Appendix B

Supplemental Water Quality Analyses

Appendix B1 – Narrative Temperature Standard Analysis for South Boulder Creek

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B1.1 Compliance with Narrative Temperature Standard in South Boulder Creek below Gross Reservoir

The Proposed Action has the potential to affect compliance with Colorado's narrative temperature standard in the portion of South Boulder Creek below Gross Reservoir. The purpose of this section is to evaluate whether potential decreases in present water temperatures below Gross Reservoir under future conditions, a potential outcome of the Proposed Action, will result in significant degradation in this waterbody.

B1.1.1 Relevant Regulatory Framework

Water Quality Standards

Colorado Regulations 31 and 38 establish water quality standards applicable to South Boulder Creek. South Boulder Creek from the outlet of Gross Reservoir to South Boulder Road (below the Diversion site) is designated Segment 4b in the Boulder Creek Basin in Regulation 38. This segment has the following designated beneficial uses: Class 1 Cold Water Aquatic Life ("Aquatic Life Cold 1), Recreation Class E - Existing Primary Contact Use, Domestic Water Supply and Agriculture. Of interest to this analysis is the Aquatic Life Cold 1 beneficial use, which Regulation 31.13(1)(c)(i) defines as:

> *These are waters that (1) currently are capable of sustaining a wide variety of cold water biota, including sensitive species, or (2) could sustain such biota but for correctable water quality conditions. Waters shall be capable of sustaining such biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of the abundance and diversity of species.*

Regulation 38 establishes narrative and numeric temperature water quality standards applicable to Colorado waters in the South Platte River basin. These standards and their applicability to South Boulder Creek are as follows:

- *Narrative Temperature Standard* – Regulation 38.5 establishes the following narrative temperature standard: "*Temperature shall maintain a normal pattern of diel and seasonal fluctuations and spatial diversity with no abrupt changes and shall have no increase in temperature of a magnitude, rate, and duration deleterious to the resident aquatic life. These criteria shall not be interpreted or applied in a manner inconsistent with section 25-8-104, C.R.S.*"

- *Numeric Temperature Standard* – Regulation 38.6 establishes waterbody-specific temperature standards for South Boulder Creek (Segment 4b). The Water Quality Control Commission (Commission) has adopted specific Tier II Cold Water temperature numeric standards on South Boulder Creek below Gross Reservoir. These not to exceed acute and chronic criteria are as follows: (a) April – October: 18.3°C (chronic); 23.9°C (acute); and (b) November – March: 9.0°C (chronic); 13.0°C (acute).

Compliance with the numeric temperature standards in the reach of South Boulder Creek below Gross Reservoir is not a concern; these acute and chronic standards are well above typical water temperatures in this waterbody (see discussion below regarding present and expected future water temperatures in Section B1.1.2).

Regulatory Review

Evaluation of what constitutes an impact and how any potential impact from a Proposed Action is evaluated is guided by the Colorado Water Quality Control Division's (Division) Antidegradation Significance Determination Guidance ("Guidance," Division Assessment Unit, Version 1, December 2001). This Guidance includes the following statements that guide evaluations of potential impacts from a Proposed Action:

- The review is intended to limit future degradation and is not intended to be applied as a means to require remediation of impacts from regulated activities that occurred prior to enactment of the antidegradation regulation (Section II, page 2).
- It is important to note that an antidegradation review applies only to activities with new or increased water quality impacts (Section II.A, page 2).
- Although virtually any impact on a waterbody could theoretically degrade the water, when the antidegradation regulations were developed, the Commission decided that a practical antidegradation policy should focus on the potential for "significant" degradation (Section II.B, page 2).

To determine what constitutes "significant" degradation, the Guidance established four significance tests with specific criteria for evaluating whether a particular action caused significant degradation: (a) Bioaccumulative Toxic Pollutant Test; (b) Dilution Test; (c) Concentration Test; and (d) Temporary Impacts Test. An evaluation of the potential for significant degradation with regards to compliance with the narrative temperature standard in South Boulder Creek below Gross Reservoir does not allow for the use of any of the traditional "significance tests" described in the Division's Guidance. Instead, two key issues that are relevant to this evaluation are consideration of the Present and Future Condition of this waterbody in the context of the Proposed Action (Note: descriptions of these conditions will be provided in more detail below):

- *Present Condition*: Existing temperatures in South Boulder Creek below Gross Reservoir have been altered by the 1954 construction of the Gross Dam and its continued operation. Because the reservoir stratifies in the summer, release of water from the bottom ensures a supply of cold water through much of the summer. Based on the current typical volume of the hypolimnion, the supply of cold water is reduced by late summer, and the temperature of the released water rises from approximately 6 to 7°C in June to about 11°C in September. Thus, the present condition is substantially different than the pre-impoundment temperature regime, which for the purposes of this analysis is presumed to have been essentially "natural."
- *Future Condition*: The Proposed Action will expand Gross Reservoir, which will result in a much deeper lake with a much larger volume of cold water in the hypolimnion. A model of lake temperature predicts that the water released from the expanded Gross Reservoir will stay cold longer and show less increase in summer temperatures than occurs under present conditions.

This analysis focuses on the difference between the present and expected future conditions as described above, in particular: *Does the anticipated alteration to the temperature regime under present conditions in South Boulder Creek below Gross Reservoir from the Proposed Action (or future condition) constitute an impact from the standpoint of the 401 Certification process?*

Because the available significance tests (as described in the Guidance) are not applicable to make this evaluation for the narrative temperature standard, this analysis will evaluate the difference between present and future conditions by considering the two key components incorporated into the narrative standard:

- *Temperature shall maintain a normal pattern of diel and seasonal fluctuations and spatial diversity with no abrupt changes ("Temperature Pattern")* – The Division's Guidance states that the antidegradation review (a) is not intended to evaluate impacts from regulated activities that occurred prior to enactment of the antidegradation regulation; and (b) the only review applies to activities with new or increased water quality impacts. Accordingly, this evaluation will compare temperature patterns as they occur under present conditions with conditions anticipated under future conditions following implementation of the Proposed Action.

- *There shall be no increase in temperature of a magnitude, rate, and duration deleterious to the resident aquatic life ("Aquatic Life Protection")* – The second part of the narrative standard involves an evaluation of the impacts of an <u>increase</u> in temperature on the resident aquatic community. Under future conditions, the Proposed Action is projected to cause a <u>decrease</u> in temperature – a condition not contemplated by the narrative temperature standard. Regardless, to evaluate whether the Proposed Action may cause significant degradation of temperature in waters below Gross Reservoir, this analysis will evaluate the potential impact of a decrease in temperatures on the resident aquatic community.

B1.1.2 Potential Impact of the Proposed Action on Water Temperature Pattern

B1.1.2.1 Predicted Project Impacts Based on Temperature Simulations

The existing Gross Reservoir Dam was completed in 1954. Water release from the reservoir occurs from the hypolimnion through submerged lower level outlet works. Dam discharge capacity ranges from 0 to 3,000 cubic feet per second (cfs). Currently, Denver Water tries to maintain a minimum discharge (or the natural inflow if less) of 5 cfs from May through October and 7 cfs from November through April (Final Environmental Impact Statement [FEIS], Section 2.3.2.1, p. 2-45).

The Proposed Action will increase the storage capacity of Gross Reservoir by 77,000 acre-feet (AF), which includes 5,000 AF for creation of an environmental pool that would be used in flow releases to enhance aquatic habitat in South Boulder Creek, below Gross Reservoir. Storage capacity will be increased by raising the existing Gross Reservoir Dam by 131 feet (6-feet of this dam raise is to establish the environmental pool) (FEIS, Section 2.3.2.1, 2014).

Enlargement of the reservoir will substantially increase water depth that is expected to result in a colder and larger reservoir hypolimnion, which will maintain a cooler temperature during the period of summer stratification. This period of summer stratification is also expected to be maintained longer than currently observed. With a larger hypolimnion maintaining cooler temperatures, temperature releases from the bottom of the reservoir are also expected to be cooler than currently observed, especially during the summer months.

As part of FEIS development, the U.S. Army Corps of Engineers (USACE) commissioned preparation of a Gross Reservoir Temperature Model to simulate potential impacts from project implementation on reservoir temperatures and the temperature of water released from the reservoir into South Boulder Creek.[1]

Figures B1-1a and B1-1b illustrate the simulated reservoir outflow temperatures for 2009 and 2012 meteorological conditions, comparing simulated baseline conditions with simulated conditions post-project implementation[2] (Hydros Consulting 2013). These figures show two key time periods when South Boulder Creek water temperatures are potentially most impacted: (a) February to May; and (b) August to October.

- *February to May* – Figure B1-1a shows varying degrees of potential impact for this period in the years used to model water temperatures in South Boulder Creek. For 1971 reservoir conditions, the average daily difference in water temperature varies from -0.85°C to -1.3°C for the months of February to May, but for 1972 reservoir conditions this differential is -1.07°C to -1.85°C (**Tables B1-1 and B1-2**). For the Proposed Action, the total number of degrees difference estimated for this 4-month period is -130.9°C for 1971 and -168.2°C for 1972.[3]

- *August to October* – Similar to the spring months, Figure B1-1b shows varying degrees of potential impact for this period. For 1971 conditions, the difference in expected average daily water temperature after project completion varies from -0.61°C in October to -1.9°C and -3.7°C each day in August and September, respectively (Tables B1-1 and B1-2). In comparison, for 1972 conditions the estimated daily average temperature differential is 1.31°C in October and 0.85°C in August, but 5.16°C each day in September. For the Proposed Action, the total estimated degree day difference for this 3-month period is -188.5°C for 1971 and -221.53°C for 1972, more than observed for the late winter-spring period, as described above. This is the period of time with the highest potential for concern as it is the period when the fish fry life stage is expected to be present (August, per the Colorado Temperature Policy 06-1[4]; see discussion below).

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[1] Hydros Consulting, 2013. *Gross Reservoir Temperature Model: Model Development, Calibration, and Application for the Moffat Collection System EIS*. Prepared for the U.S. Army Corps of Engineers. September 27, 2013.

[2] Modeled predictions based on two hydrologic years: (a) 1971 – year where surface water elevation was approximately equal to the median difference in summertime surface water elevations over the 44 year period of record; and (b) 1972 – year with the largest difference in average summertime reservoir surface water elevation between baseline (no project) and Proposed Action (Alt 1a) conditions. Model runs based on inputs from two different meteorological conditions: 2009 (cooler year) and 2012 (warmer year).

[3] Per the model, there is an estimated daily difference between baseline temperatures and temperatures that will result from the Proposed Action. These values represent the sum of the daily differences over the period described. Negative values indicate colder temperatures are expected under the Proposed Action.

[4] Water Quality Control Commission, *Colorado Temperature Policy 06-1*, August 8, 2011; default assumptions for when Early Life Stages are present for Colorado species, page 8.

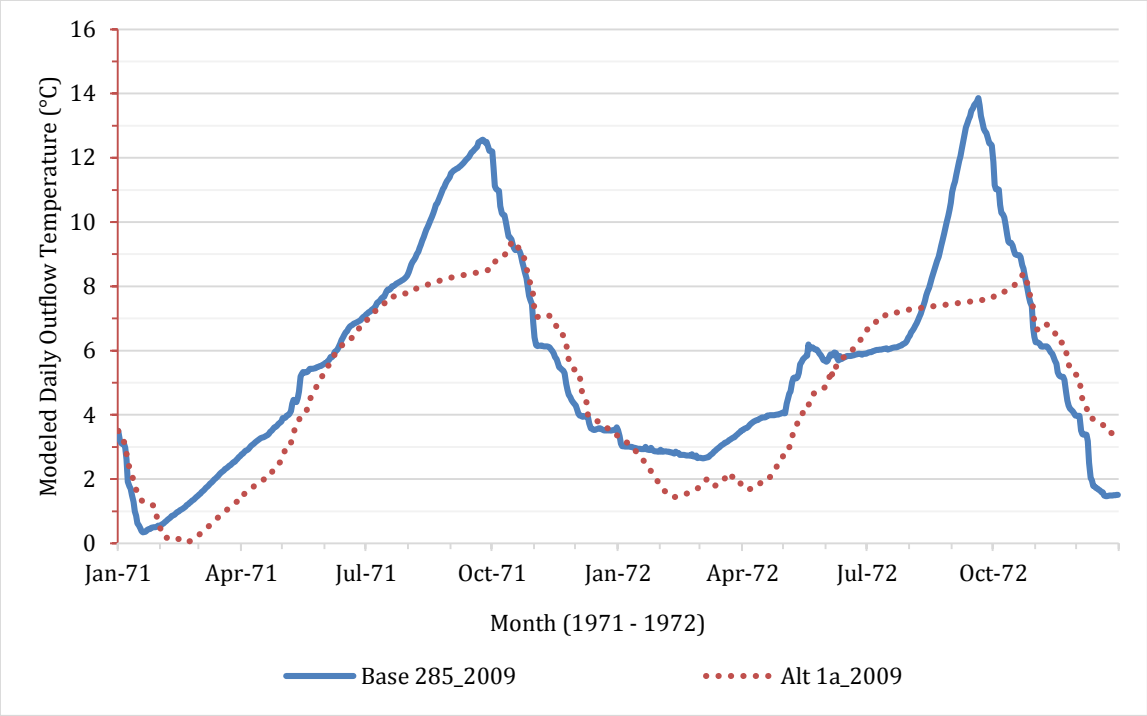

Figure B1-1a. Comparison between simulated outflow temperatures from Gross Reservoir for present conditions (Base 285) and conditions resulting from the Proposed Action (Alt 1a) using 1971-1972 hydrology and 2009 meteorology input conditions (Source: Modeled output data, Hydros Consulting 2013).

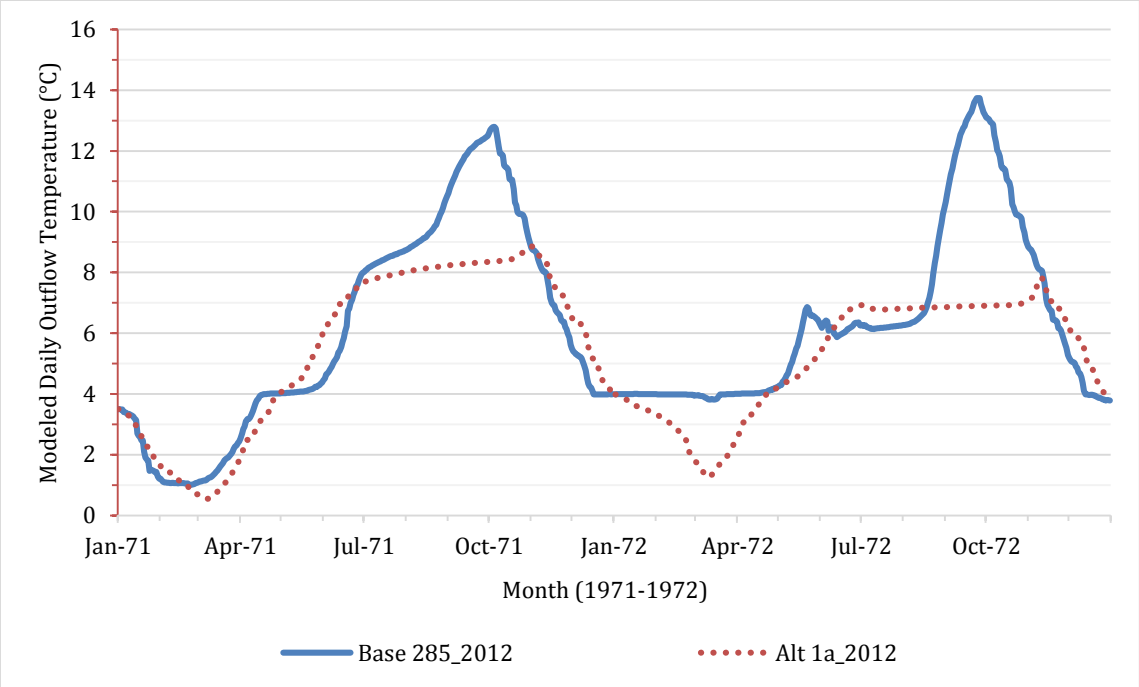

Figure B1-1b. Comparison between simulated outflow temperatures from Gross Reservoir for present conditions (Base 285) and conditions resulting from the Proposed Action (Alt 1a) using 1971-1972 hydrology and 2012 meteorology input conditions (Source: Modeled output data, Hydros Consulting 2013).

Table B1-1. Summary of temperature differences between simulated baseline water temperatures at the Gross Reservoir Outlet and simulated temperatures expected following implementation of the Proposed Action (Alt 1a) – 2009 meteorological input for 1971 reservoir conditions (Source: Data used to generate curves in Figure 39 in Hydros Consulting 2013).

Month	Average Baseline Temperature	Average Alt 1a Temperature	Average Daily Difference	Monthly Cumulative Difference
January	1.28	1.84	0.56	17.51
February	1.01	0.16	-0.85	-23.92
March	2.13	0.83	-1.30	-40.24
April	3.27	1.97	-1.30	-39.11
May	4.91	4.02	-0.89	-27.61
June	6.41	6.19	-0.22	-6.57
July	7.76	7.48	-0.28	-8.63
August	9.96	8.06	-1.90	-58.89
September	12.08	8.39	-3.69	-110.66
October	9.46	8.84	-0.61	-18.94
November	5.60	6.62	1.02	30.50
December	3.70	4.03	0.33	10.33
Annual	**5.63**	**4.87**	**-0.76**	**-276.23**

Table B1-2. Summary of temperature differences between simulated baseline water temperatures at the Gross Reservoir Outlet and simulated temperatures expected following implementation of the Proposed Action (Alt 1a) – 2009 meteorological input for the 1972 reservoir conditions (Source: Data used to generate curves in Figure 39 in Hydros Consulting 2013).

Month	Average Baseline Temperature	Average 1a Temperature	Average Daily Difference	Monthly Cumulative Difference
January	2.98	2.70	-0.28	-8.65
February	2.78	1.57	-1.21	-35.02
March	3.02	1.95	-1.07	-33.07
April	3.86	2.01	-1.85	-55.62
May	5.45	4.02	-1.44	-44.53
June	5.83	5.83	0.00	0.04
July	6.08	7.06	0.98	30.35
August	8.22	7.37	-0.85	-26.29
September	12.69	7.54	-5.16	-154.74
October	9.21	7.90	-1.31	-40.50
November	5.39	6.29	0.90	27.03
December	2.21	3.93	1.72	53.17
Annual	**5.64**	**4.85**	**-0.79**	**-287.83**

Tables B1-3 and B1-4 provide the data results for model runs using 2012 meteorological conditions (warmer year). Although the specific numbers differ, similar patterns as described above for the periods February to May and August to October are observed for this dataset.

The estimated temperature differences between present conditions and future conditions under the Proposed Action described in this section are all based on modeling outcomes using modeling procedures described in the modeling report (Hydros Consulting 2013). While useful for a general evaluation of potential impacts of the Proposed Action on waters below Gross Reservoir, it is important to consider these modeled predictions within the context of actual temperature observations from South Boulder Creek below Gross Reservoir. These will be discussed below.

B1.1.2.2 Observed Temperatures in South Boulder Creek below Gross Reservoir

The Gross Reservoir Model simulates the expected difference in reservoir outflow temperatures between the simulated baseline conditions (no project) and the simulated conditions expected after completion of the Proposed Action (Alt 1a). Of interest is how well the simulated baseline conditions reflect temperatures currently observed in South Boulder Creek below Gross Reservoir. Two datasets are available for this review, as described below.

Historical Temperature Data (1963 – 1981)

Historical temperature observations are documented in the Volume III Resource Reports prepared to support Gross Reservoir Federal Energy Regulatory Commission (FERC) relicensing in the 1990s[5]. Figure HY-34 in this report summarizes the average monthly temperature observed at the Gross Reservoir Outlet during this time period (**Figure B1-2**). **Table B1-5** provides the instantaneous data that were used to generate Figure HY-34; **Figure B1-3** illustrates both the individual temperature observations by month and the monthly average for the period of record from 1963 to 1981. One key difference in the average portrayed in Figure B1-3 and what was originally shown in Figure HY-34 (Figure B1-2) is the calculation of the July average. Two data records from July 1963 and 1964 are significant outliers from normal observations for that month (see Figure B1-3 or Table B1-5); therefore, while Figure B1-2 includes these data records in the portrayal of a monthly average, Figure B1-3 does not include these values in the monthly average.[6] Considerable variation exists in monthly observations. A 2 degree (°C) variation is common in a typical month, with one month showing a range of 7°C (March) and another showing a 5°C variation (January).

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[5] Denver Water. 1998. *Gross Reservoir Hydroelectric Project FERC No. 2035: Volume III Resource Reports – Geology and soils, water resources, aquatic resources, vegetation and wetland/riparian resources, wildlife resources*. Denver Water. April 30, 1998.

[6] It is unknown what the original data source is for these two temperature records; therefore it is not possible to evaluate the accuracy of the observations. Even if accurate, based on the long term data record (this data set and the most recent data set), these water temperature readings are anomalies and well above the norm.

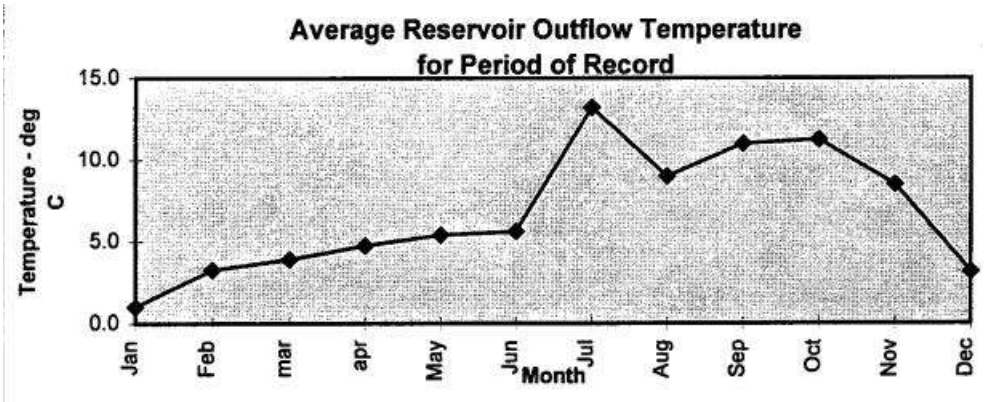


Figure B1-2. Average Gross Reservoir outflow temperatures, 1963 – 1981; see text for discussion of July elevated average (Source: Figure HY-34, Denver Water 1998)

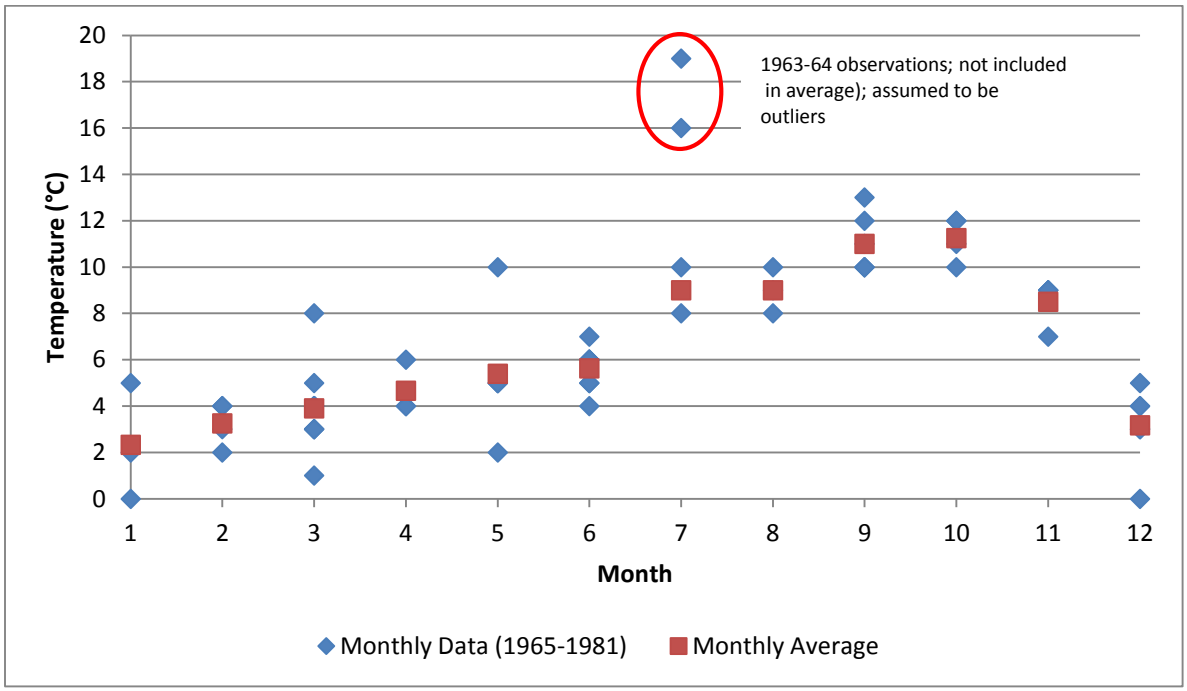


Figure B1-3. Monthly temperature observations and monthly average temperature in South Boulder Creek below Gross Reservoir – periodic observations, July 1963 – July 1981. Data provided in Table X-6 (Source: Denver Water 1998)

Table B1-3. Summary of temperature differences between simulated baseline water temperatures at the Gross Reservoir Outlet and simulated temperatures expected following implementation of the Proposed Action (Alt 1a) – 2012 meteorological input for the 1971 reservoir conditions (Source: Data used to generate curves in Figure 39 in Hydros Consulting 2013)

Month	Average Baseline Temperature	Average 1a Temperature	Average Daily Difference	Monthly Cumulative Difference
January	2.54	2.71	0.17	5.25
February	1.07	1.16	0.09	2.53
March	1.62	0.97	-0.66	-20.33
April	3.64	3.06	-0.59	-17.57
May	4.12	4.73	0.62	19.09
June	6.07	6.97	0.90	26.90
July	8.42	7.86	-0.55	-17.14
August	9.35	8.13	-1.22	-37.72
September	11.81	8.29	-3.52	-105.57
October	11.07	8.49	-2.58	-79.92
November	7.32	7.86	0.54	16.23
December	4.46	5.30	0.84	25.99
Annual	**5.96**	**5.46**	**-0.50**	**-182.26**

Table B1-4. Summary of temperature differences between simulated baseline water temperatures at the Gross Reservoir Outlet and simulated temperatures expected following implementation of the Proposed Action (Alt 1a) – 2012 meteorological input for the 1972 reservoir conditions (Source: Data used to generate curves in Figure 39 in Hydros Consulting 2013)

Month	Average Baseline Temperature	Average 1a Temperature	Average Daily Difference	Monthly Cumulative Difference
January	3.99	3.64	-0.35	-10.87
February	3.98	2.73	-1.25	-36.18
March	3.93	1.74	-2.19	-67.76
April	4.07	3.59	-0.47	-14.24
May	5.72	4.72	-0.99	-30.84
June	6.16	6.40	0.24	7.27
July	6.20	6.82	0.61	19.02
August	7.45	6.84	-0.61	-18.98
September	12.66	6.88	-5.78	-173.34
October	10.98	6.94	-4.03	-125.03
November	7.04	7.10	0.06	1.77
December	4.20	4.95	0.75	23.32
	6.36	**5.20**	**-1.17**	**-425.86**

Table B1-5. Historical temperature data record for South Boulder Creek below Gross Reservoir (Source: Denver Water 1998)

Month	Date	Observed Temperature (°C)	Average Monthly Temperature (°C)
January	1/12/1966	5	2.3
	1/15/1971	2	
	1/3/1978	0	
February	2/1/1973	4	3.3
	2/28/1974	2	
	2/7/1977	3	
	2/7/1978	4	
March	3/27/1968	8	3.9
	3/17/1969	3	
	3/21/1972	4	
	3/31/1975	3	
	3/1/1976	5	
	3/1/1977	3	
	3/7/1978	4	
	3/14/1979	4	
	3/4/1980	1	
	3/5/1980	4	
April	4/1/1965	4	4.7
	4/11/1977	6	
	4/4/1978	4	
May	5/12/1968	10	5.4
	5/31/1973	2	
	5/31/1974	5	
	5/2/1977	5	
	5/2/1978	5	
June	6/3/1971	4	5.6
	6/30/1974	6	
	6/3/1975	6	
	6/1/1976	7	
	6/5/1978	6	
	6/5/1979	6	
	6/16/1980	5	
	6/2/1981	5	
July	7/30/1963	19	9[a]
	7/2/1964	16	
	7/5/1977	8	
	7/11/1978	10	

Table B1-5. Historical temperature data record for South Boulder Creek below Gross Reservoir (Source: Denver Water 1998)

Month	Date	Observed Temperature (°C)	Average Monthly Temperature (°C)
August	8/31/1971	9	9
	8/31/1974	10	
	8/7/1978	8	
September	9/23/1965	10	11
	9/10/1975	10	
	9/7/1976	13	
	9/6/1977	11	
	9/5/1978	10	
	9/8/1980	12	
October	10/27/1970	10	11.3
	10/5/1976	11	
	10/3/1977	12	
	10/3/1978	12	
November	11/8/1972	9	8.5
	11/30/1974	9	
	11/8/1976	7	
	11/1/1977	9	
December	12/13/1972	3	3.2
	12/7/1976	4	
	12/6/1977	4	
	12/4/1978	5	
	12/12/1979	3	
	12/2/1980	0	

[a] Average for July does not include outliers 19°C and 16°C. See text for discussion

Present Conditions - Denver Water Data Set (April 2009 – December 2014)

This dataset was collected at the outlet works of Gross Reservoir just downstream of the hydropower building with a data logger that provided hourly temperature readings generally from April 2009 through December 2014 (**Figure B1-4**). A review of the hourly data showed a number of anomalies when clearly the recording device was not providing accurate data (e.g., recording negative values). The dataset used for this analysis only included data deemed representative. The average water temperature for this period of record is generally colder than the historical record, especially for the period from August to October (**Figure B1-5**). Given that the Denver Water data are hourly records vs. one-time grabs scattered over many years, it should be assumed that the Denver Water dataset is more reflective of present water temperature conditions below Gross Reservoir.

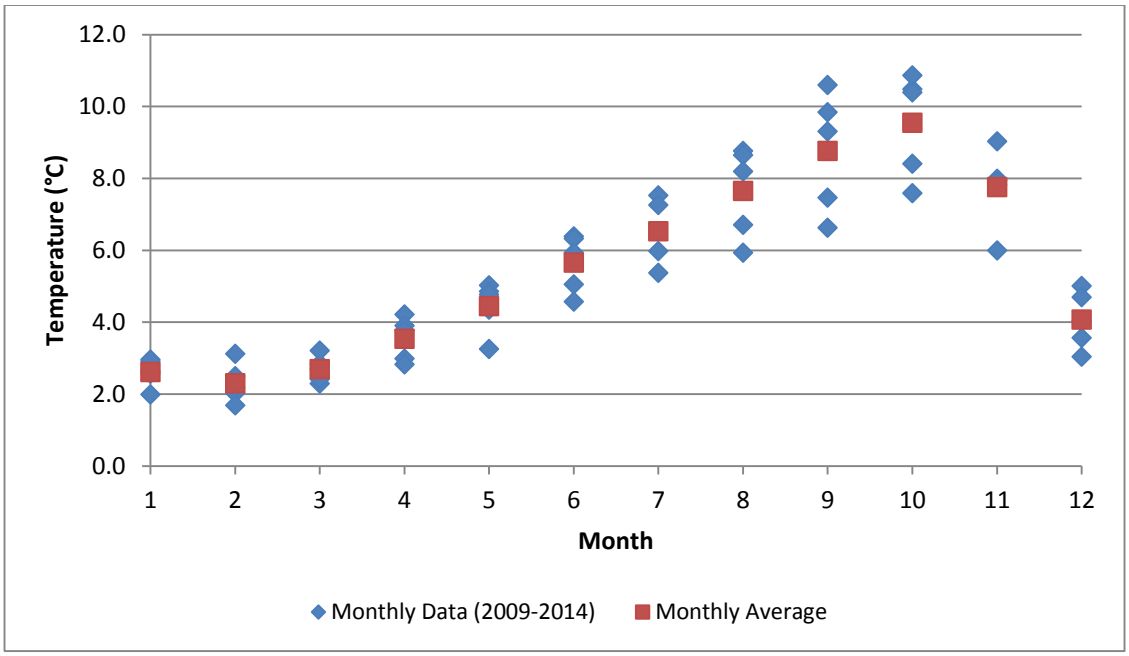


Figure B1-4. Monthly average temperature observations and overall average temperature in South Boulder Creek below Gross Reservoir, April 2009 – December 2014 (Source: Denver Water)

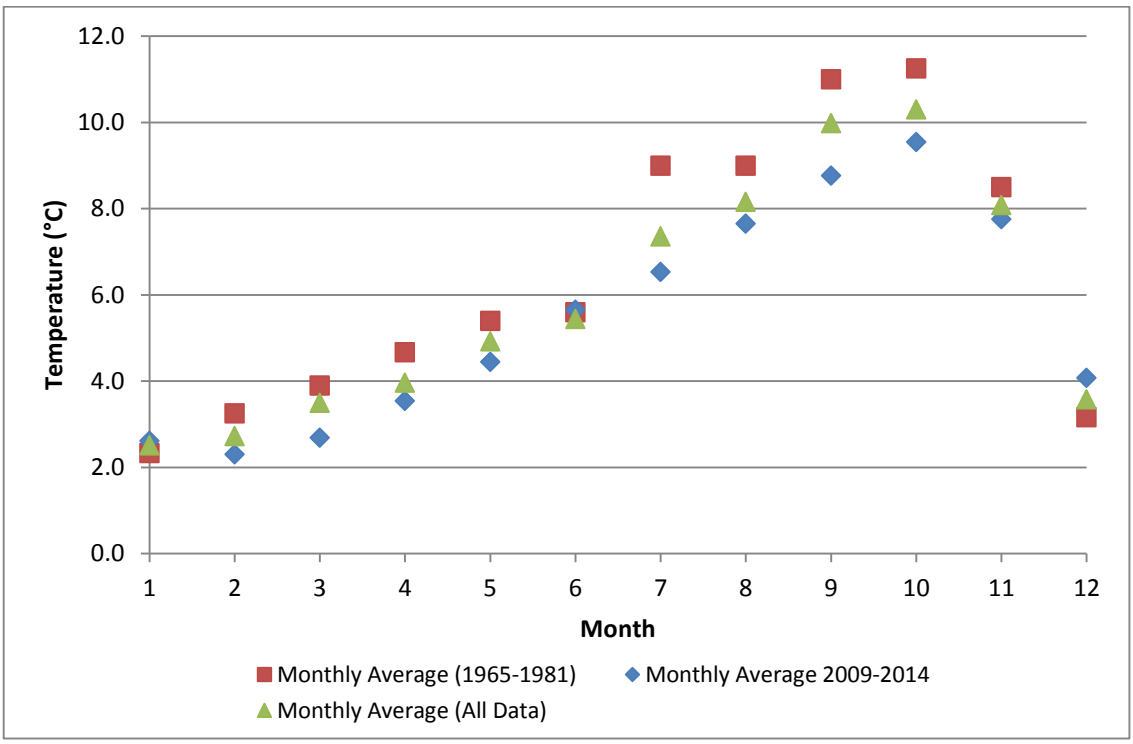


Figure B1-5. Monthly average temperature in South Boulder Creek below Gross Reservoir – All data sources (Source: Denver Water 1998 and Denver Water 2009-2014)

Figure B1-6 illustrates the overall variability observed in water temperatures below Gross Reservoir from 1963 through 2014. For any given month the range of potential temperatures is broad.

The 2009 meteorological input model simulation shows an extended period of time (> 30 days) when the simulated baseline temperature is between 10°C and 12°C for 1971 reservoir conditions; for 1972, the simulation shows the baseline with temperatures above 10°C for an even longer period and reaching highs above 14°C (see Figure B1-1). A review of the historical and Denver Water 2009 through 2014 datasets shows that a temperature of 14°C has not actually been observed in any dataset for the period from August through October (see Figure B1-6). In addition, **Figures B1-6a and B1-6b** provide a direct comparison between simulated temperatures below Gross Reservoir (all reservoir and meteorological conditions) and temperatures observed from 2009 through 2014. These figures demonstrate that water temperatures below Gross Reservoir have not ever reached 14°C under present conditions between 2009 and 2014. These observations do not mean that temperatures of 14°C cannot occur, but if they do it is not a common occurrence.

One potential reason for the cooler temperatures than expected at the Gross Reservoir Outlet based on the baseline simulation is that surface water elevations (SWE) in Gross Reservoir have been higher than what was observed in 1971 and 1972, the basis for reservoir conditions used in the Gross Reservoir model. However, a comparison between SWEs for the 2009 to 2013 period and the baseline modeling period (1971 to 1972) shows that peak SWEs in recent years are similar to 1971 and 1972 hydrology, especially the former (**Figure B1-6c**). There is a difference in how long the peak SWE has been maintained with SWE elevations staying higher longer into the summer/fall seasons in recent years. While this difference has the potential to result in a colder hypolimnion and thus colder outlet temperatures, a comparison between peak summer/fall temperatures over the 2009 to 2013 period (e.g., see blue line in Figure B1-6a) shows that peak temperatures have varied from 8°C to almost 12°C, a considerable year to year difference. This variability in outlet temperatures does not track with changes in SWE during the same period.

Figure B1-7 provides a comparison of the historical data monthly average temperatures with the monthly average temperature results from the Gross Reservoir model (2009 meteorological input – cooler year). This figure illustrates how the modeled monthly average baseline temperatures at the Gross Reservoir outlet compare to the monthly average of actual observed temperatures. The period of greatest discrepancy is the September period when the modeled baseline output shows significant temperature peaks during September (see also Figures B1-1, B1-6a and B1-6b; Tables B1-1 and B1-2). This is reflected in the higher September average temperatures in the modeled results. Compared to recent temperature data, this average modeled baseline September temperature is certainly somewhat higher than what is observed under present conditions. Accordingly, the expected impact from the Proposed Action as indicated in Figure B1-1 may be less than anticipated.

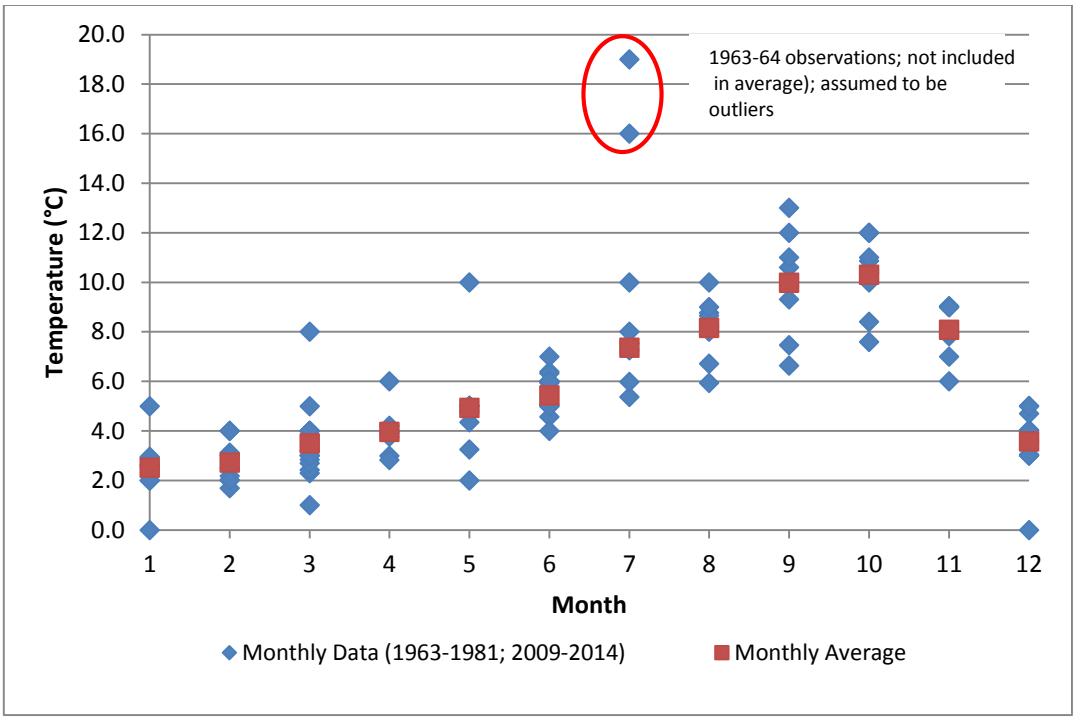


Figure B1-6. Monthly temperature observations and monthly average temperature in South Boulder Creek below Gross Reservoir – All data, July 1963 - December 2014 (Source: Denver Water 1998 and Denver Water 2009-2014).

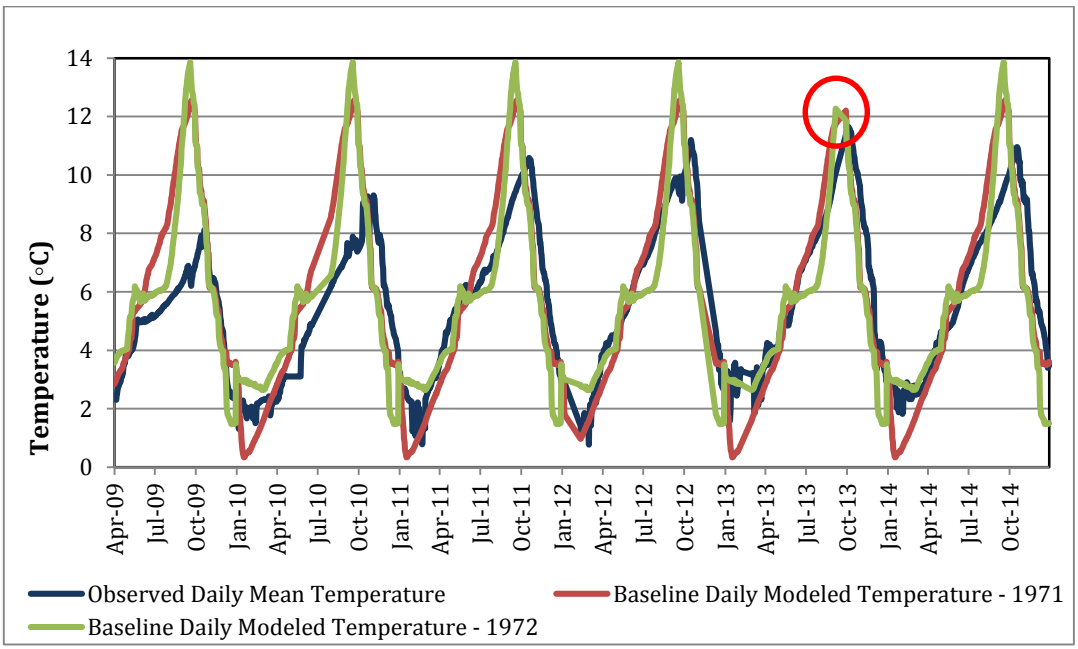


Figure B1-6a. Comparison between observed water temperatures below Gross Reservoir (2009-2014) and simulated baseline temperatures *predicted* by the Gross Reservoir model (1971/1972 hydrologic years with 2009 meteorological conditions) (Note: The lower simulated baseline temperatures for 2013, highlighted by the red circle, are the result of missing data observations during September 2013).

