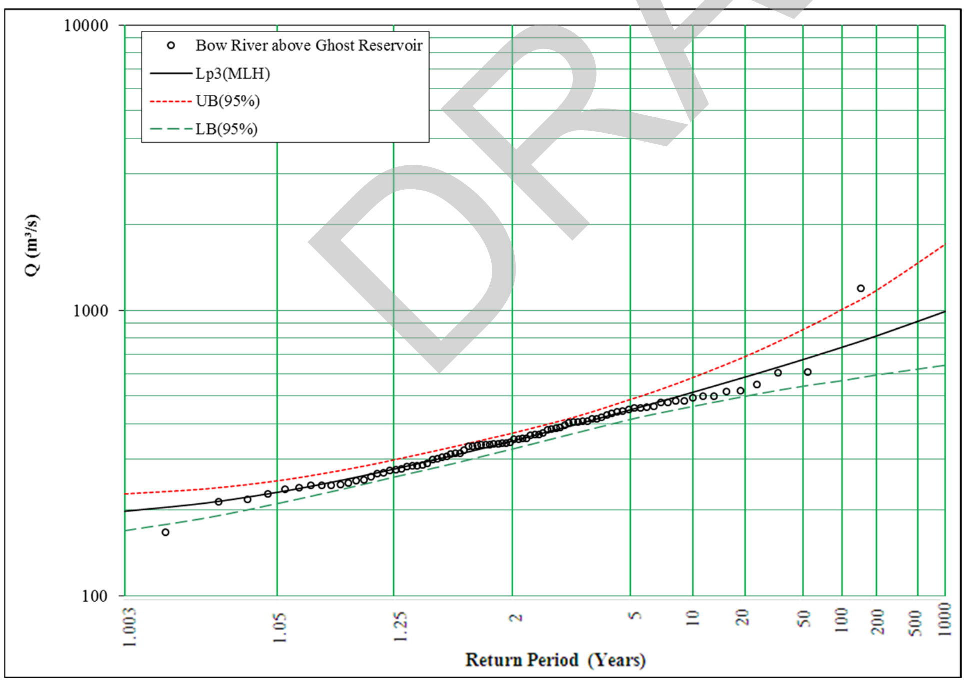




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	358	357	358	333
5	463	462	460	437
10	533	534	530	533
20	601	606	599	638
35	655	665	655	729
50	690	703	691	790
75	729	747	732	862
100	757	779	762	914
200	825	857	836	1040
350	883	922	897	1150
500	920	965	937	1220
750	959	1010	984	1310
1000	989	1050	1020	1370

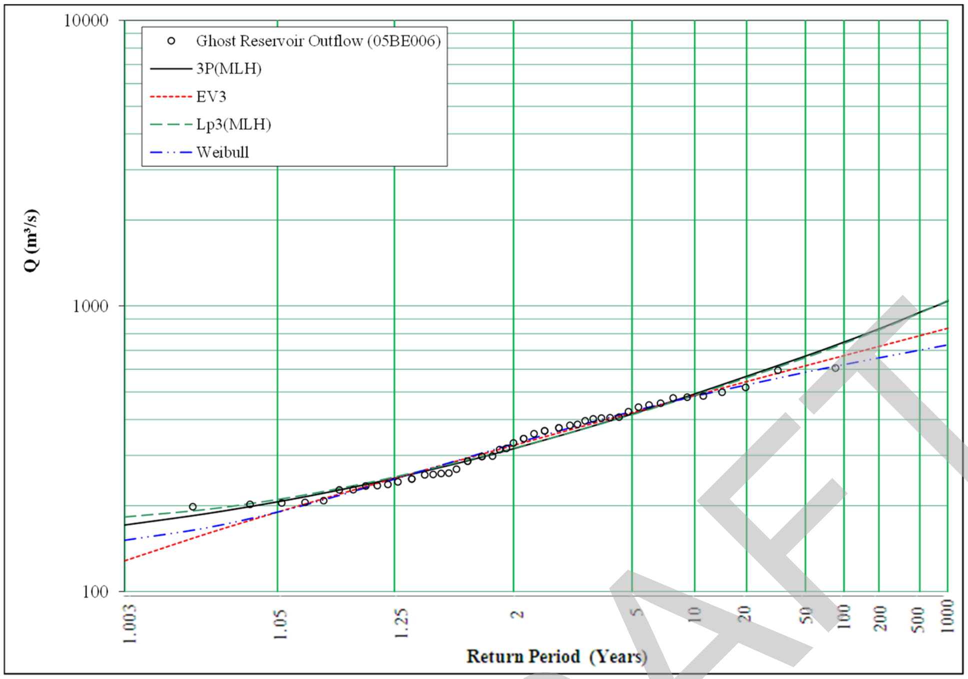
Figure C.2.6: Node 318, Bow River above Ghost Reservoir

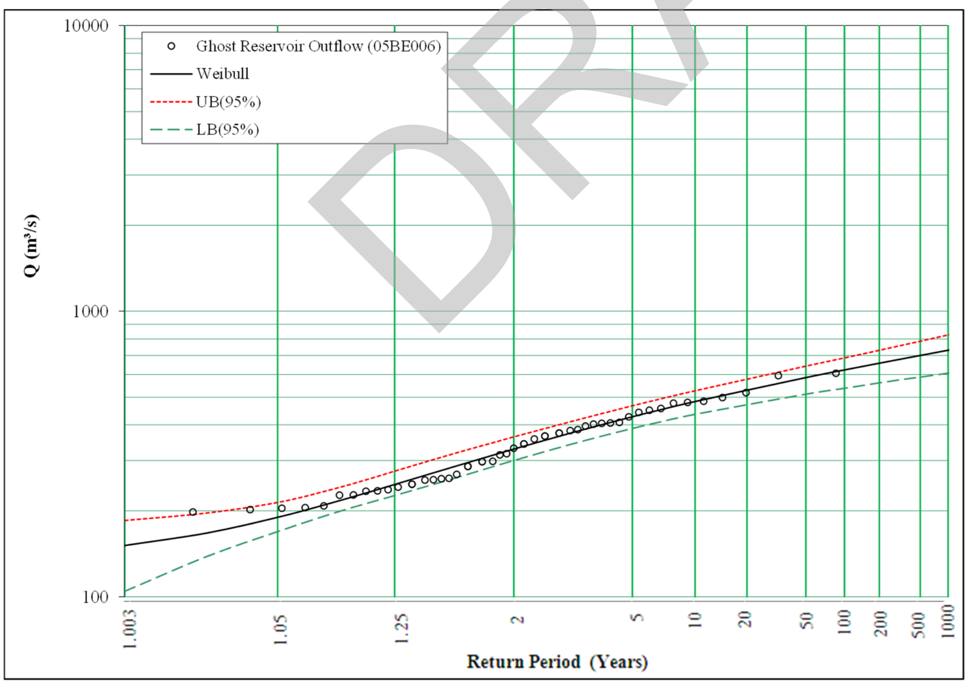




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	349	348	348	324
5	451	449	448	426
10	519	520	516	518
20	585	590	583	621
35	637	647	638	710
50	671	684	673	769
75	709	727	713	839
100	737	758	742	890
200	803	835	814	1020
350	859	898	873	1120
500	896	939	912	1190
750	934	987	958	1270
1000	963	1020	991	1330

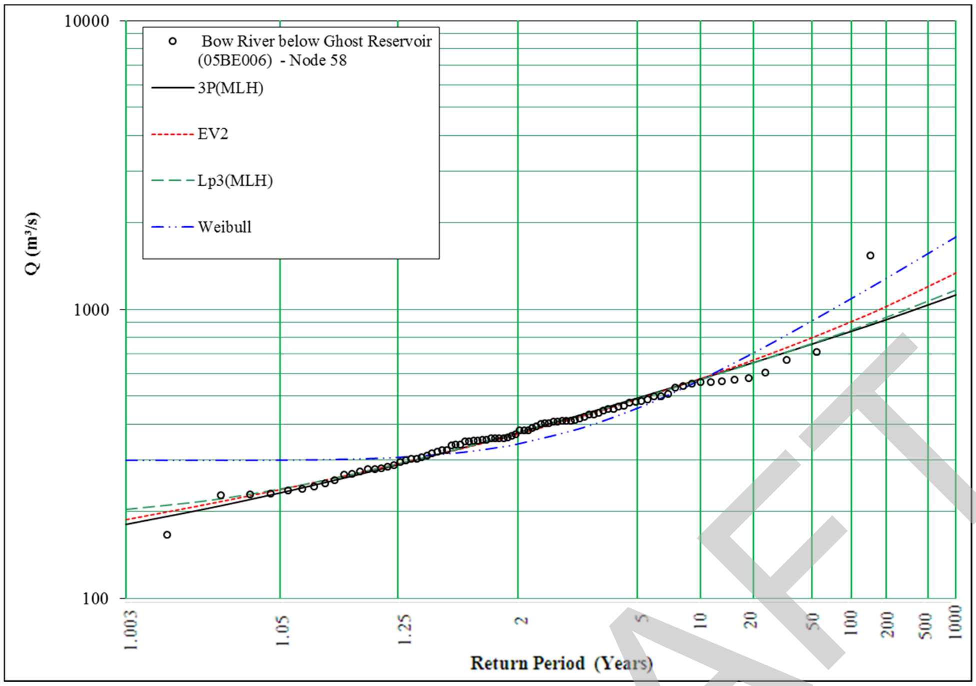
Figure C.2.7: 05BE006 / Node 58, Bow River below Ghost Dam (Ghost Reservoir Outflow) – recorded regulated

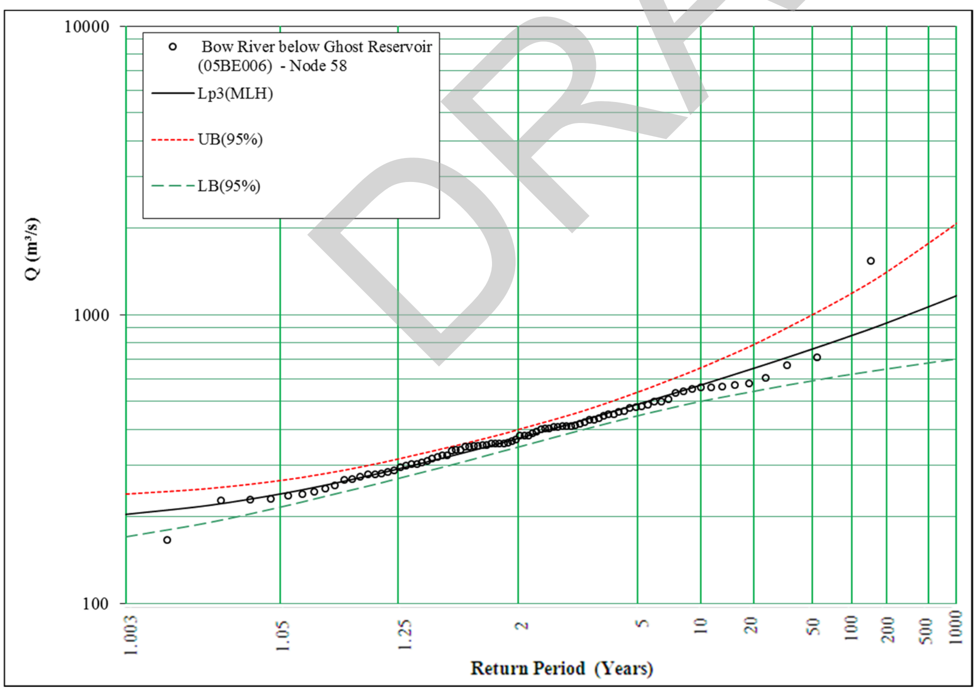




Return Period	3P(MLH)	EV3	Lp3(MLH)	Weibull
2	316	325	318	329
5	419	423	417	427
10	492	486	487	483
20	566	544	559	531
35	627	589	620	565
50	668	617	659	586
75	714	648	706	608
100	748	670	740	623
200	831	722	825	658
350	903	762	898	684
500	951	787	946	700
750	1000	816	1000	718
1000	1040	835	1050	730

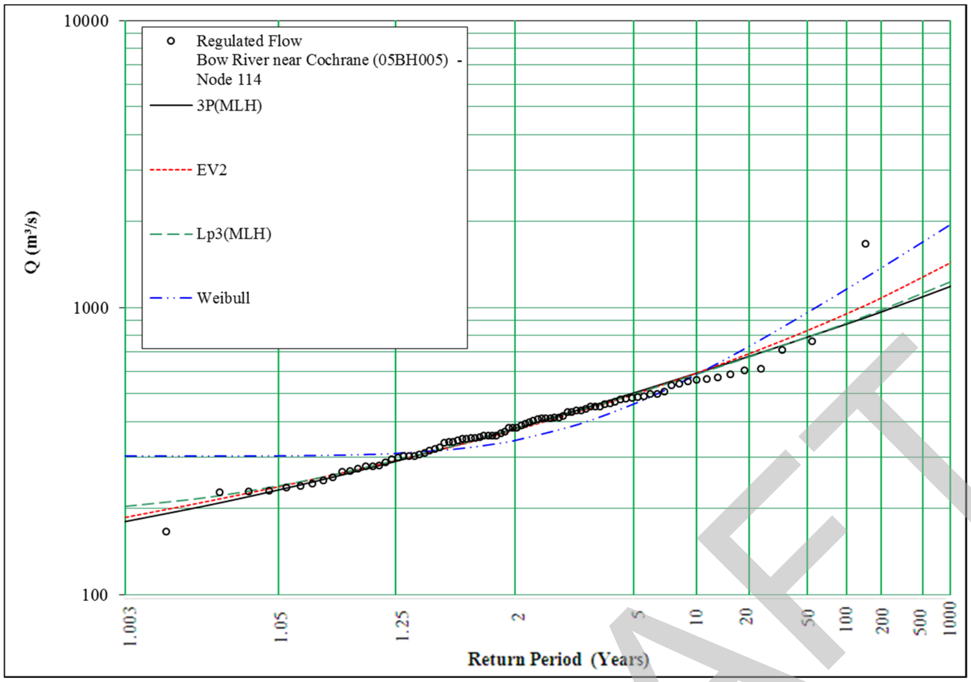
Figure C.2.8: 05BE006 / Node 58, Bow River below Ghost Dam (Ghost Reservoir Outflow) – regulated

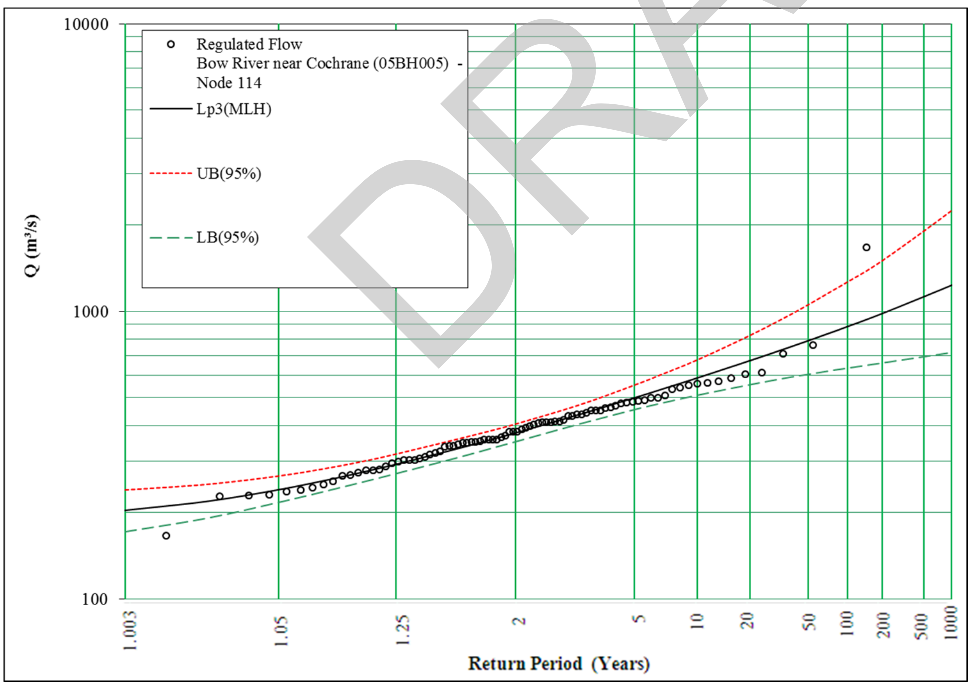




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	374	370	373	341
5	493	488	490	454
10	574	576	571	569
20	654	667	652	705
35	718	746	718	828
50	759	798	761	912
75	806	861	811	1010
100	839	907	847	1090
200	921	1020	937	1280
350	991	1130	1010	1450
500	1040	1190	1060	1560
750	1080	1280	1120	1690
1000	1120	1340	1160	1780

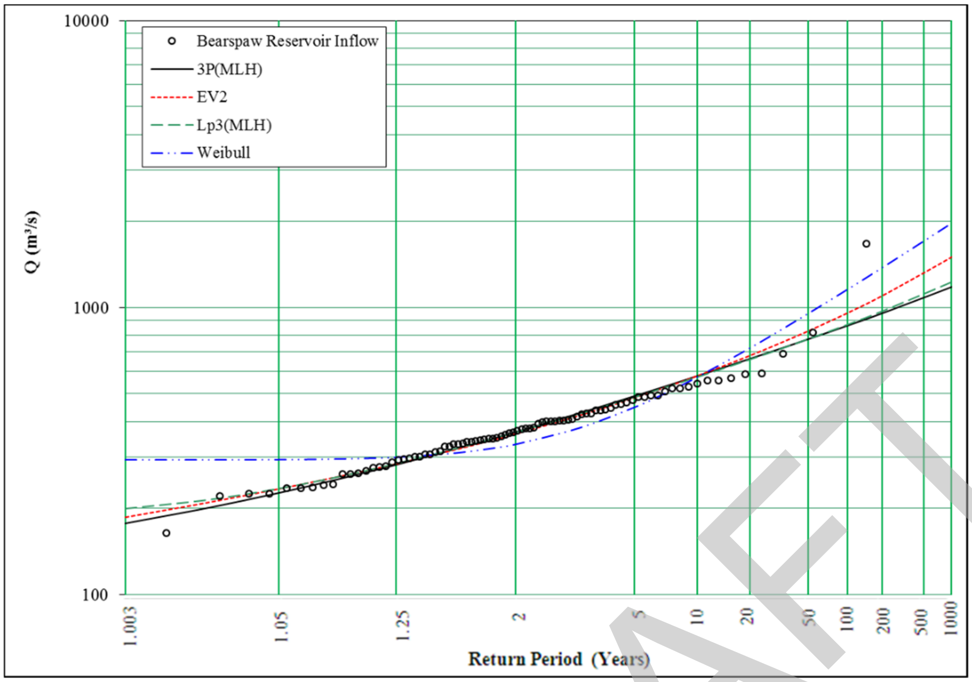
Figure C.2.9: 05BH005 / Node 114, Bow River near Cochrane

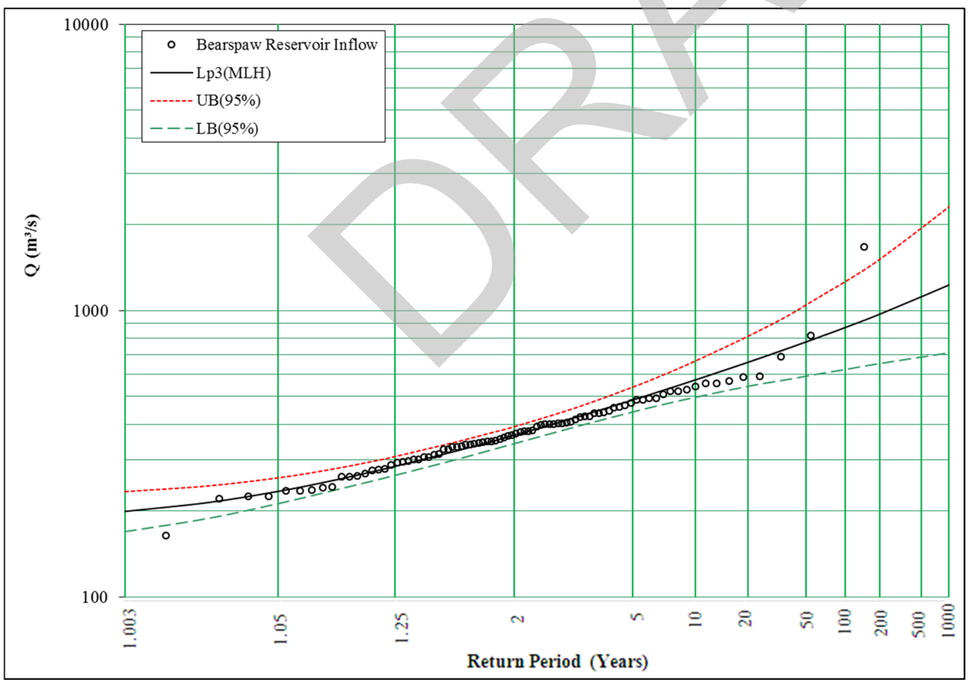




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	378	375	377	344
5	504	499	500	461
10	591	592	587	584
20	676	691	673	731
35	744	776	744	867
50	789	833	791	961
75	840	901	845	1070
100	876	952	885	1160
200	965	1080	983	1370
350	1040	1190	1070	1560
500	1090	1270	1120	1690
750	1140	1360	1180	1840
1000	1180	1430	1230	1940

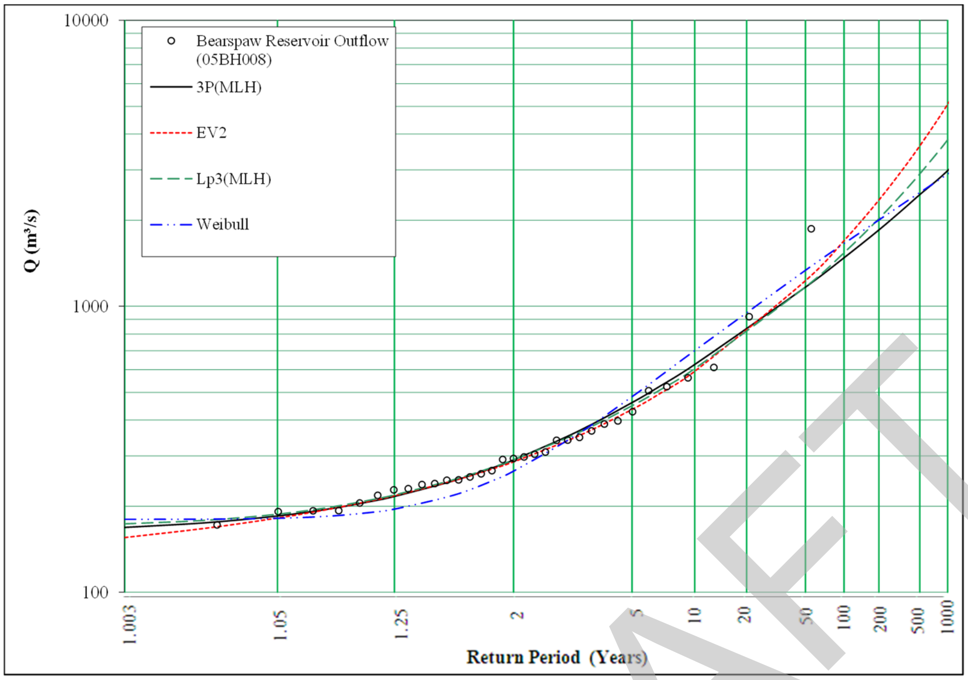
Figure C.2.10: Node 302, Bearspaw Reservoir Inflow

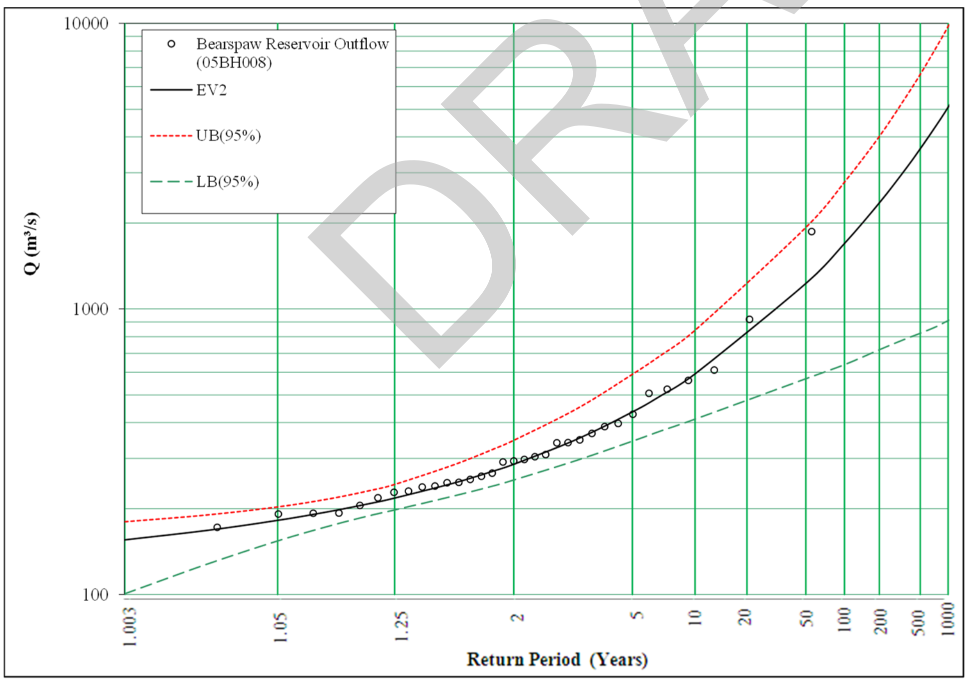




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	368	363	367	333
5	491	485	487	449
10	577	578	573	572
20	662	680	659	720
35	731	769	731	857
50	776	829	778	953
75	827	902	832	1070
100	864	957	872	1150
200	955	1100	972	1370
350	1030	1230	1060	1570
500	1080	1310	1110	1690
750	1140	1420	1180	1850
1000	1180	1500	1230	1960

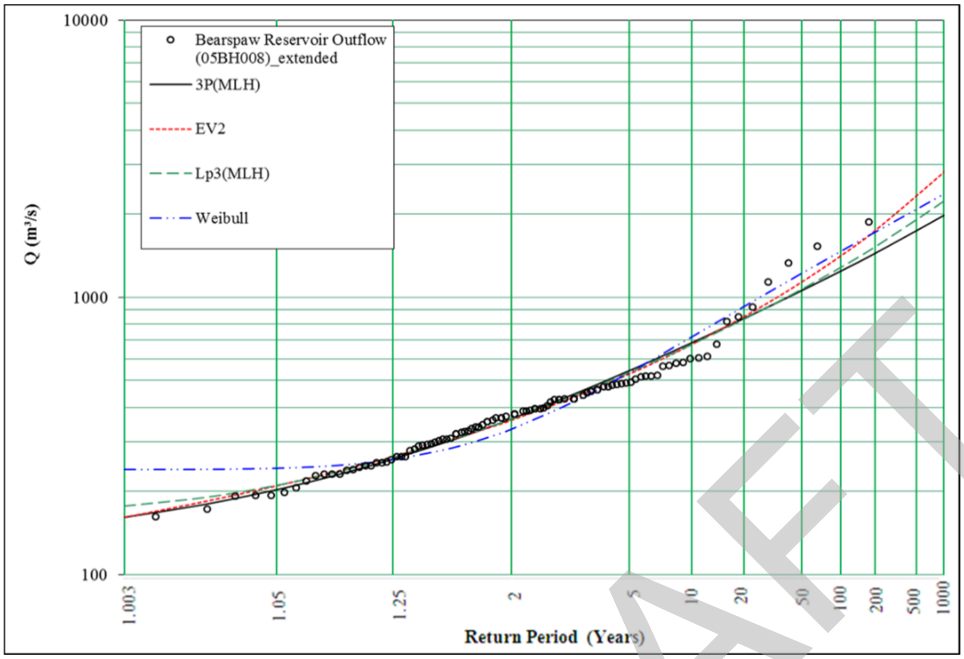
Figure C.2.11: 05BH008, Bow River below Bearspaw Dam – recorded regulated

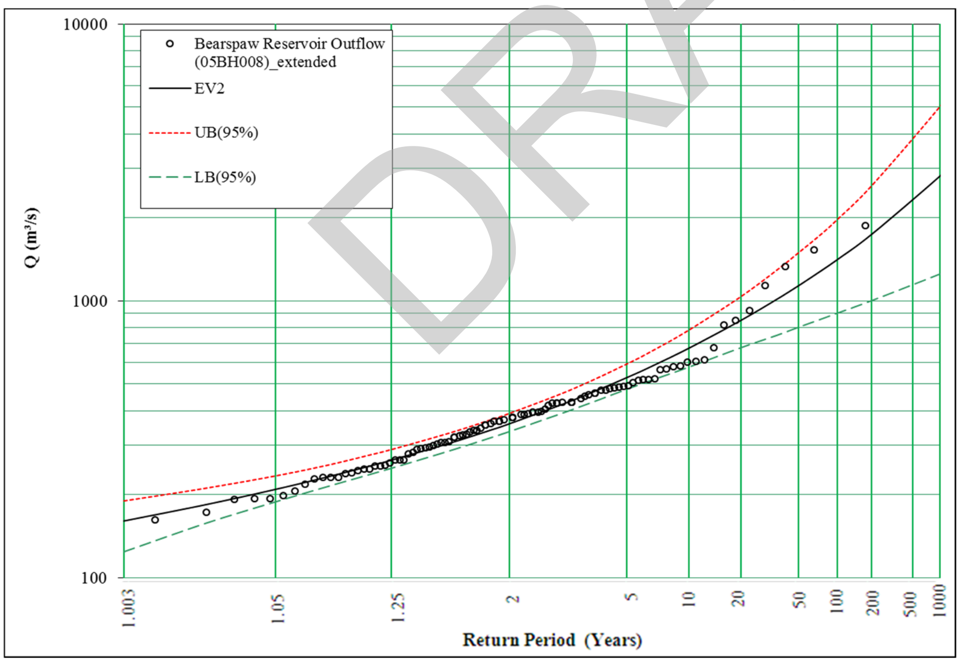




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	290	286	290	265
5	461	436	449	483
10	626	593	605	700
20	829	808	806	953
35	1020	1040	1010	1180
50	1170	1230	1170	1340
75	1340	1480	1370	1520
100	1480	1700	1540	1660
200	1850	2350	2030	2010
350	2210	3070	2530	2300
500	2460	3650	2910	2500
750	2750	4430	3410	2730
1000	2980	5090	3830	2900

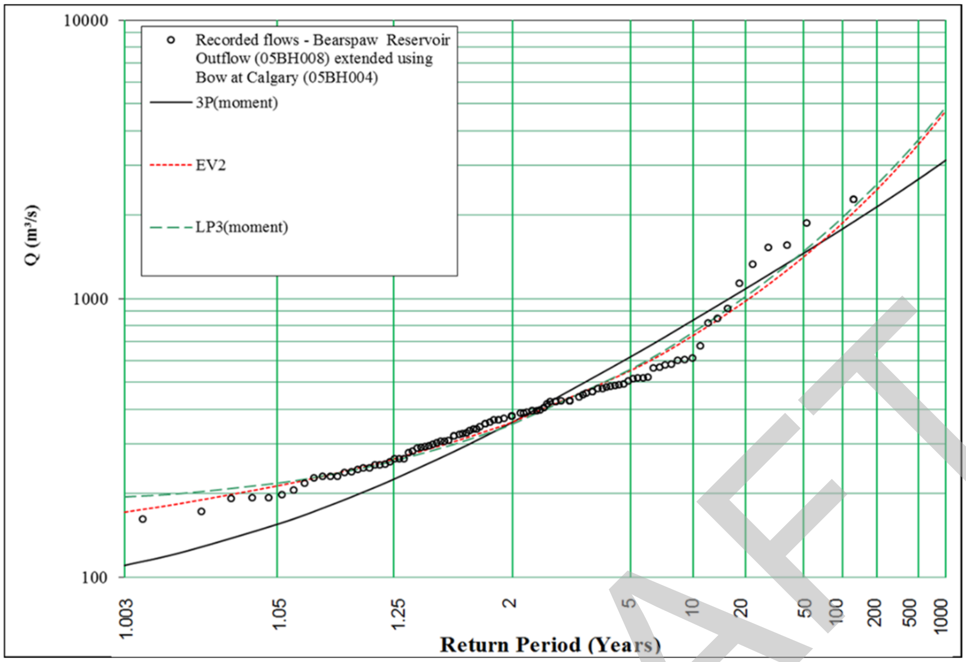
Figure C.2.12: 05BH008, Bow River below Bearspaw Dam, extended using Bow River at Calgary - all flows

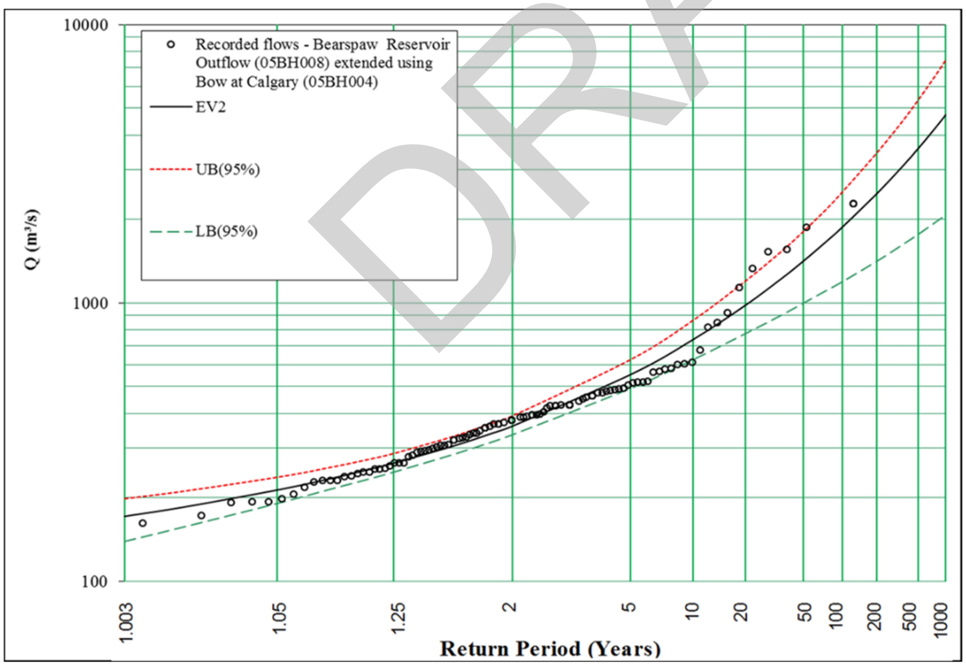




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	364	359	363	334
5	544	528	536	535
10	685	675	676	718
20	837	849	833	922
35	969	1020	974	1100
50	1060	1140	1070	1220
75	1160	1290	1190	1360
100	1240	1410	1280	1460
200	1440	1740	1520	1710
350	1620	2060	1740	1930
500	1740	2290	1890	2070
750	1870	2590	2080	2230
1000	1970	2820	2220	2350

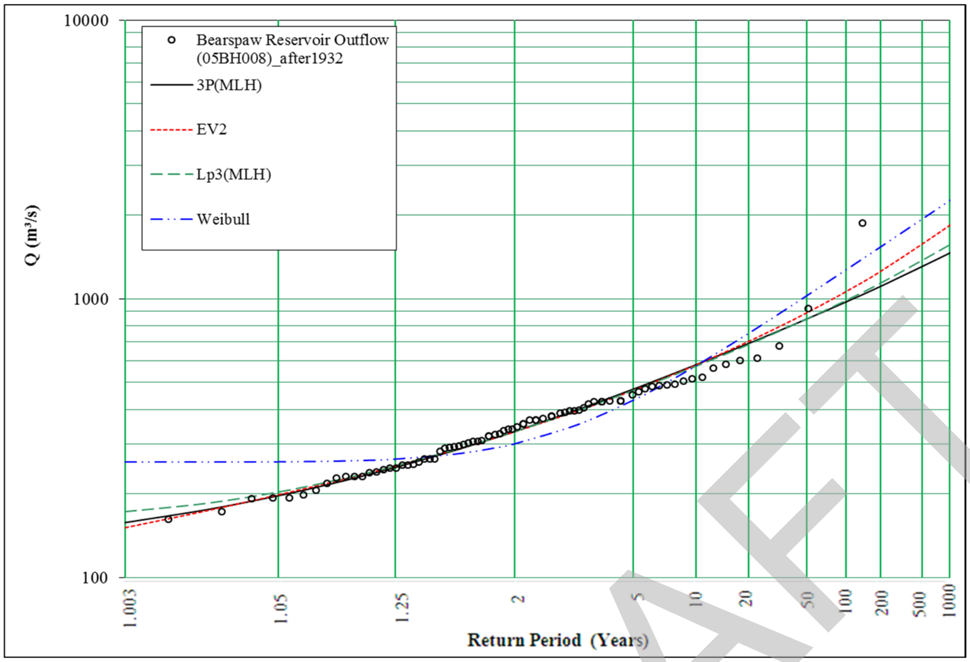
Figure C.2.13: 05BH008, Bow River below Bearspaw Dam, extended using Bow River at Calgary - all flows, historic