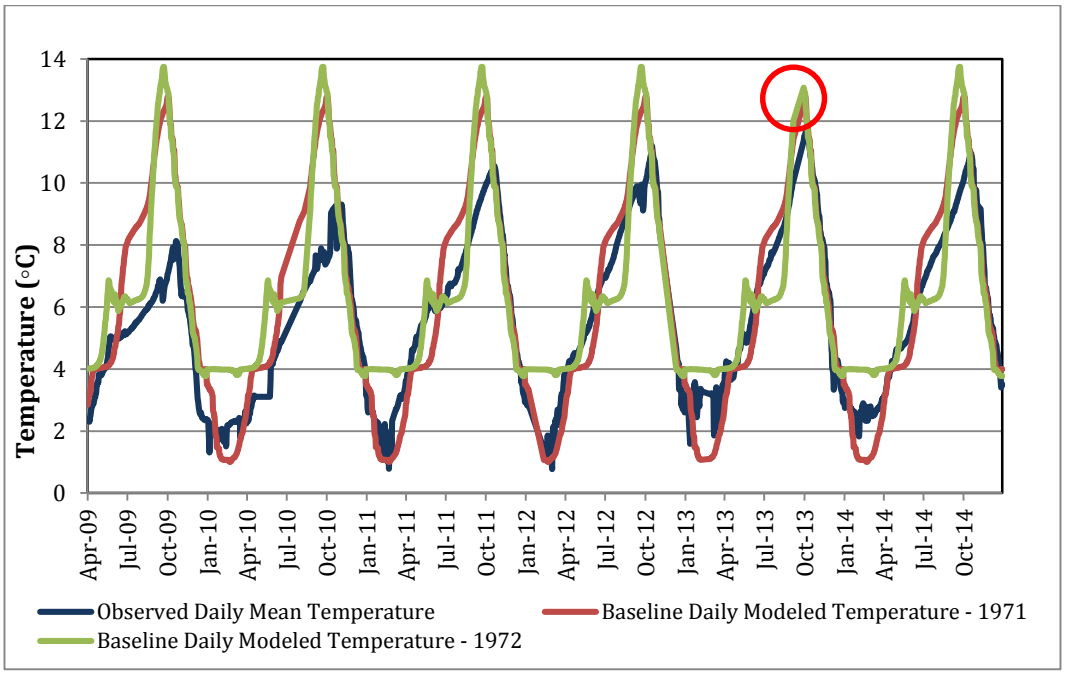


Figure B1-6b. Comparison between observed water temperatures below Gross Reservoir (2009-2014) and simulated baseline temperatures *predicted* by the Gross Reservoir model (1971/1972 hydrologic years with 2012 meteorological conditions) (Note: The lower simulated baseline temperatures for 2013, highlighted by the red circle, are the result of missing data observations during September 2013).

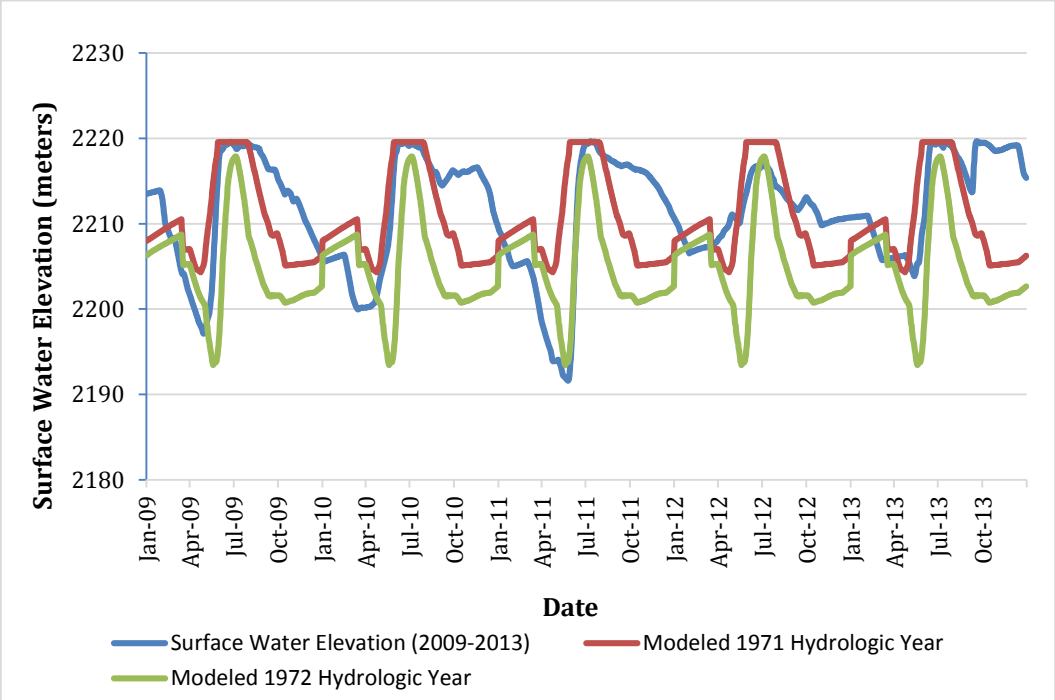


Figure B1-6c. Comparison between Gross Reservoir surface water elevations simulated by Gross Reservoir Model for baseline conditions and surface water elevations observed during 2009-2013.

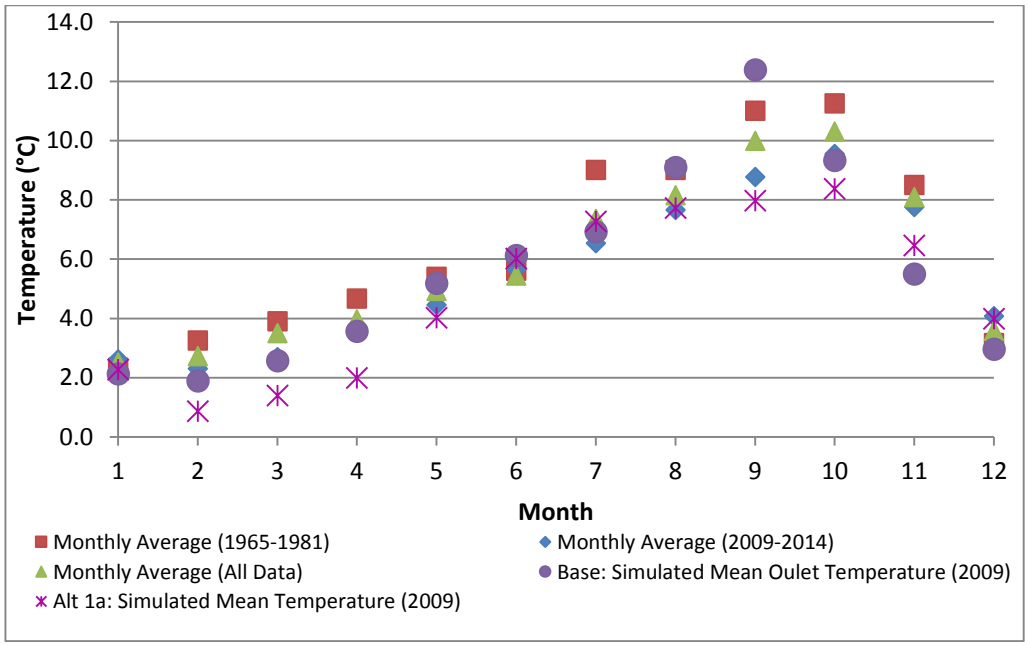


Figure B1-7. Monthly average temperature in South Boulder Creek below Gross Reservoir – Various data sources compared to simulated baseline temperatures and simulated temperatures after implementation of the Proposed Action (Alternative 1a) (based on 2009 meteorological input data) (Source: Denver Water 1998, Hydros Consulting 2013).

Diel Water Temperatures below Gross Reservoir

Figures B1-7a through B1-7c illustrate the 2014 temperature patterns for South Boulder Creek below Gross Reservoir for each month on a daily time step using hourly data. The 2014 dataset was selected due to the completeness of data[7] and because it represents the most current daily temperature patterns. Each of the monthly figures depicts the full range of variation in daily temperature, the likely range of temperature variation, and the daily median value. Visually, the boxplots show small ranges in diurnal temperature, but in order to gain a better understanding of the daily temperature fluctuation, **Figure B1-7d** provides a histogram of the daily ranges and a table of the maximum daily ranges.

The histogram confirms that insignificant daily temperature variations currently exist in the South Boulder Creek below Gross Reservoir. Figure B1-7d shows that in 2014, 97 percent of daily temperature fluctuations were less than 1°C and 85 percent were less than 0.5°C. The results further show that the maximum daily temperature variability for 2014 was 1.55°C and that the largest daily temperature changes occurred between January 24 and March 5. While typical daily temperatures vary by time of year, these figures demonstrate that a diel temperature pattern does not exist under present conditions. The lack of a diel temperature pattern would not change under future conditions.

[7] 2014 had only three days with no data and 12 days with partial data.

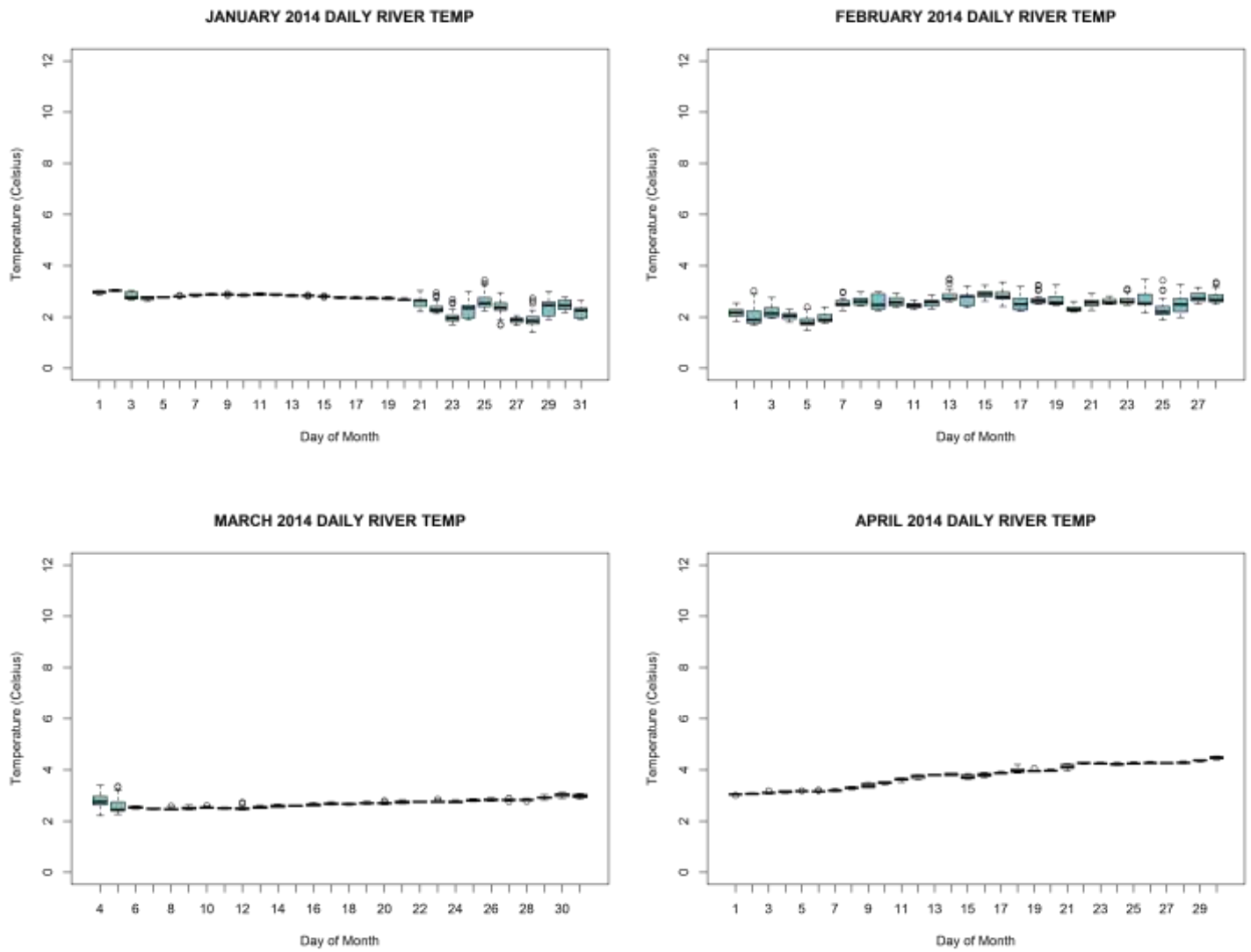


Figure B1-7a. Daily temperature variability in South Boulder Creek below Gross Reservoir for the months of January through April, 2014. Boxplots for each individual day indicate range of temperatures observed for that given day.

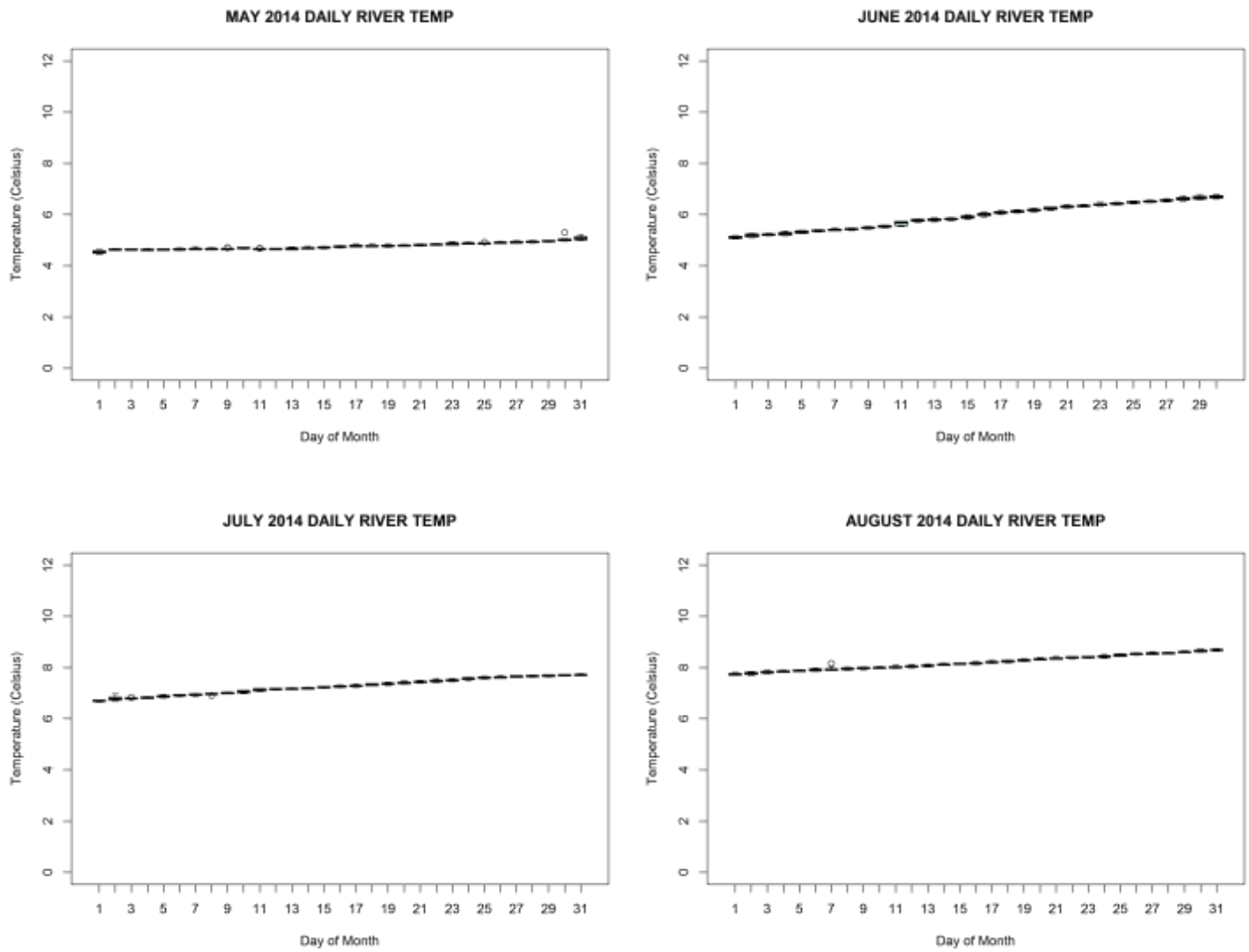


Figure B1-7b. Daily temperature variability in South Boulder Creek below Gross Reservoir for the months of May through August, 2014. Boxplots for each individual day indicate range of temperatures observed for that given day.

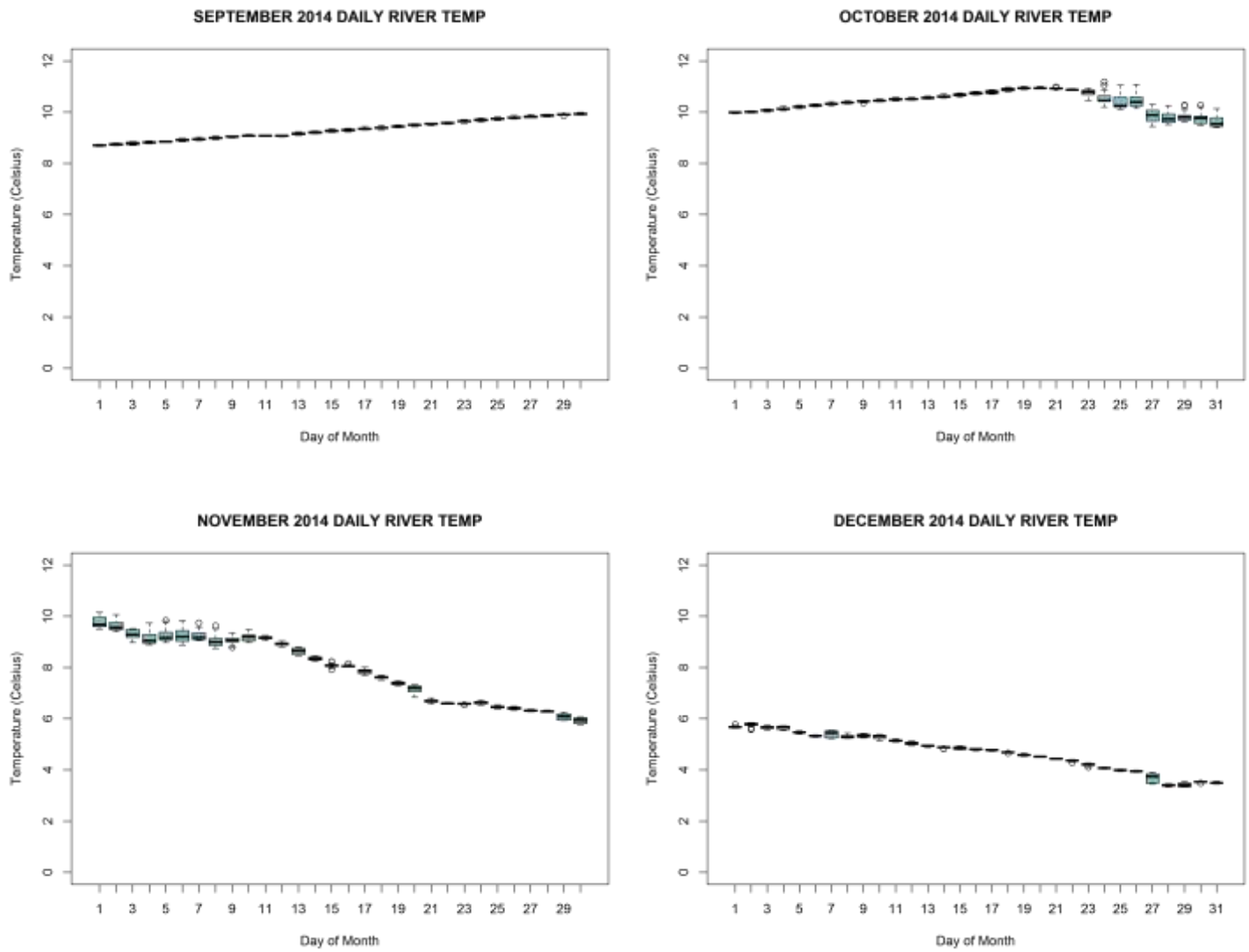
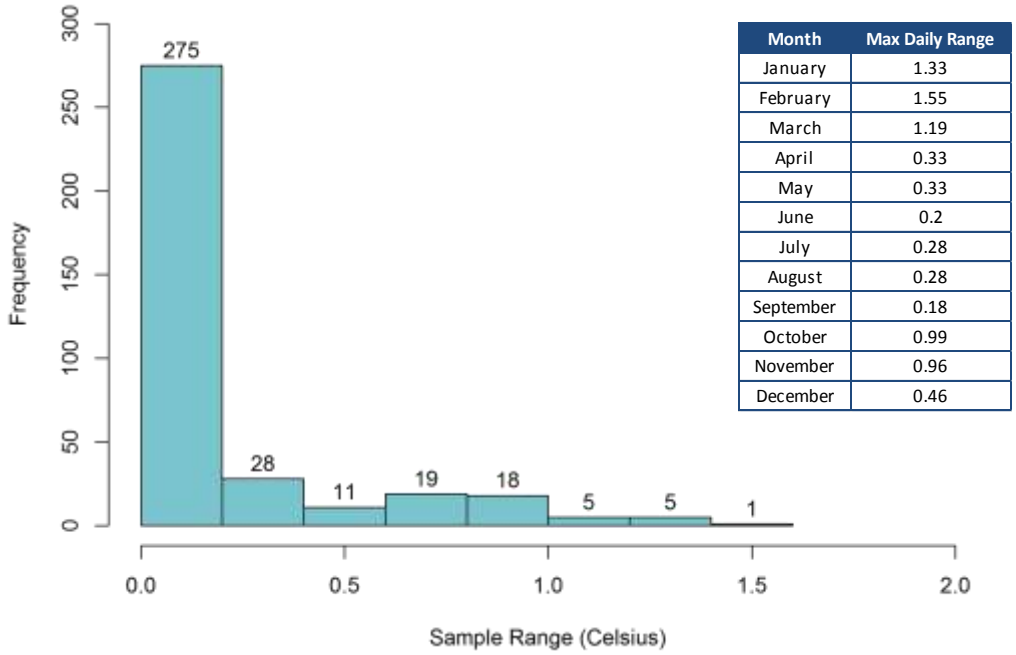


Figure B1-7c. Daily temperature variability in South Boulder Creek below Gross Reservoir for the months of September through December, 2014. Boxplots for each individual day indicate range of temperatures observed for that given day.



Month	Max Daily Range
January	1.33
February	1.55
March	1.19
April	0.33
May	0.33
June	0.2
July	0.28
August	0.28
September	0.18
October	0.99
November	0.96
December	0.46

Figure B-7d. Histogram of 2014 daily temperature ranges with table of maximum daily ranges by month.

South Boulder Creek Canal Diversion Water Temperatures (2005-2014)

One additional piece of evidence that supports the conclusion that the modeled results may overestimate baseline water temperature in the August to October period can be drawn from a review of water temperatures observed at the South Boulder Creek Canal Diversion site ("Diversion site") (WS-RL-002). **Figure B1-8** shows the range of individual monthly temperature observations and the monthly average temperature observed at this site from January 2005 through March 2014. **Figure B1-9** compares the observed water temperatures at the Gross Reservoir Outlet with the observed water temperatures at the downstream Diversion site on the same day between 2009 and 2013 (outlet water temperature data were collected hourly and averaged for the day; Diversion site data are instantaneous measurements). General observations from this temperature comparison include:

- At the Diversion site, the observed monthly water temperatures can vary significantly, e.g., ranging from 0°C to 7°C in February or 4°C to 14°C in May (see Figure B1-8). Typical monthly water temperature variability is about 5°C. This variability is likely caused by a combination of factors, e.g., variable ambient temperatures and flow volumes.
- When the Gross Reservoir Outlet temperatures are compared to the water temperatures at the Diversion site, water temperatures do warm somewhat over the 4.9 mile river reach, typically by 2°C or more (and sometimes substantially more) as was observed in 2009 (see Figure B1-9).

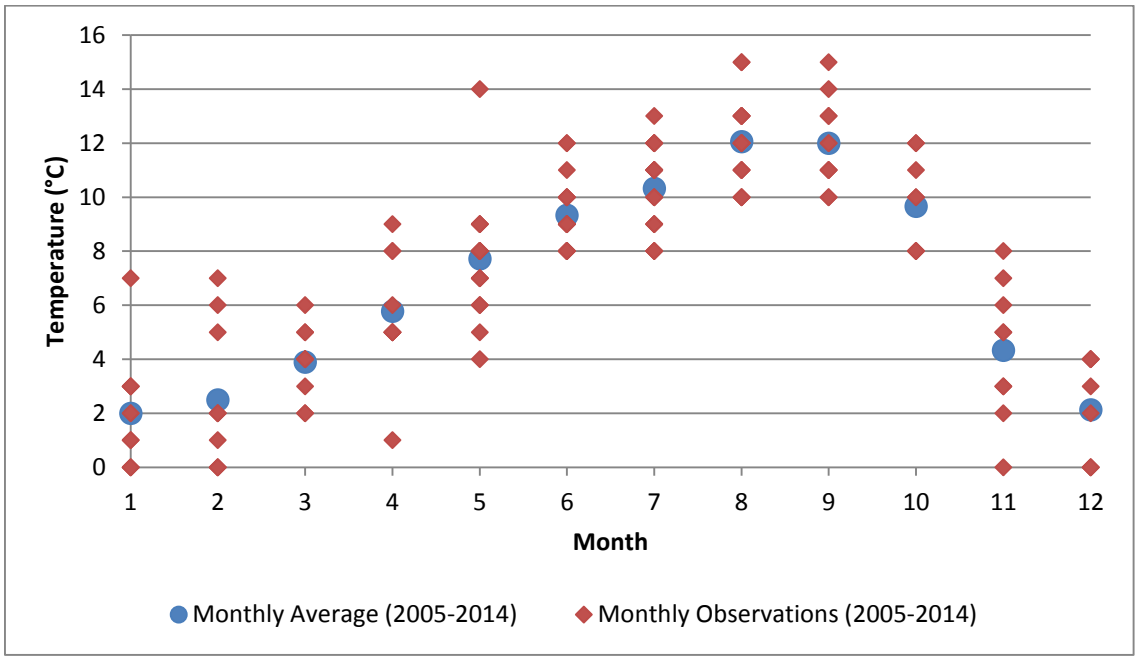


Figure B1-8. Monthly temperature observations and monthly average temperature at the South Boulder Creek Canal Diversion, January 2005 – March 2014 (Source: Denver Water temperature data collected at WS-RL-002).

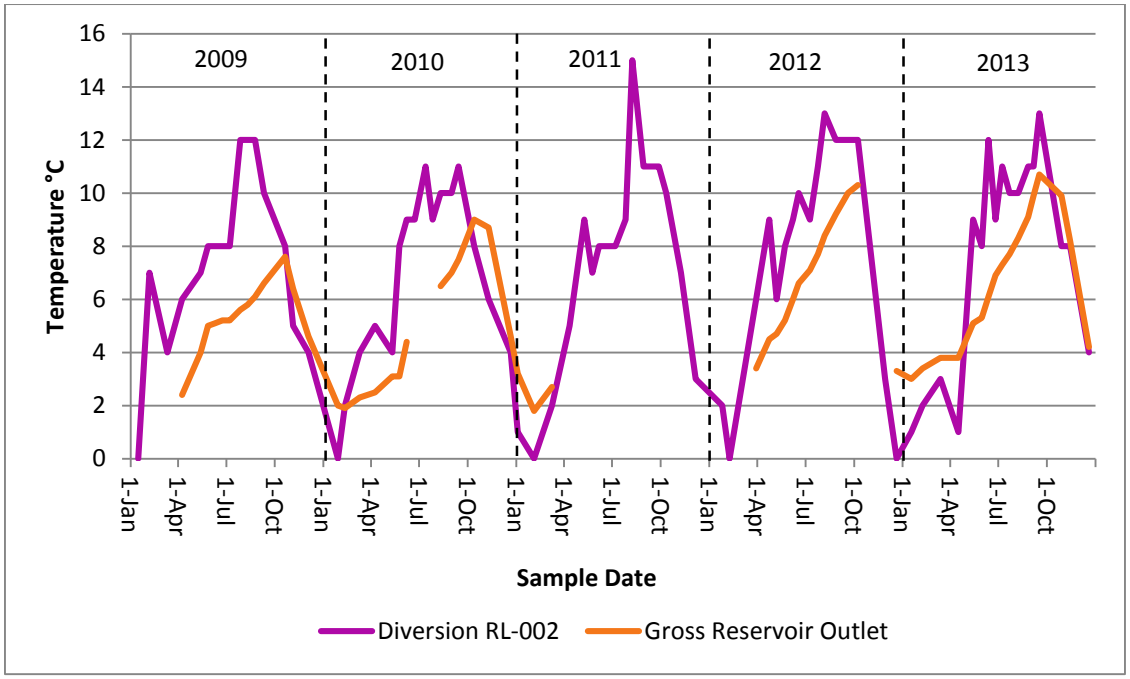


Figure B1-9. Comparison of daily temperature observations between the Gross Reservoir Outlet and South Boulder Creek Canal Diversion site (WS-RL-002) – 2009-2013. Gaps in the red line indicate missing data. Hourly temperature observations at Gross Reservoir Outlet were averaged to create a daily average temperature. Temperature observations at WS-RL-002 are instantaneous observations usually around mid-day (Source: Denver Water).

- Even with the opportunity for water temperatures to warm over the 4.9-mile reach between the Gross Reservoir Outlet and the Diversion site, water temperatures rarely reach or exceed 14°C at the Diversion site (see Figure B1-8), yet the simulated maximum baseline temperatures for the Gross Reservoir Outlet under present conditions are 12°C (cool year) and 14°C (warm year) for the two periods modeled. These temperatures are simulated to occur in September. If these types of baseline temperatures are expected under present conditions, then the expectation would be for temperatures of 2°C or higher to be observed regularly at the Diversion site (e.g., 14°C to 16°C, or even higher). A review of the observed Diversion site water temperatures shows that in September temperatures below 14°C are much more common than temperatures of 14°C or above (see Figure B1-8).

- During spring and summer months, water temperatures can be substantially warmer at the Diversion site (see Figure B1-9). In contrast, during the winter months water temperatures are typically warmer at the Gross Reservoir Outlet site than at the Diversion site (Figure B1-9). This is no doubt a reflection of the relatively constant deep reservoir temperatures that cannot reach freezing. These relatively constant lake bottom temperatures buffer the impact of cold, ambient air temperatures in the South Boulder Creek area, which can and do lower water temperatures to freezing.

B1.1.2.3 Summary

The enlargement of Gross Reservoir is expected to create a larger and colder hypolimnion. Per the FEIS, this outcome of the Proposed Action is expected to result in colder water discharged to South Boulder Creek. This finding is based on the Gross Reservoir Model, which estimated the degree to which water will be colder when discharged under future conditions.

A review of historical and recently collected temperature data below Gross Reservoir shows that under present conditions water temperatures below Gross Reservoir are colder than estimated by the simulation of baseline conditions in the model, primarily during the months of August, September, and October. The difference between the model output and observed present conditions creates uncertainty with regards to the model's predictions for water temperatures under future conditions.

Regarding the narrative temperature standard Temperature Pattern element (*Temperature shall maintain a normal pattern of diel and seasonal fluctuations and spatial diversity with no abrupt changes*), under present conditions, the normal seasonal temperature pattern below Gross Reservoir is already considered cold, compared to what may be observed in a naturally flowing stream. The model indicates a potential for truncated seasonal temperatures under future conditions during the months of August through October (the extent of which may be affected by the uncertainty described above). In addition, under present conditions, no diel temperature pattern occurs below the Gross Reservoir Outlet; this would not change under future conditions. Finally, there is no expectation of an "abrupt change" in temperature with the Proposed Action. If the project results in a colder hypolimnion and colder water is discharged, this change will occur somewhat gradually. This is important given that there will be opportunity for the aquatic community to acclimate to the gradual changes.

While a focused review of temperature data suggests the potential for some impact from the Proposed Action under future conditions (e.g., seasonal differences as noted above), the *purpose* of the narrative temperature standard is to ensure that the aquatic life beneficial use is protected. The next section

evaluates the potential for the aquatic community in South Boulder Creek below Gross Reservoir to be adversely impacted by the Proposed Action, which would result in a finding of significant degradation.

B1.1.3 Potential Impact of the Proposed Action on Aquatic Life

The FEIS documents the potential impacts of the Proposed Action on the aquatic community, evaluated here using available fish and benthic macroinvertebrate information. An underlying assumption of this evaluation is that abundant and diverse fish and macroinvertebrate communities reflect healthy aquatic systems comprised of numerous biological components, including microorganisms, algae, and aquatic macrophytes. The potential project impacts identified in the FEIS are summarized in **Table B1-6**. Some minor differences in impacts to streamflow and habitat availability are documented when Moffat Project effects and Total Environmental effects are compared. However, these differences are minor enough that the synthesis of the analysis of potential project impacts on the aquatic community (fish and macroinvertebrate) are the same regardless of whether the evaluation is project specific (Moffat Project effects) or cumulative (Total Environmental effects) (see Synthesis section of Table B1-6). Accordingly, the analysis below of potential impacts of the Proposed Action on the aquatic community will not distinguish between project-specific and cumulative effects. However, potential impacts to fish and macroinvertebrate communities will be evaluated separately to the extent data are available.

B1.1.3.1 Fish Community

Available Fish Community Data

GEI Consultants (2013)[8] Table B-25, prepared to support development of the Moffat Project FEIS, summarizes the available fish community data for South Boulder Creek, downstream of the Gross Reservoir Outlet. **Table B1-7** refines this information by providing a summary of fish community data from sites located in the reach of South Boulder Creek between the Gross Reservoir Outlet and the Diversion site (see **Figure B1-10** for the approximate locations of these fish survey locations). All sites in Table B1-7 are within so-called Segment III as shown in Figure 3.2.1 in the Two Forks EIS Technical Report[9].

Table B1-7 shows the dominance of rainbow trout (*Oncorhynchus mykiss*) in fish surveys conducted in the reach of South Boulder Creek below the Gross Reservoir Outlet. Only a few other fish species have been documented in this reach: longnose dace, longnose sucker, and brown trout.

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[8] GEI Consultants, Inc. 2013. *Aquatic Resources Technical Report for the Moffat Collection System Project Final Environmental Impact Statement.* Prepared for the U.S. Army Corps of Engineers, Denver Regulatory Office. December 2013.

[9] –*Final Environmental Impact Statement for Metropolitan Denver Water Supply* (Two Forks Dam and Reservoir, Douglas and Jefferson Counties, Colorado) (Williams Fork gravity collection system, Grand County, Colorado). March 1988.

Table B1-6. Synopsis of FEIS-documented impacts to aquatic biological resources below Gross Reservoir (Source: FEIS Total Environmental Effects – Chapter 4; FEIS Moffat Project Effects – Chapter 5)

Total Environmental Effects (Chapter 4)	Moffat Project Effects
Temperature	
• Water temperatures throughout the year are expected to be lower. • Temperatures during the growing season for trout would be several degrees cooler and would be less favorable for growth. • Cooler temperatures are expected throughout this segment downstream to the South Boulder Creek Canal Diversion as there is little warming of the water in this segment.	• Water temperatures throughout the year are expected to be lower. • Temperatures during the growing season for trout would be several degrees cooler and would be less favorable for growth. • Cooler temperatures are expected throughout this segment downstream to the South Boulder Creek Canal Diversion as there is little warming of the water in this segment.
Flow	

• Under existing conditions flows are highest in the spring but extremely low in the winter; under the Proposed Action with RFFAs flows in average, dry and wet years would be substantially different:
  • Flows increase from November to February with greatest increases in January and February;
  • Winter flows increase, but highest runoff flows would be reduced by up to 12%;
  • Flows during spring runoff would be up to 24% lower.
• Annual flows will increase 11%, 21% and 17% in average, dry and wet years, respectively.
• Peak flows will be reduced by 6% (28 cfs) in average years.
• Five-year flood would only occur every 12 years; 10-year flood would not be expected to occur. These changes may decrease bank instability and reduce need for further bank stabilization efforts.
	• Under existing and full use conditions flows are highest in the spring and extremely low in the winter. With the Proposed Action, flows would be substantially different:
	  • Flows increase from November to February with greatest increases in January and February;
	  • Winter flows increase, but highest runoff flows would be reduced by up to 13%;
	  • Flows during spring runoff would be up to 23% lower.
	• Annual flows will increase 9%, 17% and 14% in average, dry and wet years, respectively.
	• Peak flows will be reduced by 13% (65 cfs) in average years.
	• Five-year and 10-year floods would not be expected to occur. These changes may decrease bank instability and reduce need for further bank stabilization efforts.

Habitat Availability	

• Under existing conditions, minimum habitat availability for rainbow trout adults and juveniles occurs in the late winter and during spring runoff.
• With the Proposed Action and RFFAs, increases in minimum habitat availability of up to 126%, specifically:
  • Adults – increases would be 30% and 126% in median and dry years, respectively;
  • Juveniles – increase range from 11% to 53% for wet and dry years, respectively;
  • Fry – Increase by 16% in median years; but decrease by 31% in wet years.
• Average habitat availability would increase for some life stages in all types of years, specifically:
  • Adults and fry – average habitat increases by 20% and 17%, respectively, in median years;
  • Adult Weighted Usable Area (WUA) increases by 24% and 16% in dry and wet years, respectively;
  • Other life stages, changes in WUA would be 8% or less.
	• With Full use of the existing system conditions, minimum habitat availability for rainbow trout adults and juveniles occurs in the late winter and during spring runoff.
	• With the Proposed Action, increases in minimum habitat availability of up to 126%, specifically:
	  • Adults – increases would be 31% and 126% in median and dry years, respectively;
	  • Juveniles – increase range from 11% to 53% for wet and dry years, respectively;
	  • Fry – Increase by 48% in median years.
	• Average habitat availability would increase for some life stages in all types of years, specifically:
	  • Adults – average habitat availability increases by 17% in median years;
	  • Adult WUA increases by 22% and 14% in dry and wet years, respectively;
	• Other life stages, changes in WUA would be 8% or less.

Table B1-6. Synopsis of FEIS-documented impacts to aquatic biological resources below Gross Reservoir (Source: FEIS Total Environmental Effects – Chapter 4; FEIS Moffat Project Effects – Chapter 5)

Total Environmental Effects (Chapter 4)	Moffat Project Effects
Synthesis	
• Increases in winter flows would result in large increases in rainbow trout habitat availability. • Small decreases in spring runoff flows would decrease conditions that may be stressful to early life stages of this species. • Higher winter flows would likely alleviate winter low flow habitat limitations. • Cooler temperatures throughout the year would limit trout growth and survival and likely dampen the beneficial effects of greater habitat availability. • Higher winter flows and reduced peak flows would also provide more uniform flow conditions for benthic invertebrates. • With less dramatic drying of the stream in winter months, Segment 3 of South Boulder Creek may support a higher density of macroinvertebrates or a more species-rich community including more rheophilic species. • Community metrics such as diversity and the number of Ephemeroptera, Plecoptera, and Trichoptera (EPT) species may increase. • Increases in habitat availability for rainbow trout and macroinvertebrates indicate that the Proposed Action with RFFAs would have minor beneficial cumulative impacts on aquatic resources in Segment 3 of South Boulder Creek.	• Increases in winter flows would result in large increases in rainbow trout habitat availability. • Small decreases in spring runoff flows would decrease conditions that may be stressful to early life stages of this species. • Higher winter flows would likely alleviate winter low flow habitat limitations. • Cooler temperatures throughout the year would limit trout growth and survival and likely dampen the beneficial effects of greater habitat availability • Higher winter flows and reduced peak flows would also provide more uniform flow conditions for benthic invertebrates. • With less dramatic drying of the stream in winter months, Segment 3 of South Boulder Creek may support a higher density of macroinvertebrates or a more species-rich community including more rheophilic species. • Community metrics such as diversity and the number of EPT species may increase. • Increases in habitat availability for rainbow trout and macroinvertebrates indicate that the Proposed Action would have minor beneficial cumulative impacts on aquatic resources in Segment 3 of South Boulder Creek.