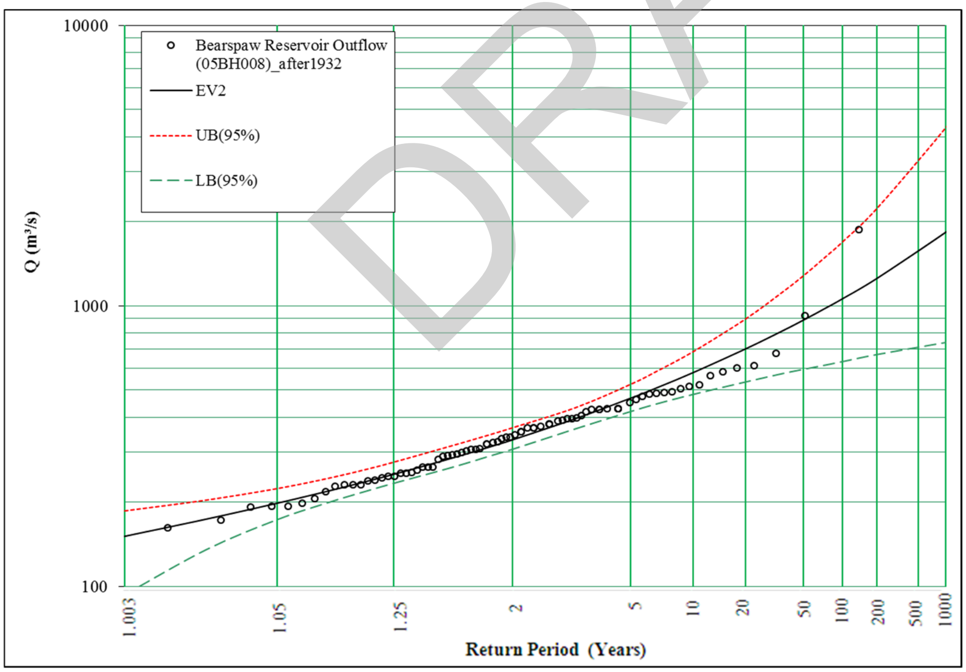




Return Period	3P (moment)	EV2	LP3 (moment)	Weibull
2	360	361	354	
5	619	553	558	
10	838	738	758	
20	1080	979	1020	
35	1300	1230	1280	
50	1460	1420	1480	
75	1640	1670	1740	
100	1780	1870	1950	
200	2140	2470	2580	
350	2460	3100	3220	
500	2680	3580	3710	
750	2940	4210	4350	
1000	3140	4730	4870	

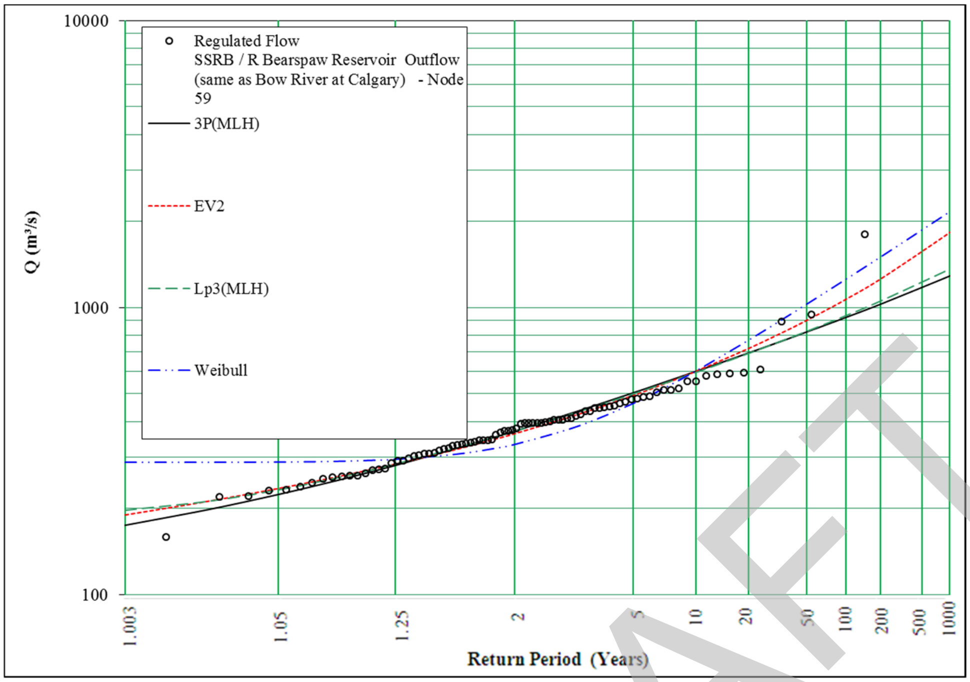
Figure C.2.14: 05BH008, Bow River below Bearspaw Dam, extended using Bow River at Calgary - post 1932 flows

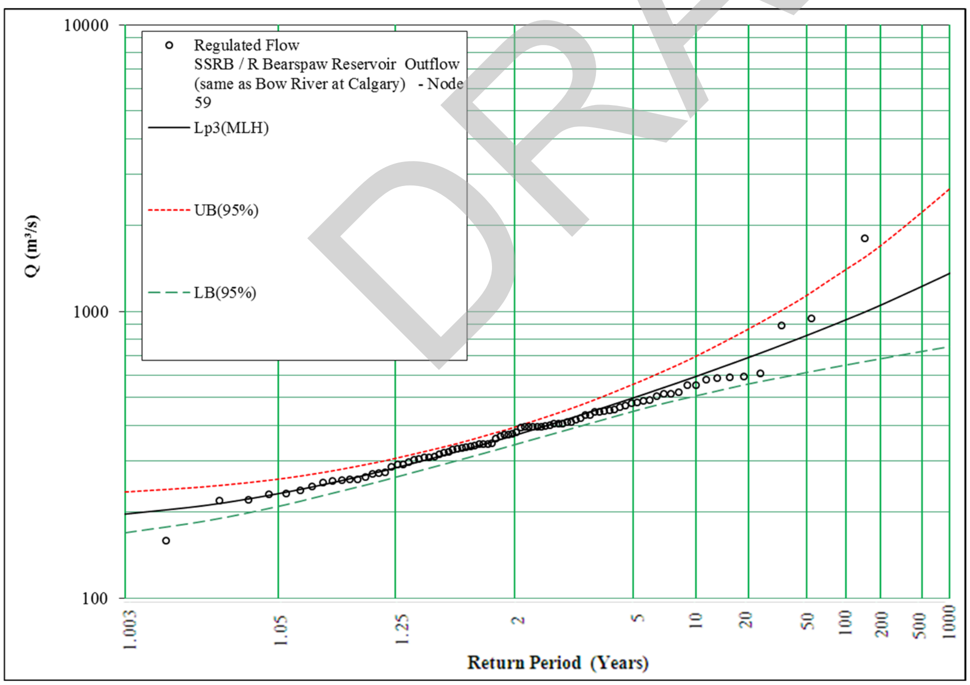




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	334	333	333	301
5	474	469	469	433
10	580	578	573	575
20	691	701	684	751
35	784	813	782	914
50	847	891	848	1030
75	920	986	927	1170
100	974	1060	986	1270
200	1110	1250	1140	1540
350	1230	1430	1270	1770
500	1310	1560	1370	1930
750	1390	1710	1480	2120
1000	1460	1830	1560	2250

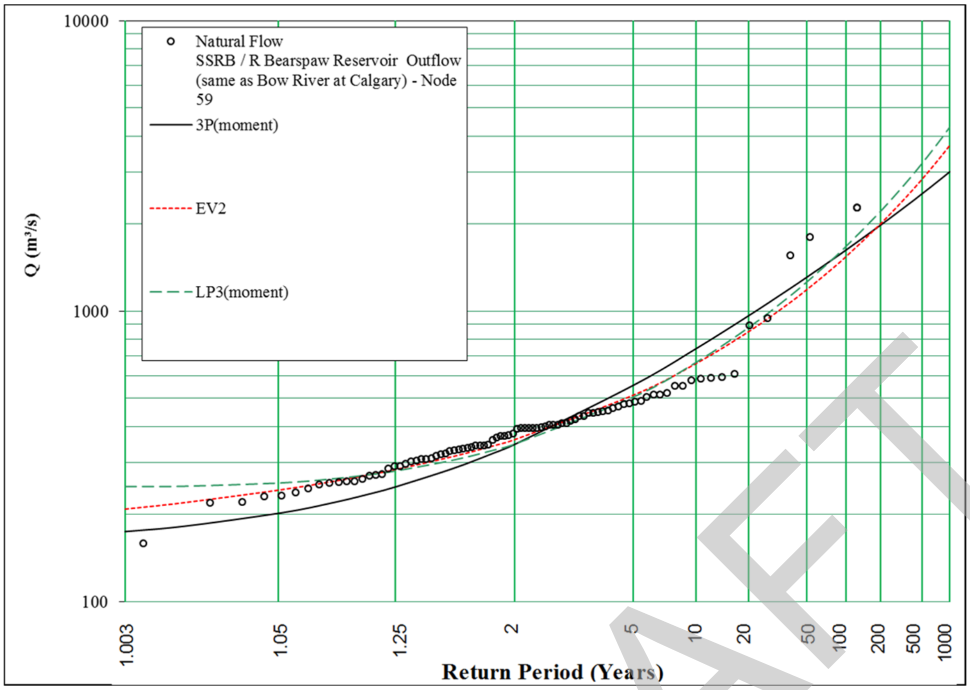
Figure C.2.15: Node 59, Bearspaw Reservoir Outflow (same as Bow River at Calgary) - regulated

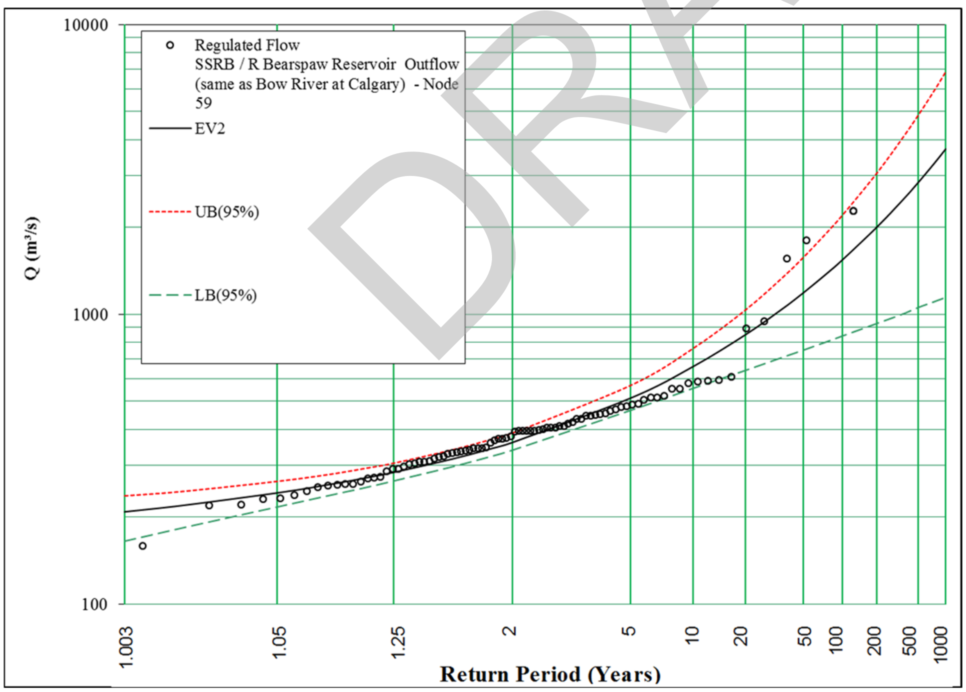




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	371	363	370	334
5	505	494	500	464
10	599	600	594	602
20	694	719	690	768
35	772	827	772	922
50	823	903	825	1030
75	881	996	888	1160
100	923	1070	935	1250
200	1030	1260	1050	1500
350	1120	1430	1150	1710
500	1180	1550	1220	1850
750	1240	1710	1300	2020
1000	1290	1820	1360	2150

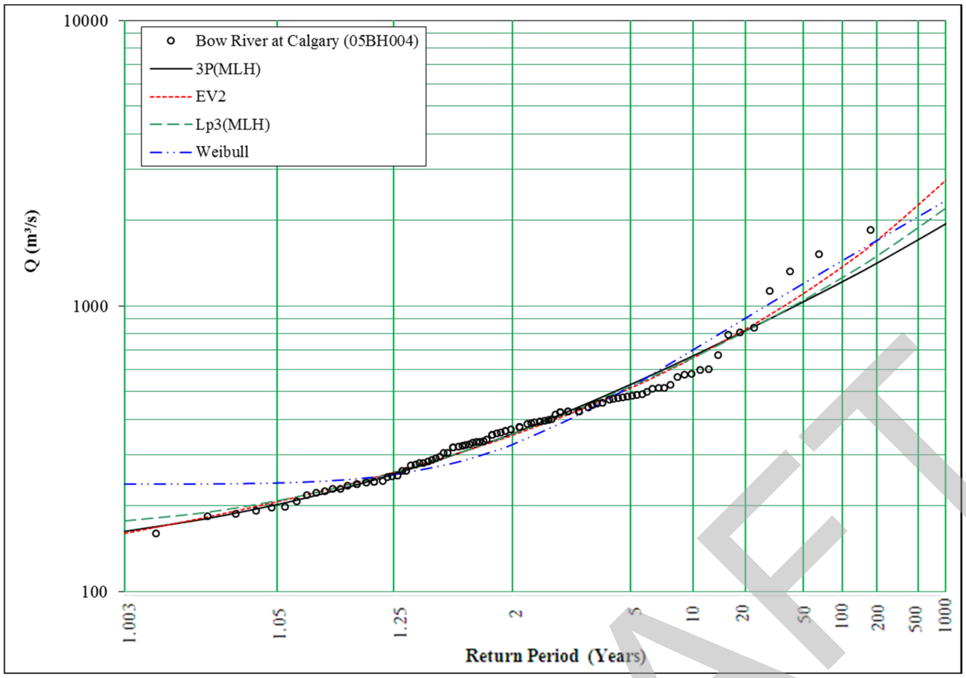
Figure C.2.16: Node 59, Bearspaw Reservoir Outflow (same as Bow River at Calgary) – historic

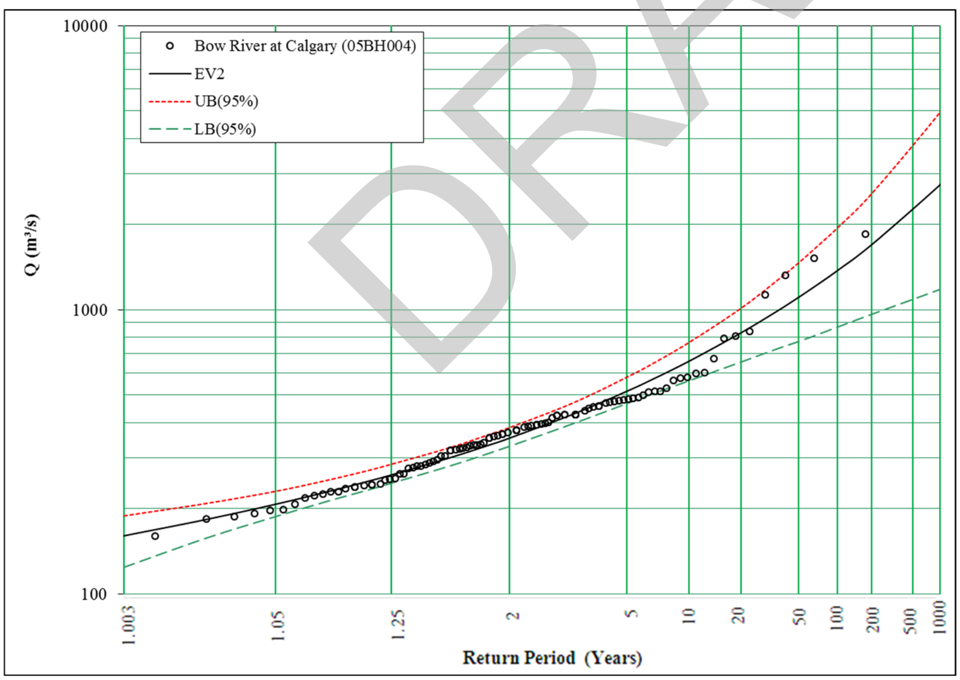




Return Period	3P (moment)	EV2	LP3 (moment)	Weibull
2	348	361	348	
5	555	514	507	
10	743	660	667	
20	963	848	878	
35	1170	1040	1100	
50	1310	1190	1260	
75	1490	1380	1490	
100	1620	1540	1670	
200	1980	2000	2210	
350	2310	2480	2790	
500	2530	2840	3230	
750	2810	3320	3820	
1000	3020	3720	4310	

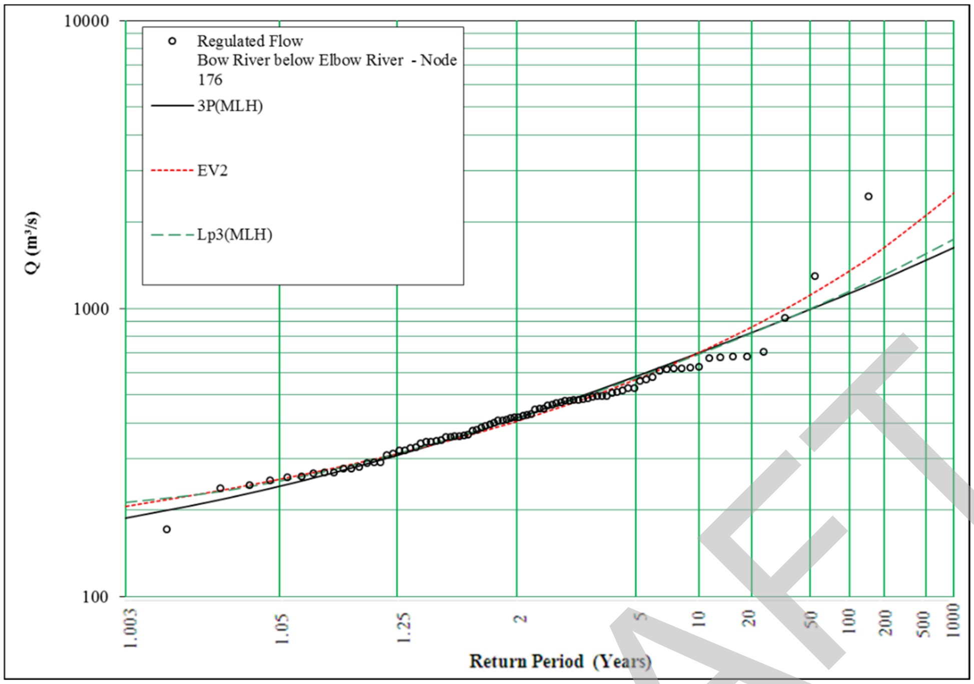
Figure C.2.17: 05BH004, Bow River at Calgary – recorded regulated

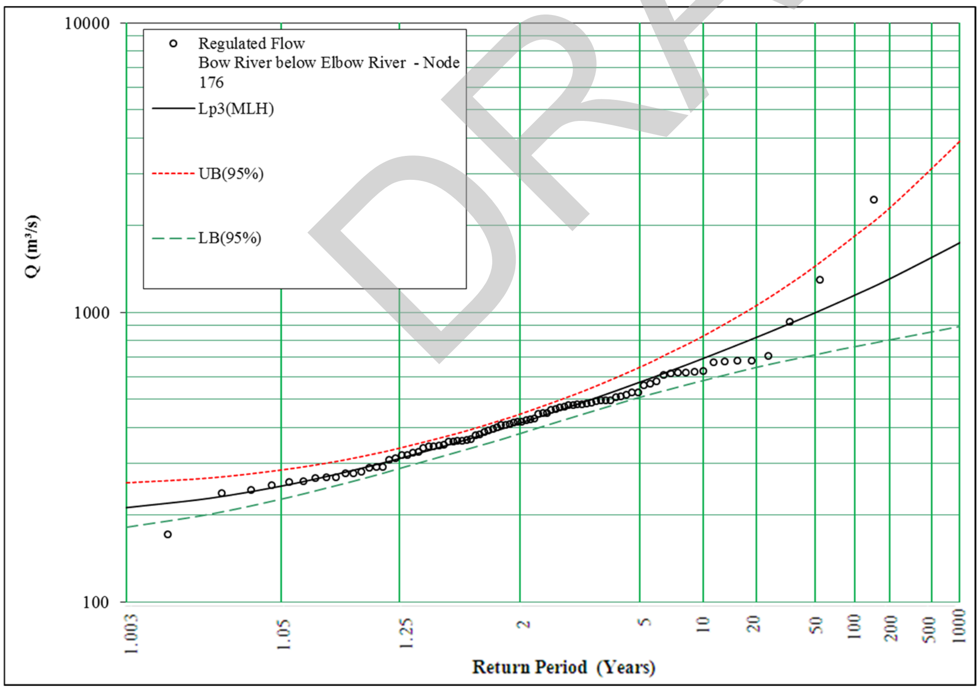




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	357	353	356	327
5	531	517	523	521
10	669	659	660	701
20	818	828	813	903
35	947	990	952	1080
50	1040	1110	1050	1200
75	1140	1260	1170	1340
100	1220	1370	1260	1440
200	1410	1700	1490	1690
350	1590	2010	1710	1910
500	1710	2240	1870	2050
750	1840	2530	2050	2210
1000	1940	2750	2200	2330

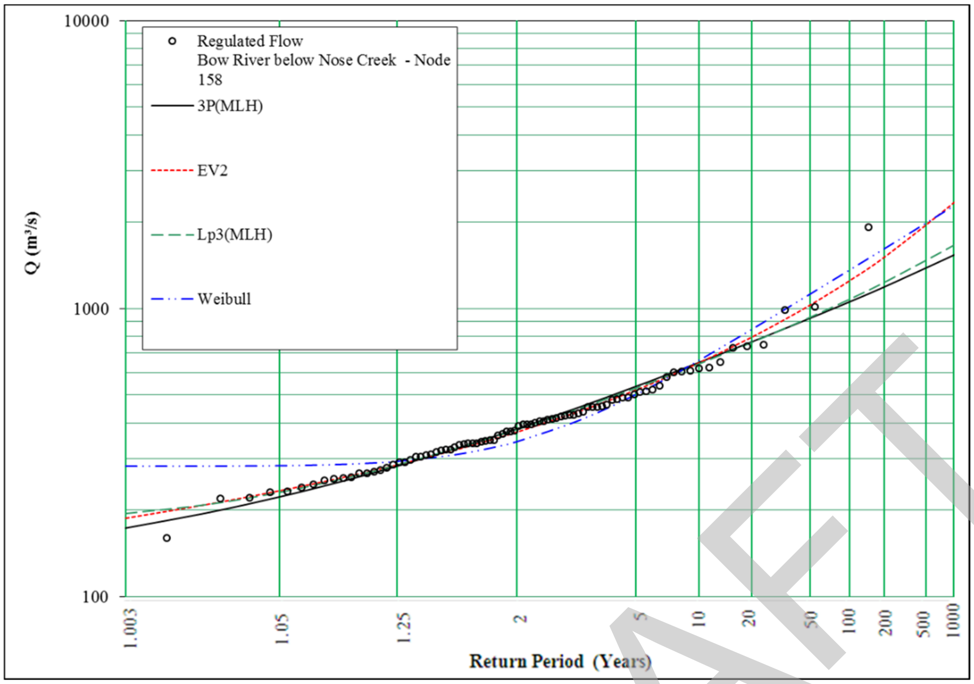
Figure C.2.18: Node 176, Bow River below Elbow River

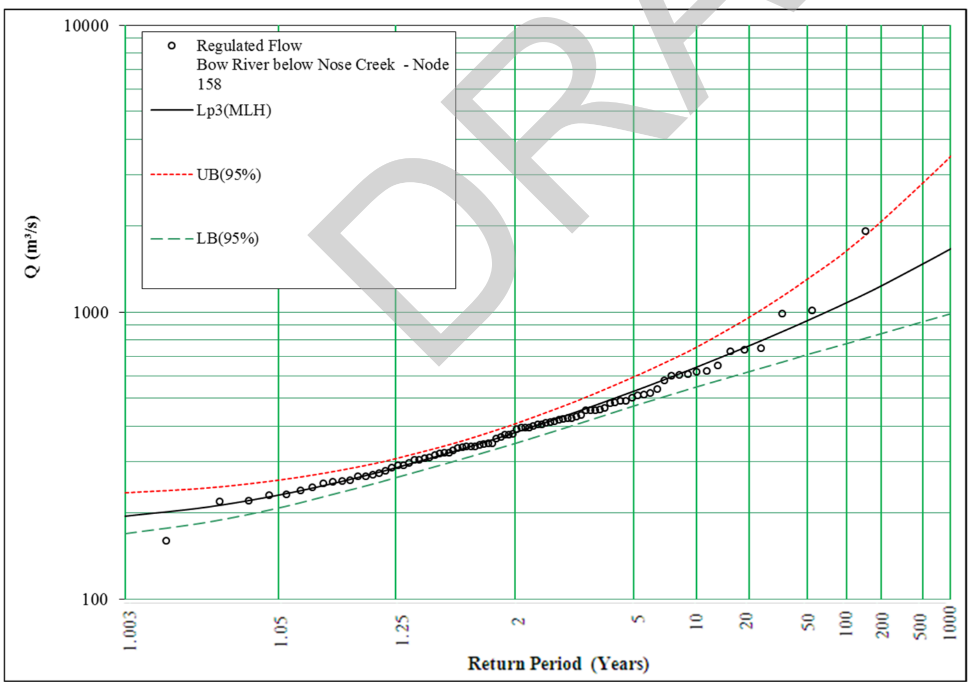




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	416	406	414	
5	581	568	574	
10	702	704	694	
20	825	863	819	
35	927	1010	926	
50	994	1120	998	
75	1070	1250	1080	
100	1130	1350	1150	
200	1270	1630	1310	
350	1390	1900	1450	
500	1470	2090	1540	
750	1560	2330	1650	
1000	1630	2520	1740	

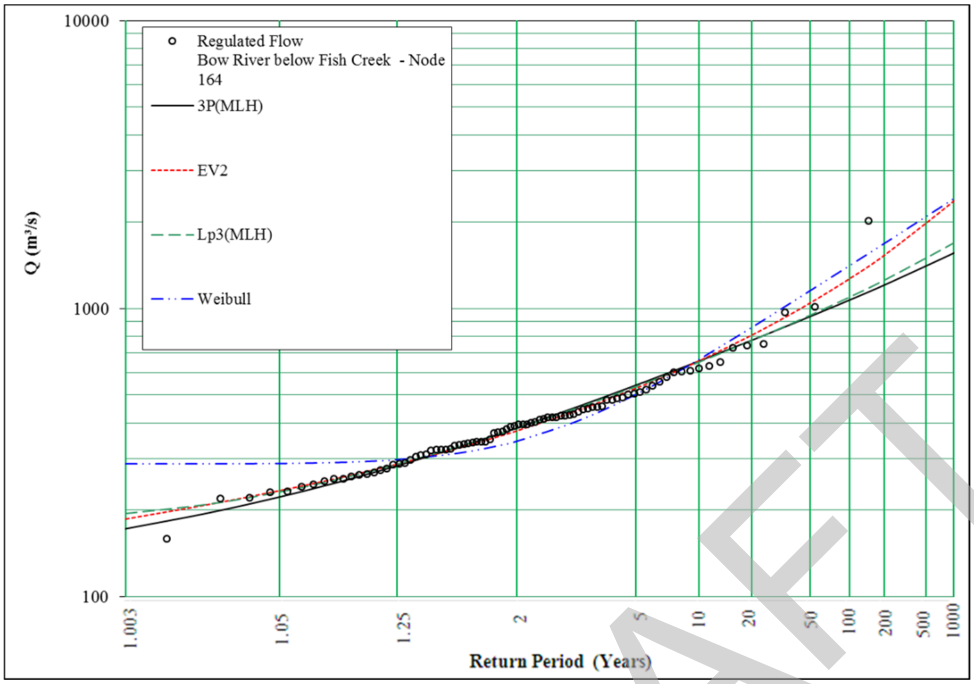
Figure C.2.19: Node 158, Bow River below Nose Creek

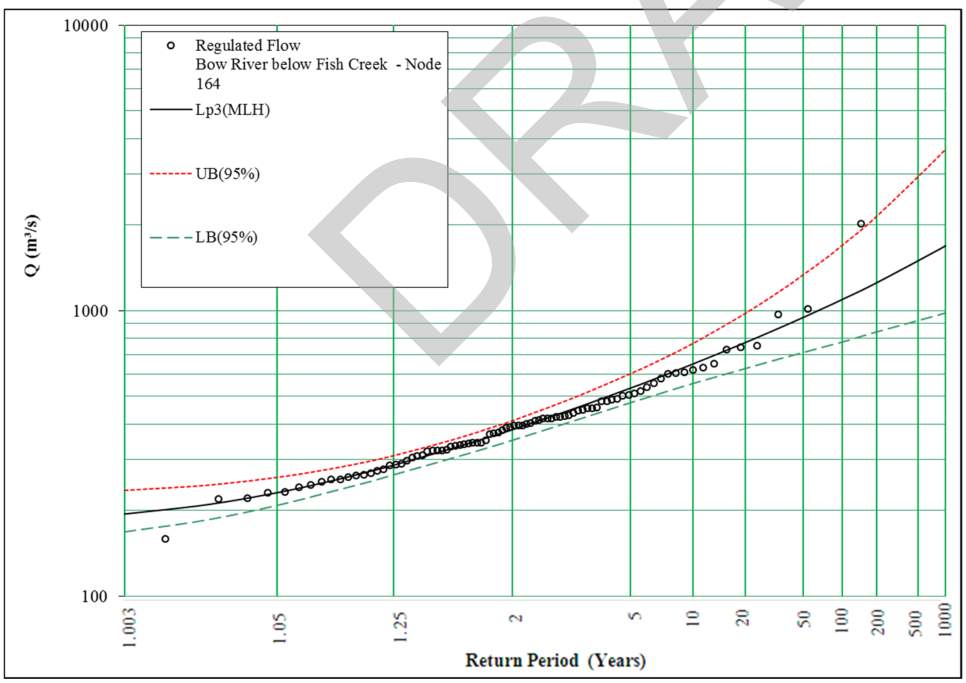




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	382	372	380	345
5	536	522	530	504
10	650	648	643	661
20	766	795	763	846
35	862	932	866	1010
50	927	1030	935	1130
75	1000	1150	1020	1260
100	1050	1250	1080	1360
200	1190	1510	1230	1620
350	1310	1760	1370	1830
500	1380	1940	1460	1980
750	1470	2160	1580	2150
1000	1530	2330	1660	2270

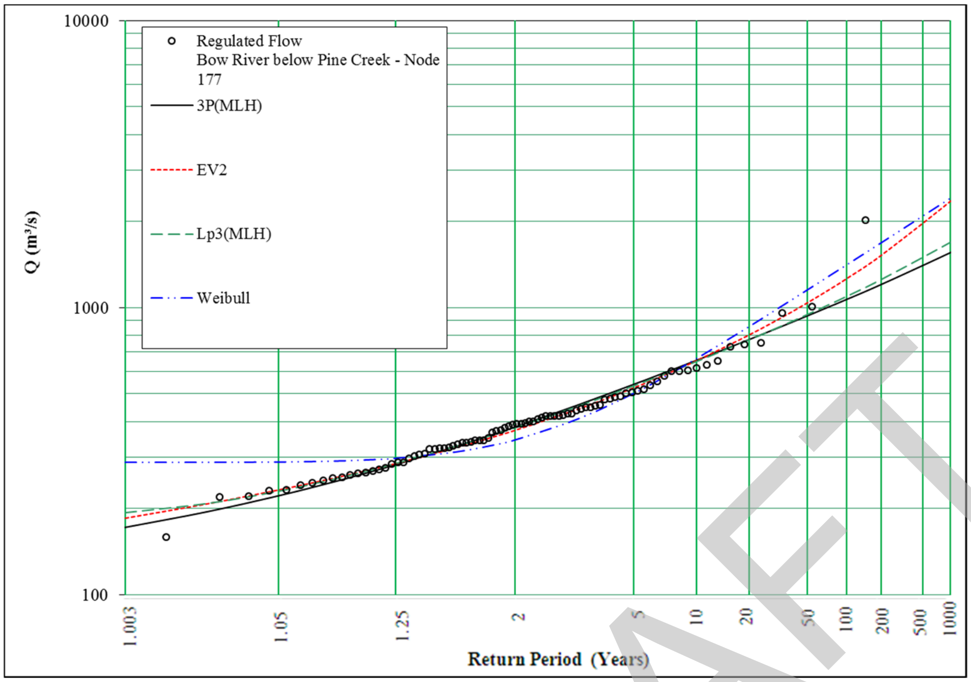
Figure C.2.20: Node 164, Bow River below Fish Creek

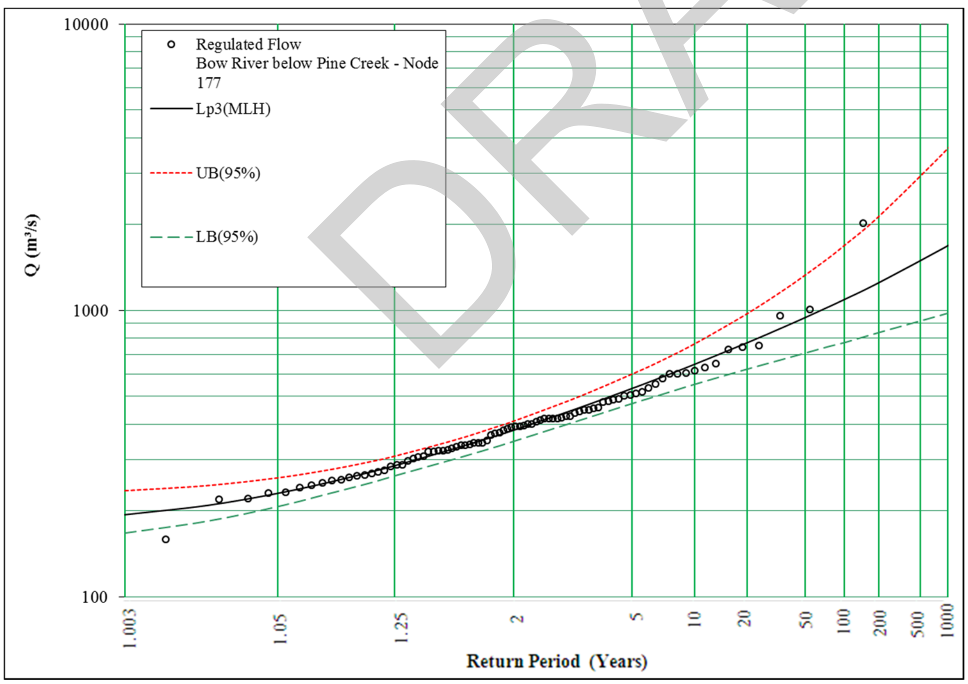




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	384	375	383	346
5	542	528	535	503
10	657	656	651	666
20	775	805	772	858
35	874	945	877	1030
50	939	1040	947	1150
75	1010	1170	1030	1300
100	1070	1260	1090	1410
200	1210	1530	1250	1680
350	1330	1780	1390	1920
500	1410	1960	1490	2080
750	1490	2180	1600	2270
1000	1560	2350	1690	2400

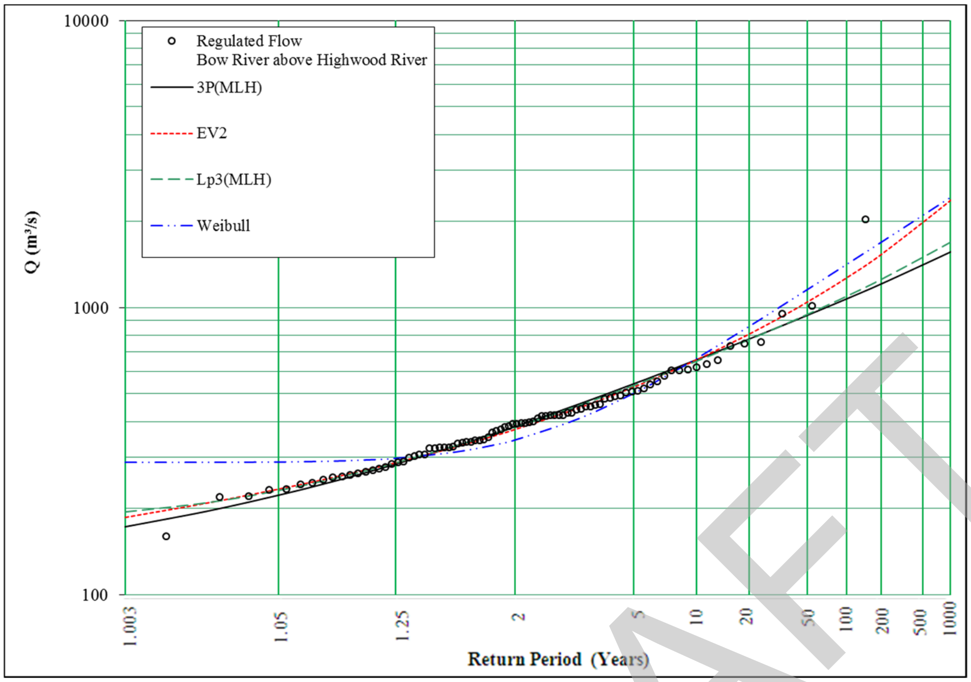
Figure C.2.21: Node 177, Bow River below Pine Creek

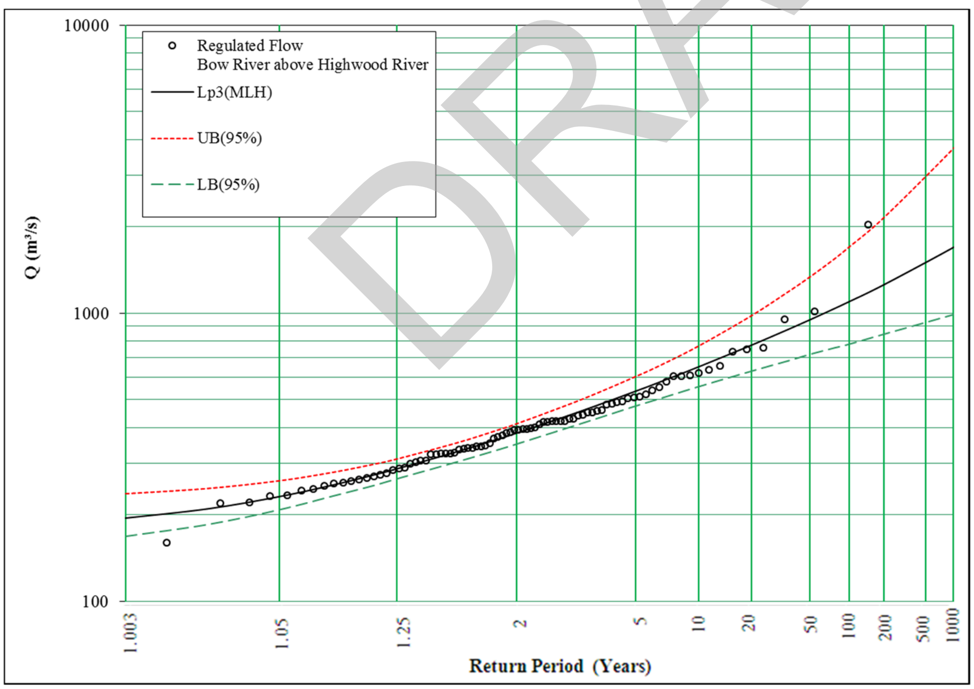




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	383	374	382	345
5	540	526	534	502
10	655	654	649	663
20	773	803	770	856
35	871	942	875	1030
50	937	1040	945	1150
75	1010	1170	1030	1300
100	1070	1260	1090	1400
200	1200	1520	1250	1680
350	1320	1770	1390	1920
500	1400	1950	1480	2080
750	1490	2170	1600	2260
1000	1550	2350	1680	2400

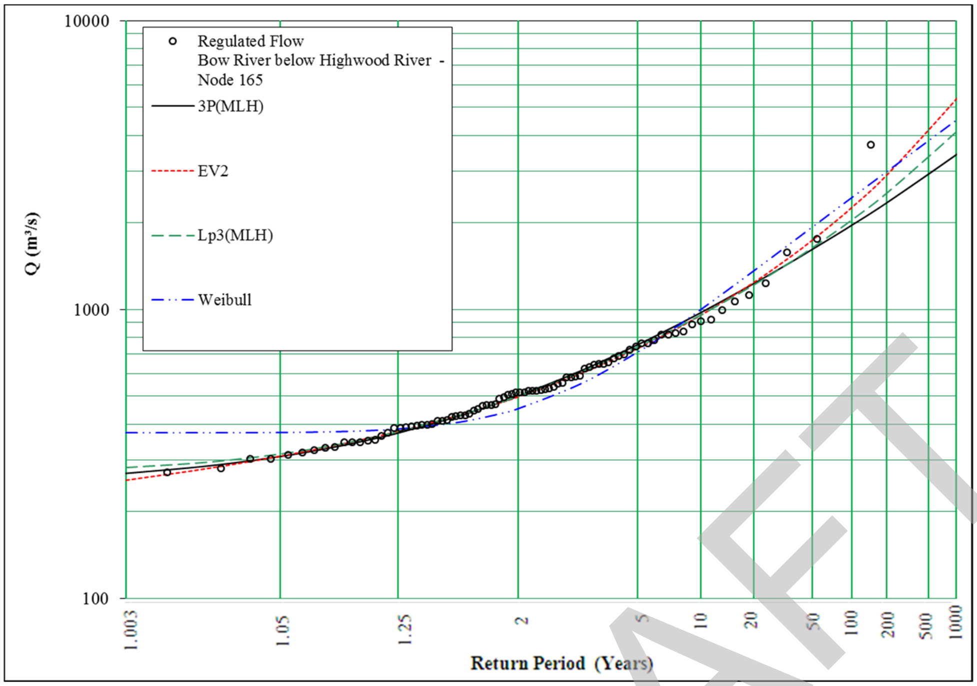
Figure C.2.22: Node 331, Bow River above Highwood River

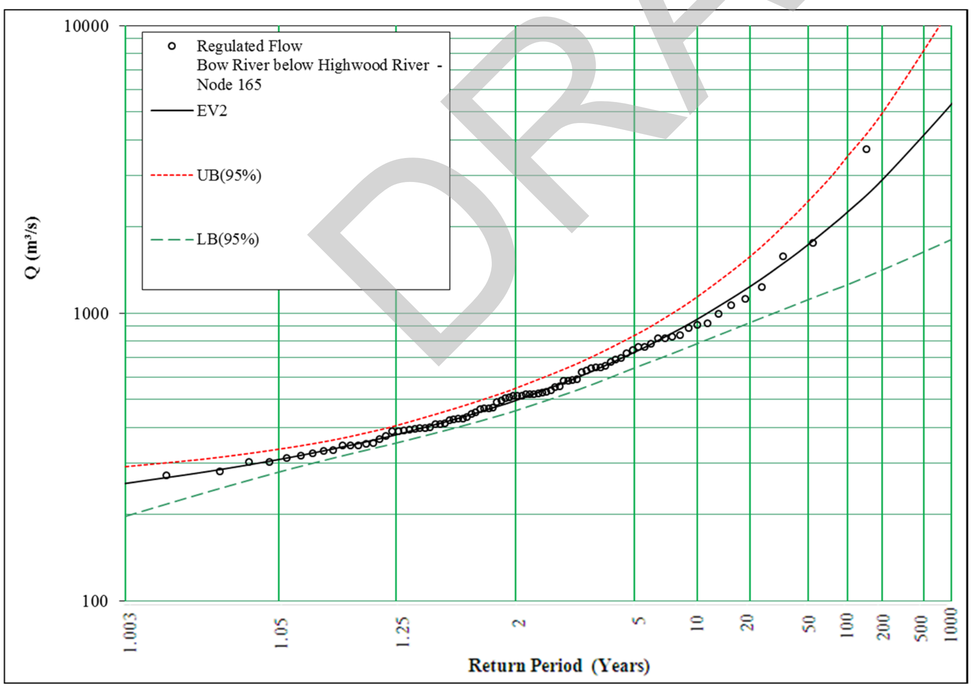




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	385	375	383	346
5	543	528	536	504
10	658	657	651	666
20	776	806	773	859
35	875	946	878	1040
50	941	1050	949	1160
75	1020	1170	1030	1300
100	1070	1270	1100	1410
200	1210	1530	1260	1690
350	1330	1780	1400	1930
500	1410	1960	1490	2090
750	1490	2180	1610	2270
1000	1560	2360	1690	2410

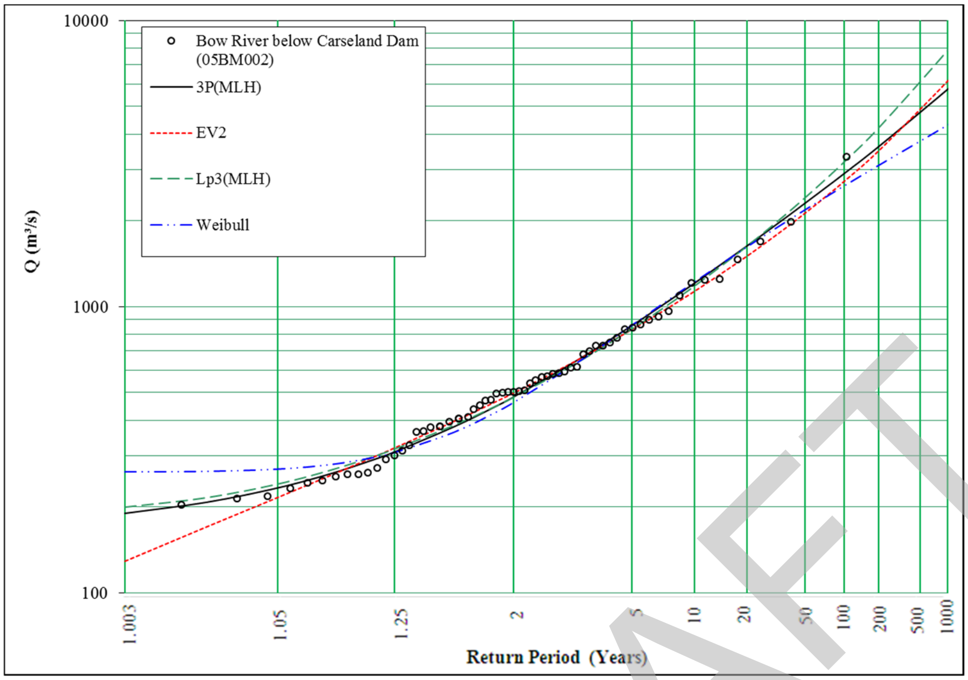
Figure C.2.23: Node 165, Bow River below Highwood River

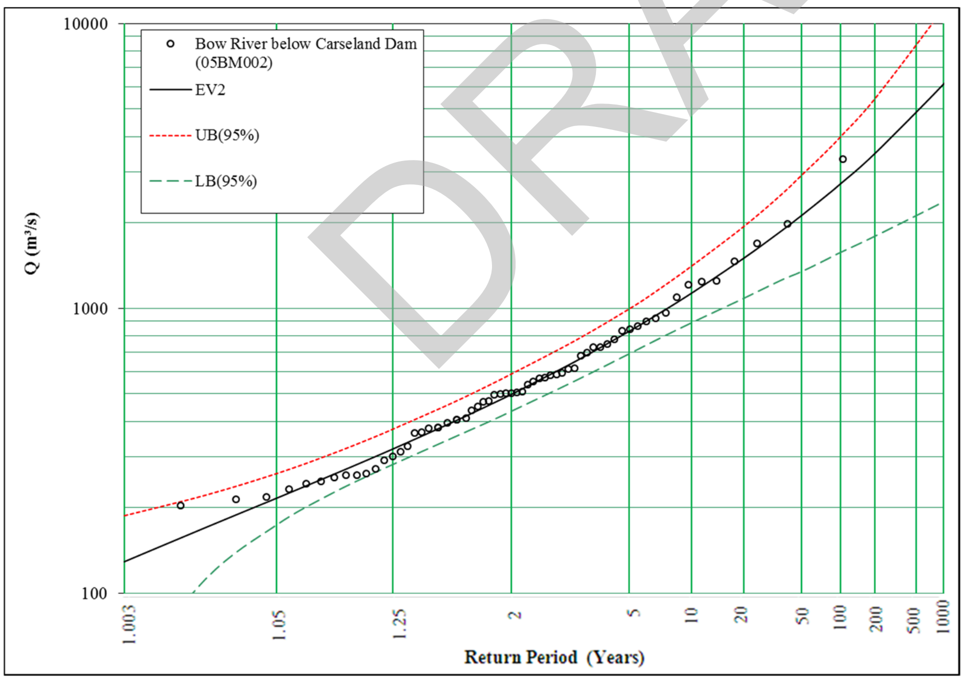




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	501	497	501	455
5	755	732	742	714
10	976	954	958	1000
20	1230	1240	1220	1360
35	1460	1520	1460	1700
50	1620	1740	1640	1940
75	1810	2020	1870	2220
100	1960	2250	2040	2440
200	2340	2910	2530	3000
350	2700	3590	3010	3500
500	2940	4100	3350	3830
750	3220	4780	3780	4230
1000	3430	5330	4130	4520

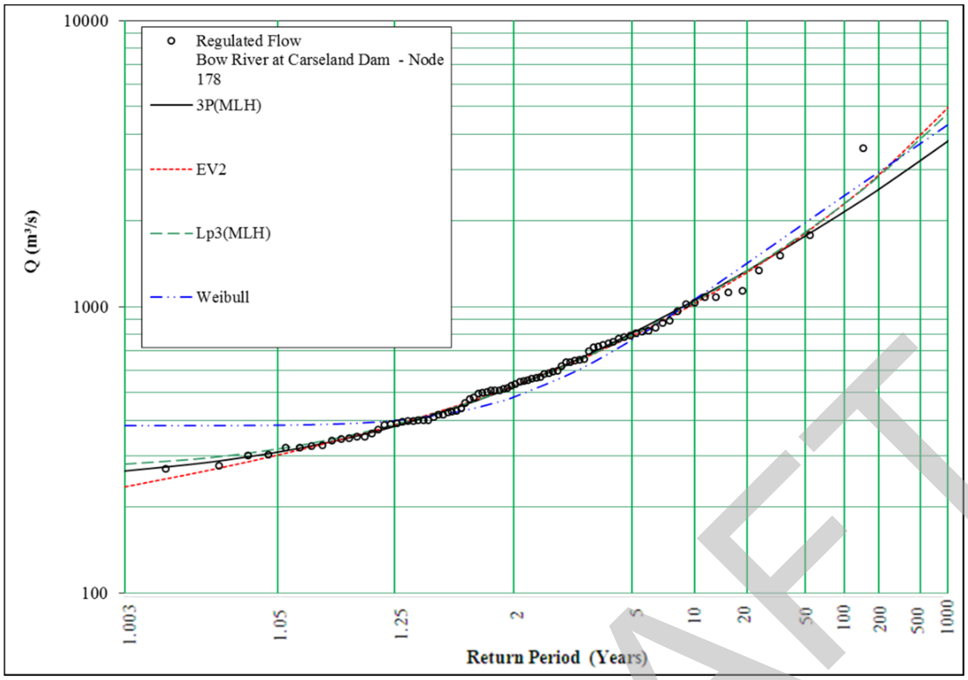
Figure C.2.24: 05BM002 / Node 178, Bow River below Carseland Dam – recorded regulated

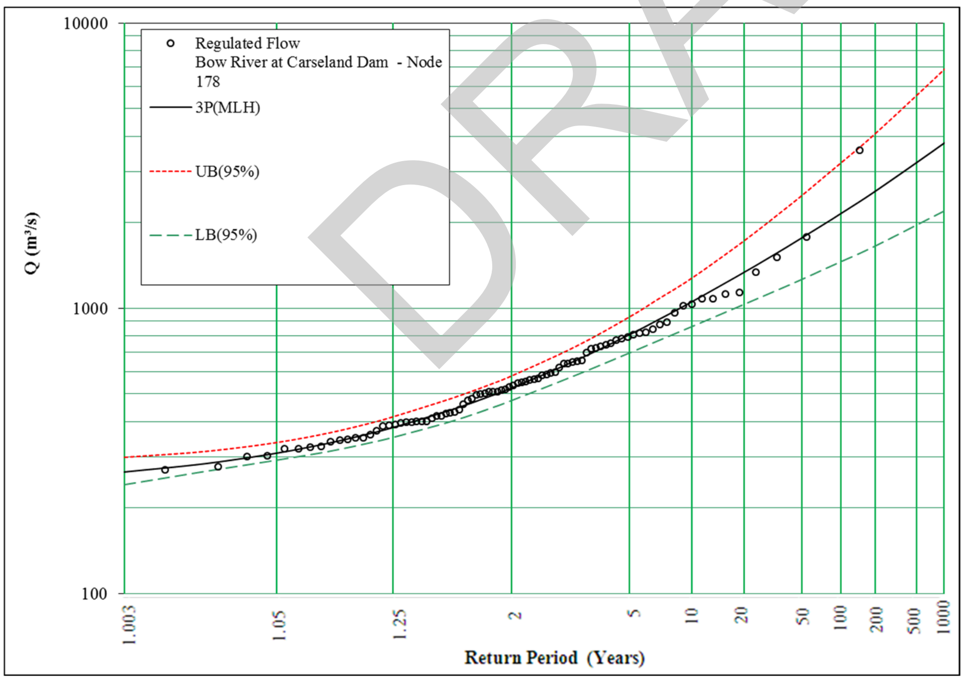




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	483	498	482	463
5	859	831	837	863
10	1210	1130	1180	1220
20	1630	1500	1620	1620
35	2020	1860	2070	1960
50	2300	2120	2400	2180
75	2650	2460	2840	2450
100	2910	2730	3200	2640
200	3630	3500	4210	3120
350	4300	4260	5240	3520
500	4780	4820	6020	3790
750	5320	5550	7030	4090
1000	5750	6120	7840	4310

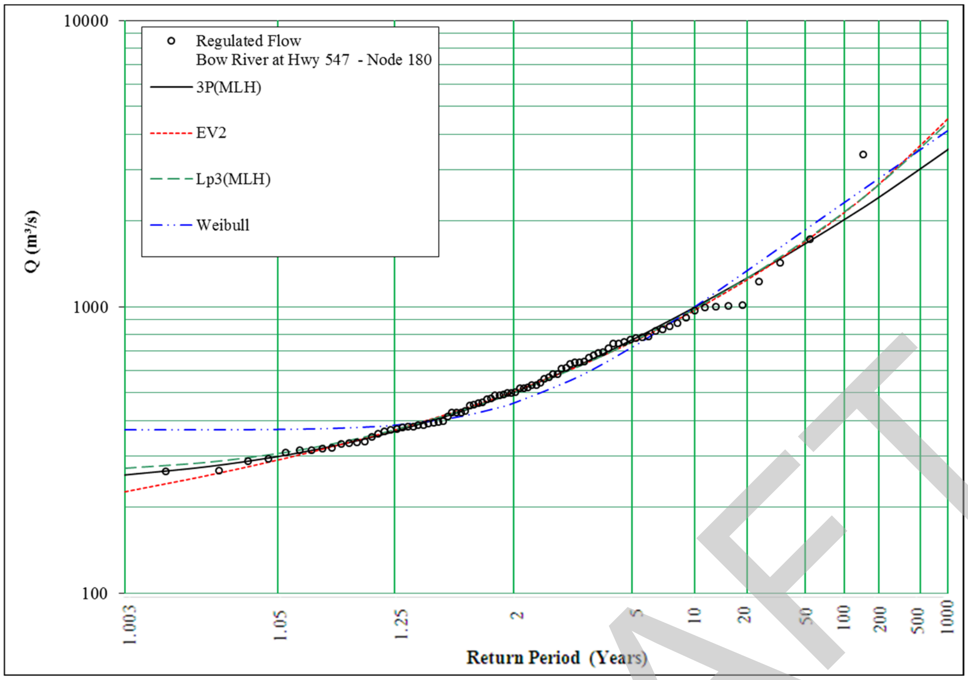
Figure C.2.25: 05BM002 / Node 178, Bow River below Carseland Dam – regulated

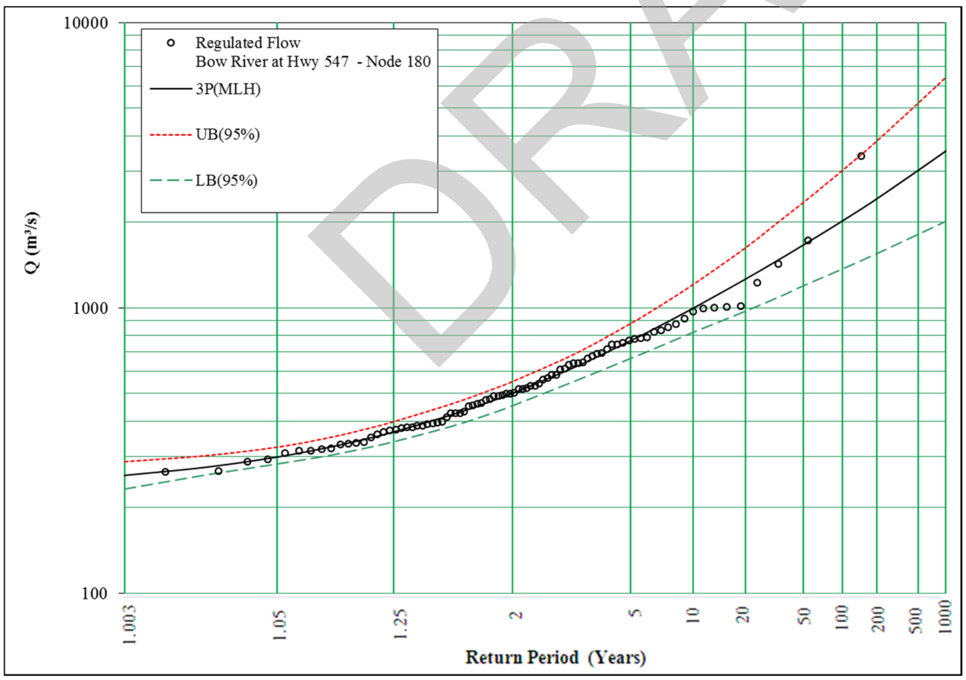




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	525	527	523	483
5	808	790	795	766
10	1050	1030	1040	1060
20	1330	1310	1330	1420
35	1590	1600	1610	1740
50	1770	1810	1820	1970
75	1980	2070	2080	2240
100	2150	2290	2280	2440
200	2570	2890	2850	2960
350	2970	3480	3410	3410
500	3240	3920	3810	3710
750	3550	4490	4320	4060
1000	3790	4940	4730	4320

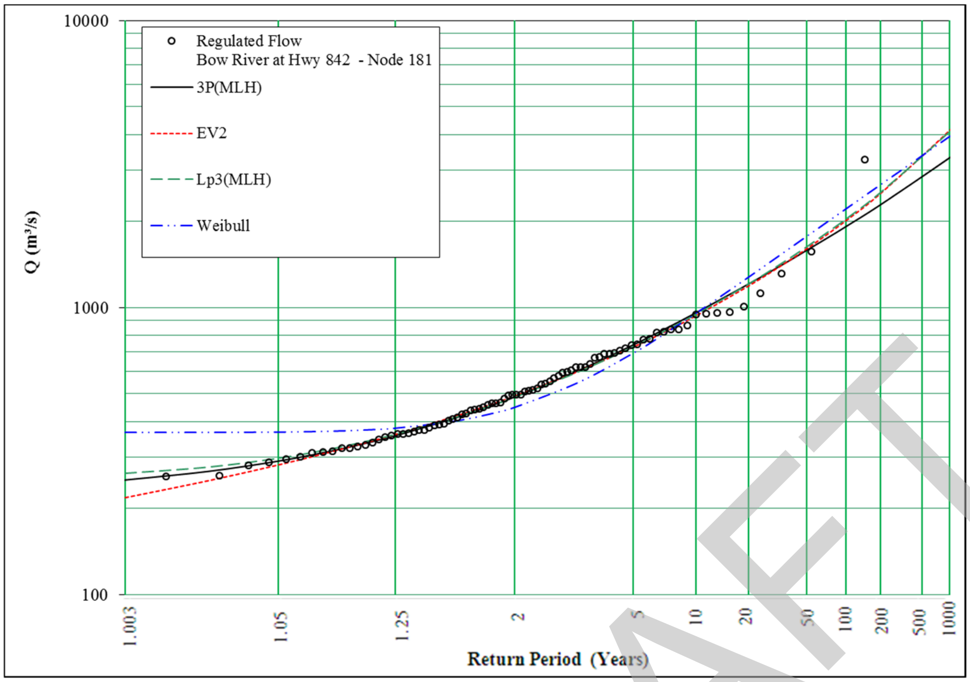
Figure C.2.26: Node 180, Bow River at Hwy. 547

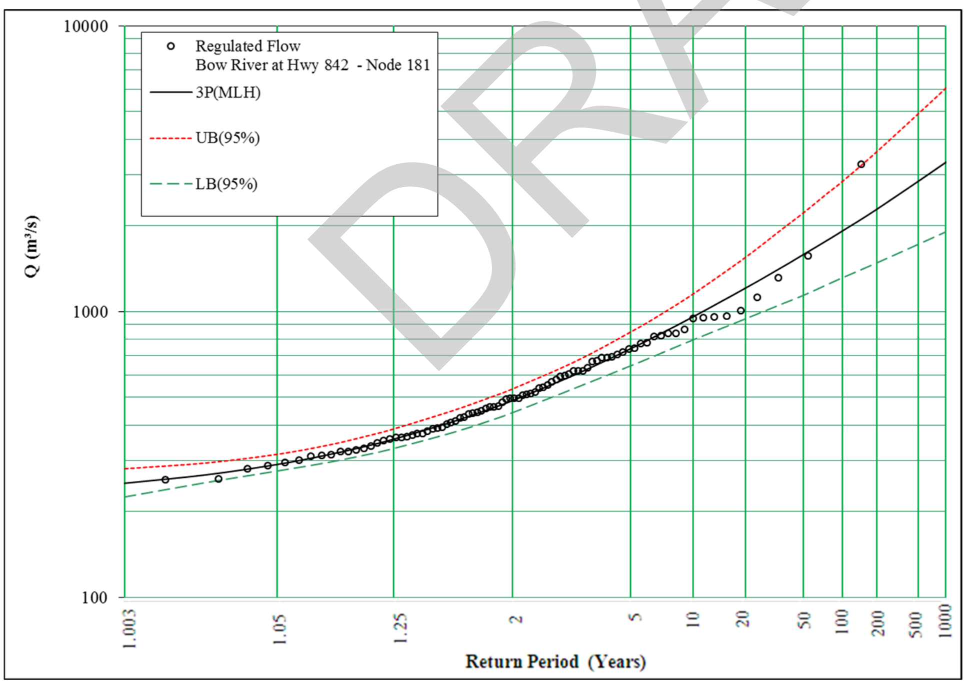




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	502	505	500	462
5	767	752	754	724
10	997	972	982	1000
20	1260	1240	1260	1340
35	1500	1500	1520	1640
50	1660	1690	1710	1860
75	1860	1940	1950	2120
100	2020	2130	2140	2310
200	2410	2670	2670	2810
350	2780	3210	3180	3240
500	3040	3610	3550	3520
750	3320	4120	4020	3870
1000	3540	4520	4390	4120

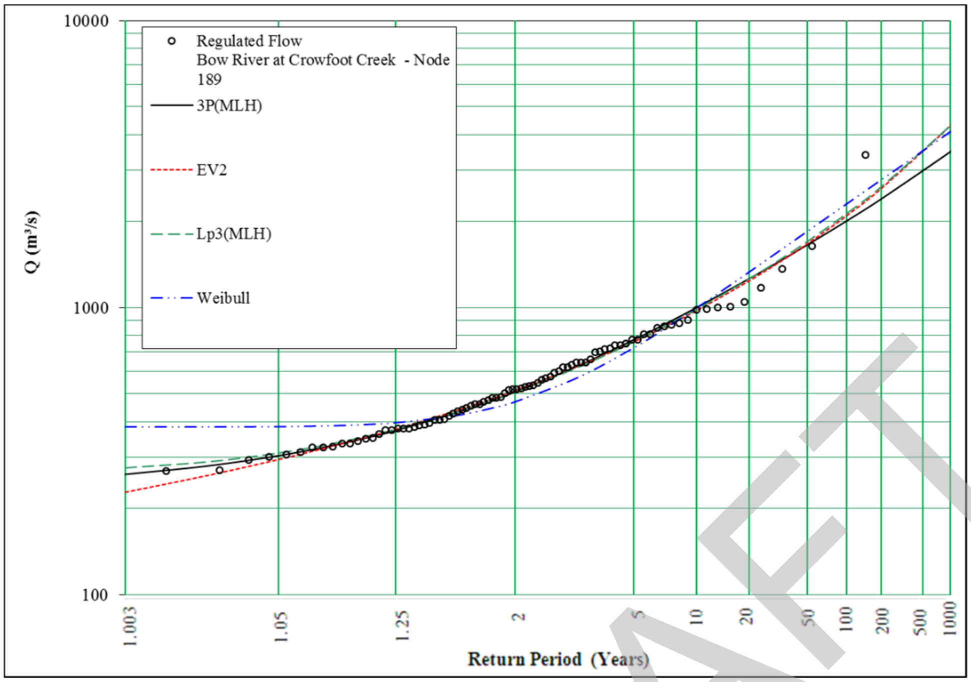
Figure C.2.27: Node 181, Bow River at Hwy. 842

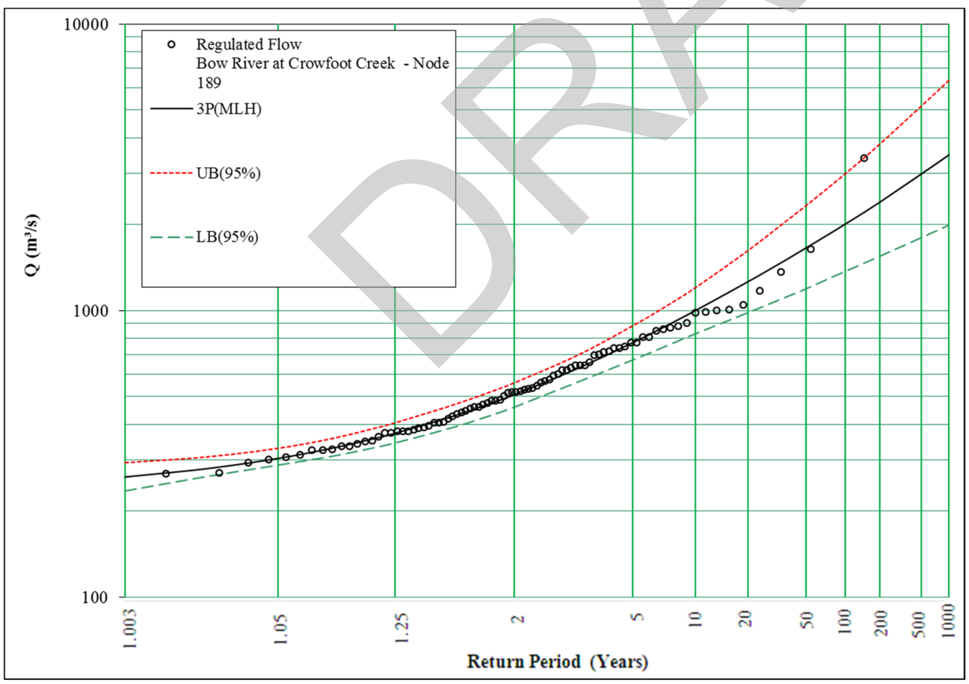




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	487	491	486	449
5	741	728	730	694
10	959	937	946	956
20	1210	1190	1200	1270
35	1430	1430	1450	1570
50	1580	1610	1630	1770
75	1770	1830	1850	2020
100	1910	2010	2030	2200
200	2280	2500	2510	2680
350	2620	2980	2980	3100
500	2860	3330	3320	3370
750	3120	3780	3750	3700
1000	3320	4140	4080	3940

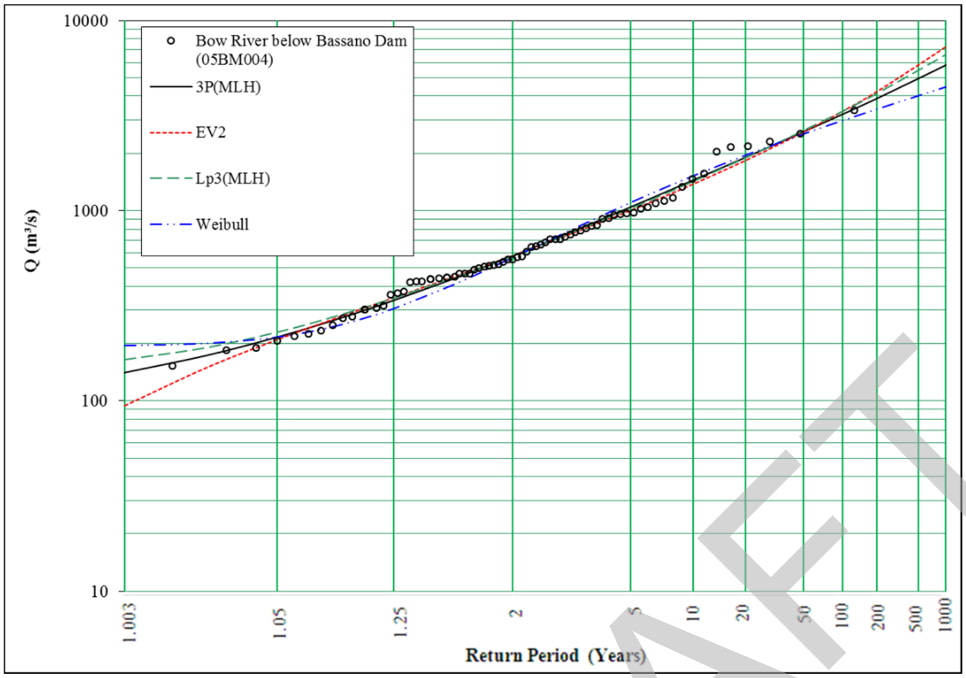
Figure C.2.28: Node 189, Bow River below Crowfoot Creek