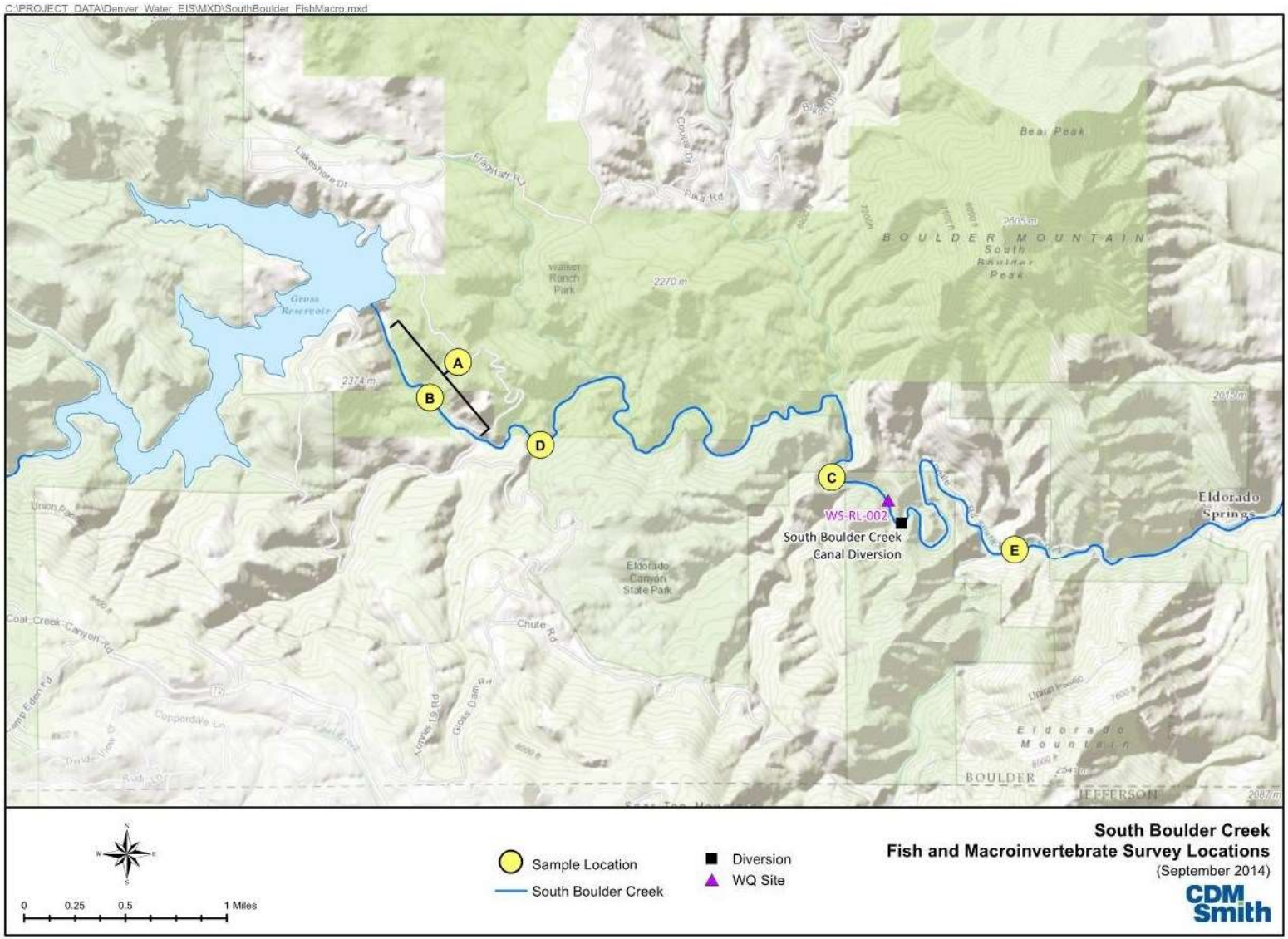

Figure B1-10. Location of fish and macroinvertebrate survey sites identified in text. Fish survey locations identified in Table B1-8: A – Below Gross Reservoir sites (1976); B – Station 3 (1983); C – IFG Site (1985); D – ¼ mile Below Gross Reservoir Bridge (1996). Site E represents the macroinvertebrate survey location (1984-1985) with data presented in Table B1-12.

Table B1-7. Fish population survey records from South Boulder Creek, Downstream of Gross Reservoir to the South Boulder Creek Canal Diversion (Source: Table B-25, GEI Consultants 2013)

Reach/Site	Collection Year	Species Observed	Density (#/hectare)	Percent Composition (% of Density)	Source
Below Gross Reservoir (Upper)	1976	Rainbow Trout	25	100	Two Forks EIS 1988; cited Colorado Department of Wildlife (CDOW) data
Below Gross Reservoir (Middle)		Rainbow Trout	37	94.9	
		Longnose Dace	2	5.1	
Below Gross Reservoir (Lower)		Rainbow Trout	48	100	
Station 3	1983	Cutbow (Rainbow/Cutthroat Trout Hybrid)	3,263	91.4	Chadwick Ecological Associates 1985
		Longnose Sucker	128	3.6	
		Longnose Dace	166	5.0	
IFG Site 3	1985	Rainbow Trout	2,113	99.0	Two Forks EIS 1988; cited CDOW data
		Longnose Sucker	20	1.0	
¼ mi. below Gross Reservoir Bridge	1996	Rainbow Trout	2,006	72.9	Miller Ecological Consultants 1997 (in Gross Reservoir Hydroelectric FERC Project Aquatic Resources Report)
		Brown Trout	526	18	
		Longnose Sucker	94	3.4	
		Longnose Dace	160	5.8	

Previous Fish Community Characterizations

Previous reports that document the findings from the fish surveys summarized in Table B1-7 have described the fish community in the following manner:

- GEI Consulting (2013)Aquatic Resources Technical Report[10]

  In the section of South Boulder Creek downstream of Gross Reservoir and upstream of the South Boulder Diversion Canal, resident rainbow trout comprise the bulk of the fishery (Appendix B: Table B-25)…Total fish density averages approximately 2,412 fish/ha. Biomass estimates are not available, except for the time period from 1983 to 1985, in which biomass averaged 127 kg/ha.

  Four density estimates are available for this segment of South Boulder Creek, and all of them exceed the small stream 50th percentile of Platts and McHenry. This suggests that the fish populations in this stream are healthy. There are insufficient data to determine whether temporal trends exist in the fish populations in this segment, but high densities and small changes between the 1980s and 1996 suggest that the observed fluctuations may be due to natural variation (Page 3-87).

- Gross Reservoir Hydroelectric FERC Project Aquatic Resources Report (Miller Ecological Consultants 1997):

  Predominant species in both locations [downstream of Gross Reservoir and downstream of Eldorado Springs] were rainbow trout and low numbers of brown trout…Additional species collected included longnose sucker, white sucker [only below Eldorado Springs], and longnose dace…

  The trout biomass in the section between Gross Reservoir and the South Boulder Diversion is the highest of any section of South Boulder Creek in the study areas. It is over five times the level found in any of the other sections. This reach of the river has a total trout biomass of approximately 129 pounds per acre when compared to approximately 17 pounds per acre for the segment of stream from South Boulder Diversion down to the Community Ditch and diversions of Lafayette and Louisville and also 17 pounds per acre upstream of the reservoir…The average size of the fish are similar in all stream sections. There may be several reasons for the high biomass in this reach of stream. These include the reservoir release which would moderate temperatures during winter and summer. The fishing access in this area is extremely limited and therefore fishing pressure due to the high amount of private land may be limiting the harvest of fish in this reach of the river. Change in harvest in streams has been shown to result in increased populations when harvest is lowered in cold water streams. An additional factor in this reach may be the increased minimum flows that exist below Gross Reservoir due to the water delivery out of Gross Reservoir to the South Boulder Diversion. The range of flows in this reach shows a 95% flow of 22.6 cfs for the reach from Gross Reservoir downstream to South Boulder Diversion as compared to a

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[10] GEI Consultants, Inc. 2013. *Aquatic Resources Technical Report for the Moffat Collection System Project Final Environmental Impact Statement.* Prepared for the U.S. Army Corps of Engineers, Denver Regulatory Office. December 2013.

> *4.6 cfs minimum flow at the 95% exceedance level for the reach from the South Boulder Diversion to the Community Ditch. These factors, in conjunction with a difference in harvest are probably factors that influence fish populations in these segments* (Page 48).
>
> *The segment from Gross Reservoir downstream to the South Boulder Diversion already contains the highest fish biomass of any reach in the stream. The increase in habitat availability may increase fish population but that is dependent on other factors as well as water temperature and food sources. Fry habitat remains the limiting life stage in the proposed action. Currently the fish populations are at a very high level and do not seem to be limited from the operation of Gross Reservoir* (Page 54).
>
> *The stream segment downstream of Gross Reservoir does not have pool habitat but does contain deep glide habitat that serves as overwinter habitat. The current fish populations in this reach are at relatively high levels and construction of habitat features (e.g., pools) would not result in a significant increase in the fish populations. The higher base flows and warmer winter temperatures from reservoir releases most likely would contribute to the higher fish populations in this reach than the creation of additional pool habitat* (Page 58).

Based on these data reviews, previous evaluations of available fish community data demonstrate that a healthy, viable fish community thrives in South Boulder Creek below Gross Reservoir. Simulated findings from the Gross Reservoir Temperature Modeling Study (Hydros Consulting 2013) suggest that with reservoir enlargement, water temperatures below the reservoir will be colder, in particular during the period from August through October. The FEIS uses this finding to state that colder water temperatures under future conditions may impact trout growth during this period (see Table B1-6); however, the FEIS also states that when the expected colder temperatures are evaluated in the context of expected increased flow and habitat availability and a potentially enhanced macroinvertebrate community (all benefits of the Proposed Action), the net expected outcome is that the Proposed Action will have a minor beneficial cumulative impact on aquatic resources (both project-specific and cumulative effects) (see Synthesis portion of Table B1-6).

The FEIS conclusion is that the fish community will benefit from the project. However, this conclusion did not consider the narrative temperature standard to ensure that the aquatic life use is still protected. To determine if the projected outcomes from the project could cause significant degradation in regards to the narrative temperature standard, it is important to evaluate potential project impacts within the context of fish temperature requirements. The next section evaluates this issue.

Fish Temperature Requirements

The Division has stated the following with regards to its interpretation of its narrative temperature standard, seasonal temperature fluctuations and protection of aquatic life[11]:

> *"Concern about the seasonal pattern of temperature variation is based on an interest in protecting all reproductive functions. 'The consideration of reproductive season is to ensure that the thermal requirements for successful migration, spawning, egg incubation, fry rearing and other reproductive functions are met. These particular life stages and behaviors warrant more protective criteria than those required for the young*

[11] Division technical memorandum, *South Boulder Creek and the Narrative Temperature Standard*, dated 11/13/14.

adult and adult life stages; however, there are many site-specific considerations.' The organisms expected to occur in Colorado's cold water streams are adapted to a seasonal pattern in which the coldest temperatures occur in winter (typically January) and the warmest temperatures occur in summer (typically late July or August).'

The Commission added winter criteria as a mechanism for preserving "thermal cues necessary for protection of aquatic life cycles". Although not stated explicitly, it is clear that the Commission assumed summer temperatures would be warm. Otherwise, there would be no need to preserve a normal seasonal pattern.

The Division follows the Commission's guidance regarding the protection of all reproductive functions. It is a basic tenet of physiology that the energy assimilated by adult fish will be distributed between growth and reproduction. These functions are best supported when growth conditions are optimal."

Given these concerns regarding protecting reproductive functions, this section provides information on rainbow trout temperature requirements and compares these requirements to present and future conditions using both modeled and observed temperatures. This comparison provides the basis for evaluating the potential significance of impacts from the Proposed Action.

As noted above, the dominant fish species in the South Boulder Creek reach below Gross Reservoir is rainbow trout. Accordingly, this fish species will provide the primary basis for the evaluation of fish temperature requirements[12] and protection of the aquatic life beneficial use. Supplemental information on other species observed in the reach will be provided, where available.

Rainbow trout temperature requirements are documented in a number of literature sources – both peer-reviewed publications and in federal fishery management documents developed by the U.S. Fish and Wildlife Service (USFWS). The former provides the findings from specific fish species studies, while the latter synthesizes this information to create estimates of the range of optimal and acceptable temperature requirements for different life stages of rainbow trout. Emphasis of this section will be on USFWS fishery management documents, but information from selected literature resources will be summarized as well. Temperature requirements defined by these information sources will be used to evaluate the potential impacts of the Proposed Action on rainbow trout in South Boulder Creek below Gross Reservoir.

Peer-reviewed studies tend to focus on the critical thermal maxima for a fish species as a common environmental concern is elevated water temperature and its impact on the fish community (hence, the establishment of maximum rather than minimum temperatures in state water quality standards). The peer-reviewed literature is limited with regards to studies on critical thermal minima temperatures. Following is a summary of key findings from review studies that are relevant to understanding temperature requirements for rainbow trout:

- *Rainbow Trout (McAfee 1966)*[13] – McAfee (1966) provides an overall description of the life history attributes of rainbow trout with emphasis on California waters. McAfee notes that rainbow trout are an adaptive fish species and tolerate water temperatures from about 32°F to

[12] This is consistent with the FEIS and FERC studies which relied on potential impacts to rainbow trout as the primary basis for evaluating impacts to the fish community.

[13] McAfee, W.B. 1966. *Rainbow Trout*. Pages 192-215 in A. Calhoun ed. Inland Fisheries Management. California Department of Fish and Game. 546 pp.

over 80°F (0°C to over 26.7°C). Wild rainbow trout usually spawn from February to June depending on factors such as water temperature, fish strain, and locality. However, McAfee notes studies that have shown that spawning may not occur until July or August in cold water at higher elevations. The egg incubation period varies with water temperature averaging 80 days at 40°F (4.4°C) and 19 days at 60°F (15.6°C) and tends to be more variable and less predictable at low temperatures. The rate of growth of rainbow trout varies by season and fish age. Factors influencing growth rate include water temperature, strain of rainbow trout, feeding conditions, age at maturity, and other undefined factors.

- *Temperatures Selected and Avoided by Fishes at Various Acclimation Temperatures (Cherry et al. 1975)*[14] – Cherry et al. (1975) evaluated the preferred temperatures (with 95 percent confidence) of a number of fish species including rainbow trout as a function of acclimation temperature. For all fish species tested, including rainbow trout, as the acclimation temperature decreased, the avoidance temperature declined as well with the minimum avoidance temperature occurring at the lowest acclimation temperature. For the study, the relationship between the acclimation temperature and the temperature selected (or preferred) along with the 95 percent confidence levels is shown in **Figure B1-11** (created from data in Table 1 in Cherry et al. 1975). A trendline was added using Excel. While acclimation temperatures below 6°C were not included in this study, the linear nature of the trendline associated with the preferred temperature data suggests that the preferred temperature could be even lower if rainbow trout were acclimated to a temperature less than 6°C.

- *Critical Thermal Minima and Maxima of Three Freshwater Game-Fish Species Acclimated to Constant Temperatures (Currie et al. 1998)*[15] – Currie et al. (1998) determined critical thermal (CT) minima for a number of species including rainbow trout. These minima were determined for fish acclimated to three constant temperatures: 10, 15, and 20°C. For rainbow trout the lowest mean thermal minimum was measured at approximately 0.0°C. Study findings also suggested that acclimation temperature has a greater influence on tolerance to low temperatures rather than high temperatures. These findings were compared to work by Becker et al. (1977)[16]:

  The most complete picture of rainbow trout low temperature tolerance is provided by Becker et al. (1977) who measured CT minima reported as LOE_{50} (the temperature at which 50% of the sample lost equilibrium[17]) at five different rates of temperature decrease for rainbow trout acclimated to 10, 15 and 20 °C. Becker et al. (1977) estimated CT minima of < 0.0, 0.7 and 2.0°C for rainbow trout acclimated at 10, 15 and 20°C and exposed to a 0.3°C min^{-1} rate of temperature change. These values are nearly identical to ours (< 0.0, 0.7 and 2.0°C). At slower rates of temperature decrease (0.167, 0.083, 0.05, and 0.0167 C min^{-1}) rainbow trout had lower CT minima, suggesting that

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[14] Cherry, D.S., K.L. Dickson, and J. Cairns Jr. 1975. *Temperatures Selected and Avoided by Fish at Various Acclimation Temperatures*. J. Fish. Res. Board Can. 32: 485-491.

[15] Currie, R.J., Bennett, W.A. and Beitinger, T.L. 1998. *Critical Thermal Minima and Maxima of Three Freshwater Game-Fish Species Acclimated to Constant Temperatures*. Environ. Biol. Fish. 51: 198-200.

[16] Becker, C.D., R.G. Genoway, and M.J. Schneider. 1977. *Comparative Cold Resistance of Three Columbia River Organisms*. Trans. of American Fisheries Society 106:178-184.

[17] Loss of equilibrium is a standard endpoint measured during critical thermal maxima or minima trials; LOE is defined as failure of a fish to maintain dorso-ventral orientation for at least one minute (Currie et al. 1998).

fish may have gained low temperature tolerance acclimation during the trials. We found no published reports of ILLT [incipient lower lethal temperature] for rainbow trout (page 197).

- *Environmental Requirements and Tolerances of Rainbow Trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*) with Special Reference to Western Australia: A Review (Molony 2001)*[18] - Molony (2001) summarizes the literature regarding environmental preferences for trout species to provide information to support aquaculture efforts in Australia. Molony notes that rainbow trout can survive in waters between temperature of about 0.0°C and 29.8°C, "depending on the temperature history and strain of the fish being tested…and the rate of temperature change…However, within this temperature range for survival, or for any other variable, [rainbow trout] have a preferred range in which growth, reproduction and/or other physiological characteristics are optimized." Molony (2001) also notes that many of the references reviewed for the purpose of the article are based on "relatively short-term experiments….and therefore long-term effects, such as reduced growth rate or reproductive success, have not been adequately assessed or quantified".

  Of particular interest in this publication is the presentation of data that summarizes the effect of temperature on the growth of rainbow trout fry in freshwater (based on a "generalized salmonid fish"). **Figure B1-12** reproduces figures in Molony (2001) that illustrate this relationship. The upper figure shows that the optimal growth rate occurs between water temperatures of about 10°C and 20°C. The lower figure shows overall weight gain for fish reared in a laboratory at different temperatures. For example, at a water temperature of 10°C, the overall weight gain for trout at 100 days was about 7 or 8 grams, while at 5°C the weight gain was considerably less at 2 to 3 grams.

As noted above, two USFWS fishery management documents, which contain rainbow trout temperature preference data, were reviewed. These documents synthesize species-specific requirements for a number of habitat factors, including temperature, as known at the time of their development. Following is a summary of the findings from each of the USFWS documents.

- *Probability of Use Criteria for the Family Salmonidae (Bovee 1978)*[19] - Bovee (1978) developed habitat "probability of use" criteria for several parameters (temperature, substrate, velocity, and depth) for salmonid species including rainbow trout. Temperature curves were developed for spawning, fry, juvenile, and adult trout life stages. In addition, curves were established for egg incubation as a function of sediment concentration (clear vs. turbid) and channel slope. However, because of the lack of a relationship between temperature and these parameters, the temperature curve for egg incubation is the same regardless of slope or sediment conditions. **Figure B1-13 (A through E)** shows the temperature curves for rainbow trout contained in Bovee (1978). The estimated temperature range and optimal temperatures for each life stage is as follows (Note: Original document provided temperatures in Fahrenheit; these were read directly off the figure as accurately as possible and converted to Celsius for this analysis):

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[18] Molony, B. 2001. *Environmental Requirements and Tolerances of Rainbow Trout (*Oncorhynchus mykiss*) and Brown Trout (*Salmo trutta*) with Special Reference to Western Australia*. Fisheries Research Report No. 130, Department of Fisheries, Government of Western Australia.

[19] Bovee, K.D. 1978. *Probability of Use Criteria for the Family Salmonidae*. Instream Flow Information Paper No. 4. U.S. Fish & Wildlife Service, Department of Interior, FWS/OBS-78/07. January 1978.

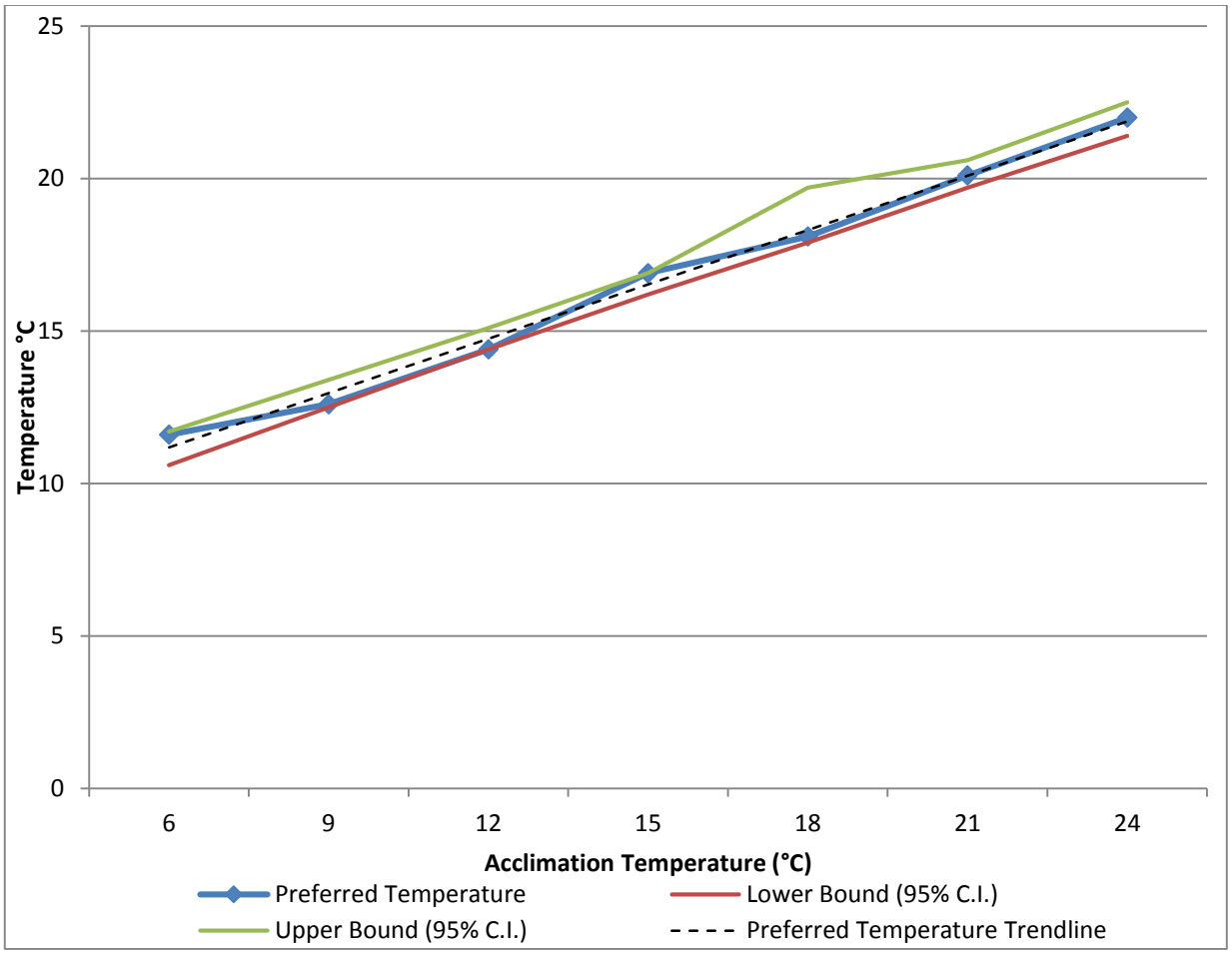


Figure B1-11. Preferred temperature for rainbow trout at different acclimation temperatures based on Table 1 in Cherry et al. 1975. Lower and upper bound lines represent 95% confidence levels. Dotted line shows preferred temperature trendline (added for purposes of this analysis; not included in Cherry et al. 1975).

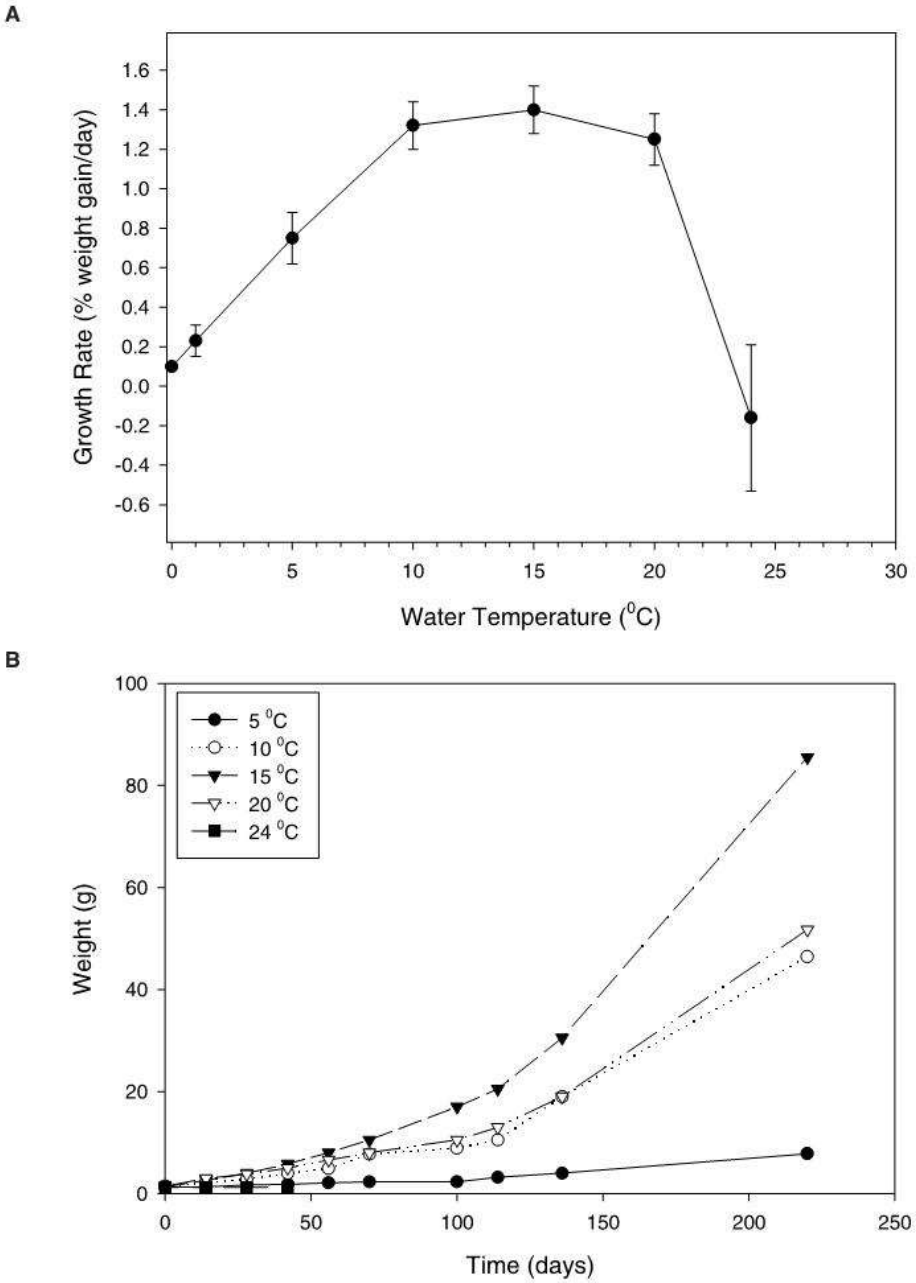
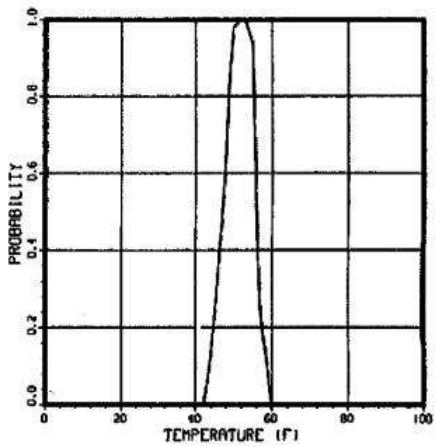


Figure 2. The effect of temperature on the growth of fingerlings of a generalised salmonid fish, *(Oncorhynchus nerka)* in freshwater (figures from Brett et al. 1969).

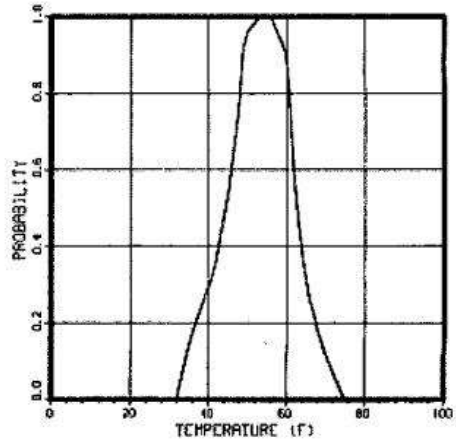
A). Growth rate as percent increase per day as a function of temperature.

B). Overall weight gain of fish reared at a range of temperatures. Figures redrawn from data presented in Brett *et al.* (1969). Note that these figures are based on Northern Hemisphere fishes where water temperature rarely exceeds 20 °C. It is expected that the WA strain of fish will display a similar pattern of growth but the optimum growth rate will be achieved between 20 - 24 °C.

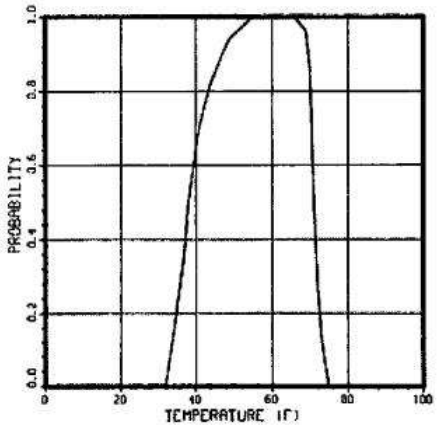
Figure B1-12. Figures 2A and 2B, reproduced from Molony (2001). Figures illustrate relationship between water temperature and growth for a "generalized salmonid fish".



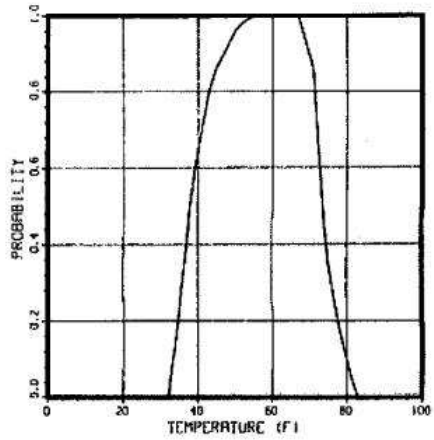
A. Spawning



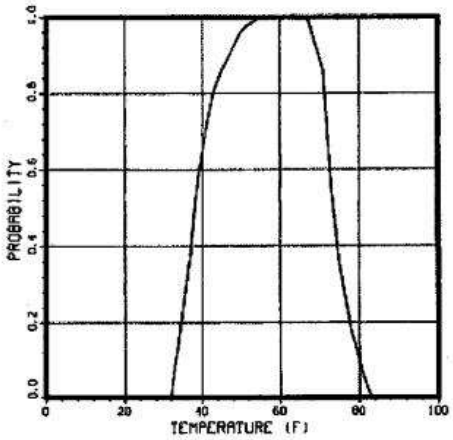
B. Egg



C. Fry



D. Juvenile



E. Adult

Figure B1-13 A through E. Probability of use curves for rainbow trout life stages (Source: Bovee 1978)

- *Spawning* – Spawning activity occurs over a temperature range of approximately 5.6°C (42.1°F) to 15.6°C (60.1°F) with an optimal temperature of about 11.1°C (52°F) (Figure B1-13.A).
- *Incubation* – Egg incubation occurs over a temperature range of approximately 0°C(32°F) to 23.9°C (75°F) with an optimal temperature in a narrow range between 11.1°C (52°F) and 13.3°C (55.9°F) (Figure B1-13.B).
- *Fry* - – The temperature range for this life stage is approximately 0°C (32°F) to 23.9°C (75°F) with an optimal temperature range between 11.1°C (52°F) and 19.4°C (66.9° F) (Figure B1-13.C).
- *Juvenile and Adult* – The temperature range for these life stages is approximately 0°C (32°F) to 28.3°C (82.9°F) with an optimal temperature range between 12.2°C (54°F) and 20°C (68°) (Figures B1-13.D and B1-13.E).

Notable in the spawning, fry, juvenile, and adult curves in Figure B1-13 (A through E) is the similarity between the total and optimal temperature ranges.

- *Habitat Suitability Information: Rainbow Trout (Raleigh et al. 1984)*[20] – The USFWS has created Habitat Suitability Indices (HSI) for a number of species, including rainbow trout. These models were developed based on extensive literature reviews and establish hypotheses regarding species-habitat relationships. These models represent general expectations for a species but could vary based on geographical areas and the data available. The USFWS states that HSI models may be used to evaluate specific impact assessment problems, but should be tested with independent datasets if possible.

  The suitability index graphs quantify information of the effect of the variable of interest on growth, survival, or biomass. Development of the curves assumes that, "*…increments of growth, survival, or biomass plotted on the y-axis of the graph could be directly converted into an index of suitability for 0.0 to 1.0 for the species, with 0.0 indicating unsuitable conditions and 1.0 indicating optimal conditions. Graph trend lines represent the author's best estimate of suitability for the various levels of each variable….The user is encouraged to modify the shape of the graphs when existing regional information indicates that the variable suitability relationship is different from what is illustrated*" (Raleigh et al. 1984, page 13).

  With regards to lower index values, Raleigh et al. (1984) states: *"The model utilizes a modified limiting factor procedure. This procedure assumes that model variables and components with suitability indices in the average to good range, > 0.4 but < 1.0, can be compensated for by higher suitability indices of other related model variables and components. However, variables and components with suitabilities ≤ 0.4 cannot be compensated for and, thus, become limiting factors for the habitat suitability*" (Raleigh et al. 1984, page 11).

  Given the quotes above regarding the interpretation of HSI values, for the purposes of this analysis, the temperature range captured by a 1.0 index value will be used to represent the range of conditions that are considered optimal, as described by Raleigh et al. (1984). Similarly,

[20] Raleigh, R.F., T. Hickman, R.C. Solomon, and P.C. Nelson. 1984. *Habitat Suitability Information: Rainbow Trout*. U.S. Fish & Wildlife Service FWS/OBS-82/10.60. 64 pp.

the temperature range captured by a 0.4 index value will be used to represent the minimum range of temperatures considered acceptable. As noted above, index values > 0.4 but less than 1.0 can be compensated for by other habitat factors.

The HSI for rainbow trout includes 18 habitat factors, ranging from flow and sediment conditions to habitat and water quality. The HSI model includes two factors specific to temperature:

- *Variable V_1* – Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry). **Figure B1-14** provides the curve for resident rainbow trout (V_1, Line A). The range of acceptable temperatures is large, from 3.5°C to 23°C with the optimum average maximum water temperature between approximately 11°C and 18°C.
- *Variable V_2* – Average maximum water temperature (°C) during embryo development. **Figure B1-15** provides an estimate for rainbow trout embryos (V_2, Line B). The range of acceptable temperatures is significant from 3.5°C to 14°C. Optimum average maximum water temperature during the embryo stage is between approximately 7°C and 11°C.

Raleigh et al. (1984) also includes suitability index curves to support Instream Flow Incremental Methodology (IFIM) analyses to evaluate instream flow concerns. Five habitat variables are utilized (velocity, depth, substrate, temperature, and cover) for each fish life stage (spawning, egg incubation, fry, juvenile, and adult). For rainbow trout, the USFWS recommends the use of **Figure B1-16 (A through D)** as suitability index curves for evaluation of temperature impacts on spawning, egg incubation, fry, juvenile, and adult life stages, respectively. While these curve recommendations are to support instream flow analyses they can provide additional insight on temperature requirements for different rainbow trout life stages.

Table B1-8 summarizes the minimum acceptable temperature range (based on a minimum HSI of 0.4) and optimum water temperature range (based on an HSI of 1.0) for various life stages – as reported in Raleigh et al. (1984) and Bovee (1978). **Table B1-9** compares optimal temperatures for each rainbow trout life stage (based on Raleigh et. al. (1984)[21]) with observed water temperatures and simulated water temperatures in South Boulder Creek below Gross Reservoir following project implementation. The orange shading indicates approximately when various life stages should be present in Colorado waters. The timing of life stages is based on the Colorado Temperature Policy 06-1 rather than general literature data, e.g., as shown in Table B1-8.

Clearly, present temperature conditions – whether modeled or observed – are already typically colder than the "optimal" temperatures reported in the literature for rainbow trout life stages, especially egg incubation and fry life stages. Given this finding, when one considers the importance of the relationship between temperature acclimation and preferred temperature (as described above) and the earlier descriptions of rainbow trout biomass in South Boulder Creek below Gross Reservoir (see "Previous Fish Community Characterizations" in Section 1.1.3.1), it appears that the rainbow trout in South Boulder Creek have adapted well to the existing cold water conditions below Gross Reservoir. Given the expected acclimation that has occurred under present conditions, the rainbow trout reside

[21] Raleigh et al. (1984) was used as the basis for Tables B1-10 and B1-11 because it was the more recent publication of rainbow trout preferences. Relevant work by Bovee is cited in Raleigh et al. (1984).

in waters within the acceptable temperature range for each life stage (**Table B1-10**). This finding would change little even if water temperatures become cooler under the Proposed Action.

With regards to the use of "optimal" temperatures to evaluate rainbow trout requirements, "optimal" conditions rarely, if ever, exist in a given waterbody, even under fully natural, undisturbed conditions. The HSI recognizes this reality by noting that HSI scores between 0.4 and 1.0 represent the acceptable range, meaning that any impact from a habitat factor that falls outside this range can be compensated for by other habitat factors. Given that there are 18 factors included in the HSI model for rainbow trout, temperatures that are not "optimal" may have no impact on the fish community.

Habitat	Variable		Suitability Graph
R,L	V_1	Average maximum water temperature (°C) during the warmest period of the year (adult, juvenile, and fry), and during upstream migrations of adult steelhead. For lacustrine habitats, use the temperature strata nearest to optimal in dissolved oxygen zones > 3 mg/l. A = resident rainbow trout B = migrating adult steelhead	

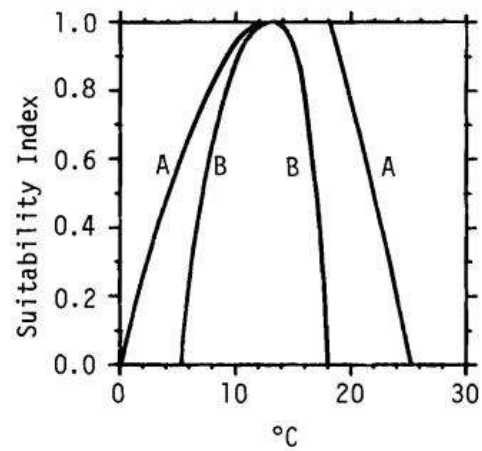


Figure B1-14. Habitat suitability graph for resident rainbow trout for average maximum water temperature during the warmest period of the year (Curve A) – fry, juvenile and adult stages (see text; from Raleigh et al. 1984).

R	V_2	Average maximum water temperature (°C) during embryo development (all rainbows) and during the March to June smoltification period (steelhead juveniles). A = steelhead smolts B = embryos

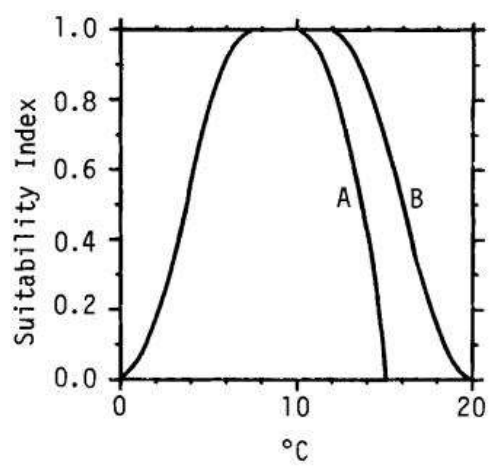


Figure B1-15. Habitat suitability graph for rainbow trout (B Curve) for average maximum water temperature during embryo development (see text; from Raleigh et al. 1984).

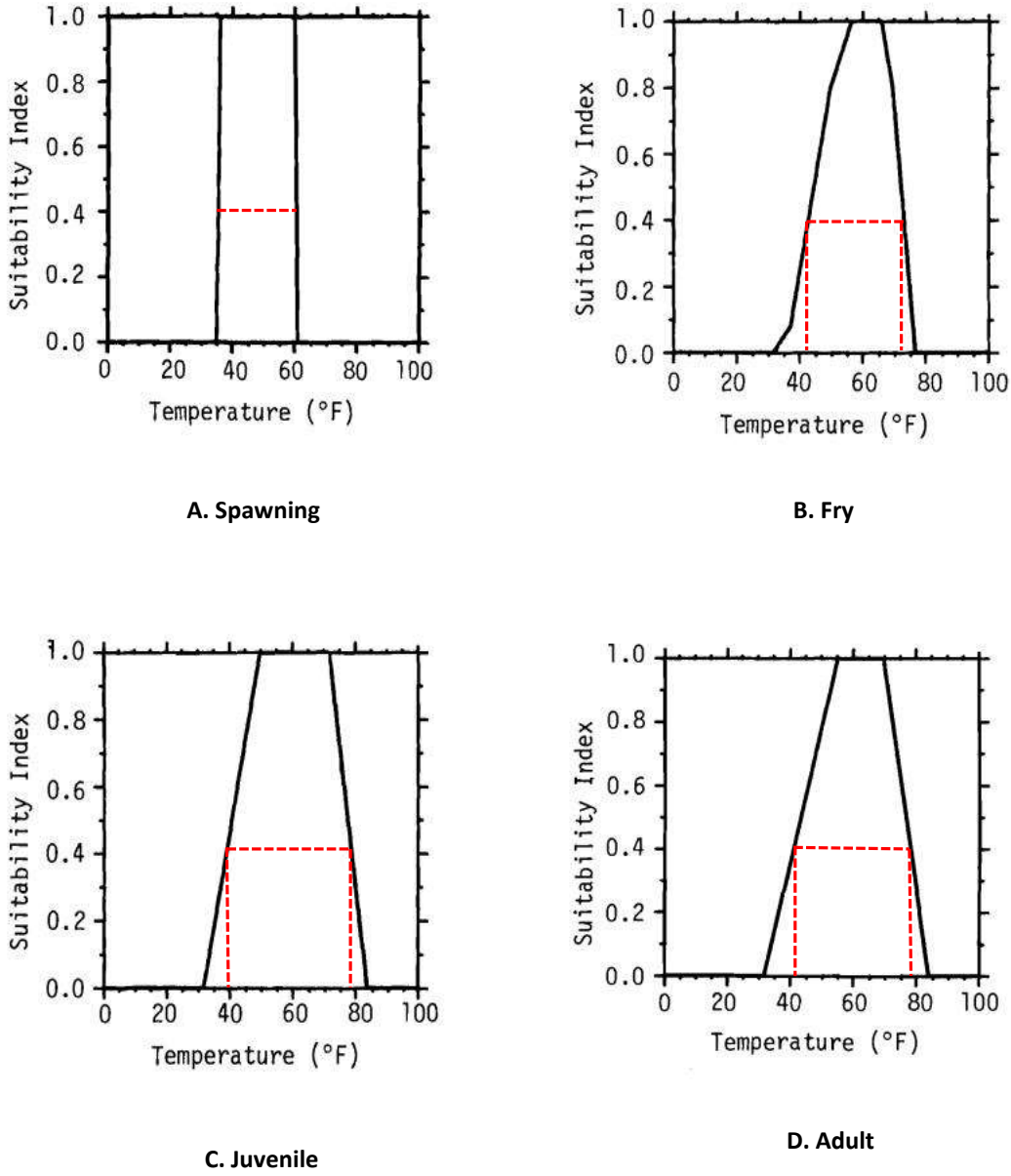


Figure B1-16 (A through E). Suitability index curves for IFIM analyses for rainbow trout. For the egg incubation life stage, the V_{2B} curve should be used (see Figure B1-15) (from Raleigh ~~et al. 1~~984) (red dashed line indicates the estimated temperatures associated with a 0.4 HSI value.