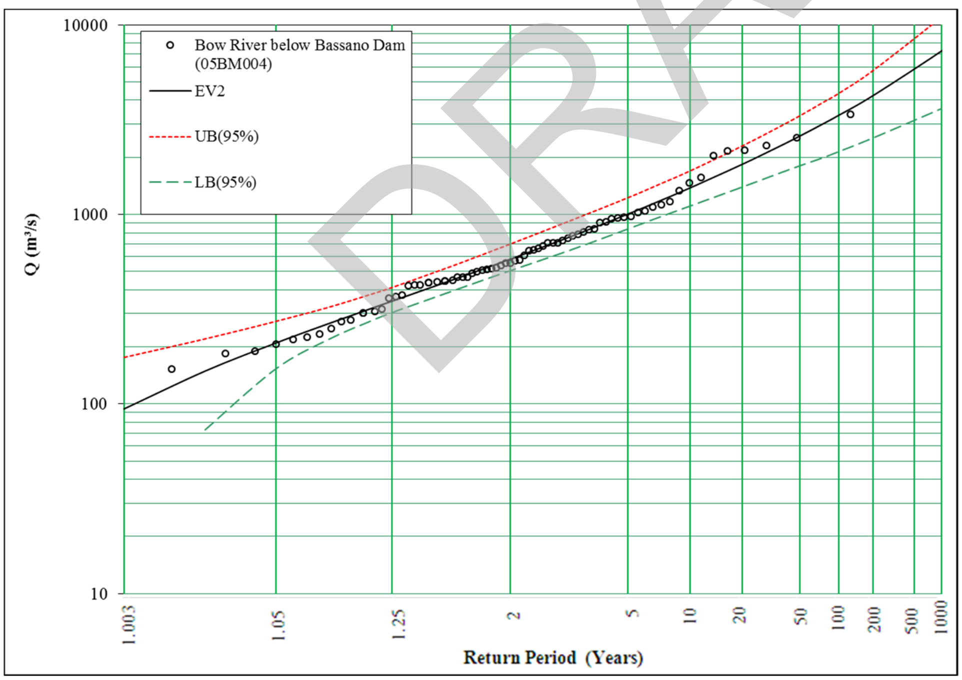




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	508	512	507	468
5	773	759	760	723
10	1000	977	987	996
20	1260	1240	1260	1330
35	1490	1490	1520	1630
50	1660	1670	1700	1850
75	1850	1900	1940	2100
100	2000	2090	2120	2290
200	2390	2600	2640	2790
350	2750	3100	3130	3220
500	3000	3470	3490	3510
750	3270	3940	3950	3850
1000	3490	4300	4300	4100

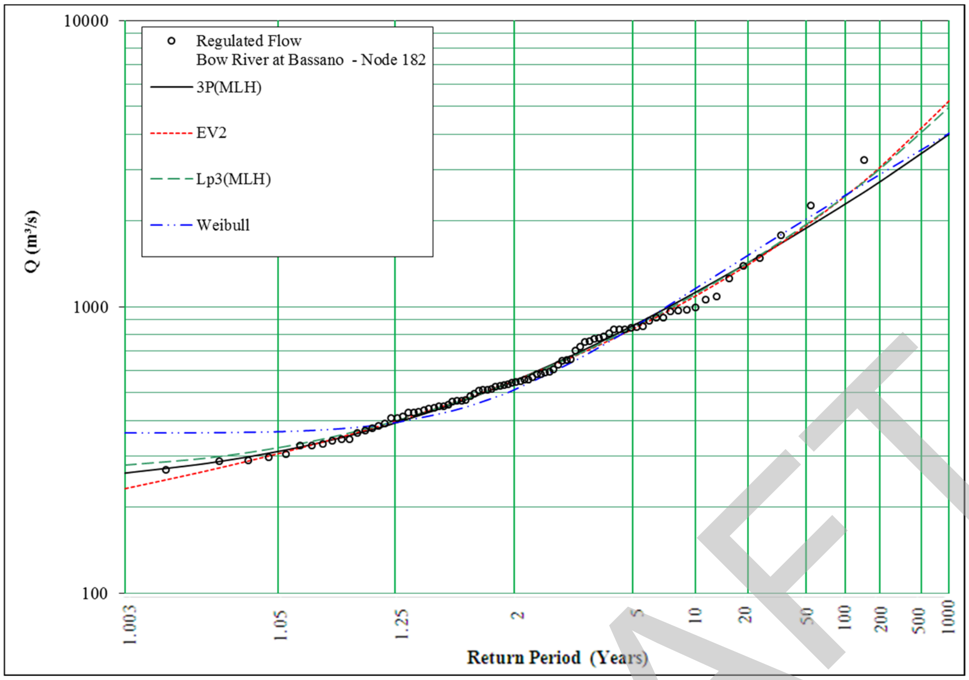
Figure C.2.29: 05BM004 / Node 182, Bow River below Bassano Dam – recorded regulated

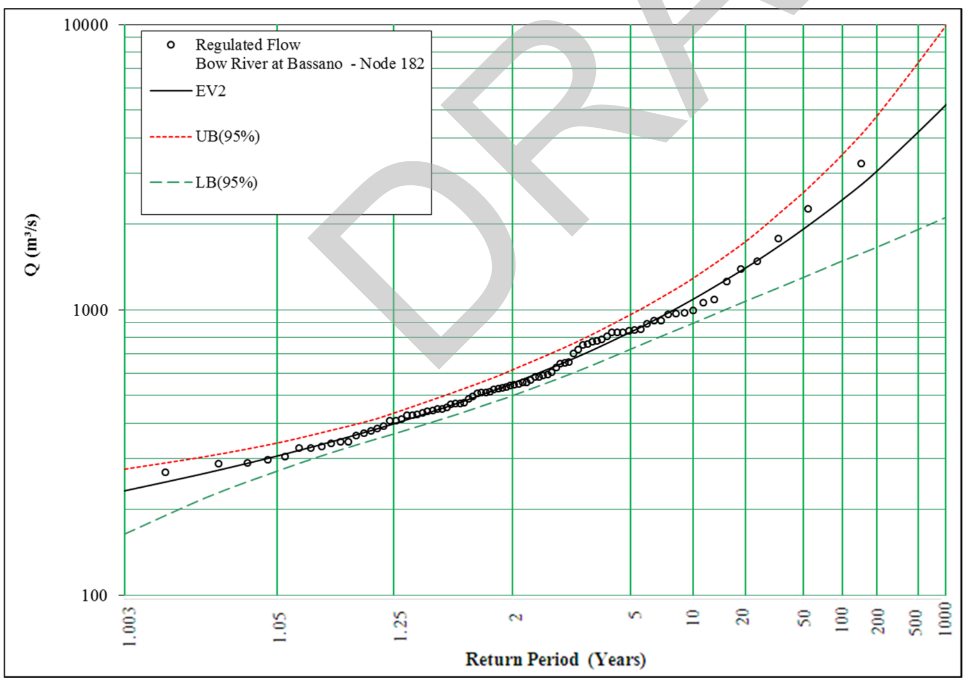




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	577	580	576	564
5	1050	1000	1030	1100
10	1450	1380	1420	1520
20	1900	1830	1890	1950
35	2310	2270	2320	2290
50	2600	2600	2630	2520
75	2950	3010	3020	2780
100	3210	3330	3320	2960
200	3890	4240	4130	3400
350	4520	5130	4880	3760
500	4960	5780	5410	3990
750	5440	6620	6080	4260
1000	5820	7280	6590	4450

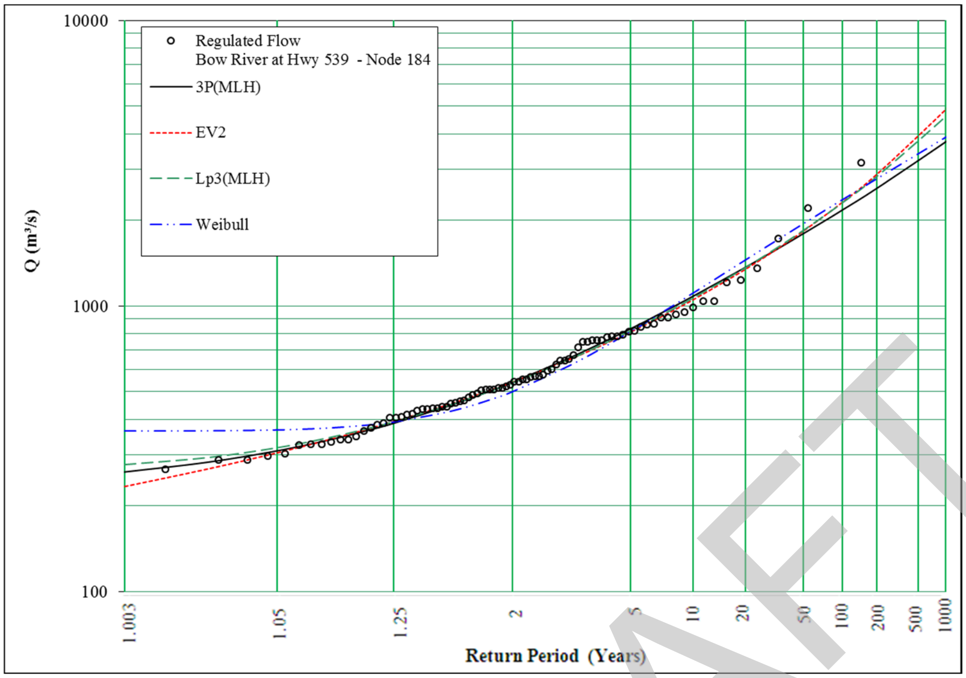
Figure C.2.30: 05BM004 / Node 182, Bow River below Bassano Dam – regulated

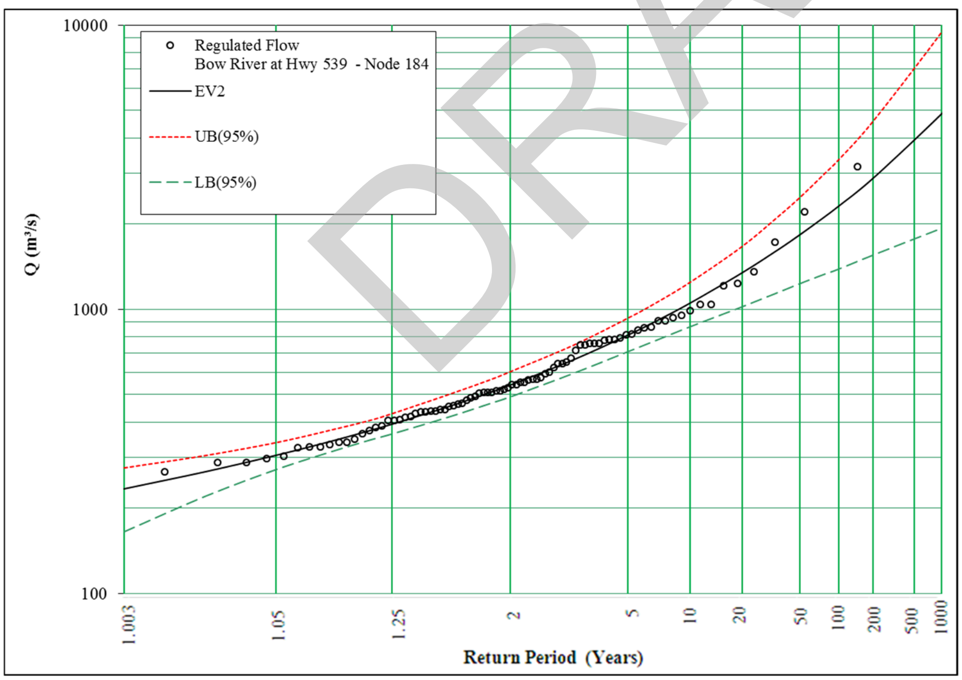




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	550	552	549	514
5	859	836	844	847
10	1120	1090	1110	1160
20	1420	1400	1420	1510
35	1700	1700	1720	1820
50	1880	1920	1940	2020
75	2110	2200	2220	2270
100	2280	2430	2430	2440
200	2730	3060	3030	2890
350	3150	3690	3610	3270
500	3430	4150	4020	3520
750	3750	4740	4550	3810
1000	4000	5210	4970	4020

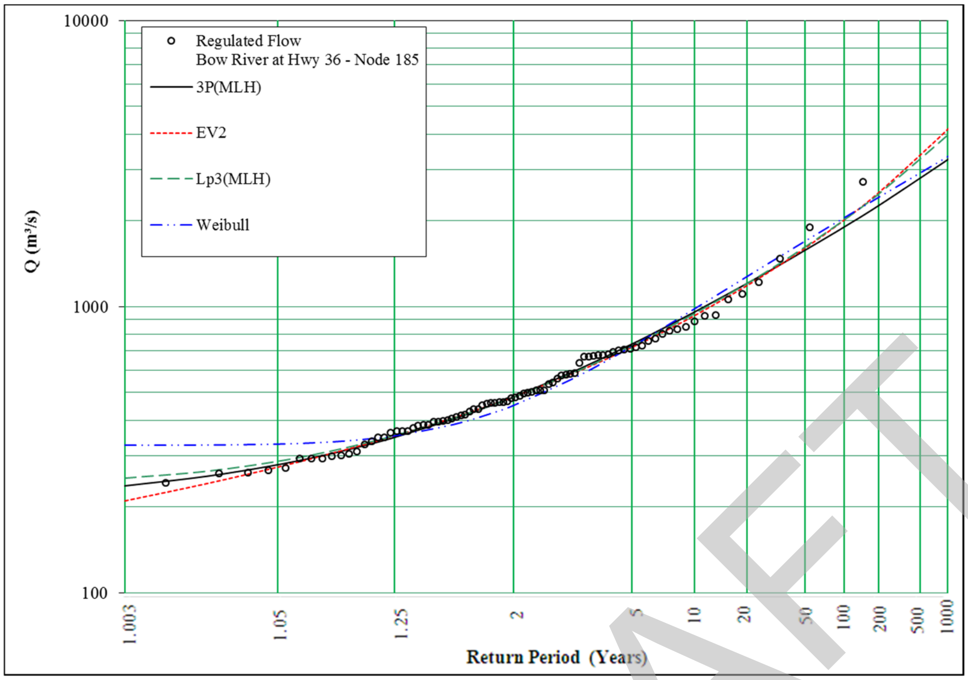
Figure C.2.31: Node 184, Bow River at Hwy. 539

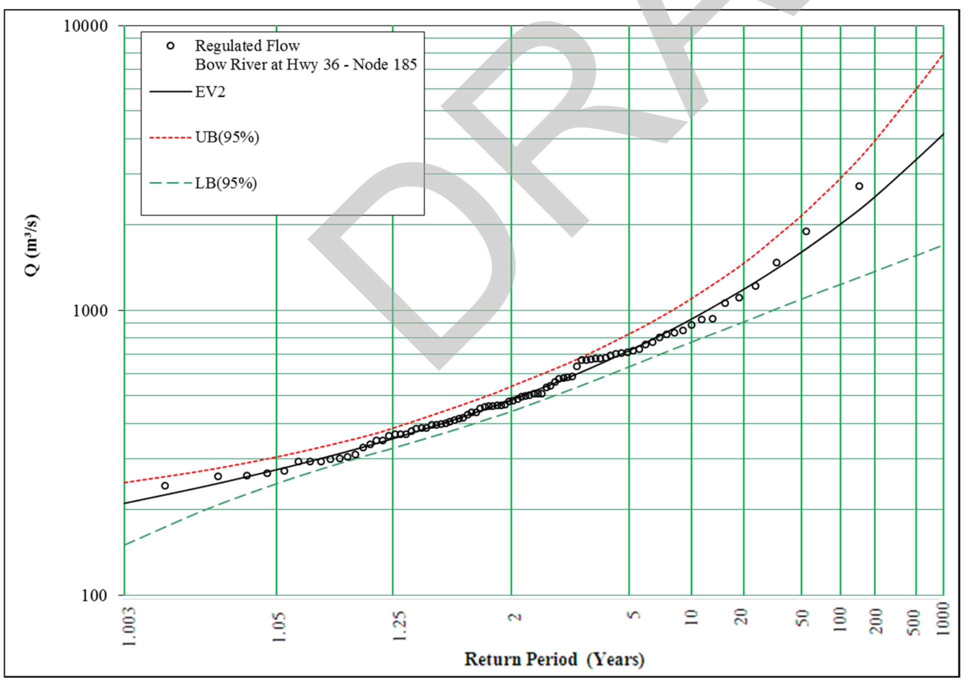




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	540	541	538	502
5	833	811	818	815
10	1080	1050	1070	1110
20	1360	1340	1360	1450
35	1620	1630	1640	1750
50	1790	1830	1840	1950
75	2010	2100	2100	2180
100	2170	2310	2290	2360
200	2580	2890	2840	2790
350	2970	3470	3370	3160
500	3230	3890	3750	3410
750	3520	4440	4230	3690
1000	3760	4870	4600	3900

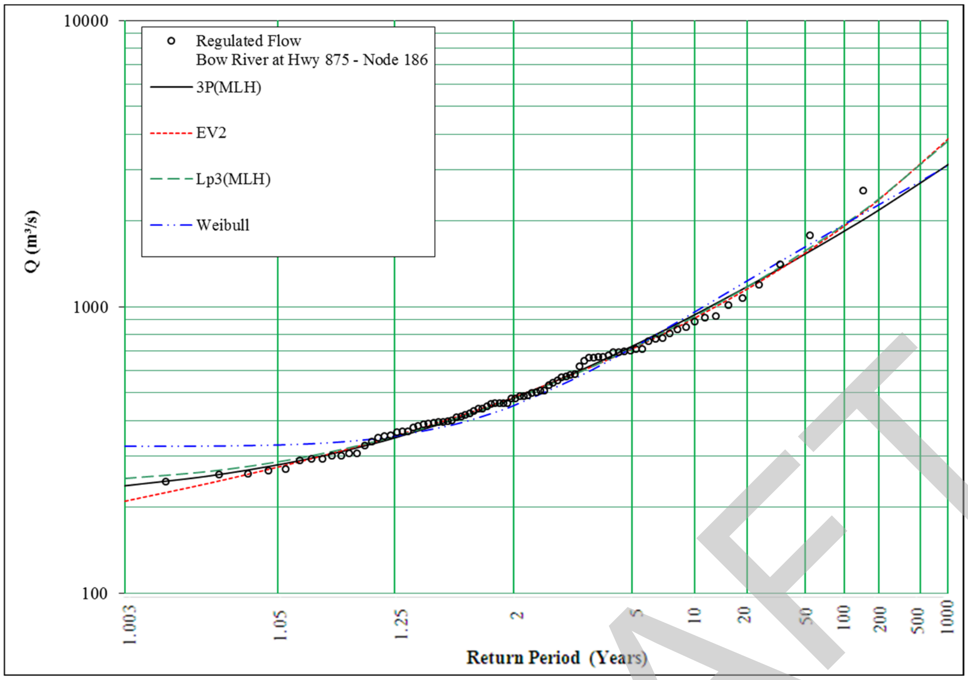
Figure C.2.32: Node 185, Bow River at Hwy. 36

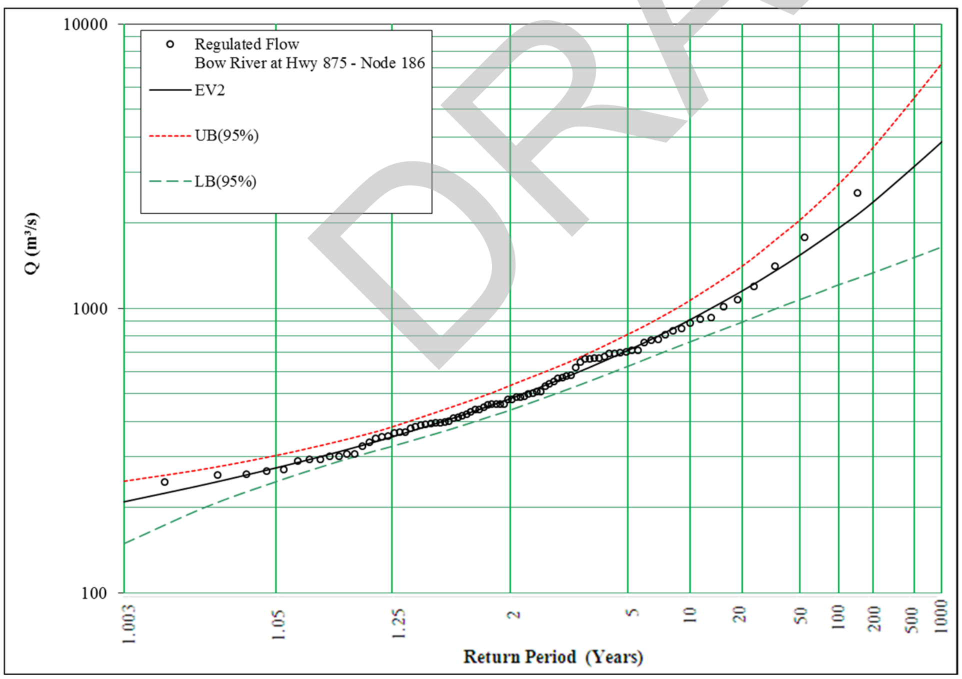




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	483	484	482	452
5	740	722	728	726
10	958	932	945	982
20	1200	1180	1200	1270
35	1420	1430	1440	1520
50	1580	1600	1620	1690
75	1760	1830	1830	1890
100	1900	2010	2010	2040
200	2260	2500	2470	2410
350	2590	2990	2920	2720
500	2810	3340	3240	2920
750	3060	3800	3650	3160
1000	3260	4160	3970	3330

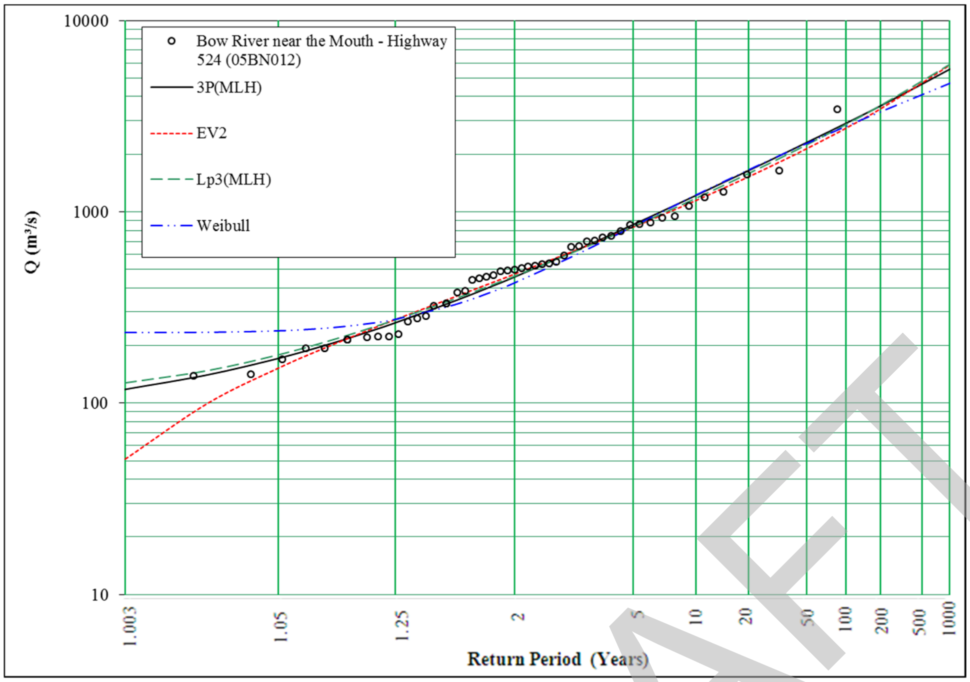
Figure C.2.33: Node 186, Bow River at Hwy. 875

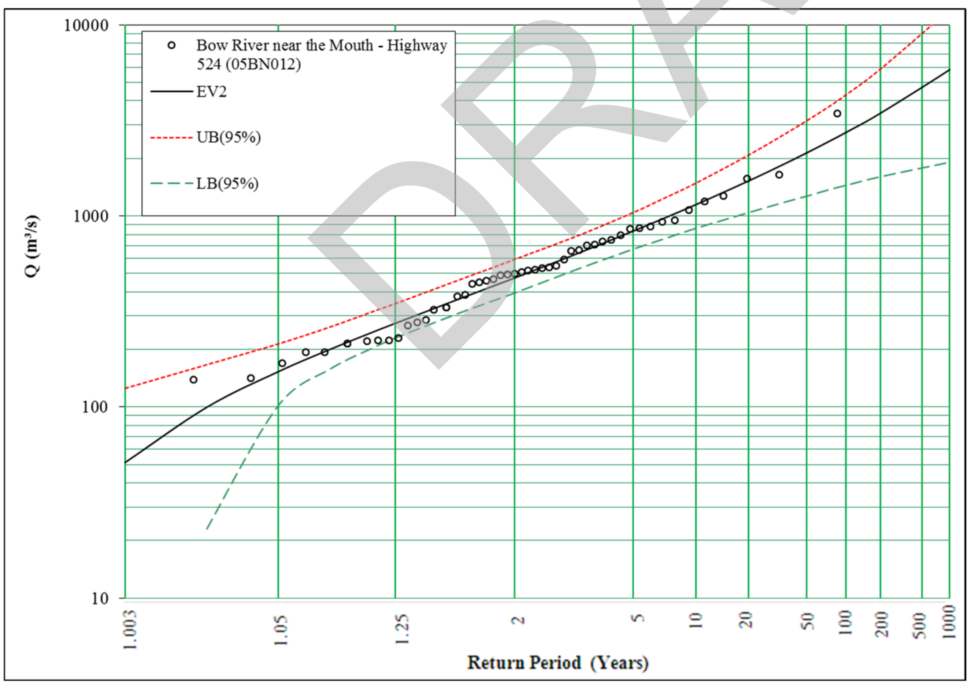




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	479	481	478	451
5	728	712	717	716
10	938	912	926	958
20	1170	1150	1170	1230
35	1380	1380	1400	1460
50	1530	1540	1570	1620
75	1710	1750	1780	1800
100	1840	1910	1940	1930
200	2180	2370	2380	2270
350	2490	2800	2800	2550
500	2710	3120	3110	2730
750	2950	3530	3490	2940
1000	3130	3840	3790	3100

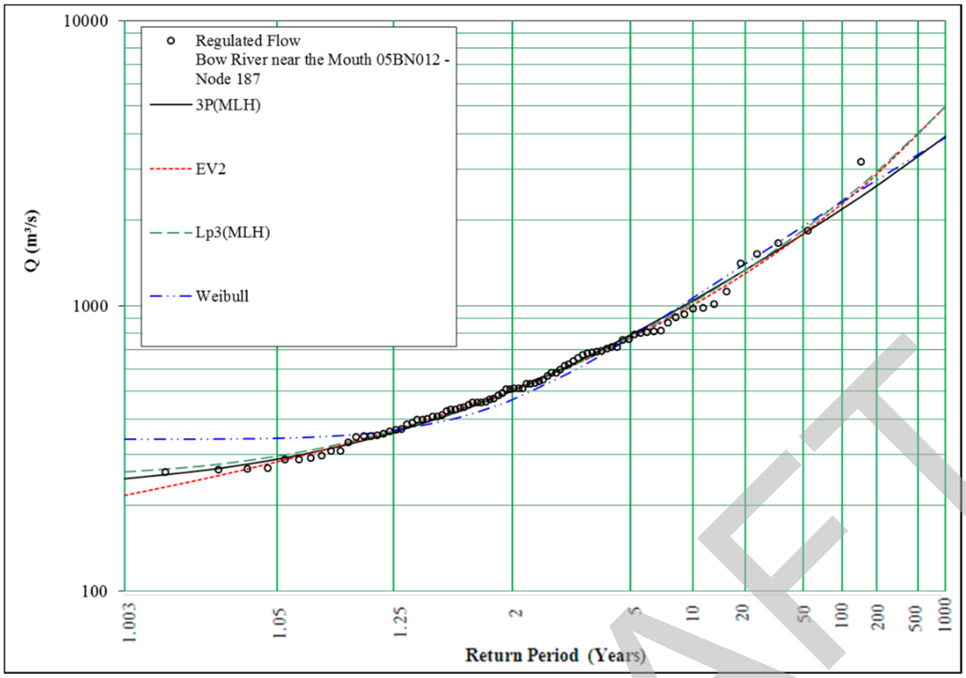
Figure C.2.34: 05BN012 / Node 187, Bow River near the Mouth – recorded regulated

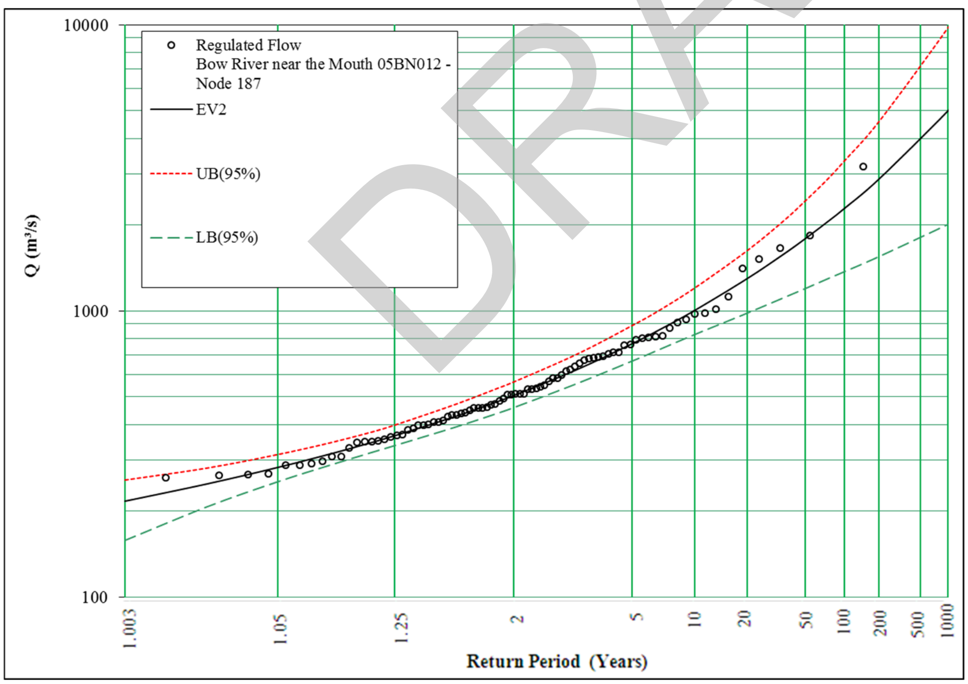




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	456	473	462	424
5	858	833	840	838
10	1220	1150	1180	1220
20	1640	1520	1590	1650
35	2030	1880	1970	2020
50	2310	2140	2250	2270
75	2640	2470	2600	2570
100	2900	2730	2860	2780
200	3580	3450	3600	3320
350	4220	4150	4300	3770
500	4660	4660	4790	4070
750	5160	5310	5420	4420
1000	5560	5820	5900	4670

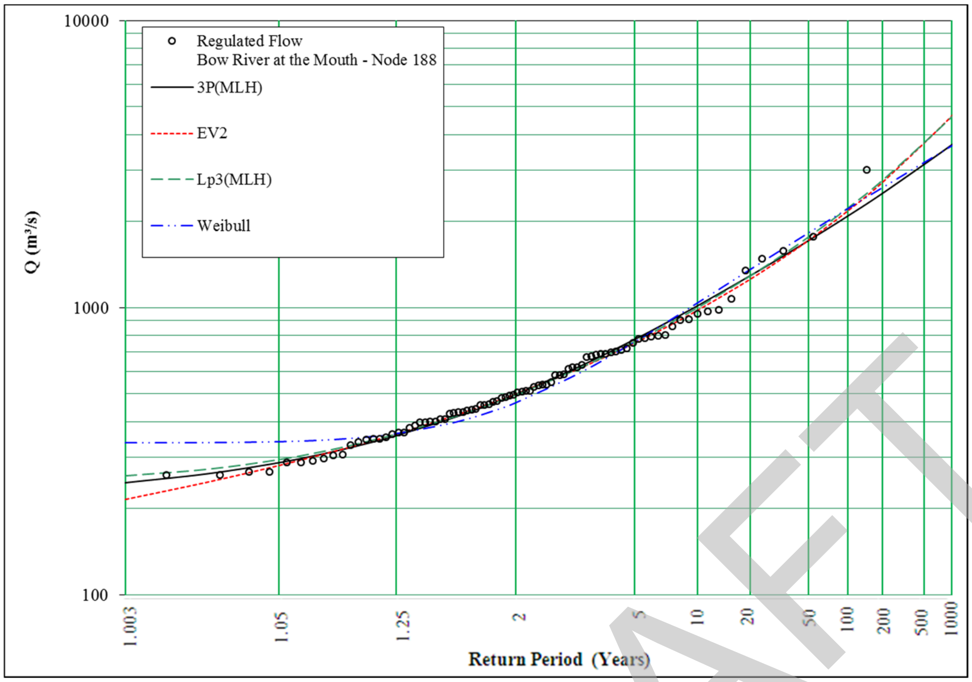
Figure C.2.35: 05BN012 / Node 187, Bow River near the Mouth – regulated

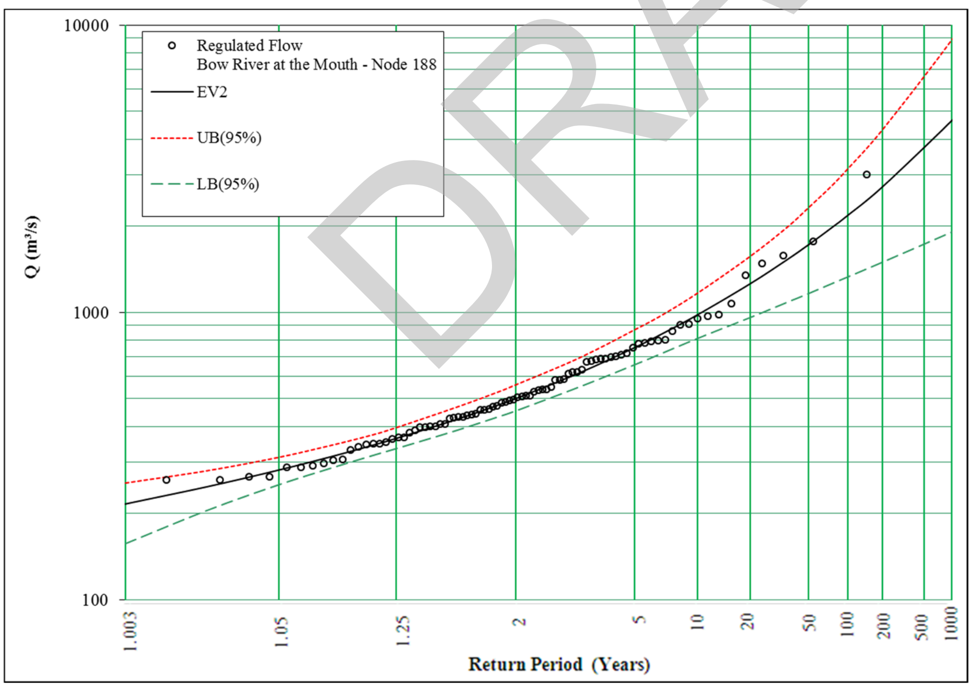




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	503	506	501	469
5	790	768	776	774
10	1040	1000	1030	1070
20	1330	1300	1330	1400
35	1600	1580	1630	1700
50	1790	1790	1840	1900
75	2010	2060	2120	2140
100	2180	2280	2340	2320
200	2630	2890	2950	2760
350	3050	3500	3550	3140
500	3340	3950	3990	3380
750	3670	4540	4550	3670
1000	3920	5000	5000	3890