Table B1-8. Temperature requirements for rainbow trout life stages – primarily from Raleigh et al. (1984) and Bovee (1978); see text.

Life Stage	Timing	Acceptable Temperature Range	Optimum Temperature
Spawning	January to June; Peak: March to April	• See Figure B1-16.A (Figure 2 in Raleigh et al. 1984). Per this figure the estimated range is about 1.7°C to 16.1°C. • Estimated range of 5.6°C to 15.6°C (Bovee 1978).	• Optimal range is about 1.7°C to 16.1°C (Raleigh et al. 1984). • Optimal temperature range is estimated at 10.0°C to 11.1°C (Bovee 1978).
Egg Incubation	Typically occurs during spring, could last into early summer	• Range of 3.8°C to 16.5°C (Raleigh et al. 1984). • Estimated range of 0.0°C to 23.9°C (Bovee 1978).	• Optimal range is 7°C to 12°C (Raleigh et al. 1984). • Optimal temperature range is estimated at 11.1°C to 13.3°C (Bovee 1978).
Fry	Summer, life stage lasts about 4 months	• See Figure B1-16.B (Figure 3 in Raleigh et al. 1984) for fry up to 1.8 inches and length and up to four months after hatching. Per this figure the estimated range is about 6.7°C to 22.8 °C. • Estimated range of 0.0°C to 23.9°C (Bovee 1978).	• Optimum from about 14.4°C to 16.3°C (Raleigh et al. 1984). • Optimal temperature range is estimated at 11.1°C to 19.4°C (Bovee 1978). • Mantelman (1958) reported preferred range of 13°C to 19°C.
Juvenile	Year round	• Variable (see summary in Raleigh et al. 1984); likely a function of acclimation temperature. Figure B1-16.C (Figure 4 in Raleigh et. al. 1984) provides a suitability index curve for temperature; estimated range is about 4.4°C to 26.7°C. • Estimated range of 0.0°C to 28.3°C (Bovee 1978).	• Optimum from about 8.9°C to 21.1°C (Raleigh et al. 1984). • Optimal temperature range is estimated at 12.2°C to 20.0°C (Bovee 1978).
Adult	Year round	• Variable (see summary in Raleigh et al. 1984); likely a function of acclimation temperature. Figure B1-16.D (Figure 4 in Raleigh et. al. 1984) provides a suitability index curve for temperature; estimated range is about 5.6°C to 25.6°C. • Estimated range of 0.0°C to 28.3°C (Bovee 1978).	• Optimum from about 12.8°C to 20.6°C (Raleigh et al. 1984). • Optimal temperature range is estimated at 12.2°C to 20.0°C (Bovee 1978).

Table B1-9. Comparison of rainbow trout life stage estimated optimum water temperatures (°C) (Based on an HSI value of 1.0; Raleigh et al. 1984; see text and Figure B1-16) with existing South Boulder Creek below Gross Reservoir water temperatures and simulated water temperatures following implementation of the Proposed Action (Alt 1a). Expected timing of early life stages is based on Colorado Temperature Policy 06-1 (see text).

Month	Simulated Average 1a Temperature				Actual Temperature Observations				Rainbow Trout Life Stage - Optimal Temperature (Raleigh et al. 1984)				
	2009 (1971-1972)		2012 (1971-1972)		Gross Reservoir Outlet (2009-2014)		South Boulder Creek Canal Diversion (2005-2014)						
	Range	Average	Range	Average	Range	Average	Range	Average	Spawning	Incubation	Fry	Juvenile	Adult
January	0.5-3.5	2.3	1.7-4.0	3.2	2.0-3.0	2.6	0-7	2				8.9 – 21.1	12.8-20.6
February	0.0-1.8	0.9	0.7-3.3	1.9	1.7-3.1	2.3	0-7	3					
March	0.3-2.2	1.4	0.6-2.6	1.4	2.3-3.2	2.7	2-6	4	1.7 – 16.1				
April	1.4-2.7	2.0	1.9-4.2	3.3	2.8-4.2	3.5	1-9	6					
May	2.7-5.3	4.0	4.1-5.9	4.7	3.3-5.0	4.4	4-14	8					
June	4.9-6.9	6.0	5.5-7.7	6.7	4.6-6.4	5.7	8-12	9					
July	6.7-7.8	7.3	6.8-8.0	7.3	5.4-7.5	6.5	8-13	10		7.0 – 12.0			
August	7.3-8.3	7.7	6.8-8.2	7.5	5.9-8.8	7.7	10-15	12			14.4 - 16.3		
September	7.5-8.6	8.0	6.9-8.3	7.6	6.6-10.6	8.8	10-15	12					
October	6.9-9.4	8.4	6.9-8.8	7.7	7.6-10.9	9.5	8-12	10					
November	5.3-7.2	6.5	6.2-8.9	7.5	6.0-9.0	7.8	0-8	4					
December	3.3-5.4	4.0	3.9-6.5	5.1	3.0-5.0	4.1	0-4	2					
Average		**4.9**		**5.3**	**4.3-6.4**	**5.5**	**4.3-10.2**	**7.0**					

Table B1-10. Comparison of rainbow trout life stage estimated minimum acceptable water temperature (°C) (Based on an HSI value of 0.4; Raleigh et al. 1984; see text and Figure B1-16) with existing South Boulder Creek below Gross Reservoir water temperatures and simulated water temperatures following implementation of the Proposed Action (Alt 1a). Expected timing of early life stages is based on Colorado Temperature Policy 06-1 (see text).

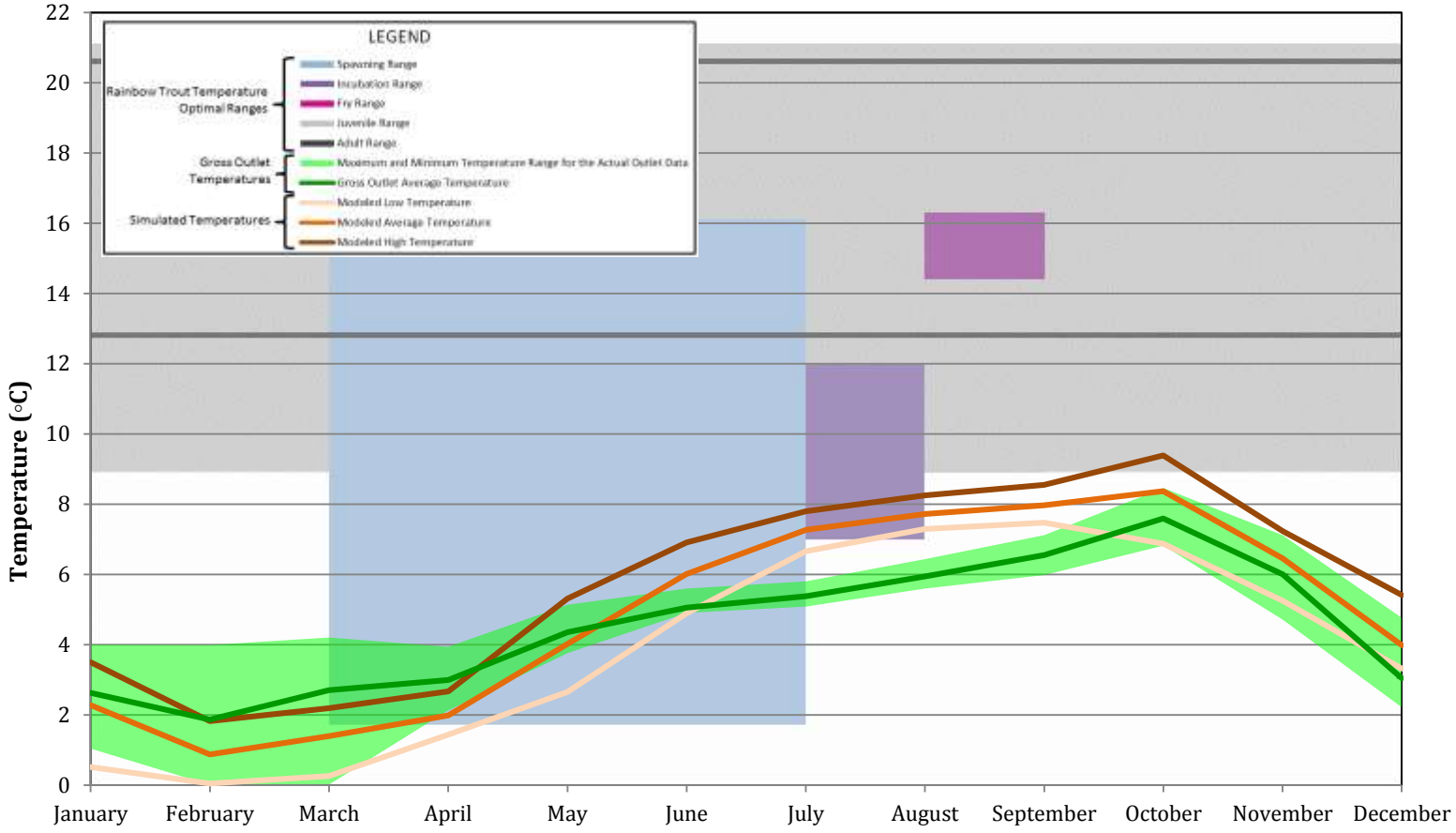
Month	Simulated Average 1a Temperature				Actual Temperature Observations				Rainbow Trout Life Stage - Acceptable Temperature Range (Raleigh et al. 1984)				
	2009 (1971-1972)		2012 (1971-1972)		Gross Reservoir Outlet (2009-2014)		South Boulder Creek Canal Diversion (2005-2014)						
	Range	Average	Range	Average	Range	Average	Range	Average	Spawning	Incubation	Fry	Juvenile	Adult
January	0.5-3.5	2.3	1.7-4.0	3.2	2.0-3.0	2.6	0-7	2				4.4 – 26.7	5.6 – 25.6
February	0.0-1.8	0.9	0.7-3.3	1.9	1.7-3.1	2.3	0-7	3					
March	0.3-2.2	1.4	0.6-2.6	1.4	2.3-3.2	2.7	2-6	4	1.7 – 16.1				
April	1.4-2.7	2.0	1.9-4.2	3.3	2.8-4.2	3.5	1-9	6					
May	2.7-5.3	4.0	4.1-5.9	4.7	3.3-5.0	4.4	4-14	8					
June	4.9-6.9	6.0	5.5-7.7	6.7	4.6-6.4	5.7	8-12	9					
July	6.7-7.8	7.3	6.8-8.0	7.3	5.4-7.5	6.5	8-13	10		3.8 – 16.5			
August	7.3-8.3	7.7	6.8-8.2	7.5	5.9-8.8	7.7	10-15	12			6.7 – 22.8		
September	7.5-8.6	8.0	6.9-8.3	7.6	6.6-10.6	8.8	10-15	12					
October	6.9-9.4	8.4	6.9-8.8	7.7	7.6-10.9	9.5	8-12	10					
November	5.3-7.2	6.5	6.2-8.9	7.5	6.0-9.0	7.8	0-8	4					
December	3.3-5.4	4.0	3.9-6.5	5.1	3.0-5.0	4.1	0-4	2					
Average		**4.9**		**5.3**	**4.3-6.4**	**5.5**	**4.3-10.2**	**7.0**					

Using the contrasting temperature ranges shown in Tables B1-10 and B1-11, an analysis was completed to determine how often under present conditions the waters below Gross Reservoir are within the acceptable or optimum ranges for temperature for each life stage and when these life stages are expected to occur given Colorado Temperature Policy 06-1. These findings were then compared to the predictions of future conditions based on the Gross Reservoir Temperature Model. **Figures B1-17 and B1-18** provide these findings for optimum and acceptable temperature ranges, respectively, using the 2009 modeled output (cooler year); **Figures B1-19 and B1-20** provide related findings for the 2012 modeled output (warmer year). Figures B1-17 and B1-19, compare optimum life stage temperatures to present and modeled future temperature conditions for 2009 and 2012, respectively, and indicate the following:

- Since South Boulder Creek is high in elevation and has cool temperatures, rainbow trout will spawn later in the year than lower elevation warmer waters. Per the Colorado Temperature Policy 06-1, spawning in South Boulder Creek is expected to occur from March through June. During this timeframe temperatures are within the optimal range under both present and future conditions.
- Optimum egg incubation temperatures are expected to be met under present conditions and mostly likely met under future conditions based on 2012 modeled conditions. For 2009 modeled conditions, optimal temperatures are not met under present conditions, but will likely be met under future conditions.
- Optimal temperatures for fry are not met under present or modeled future conditions.
- Optimal temperatures for juveniles can be met for short periods of time under present conditions, but only in 2012 when optimum temperatures for juveniles were observed generally from August to November. For 2009 modeled conditions, optimum temperatures are not met under present or future conditions.
- Optimum temperatures for adults are not met under either present or modeled future conditions for either the 2009 or 2012 meteorological conditions.

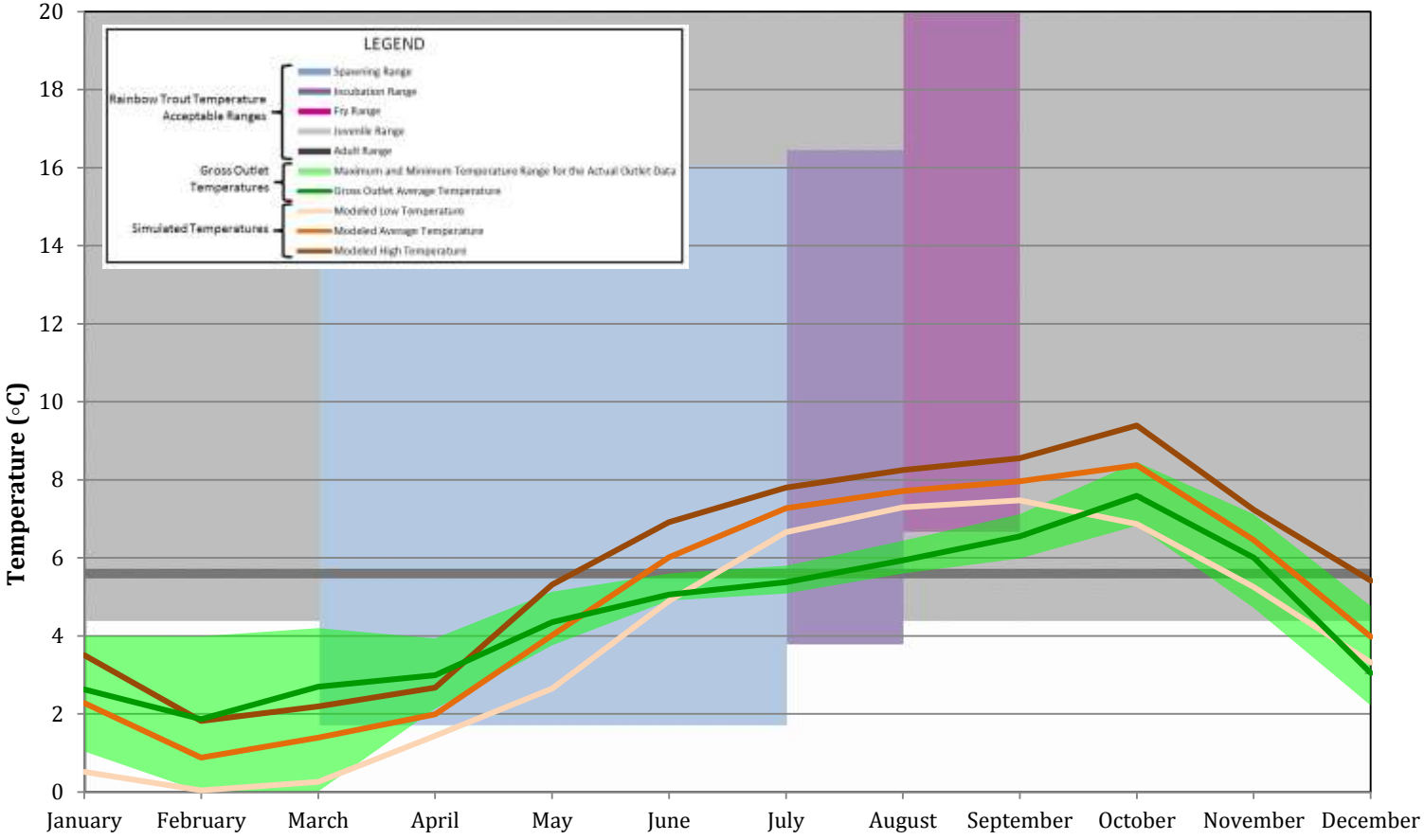
Figures B1-18 and B1-20, which compare minimum acceptable life stage temperatures to present and modeled future temperature conditions for 2009 and 2012, respectively, indicate the following:

- Temperatures for spawning and egg incubation life stages are for the most part within acceptable ranges under both present and modeled future conditions.
- For the 2009 modeled year, acceptable temperatures for fry are rarely met now, but will be met under future conditions; under 2012 modeled conditions, acceptable temperatures are met under both present and future conditions.
- Acceptable temperatures for juveniles are typically not met from January through April/May under present or future modeled conditions.
- Acceptable temperatures for adults are typically not met from November/December through May or June under 2009 present and future modeled conditions. This range narrows slightly to December/January through May/June under 2012 present and future modeled conditions.



*For January, February and March 2009, data were unavailable. Therefore, for January, February, and March, 2010-2013 monthly average data were used.

Figure B1-17. Averaged 1971 and 1972 modeled Gross Reservoir outlet temperatures (Proposed Action with RFFAs using 2009 weather conditions) compared to actual 2009 temperatures and rainbow trout optimal temperatures for each life stage (optimal temperature based on Raleigh et al. 1984, see Table B1-9 and Figure B1-16). Timing of early life stages based on Colorado Temperature Policy 06-1.



* The start of the adult range is defined by the dark grey line. Anything above this line displayed on the graph is within the acceptable range.
**For January, February and March 2009, data were unavailable. Therefore, for January, February, and March, 2010-2013 monthly average data were used.

Figure B1-18. Averaged 1971 and 1972 modeled Gross Reservoir outlet temperatures (Proposed Action w/ RFFAs using 2009 weather conditions) compared to actual 2009 temperatures and rainbow trout minimum acceptable temperature ranges for each life stage (see text for definition of minimum acceptable; based on Raleigh et al. 1984, see Table B1-10 and Figure B1-16). Timing of early life stages based on Colorado Temperature Policy 06-1.

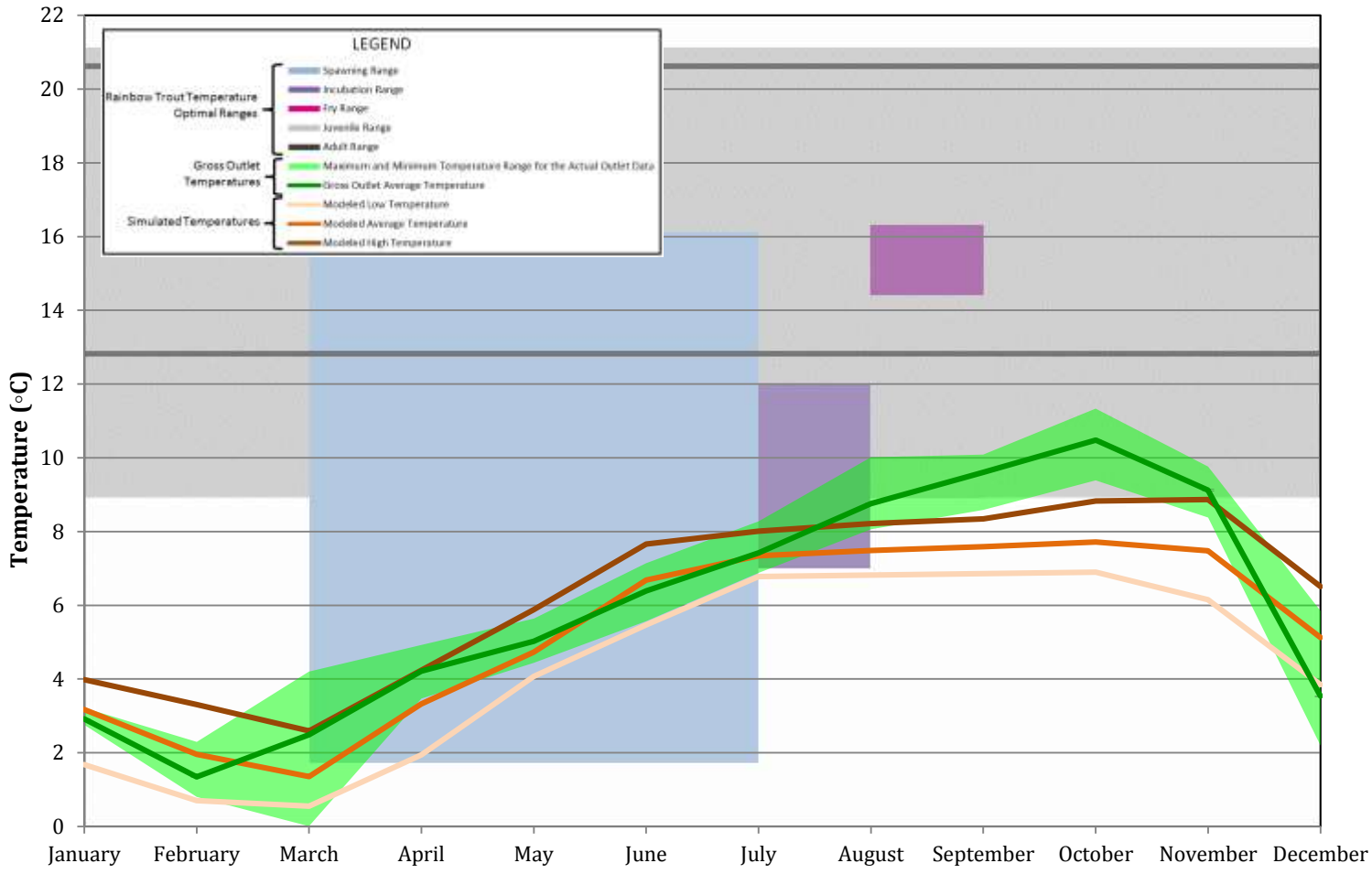
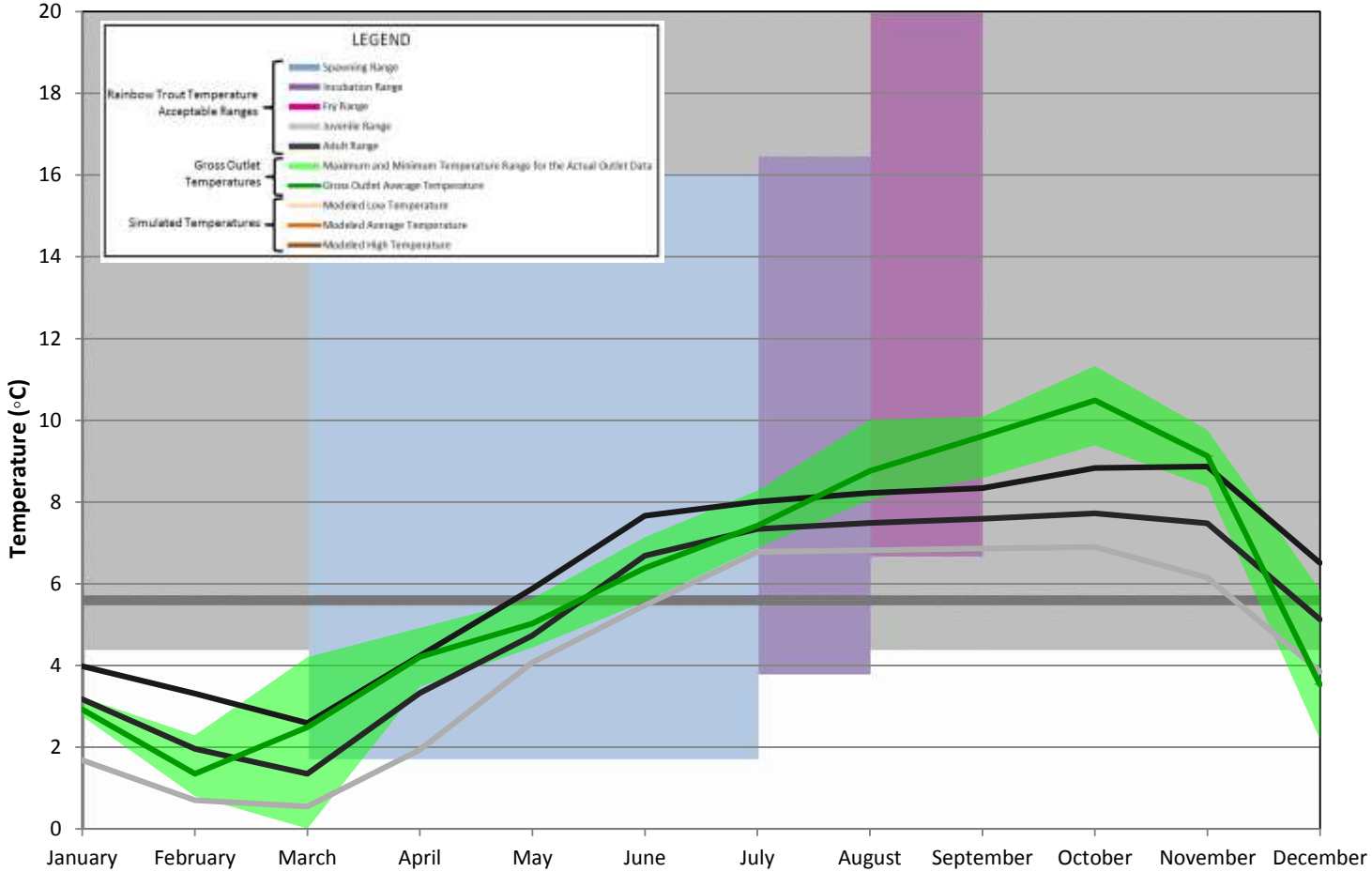


Figure B1-19. Averaged 1971 and 1972 modeled Gross Reservoir outlet temperatures (Proposed Action w/ RFFAs using 2012 weather conditions) compared to actual 2012 temperatures and Rainbow Trout optimal temperatures for each life stage (see text for definition of optimal; temperature based on Raleigh et al. 1984, see Table B1-9 and Figure B1-16). Timing of early life stages based on Colorado Temperature Policy 06-1.



* The start of the adult range is defined by the dark grey line. Anything above this line displayed on the graph is within the acceptable range.

Figure B1-20. Averaged 1971 and 1972 modeled Gross Reservoir outlet temperatures (Proposed Action w/ RFFAs using 2012 weather conditions) compared to actual 2012 temperatures and rainbow trout minimum acceptable temperature ranges for each life stage (see text for definition of minimum acceptable; based on Raleigh et al. 1984, see Table B1-10 and Figure B1-16). Timing of early life stages based on Colorado Temperature Policy 06-1.

Table B1-11a summarizes the number of days and percent of time water temperatures are optimum under existing and future modeled conditions. These findings illustrate that for spawning, optimum conditions are commonly experienced under present conditions and will still be experienced frequently under future conditions. For other life stages, including fry, juveniles, and adults, optimum temperatures are not experienced at all or only rarely under both present and future conditions.

Table B1-11b summarizes the number of days and percent of time water temperatures are within minimum acceptable temperature ranges under present conditions and future modeled conditions. These findings illustrate that for spawning and incubation life stages, acceptable temperatures are experienced under present conditions and will still be experienced either frequently or always for spawning and incubation life stages, respectively, under future conditions. For the fry life stage, acceptable temperature conditions are experienced about 71 percent of the time under existing conditions, but under future conditions, acceptable temperatures will always be experienced. For other life stages (juveniles and adults), minimum acceptable temperatures are experienced at about the same frequency under both present and future conditions.

Other Fish Species

As noted above, the focus of the review of potential project impacts would focus on rainbow trout since it is the dominant species in the reach of concern. As such, it is intended to serve generally as a surrogate for other fish species in the reach. However, Table B1-7 identifies two other fish species common to South Boulder Creek below Gross Reservoir: longnose dace and longnose sucker. A brief review of USFWS HSI documents for these fish species was conducted to determine if any temperature concerns could be identified:

- Longnose dace[22]: The HSI model for longnose dace includes one temperature variable (among a total of six habitat variables):
  - *Variable V_5* – Average maximum water temperature (°C) during spring and summer in riffle and nearshore areas (adult, juvenile, fry, and embryo life stages) - The acceptable range of water temperatures is from approximately 11.9°C to 21.6°C with the optimum mean water temperature ranging from 14°C to 19°C.
- Longnose sucker[23]: The HSI model for longnose sucker includes two temperature variables (among a total of 13 habitat variables):
  - *Variable V_4* – Mean water temperature (°C) during spawning and incubation - The acceptable range of water temperatures is large, from approximately 4.3°C to 15.8°C with the optimum mean water temperature ranging from 9°C to 15°C.
  - *Variable V_{13}* – Mean water temperature (°C) during summer - The acceptable range of water temperatures is large, from 5°C to 22°C with the optimum mean summer water temperature approximately 12°C.

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[22] Edwards, E.A., H. Li, and C.B. Schreck. 1983. *Habitat Suitability Index Models: Longnose dace.* U.S. Department of Interior, Fish & Wildlife Service, FWS/OBS-82/10.33. 13 pp.

[23] Edwards, E.A. 1983. *Habitat Suitability Index Models: Longnose sucker.* U.S. Department of Interior, Fish & Wildlife Service, FWS/OBS-82/10.35. 21 pp

Table B1-11a. Comparison of the number of days and percent of time water temperatures are within the optimum range under present and modeled future conditions (see text for definition of optimum temperatures; calculations performed on daily averages for both the current and modeled datasets)

Life Stage	Present Conditions (2009-2013 Temperature Observations)		2009 Future Modeled Conditions (1971 and 1972 Hydrology)		2012 Future Modeled Conditions (1971 and 1972 Hydrology)	
	No. Days	% Time	No. Days	% Time	No. Days	% Time
Spawning	553[1]	99%	202[2]	83%	199[2]	82%
Incubation	60[3]	51%	49[4]	79%	31[4]	50%
Fry	0	0%	0	0%	0	0%
Juvenile	205[5]	13%	17[6]	2%	0[6]	0%
Adult	0	0%	0	0%	0	0%

[1] For spawning between April 2009 and December 31, 2013 actual daily average temperatures are within optimal rainbow trout temperature ranges (1.7-16.1◦C) 553 days out of the possible 560 (total days in March, April, May, and June in the dataset with temperature measurement).
[2] Out of a total of 244 days.
[3] For incubation between April 2009 and December 31, 2013 actual daily average temperatures are within optimal rainbow trout temperature ranges (7-12◦C) 60 days out of the possible 117 (total days in July in the dataset with temperature measurement).
[4] Out of a total of 62 days.
[5] For juveniles between April 2009 and December 31, 2013 actual daily average temperatures are within optimal rainbow trout temperature ranges (8.9-21.1◦C) 205 days out of the possible 1550 (total dataset with temperature measurement).
[6] Out of a total of 731 days.

Table B1-11b. Comparison of the number of days and percent of time water temperatures are within minimum acceptable temperature ranges under present and modeled future conditions (see text for definition of minimum acceptable temperatures; calculations performed on daily averages for both the current and modeled datasets)

Life Stage	Present Conditions (2009-2013 Temperature Observations)		2009 Future Modeled Conditions (1971 and 1972 Hydrology)		2012 Future Modeled Conditions (1971 and 1972 Hydrology)	
	No. Days	% Time	No. Days	% Time	No. Days	% Time
Spawning	553[1]	99%	202[2]	83%	199[2]	82%
Incubation	117[3]	100%	62[4]	100%	62[4]	100%
Fry	100[5]	71%	62[4]	100%	62[4]	100%
Juvenile	974[6]	63%	402[7]	55%	453[7]	62%
Adult	742[8]	48%	344[7]	47%	389[7]	53%

[1] For spawning between April 2009 and December 31, 2013 actual daily average temperatures are within acceptable rainbow trout temperature ranges (1.7 - 16.1◦C) 553 days out of the possible 560 (total days in March, April, May, and June in the dataset with temperature measurement).
[2] Out of a total of 244 days.
[3] For incubation between April 2009 and December 31, 2013 actual daily average temperatures are within acceptable rainbow trout temperature ranges (3.8 – 16.5◦C) 117 days out of the possible 117 (total days in July in the dataset with temperature measurement).
[4] Out of a total of 62 days.
[5] For fry between April 2009 and December 31, 2013 actual daily average temperatures are within acceptable rainbow trout temperature ranges (6.7 – 22.8◦C) 100 days out of the possible 141 (total days in August in the dataset with temperature measurement).
[6] For juveniles between April 2009 and December 31, 2013 actual daily average temperatures are within acceptable rainbow trout temperature ranges (4.4 - 26.7◦C) 974 days out of the possible 1550 (total dataset with temperature measurement).
[7] Out of a total of 731 days.
[8] For adults between April 2009 and December 31, 2013 actual daily average temperatures are within acceptable rainbow trout temperature ranges (5.6 – 25.6◦C) 742 days out of the possible 1050 (total dataset with temperature measurement).

The findings from the review for longnose sucker are no different from the review of rainbow trout temperature preference data. While optimal temperature conditions may or may not be met, the range of temperature tolerance is high and both present and projected future water temperature conditions fall well within this range. It is more difficult to evaluate longnose dace given the available temperature preference data above as it applies to riffles/nearshore areas, and such site-specific temperature data are not available. However, existing water temperature conditions would be considered quite cold for longnose dace, yet survey data from 1983 to 1996 show the species to be consistently present.

B1.1.3.2 Macroinvertebrate Community

Macroinvertebrates are important components of aquatic communities for numerous reasons, including nutrient cycling and serving as prey for fish and other aquatic-dependent biota. Table B1-6 summarizes the FEIS findings with regards to potential impacts to the macroinvertebrate community in the South Boulder Creek reach below Gross Reservoir Outlet (see last few bullets in each column under Synthesis section of Table B1-6). GEI Consultants (2013) provides the basis for this finding:

> *Higher winter flows and reduced peak flows would also provide more uniform flow conditions for benthic invertebrates. With less dramatic drying of the stream in winter months, Segment 3 of South Boulder Creek may support a higher density of macroinvertebrates or a more species-rich community including more rheophilic species. Community metrics such as diversity and the number of EPT species may increase. The increases in habitat availability for rainbow trout and macroinvertebrates indicate that the Proposed Action would have a minor beneficial impact on aquatic resources in Segment 3 of South Boulder Creek* (Page 5-37).

GEI Consultants (2013) also provides the following summary of previously collected macrobenthic community data from South Boulder Creek in the study area:

> *Benthic macroinvertebrate populations were sampled at two sites in the fall of 1984 and spring of 1985 in the section of South Boulder Creek in the Project area (Appendix D: Table D-14). Downstream of Gross Reservoir, density estimates averaged 2,118 organisms/m^2, represented by an average of 28 taxa/site (Table 3.5-31). Taxonomic groups included the Ephemeroptera, Plecoptera, Trichoptera, Coleoptera, Diptera, and Oligochaeta (C&A 1986), the typical groups for streams in the mountains of Colorado (Ward 1986, 1994; Ward et al. 2002)…Shannon-Weaver Diversity Index values ranged from 3.22 to 3.38, indicating healthy, balanced benthic macroinvertebrate communities (Table 3.5-31)* (Page 3-88).

Table B1-12 provides the specific macroinvertebrate community data referenced by GEI Consultants (2013). These data were originally reported in the Two Forks Dam EIS (personal communication, Don Conklin, GEI Consultants). The location of this macroinvertebrate community sampling site is not directly within the reach above the Diversion site; instead it is located 1 to 2 miles downstream of the Diversion site within the El Dorado Canyon State Park (see Figure B1-10). This is the most representative macroinvertebrate community dataset known to be available near the project area. Water temperatures at this location may be warmer than in the reach above the Diversion (e.g., see Figure B1-9).

Table B1-12. Estimated temperature preference and range of temperature tolerance for macroinvertebrates identified from site nearest to study area in South Boulder Creek below Gross Reservoir. Estimated temperature preference and tolerance based on Brandt (2001); see text.

Order	Family	Genus	Species/ Group	Survey Results		Temperature Preference (C°)	Estimated Range of Tolerance	Comments/Data Source within Brandt (2001)
				Fall October 1984	March Spring 1985			
Ephemeroptera	Ameletidae	*Ameletus sp.*		3	3	11.5	1.84	As reported
	Baetidae	*Baetis*	*tricaudatus*	293	107	14.55	1.5	As reported
	Heptageniidae	*Cinygmula sp.*		0	3	10.31	2.06	As reported
	Ephemerellidae	*Drunella*	*doddsi*	100	67	10.47	1.96	As reported
	Ephemerellidae	*Drunella*	*grandis*	20	7	14.74	2.07	As reported
	Heptageniidae	*Epeorus*	*longimanus*	0	17	12.32	2.1	As reported
	Ephemerellidae	*Ephemerella*	*infrequens*	33	210	10.97	1.97	Based on values reported for family Ephemerellidae
	Leptophlebiidae	*Paraleptophlebia sp.*		53	7	NA	NA	No applicable data for family, genus or species
	Heptageniidae	*Rithrogena*	*hageni*	689	776	8.25	3.86	As reported
Plecoptera	Perlidae	*Hesperoperla*	*pacifica*	7	3	15.03	2.04	As reported
	Perlodidae	*Skwala*	*parallela*	10	0	18	1.9	Estimated for Genus *Skwala*, but note family-level value for Perlodidae is much lower at 9.64 (1.19)
	Perlodidae	*Isoperla*	*fulva*	0	30	9.64	1.19	Based on family Perlodidae
	Nemouridae	*Zapada*	*oregonensis* group	0	3	8.8	2.27	As reported
	Chloroperlidae			120	187	10.82	1.67	As reported
	Leuctridae	*Paraleuctra sp.*		0	37	9.43	2.24	Based on family Leuctridae
	Nemouridae	*Prostoia*	*besametsa*	0	47	10.03	1.98	Based on family Nemouridae
Trichoptera	Arctopsychidae	*Arctopsyche*	*grandis*	143	150	14.2	1.81	As reported
	Brachycentridae	*Brachycentrus*	*americanus*	13	7	14.29	1.86	As reported
	Glossosomatidae	*Glossoma sp.*		266	230	12.88	1.52	As reported
	Hydropsychidae	*Hydropsyche sp.*		13	17	18.49	1.92	As reported
	Lepidostomatidae	*Lepidostoma sp. 1*		160	77	NA	NA	No applicable data for family, genus or species
	Lepidostomatidae	*Lepidostoma sp. 2*		30	30	NA	NA	No applicable data for family, genus or species
	Rhyacophilidae	*Rhyacophila*	*coloradensis* group	3	3	8.7	1.38	Averaged data for 14 species/groups of *Rhyacophila*; range of tolerance = 6.47 - 10.56; range based on calculated 1 standard deviation (sd) for mean of these 14 species/groups

Table B1-12. Estimated temperature preference and range of temperature tolerance for macroinvertebrates identified from site nearest to study area in South Boulder Creek below Gross Reservoir. Estimated temperature preference and tolerance based on Brandt (2001); see text.

Order	Family	Genus	Species/ Group	Survey Results		Temperature Preference (C°)	Estimated Range of Tolerance	Comments/Data Source within Brandt (2001)
				Fall October 1984	March Spring 1985			
Diptera	Tipulidae	*Antocha sp.*		10	0	16	1.7	Estimated from figure in report
	Tipulidae	*Hexatoma sp.*		33	17	15	1.6	Estimated from figure in report
	Empididae	*Hemerodromia sp.*		0	3	10.9	1.71	Values based on calculated mean/1 sd using data from other genera in this family: *Clinocera sp.* (12.7; 1.5); *Oreogeton sp.* (9.3; 2.6); *Wiedemannia sp.* (10.7; 1.4)
	Chironomidae	*Cricotopus sp.*		0	3	14.3	1.4	Estimated from figure in report
	Chironomidae	*Orthocladius sp.*		3	17	Based on other species within these subfamilies, it can be generally assumed that the preferred temperature for these genera is likely > 15°C		Part of Orthocladinae subfamily - *Cricotopus* part of this group (see above); Brandt (2001) also reports values for *Brillia sp*. (13.1; 1.6) and two specific *Cricotopus* species (19.7; 2.1) and (21.2; 2.6)
	Chironomidae	*Parametriocnemus sp.*		20	3			
	Chironomidae	*Micropsectra sp.*		7	47			Part of Chironominae subfamily – Brandt (2001) reports *Polypedilum sp.* (18.6; 1.8)
	Chironomidae	*Thienemanniella sp.*		0	43			Part of Tanypodinae subfamily – Brandt (2001) reports values for *Stempellinella sp.* (13.7; 1.5); *Pentaneura sp.* (18.9; 1.2); and *Tanytarsus sp.* (19.5; 2.2)
	Chironomidae	*Thienemannimyia*	group	20	0	19.2	1.9	Estimated from figure in report
	Chironomidae	*Chironomidae*	Pupae	17	3	NA	NA	No value for this life stage; also not included in count of number of taxa below
Coleoptera	Elmidae	*Heterlimnius*	*corpulentus*	0	10	11.5	2.5	Estimated from figure in report
	Elmidae	*Narpus*	*concolor*	3	0	12.7	2.3	Estimated from figure
	Elmidae	*Optioservus*	*castanipennis*	3	0	16.9	1.8	Based on genus *Optioservus*
			Totals	2072	2164			
			Number of Taxa	25	30			
			Number of EPT Taxa (%)	17 (68)	22 (73)			
			Diversity (H)	3.22	3.38			

The availability of temperature tolerance data for macroinvertebrates is highly limited, especially critical thermal minima. However, one Idaho study was identified where the authors applied statistical techniques to an extensive bioassessment and water temperature dataset to generate a preferred water temperature and temperature tolerance range for 137 macroinvertebrate taxa (Brandt 2001)[24]. Brandt (2001) states that the State of Idaho's bioassessment database was used for this analysis; therefore, it was assumed that the reported preferred temperatures represent the period of time when the State of Idaho implements its bioassessment program: July 1 to October 15, during low flow[25].

A number of the taxa reported by Brandt (2001) are also observed in the South Boulder Creek dataset. Where direct matches were not available, surrogate values were applied if deemed appropriate. Table B1-12 summarizes the preferred water temperature and estimated water temperature tolerance range for the taxa recorded at South Boulder Creek[26]. Where surrogate data were used, notes are provided to define the basis for the selection of a preferred temperature and tolerance range.

The average preferred temperature for EPT taxa is 11.6, 11.7, and 13.7°C, respectively. The tolerance range for most of the taxa within these insect orders is between +/-1 and 2°C. Assuming these same taxa are present in the reach of South Boulder Creek upstream of the Diversion and assuming a range of +/- 1-2°C temperature tolerance, then temperatures in the 9.5 to 10.5°C range during the July to October period would not be detrimental to these key taxa[27]. Existing water temperatures at the Diversion site in the July to October time period average 10°C to 12°C over the 2005 to 2014 period of record (e.g., see Table B1-11 and Figure B1-8). Even with the expected discharge of colder water to South Boulder Creek following project implementation, no observable impact would be expected to the important and sensitive EPT components of the macroinvertebrate community.

B1.1.3.3 Summary of Key Findings – Aquatic Life Protection

Rainbow trout is the dominant fish species in South Boulder Creek below Gross Reservoir; a review of temperature preferences for this fish species demonstrates that under present conditions, water temperatures in the reach of concern are already well below "optimal" temperatures for all life stages, including adult fish. While present water temperature conditions are well below optimal, minimum acceptable temperatures for rainbow trout currently exist under present conditions and will continue to exist for the most part under future conditions. If the Proposed Action results in colder water temperatures to the degree simulated in the Gross Reservoir model, the resulting temperatures are still well within the minimum acceptable temperature range for rainbow trout life stages. Findings from evaluations of other fish species and macroinvertebrates do not change this conclusion.

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[24] Brandt, D., 2001. *Temperature Preferences and Tolerances for 137 Common Idaho Macroinvertebrate Taxa*. Idaho Department of Environmental Quality. November 2001.

[25] Clark, W.H. and T. R. Maret. 1993. *Protocols for Assessment of Biotic Integrity (Macroinvertebrates) for Wadeable Idaho Streams*. Idaho Division of Environmental Quality. March 1993.

[26] Brandt (2001) records the preferred temperature and lists the tolerance range as 1 standard deviation of the preferred temperature value. For some taxa, the tolerance range had to be read from a figure; thus a number of values in Table B1-13 are estimates.

[27] It is also assumed of course that the thermal tolerance of the Idaho populations of these macroinvertebrate taxa are similar to populations in Colorado; however, the importance of factors such as temperature acclimation, which is found to be important in rainbow trout, cannot be evaluated for these macroinvertebrates.

While the available fish and macroinvertebrate community data are dated for the reach of South Boulder Creek below Gross Reservoir, evaluation of the potential impact of lower water temperatures finds no evidence that the most well-studied components of the aquatic community would be impacted, much less experience "substantial impairment." In fact, as noted in the FEIS, it is possible that the aquatic community would benefit from increased flows in the reach. This possibility is based on the expectation of increased suitable habitat due to increased winter flow. Low flows under present conditions have previously been identified as a concern for this waterbody.

B1.1.4 Conclusion

The purpose of this section was to evaluate whether the implementation of the Proposed Action could cause significant degradation with regards to the narrative temperature water quality standard applicable to South Boulder Creek (Regulation 38.5). This evaluation considered the two key elements associated with the narrative temperature standard. Paraphrased for simplicity, these two elements include: (a) maintenance of a normal temperature pattern with no abrupt changes; and (b) ensuring that the resident aquatic community is not impacted in a deleterious manner. Because the purpose of the narrative temperature is to protect aquatic life, the best means to evaluate the potential for significant degradation is to evaluate potential impacts to the aquatic community, in particular reproductive function in fish.

Sections B1.1.2 and B1.1.3 above evaluated the potential for (a) changes in water temperature patterns; and (b) impacts of water temperature changes on resident fish and macroinvertebrate communities. Following are key findings from each evaluation.

B1.1.4.1 Water Temperature Patterns – Key Technical Findings

Table B1-13 summarizes the average monthly water temperatures in South Boulder Creek below Gross Reservoir based on various data sources, including both modeled and observed results. Based on the discussion above and Table B1-13, the following findings can be made:

- The enlargement of Gross Reservoir is expected to create a larger and colder hypolimnion. This outcome is expected to result in colder water to be discharged to South Boulder Creek.
- The FEIS incorporates the findings of modeling analyses that attempt to quantify the degree to which water will be colder when discharged and the effect this colder water will have on South Boulder Creek below Gross Reservoir. The primary period of time when the discharged water is expected to have the most impact on downstream water temperatures is August to October (highlighted in Table B1-13).
- A comparison of observed water temperature data from South Boulder Creek below Gross Reservoir (historical and present conditions) and the Diversion site with simulated data generated by the model, suggests that the estimated impact of the Proposed Action on water temperatures below the dam is potentially overestimated.
- Table B1-13 shows that the average monthly water temperatures observed from 2009 to 2014 below Gross Reservoir are more like the simulated temperatures expected following project implementation for the months of August and September than the simulated baseline temperatures (compare average Alt 1a monthly temperatures with Gross Reservoir Outlet [2009 to 2014] average monthly temperatures).

Table B1-13. Comparison of simulated monthly average baseline and Proposed Action (Alt 1a) water temperatures with actual monthly average water temperature observations in South Boulder Creek at the Gross Reservoir Outlet and Diversion Sites. Both the range and average of the range are provided for each month (simulated or observed data). The highlighted months are the months when the impact of the Proposed Action(w/ RFFAs) is expected to be the most significant, based on modeled results.

Month	Simulated Average Baseline Temperature				Simulated Average 1a Temperature				Actual Temperature Observations			
	2009 (1971-1972)		2012 (1971-1972)		2009 (1971-1972)		2012 (1971-1972)		Gross Reservoir Outlet (2009-2014)		South Boulder Creek Canal Diversion (2005-2014)	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range)	Average
January	1.3-3.0	2.1	2.5-4.0	3.3	1.8-2.7	2.3	2.7-3.6	3.2	2.0-3.0	2.6	0-7	2
February	1.0-2.8	1.9	1.1-4.0	2.5	0.2-1.6	0.9	1.2-2.7	1.9	1.7-3.1	2.3	0-7	3
March	2.1-3.0	2.6	1.6-3.9	2.8	0.8-2.0	1.4	1.0-1.7	1.4	2.3-3.2	2.7	2-6	4
April	3.3-3.9	3.6	3.6-4.1	3.9	2.0-2.0	2.0	3.1-3.6	3.3	2.8-4.2	3.5	1-9	6
May	4.9-5.5	5.2	4.1-5.7	4.9	4.0-4.0	4.0	4.7-4.7	4.7	3.3-5.0	4.4	4-14	8
June	5.8-6.4	6.1	6.1-6.2	6.1	5.8-6.2	6.0	6.4-7.0	6.7	4.6-6.4	5.7	8-12	9
July	6.1-7.8	6.9	6.2-8.4	7.3	7.1-7.5	7.3	6.8-7.9	7.3	5.4-7.5	6.5	8-13	10
August	8.2-10.0	9.1	7.5-9.4	8.4	7.4-8.1	7.7	6.8-8.1	7.5	5.9-8.8	7.7	10-15	12
September	12.1-12.7	12.4	11.8-12.7	12.2	7.5-8.4	8.0	6.9-8.3	7.6	6.6-10.6	8.8	10-15	12
October	9.2-9.5	9.3	11.0-11.1	11.0	7.9-8.8	8.4	6.9-8.5	7.7	7.6-10.9	9.5	8-12	10
November	5.4-5.6	5.5	7.0-7.3	7.2	6.3-6.6	6.5	7.1-7.9	7.5	6.0-9.0	7.8	0-8	4
December	2.2-3.7	3.0	4.2-4.5	4.3	3.9-4.0	4.0	5.0-5.3	5.1	3.0-5.0	4.1	0-4	2
Average	**5.6**	**5.6**	**6.0-6.4**	**6.2**	**4.9-4.9**	**4.9**	**5.2-5.5**	**5.3**	**4.3-6.4**	5.5	**4.3-10.2**	**7.0**

- Regarding the narrative temperature standard Temperature Pattern element (*Temperature shall maintain a normal pattern of diel and seasonal fluctuations and spatial diversity with no abrupt changes*):
  - The present conditions for the reach of South Boulder Creek below Gross Reservoir is dictated by the presence of the dam, which was completed in 1954; thus a colder temperature pattern already exists as part of the present condition.
  - Under future conditions, it is reasonable to expect somewhat cooler water temperatures overall as a result of project implementation – both in the hypolimnion and in the water discharged from the hypolimnion.
  - While the overall water temperature may become cooler under future conditions, there is no expectation for the diel and spatial diversity of temperatures to change in any ecologically significant manner, i.e., the lack of a diel pattern under present conditions will not change in the future.
  - The simulated baseline temperatures from the Gross Reservoir model (simulated present conditions) do not correspond well with water temperatures observed during the 2009 to 2014 period (actual present conditions) below Gross Reservoir for the months of August to October. Existing temperatures are cooler. Given the observed differences between the model and observations in recent years, uncertainty has been created with regards to the degree that the model simulates future conditions, which predict a truncated peak temperature, generally in the months of August to October.
  - To the degree that peak temperatures are actually truncated under future conditions, this would constitute an impact to the seasonal temperature pattern that occurs under present conditions. However, as noted above, uncertainty exists with regards to the degree that peak temperatures will be truncated in the future.
  - There is no expectation of an "abrupt change" in temperature with the Proposed Action. If the project results in a colder hypolimnion and colder water is discharged, this change will occur somewhat gradually. This is important given that there will be opportunity for the aquatic community to acclimate to the small changes (see text regarding importance of acclimation with regards to potential temperature impacts).

B1.1.4.2 Aquatic Life Protection – Key Technical Findings

Based on a review of potential impacts of the Proposed Action on the resident aquatic community, the following findings can be made:

- Rainbow trout is the dominant fish species in South Boulder Creek below Gross Reservoir; a review of temperature preferences for this fish species demonstrates the following:
  - Under present conditions, water temperatures in the reach of concern are already well below "optimal" temperatures for all life stages except spawning (see Tables B1-10, B1-11a; Figures B1-17 and B1-19).
  - While present water temperature conditions are well below optimal, minimum acceptable temperatures for rainbow trout currently exist under present conditions and will continue

to exist for the most part under future conditions (see Tables B1-10, B1-11a; Figures B1-18 and B1-20).

  - If the Proposed Action results in the colder water temperatures to the degree simulated in the temperature model, the resulting temperatures are still well within the minimum acceptable temperature range for rainbow trout life stages (see Table B1-10).

  - Even with existing cold temperatures, previous studies in the reach of concern observed that the biomass of rainbow trout is "the highest of any section of South Boulder Creek in the study areas. It is over five times the level found in any of the other sections" (Denver Water 1998). It is a reasonable assumption that the local population has acclimated well to temperatures below Gross Reservoir and reproductive functions of adult fish are not being impacted.

  - If colder temperatures result from project implementation, the FEIS notes that the primary impact of these colder temperatures will be on trout growth rates, and as noted by the Division can also influence reproductive function. A review of the literature agrees with this finding (e.g., see Figure B1-12).

  - The most likely period of impact from lower temperatures would be the months of August to October (e.g., see Tables B1-6 or B1-10). During this period, fry, juvenile and adult life stages will be present. While growth rates may be lower, the minimum temperature needs for all of these life stages is within the modeled future temperature conditions for the reach.

  - The effect of the cooler temperatures expected as a result of the Proposed Action and RFFAs on the metabolism and growth of the fish community below Gross Reservoir cannot be estimated based on available data. This creates uncertainty with regards to evaluating potential impacts to this characteristic of the fish community; thus, it is not possible to classify the impact of the Proposed Action and RFFAs as significant or not within the context of this antidegradation review.

- A brief review of the temperature preferences of the other two common species in the reach of concern, longnose dace and longnose sucker, finds that the temperature preferences for longnose sucker are similar to those of rainbow trout. Longnose dace appear to prefer warmer water, yet they have been found to be regularly present under present cold temperature conditions.

- The reach between Gross Reservoir Outlet and the Diversion site is approximately 4.9 river miles. Figure B1-9 illustrated the typical temperature differential in this reach over the last few years. Given the > 2°C temperature difference over the reach and the expected warmer water near the Outlet during winter months (in particular December and January), the impact of colder water during certain months would likely be mitigated in part by fish movement within the reach.

- An evaluation of potential impairment of the Aquatic Life Cold 1 designated use centers on a demonstration of fulfillment of this requirement: *Waters shall be capable of sustaining such biota where physical habitat, water flows or levels, and water quality conditions result in no substantial impairment of the abundance and diversity of species* (Regulation 31.13(1)(c)(i)). A review of the available fish and macroinvertebrate community data demonstrate the following support for this requirement:

- Fish surveys have shown that the existing fish community is sustaining; in fact, it has been previously reported that fish biomass in South Boulder Creek below Gross Reservoir is substantially higher than other sites in the upper watershed of South Boulder Creek (Denver Water 1998). It is a reasonable assumption from these findings that the reproductive function of adult fish is not being impacted.

- Fish abundance is high as evidenced by the 1983-1996 fish surveys (see Table B1-7).

- Overall fish diversity is low compared to some waters (only 3-4 species/survey, see Table B1-7). However, low fish diversity is common in cooler waters. Moreover, low fish diversity has been reported from this reach of South Boulder Creek over a 20-year period and represents the present condition before project implementation. Based on a review of temperature preferences for the resident fish community, no significant impact on existing fish diversity would be expected following project implementation.

- Available macroinvertebrate data from the location below the Diversion site demonstrate an abundant and diverse community. Macroinvertebrate metabolism and growth can be affected by cooler temperatures; however, similar to the fish community potential effects cannot be estimated based on available data. This creates uncertainty with regards to evaluating potential impacts from cooler temperatures on metabolism and growth. Accordingly, it is not possible to classify the potential impact of the Proposed Action and RFFAs as significant or not within the context of this antidegradation review.

B1.1.4.3 Conclusion

The final conclusions from the temperature and aquatic life technical analyses are as follows:

- *Temperature Pattern* – Under present conditions, the temperature pattern in the reach below Gross Dam is influenced by the operation of Gross Reservoir Dam. While the existing diel pattern and spatial diversity of temperature is not expected to change below the reservoir under future conditions, the potential exists for peak temperatures during the August to October period to be truncated, resulting in a seasonal change in the existing temperature pattern (cooler water temperature). This has been documented through a model simulation, but as noted above, based on actual temperature observations, the model may be overestimating the degree to which peak temperatures will be truncated. Moreover, as ambient temperatures naturally increase as waters flow downstream, the potential impact from truncated temperatures would decrease.

- *Aquatic Life Protection* – A review of the known resident fish and macroinvertebrate communities below Gross Reservoir coupled with an evaluation of species-specific water temperature preferences and tolerances finds that the Proposed Action and RFFAs will likely not impact overall aquatic community characteristics. The potential does exist for cooler temperatures to impact the metabolism and growth of fish and macroinvertebrate species. However, it is not possible to measure or classify this impact given the available data to determine if the impact is significant. . Decreases in water temperature at this location would be gradual allowing time for aquatic life to adjust and benefit from improved habitat as a result of higher flows during normal low flow period. Moreover, with distance downstream ambient water temperatures would naturally increase, thus under future conditions water temperatures would remain in the acceptable range.

Appendix B2 – Temperature Modeling Report

Final Report

Fraser River Dynamic Water Temperature Model

Moffat Collection System Project

Section 401 Certification Review

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February 10, 2015

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EXECUTIVE SUMMARY

The Fraser River dynamic water temperature model was developed for Denver Water in support of the Section 401 Certification review for the proposed Moffat Collection System Project (Moffat Project). Denver Water proposed to enlarge its existing Gross Reservoir, located in Boulder County, by 72,000 acre-feet (AF) to provide 18,000 acre-feet per year (AF/yr) of new firm yield for its customers. The model was used to simulate hourly stream temperatures in the Fraser River and its tributaries under four different streamflow scenarios:

- EIS 285 – Current Conditions - Streamflow conditions associated with Denver Water's existing system and an average demand of 285,000 AF/yr.
- EIS 345 – Full Use of the Existing System - Future streamflow conditions associated with Denver Water's existing system and Denver Water's demand has grown to an average of 345,000 AF/yr, plus other reasonably foreseeable future actions (RFFAs) are assumed to have occurred.
- Alternative 1a – Cumulative Effects with Moffat Project - Future streamflow conditions associated with Denver Water's proposed 72,000-AF enlargement of Gross Reservoir, a future average demand of 363,000 AF/yr and the same RFFAs assumed in EIS 345. The only differences between Alt 1a and EIS 345 are the proposed increase in reservoir storage and an increase in demand of 18,000 AF/yr.
- Alternative 8a – Cumulative Effects with Smaller Gross Reservoir Enlargement - Future streamflow conditions associated with a proposed 52,000-AF enlargement of Gross Reservoir, 5,000 AF of storage in gravel pits along the South Platte River, a future average demand of 363,000 AF/yr and the same RFFAs assumed in EIS 345. The only difference between Alt 1a and Alt 8a is a smaller reservoir expansion and slightly less diversion from the West Slope through the Moffat Tunnel.

The Fraser River was modeled from downstream of the Winter Park Water and Sanitation District to the Colorado River confluence. The model simulated temperatures from May 16 to Oct 15, a time period that included all of the summer months in which the warmest water temperatures are observed, as well as the "shoulder-season" months in which the Tier I temperature standard changes. The model was first calibrated with 2010 data and then validated with data from 2007. Calibration and validation runs met all targets.

The temperature model was then run for the five years proposed by the Colorado Department of Public Health and Environment (CDPHE): 1948, 1959, 1963, 1978 and 1987. These years were selected because they represent the critical conditions under which cumulative flow effects are greatest and temperature impacts are most likely to occur. Meteorological data from 2007 were used for each model simulation because it was one of the warmest years in 63 years of temperature record (1948-2010). Both of these factors (the five selected years and 2007 meteorological data) may cause this analysis to overestimate the impacts of the various streamflow scenarios.

The modeling results focus on three locations on the mainstem of the Fraser River and three tributaries:

- Fraser River below Vasquez Creek at Rendezvous Bridge
- Fraser River downstream of Crooked Creek
- Fraser River at the Colorado River confluence
- Vasquez Creek
- St. Louis Creek
- Ranch Creek

Exceedances of the state-established chronic and acute temperature standards are summarized by location below. The chronic standard is defined as the weekly average temperature (WAT) and the acute standard is defined as daily maximum (DM) temperature. Note that there are no exceedances for any year or any streamflow scenario for the Fraser River below Crooked Creek or Vasquez Creek.

Fraser River Downstream of Vasquez Creek at Rendezvous Bridge

Weekly Average Temperature (WAT)

There are no exceedances of the WAT standard at this location throughout the five years for any of the four streamflow scenarios.

Daily Maximum (DM)

- EIS 285: The DM standard is exceeded a total of 12 days throughout the five years.
- EIS 345: The DM standard is exceeded a total of 28 days throughout the five years.
- Alt 1a: With Alt 1a, the DM standard is exceeded a total of 32 days. Therefore, with Alt 1a the DM standard is exceeded 20 additional days compared to current conditions; 4 of the additional days are attributable to the Moffat Project.

Fraser River at the Colorado River Confluence

Weekly Average Temperature (WAT)

- EIS 285: The WAT standard is exceeded a total of 206 days throughout the five years.
- EIS 345: The WAT standard is exceeded a total of 236 days throughout the five years.
- Alt 1a: The WAT standard is exceeded a total of 231 days throughout the five years. Therefore, with Alt 1a the WAT standard is exceeded 25 additional days compared to current conditions. The Moffat Project would decrease the number of exceedances by 5 days as compared to full use of the existing system.

Daily Maximum (DM)

- EIS 285: The DM standard is exceeded a total of 47 days throughout the five years.
- EIS 345: The DM standard is exceeded a total of 56 days throughout the five years.
- Alt 1a: The DM standard is exceeded a total of 54 days throughout the five years. Therefore, with Alt 1a the DM standard is exceeded 7 additional days compared to current conditions. The

Moffat Project would decrease the number of exceedances by 2 days as compared to full use of the existing system.

Overall Summary for the Fraser River Mainstem – The mainstem of the Fraser River from Hammond Ditch (just downstream of the Town of Fraser) to the confluence with the Colorado River is on the 303(d) List of Impaired Waters with a State-assigned low priority. The model identifies temperature exceedances under current conditions near the Town of Fraser (Rendezvous Bridge), none near the confluence with Crooked Creek and temperature exceedances again at the confluence with the Colorado River. With Alt 1a, under future, cumulative conditions, there will be additional temperature exceedances at both locations. However, 20% of the exceedances (4 days out of 20 days) at Rendezvous Bridge are attributable to the Moffat Project and none of the exceedances at the confluence with the Colorado River are attributable to the Moffat Project.

Based on the simulated conditions, the additional diversions associated with the Moffat Project do not contribute to violations of the summertime (June-September) stream temperature standards. The Moffat Project does contribute to DM temperature standard violations in the Fraser River at Rendezvous Bridge in the month of May (4 days out of the 5 years simulated).

St. Louis Creek at the Fraser River Confluence

Weekly Average Temperature (WAT)

The WAT standard is exceeded for 1 day throughout the five years under all streamflow scenarios. Therefore, with Alt 1a there is no change in exceedances of the WAT standard.

Daily Maximum (DM)

- EIS 285: The DM standard is exceeded a total of 17 days throughout the five years.
- EIS 345: The DM standard is exceeded a total of 16 days throughout the five years.
- Alt 1a: The DM standard is exceeded a total of 21 days throughout the five years. Therefore, with Alt 1a the DM standard is exceeded 4 additional days compared to current conditions. With the Moffat Project there are 5 days of additional exceedances as compared to full use of the existing system.

Ranch Creek at the Fraser River Confluence

Weekly Average Temperature (WAT)

- EIS 285: The WAT standard is exceeded a total of 19 days throughout the five years.
- EIS 345: The WAT standard is exceeded a total of 19 days throughout the five years.
- Alt 1a: The WAT standard is exceeded a total of 24 days throughout the five years. Therefore, with Alt 1a the WAT standard is exceeded 5 additional days compared to current conditions; these 5 additional days are attributable to the Moffat Project.

Daily Maximum (DM)

- EIS 285: The DM standard is exceeded a total of 36 days throughout the five years.
- EIS 345: The DM standard is exceeded a total of 35 days throughout the five years.
- Alt 1a: The DM standard is exceeded a total of 45 days throughout the five years. Therefore, with Alt 1a the DM standard is exceeded 9 additional days compared to current conditions. With the Moffat Project there are 10 days of additional exceedances as compared to full use of the existing system.

Overall Summary for Fraser River Tributaries – There are no WAT or DM exceedances identified in any of the five years for any of the four streamflow scenarios on Vasquez Creek. There are exceedances of the DM standard in St. Louis Creek under current and future conditions. With Alt 1a the DM standard is exceeded 4 more days compared to current conditions. With the Moffat Project there are 5 days of additional exceedances as compared to full use of the existing system. There are exceedances of both the WAT and DM standard in Ranch Creek under current and future conditions. With Alt 1a the WAT standard is exceeded 5 additional days compared to current conditions and the days are attributable to the Moffat Project. With Alt 1a the DM standard is exceeded 9 more days compared to current conditions. With the Moffat Project there are 10 days of additional exceedances as compared to full use of the existing system.

Based on the simulated conditions, the additional diversions associated with the Moffat Project do contribute to DM and WAT temperature standard exceedances in St. Louis and Ranch creeks. These exceedances occur in the month of May (St. Louis Creek: 5 days of DM standard exceedances and Ranch Creek: 10 days of DM and 5 days of WAT standard exceedances).

Colorado River

Potential effects to stream temperature in the Colorado River were evaluated using results from the Upper Colorado River dynamic temperature model prepared for the Windy Gap Firming Project. The Moffat Project was included as one of the reasonably foreseeable future actions (RFFAs) in the cumulative effects analysis. The model results indicated that under future conditions with RFFAs, the number of exceedances of both acute (DM) and chronic (WAT) standards will increase in July compared to existing conditions. However, releases of water from Granby Reservoir in August for compliance with the Endangered Species Act (5412 Releases) will decrease stream temperatures and decrease exceedances. The net cumulative effect is fewer exceedances of both the acute and chronic standards in the future compared to existing conditions.

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INTRODUCTION

Overview of Moffat Collection System Project

The Moffat Collection System Project (herein referred to as the Moffat Project or Project) is a water supply project proposed by Denver Water to develop 18,000 acre-feet per year (AF/yr) of new firm yield for its customers. Denver Water proposes to enlarge its existing Gross Reservoir by 72,000 AF to a total storage capacity of 113,811 AF.[1] Water from the Fraser River, Williams Fork River and South Boulder Creek would be diverted and delivered during average and wet years via the Moffat Tunnel and South Boulder Creek to Gross Reservoir. There would be no additional diversions in dry years because Denver Water already can divert the maximum amount physically and legally available with its existing water rights and facilities. Refer to the Moffat Collection System Project Final Environmental Impact Statement (EIS), issued by the U.S. Army Corps of Engineers on April 25, 2014, for more details on the Project.

Concerns were raised by Colorado Department of Public Health and Environment (CDPHE) and U.S. Environmental Protection Agency (EPA) during their review of the Preliminary Final EIS that segments of the Fraser River basin are currently listed as impaired for temperature. In the Fraser River basin, two reaches are currently on the State of Colorado's Section 303(d) List of Impaired Waters: the mainstem Fraser River downstream of the Hammond Ditch to the Colorado River and Ranch Creek. St. Louis Creek has had some temperature exceedances but is not currently on the 303(d) list. Further reductions in flow associated with the Moffat Project could cause or contribute to additional exceedances of temperature standards. Both CDPHE and EPA recommended developing a dynamic (mechanistic) model that can predict daily stream temperatures under a range of flow conditions to evaluate the cumulative and Project-related effects.

Study Area

The Fraser River dynamic water temperature model focuses on the Fraser River from downstream of the Winter Park Water and Sanitation District to its confluence with the Colorado River, a distance of approximately 23 miles (Figure 1). (For a more detailed map that shows all tributaries and diversions, see Wilson Water Group 2014, Figure 1.) The river has a steep gradient for much of its length. Downstream of the town of Tabernash the river is confined by a narrow canyon for approximately six miles. Upon exiting the canyon, the river's gradient declines and the channel widens, with some meandering. Seven key tributaries add flow to the Fraser River: Vasquez, Elk, St. Louis, Ranch, Crooked, Strawberry and Tenmile creeks. Several diversions are present that remove flow from the river; these

[1] This storage capacity does not include the 5,000-AF Environmental Pool, which will be filled with water rights owned and provided by the cities of Boulder and Lafayette.

are primarily agricultural and municipal diversions. Many of the diversions subsequently return some flow to the river. Additionally, there are several sanitation districts and wastewater treatment plants that discharge water to the Fraser River.

Modeling Objectives

The objective of modeling water temperature in the Fraser River was to assess the potential effects of four streamflow scenarios for the Moffat Project. The four streamflow scenarios are:

- EIS 285 – Current Conditions - Streamflow conditions associated with Denver Water's existing system and an average demand of 285,000 acre-feet per year (AF/yr).
- EIS 345 – Full Use of the Existing System - Future streamflow conditions associated with Denver Water's existing system and Denver Water's demand has grown to an average of 345,000 AF/yr, plus other reasonably foreseeable future actions (RFFAs) are assumed to have occurred.
- Alternative 1a (Alt 1a) – Cumulative Effects with Moffat Project - Future streamflow conditions associated with Denver Water's proposed 72,000-AF enlargement of Gross Reservoir, a future average demand of 363,000 AF/yr and the same RFFAs assumed in EIS 345. The only differences between Alt 1a and EIS 345 are the proposed increase in reservoir storage and an increase in demand of 18,000 AF/yr.
- Alternative 8a (Alt 8a) – Cumulative Effects with Smaller Gross Reservoir Enlargement - Future streamflow conditions associated with a proposed 52,000-AF enlargement of Gross Reservoir, 5,000 AF of storage in gravel pits along the South Platte River, a future average demand of 363,000 AF/yr and the same RFFAs assumed in EIS 345. The only difference between Alt 1a and Alt 8a is a smaller reservoir expansion and slightly less diversion from the West Slope through the Moffat Tunnel.

The Fraser River basin has water temperature standards for weekly average temperatures and daily maximum temperatures. Weekly average temperatures and daily maximum temperatures were calculated from the modeled (simulated) water temperatures using CDPHE protocols. This was done to determine whether or not the streamflow scenarios would potentially exceed acute and/or chronic water temperature standards.

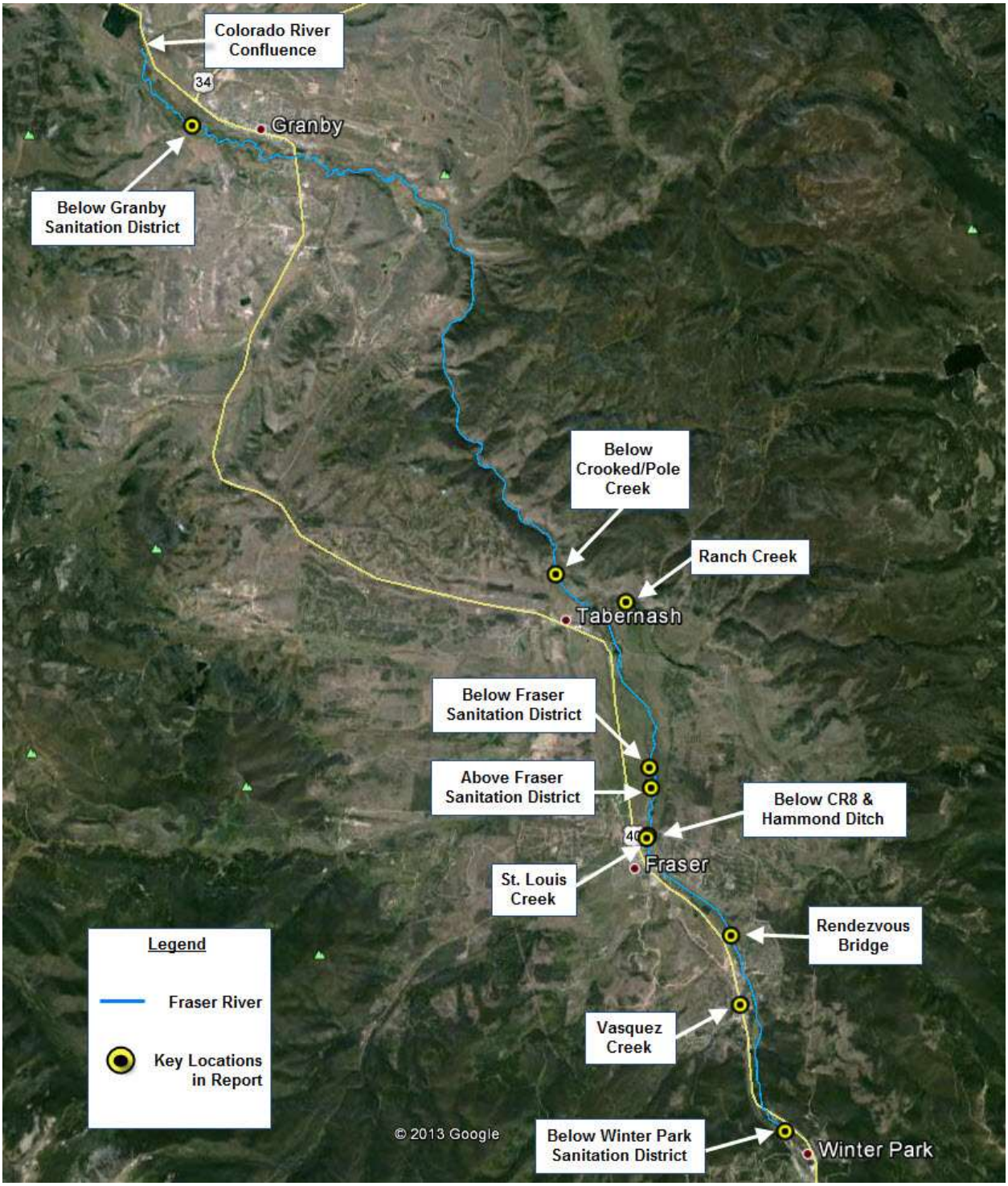

Figure 1. Fraser River study area.

MODEL DEVELOPMENT

A dynamic water temperature model was developed to assess the potential effects of streamflow scenarios with the Moffat Project. A dynamic model was required to simulate water temperatures for calculation of weekly average and daily maximum temperatures. River Modeling System (RMS, v4.5) software was used to develop the temperature model (Hauser et al. 2013). When using RMS, two separate models are created. The first model (called ADYN) is a one-dimensional, longitudinal, dynamic model of hydrodynamics. ADYN simulates varying flows and water surface elevations at multiple locations along a river using cross-section geometry and user-specified inflows, among other variables. This model is then incorporated into a water quality model (RQUAL) that simulates time-varying water temperature using user-specified meteorology and inflow temperatures, among other variables.

The ADYN and RQUAL models require several types of data. All data for model configuration and simulation came from existing data sources and were adapted for use in the dynamic water temperature model. The following sections describe the data needed to develop the models and present the rationale for the extent of the Fraser River that was modeled and the time period of simulation.

Period of Simulation

The model simulates temperatures from May 16 to October 15. This time period was agreed to during discussions between Denver Water and CDPHE. This time period includes all of the summer months in which the warmest water temperatures are observed. May and October were included because they are “shoulder-season” months in which the Cold-Season Tier I temperature standard changes. The entire months were not included due to lack of temperature data in early May and late October and because the Moffat Project will cause minimal flow changes during these times.

Geographic Extent

The Fraser River was modeled from downstream of the Winter Park Water and Sanitation District (WPSD) to the Colorado River confluence. The upstream location was chosen because a temperature logger located there had the most complete water temperature dataset for the simulation period and because this location is several miles upstream of the upper boundary of the 303(d)-listed reach. The river was modeled to its confluence with the Colorado River so that temperatures within the 303(d)-listed reaches could be simulated. Simulated temperatures at the mouth of the Fraser River would also help determine if the Colorado River would be impacted by the Project.

Data Types and Sources

Hydrologic Data

The ADYN (flow) portion of the model required hydrologic data at several locations. Flow data were needed for the Fraser River at the upstream boundary (WPSD), as well as all major tributaries and diversions. Flow data were modeled by a daily point flow model (Wilson Water Group 2014). Data were compiled from Denver Water, Northern Colorado Water Conservancy District (Northern Water) and the Colorado Division of Water Resources. The data included gaged flow at key locations on the Fraser River and its tributaries, key agricultural and municipal diversions and corresponding return flows, wastewater treatment plant discharges, and node information from Denver Water's PACSM (Platte and Colorado Simulation Model) water allocation model. The point flow model used flow records for points of known flow rate within the Fraser River basin (gage/diversion data) and mass balance equations to perform a water balance and estimate unknown stream reach gains (ungaged tributary inflow) and losses (depletions not represented in PACSM) at points of interest.

Cross-Section Geometry

Cross-section data were necessary to describe the shape of the river channel, including thalweg locations and channel roughness. This helps to ensure that flows are routed correctly down the river within the ADYN flow model. Ideally, cross-sections would be measured at regular intervals throughout the reach to be modeled. Surveyed cross-section data were limited to a few discreet locations within the model extent on the Fraser River. Station/elevation data were available that were taken as part of previous studies of habitat and sediment transport and were provided by Ecological Resource Consultants, Grand County and Hydros Consulting, Inc. The data were limited to five locations within the 23-mile reach of the Fraser River that was modeled: 0.5 miles downstream of the upstream boundary, 0.5 miles upstream of the Vasquez Creek confluence, just upstream of the Fraser Sanitation District outfall, 1.5 miles downstream of Tabernash and at the Granby Ranch Golf Course. No cross-section data were available for the canyon-bound stretch of river. The ADYN flow model requires cross-section data at all sources of inputs (i.e., tributaries) and outputs (i.e., diversions). Since these data were not available, the nearest existing cross-section was used. Adjustments to bed elevations were made by comparing elevations from Google Earth imagery. This approach assumed that channel shape and roughness were similar from one location to the next. The ADYN model can also interpolate between known cross-sections. Cross-section interpolation was used as another method to fill in missing geometry data.

Meteorological Data

The RQUAL temperature model requires meteorological data on the same time step as the simulation time step. An hourly time step was used for the Fraser River simulations. Hourly meteorological data were obtained for this study. Specifically, air temperature, dew point temperature, wind speed, barometric pressure, solar radiation and cloud cover data are used. Data were obtained from a weather station located near Tabernash (MesoWest station CW5469) except for solar radiation and cloud cover.

Solar radiation data were obtained from Northern Water's weather station near Windy Gap. The nearest weather station that had cloud cover data was at Kremmling (MesoWest station K20V). Meteorological data were generally complete, although there were some gaps in the 2010 data used for calibration. To fill in those gaps, comparisons of data between Tabernash and Windy Gap were made and missing data filled from the appropriate source.

Inflow Temperature Data

The RQUAL temperature model required hourly water temperature data for all inflows to the model. Temperature data were needed for the Fraser River at the upstream boundary as well as all tributaries (discussed below) and other sources that contributed flow to the river. Grand County Water Information Network (GCWIN) has been monitoring water temperature at various locations in the Fraser River basin and has regularly collected data at 15-minute intervals; the most complete datasets begin in 2007. Many of the temperature loggers record data from mid- to late-May into late October, although the dates vary by year and location. For the upstream boundary, GCWIN logger FR-blwWPSD (Fraser River below Winter Park Sanitation District) was used for calibration and validation. For the simulated scenario years (in which temperature data were not available), an empirical model to estimate water temperature was developed and is discussed below.

Tributary Temperature Data

As stated above, the RQUAL temperature model required temperature data for all inputs into the Fraser River. According to the point flow model, there are fourteen tributaries or sources of temperature input. Of these, only three tributaries had water temperature data associated with them: Vasquez Creek, St. Louis Creek and Ranch Creek. The temperature datasets were not complete though for the calibration and validation years of 2010 and 2007. It was therefore necessary to develop empirical water temperature models that could fill in the missing temperature data for these three tributaries, as well as estimate temperatures at the remaining tributaries that did not have any data. The tributary water temperature models would also be used to predict temperatures for the scenario year model runs. The methodology that was used to develop the empirical models has been described and presented in previous reports (Miller Ecological Consultants, Inc. 2014a) and has gone through several reviews with CDPHE. A general summary of the effort is described below.

Empirical models were developed using meteorological, hydrologic and water temperature data. All available data from 2007 to 2012 were compiled for Vasquez, St. Louis and Ranch creeks, as well as the Fraser River below WPSD. While the Fraser River below WPSD had the data necessary for calibration and validation, data were not available for the scenario years and therefore it was necessary to develop an equation to predict temperatures for those years. Regression analyses were performed using the Statistica software package and separate equations were developed for each tributary. Initial analyses indicated that stronger relationships could be achieved with the use of equations that were developed for each month separately. Analyses also indicated that water temperature could be sufficiently modeled with just two or three predictor variables. At that point, it was decided that flow, air temperature and solar radiation would be used to predict temperature.

After these analyses were presented, it was noted that some of the relationships between variables were not mechanistically correct. In some instances there was a positive relationship with flow and water temperature. Typically, an increase in discharge tends to cool water temperature (a negative relationship). There was also a negative relationship between solar radiation and water temperature for all equations, which is contradictory to physical processes. More solar radiation should equate to warmer water temperatures and vice versa (a positive relationship). To address concerns with flow, data were combined for some months, but this did not produce a negative relationship between flow and temperature for all locations. It was then suggested to add Julian date[2] as a predictor variable. Julian date is potentially a surrogate for unmeasured variables that could not be incorporated into the equations (solar angle, for example). The addition of Julian date resulted in a negative regression coefficient for flow for all months and locations.

To address the improbable negative relationship between solar radiation and water temperature, further analyses were conducted in which it was determined that the cause of the relationship is the lag between peak solar radiation and peak water temperature. The time of peak solar radiation was then shifted to match the time of peak air and water temperature. This resulted in a positive regression coefficient for solar radiation (with the exception of August, September and October in Vasquez Creek). One concern with using the shifted-solar data was that air temperature and solar radiation data were highly correlated. In general, auto-correlated variables are not included as independent variables in regression equations. In this case, however, it was decided that both variables should be included as predictors in the equations to provide a mechanistically correct relationship. Solar radiation is the source of heat for several heat flux parameters that were not measured. These include topographic radiation, vegetative radiation and stream bed conduction.

The final empirical models contained flow, air temperature, shifted solar radiation and Julian date as predictor variables. There were a few instances where not all of the predictor variables were significant in the models. Julian date was not significant in May in St. Louis and Ranch creeks. Flow was not significant in September in Ranch Creek and October in Vasquez Creek. To maintain consistency across sites and months, these variables were kept in the models. Leaving non-significant variables in the models minimally affects water temperature predictions.

Table 1 - Table 4 provide the parameter estimates for Vasquez, St. Louis and Ranch creeks, as well as the Fraser River below WPSD. The R^2 for each equation is given, as well as the number of observations. It is worth noting that the primary objective in developing the empirical tributary models was to make sure the models were mechanistically correct. This resulted in lower R^2 values for some months and locations.

[2] Julian date – The number of elapsed days since the beginning of a calendar year. For example, a Julian date of 32 would represent the 32nd day of the year or February 1.

Table 1. Regression parameter estimates for Vasquez Creek.

Month	Parameter Estimate						
	Flow	Air Temp.	Shifted Solar Radiation	Julian Date	Intercept	R^2	# of Obs.
May	-4.963329	0.203862	0.000962	0.072788	-4.787908	0.72	636
June	-0.627368	0.119542	0.003483	0.124080	-14.647167	0.74	2647
July	-0.667625	0.071010	0.002999	0.021587	4.599705	0.68	3692
August	-1.779478	0.217069	-0.001106	-0.045711	18.871883	0.58	4827
September	-1.624268	0.235709	-0.001675	-0.107127	33.501401	0.71	3894
October	-1.120295	0.240062	-0.001184	-0.169000	50.866856	0.69	2042

Table 2. Regression parameter estimates for St. Louis Creek.

Month	Parameter Estimate						
	Flow	Air Temp.	Shifted Solar Radiation	Julian Date	Intercept	R^2	# of Obs.
May	-1.190483	0.255795	0.004316	0.001695	6.186371	0.74	638
June	-0.835424	0.226467	0.004351	0.110377	-10.598702	0.83	2648
July	-0.766097	0.217283	0.003373	0.032585	3.434665	0.80	3525
August	-2.231363	0.328376	0.001109	-0.040263	19.039571	0.77	4291
September	-1.808260	0.294343	0.001820	-0.076999	27.764074	0.81	3525
October	-1.686503	0.286897	0.002246	-0.171809	53.525834	0.79	1800

Table 3. Regression parameter estimates for Ranch Creek.