Figure C.2.36: Node 188, Bow River at the Mouth

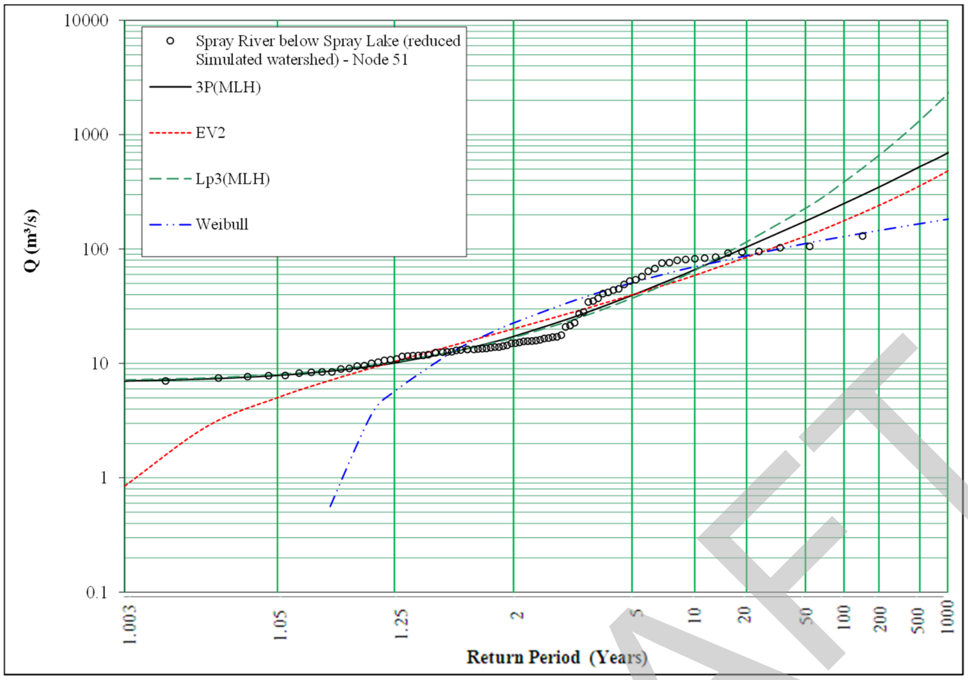


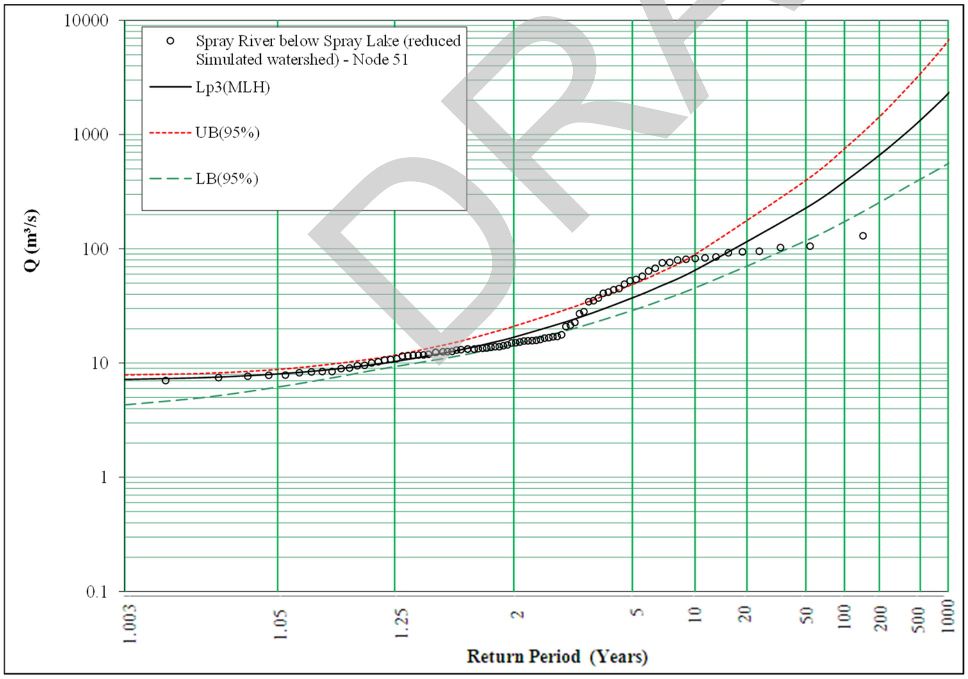


Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	498	501	497	466
5	775	754	762	760
10	1020	981	1000	1040
20	1290	1260	1290	1350
35	1540	1520	1560	1630
50	1710	1720	1770	1820
75	1920	1970	2020	2040
100	2080	2170	2220	2200
200	2500	2740	2780	2610
350	2890	3300	3320	2960
500	3160	3710	3720	3190
750	3450	4230	4220	3460
1000	3690	4650	4620	3650

BOW RIVER TRIBUTARIES

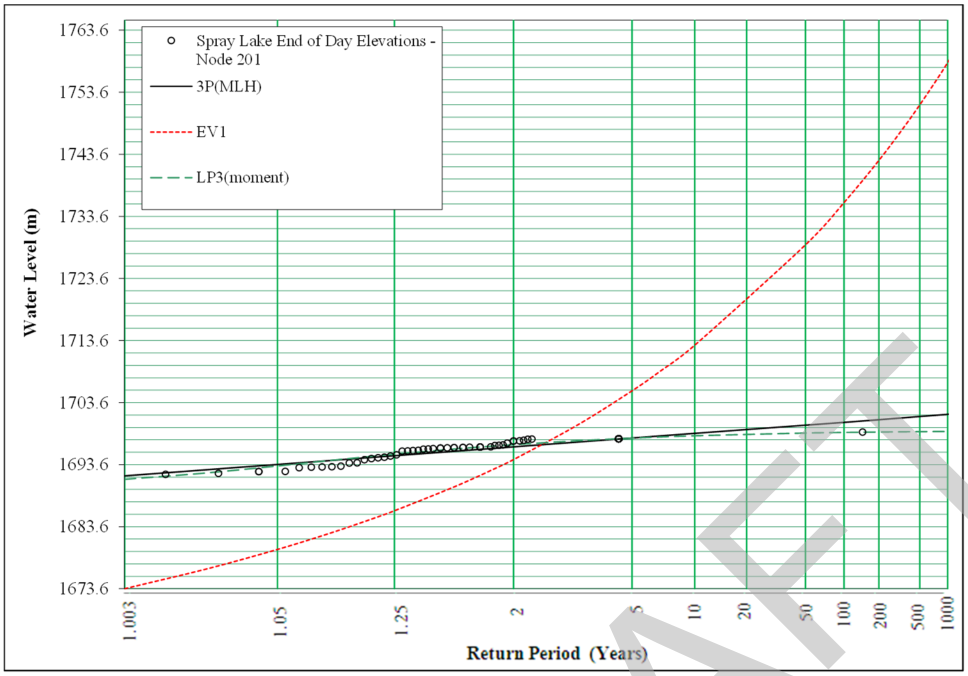
Figure C.2.37: 05BC002 / Node 51, Spray River near Spray Lake - reduced simulated watershed

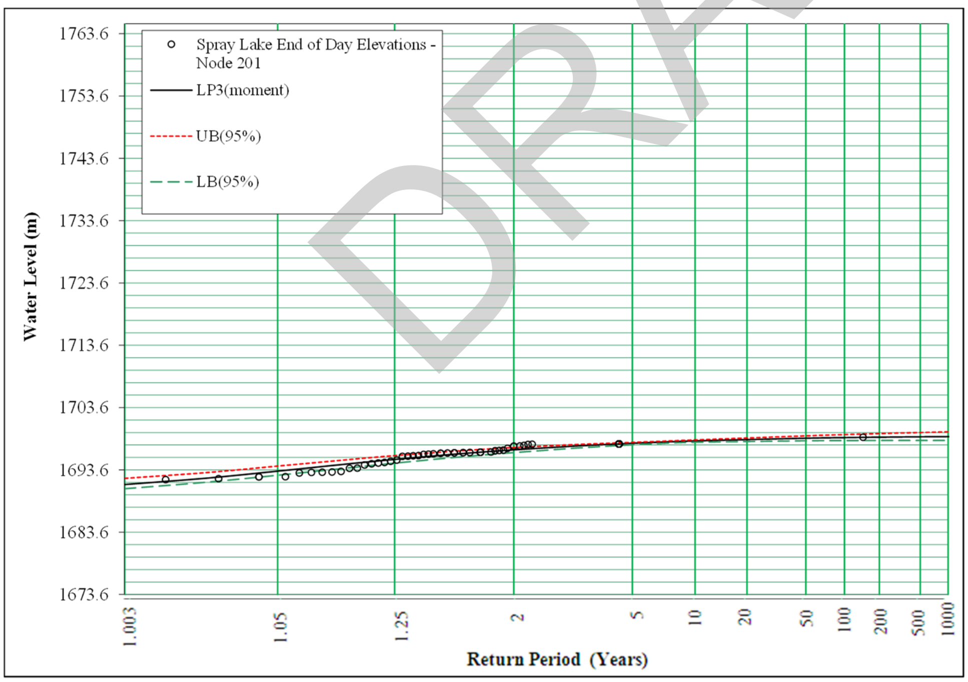




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	17.2	20.1	16.8	22.6
5	39.5	39.8	37.2	50.8
10	66.1	59.0	65.0	70.2
20	104	84.0	112	88.6
35	144	110	173	103
50	176	130	227	112
75	217	156	311	122
100	250	178	387	129
200	348	241	660	146
350	450	308	1020	159
500	526	359	1340	167
750	616	427	1830	176
1000	692	483	2290	183

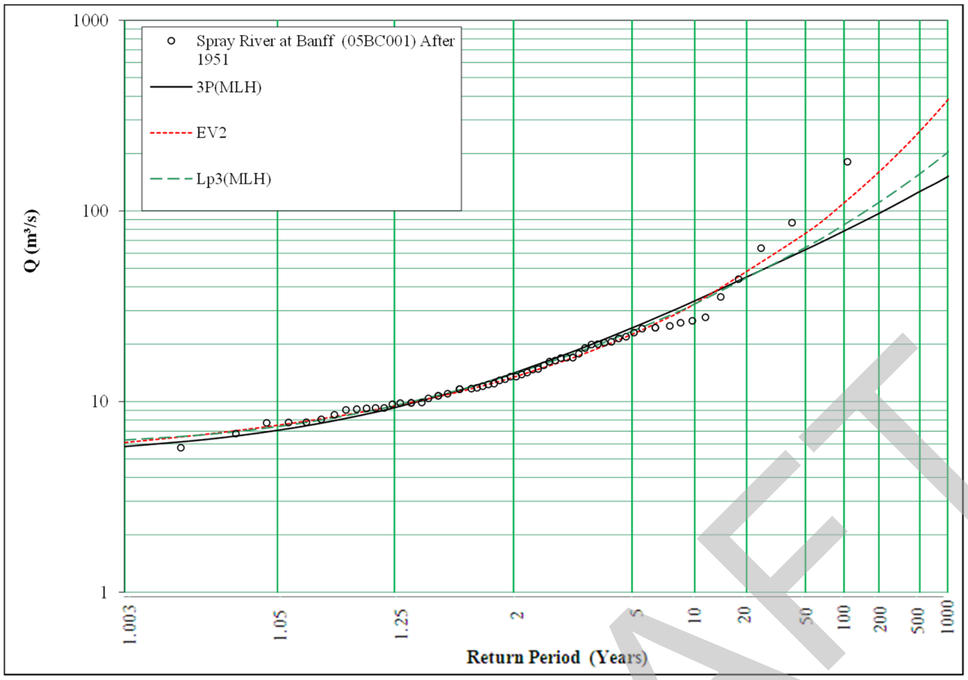
Figure C.2.38: 05BC006 / Node 201, Spray Reservoir at Three Sisters Dam, End of Day Elevations (m)

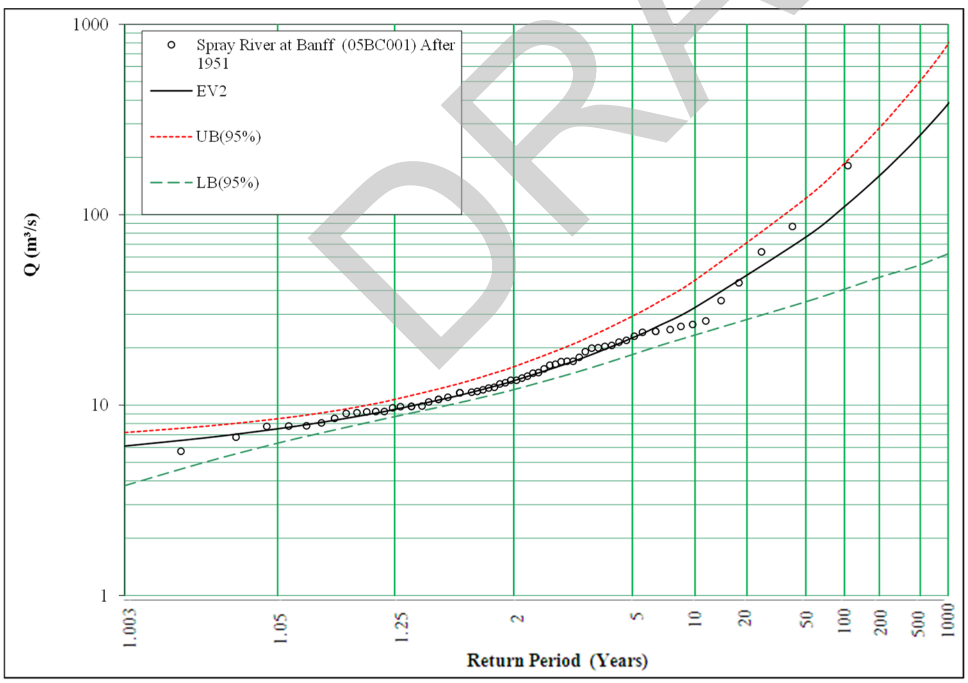




Return Period	3P(MLH)	EV1	LP3 (moment)	Weibull
2	1696.46	1694.40	1696.83	
5	1697.89	1705.49	1697.88	
10	1698.64	1712.83	1698.25	
20	1699.26	1719.87	1698.49	
35	1699.69	1725.45	1698.63	
50	1699.95	1728.99	1698.69	
75	1700.23	1732.98	1698.75	
100	1700.41	1735.82	1698.79	
200	1700.84	1742.62	1698.86	
350	1701.16	1748.10	1698.89	
500	1701.36	1751.60	1698.91	
750	1701.56	1755.57	1698.93	
1000	1701.71	1758.38	1698.94	

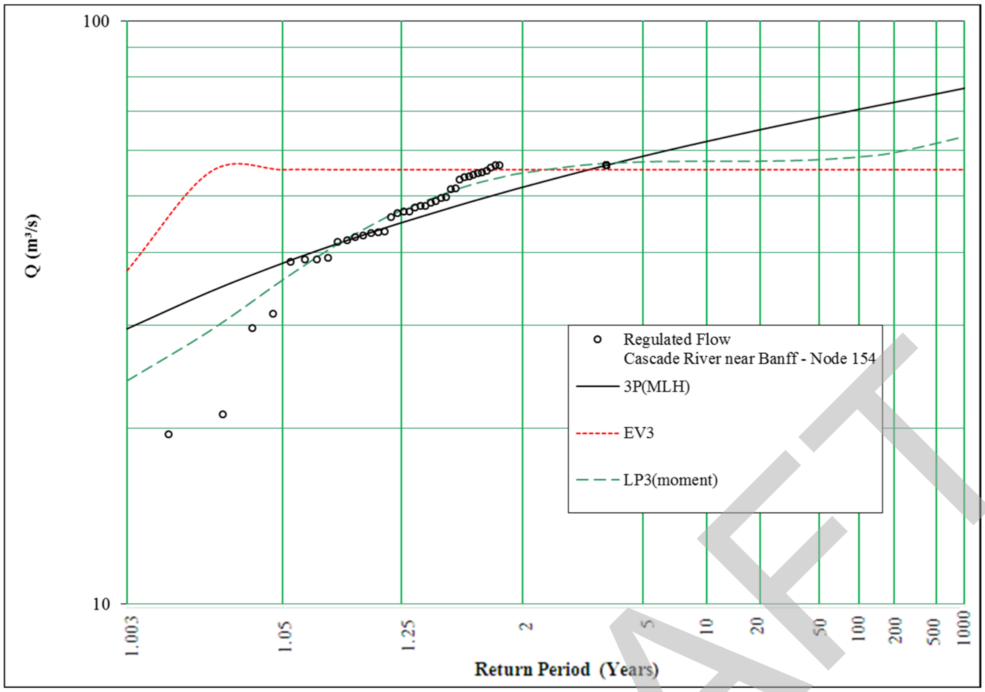
Figure C.2.39: 05BC001 / Node 106, Spray River at Banff - after 1951

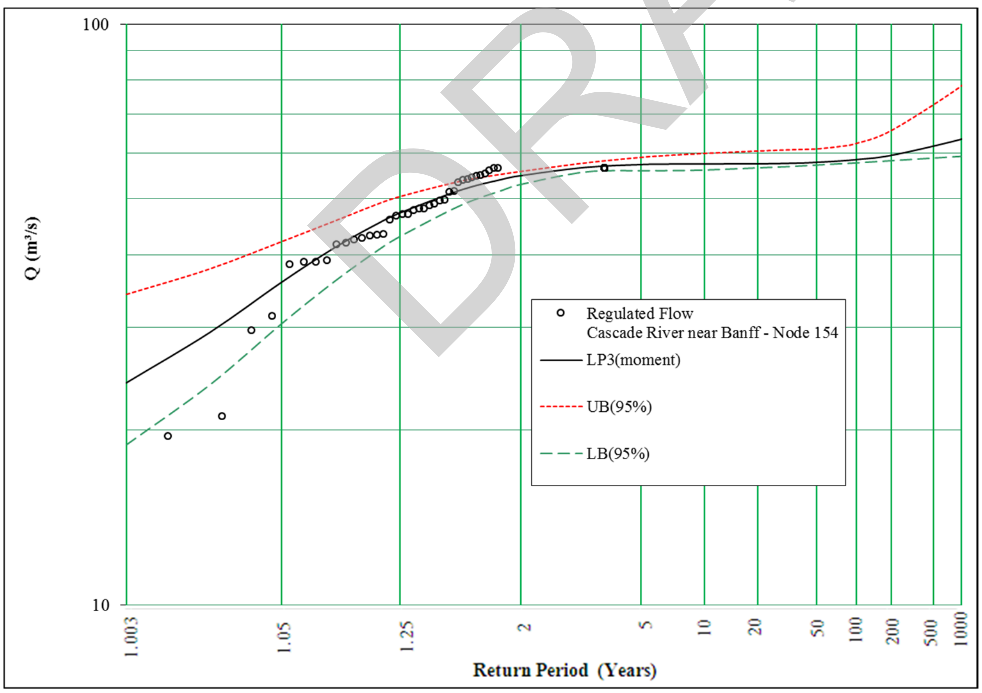




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	14.1	13.4	14.0	
5	24.4	22.6	23.4	
10	33.7	32.6	32.5	
20	44.8	47.0	44.1	
35	55.2	63.2	55.7	
50	62.6	76.3	64.4	
75	71.6	94.7	75.7	
100	78.6	110	84.8	
200	97.0	160	111	
350	114	217	137	
500	127	263	157	
750	140	327	183	
1000	151	382	203	

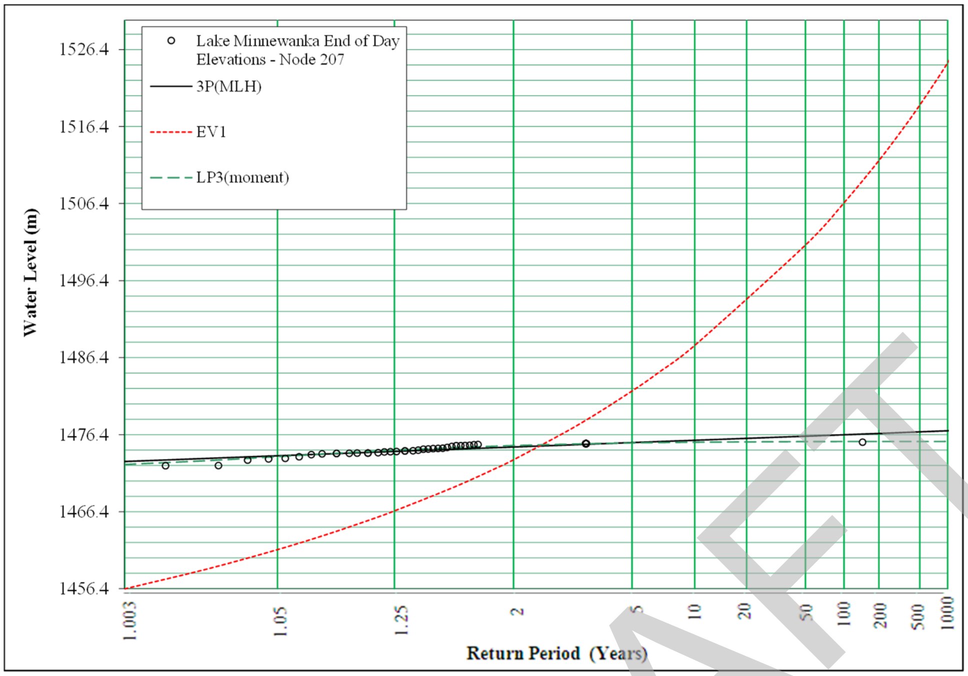
Figure C.2.40: 05BD002 / Node 154, Cascade River near Banff

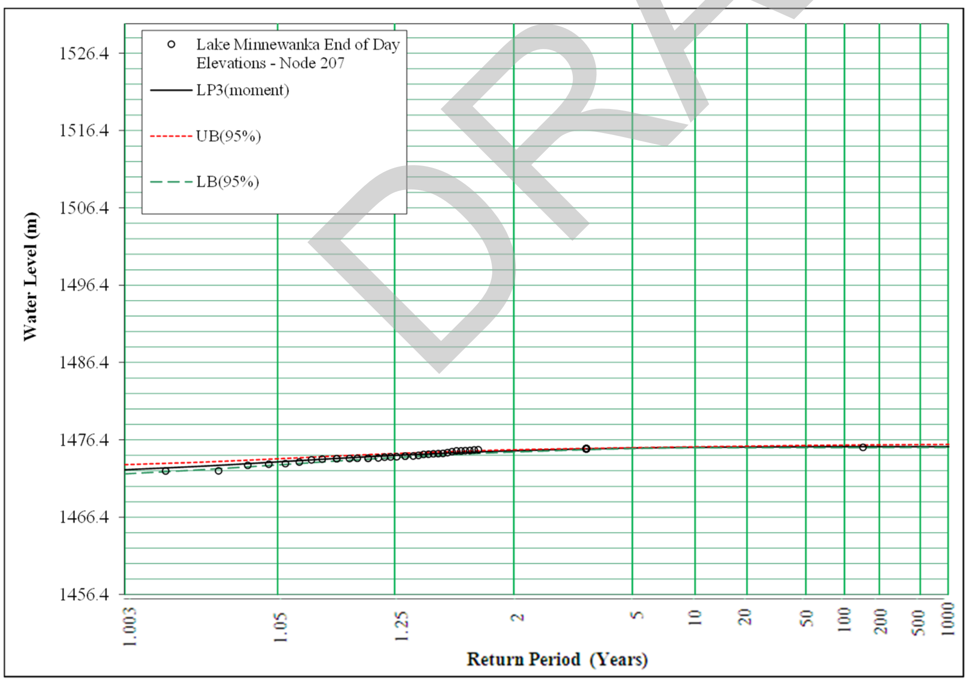




Return Period	3P(MLH)	EV3	LP3 (moment)	Weibull
2	51.8	55.6	54.8	
5	58.6	55.6	57.3	
10	62.1	55.6	57.4	
20	65.0	55.6	57.4	
35	67.1	55.6	57.6	
50	68.3	55.6	57.8	
75	69.6	55.6	58.1	
100	70.5	55.6	58.4	
200	72.5	55.6	59.4	
350	74.0	55.6	60.5	
500	74.9	55.6	61.4	
750	75.9	55.6	62.5	
1000	76.6	55.6	63.3	

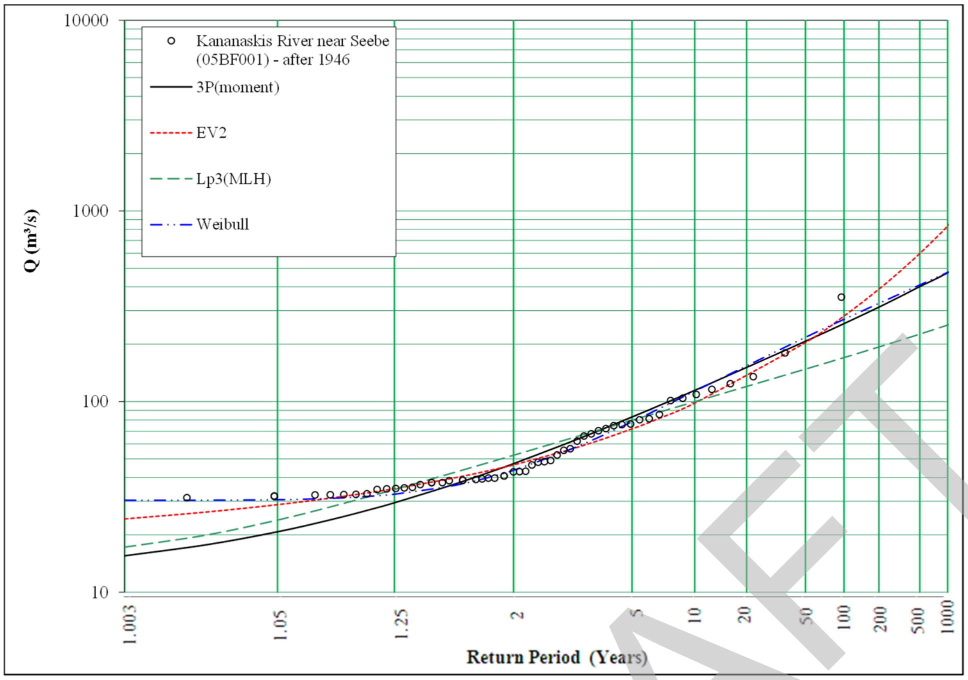
Figure C.2.41: 05BD003 / Node 207, Lake Minnewanka near Banff, End of Day Elevations (m)

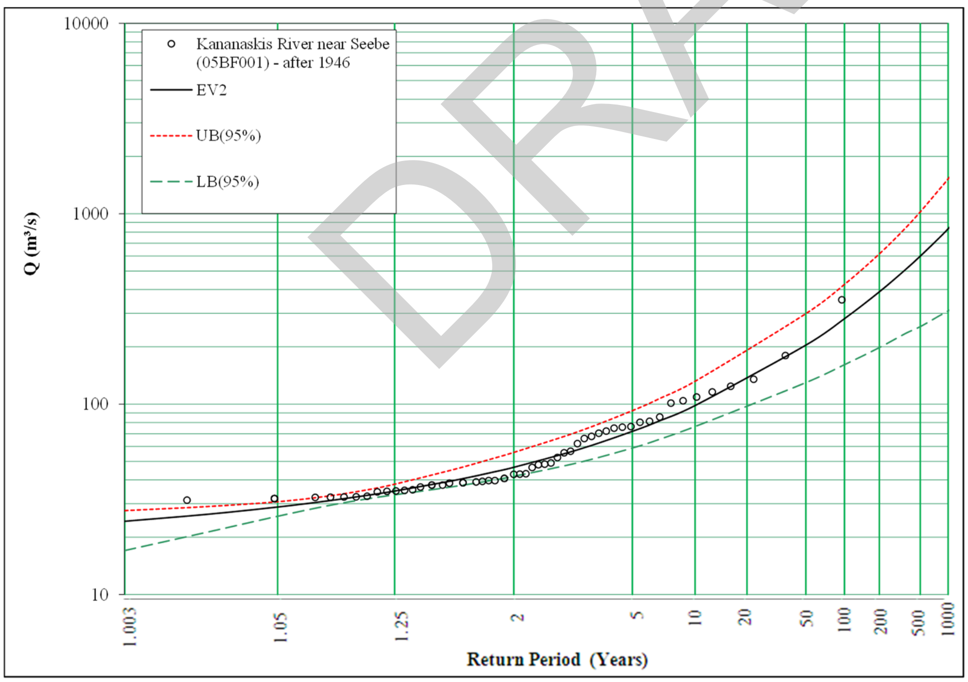




Return Period	3P(MLH)	EV1	LP3 (moment)	Weibull
2	1474.80	1473.14	1474.99	
5	1475.38	1482.07	1475.34	
10	1475.68	1487.99	1475.44	
20	1475.92	1493.66	1475.48	
35	1476.10	1498.16	1475.51	
50	1476.20	1501.01	1475.51	
75	1476.31	1504.23	1475.52	
100	1476.39	1506.51	1475.52	
200	1476.56	1511.99	1475.52	
350	1476.69	1516.41	1475.53	
500	1476.77	1519.23	1475.53	
750	1476.85	1522.42	1475.53	
1000	1476.91	1524.69	1475.53	

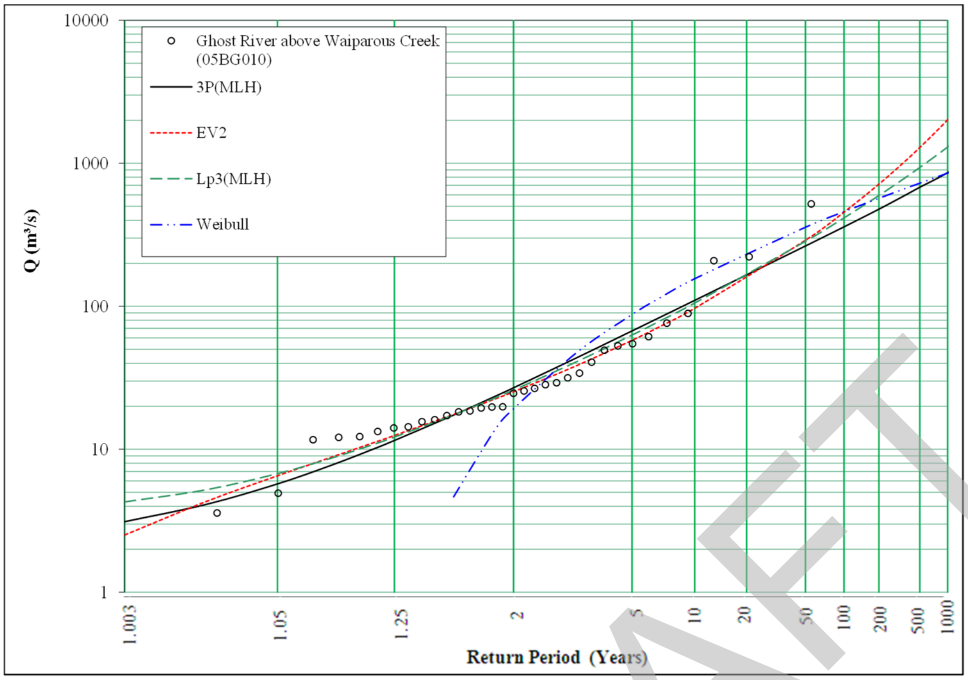
Figure C.2.42: 05BF001, Kananaskis River near Seebe - after 1946

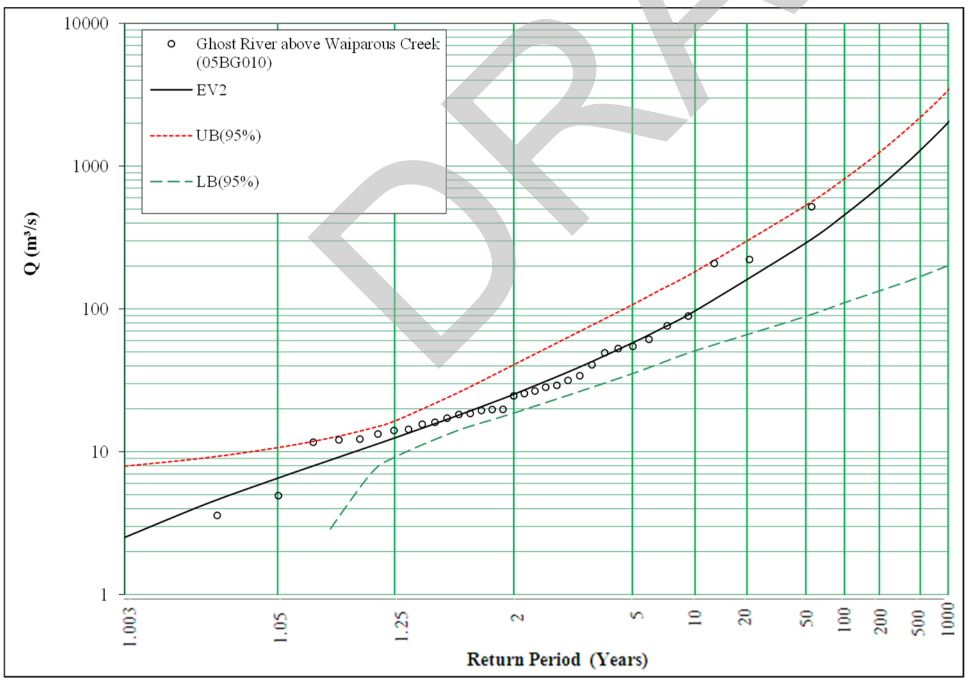




Return Period	3P (moment)	EV2	Lp3(MLH)	Weibull
2	47.3	46.6	52.4	43.6
5	83.1	72.0	80.0	78.5
10	115	98.4	100	114
20	151	134	120	155
35	184	173	137	192
50	207	204	148	217
75	235	246	161	248
100	257	281	170	270
200	313	389	194	328
350	365	507	213	377
500	402	600	226	410
750	442	728	241	448
1000	474	835	252	476

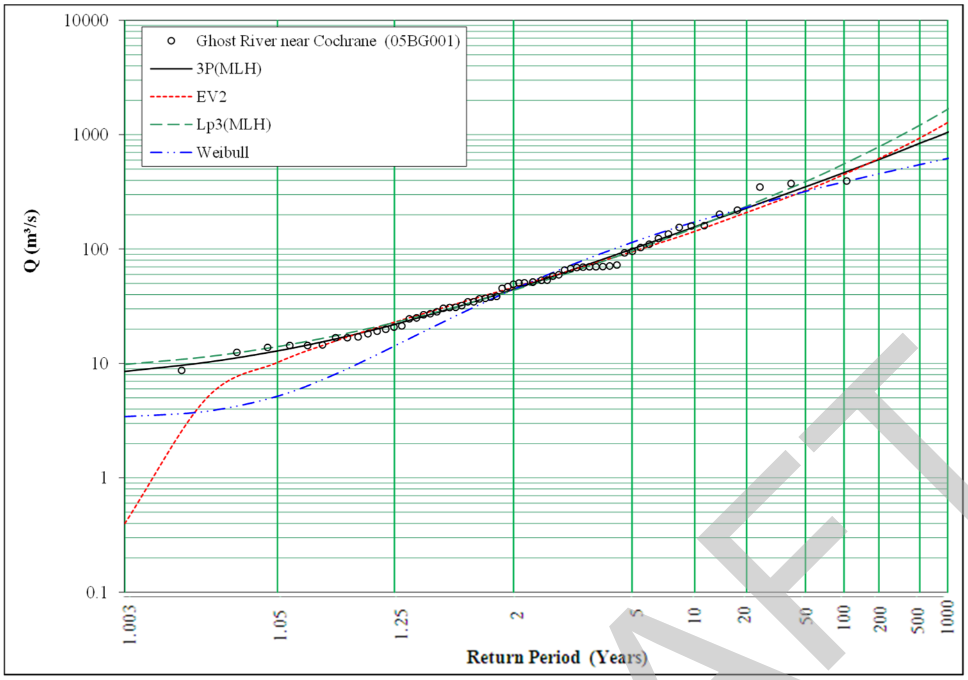
Figure C.2.43: 05BG010, Ghost River above Waiparous Creek

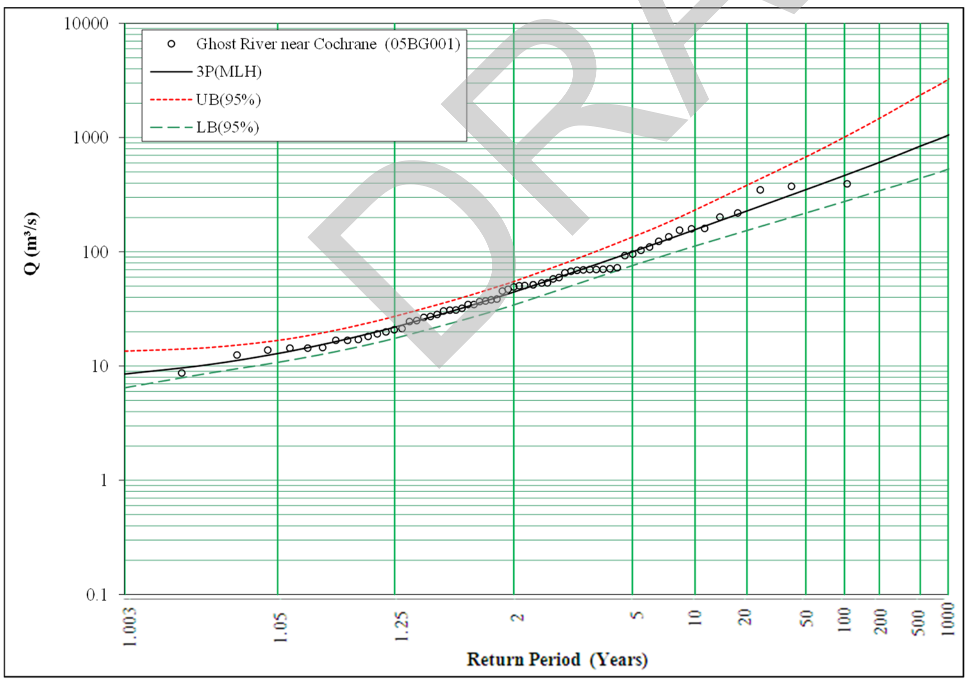




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	26.9	25.3	25.9	19.2
5	67.3	57.9	63.0	87.6
10	110	97.0	105	156
20	166	157	166	236
35	222	229	232	308
50	264	290	285	357
75	317	378	356	415
100	360	456	416	459
200	478	716	596	569
350	595	1030	788	664
500	681	1290	937	727
750	780	1680	1140	800
1000	861	2020	1300	854