Month	Parameter Estimate						
	Flow	Air Temp.	Shifted Solar Radiation	Julian Date	Intercept	R^2	# of Obs.
May	-0.870229	0.193331	0.005054	-0.032216	13.284926	0.72	607
June	-0.523869	0.228102	0.004803	0.098237	-7.918250	0.75	2648
July	-0.845274	0.208744	0.004926	0.050363	1.684450	0.78	3265
August	-2.587202	0.359447	0.001257	-0.017878	15.433792	0.70	4389
September	-0.077773	0.321721	0.001287	-0.117633	38.840602	0.74	3811
October	-5.492075	0.289084	0.001502	-0.208178	65.522549	0.70	1776

Table 4. Regression parameter estimates for the Fraser River below the Winter Park Sanitation District.

Month	Parameter Estimate						
	Flow	Air Temp.	Shifted Solar Radiation	Julian Date	Intercept	R^2	# of Obs.
May	-0.576390	0.139124	0.002912	0.080703	-8.257730	0.66	1490
June	-0.477836	0.149936	0.002691	0.068754	-6.497744	0.77	3475
July	-0.694936	0.134792	0.002915	0.052977	-2.988087	0.74	4003
August	-1.918900	0.206116	0.000824	-0.032242	14.933024	0.73	4430
September	-1.740635	0.215781	0.000331	-0.051615	19.385009	0.78	3570
October	-3.816802	0.234886	0.000530	-0.143662	44.663996	0.79	1824

Water temperatures were required at 11 other locations. Of these, Elk Creek, Crooked Creek, Strawberry Creek and Tenmile Creek were of primary concern. The equations developed from the measured tributaries were used for these four creeks, substituting in the flows for each location provided by the point flow model. Elk Creek water temperatures were generated by using the equation for St. Louis Creek. Crooked Creek, Tenmile Creek and Strawberry Creek temperatures were generated by using the equation for Ranch Creek. The choice of creek was based upon data from 2013 (Andrew Todd, personal communication). Temperature data were available for Crooked, Strawberry and Tenmile creeks. While the data could not be directly compared to 2013 data for Ranch Creek (which were not yet available at the time of model development), the temperatures recorded in these three creeks in 2013 were similar to or warmer than the temperatures observed in Ranch Creek from 2007 to 2012. Therefore, the equation from Ranch Creek was deemed most appropriate for Crooked, Strawberry and Tenmile creeks. For Elk Creek, the decision to use the St. Louis Creek equation was based on the similar aspect of the creeks.

For the Fraser Wastewater Treatment Plant, temperature data were available from 2007 to 2009. Temperature patterns were fairly consistent across the three years, thus the data were averaged and used for calibration and for scenario year model runs. For the Granby Wastewater Treatment Plant, temperature data were not available. Instead, average annual air temperature from a weather station near Grand Lake was used for calibration and validation. After calibration and validation, there was a question as to whether this temperature was too cold to represent wastewater effluent and whether the colder effluent resulted in cooler temperatures in the Fraser River. To test the effect of the effluent temperature, a much warmer 13.0°C temperature was substituted into the model to see if the predicted water temperatures changed downstream of the Granby WWTP. Results showed that predicted temperatures changed very little; the largest difference in predicted temperatures was 0.22°C. Even though there was very little change in predicted temperatures, it was decided to use average *daily* air temperature data for the scenario year model runs. Average daily air temperature data came from climate normals data from 1981-2010, Grand Lake station, and ranged from approximately 5 to 15°C.

For the remaining five sources of temperature input, the average annual air temperature at either the town of Fraser or at Grand Lake was used. Average annual air temperature approximates groundwater temperature. Groundwater temperatures were used at these locations because they overall contribute very little flow to the Fraser River. It was expected that inputs from these locations would minimally affect temperature in the Fraser River.

Uncertainties

All models have uncertainties and unknowns. The following paragraphs summarize the known uncertainties in developing the water temperature model.

- **Hydrology** – the point flow model simulated some net losses in flow. The losses could not fully be explained by diversions that are not represented explicitly in PACSM. It is estimated that the

unexplained losses may be attributed to several inherent uncertainties in the data, including timing issues and potential gage error. The periods with the greatest simulated net loss occurred during peak flows in early- to mid-June. These high peak flows reached up to 1,800 cfs, which could have a direct impact on the level of potential error on those gages. Other uncertainties that may have impacted the simulated net losses include monitoring records of diversion gages (e.g., infrequent measurements or user-supplied data), consumptive use of natural riparian and wetland areas, model assumptions on lagged return flows or bank storage and routing considerations. Additionally, the point flow model was a *daily* model, whereas hourly flows were needed to run the ADYN flow model. This required taking the average daily flow and using it for each hour of a given day (i.e. an average daily flow of 12 cfs resulted in hourly flows also of 12 cfs). Consequently, from one day to another, flow could greatly increase or decrease from 23:00 at the end of one day to 0:00 at the beginning of the next. In contrast, a natural stream has a more gradual ramping up or down of flow.

- **Hydrology within the ADYN model** – for several dates in all five scenario years under EIS 345, Alt 1a and Alt 8a, corresponding PACSM simulation data showed low flows in the mainstem Fraser River between the Fraser at Winter Park gage and the Hammond No. 1 Ditch diversion. These low flows caused the ADYN portion of the dynamic temperature model to stop running. Modifications were made to some of the cross-sections (such as deepening a cross-section) in an attempt to prevent the model from crashing but this did not correct the model problems. Changes to the THETA and FNMAX parameters also did not correct the problem. We consulted with the model author to determine other means to correct the error. The model's author tried to recompile the model using double precision, however, this approach was not feasible and did not correct the error. We were advised that the best approach was to add the smallest amount of flow that would allow the model to run (G. Hauser personal communication February 10, 2014). It was therefore necessary to add a small amount of flow in certain locations and for certain dates to allow the ADYN model to run. The additional flow was added to the nearest tributary or the upstream model boundary. The amount of flow added to allow the model to run is provided in the results for each scenario year.
- **Cross-section Geometry** – cross-section data were very limited. It was necessary to take the existing cross-section data and extrapolate to sections of the Fraser River that needed geometry data in order for the ADYN model to run. This assumed that general channel shape at one location could represent general channel shape at another location. While this assumption may be correct for general cross-section shape, this assumption was likely not always valid for a specific channel shape. In order to have cross-section data that represented all reaches within the Fraser River and all inputs and outputs it would have been necessary to collect new data from 20 or more new locations and this was not deemed feasible for this model application.
- **Meteorology** – a single meteorological dataset (that is, a single set of meteorological conditions) was used to describe the meteorology of the entire 23-mile reach. While the Tabernash weather station was centrally located, some of the data came from Windy Gap and Kremmling, where it could be expected that weather conditions could be different. Additionally, data that were missing from the 2010 dataset used for calibration needed to be filled in. Every attempt

was made to correctly estimate the missing data; however it was not possible to determine how well the estimates matched actual weather conditions. Wind speed, in particular, is a highly-varying weather parameter that is difficult to estimate and can be highly variable by location.

- **Observed Water Temperatures** – there is the potential for temperature loggers to be placed in locations that do not accurately represent actual temperatures. For example, a logger placed in a deep pool may underestimate temperature, whereas one placed in a shallower, sunny location may overestimate temperature. However, Grand County personnel follow standard procedures for placement of loggers (Jane Tollett, personal communication) and the data should be representative of stream temperatures.
- **Empirically-Modeled Water Temperatures** – predicted tributary water temperatures are limited by the accuracy of the regression equations. The accuracy of the equation is represented by the R^2 values for each equation. Some trends in the empirical models were apparent. Low water temperatures were consistently overpredicted in all months except July. High temperatures tended to be underpredicted in all months, on average by 1.5°C. Since the regression equations were developed from six years of data any single year may not show these same trends. It is important to note that since the tributary equations from St. Louis and Ranch creeks were then used for four other tributaries, the same over- and underprediction of temperature likely then occurred in those tributaries. As each tributary was added to the overall RQUAL temperature model for the Fraser River, the amount of error (that is, over- and underprediction) potentially increased from upstream to downstream. The influence of the uncertainty is approximately proportional to the volume of tributary flow compared to the mainstem Fraser River flow. Lower tributary flows have smaller influence on mainstem temperature than higher flows.
- **ADYN and RQUAL models** – these models were developed by the Tennessee Valley Authority and were designed with eastern U.S. rivers in mind, particularly segments of rivers below dams. These locations are typically large, wide rivers with high flow volumes. A steep and shallow river that frequently has very low flows, such as the Fraser River, is pushing the limits as to what this software can realistically model. The RQUAL model tends to underpredict water temperatures when air temperatures are less than 5°C (Gary Hauser, personal communication), a common occurrence in the mountains.
- **Model Error** – water temperature calibration and validation error targets were <1.5°C (see "Model Calibration and Validation"). Differences in water temperature between streamflow scenarios that are within this error may therefore introduce uncertainty into the analysis. This is particularly important in the calculations of exceedances of the chronic and acute water temperature standards. Differences in temperature between streamflow scenarios as small as 0.10°C can result in different counts of temperature exceedances. Thus, some exceedances may not be fully realized since they are within the model error. The calculations for DM and WAT values in this report included all exceedances whether outside or within model error.

MODEL CALIBRATION AND VALIDATION

For model calibration, it was necessary to select a year that had adequate meteorological and water temperature data. Preferably, this year would have had a wide range of flows (but not extreme flows) that would result in a wide range in observed water temperatures, including those that exceed temperature standards. Based on these factors, 2010 was selected as the calibration year.

Once calibration was complete, the model was validated against a second year of data. Validation was a test of both the flow (ADYN) and temperature (RQUAL) models. Within ADYN, validation assesses how well the input cross-sections match the actual river channel under a different flow scenario. No changes are made to the cross-sections; the only change is the input of new flows. Within RQUAL, validation assesses how well the calibration parameter settings (parameters like channel bed thickness) are able to predict a new set of water temperatures. 2007 was selected as the validation year. This year had adequate meteorological and water temperature data (although less temperature data than for 2010) and had flows and temperatures that were different from 2010.

A separate model calibration and validation report was previously prepared (Miller Ecological Consultants, Inc. 2014b) and is summarized here.

Calibration (2010 Data)

Calibration was completed in two primary steps. First, the flow (ADYN) portion of the model was calibrated. This required some adjustments to cross-section geometry and the addition of interpolated cross-sections. The target mass balance error range was -1.5% to +1.5% (Gary Hauser, personal communication). Once the mass balance error was satisfactory, simulated flow and stage were compared to observed flow and stage at two locations: near the confluence with the Colorado River and downstream of Crooked Creek. Comparison of flow and stage resulted in some additional adjustments to cross-section geometry, which typically entailed widening a cross-section to better represent stream conditions and obtain a better stage-discharge fit.

The overall mass balance error was -1.28%, which was within the recommended error range. Simulated flow closely matched observed flow at both locations, with R^2 values of 0.99. Differences were likely due to the nature of the point flow model being a daily, not hourly, model. Simulated stage also matched well to observed stage. The average difference in simulated and observed stage was +0.06 feet, ranging from -0.41 to +0.53 feet. The largest differences occurred during peak flows.

The second step was calibration of the water temperature (RQUAL) model. The model was first run with the recommended average settings for parameters such as evaporative cooling and channel bed thickness (Hauser et al. 2007). Then adjustments were made to these parameters depending on whether the simulated temperatures were either too cool or too warm compared to the observed

temperatures. Table 5 shows the calibration parameter settings applied to the water temperature model.

Water temperature calibration targets followed those applied to the Upper Colorado River dynamic temperature model (Hydros Consulting Inc. 2011). Daily mean, daily minimum and daily maximum temperatures were calculated at six sites. For the three metrics, the root-mean-square error (RMSE) and mean absolute error (MAE) were calculated, with a calibration target of <1.5°C. The observed vs. simulated R^2 was also calculated. Graphs of simulated vs. observed temperature were produced to compare monthly and diurnal trends. Residuals were plotted and evaluated for any trends in space, time, or temperature and for the identification of possible outliers. Table 6 shows the R^2, RMSE, and MAE calculated for the daily average, minimum, and maximum temperature at each site. All RMSE and MAE values were less than 1.5°C.

While not universal, there was a general trend of underprediction of maximum temperatures in June and early July and an overprediction of maximum temperatures in September. An effort was made to find a balance between sites and between temperatures in early summer versus temperatures later in the summer. If calibration parameters were changed to attempt to cool the maximum temperatures in late summer to observed values then the model would further underpredict maximum and minimum temperatures in early summer. Simulated temperatures from the model did follow observed monthly trends and temperatures rose and fell accordingly with meteorological conditions. Residuals tended to increase from upstream to downstream. This was likely due to the unknowns and uncertainties in the tributary water temperature models, which was discussed previously.

Validation (2007 Data)

2007 meteorology and hydrology data were used to validate the water temperature model. Tributary temperatures (both observed and those predicted from empirical models) were updated based on 2007 data. Validation targets were the same as those for calibration; the same root-mean-square error (RMSE), mean absolute error (MAE), and R^2 statistics were calculated. For 2007, water temperature data were not available for the Fraser River at Rendezvous Bridge or the Fraser River downstream of Crooked Creek.

For the ADYN flow simulation, the overall mass balance error was +0.84%, which was within the recommended error range. Simulated flow closely matched observed flow at both locations, with R^2 values of 0.99. Simulated stage also matched well to observed stage. The average difference in simulated and observed stage was +0.04 feet, ranging from -0.36 to +0.39 feet. The largest differences occurred during peak flows.

Table 5. Calibration parameter settings.

Parameter	Definition	Value(s)	Comments
Bank Width	Bank width to effective barrier for shading	5 - 40 ft.	Based on review of Google Earth images from July and September 2011
Barrier Height	Effective barrier height for shading	5 - 300 ft.	Based on review of Google Earth images from July and September 2011; for the canyon below Tabernash, heights were set to 300 ft. to simulate the shading effect of canyon walls
AA	Coefficient in wind speed function for evaporative cooling	0.5E-09 - 4.0E-09 m^3/mb/s	Within recommended range of 0E-09 - 4E-09 (Hauser et al. 2007)
BB	Exponent in wind speed function for evaporative cooling	1.0E-09 - 3.0E-09 m^2/mb	Within recommended range of 1E-09 - 3E-09 (Hauser et al. 2007)
XL	Effective channel bed thickness of upper layer for bed heat conduction	5 - 25 cm	Within recommended range of 5 - 50 (Hauser et al. 2007)
XL2	Effective channel bed thickness of lower layer for bed heat conduction	15 cm	Within recommended range of 10 - 200 (Hauser et al. 2007)
DIF	Thermal diffusivity of bed material	27.7 cm^2/hr	Recommended value (Hauser et al. 2007)
CV	Bed heat storage capacity	0.68 cal/cm^3°C	Recommended value (Hauser et al. 2007)
BETW	Fraction of solar radiation absorbed in surface 0.6 m of water	0.4 cal/cm^3°C	Recommended value (Hauser et al. 2007)
BEDALB	Albedo of bed material	0.2	From Hauser et al. (2007): 0.05 - 0.1 = dark, algae-covered bed; 0.25 = average channel bed; 0.5 = light-colored sandy bed
SHSOL	Fraction of solar radiation absorbed by shaded water	0.2	Recommended value (Hauser et al. 2007)
SHDBT	Fraction of drybulb/dewpoint depression by which drybulb is cooler over shaded water	0.5	Recommended value (Hauser et al. 2007)
EXCO	Light extinction coefficient	0.05	Recommended for clean water (Hauser et al. 2007)
Manning's n	Roughness coefficient	0.027 - 0.100	Within reasonable range for river (Chow 1959)

Table 6. Calibration summary table for 2010.

		At Rendezvous Bridge	Below CR8 & Hammond Ditch	Above Fraser San. Dist.	Below Fraser San. Dist.	Below Crooked/Pole Creek	Below Granby San. Dist.
Daily Average Temperature	**R^2**	0.98	0.97	0.97	0.96	0.90	0.89
	RMSE (°C)	0.40	0.48	0.54	0.55	0.99	1.16
	MAE (°C)	0.30	0.39	0.41	0.41	0.84	0.99
Daily Minimum Temperature	**R^2**	0.97	0.97	0.96	0.95	0.90	0.87
	RMSE (°C)	0.33	0.48	0.57	0.61	1.00	1.35
	MAE (°C)	0.24	0.35	0.42	0.45	0.78	1.10
Daily Maximum Temperature	**R^2**	0.95	0.92	0.93	0.89	0.89	0.87
	RMSE (°C)	0.68	0.92	0.89	1.22	1.26	1.36
	MAE (°C)	0.51	0.78	0.66	0.93	1.06	1.14

Table 7 shows the R^2, RMSE, and MAE calculated for the daily average, minimum, and maximum temperature at each site. All RMSE and MAE values were less than 1.5°C. As with the calibration run, there was a general trend of underprediction of maximum temperatures in early summer and overprediction of maximum temperatures in late summer. Simulated temperatures from the model did follow observed monthly trends and temperatures rose and fell accordingly with meteorological conditions. While the mean error values did not increase spatially, the residuals were largest at the site furthest downstream. This is likely due to the unknowns and uncertainties in the model that were mentioned previously.

Table 7. Validation summary table for 2007.

		At Rendezvous Bridge	Below CR8 & Hammond Ditch	Above Fraser San. Dist.	Below Fraser San. Dist.	Below Crooked/Pole Creek	Below Granby San. Dist.
Daily Average Temperature	**R^2**	No data	0.96	0.97	0.95	No data	0.84
	RMSE (°C)	No data	0.65	0.64	0.73	No data	1.19
	MAE (°C)	No data	0.53	0.53	0.59	No data	0.96
Daily Minimum Temperature	**R^2**	No data	0.97	0.96	0.95	No data	0.80
	RMSE (°C)	No data	0.79	0.60	0.72	No data	1.44
	MAE (°C)	No data	0.64	0.50	0.60	No data	1.12
Daily Maximum Temperature	**R^2**	No data	0.88	0.92	0.91	No data	0.79
	RMSE (°C)	No data	1.16	1.11	1.14	No data	1.45
	MAE (°C)	No data	0.95	0.92	0.88	No data	1.20

Calibration and Validation Summary

Simulated flows and stages were very similar to observed flows and stages. Mass balance errors were low and within the recommended range. The calibration and validation runs of the water temperature model met all targets. Simulated temperatures tracked well with observed temperatures and followed the same monthly trends. RSME and MAE were all less than 1.5°C. While some errors and residuals increased in a downstream fashion, this was likely due to the unknowns associated with predicting tributary temperatures and was probably not indicative of an overall error in the model.

MODEL APPLICATION

Scenario Years

Following calibration and validation, the Fraser River dynamic water temperature model was applied to simulate hourly water temperatures on the Fraser River under different flow years and scenarios. This section documents the results from the flow scenario years selected by CDPHE: 1948, 1959, 1963, 1978 and 1987. These years were selected because they represent the critical conditions under which cumulative flow effects are greatest and temperature impacts are most likely to occur. The months of May to October were selected because these are the months when temperature exceedances have occurred in the Fraser River basin.

Simulated flows for the five years were estimated using data from PACSM simulations of streamflow scenarios. A point flow model (Wilson Water Group 2014) used the PACSM data and mass balance equations to estimate streamflow at points of interest that were not available from the PACSM simulations. 2007 meteorological data were used for all simulations, thus the primary difference between years and streamflow scenarios is flow. Since flow was one of the variables within the empirical models used to predict tributary water temperatures (as well as the Fraser River at the Winter Park Sanitation District), tributary water temperatures also vary between years and streamflow scenarios.

Meteorological data from 2007 were used for each model simulation because it was one of the hottest years in 63 years of temperature record (1948-2010) according to a weather station located at Grand Lake (Hydros Consulting Inc. 2011). In particular, July and August 2007 were very hot months. July was the 6th hottest in the 62 years of record for that month (1949-2010). The average July 2007 temperature was 1.6°C warmer than the 62-year average. August 2007 was the hottest in the 63 years of record for that month (1948-2010). The average August 2007 temperature was 2.0°C warmer than the 63-year average (Hydros Consulting Inc. 2011). 2007 temperatures were also warmer than average at the weather station located in Fraser (National Climatic Data Center climate normals data 1981-2010). Compared to the 30-year average, June 2007 was 2.12°C warmer, July 2007 was 2.31°C warmer, August 2007 was 2.26°C warmer and September 2007 was 1.23°C warmer. May and October 2007 were similar to the 30-year average (Figure 2). Since air temperature is an important factor influencing river temperatures, using 2007 meteorological data may cause the analysis to overestimate the impacts of the various scenarios. For instance, the number of exceedances predicted for July and August by the model is likely to be higher than would be simulated for a more average meteorological year.

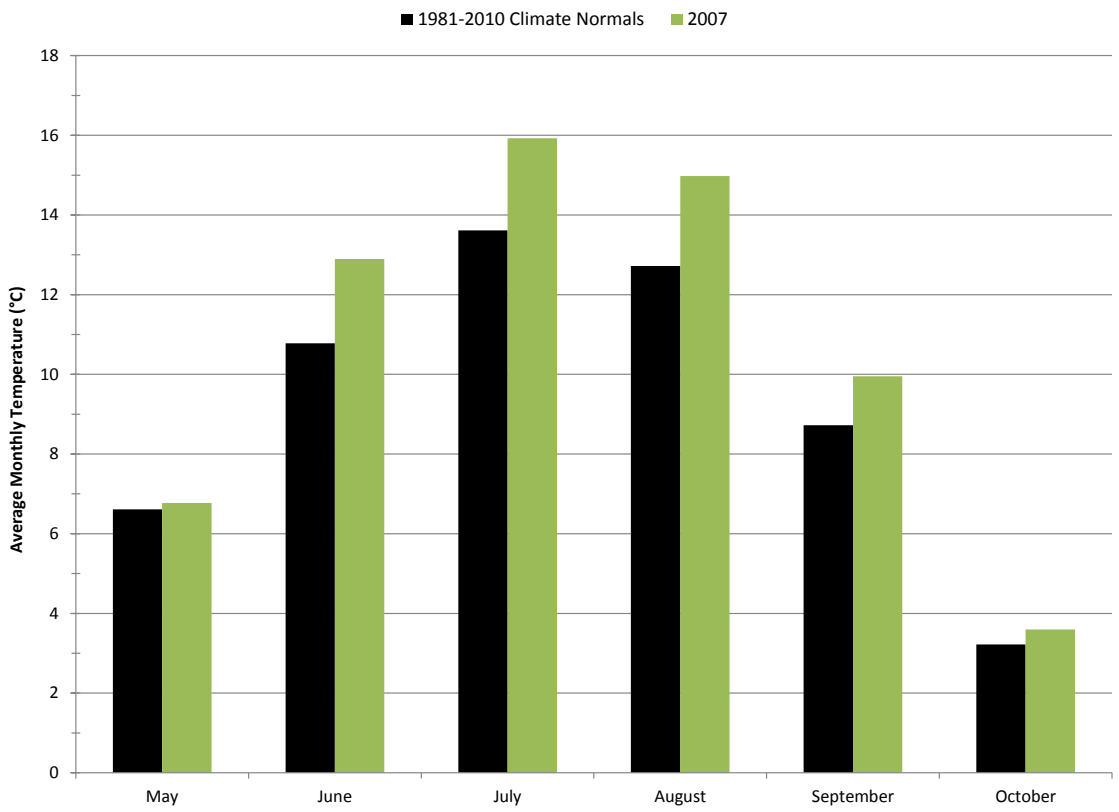

Figure 2. 2007 average monthly air temperature vs. 1981-2010 average monthly air temperature. Data are from the National Climatic Data Center's climate normals data, Fraser weather station.

Modeling results focus on three locations in the Fraser River: at the Rendezvous Bridge, downstream of Crooked Creek and at the Colorado River confluence. Modeling results are also presented for the tributaries of Vasquez, St. Louis and Ranch creeks.

CDPHE's Water Quality Control Division has established acute and chronic water temperature criteria to protect against negative effects to aquatic life (CDPHE 2013). The acute criterion protects against lethal effects and the chronic criterion protects against sublethal effects on behavior, metabolism, growth and reproduction (CDPHE 2011). CDPHE defines the chronic standard for temperature as the weekly average temperature (WAT), which is the mathematical mean of multiple, equally-spaced temperatures over a seven-day consecutive period, with a minimum of three data points spaced equally throughout the day (CDPHE 2011). CDPHE defines the acute standard for temperature as the daily maximum (DM), which is the highest two-hour average water temperature recorded during a 24-hour period (CDPHE 2011). The acute and chronic standards depend upon the classification of the stream. The Fraser River upstream of Rendezvous Bridge is considered a Tier I coldwater stream, as are all tributaries to the Fraser River. The Fraser River downstream of Rendezvous Bridge is considered a Tier II coldwater stream. Temperature standards are listed in Table 8. WATs and DMs were calculated using the Water Quality Control Division's Temperature Analysis Program, v4.3.

For each flow scenario year, hydrographs of the Fraser River at each location as calculated from the point flow model are included. Simulated hourly temperature graphs are also included, as well as graphs of WATs and DMs. WAT and DM exceedances (number of days above the temperature standard) are provided. Typically, WAT exceedances are listed in weeks, rather than days. However, to provide for more precise comparisons between flow scenarios, WAT exceedances are reported on a daily time step. Graphs of WATs, DMs and exceedances for the three primary tributaries of interest (Vasquez, St. Louis and Ranch creeks) are also included.

Table 8. CDPHE water temperature standards.

		Temperature Standard (°C)		
Stream Classification	**Applicable Months**	**WAT (Chronic)**	**DM (Acute)**	**Location Where Applied**
Cold Stream Tier I	June – Sept.	17.0	21.7	Rendezvous Bridge; Vasquez Creek; St. Louis Creek; Ranch Creek
	Oct. - May	9.0	13.0	
Cold Stream Tier II	April – Oct.	18.2	23.8	Below Crooked Creek; Colorado River Confluence
	Nov. - March	9.0	13.0	

1948 Scenario Year

Hydrology

For each scenario year, it is important to understand the nature of the differences between streamflow scenarios. Flow changes in the Fraser River basin are largely reflective of diversions via the Moffat Tunnel and the tunnel diversions depend on if and when Gross Reservoir would fill, how long it stays "topped-off" and when contents begin to decline. Whether or not Gross Reservoir would fill in any given year can also depend on its contents and the hydrology in previous years. For each scenario year, a description of the hydrology and how it changes under the streamflow scenarios (EIS 285, EIS 345 and Alt 1a) is provided.

As noted previously, streamflow in the mainstem Fraser River was estimated with a point flow model that uses PACSM simulated flows for streamflow scenarios and mass balance equations. For several dates in 1948 under scenarios EIS 345, Alt 1a and Alt 8a, corresponding PACSM simulation data showed low flows in the mainstem Fraser River between the Fraser at Winter Park gage (USGS Gage 09024000) and the Hammond No. 1 Ditch diversion. These low flows caused the ADYN portion of the dynamic temperature model to stop running. It was therefore necessary to add a small amount of flow to scenarios EIS 345, Alt 1a and Alt 8a in certain locations and for certain dates to allow the ADYN model to run. Through trial and error, it was found that an additional 1 cfs (flow increased from 4 cfs to 5 cfs)

added to the upstream boundary (Fraser River at the Winter Park Water and Sanitation District) from September 16 to September 26 was sufficient to allow the ADYN model to run. Since input temperatures at the upstream boundary were developed from empirical models, it was possible to test whether the 1-cfs increase in flow resulted in a change in temperature at the upstream boundary. Results indicated that adding this small amount of flow changed temperatures at most by 0.05°C.

Discharges at the three focus locations are shown in Figure 3 - Figure 5. According to the PACSM/point flow model simulations, the differences in flow between Alt 1a and Alt 8a are minimal except for a few dates. Overall, the annual virgin flow for the Fraser River below Crooked Creek in 1948 was 95% of average, and it followed a wet year (virgin flow in 1947 was 117% of average annual). The virgin flow in May was slightly above average (109% of the monthly average), while the virgin flow in June and July was much less than average (81% and 69% of the monthly average, respectively).

In 1948 the Moffat Project would cause large flow decreases from late May through mid-June, with small decreases from mid-June through the end of June (this is the difference between EIS 345 and Alt 1a). For cumulative conditions, there are large flow decreases from late May through mid-June, with smaller decreases primarily from mid-June through early July (this is the difference between EIS 285 and Alt 1a). In the previous year, 1947, Gross Reservoir would fill under EIS 285, EIS 345 and Alt 1a. Contents would decline during the winter months prior to the spring runoff in 1948 because the supply is being used to meet customer demand. Gross Reservoir begins the runoff season in 1948 with slightly less contents with EIS 345 than EIS 285. Consequently, it takes an extra day to fill Gross Reservoir with EIS 345 as compared to EIS 285, and it takes over 2 ½ weeks longer to fill the enlarged Gross Reservoir with Alt 1a. After Gross Reservoir fills, the flow in the Fraser River increases.

While Gross Reservoir is full, much of the difference in Fraser River flows between the three streamflow scenarios is attributable to the diversions needed to keep Gross Reservoir full and to meet customer demands. The demands for Alt 1a are higher than EIS 345, which are higher than the demand for EIS 285, so there are slight differences in the amount diverted and the remaining flow in the Fraser River basin while Gross Reservoir remains topped-off. The difference in Fraser River basin flows between EIS 285 and the other two scenarios is also due to higher demands of entities within the Fraser River basin (e.g., municipal and snowmaking demands).

After the runoff declines and Gross Reservoir is no longer full, the amount diverted for all three scenarios is once again similar, and thus Fraser River flows are also more similar. By the end of June the runoff has diminished and both Alt 1a and EIS 345 divert the same amount of water. There is slightly less water diverted in July with EIS 285 as Gross Reservoir remains topped-off, but by late July all three scenarios are diverting similar amounts of water because Gross Reservoir, existing and enlarged, has space to store water. Note that there is a slight decrease in flows in the Fraser River on September 15, when the U.S. Forest Service bypass flow requirement at upstream diversions also decreases.

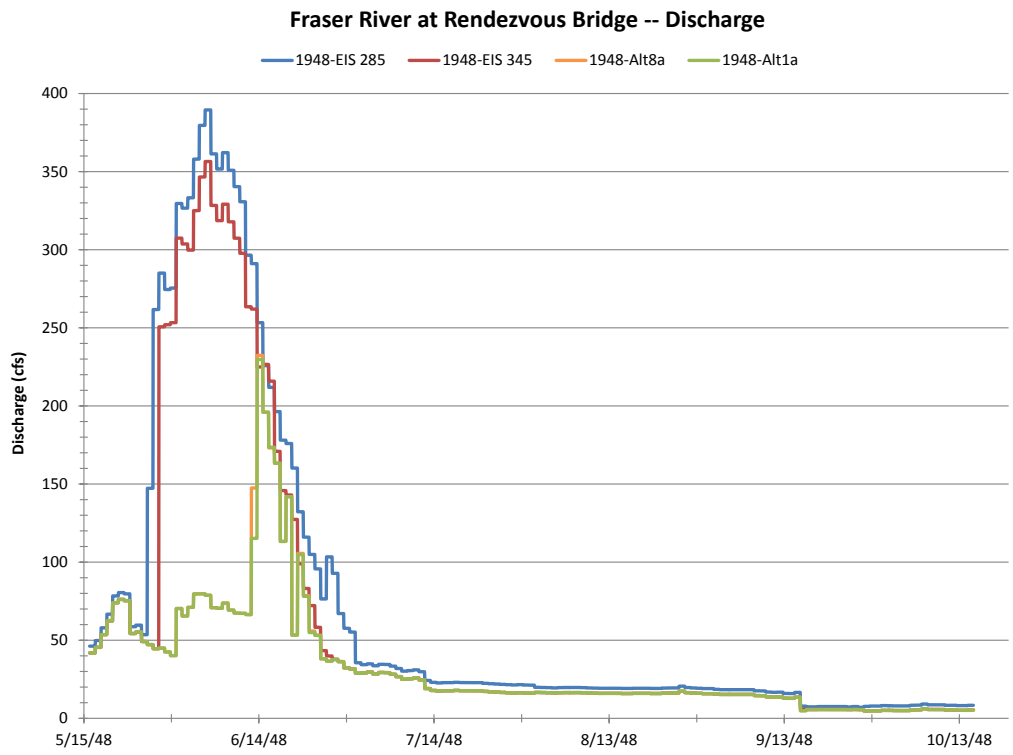

Figure 3. Discharge in the Fraser River at Rendezvous Bridge, 1948.

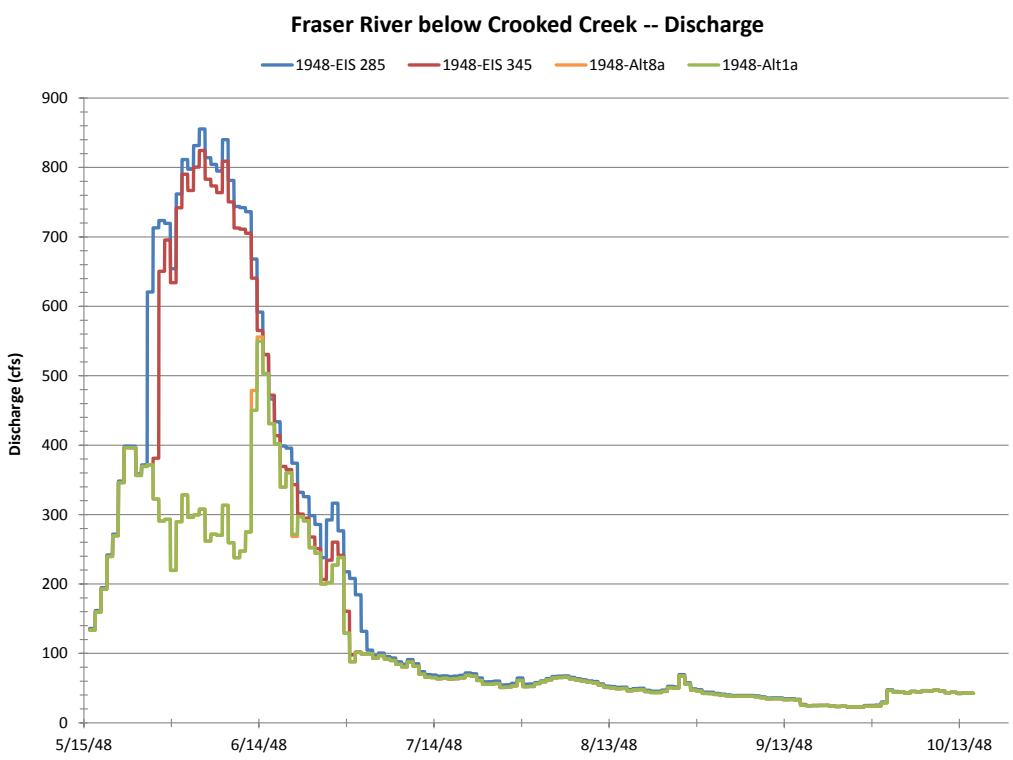

Figure 4. Discharge in the Fraser River below Crooked Creek, 1948.

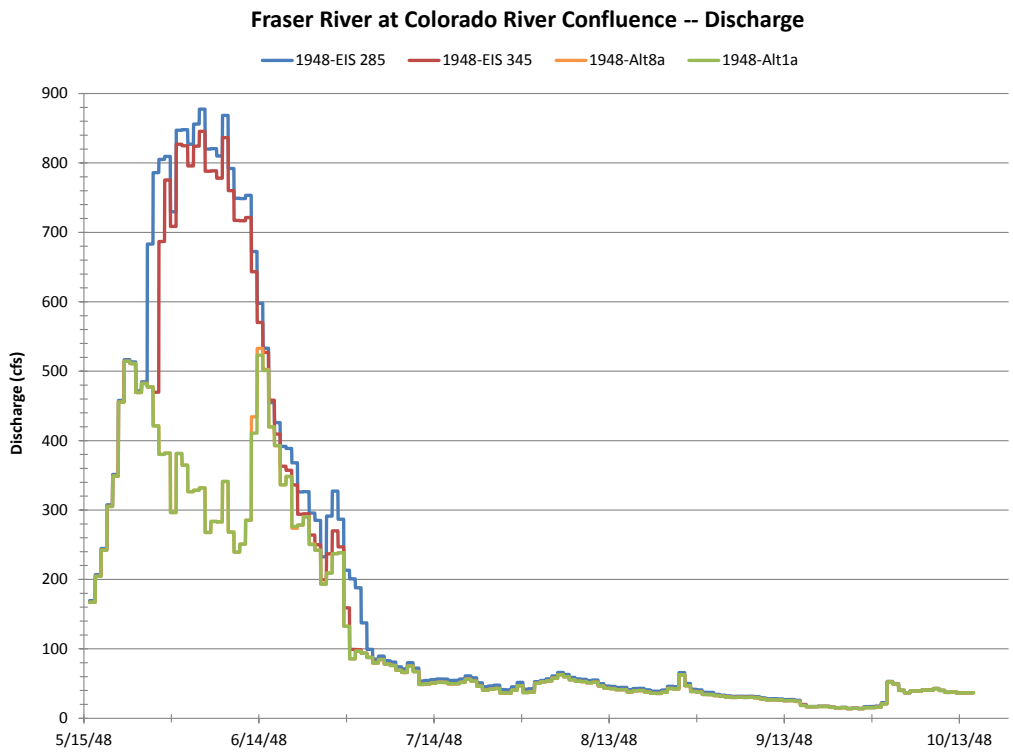

Figure 5. Discharge in the Fraser River at the Colorado River confluence, 1948.

Temperatures

Figure 6 - Figure 8 show the simulated hourly temperatures for the three focus locations. Because there are only small differences in flow between Alt 1a and Alt 8a, the simulated temperatures are also the same. For the Fraser River at Rendezvous Bridge, temperatures are warmer with the EIS 345 scenario compared to EIS 285 for nearly every day of the simulation. The average difference in temperature is 0.45°C and the maximum difference is 5.67°C. Temperatures are also warmer under Alt 1a compared to EIS 285. The average difference in temperature is 0.76°C and the maximum difference is 5.67°C. Comparing EIS 345 to Alt 1a, the average difference in temperature is 0.31°C and the maximum difference is 5.52°C. From July through mid-October, temperatures for these two scenarios are nearly equal. It is apparent from Figure 6 that the lower flows observed under Alt 1a in June translate to warmer temperatures. For the Fraser River below Crooked Creek, similar temperature profiles were observed as for the Rendezvous Bridge location except that the temperature differences between scenarios are smaller. Between EIS 285 and EIS 345, the average difference in temperature is 0.32°C and the maximum difference is 2.97°C. Between EIS 285 and Alt 1a, the average difference in temperature is 0.66°C and the maximum difference is 4.67°C. Between EIS 345 and Alt 1a, the average difference in temperature is 0.34°C and the maximum difference is 4.52°C. From July through mid-October, temperatures for these two scenarios are nearly equal. It is again apparent from Figure 7 that the lower flows observed under Alt 1a in June translate to warmer temperatures. For the Fraser River at the Colorado River confluence, the average difference in temperature between EIS 285 and EIS 345 is 0.18°C and the maximum difference is 3.23°C. Between EIS 285 and Alt 1a, the average difference in

temperature is 0.56°C and the maximum difference is 4.93°C. Between EIS 345 and Alt 1a, the average difference in temperature is 0.38°C and the maximum difference is 4.70°C. From July through mid-October, temperatures for these two scenarios are nearly equal. Maximum temperatures under EIS 345 and Alta 1a are actually slightly cooler than those under EIS 285 from August through mid-October.

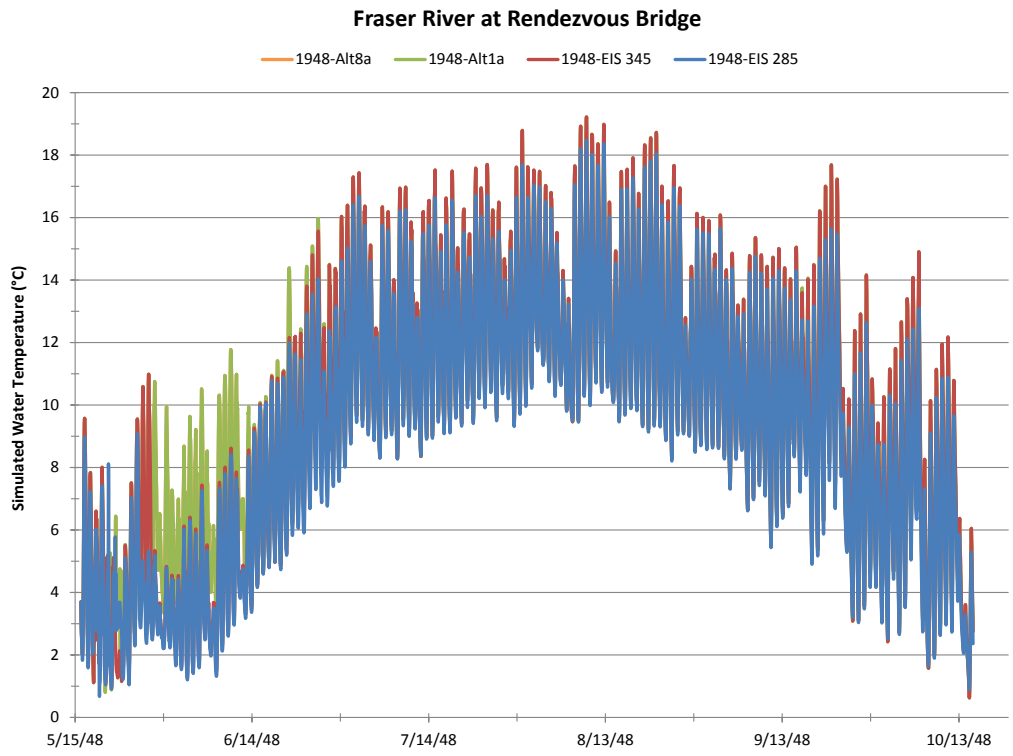

Figure 6. Simulated hourly temperatures in the Fraser River at Rendezvous Bridge, 1948.