Figure C.2.44: 05BG001, Ghost River near Cochrane

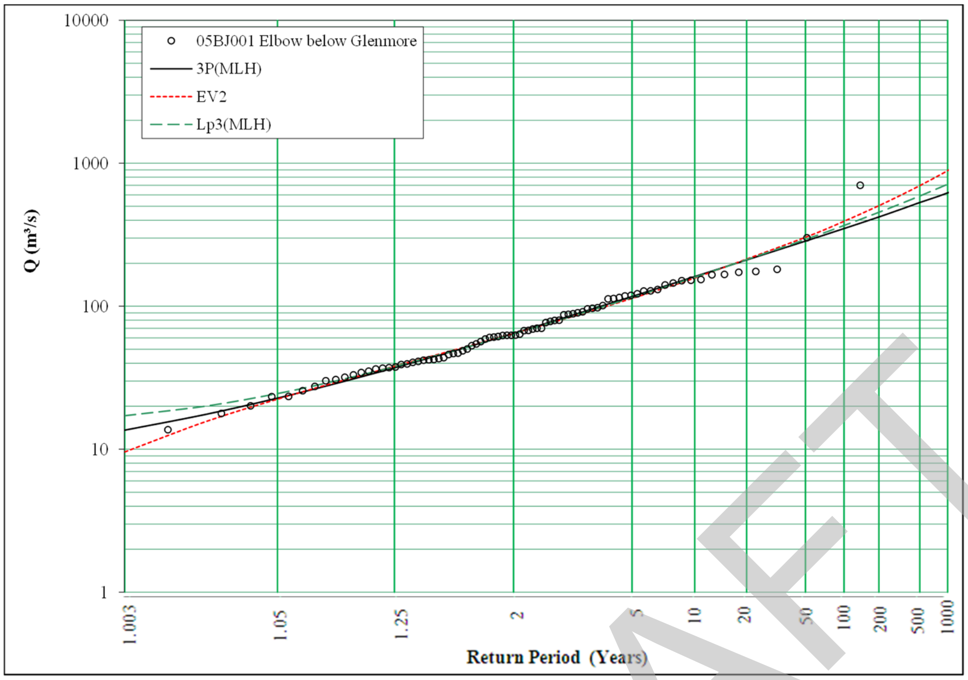


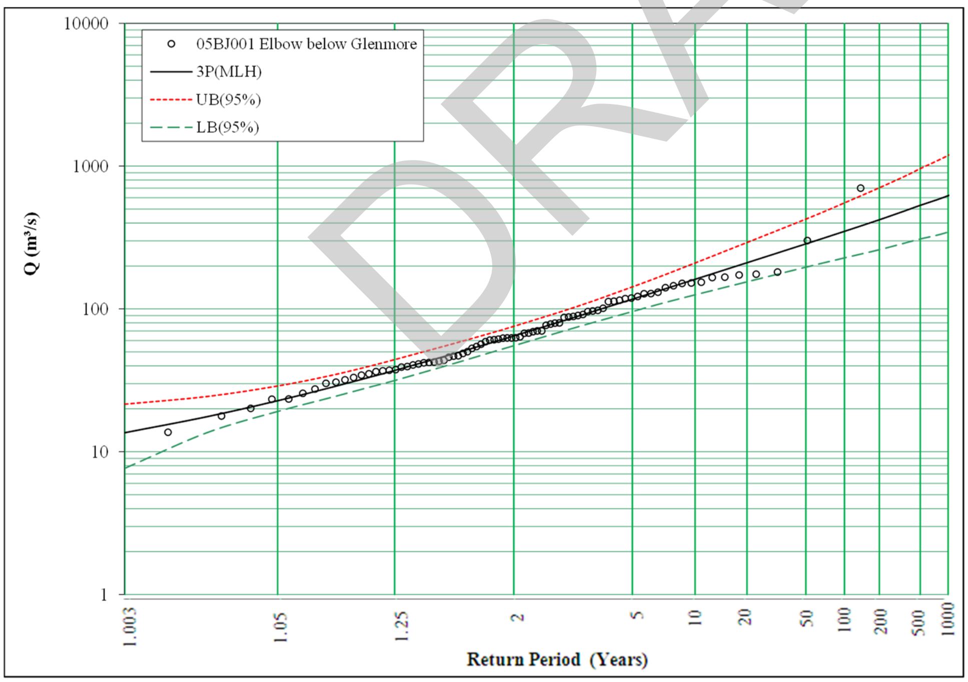


Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	44.5	46.4	43.6	44.6
5	100	94.9	96.1	115
10	157	143	154	173
20	228	207	234	235
35	298	273	320	286
50	350	325	388	320
75	415	394	480	359
100	466	451	556	387
200	607	620	784	456
350	744	800	1030	513
500	844	939	1210	549
750	957	1130	1460	591
1000	1050	1280	1670	622

ELBOW RIVER

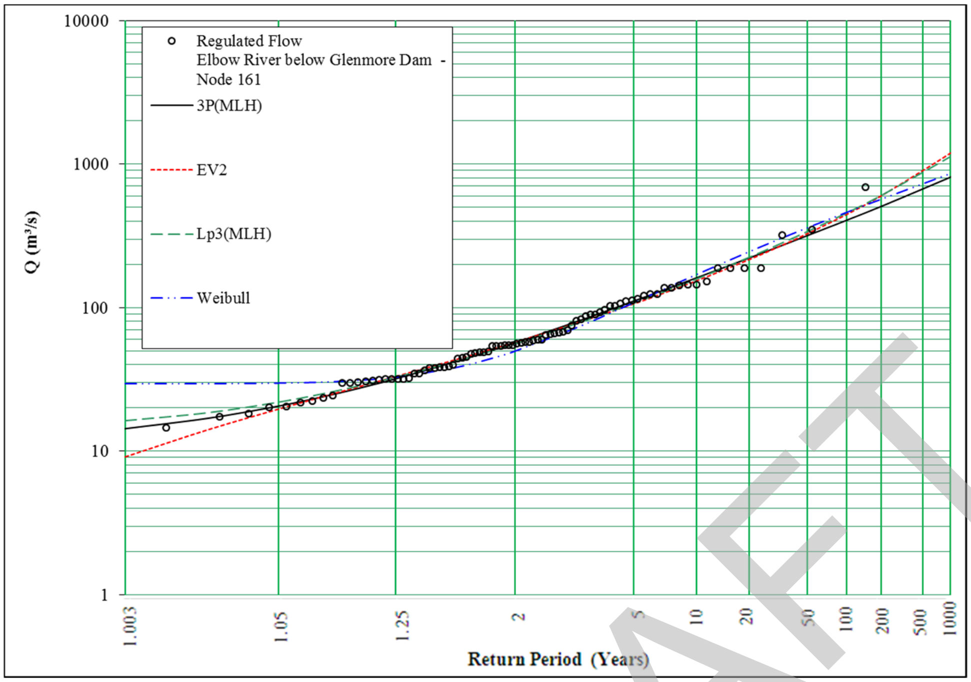
Figure C.2.45: 05BJ001 / Node 161, Elbow River below Glenmore Dam – recorded regulated

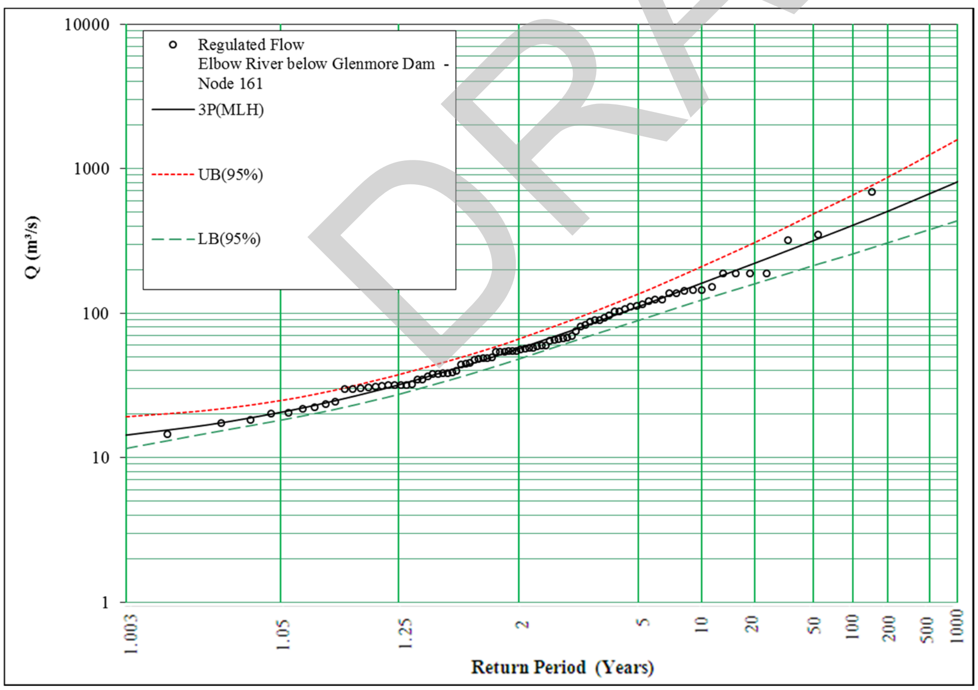




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	64.7	64.5	64.2	
5	117	114	115	
10	161	158	160	
20	211	212	211	
35	255	265	259	
50	286	304	293	
75	322	354	335	
100	350	394	367	
200	422	506	454	
350	487	618	534	
500	532	700	591	
750	582	807	661	
1000	621	891	714	

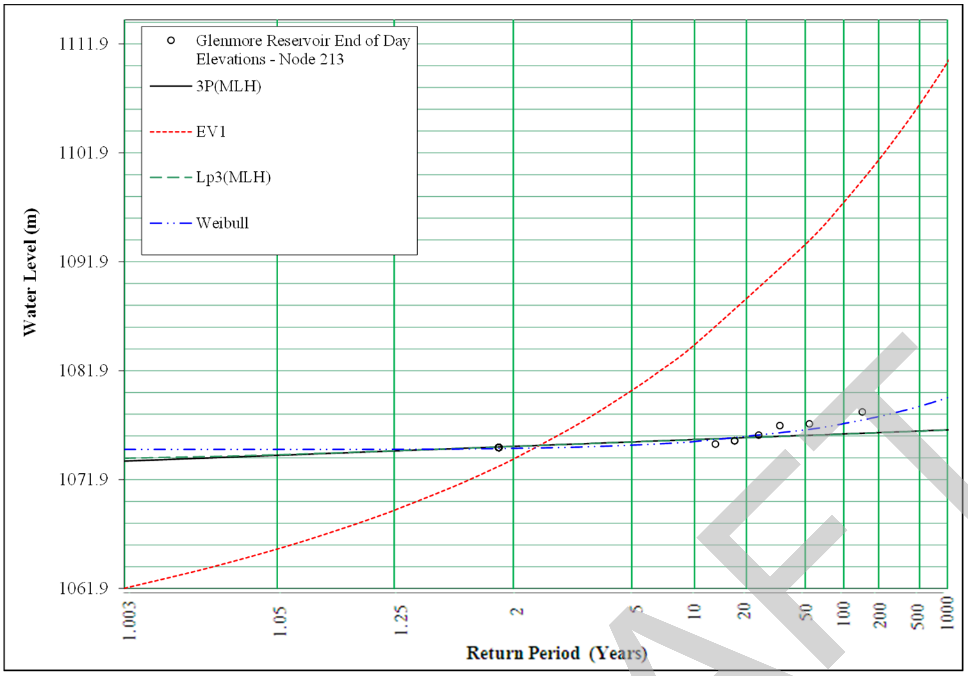
Figure C.2.46: 05BJ001 / Node 161, Elbow River below Glenmore Dam – regulated

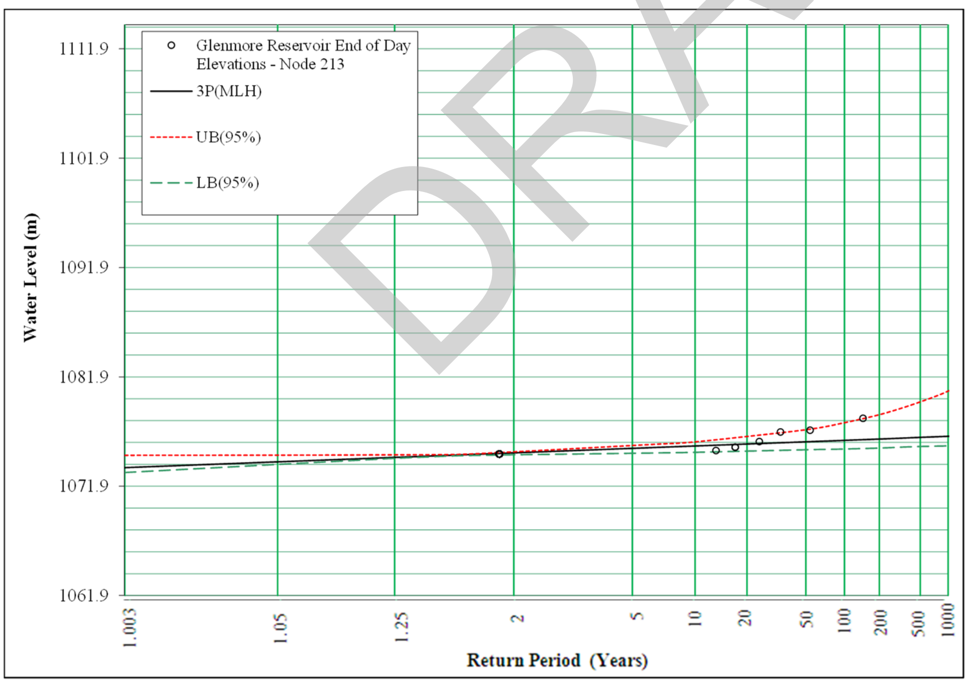




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	56.8	57.1	56.1	49.4
5	111	106	107	108
10	161	153	158	169
20	221	215	223	244
35	277	278	289	312
50	318	326	339	359
75	367	391	403	416
100	405	443	455	459
200	507	598	603	568
350	604	759	751	663
500	672	883	862	726
750	748	1050	1010	801
1000	810	1180	1120	856

Figure C.2.47: Node 213, Glenmore Reservoir End of Day Elevations (Water Level, m.a.s.l)

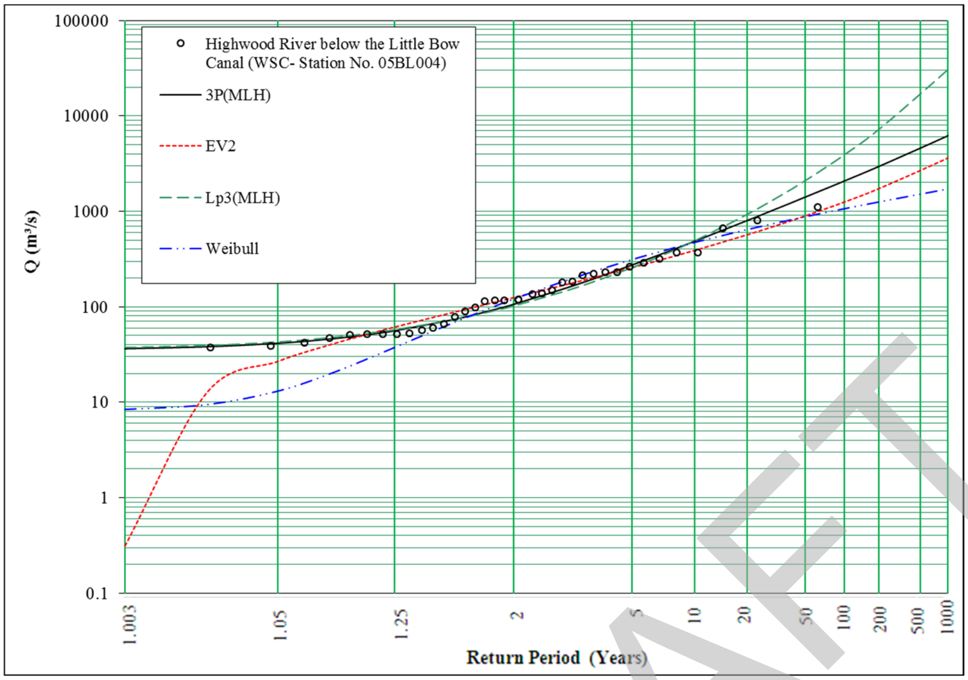


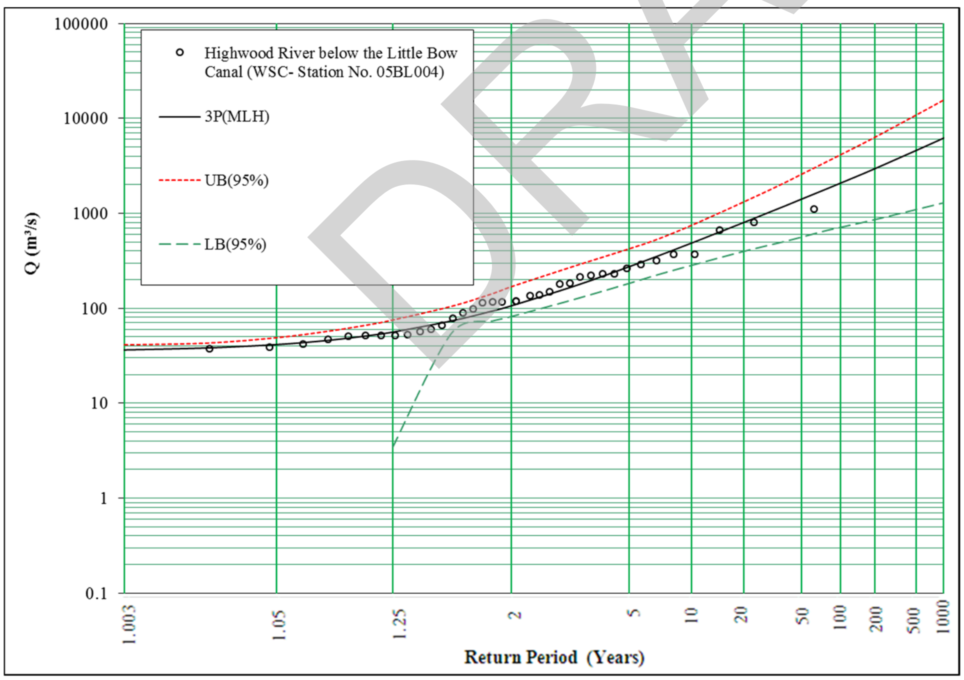


Return Period	3P(MLH)	EV1	Lp3(MLH)	Weibull
2	1074.95	1073.77	1074.95	1074.77
5	1075.36	1080.09	1075.35	1075.07
10	1075.58	1084.27	1075.57	1075.40
20	1075.76	1088.28	1075.74	1075.81
35	1075.88	1091.46	1075.87	1076.2
50	1075.96	1093.47	1075.94	1076.47
75	1076.04	1095.75	1076.02	1076.80
100	1076.09	1097.36	1076.07	1077.05
200	1076.21	1101.24	1076.19	1077.69
350	1076.31	1104.36	1076.28	1078.25
500	1076.37	1106.35	1076.34	1078.63
750	1076.42	1108.62	1076.4	1079.09
1000	1076.47	1110.22	1076.44	1079.42

HIGHWOOD RIVER AND TRIBUTARIES

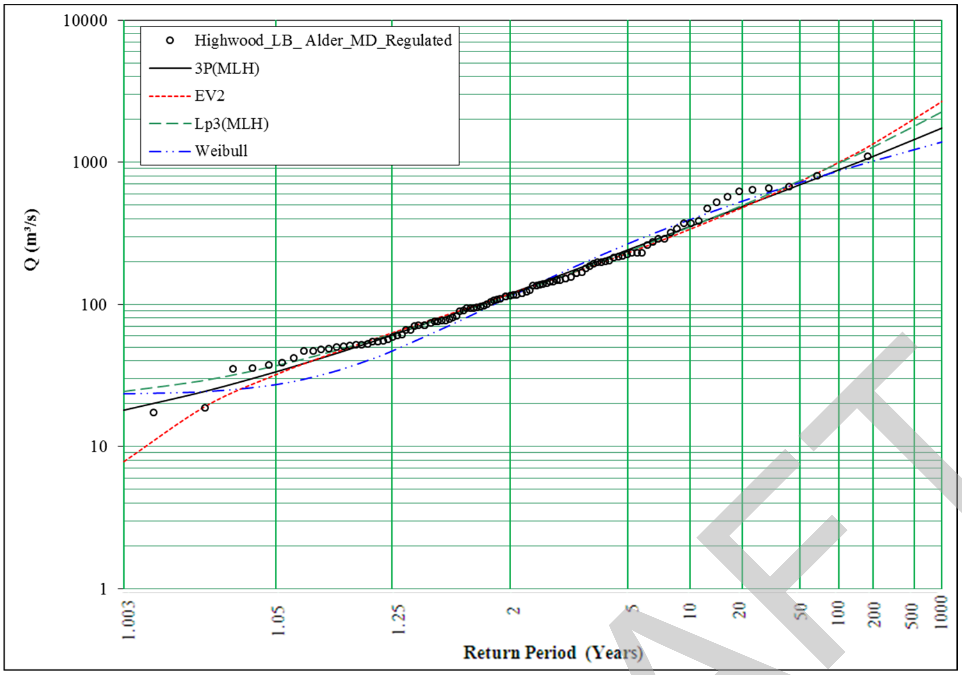
Figure C.2.48: 05BL004, Highwood River below Little Bow Canal

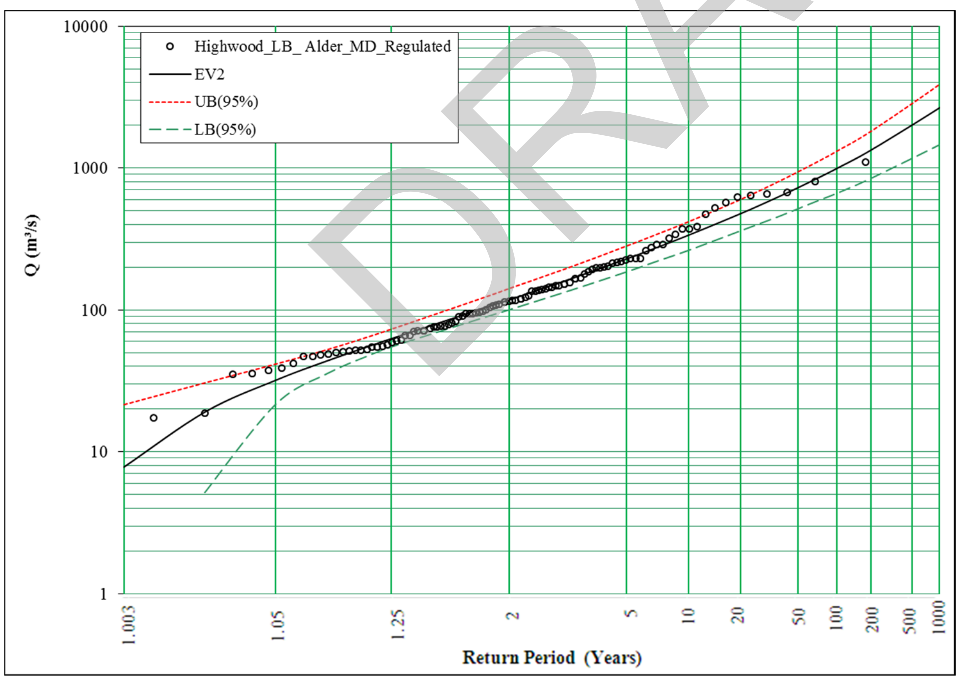




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	106	125	102	121
5	274	258	257	313
10	487	391	492	475
20	799	568	923	645
35	1140	755	1530	788
50	1410	900	2100	882
75	1780	1090	3010	990
100	2080	1260	3890	1070
200	2960	1740	7210	1260
350	3900	2250	11900	1420
500	4610	2650	16300	1520
750	5470	3190	23400	1640
1000	6190	3640	30300	1720

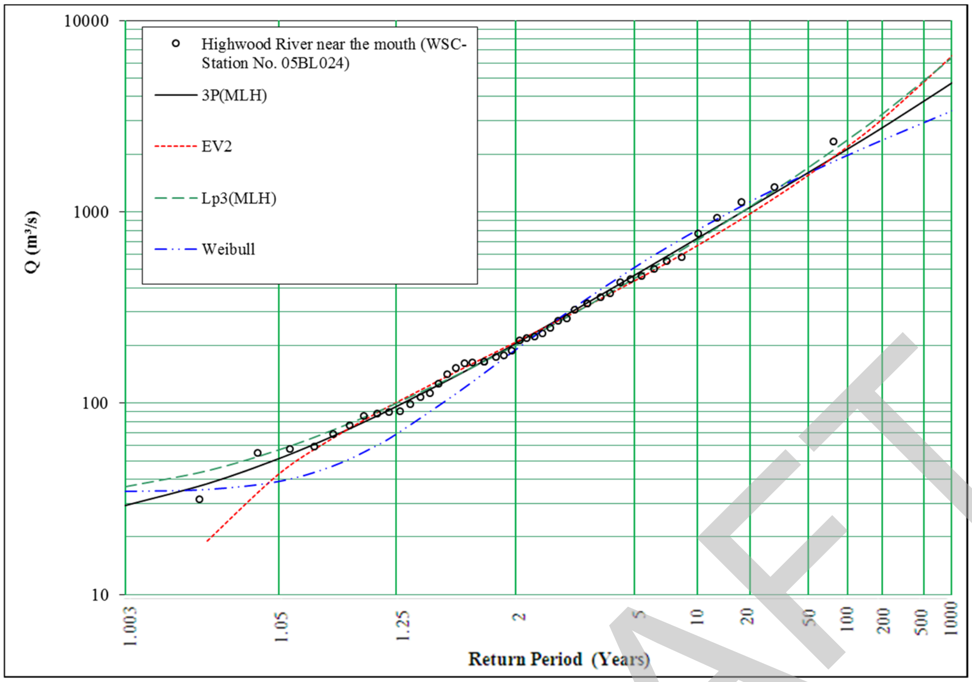
Figure C.2.49: 05BL004, Highwood River below Little Bow Canal – extended

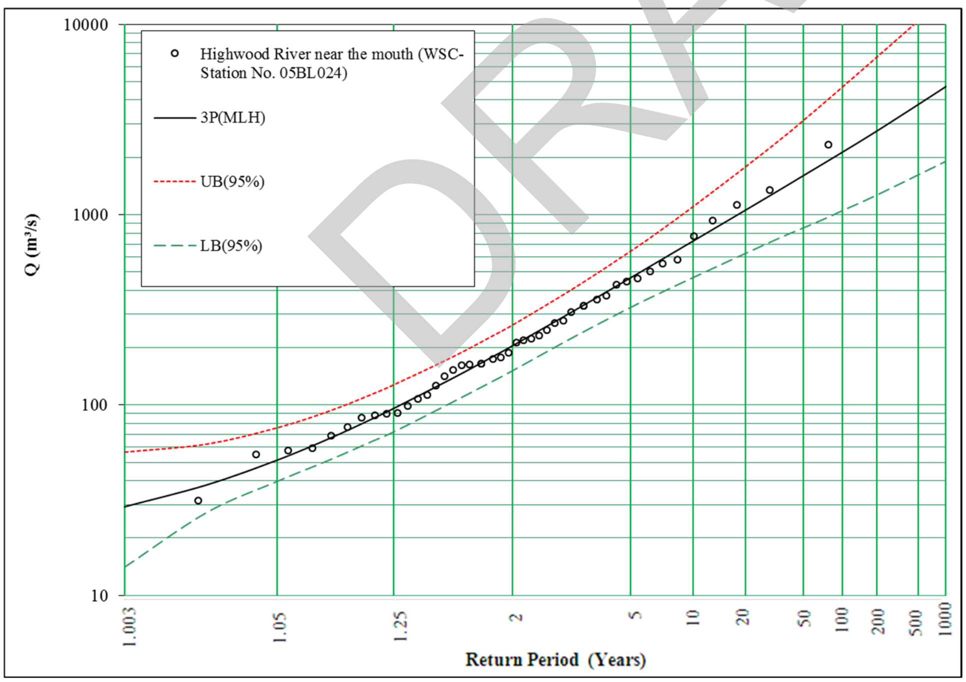




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	119	118	116	113
5	242	229	236	266
10	354	336	352	394
20	485	476	497	529
35	608	619	640	642
50	696	728	745	717
75	802	873	879	802
100	883	992	986	864
200	1100	1340	1280	1020
350	1300	1700	1570	1140
500	1450	1980	1780	1220
750	1610	2350	2050	1310
1000	1740	2650	2260	1380

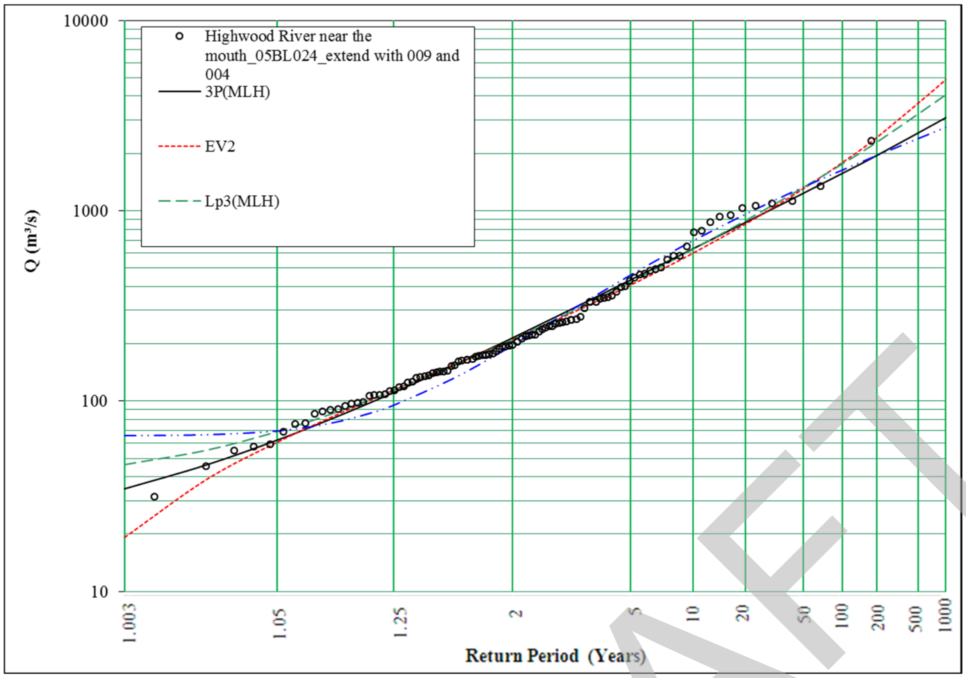
Figure C.2.50: 05BL050, Highwood River near the Mouth

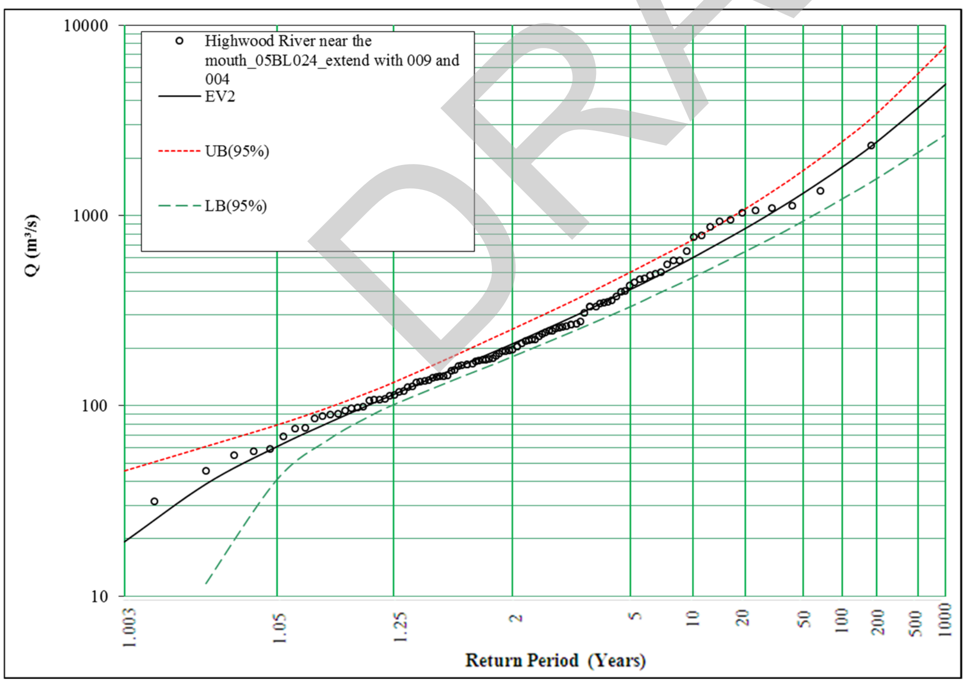




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	205	208	201	190
5	467	436	450	513
10	728	666	712	806
20	1050	975	1060	1130
35	1370	1300	1430	1410
50	1610	1560	1710	1600
75	1900	1900	2080	1820
100	2130	2190	2370	1980
200	2750	3050	3240	2380
350	3360	3980	4130	2710
500	3800	4700	4790	2930
750	4300	5680	5660	3190
1000	4700	6500	6360	3370

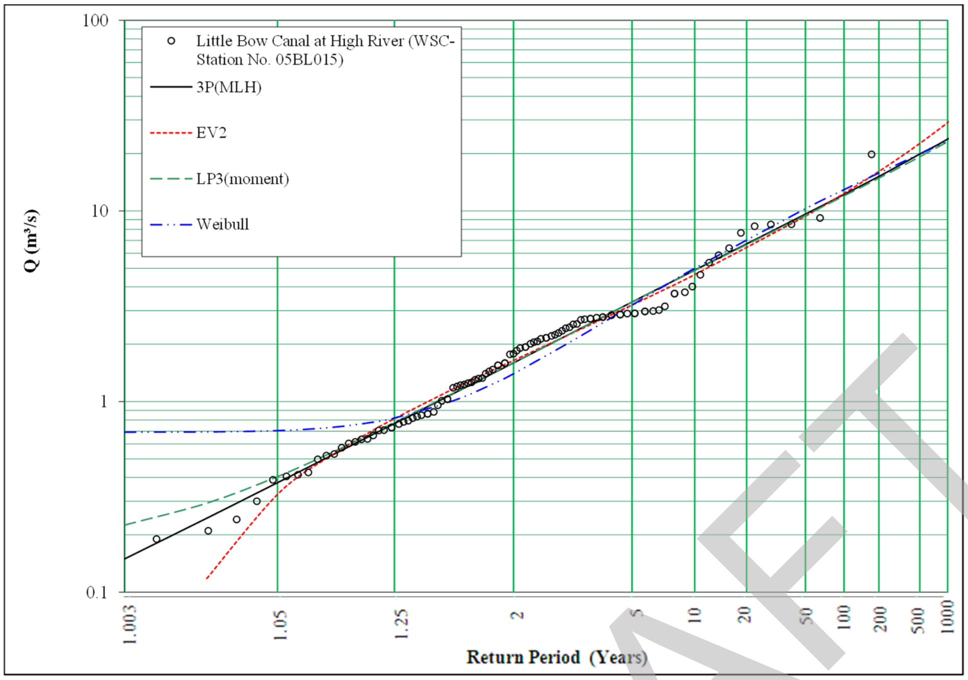
Figure C.2.51: 05BL024, Highwood River near the Mouth – extended