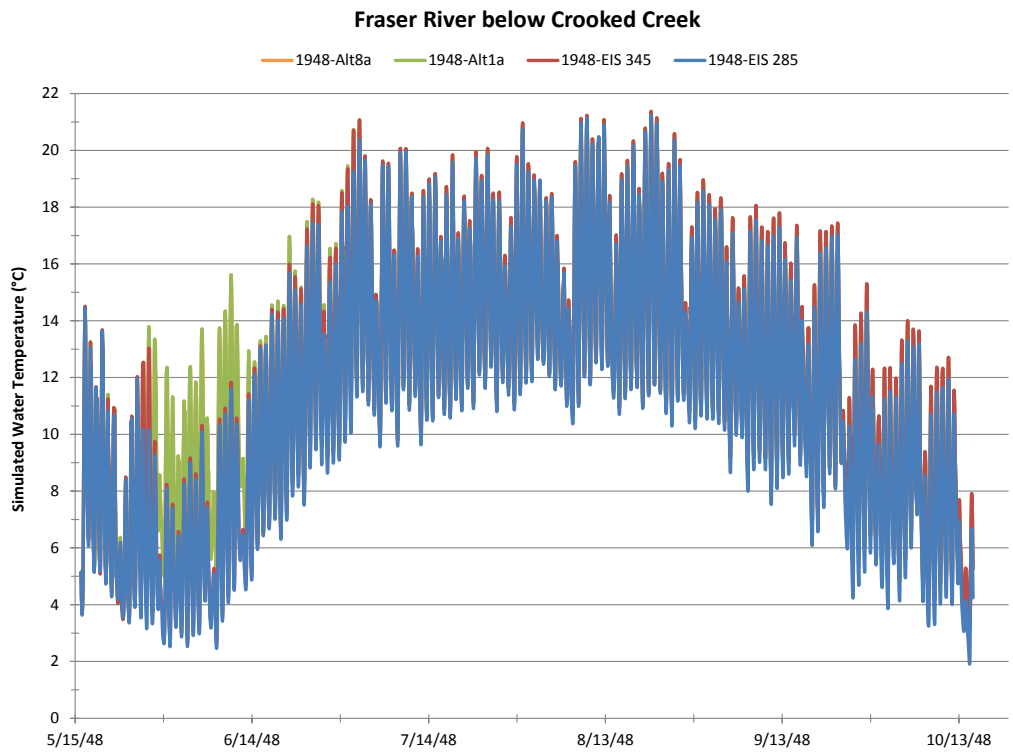

Figure 7. Simulated hourly temperatures in the Fraser River below Crooked Creek, 1948.

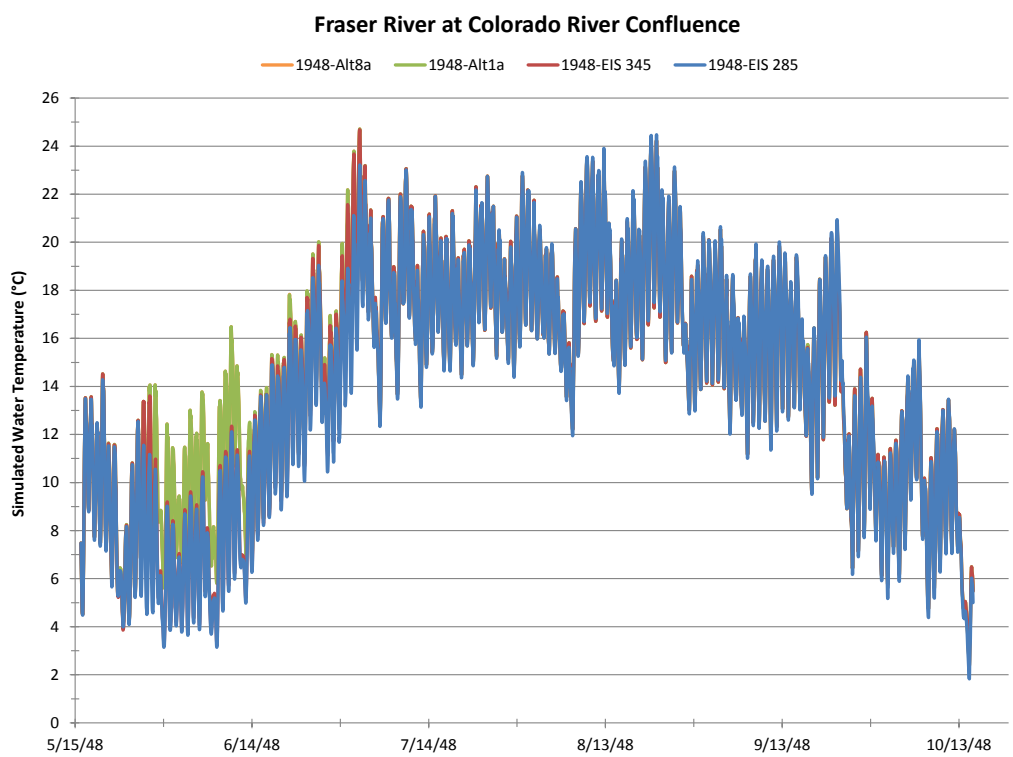

Figure 8. Simulated hourly temperatures in the Fraser River at the Colorado River confluence, 1948.

WATs and DMs

Fraser River at Rendezvous Bridge

Weekly Average Temperature (WAT) (Figure 9)

EIS 345 and Alt 1a WATs are greater than those for EIS 285 but all are below the chronic temperature standard.

Daily Maximum (DM) (Figure 10)

- EIS 285: The DM standard is not exceeded.
- EIS 345: The DM standard is exceeded for 3 days in October.
- Alt 1a: The DM standard is exceeded for 3 days in October. Therefore, with Alt 1a the DM standard is exceeded 3 more days compared to current conditions; none of the days are attributable to Denver Water's Moffat Project.

Table A - 1 (see Appendix A) provides the temperatures and days for which exceedances occur. These days are within the winter shoulder-season and could possibly be considered exemptions. The exemption is stated as follows (CDPHE 2011): "A winter shoulder-season exemption that allows temperature exceedances in cold-water streams for 30 days before the winter/summer transition, and 30 days after the summer/winter transition, provided that the natural seasonal progression of temperature is maintained and those exceedances are not the result of anthropogenic activities in the watershed."

Fraser River below Crooked Creek

Weekly Average Temperature (WAT) (Figure 11)

There are no exceedances of the WAT standard for any of the four streamflow scenarios. WATs are similar between scenarios with the exception of June.

Daily Maximum (DM) (Figure 12)

There are no exceedances of the DM standard for any of the four streamflow scenarios. DMs are similar between scenarios with the exception of June.

Fraser River at the Colorado River Confluence

Weekly Average Temperature (WAT) (Figure 13)

- EIS 285: The WAT standard is exceeded for 8 days in July and 20 days in August, for a total of 28 days.
- EIS 345: The WAT standard is exceeded for 17 days in July and 20 days in August, for a total of 37 days.
- Alt 1a: The WAT standard is exceeded for 17 days in July and 20 days in August, for a total of 37 days. Therefore, with Alt 1a the WAT standard is exceeded 9 additional days compared to current conditions; these additional days are not attributable to Denver Water's Moffat Project.

Table A - 2 provides the temperatures and days for which exceedances occur.

Daily Maximum (DM) (Figure 14)

- EIS 285: The DM standard is exceeded for 2 days in August.
- EIS 345: The DM standard is exceeded for 1 day in July and 2 days in August, for a total of 3 days.
- Alt 1a: The DM standard is exceeded for 1 day in July and 2 days in August, for a total of 3 days. Therefore, with Alt 1a the DM standard is exceeded 1 more day compared to current conditions; this day is not attributable to Denver Water's Moffat Project. Table A - 2 provides the temperatures and days for which exceedances occur.

Vasquez Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 15)

There are no exceedances of the WAT standard for any of the four streamflow scenarios. WATs are similar between scenarios with the exception of June.

Daily Maximum (DM) (Figure 16)

There are no exceedances of the DM standard for any of the four streamflow scenarios. DMs are similar between scenarios with the exception of June.

St. Louis Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 17)

There are no exceedances of the WAT standard for any of the four streamflow scenarios. WATs are similar between scenarios with the exception of June.

Daily Maximum (DM) (Figure 18)

- EIS 285: The DM standard is exceeded for 2 days in May.
- EIS 345: The DM standard is exceeded for 2 days in May.
- Alt 1a: The DM standard is exceeded for 2 days in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Table A - 3 provides the temperatures and days for which exceedances occur. These could possibly be considered exemptions since they fall within the shoulder-season.

Ranch Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 19)

There are no exceedances of the WAT standard for any of the four streamflow scenarios. WATs are similar between scenarios with the exception of June.

Daily Maximum (DM) (Figure 20)

- EIS 285: The DM standard is exceeded for 4 days in May.
- EIS 345: The DM standard is exceeded for 4 days in May.
- Alt 1a: The DM standard is exceeded for 5 days in May. Therefore, with Alt 1a the standard is exceeded 1 more day compared to current conditions. There is 1 day of additional exceedances as compared to full use of the existing system, which is attributable to the Moffat Project.

Table A - 4 provides the temperatures and days for which exceedances occur. The May exceedances could possibly be considered exemptions since they fall within the shoulder season.

Table 9 summarizes all exceedances for all locations. Table 10 summarizes the predicted increase in water temperature due to EIS 345 and Alt 1a (cumulative effects, plus Moffat Project) relative to EIS 285 (current conditions). In general, the stream temperatures will be higher in the Fraser River compared to current conditions. On average, the increase in WAT ranges from 0.1 to 2.1°C, with the largest WAT increase at the Colorado River confluence (3.67°C on June 11). On average, the increase in DM ranges from 0.2 to 2.1°C, with the largest DM increase at Rendezvous Bridge (5.51°C on May 27). Note that for the Fraser River at the Colorado River confluence, the average August and September WATs and DMs for EIS 345 and Alt 1a are slightly less than those for EIS 285 because the flows are slightly higher. This is due to slightly more carry-over storage in Gross Reservoir with EIS 345 and Alt 1a, which then fills sooner compared to EIS 285. This operation is needed to meet the higher customer demands in Denver Water's north system and reduce the risk of running out of water in the subsequent year for EIS 345 and Alt 1a.

Table 11 summarizes the predicted increase in water temperature due to the Moffat Project, i.e., Alt 1a WAT and DM increases relative to EIS 345. In general, the predicted increase in stream temperatures attributable to the Moffat Project diversions occur primarily in May and June.

Summary for the Fraser River Mainstem

For 1948, the model simulates temperatures that have exceedances under current conditions (EIS 285) at Rendezvous Bridge, none below the confluence with Crooked Creek and temperature exceedances again at the confluence with the Colorado River. With Alt 1a (cumulative effects with the Moffat Project), there will be additional temperature exceedances at the same two locations. However, none of the exceedances are attributable to the Moffat Project.

Summary for the Fraser River Tributaries

In Vasquez Creek, there are no WAT or DM exceedances identified for any of the four streamflow scenarios. In St. Louis Creek, there are exceedances of the DM standard under current and future conditions, but the number of exceedances is the same for all four scenarios. In Ranch Creek, there are exceedances of the DM standard under current and future conditions. In EIS 285 and EIS 345 the DM standard is exceeded a total of 4 days. In Alt 1a the DM standard is exceeded a total of 5 days. Therefore, with Alt 1a the DM standard is exceeded 1 more day compared to current conditions, which is attributable to the Moffat Project.

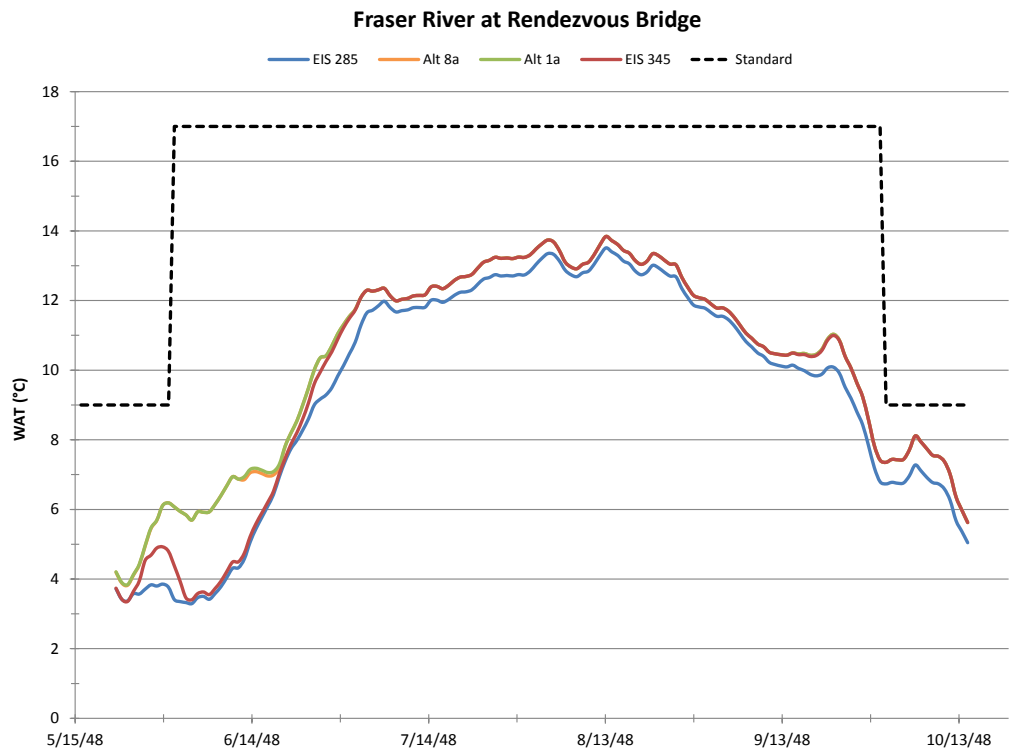

Figure 9. 1948 WATs, Fraser River at Rendezvous Bridge.

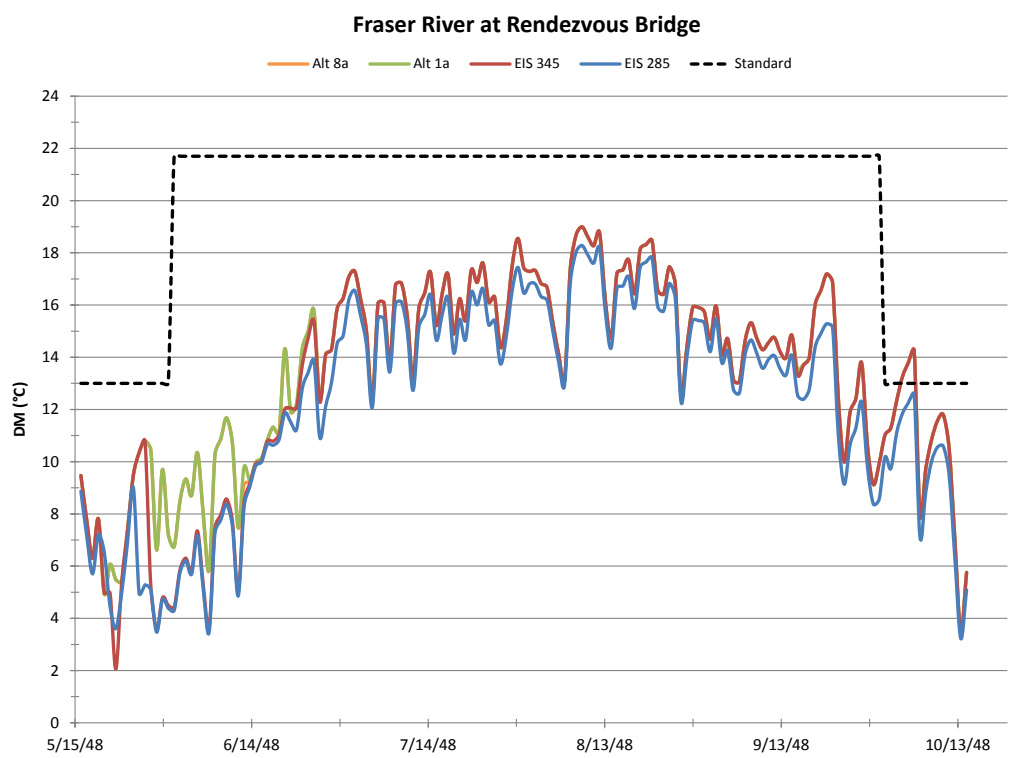

Figure 10. 1948 DMs, Fraser River at Rendezvous Bridge.

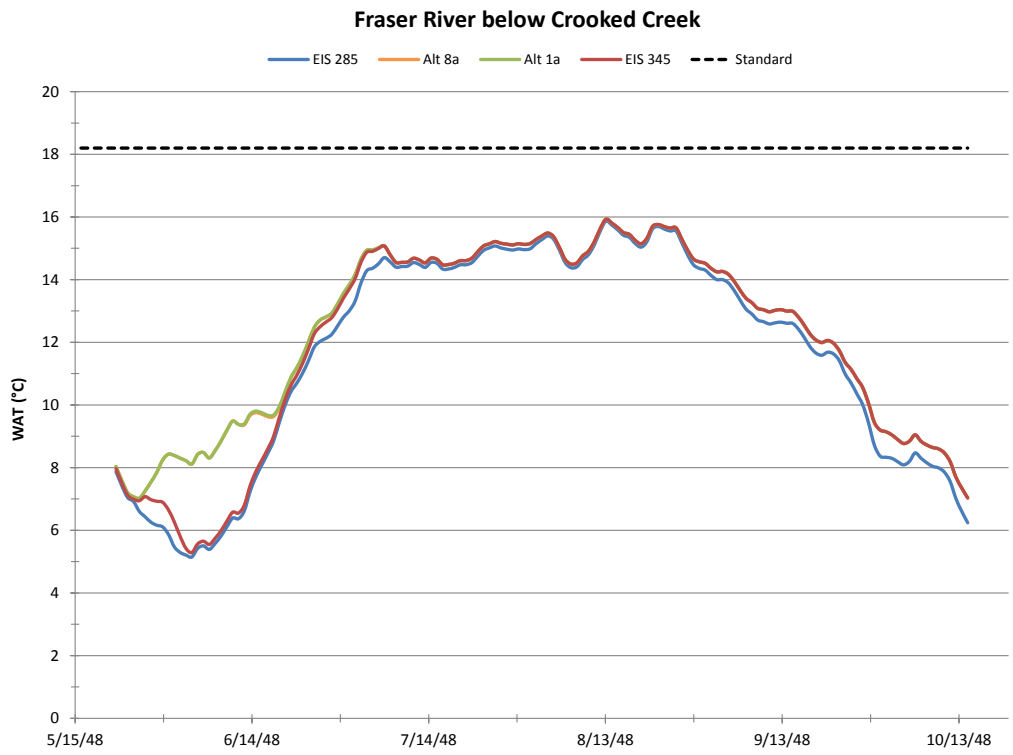

Figure 11. 1948 WATs, Fraser River below Crooked Creek.

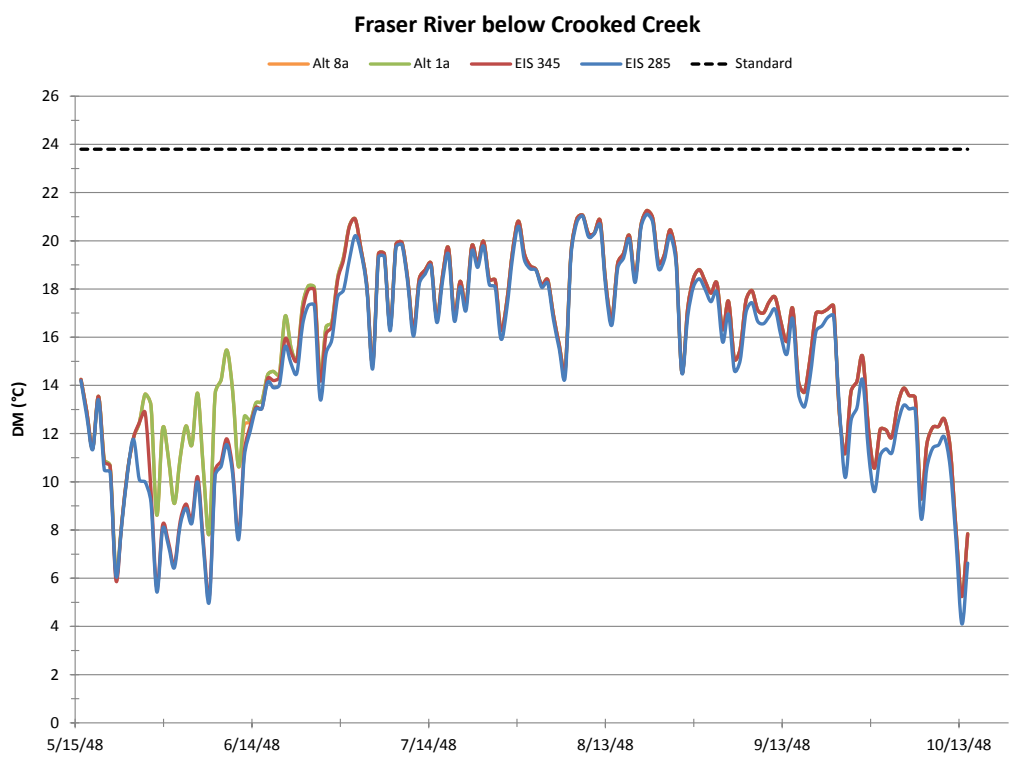

Figure 12. 1948 DMs, Fraser River below Crooked Creek.

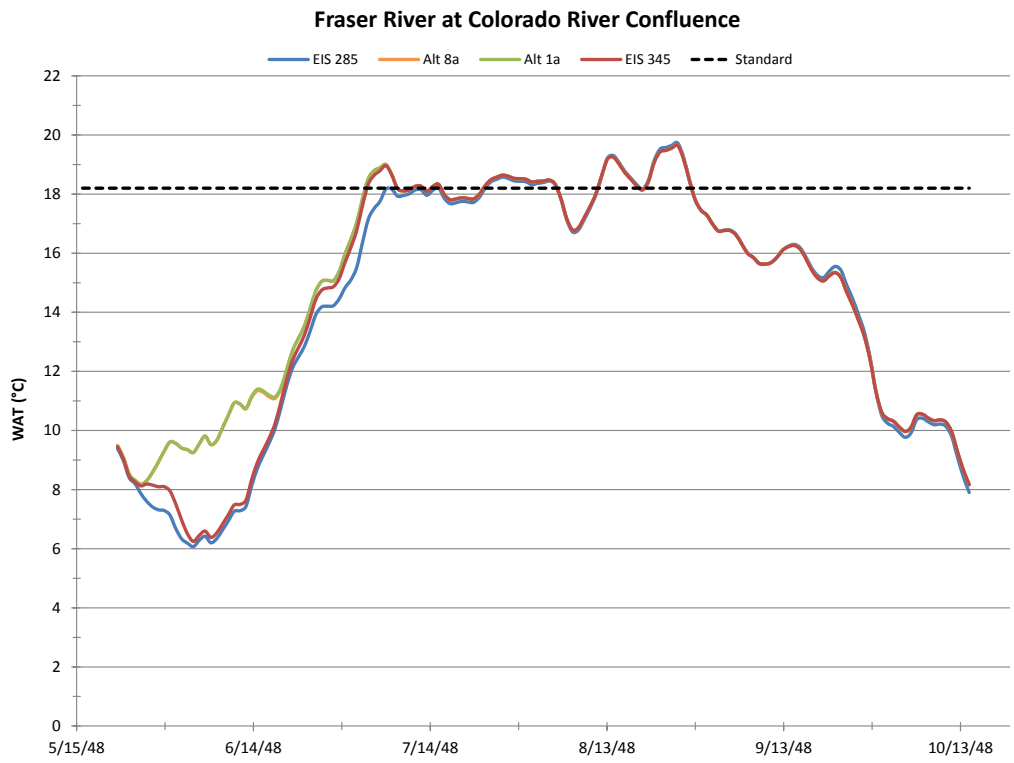

Figure 13. 1948 WATs, Fraser River at the Colorado River confluence.

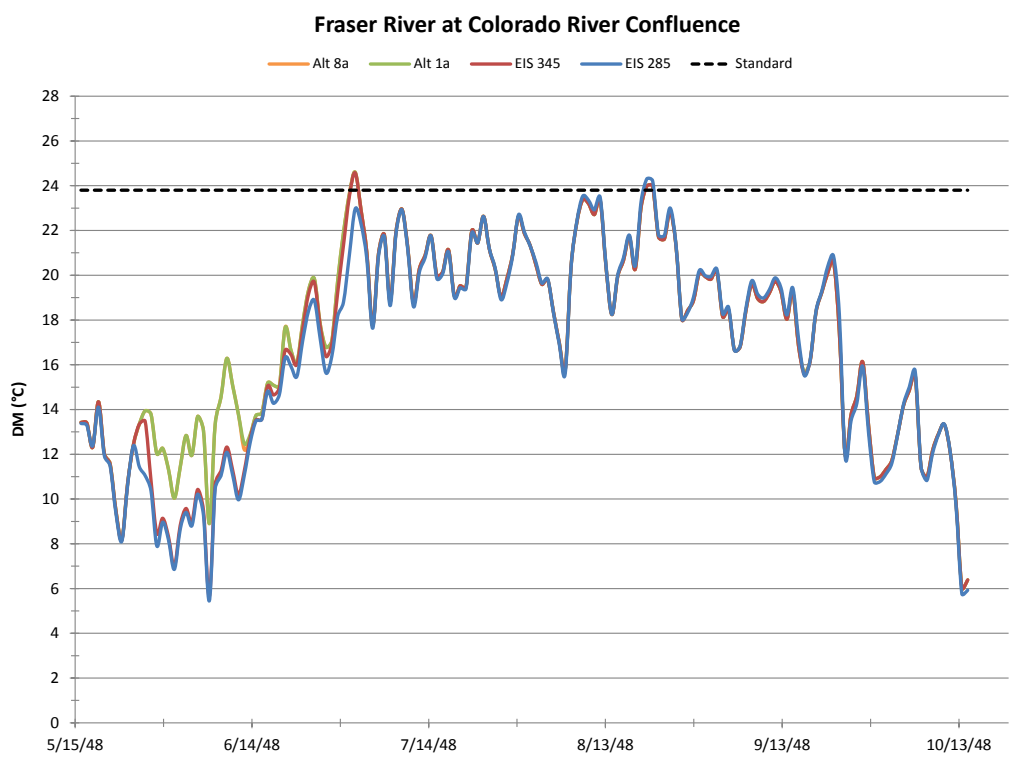

Figure 14. 1948 DMs, Fraser River at the Colorado River confluence.

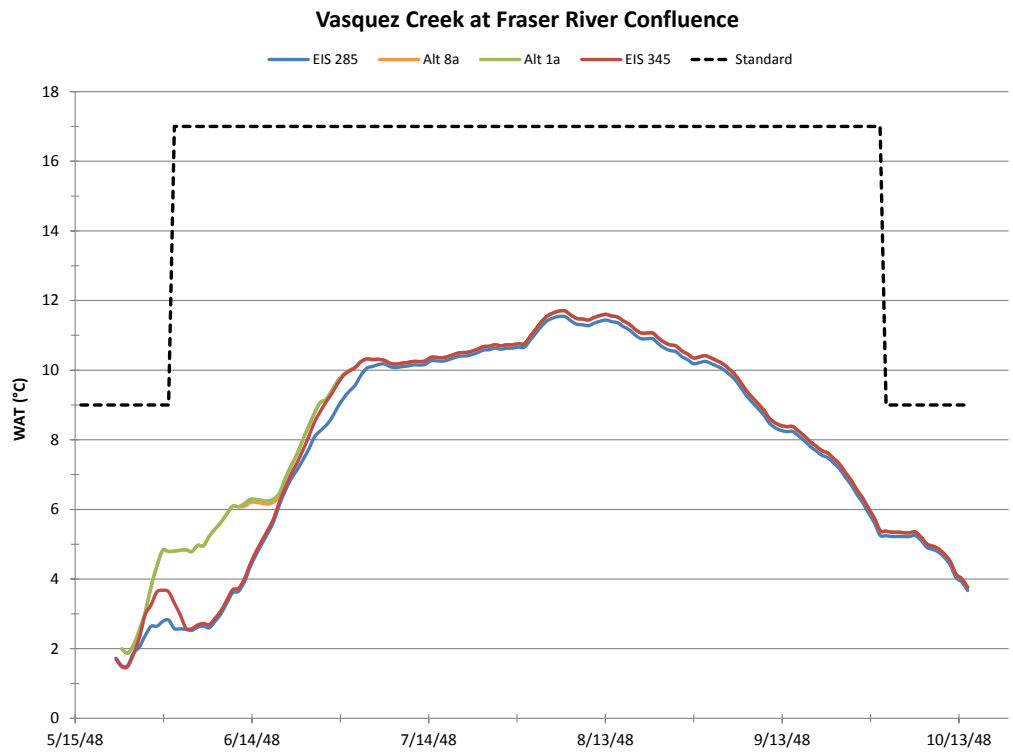

Figure 15. 1948 WATs, Vasquez Creek at the Fraser River confluence.

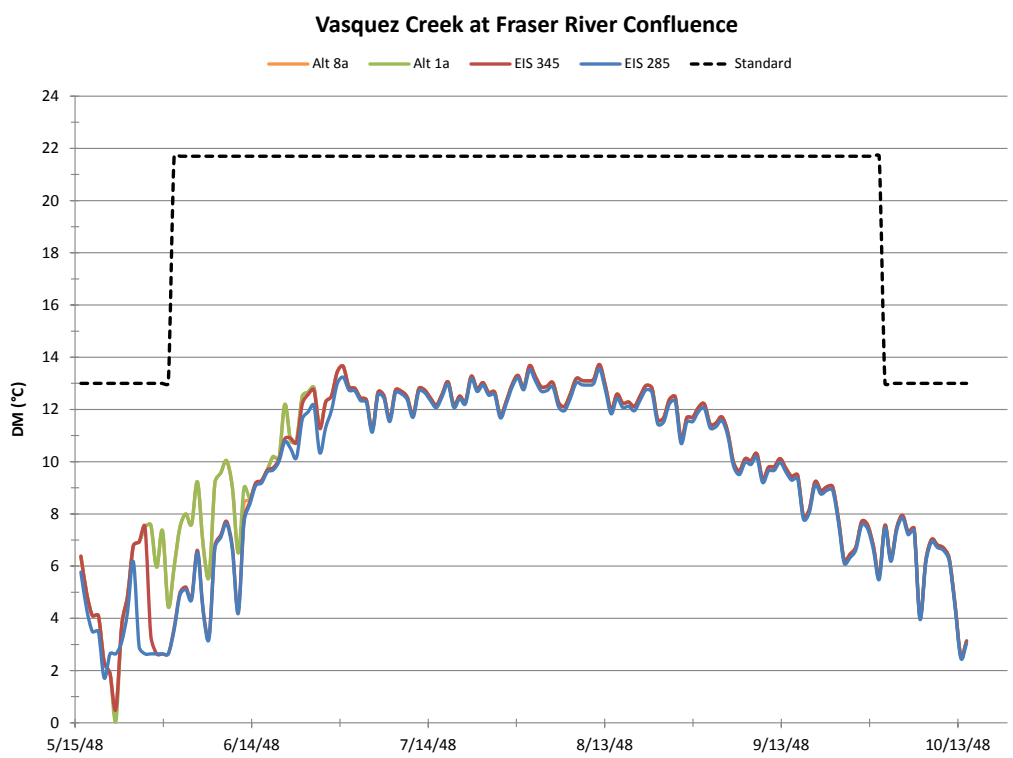

Figure 16. 1948 DMs, Vasquez Creek at the Fraser River confluence.

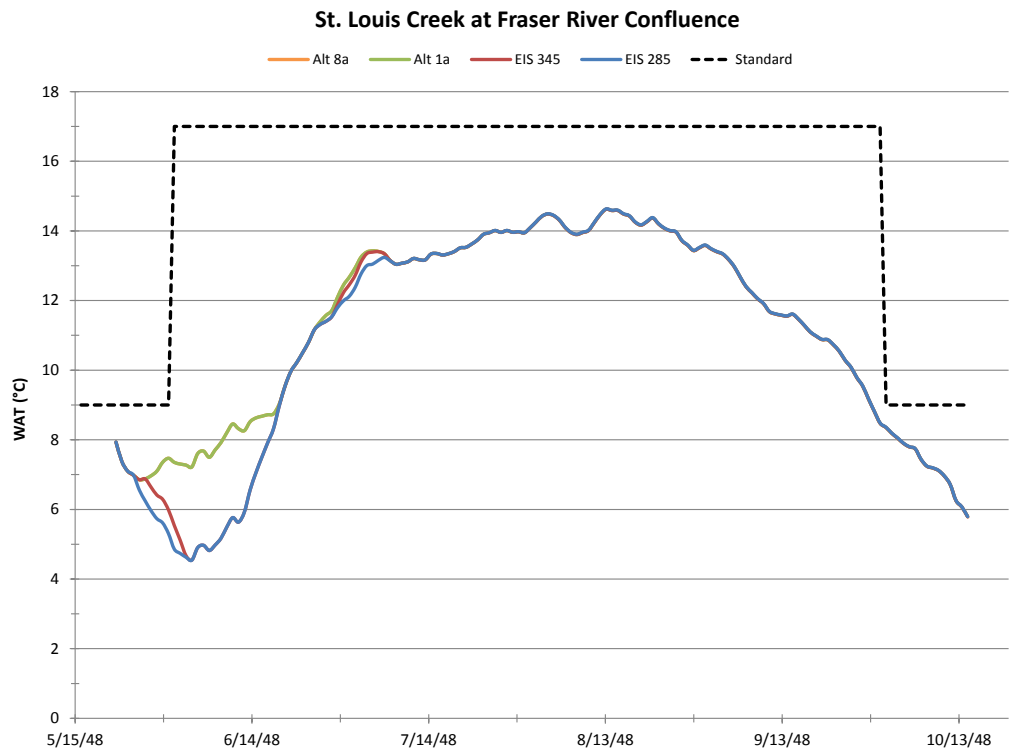

Figure 17. 1948 WATs, St. Louis Creek at the Fraser River confluence.

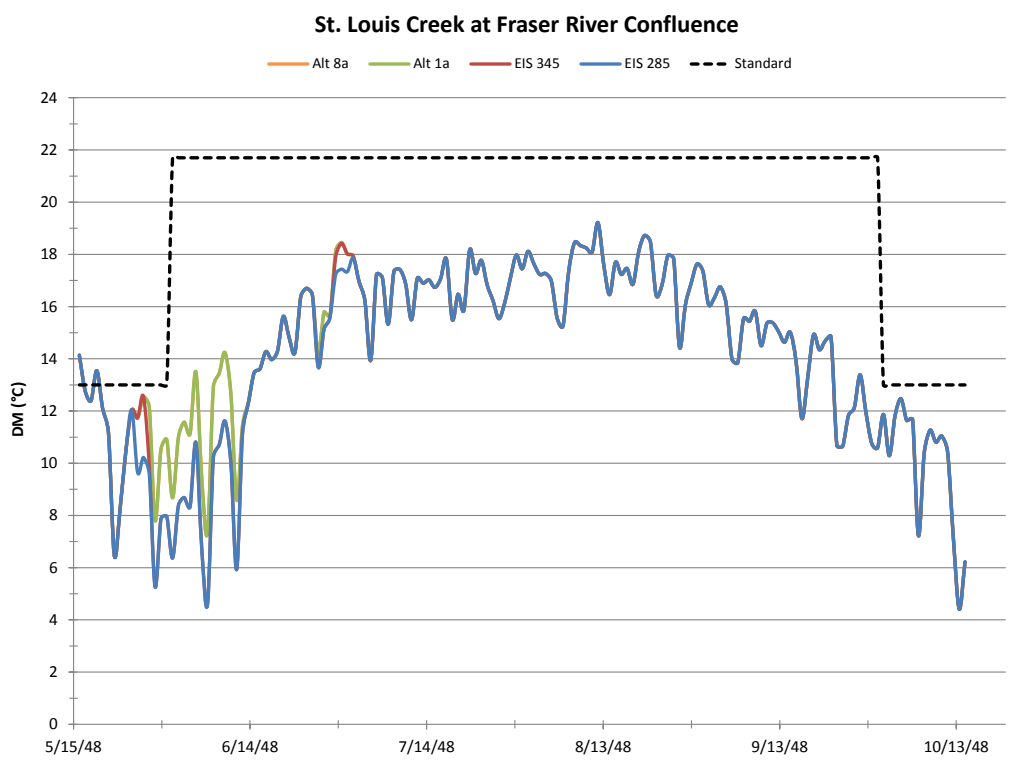

Figure 18. 1948 DMs, St. Louis Creek at the Fraser River confluence.

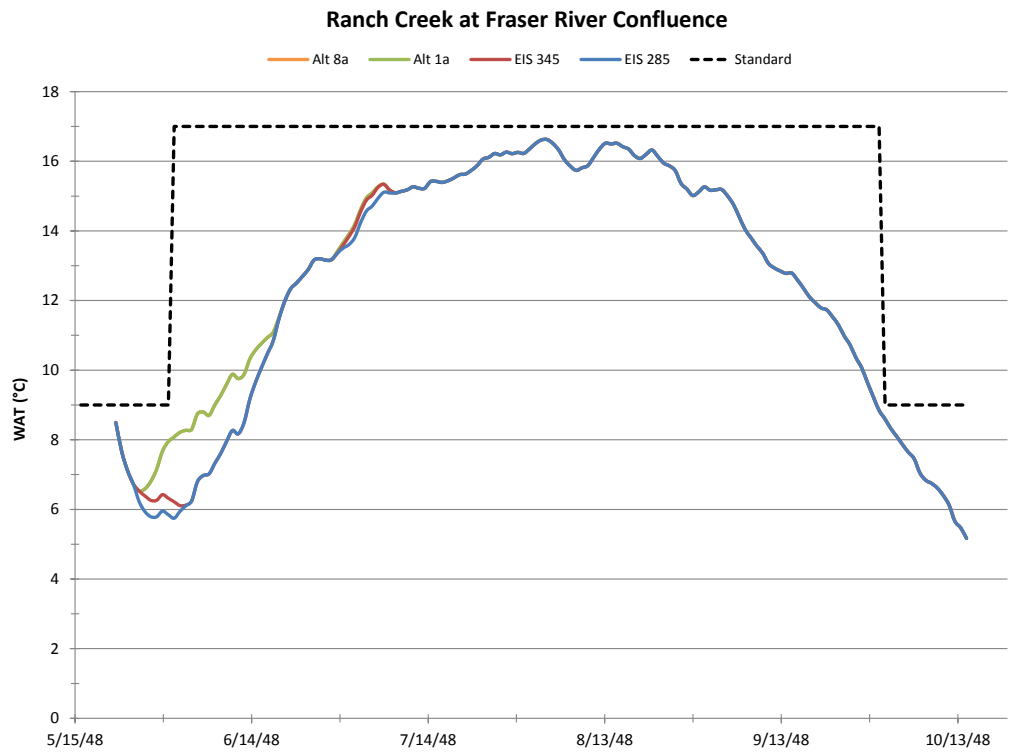

Figure 19. 1948 WATs, Ranch Creek at the Fraser River confluence.

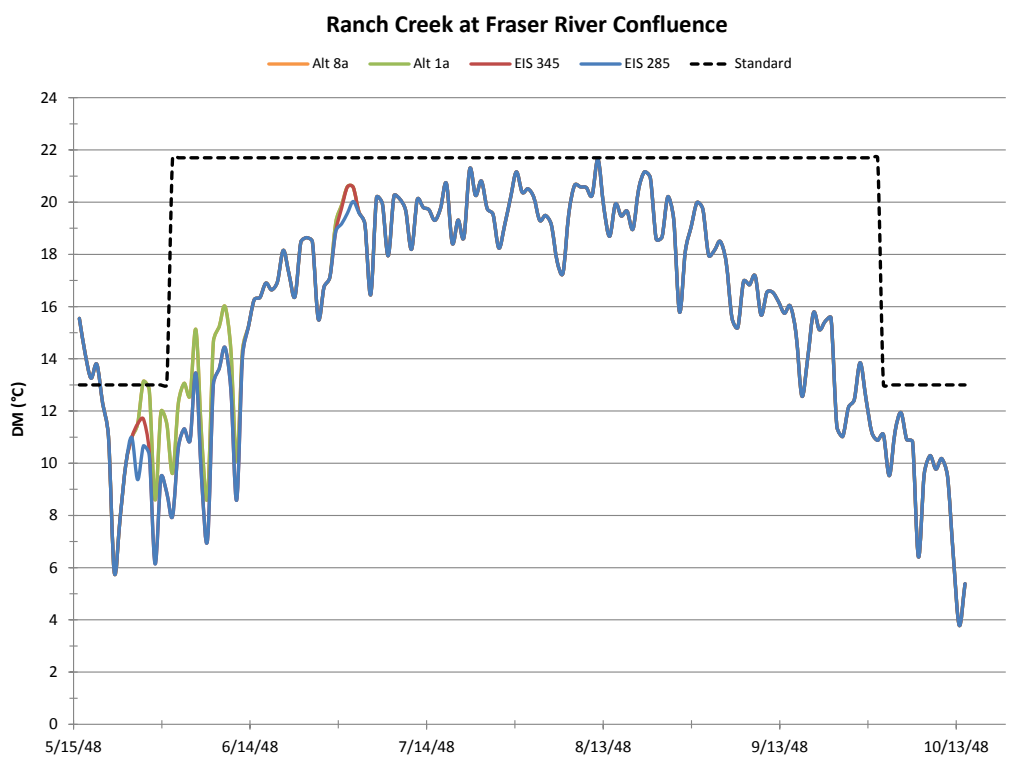

Figure 20. 1948 DMs, Ranch Creek at the Fraser River confluence.

Table 9. Summary of WAT and DM exceedances, 1948 flow scenario year.

1948	Rendezvous Bridge				Below Crooked Creek				Colorado River Confluence			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	13.51	13.84	13.84	13.84	15.87	15.93	15.93	15.93	19.73	19.65	19.66	19.65
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	8	17	17	17
August	0	0	0	0	0	0	0	0	20	20	20	20
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	18.28	19.00	19.00	19.00	21.10	21.26	21.26	21.26	24.31	24.58	24.61	24.61
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	1	1	1
August	0	0	0	0	0	0	0	0	2	2	2	2
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	3	3	3	0	0	0	0	0	0	0	0

1948	Vasquez Creek				St. Louis Creek				Ranch Creek			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	11.55	11.70	11.70	11.70	14.63	14.62	14.62	14.62	16.63	16.63	16.63	16.63
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	13.56	13.72	13.72	13.72	19.22	19.21	19.21	19.21	21.65	21.65	21.65	21.65
# of Days Above Standard:												
May	0	0	0	0	2	2	2	2	4	4	5	5
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0

Table 10. EIS 345 and Alt 1a WAT and DM increases relative to EIS 285, 1948 flow scenario year.