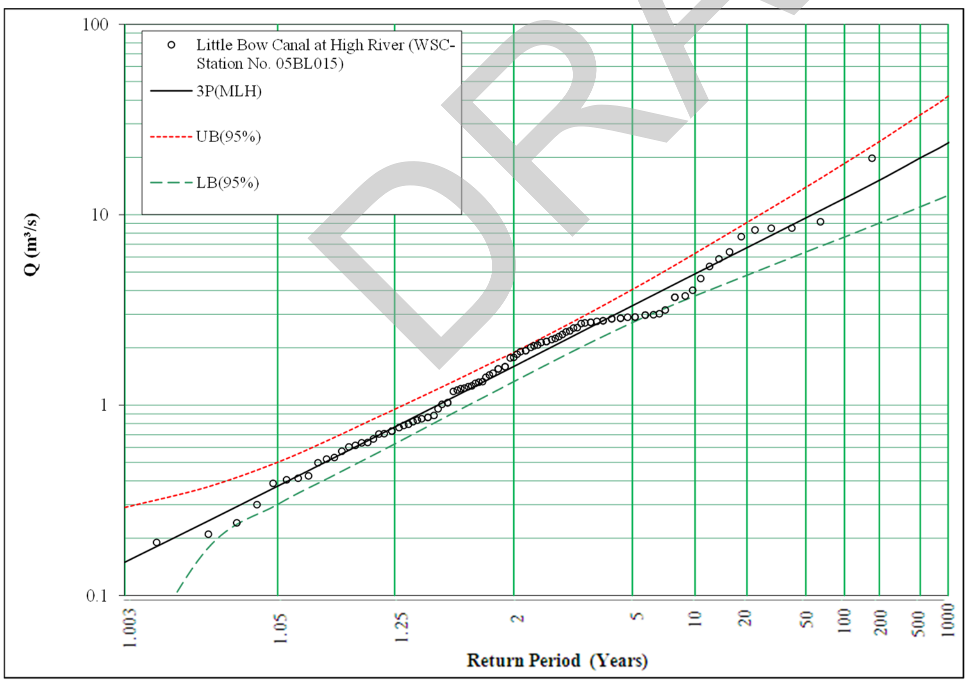




Return Period	3P(MLH)	EV2	Lp3(MLH)	Weibull
2	215	211	210	196
5	434	409	423	460
10	632	602	629	696
20	866	853	887	956
35	1080	1110	1140	1180
50	1240	1310	1330	1330
75	1430	1580	1570	1500
100	1570	1790	1760	1630
200	1960	2440	2300	1950
350	2320	3110	2820	2210
500	2570	3630	3200	2380
750	2850	4320	3690	2590
1000	3080	4880	4070	2730

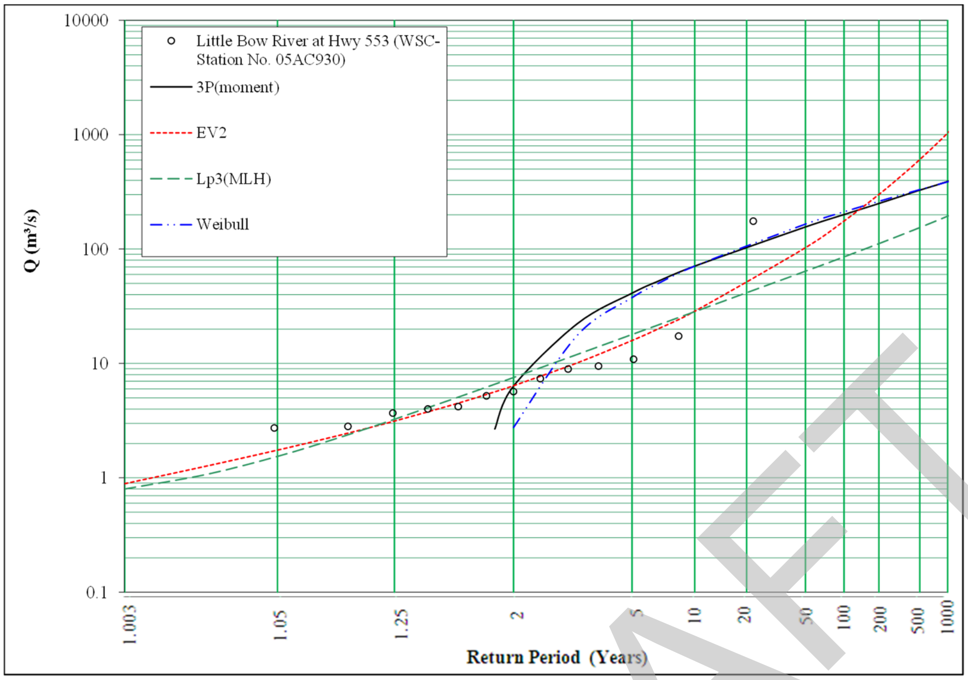
Figure C.2.52: 05BL015, Little Bow Canal at High River

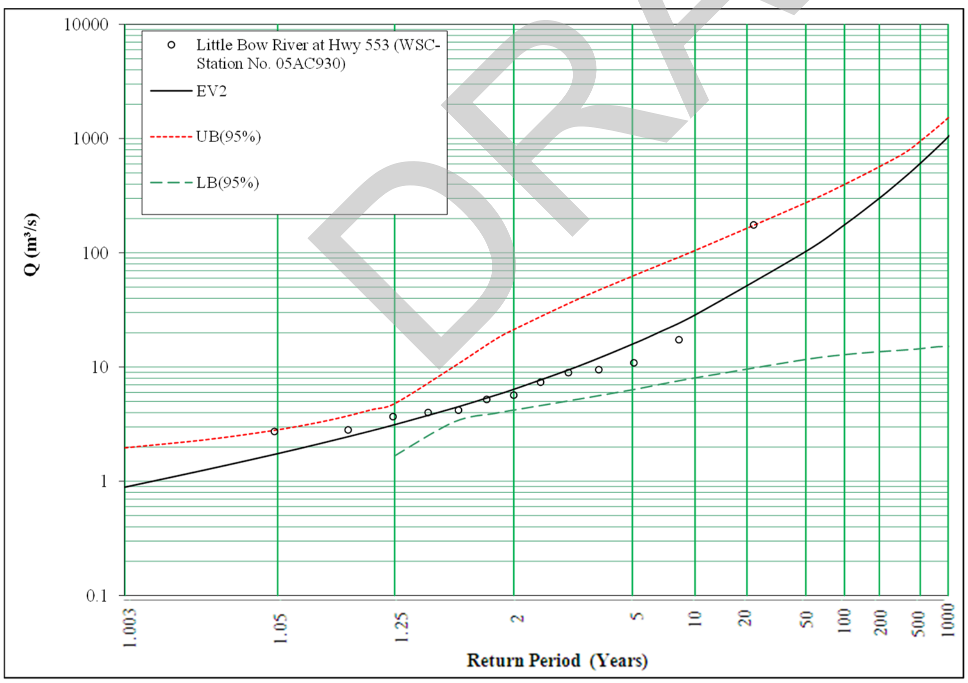




Return Period	3P(MLH)	EV2	LP3 (moment)	Weibull
2	1.60	1.65	1.60	1.40
5	3.33	3.22	3.33	3.21
10	4.89	4.64	4.88	5.01
20	6.72	6.40	6.67	7.11
35	8.42	8.13	8.33	9.00
50	9.62	9.41	9.50	10.3
75	11.1	11.1	10.9	11.8
100	12.2	12.4	12.0	12.9
200	15.2	16.1	14.9	15.8
350	18.0	19.9	17.5	18.3
500	19.9	22.7	19.3	19.9
750	22.1	26.3	21.5	21.9
1000	23.8	29.1	23.1	23.2

Figure C.2.53: 05AC930, Little Bow River at Highway No. 533





Return Period	3P (moment)	EV2	Lp3(MLH)	Weibull
2	6.34	6.39	7.54	2.76
5	41.2	15.9	17.9	37.7
10	71.0	28.6	28.4	71.0
20	105	50.0	41.5	109
35	135	77.8	54.5	143
50	156	103	64.0	165
75	181	141	76.0	192
100	201	176	85.5	212
200	250	301	112	262
350	296	463	136	304
500	328	609	154	332
750	363	832	177	364
1000	391	1040	194	388

ELBOW RIVER – INFLOW HYDROGRAPH ROUTING METHOD

- **Water Levels are relative to the Crest of the Weir.**

Figure C.3.1: Elbow River Inflow and Outflow Hydrographs and Water Levels – 2-year Return Period

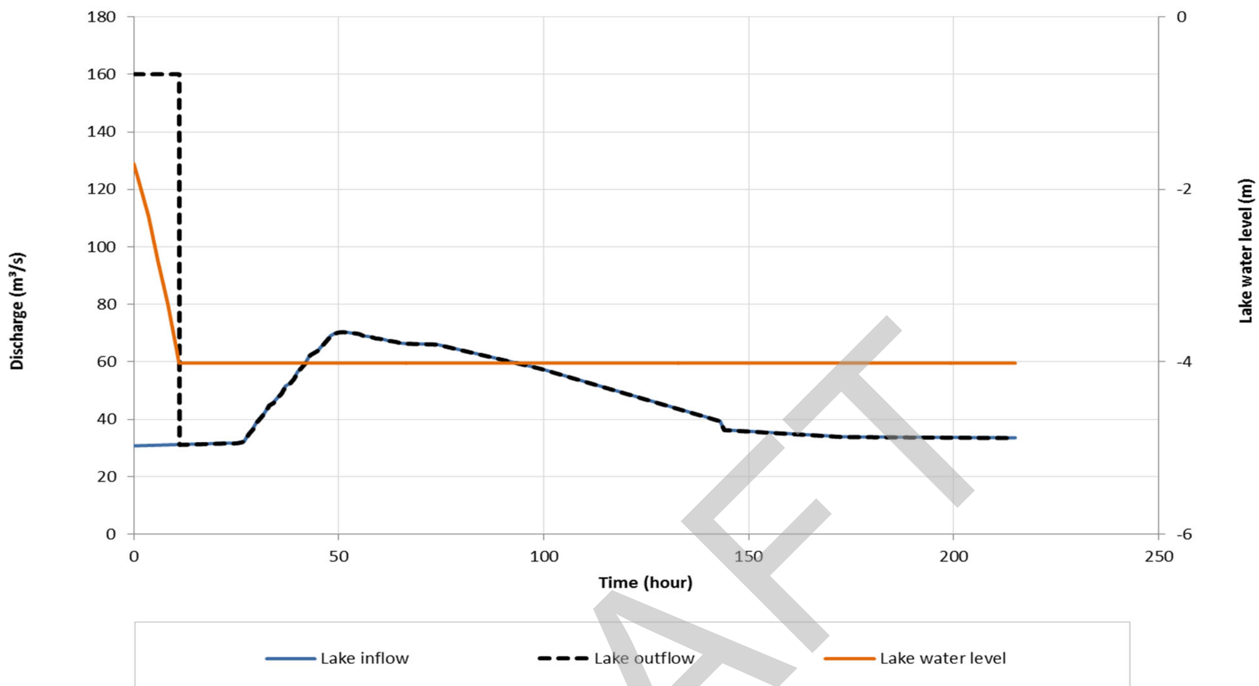


Figure C.3.2: Elbow River Inflow and Outflow Hydrographs and Water Levels – 5-year Return Period

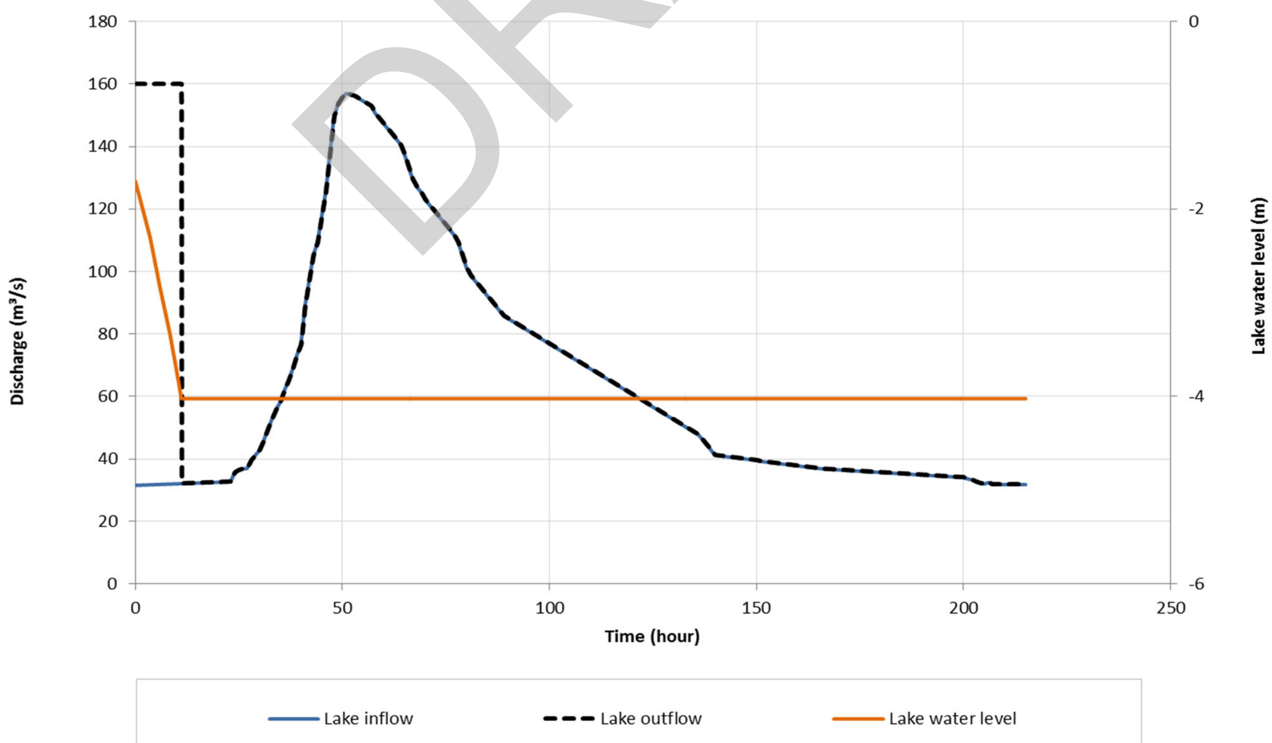


Figure C.3.3: Elbow River Inflow and Outflow Hydrographs and Water Levels – 10-year Return Period

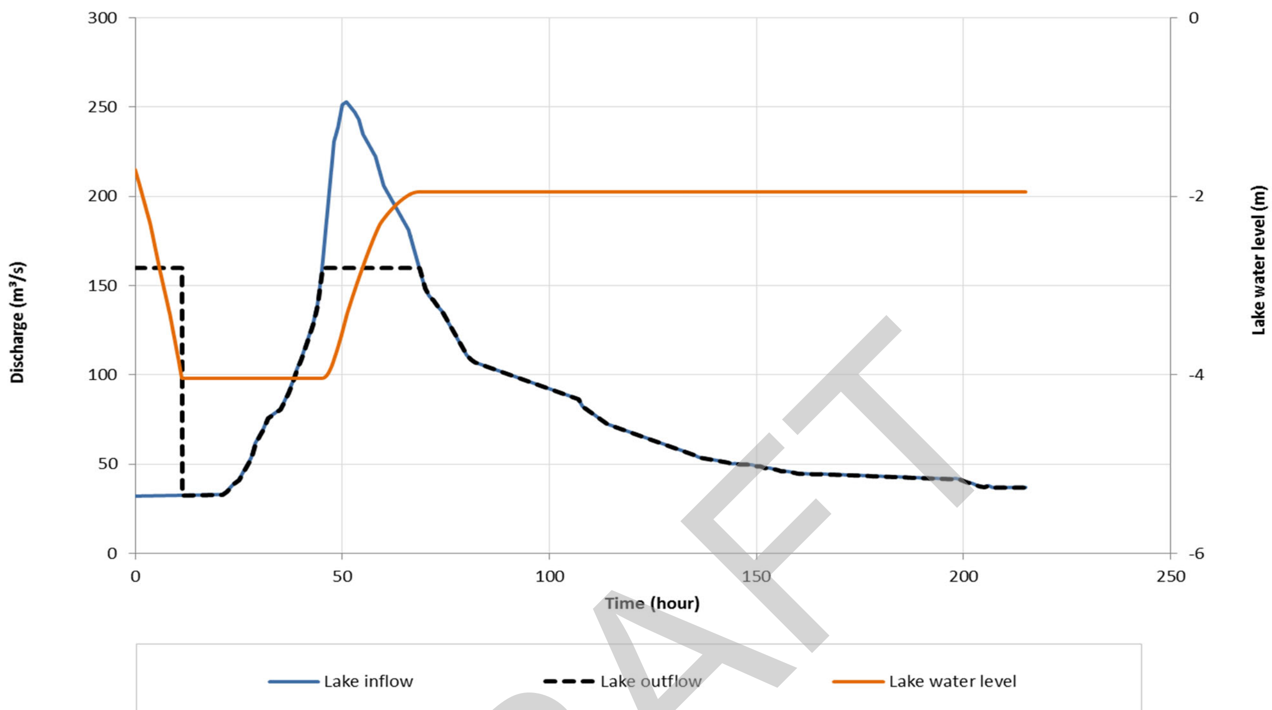


Figure C.3.4: Elbow River Inflow and Outflow Hydrographs and Water Levels – 20-year Return Period

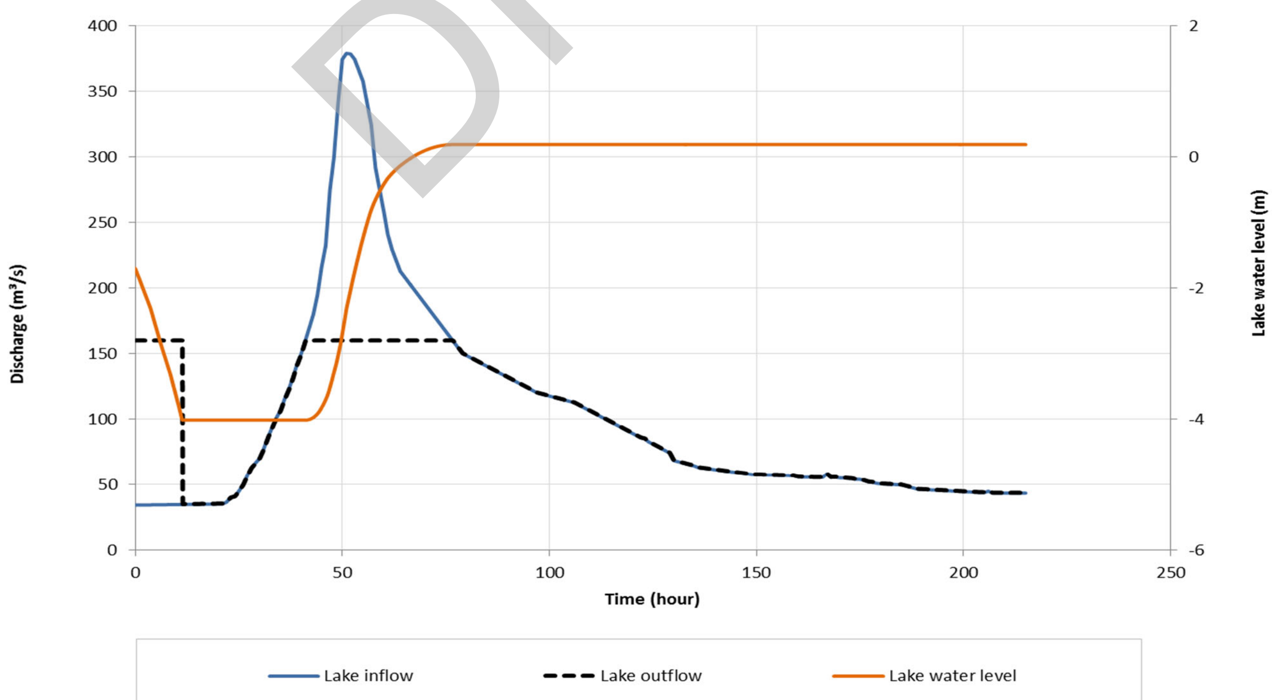


Figure C.3.5: Elbow River Inflow and Outflow Hydrographs and Water Levels – 35-year Return Period

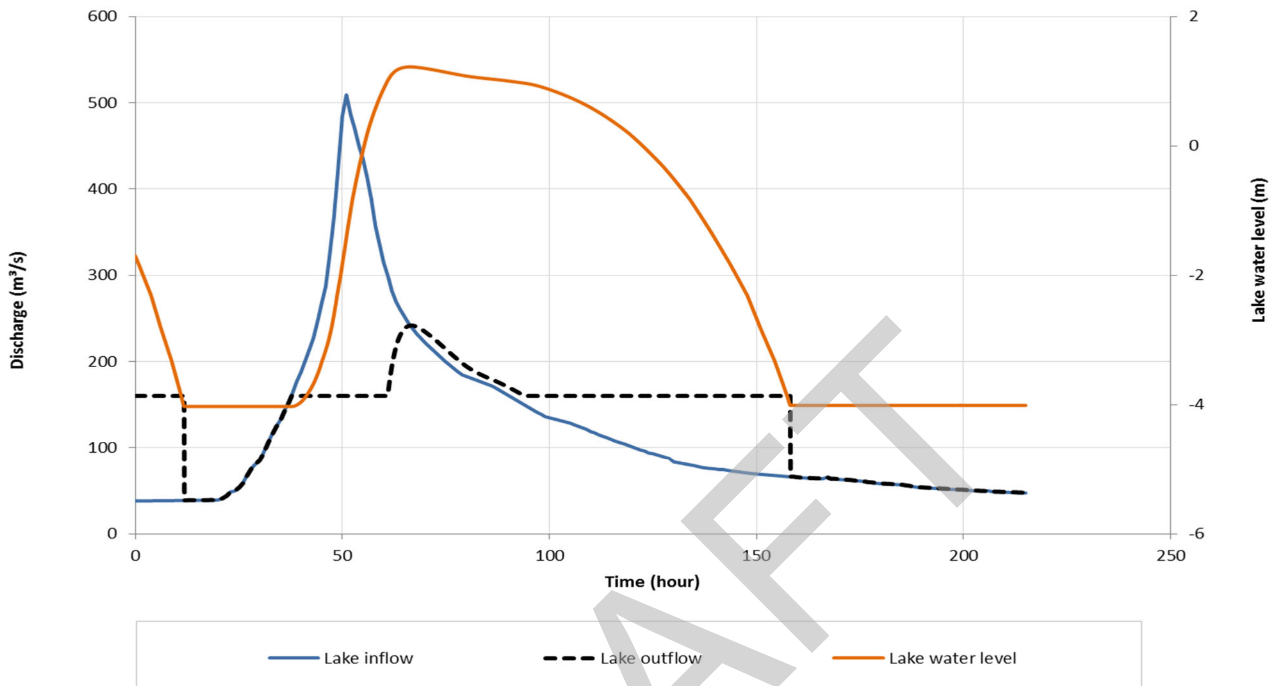


Figure C.3.6: Elbow River Inflow and Outflow Hydrographs and Water Levels – 50-year Return Period

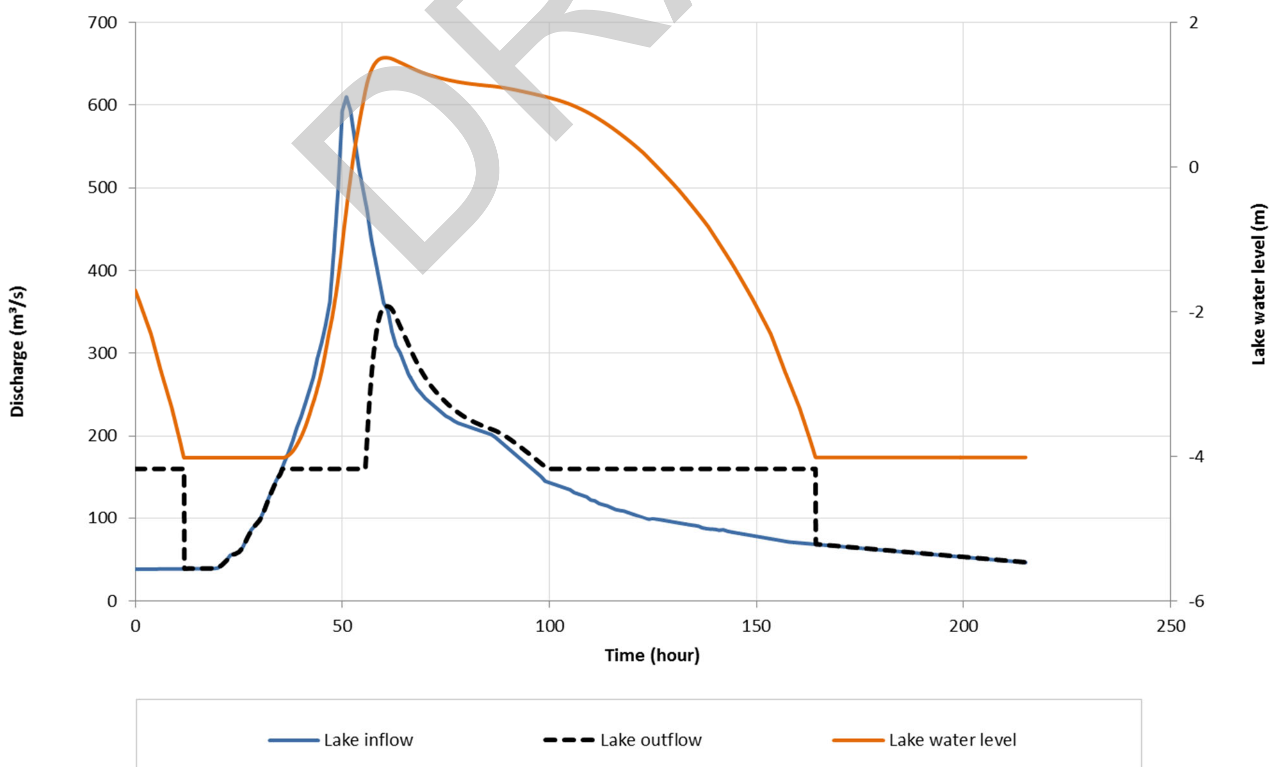


Figure C.3.7: Elbow River Inflow and Outflow Hydrographs and Water Levels – 75-year Return Period

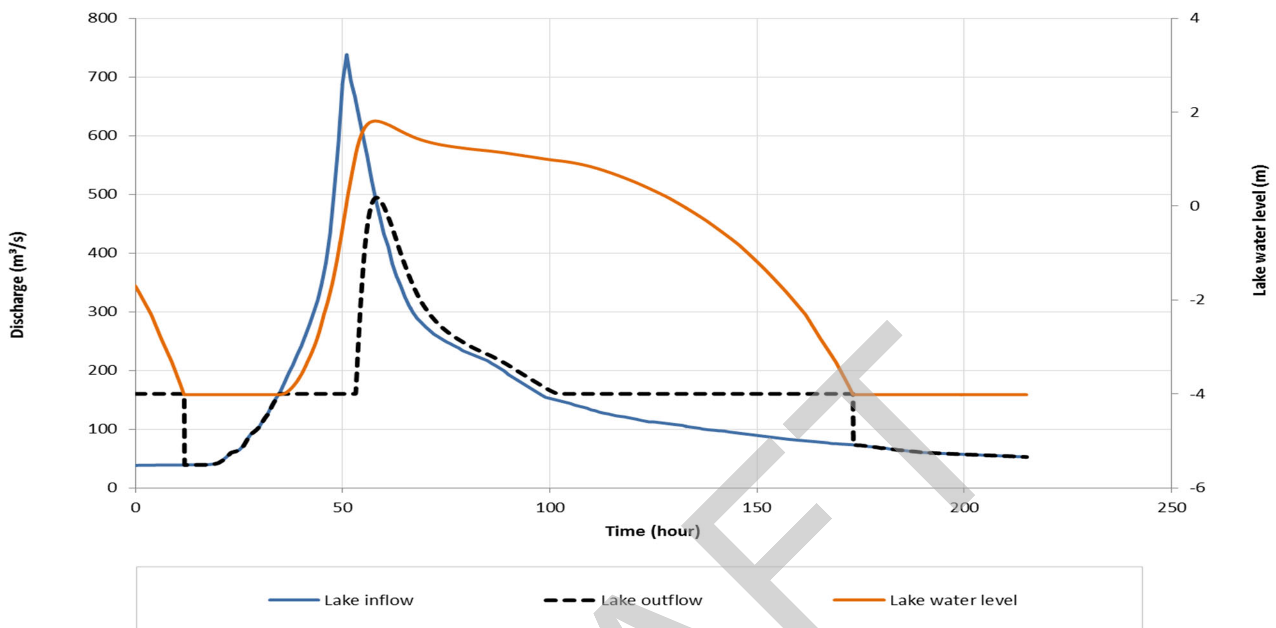


Figure C.3.8: Elbow River Inflow and Outflow Hydrographs and Water Levels – 100-year Return Period

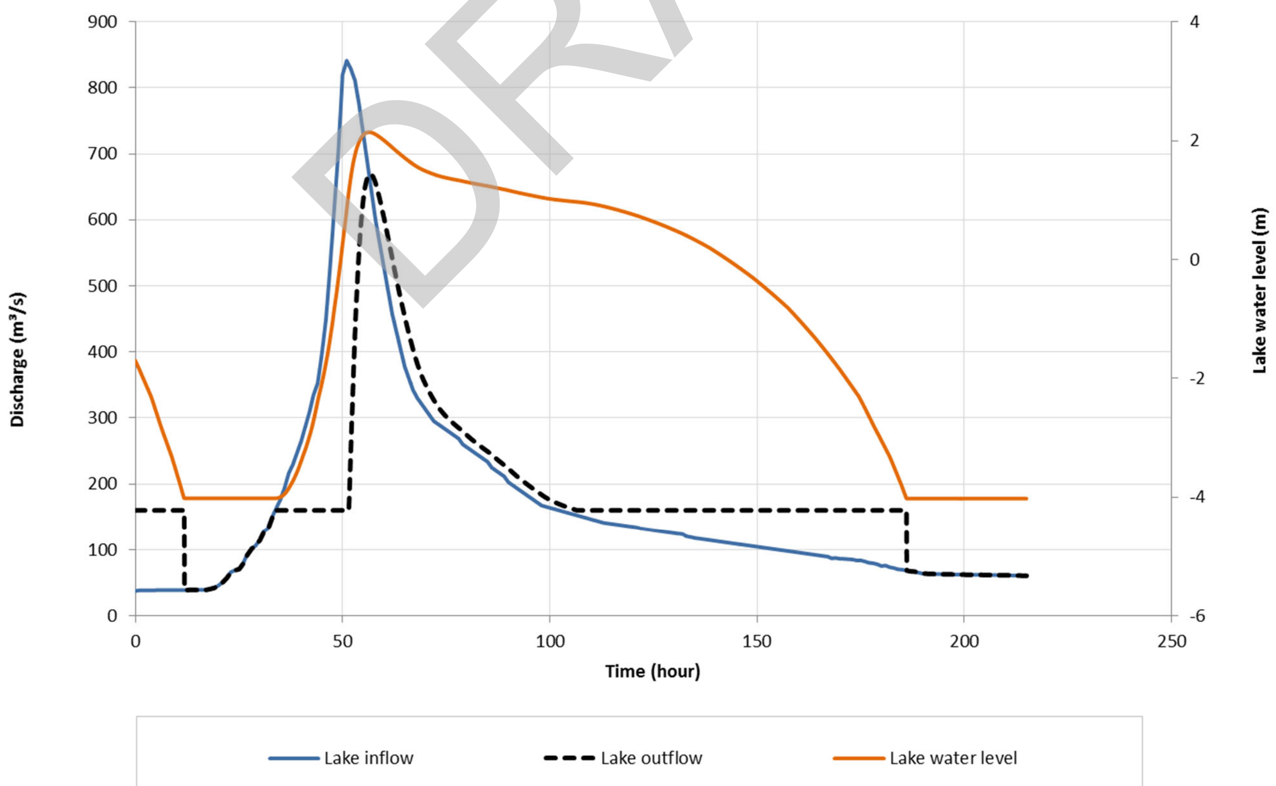


Figure C.3.9: Elbow River Inflow and Outflow Hydrographs and Water Levels – 200-year Return Period

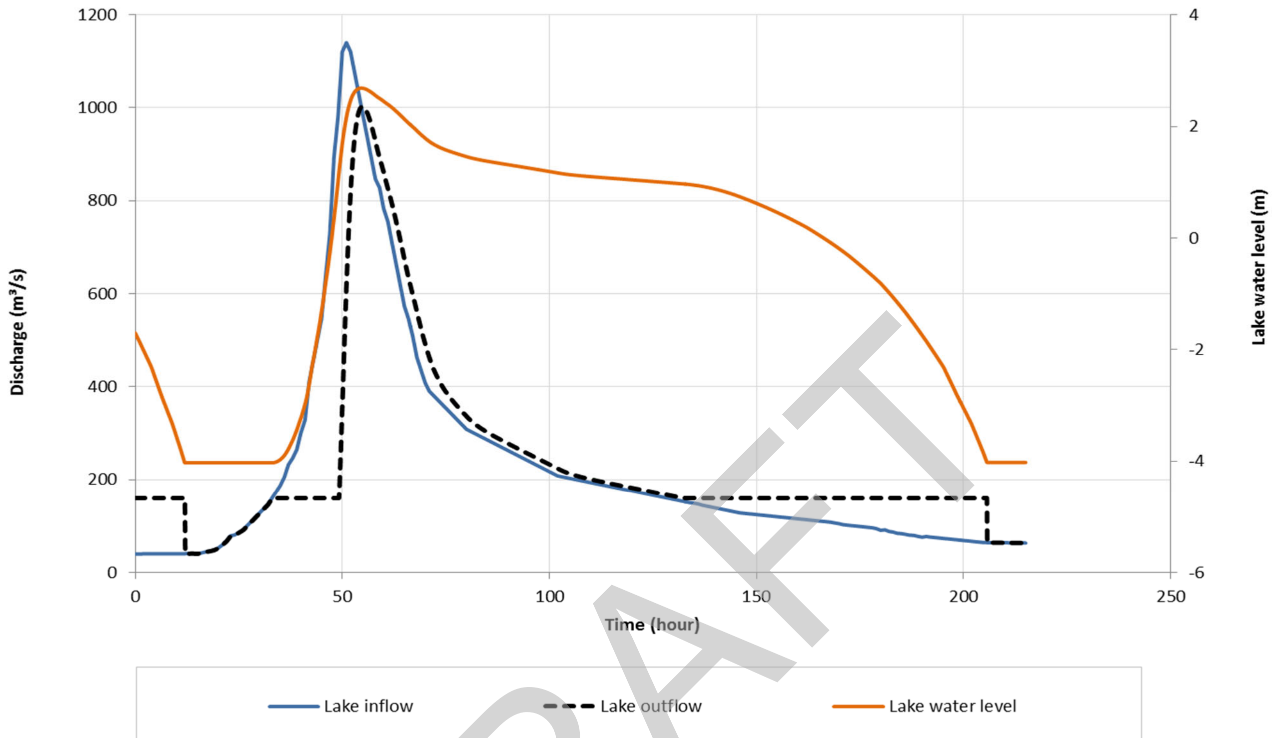


Figure C.3.10: Elbow River Inflow and Outflow Hydrographs and Water Levels – 350-year Return Period

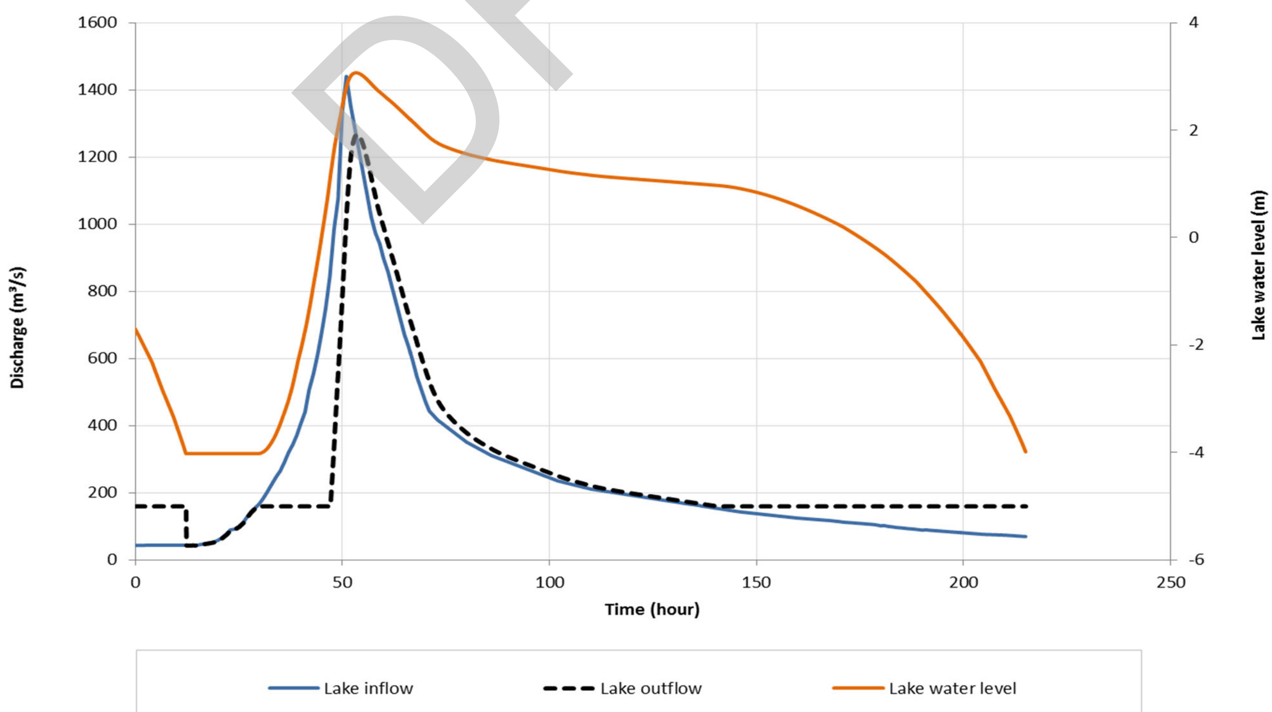


Figure C.3.11: Elbow River Inflow and Outflow Hydrographs and Water Levels –500-year Return Period

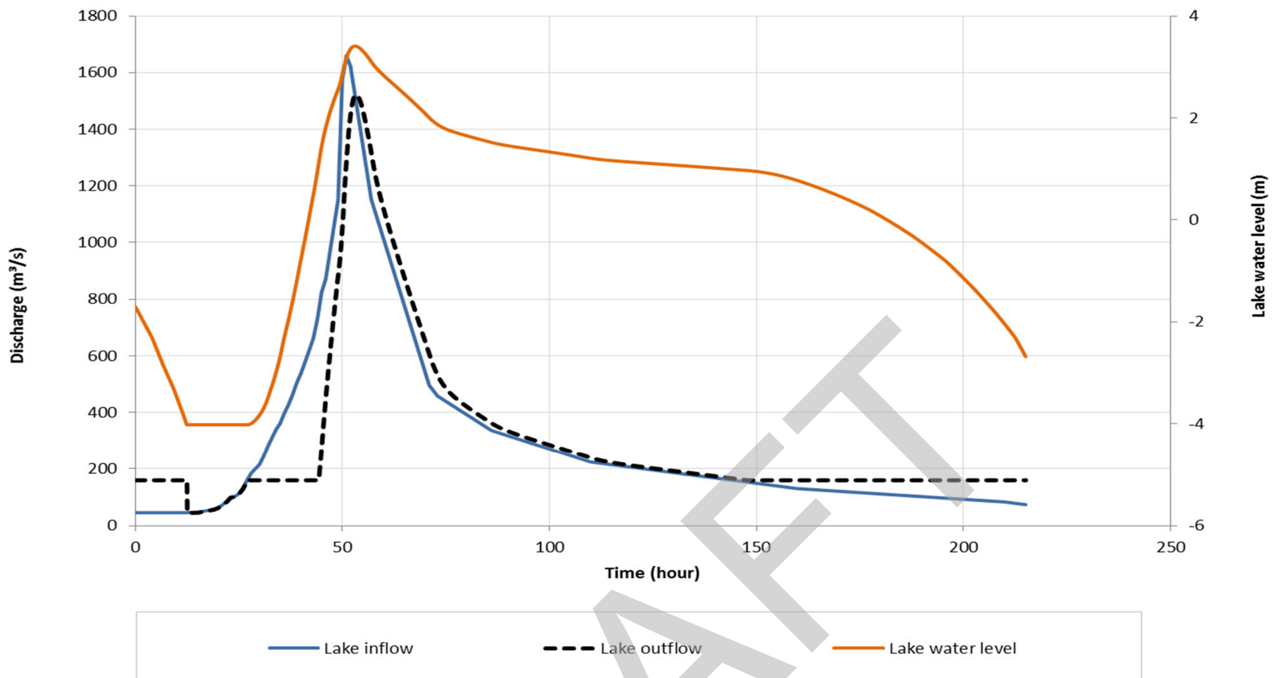


Figure C.3.12: Elbow River Inflow and Outflow Hydrographs and Water Levels – 750-year Return Period

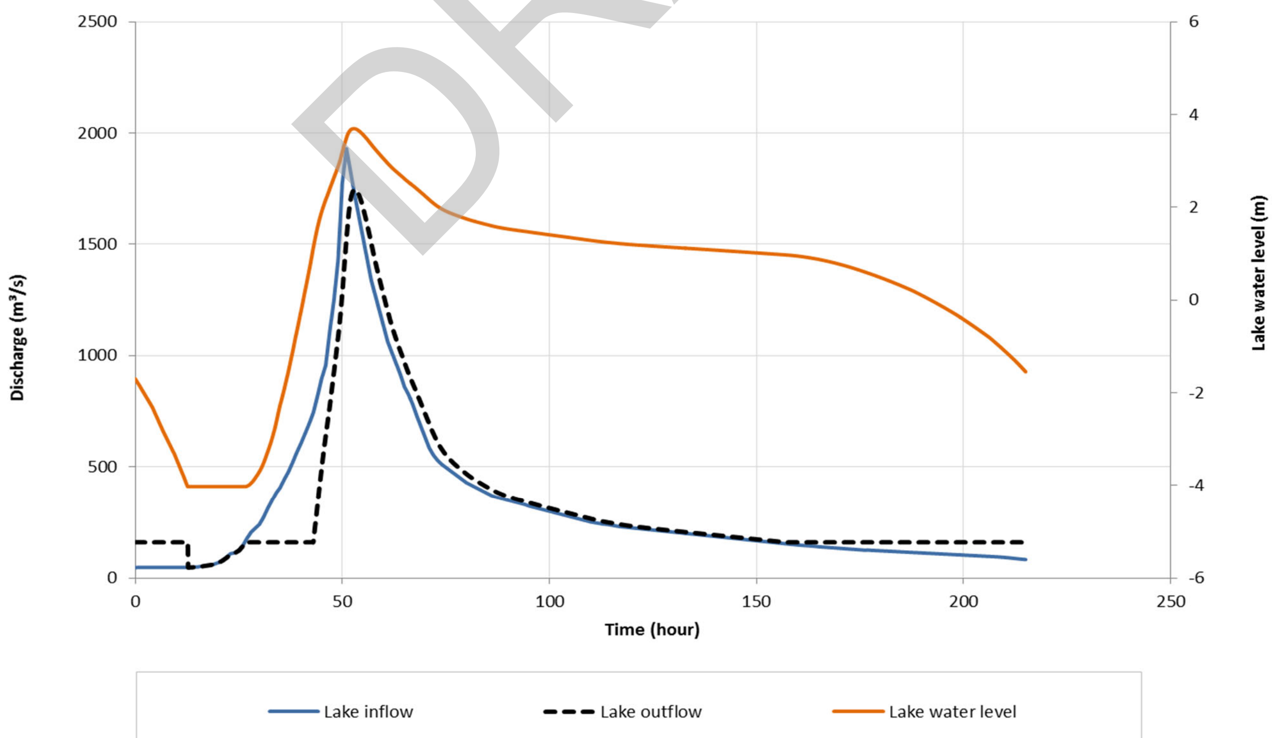
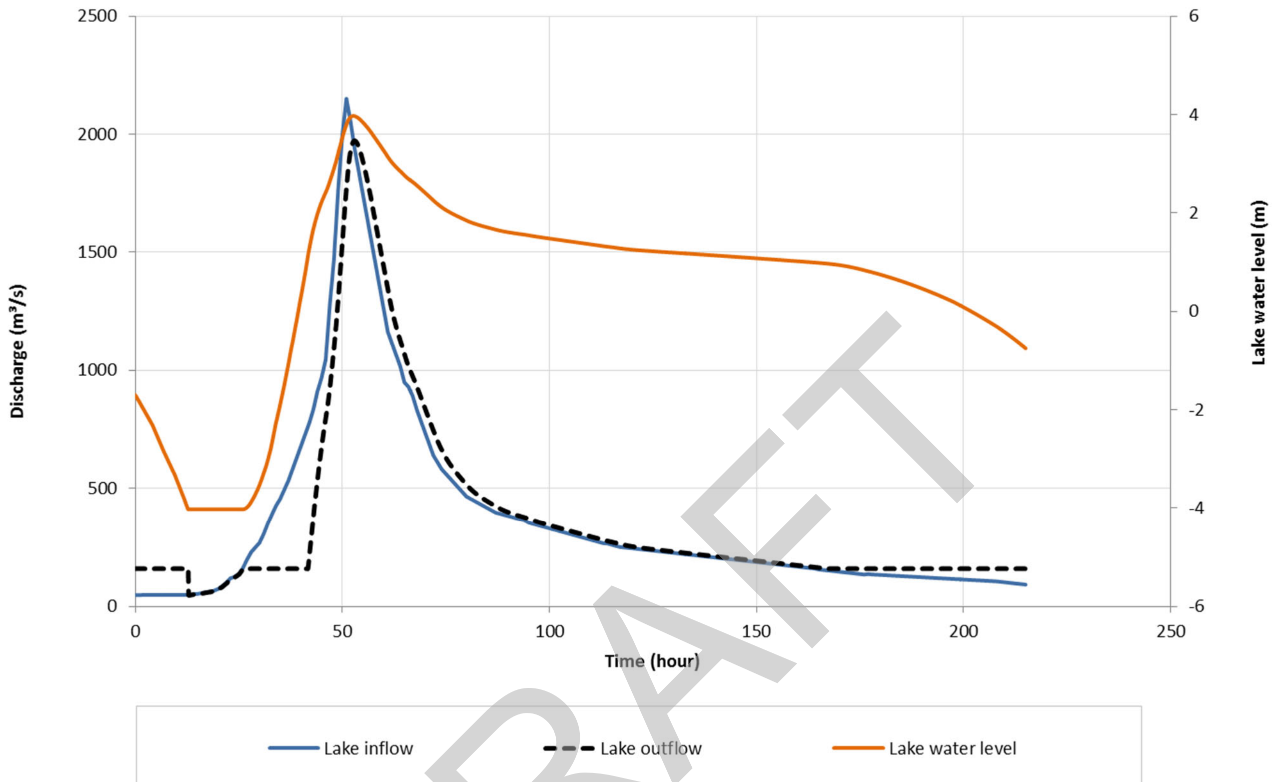


Figure C.3.13: Elbow River Inflow and Outflow Hydrographs and Water Levels – 1000-year Return Period



APPENDIX C.3
Water Survey of Canada Stations used for Regional Analysis

Table C.3.1: Water Survey of Canada Station used for Mountain Region

						Return Period												
WSC Station Name or Location of Interest	**WSC Station ID**	**Latitude**	**Longitude**	**Gross Drainage Area (km^2)**	**Effective Drainage Area (km^2)**	**1000-year**	**750-year**	**500-year**	**350-year**	**200-year**	**100-year**	**75-year**	**50-year**	**35-year**	**20-year**	**10-year**	**5-year**	**2-year**
Cataract Creek near Forestry Road	05BL022	50° 17' 07"	-114° 35' 19"	165.5	165.5	491	449	397	351	288	222	199	168	144	111	77.2	50.2	23.3
Waiparous Creek near the Mouth	05BG006	51° 16' 58"	-114° 50' 18"	333.0	333.0	1020	913	787	679	534	391	341	280	232	169	109	65.3	26.7
Trapp Creek near Longview	05BL027	50° 28' 38"	-114° 25' 35"	137.0	137.0	661	564	450	369	270	183	155	123	100	71.6	46.5	29.0	13.1
Highwood River at Diebel's Ranch	05BL019	50° 24' 18"	-114° 30' 03"	774.0	774.0	1390	1250	1080	945	765	583	519	439	378	295	212	146	78.8
Elbow River at Bragg Creek	05BJ004	50° 56' 56"	-114° 34' 15"	791.0	791.0	1510	1380	1210	1070	873	671	597	504	430	329	227	146	66.5
Fish Creek near Priddis	05BK001	50° 53' 08"	-114° 19' 37"	261.0	261.0	926	829	713	614	481	350	305	248	204	148	93.3	53.7	19.1
Pekisko Creek near Longview	05BL023	50° 28' 27"	-114° 12' 26"	232.0	232.0	680	608	522	449	350	254	221	180	148	106	66.9	38.4	13.7
Threepoint Creek near Millarville	05BL013	50° 46' 16"	-114° 16' 44"	507.0	507.0	1140	1040	914	803	650	495	439	368	312	235	158	98.2	39.8
Jumpingpound Creek near the mouth	05BH009	51° 09' 16"	-114° 31' 42"	571.0	571.0	1030	936	815	710	568	425	374	310	260	193	127	76.8	30.0
Elbow River at Sarcee Bridge combined with Inflow to Glenmore	05BJ010	50° 59' 41"	-114° 09' 53"	1189.0	1189.0	1510	1377	1214	1071	874	672	599	506	431	331	229	148	69.4
Sheep River at Black Diamond	05BL014	50° 59' 41"	-114° 09' 53"	592.0	592.0	1900	1720	1500	1310	1050	787	693	576	484	361	240	148	61.5
Stimson Creek near Pekisko	05BL007	50° 25' 48"	-114° 10' 01"	236.0	236.0	456	413	360	314	252	189	167	138	116	86.2	56.6	34.0	12.7
Elbow River above Elbow Falls	05BJ006	50° 51' 20"	-114° 47' 37"	437.0	437.0	411	375	329	293	244	194	176	153	135	111	85.6	64.7	41.0
Sheep River at Okotoks	05BL012	50° 43' 26"	-113° 58' 25"	1494.0	1494.0	2620	2420	2180	1950	1640	1310	1180	1020	886	701	504	338	158
Sheep River at Buck Ranch	05BL018	50° 37' 20"	-114° 25' 40"	454.0	454.0	1390	1260	1100	969	783	595	528	443	376	286	197	128	62.8
Highwood River below Picklejar Creek	05BL021	50° 29' 55"	-114° 49' 02"	132.0	132.0	74.3	72.3	69.7	67.2	63.3	58.5	56.4	53.6	51.0	46.9	41.5	35.7	26.4
Willow Creek above Chain Lakes	05AB028	50° 11' 47"	-114° 12' 46"	162.0	162.0	134	128	120	113	102	88.3	82.6	74.6	67.6	56.6	43.4	30.4	14.0

Table C.3.2: Water Survey of Canada Station used for Foothills Region

						Return Period												
WSC Station Name or Location of Interest	**WSC Station ID**	**Latitude**	**Longitude**	**Gross Drainage Area (km^2)**	**Effective Drainage Area (km^2)**	**1000-year**	**750-year**	**500-year**	**350-year**	**200-year**	**100-year**	**75-year**	**50-year**	**35-year**	**20-year**	**10-year**	**5-year**	**2-year**
West Arrowwood Creek near Arrowwood	05BM014	50° 45' 51"	-113° 14' 11"	777.0	664	348	320	284	253	208	159	140	116	96.8	70.2	43.3	23.0	5.89
Rosebude River below Carstairs Creek	05CE006	51° 24' 57"	-113° 43' 40"	753.0	642	147	136	120	108	89.4	69.4	61.9	52.1	44.3	33.4	22.0	13.0	4.42
Trout Creek near Granum	05AB005	49° 58' 39"	-113° 41' 10"	441.0	441.0	329	300	263	233	190	143	126	104	86.5	62.8	39.2	21.5	6.17
Meadow Creek near the mouth	05AB029	49° 57' 15"	-113° 39' 49"	130.0	130.0	79.6	71.4	61.6	53.1	41.7	30.5	26.6	21.7	17.9	12.9	8.17	4.68	1.58
Prairie Blood Coulee near Lethbridge	05AD035	49° 57' 15"	-113° 39' 49"	224.0	224.0	103	101	96.9	93.0	86.1	76.2	71.6	64.8	58.4	47.7	33.8	20.2	5.30
Ray Creek near Innisfail	05CE010	52° 00' 04"	-113° 35' 59"	44.0	44.0	18.3	17.6	16.6	15.7	14.2	12.4	11.6	10.5	9.48	7.90	5.96	4.05	1.68

Table C.3.3: Water Survey of Canada Station used for Foothills Region

Return Period (Years)	**Fish Creek near Priddis**	**Threepoint Creek near Millarville**	**Ln (Qf/Qt)**	**Power Factor**
2	14.1	26.7	-0.637	0.959
5	38.0	64.8	-0.534	0.804
10	64.4	104	-0.479	0.721
20	100	154	-0.433	0.652
35	136	204	-0.401	0.604
50	164	241	-0.382	0.575
75	200	287	-0.362	0.544
100	229	324	-0.348	0.524
200	310	425	-0.317	0.477
350	391	524	-0.293	0.441
500	452	597	-0.278	0.418
750	522	679	-0.263	0.396
1000	580	747	-0.252	0.380

$$Q_{\text{Fish Creek}}/Q_{\text{Threepoint Creek}} = (A_{\text{Fish Creek}}/A_{\text{Threepoint Creek}})^{\text{Power Factor}}$$

Table C.4.1: Flood Frequency Estimates for Bow River and Its Tributaries Through Calgary (Including Historical Floods) on Naturalized Flow Series

Return Period (Years)	Bow River at Calgary[1]	Elbow River below Glenmore Dam[2]	Bow River below Elbow River[3]	Nose Creek at the Mouth[4]	Bow River below Nose Creek[5]	Fish Creek at the Mouth[4]	Bow River below Fish Creek[5]	Pine Creek at the Mouth[6]	Bow River below Pine Creek[5]	Bow River above Highwood River[7]
2	401	70.4	464	0.58	465	4.91	469	2.71	472	478
5	627	157	739	6.51	746	16.0	762	8.51	770	780
10	845	253	996	11.5	1007	29.5	1037	14.4	1051	1065
20	1120	379	1310	17.0	1327	50.4	1377	21.5	1399	1417
35	1400	509	1630	21.9	1652	75.6	1728	28.0	1756	1778
50	1610	610	1860	25.3	1885	97.2	1983	32.5	2015	2041
75	1880	738	2150	29.4	2179	129	2308	38.0	2346	2377
100	2090	841	2390	32.5	2422	157	2579	42.1	2621	2655
200	2710	1140	3050	40.4	3090	250	3340	52.7	3393	3437
350	3330	1440	3710	47.5	3757	363	4121	61.9	4183	4237
500	3790	1660	4190	52.3	4242	460	4702	68.3	4771	4833
750	4400	1930	4820	58.1	4878	602	5480	75.5	5555	5627
1000	4880	2150	5310	62.4	5372	728	6100	80.8	6181	6261

1. Historical information included based on Bulletine 17C method
2. Historical Adjusted Ratio Applied: Derived based on scaling the frequency analysis for Bow River at Calgary with and without historical floods (i.e., by applying a percentage multiplier to each return period)
3. Coincident: Estimates based on adding Bow and tributary flood flows (i.e., assume coincident instantaneous flood peaks)
4. Flood frequency estimated taking daily discharge on the day when instantaneous flood occurred on Bow River
5. Estimates by adding flood freqency estimates based on daily flows from tributary to flood frequency estimates for Bow River above the tributary
6. Fllod frequency estimates for daily flows were obtained by reducing the instantaneous flood estimates by peaking factor from regional station
7. Prorated: Estimated by prorating flood flows for Bow River below Pine Creek by drainage area

Figures C.5.1 to C.5.4 provides precipitation and air temperature recorded at three stations in 1897 and 1902. Annual precipitation data recorded since 1884 at the Calgary Airport station shows that the precipitation patterns pre-1911 (i.e., period prior to beginning of the systematically record of flow data) is similar to precipitation patterns post-1911.

Figure C.5.1: Precipitation and Air Temperature recorded at Calgary and Banff Climate Stations – Year 1897

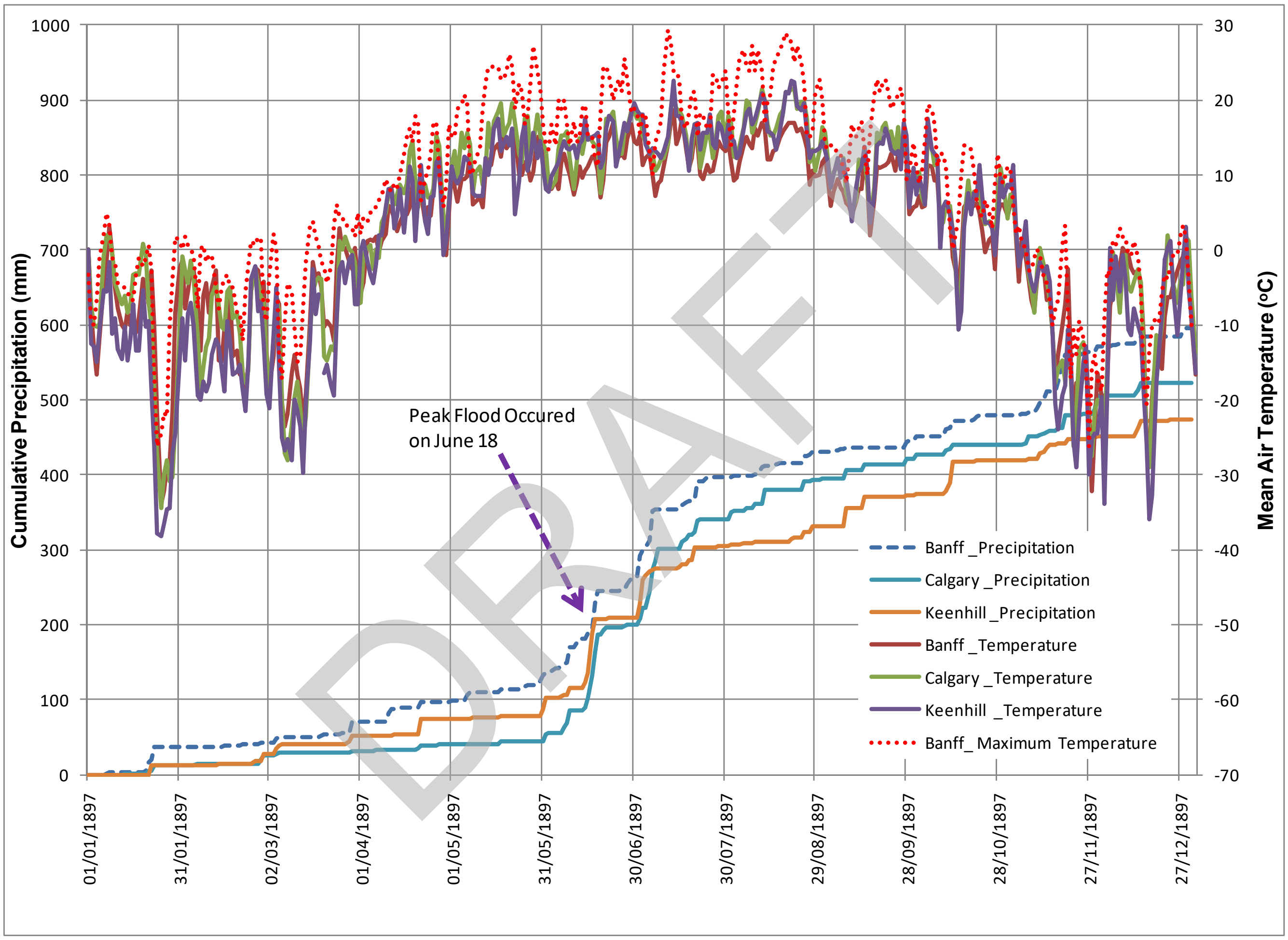


Figure C.5.2: Precipitation and Air Temperature recorded at Calgary and Banff Climate Stations – Year 1902

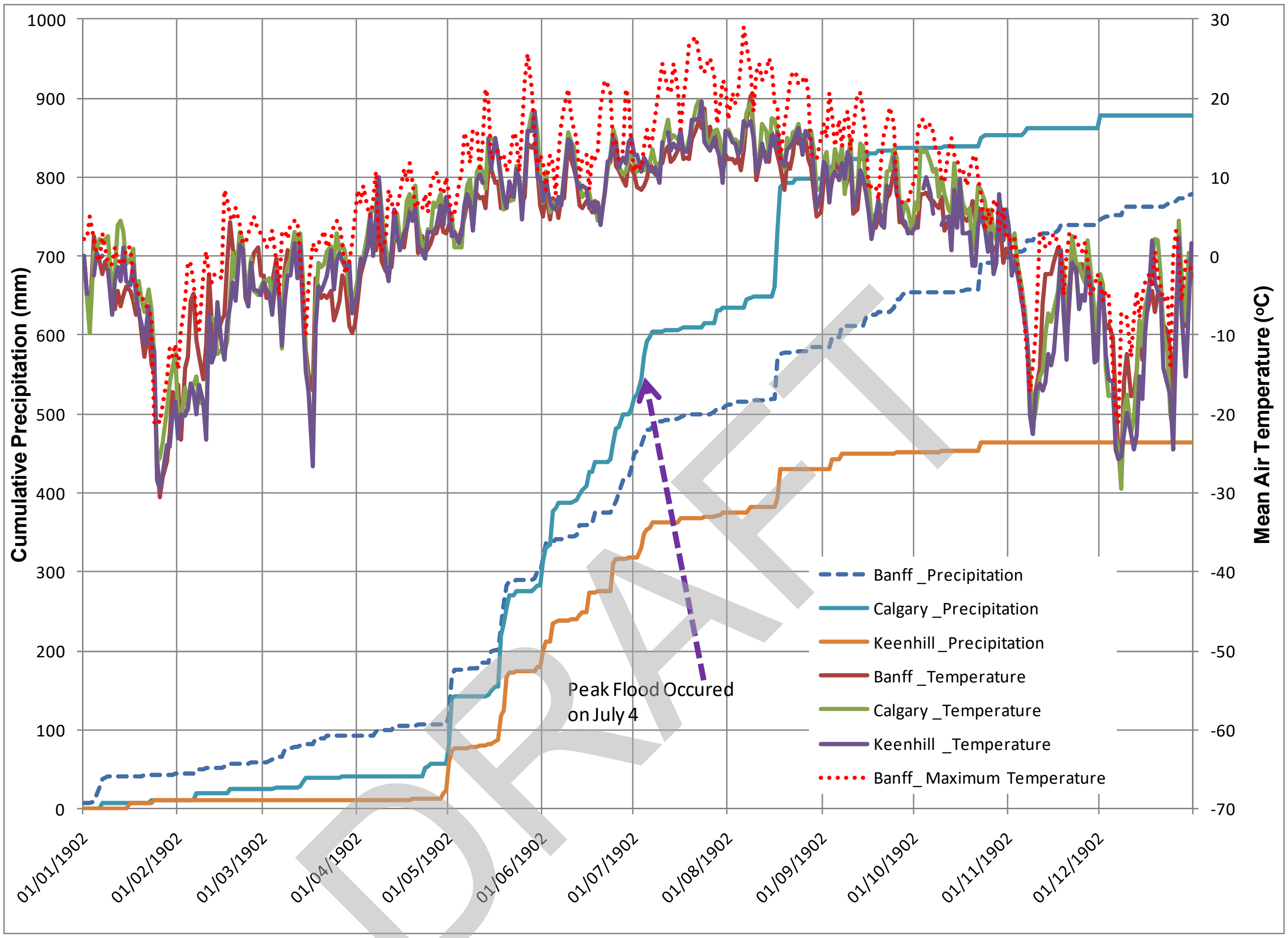


Figure C.5.3: Precipitation and Air Temperature recorded at Calgary and Banff Climate Stations – Annual Precipitation at Calgary Airport

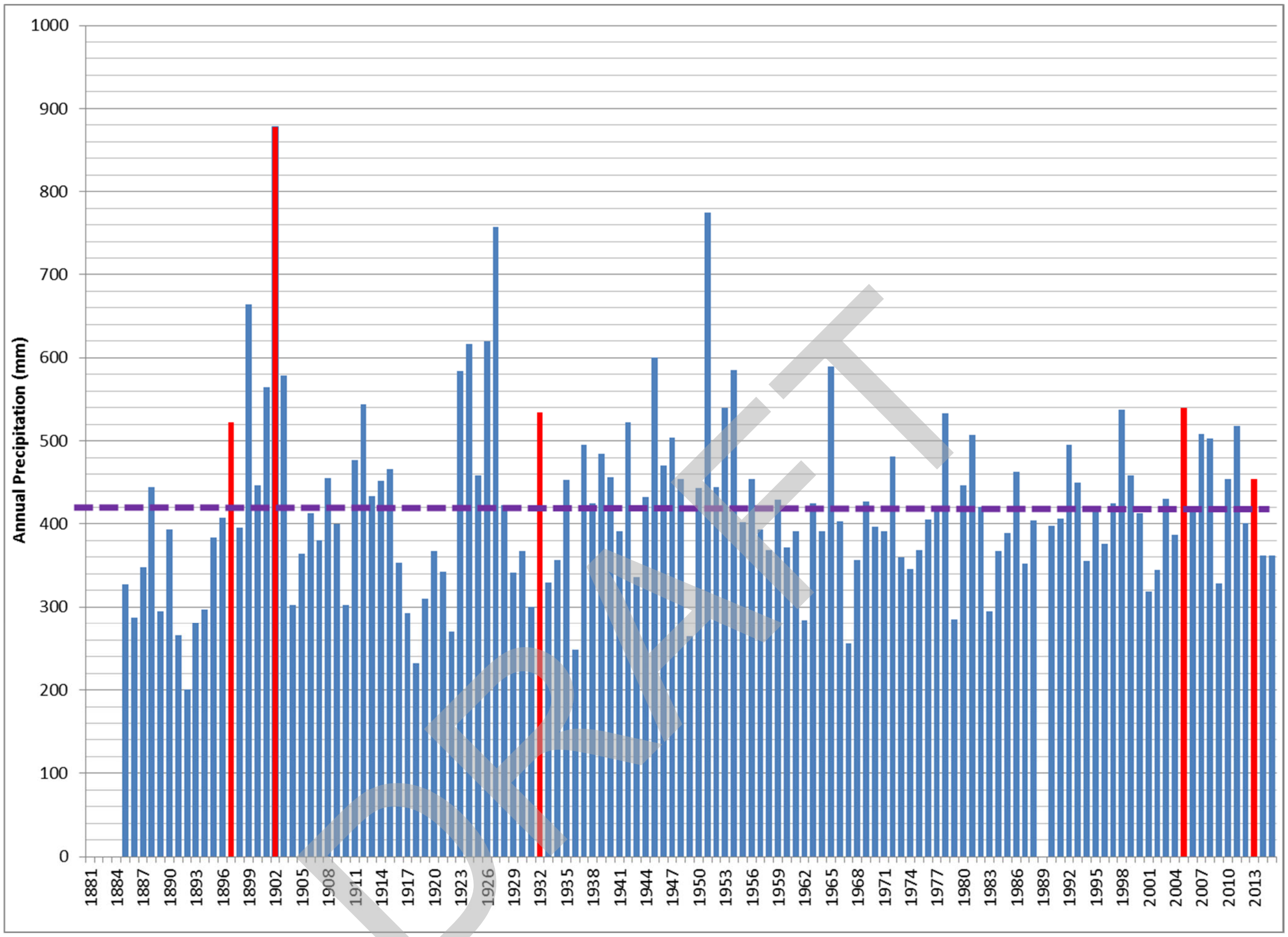
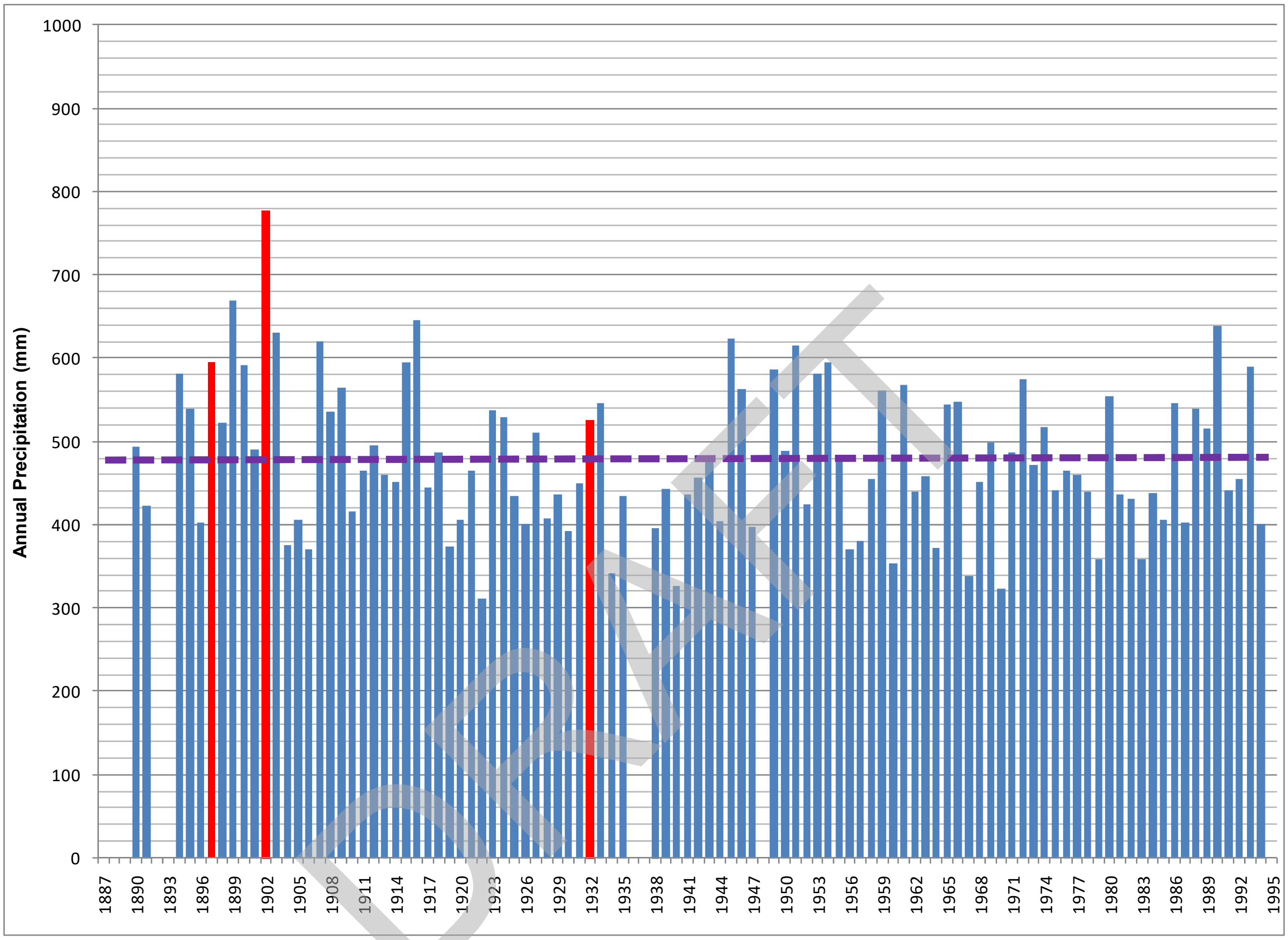


Figure C.5.4: Precipitation and Air Temperature recorded at Calgary and Banff Climate Stations – Annual Precipitation at Banff



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