1948	Rendezvous Bridge		Below Crooked Creek		Colorado River Confluence	
	EIS 345	Alt 1a	EIS 345	Alt 1a	EIS 345	Alt 1a
Largest WAT Increase (°C)	1.09	2.66	0.83	3.10	1.25	3.67
Avg. WAT Increase (°C):						
May	0.53	1.23	0.44	0.96	0.42	0.88
June	0.35	1.67	0.28	1.81	0.35	2.11
July	0.48	0.48	0.24	0.26	0.35	0.39
August	0.31	0.32	0.11	0.11	-0.01	-0.01
September	0.49	0.50	0.40	0.40	-0.06	-0.06
October	0.72	0.72	0.66	0.66	0.17	0.17
Largest DM Increase (°C)	5.51	5.51	2.87	4.16	2.62	4.20
Avg. DM Increase (°C):						
May	0.78	2.06	0.45	1.41	0.40	1.23
June	0.52	1.82	0.36	1.77	0.42	1.94
July	0.74	0.74	0.26	0.26	0.23	0.23
August	0.53	0.53	0.19	0.19	-0.08	-0.08
September	0.92	0.93	0.61	0.61	-0.07	-0.06
October	1.05	1.05	0.79	0.79	0.07	0.07

Table 11. Alt 1a WAT and DM increases relative to EIS 345, 1948 flow scenario year.

1948	Rendezvous Bridge	Below Crooked Creek	Colorado River Confluence
Largest WAT Increase (°C)	2.46	2.91	3.46
Avg. WAT Increase (°C):			
May	0.70	0.52	0.45
June	1.32	1.52	1.76
July	0.00	0.02	0.04
August	0.00	0.00	0.00
September	0.01	0.00	0.00
October	0.00	0.00	0.00
Largest DM Increase (°C)	5.21	4.00	3.96
Avg. DM Increase (°C):			
May	1.28	0.96	0.83
June	1.30	1.41	1.51
July	0.00	0.00	0.01
August	0.00	0.00	0.00
September	0.01	0.00	0.00
October	0.00	0.00	0.00

1959 Scenario Year

Hydrology

For several dates in 1959 under scenarios EIS 345, Alt 1a and Alt 8a, corresponding PACSM simulation data showed low flows in the mainstem Fraser River between the Fraser at Winter Park gage (USGS Gage 09024000) and the Hammond No. 1 Ditch diversion. These low flows caused the ADYN portion of the dynamic temperature model to stop running. It was therefore necessary to add a small amount of flow to scenarios EIS 345, Alt 1a and Alt 8a in certain locations and for certain dates to allow the ADYN model to run. Through trial and error, it was found that an additional 2 cfs added to St. Louis Creek (flow increased from 4.5 cfs to 6.5 cfs) from September 17 to September 21 was sufficient to allow the ADYN model to run. Since input temperatures from St. Louis Creek were developed from empirical models, it was possible to test whether the 2-cfs increase in flow in St. Louis Creek resulted in a change in St. Louis Creek water temperature. Results indicated that adding this small amount of flow changed temperatures by less than 0.1°C.

Discharges at the three focus locations are shown in Figure 21 - Figure 23. According to the PACSM/point flow model simulations, the differences in flow between Alt 1a and Alt 8a are minimal except for a few dates. Flows between EIS 345 and Alt 1a (and therefore Alt 8a) are also very similar; in the figures, except where there are obvious differences, EIS 345 flows are the same as for Alt 1a. Overall, the annual virgin flow for the Fraser River below Crooked Creek in 1959 was 90% of average and followed another average year, 1958 (104% of average annual). The virgin flow in May, June, July and August of 1959 was 80%, 103%, 79% and 87% of the monthly average, respectively.

In 1959 the Moffat Project would cause a reduction of Fraser River flows for only a few days in July (this is the difference between EIS 345 and Alt 1a). For cumulative conditions, there are larger flow reductions in June and July, with smaller reductions primarily in late May and early August (this is the difference between EIS 285 and Alt 1a). The difference in Fraser River basin flows between EIS 285 and the other two scenarios is also due to higher demands of entities within the Fraser River basin (e.g., municipal and snowmaking demands).

In the previous year, 1958, Gross Reservoir would fill under EIS 285, EIS 345 and Alt 1a. Contents would decline during the winter months prior to the spring runoff in 1959 because the supply is being used to meet customer demand. With EIS 345 Gross Reservoir begins the runoff season in 1959 with slightly less contents than EIS 285. Consequently, it takes an extra week to fill Gross Reservoir with EIS 345 as compared to EIS 285. With EIS 345 Gross Reservoir stays topped-off for only a few days with corresponding reduced diversion from the Fraser River basin, and then begins to divert all available supply. The Gross Reservoir enlargement under Alt 1a does not fill in 1959 and continues to divert all available water. As a result, between EIS 345 and Alt 1a there is no difference in Fraser River flows except during a few days in July. The difference in Fraser River basin flows between EIS 285 and Alt 1a is mostly in late June and early July when the enlarged Gross Reservoir does not fill whereas the existing Gross Reservoir would fill and only diverts water needed to stay topped-off and meet the lower demand with EIS 285. By the end of July when runoff has declined and Gross Reservoir is no longer full, the

amount diverted for all three scenarios is similar, with slightly less water diverted in August and September with EIS 285.

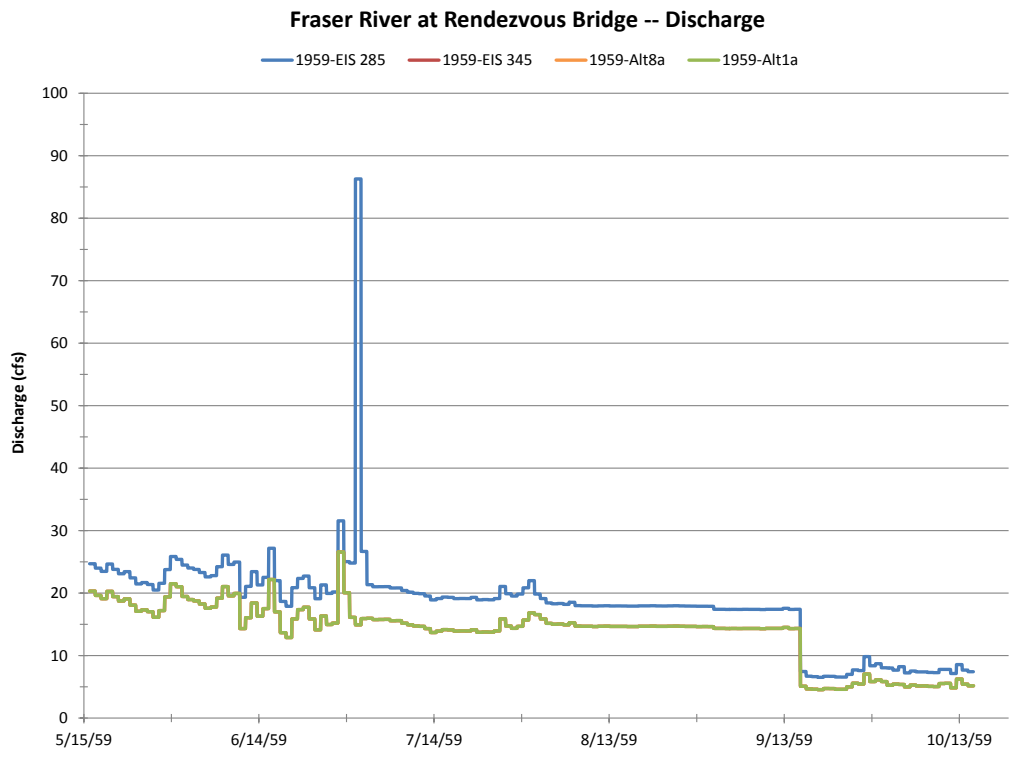

Figure 21. Discharge in the Fraser River at Rendezvous Bridge, 1959.

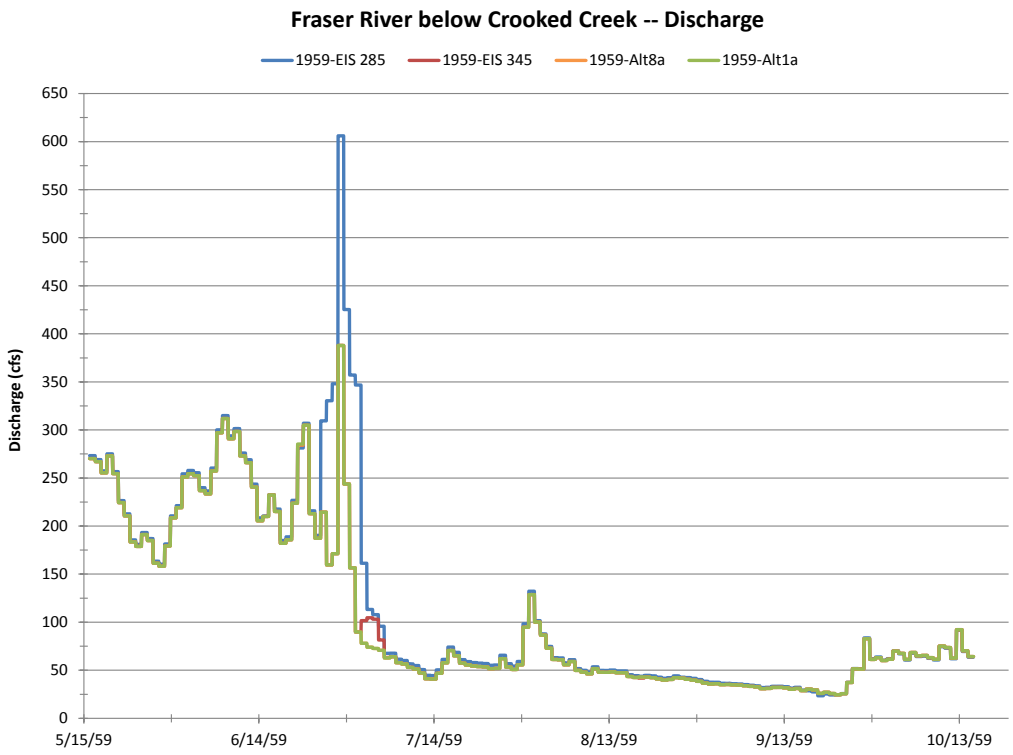

Figure 22. Discharge in the Fraser River below Crooked Creek, 1959.

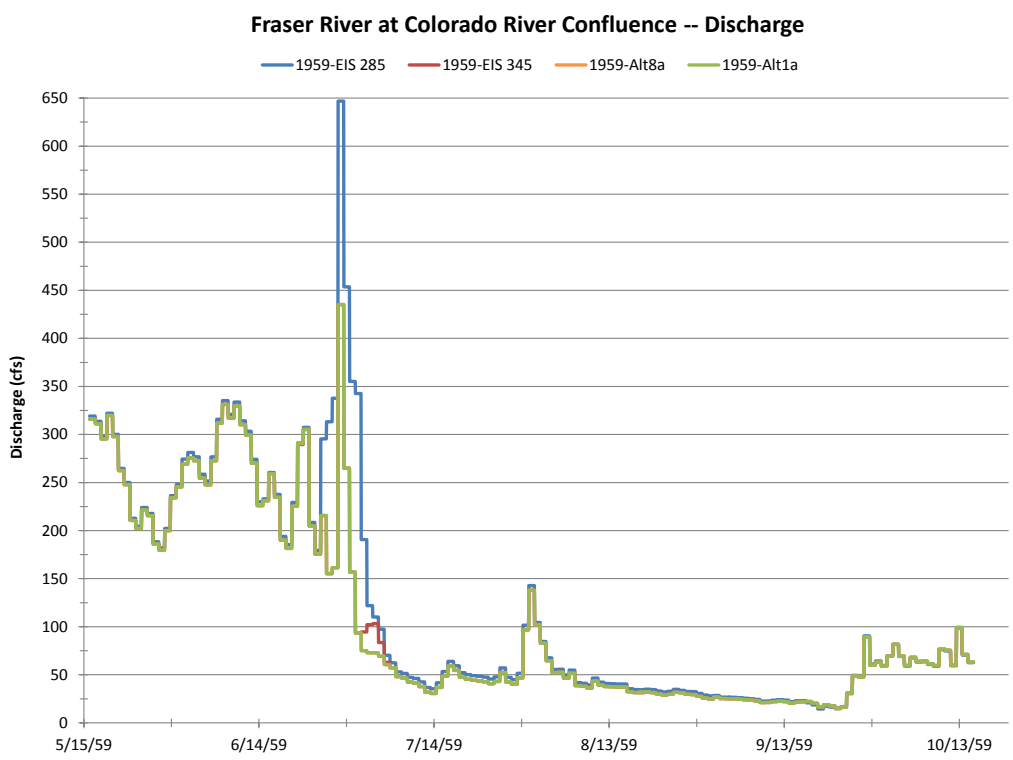

Figure 23. Discharge in the Fraser River at the Colorado River confluence, 1959.

Temperatures

Figure 24 - Figure 26 show the simulated hourly temperatures for the three focus locations. Because there are only small differences in flow between Alt 1a and Alt 8a, the simulated temperatures are also the same. Except where there are obvious differences in the figures, EIS 345 and Alt 1a temperatures are the same. For the Fraser River at Rendezvous Bridge, temperatures are warmer with the EIS 345, Alt 1a and Alt 8a scenarios compared to EIS 285 for every day of the simulation. The average difference in temperature is 0.51°C and the maximum difference is 6.90°C. For the Fraser River below Crooked Creek, temperatures are similar across all scenarios from mid-May to the last week in June. Between EIS 285 and EIS 345, the average difference in temperature is 0.21°C and the maximum difference is 3.67°C. Between EIS 285 and Alt 1a, the average difference in temperature is 0.23°C and the maximum difference is 3.67°C. Between EIS 345 and Alt 1a, the only differences in temperature occur for a few days in early July. During those days, the average difference in temperature is 0.47°C and the maximum difference is 0.99°C. For the Fraser River at the Colorado River confluence, temperatures are similar across all scenarios from mid-May to the last week in June. Between EIS 285 and EIS 345, the average difference in temperature is 0.13°C and the maximum difference is 5.79°C. Between EIS 285 and Alt 1a, the average difference in temperature is 0.16°C and the maximum difference is 5.79°C. Between EIS 345 and Alt 1a, the only differences in temperature occur for a few days in early July. During those days, the average difference in temperature is 0.75°C and the maximum difference is 1.94°C. For most days in August and September, maximum temperatures under the EIS 345, Alt 1a and Alt 8a scenarios are slightly cooler than those under EIS 285.

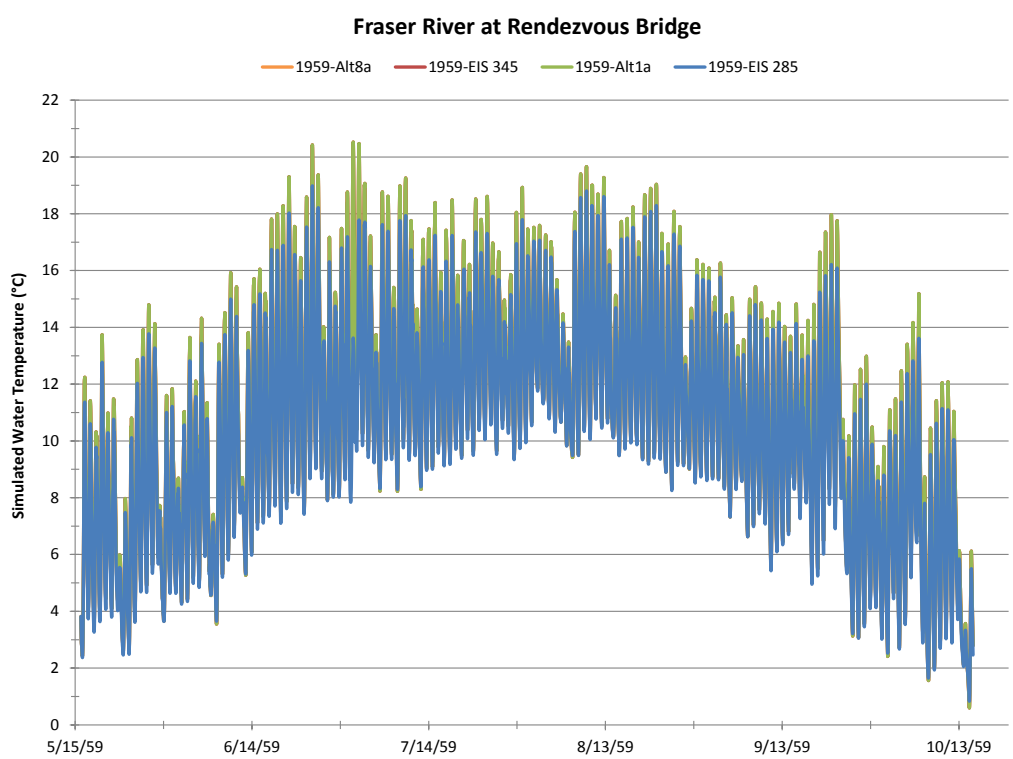

Figure 24. Simulated hourly temperatures in the Fraser River at Rendezvous Bridge, 1959.

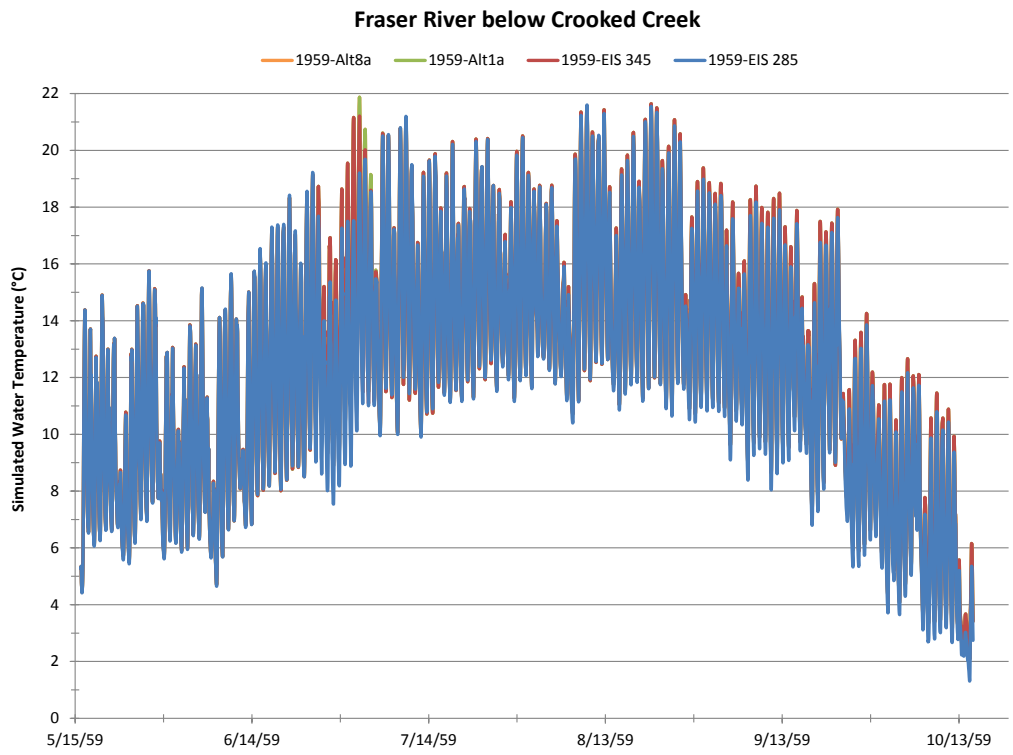

Figure 25. Simulated hourly temperatures in the Fraser River below Crooked Creek, 1959.

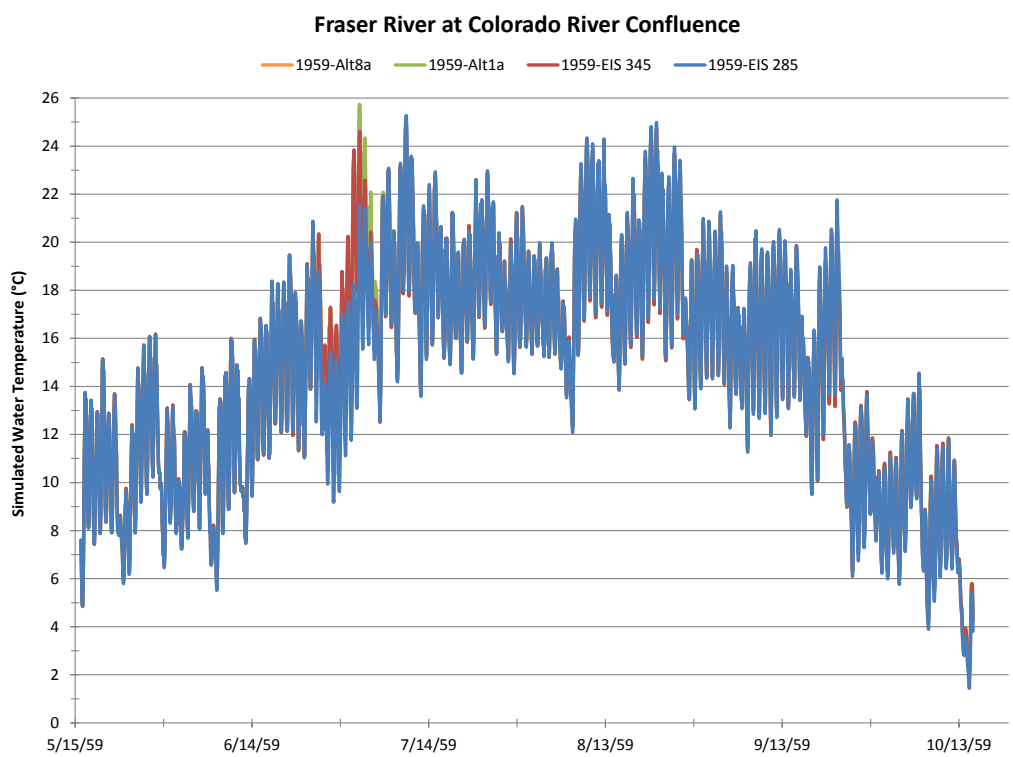

Figure 26. Simulated hourly temperatures in the Fraser River at the Colorado River confluence, 1959.

WATs and DMs

Fraser River at Rendezvous Bridge

Weekly Average Temperature (WAT) (Figure 27)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 28)

- EIS 285: The DM standard is exceeded for 1 day in May and 1 day in October, for a total of 2 days.
- EIS 345: The DM standard is exceeded for 4 days in May and 3 days in October, for a total of 7 days.
- Alt 1a: The DM standard is exceeded for 4 days in May and 3 days in October, for a total of 7 days. Therefore, with Alt 1a the DM standard is exceeded 5 more days compared to current conditions; none of the days are attributable to the Moffat Project.

Table A - 5 provides the temperatures and days for which exceedances occur. These days are within the winter shoulder-season and could possibly be considered exemptions.

Fraser River below Crooked Creek

Weekly Average Temperature (WAT) (Figure 29)

There are no exceedances of the WAT standard for any of the four streamflow scenarios. WATs are similar between scenarios except for from late June to early July.

Daily Maximum (DM) (Figure 30)

There are no exceedances of the DM standard for any of the four streamflow scenarios. DMs are similar between scenarios except for from late June to early July.

Fraser River at the Colorado River Confluence

Weekly Average Temperature (WAT) (Figure 31)

- EIS 285: The WAT standard is exceeded for 18 days in July and 19 days in August, for a total of 37 days.
- EIS 345: The WAT standard is exceeded for 25 days in July and 18 days in August, for a total of 43 days.
- Alt 1a: The WAT standard is exceeded for 26 days in July and 18 days in August, for a total of 44 days. Therefore, with Alt 1a the WAT standard is exceeded 7 additional days compared to current conditions; 1 exceedance in July is attributable to the Moffat Project.

Table A - 6 provides the temperatures and days for which WAT exceedances occur.

Daily Maximum (DM) (Figure 32)

- EIS 285: The DM standard is exceeded for 1 day in July and 6 days in August, for a total of 7 days.
- EIS 345: The DM standard is exceeded for 2 days in July and 3 days in August, for a total of 5 days.
- Alt 1a: The DM standard is exceeded for 3 days in July and 3 days in August, for a total of 6 days. Therefore, with Alt 1a the DM standard is exceeded 1 less day compared to current conditions and 1 more day compared to full use of the existing system.

Vasquez Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 33)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 34)

There are no exceedances of the DM standard for any of the four streamflow scenarios.

St. Louis Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 35)

There are no exceedances of the WAT standard for any of the four streamflow scenarios. WATs are similar between scenarios except for from late June to early July.

Daily Maximum (DM) (Figure 36)

- EIS 285: The DM standard is exceeded for 5 days in May.
- EIS 345: The DM standard is exceeded for 5 days in May.
- Alt 1a: The DM standard is exceeded for 5 days in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Table A - 7 provides the temperatures and days for which exceedances occur. These could possibly be considered exemptions since they fall within the shoulder-season.

Ranch Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 37)

- EIS 285: The WAT standard is exceeded for 5 days in May.
- EIS 345: The WAT standard is exceeded for 5 days in May.
- Alt 1a: The WAT standard is exceeded for 5 days in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Daily Maximum (DM) (Figure 38)

- EIS 285: The DM standard is exceeded for 8 days in May.

- EIS 345: The DM standard is exceeded for 8 days in May.
- Alt 1a: The DM standard is exceeded for 8 days in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Table A - 8 provides the temperatures and days for which exceedances occur. The exceedances could possibly be considered exemptions since they fall within the shoulder-season.

Table 12 summarizes all exceedances for all locations. Table 13 summarizes the predicted increase in water temperature due to EIS 345 and Alt 1a (cumulative effects, plus Moffat Project) relative to EIS 285 (current conditions). In general, the stream temperatures will be higher in the Fraser River compared to current conditions. On average, the increase in WAT ranges from 0.03 to 0.7°C, with the largest WAT increase at the Colorado River confluence (2.75°C on July 3). On average, the increase in DM ranges from 0.02 to 1.3°C, with the largest DM increase at Rendezvous Bridge (6.79°C on July 1). Note that for the Fraser River at the Colorado River confluence, the average August and September WATs and DMs for EIS 345 and Alt 1a are slightly less than those for EIS 285 because the flows are slightly higher. This is due to slightly more carry-over storage in Gross Reservoir with EIS 345 and Alt 1a, which then fills sooner compared to EIS 285. This operation is needed to meet the higher customer demands in Denver Water's north system and reduce the risk of running out of water in the subsequent year for EIS 345 and Alt 1a.

Table 14 summarizes the predicted increase in water temperature due to the Moffat Project, i.e., Alt 1a WAT and DM increases relative to EIS 345. The predicted increase in stream temperatures attributable to the Moffat Project diversions occur in July only, which results in one additional day of DM and WAT exceedances.

Summary for the Fraser River Mainstem

For 1959, the model simulates temperatures that have exceedances under current conditions (EIS 285) at Rendezvous Bridge, none below the confluence with Crooked Creek and temperature exceedances again at the confluence with the Colorado River. With Alt 1a (cumulative effects with the Moffat Project), there will be additional temperature exceedances at the same two locations. However, none of the exceedances at Rendezvous Bridge are attributable to the Moffat Project. With the Moffat Project there is 1 day of additional DM exceedances as compared to full use of the existing system at the Colorado River confluence. With the Moffat Project there is 1 day of additional WAT exceedances as compared to full use of the existing system at the Colorado River confluence.

Summary for the Fraser River Tributaries

In Vasquez Creek, there are no WAT or DM exceedances identified for any of the four streamflow scenarios. In St. Louis Creek, there are exceedances of the DM standard under current and future conditions but the number of exceedances is the same for all four scenarios. In Ranch Creek, there are exceedances of the WAT standard under current and future conditions but the number of exceedances is the same for all four scenarios. There are also exceedances of the DM standard in Ranch Creek under current and future conditions but the number of exceedances is the same for all four scenarios.

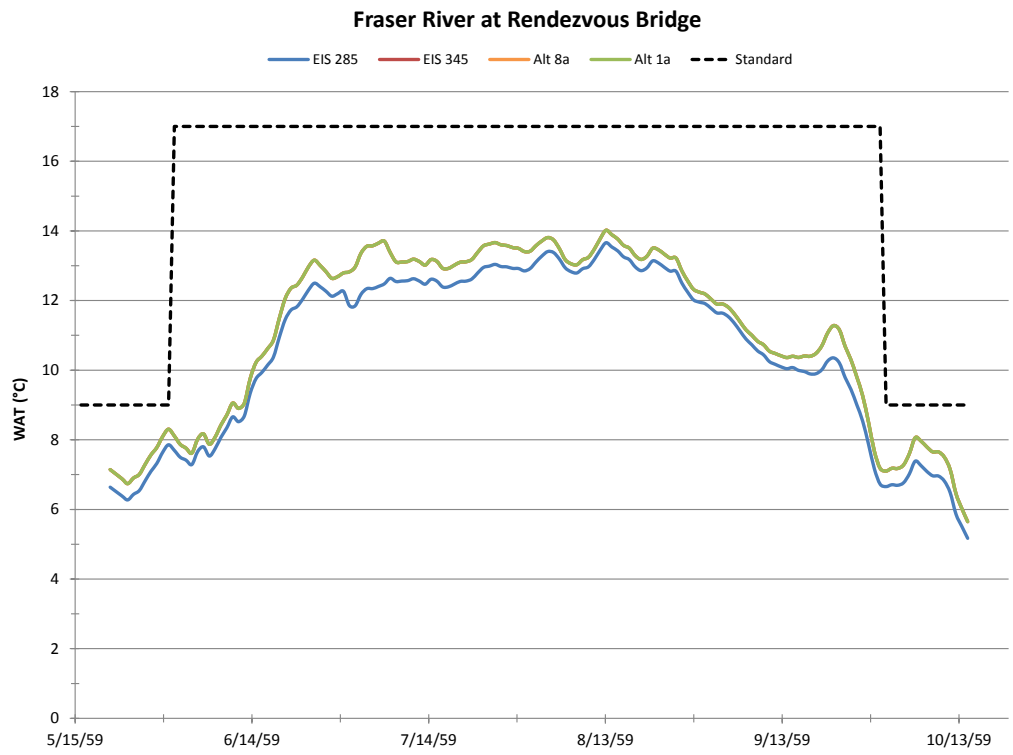

Figure 27. 1959 WATs, Fraser River at Rendezvous Bridge.

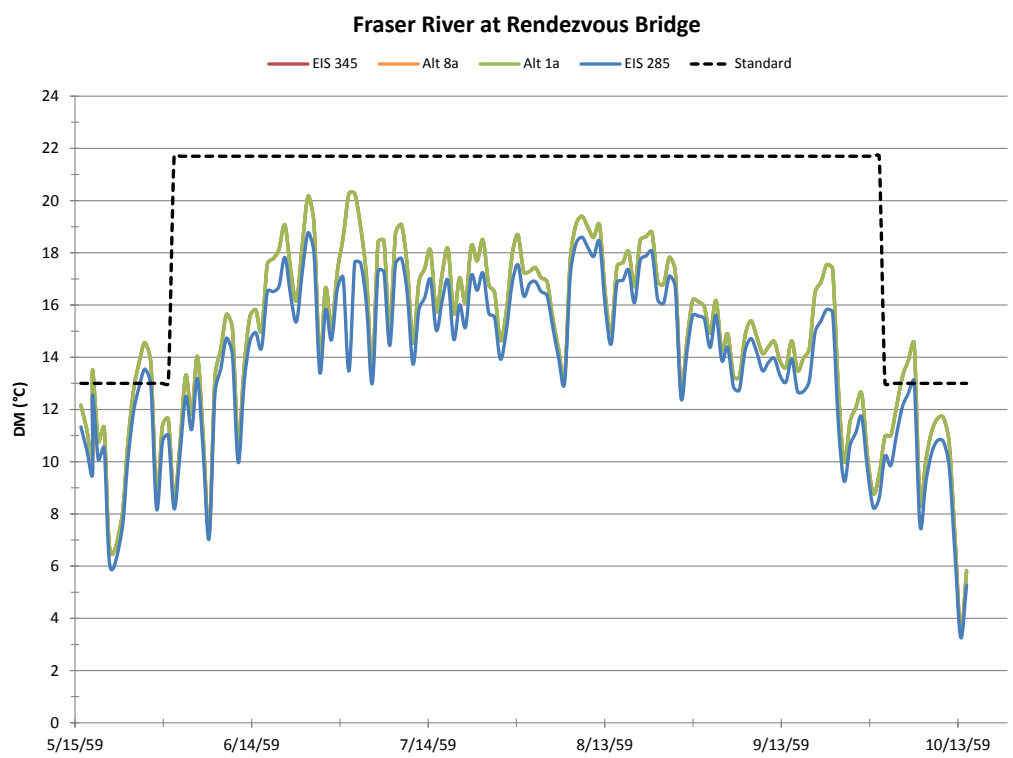

Figure 28. 1959 DMs, Fraser River at Rendezvous Bridge.

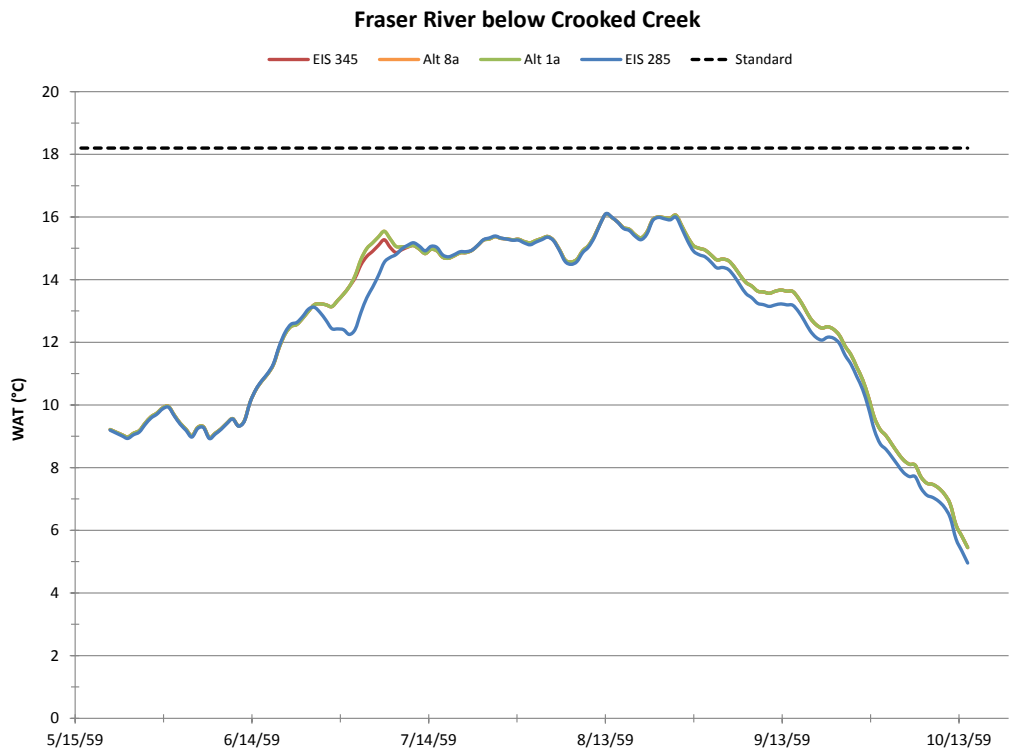

Figure 29. 1959 WATs, Fraser River below Crooked Creek.

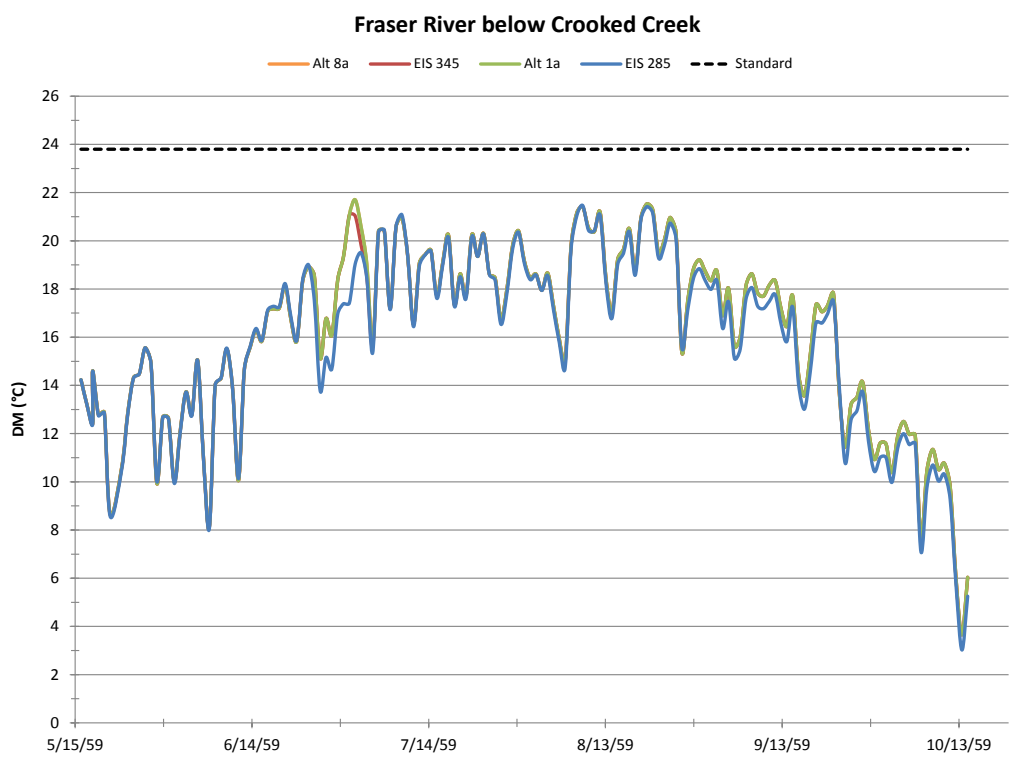

Figure 30. 1959 DMs, Fraser River below Crooked Creek.

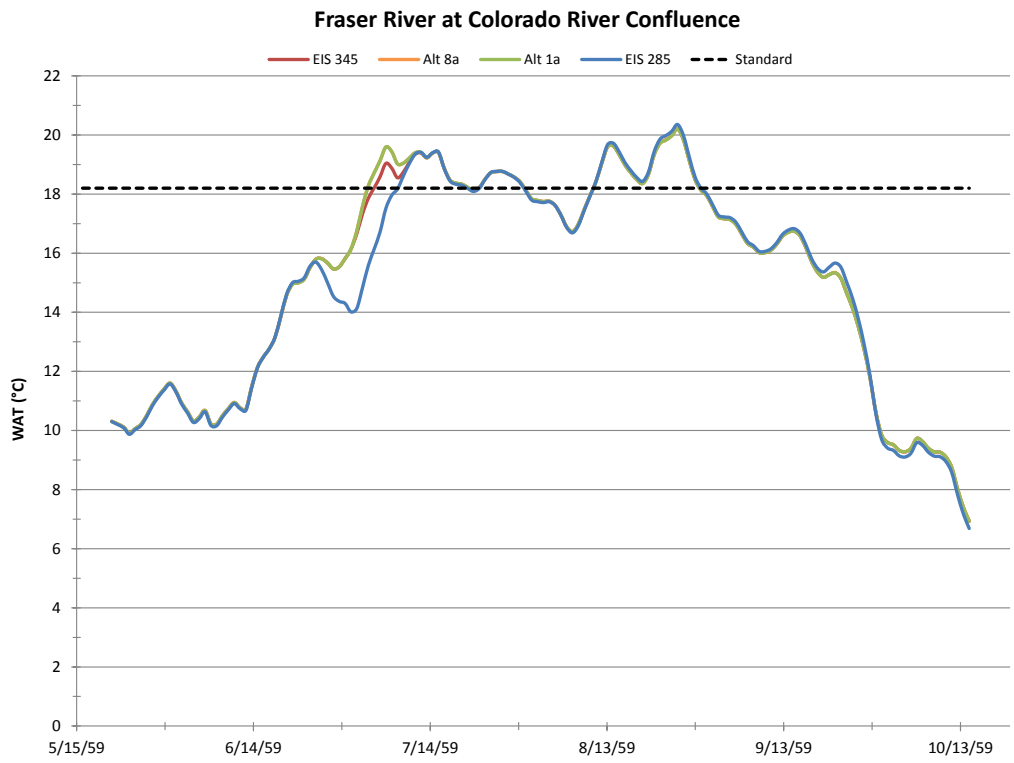

Figure 31. 1959 WATs, Fraser River at the Colorado River confluence.

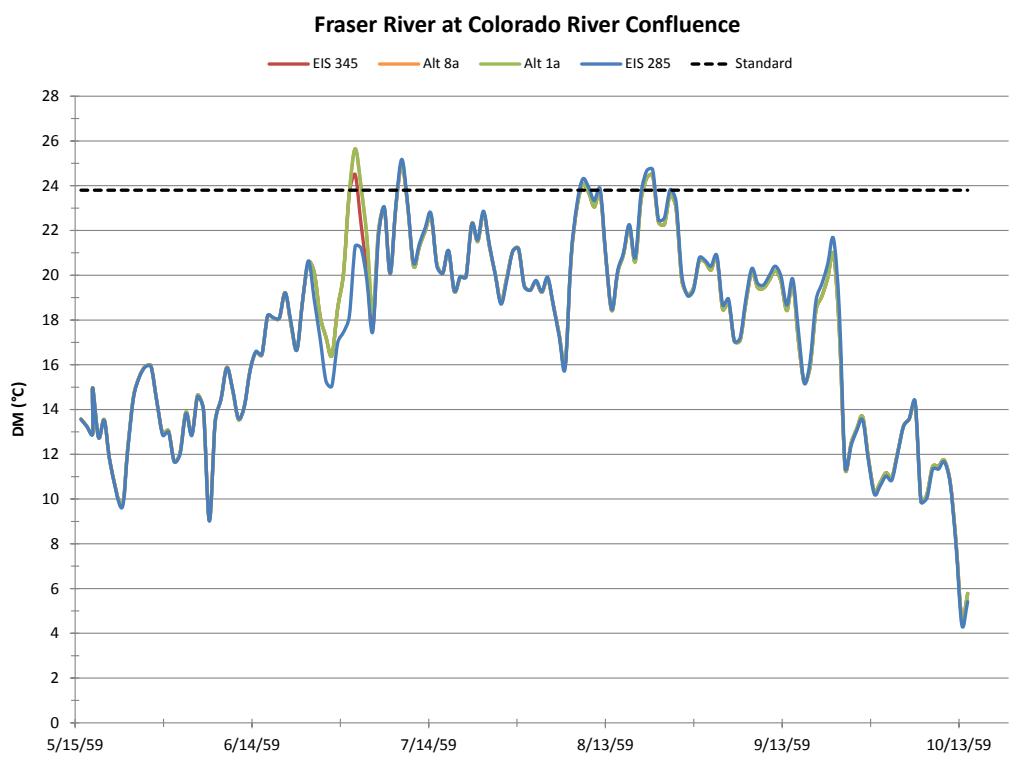

Figure 32. 1959 DMs, Fraser River at the Colorado River confluence.

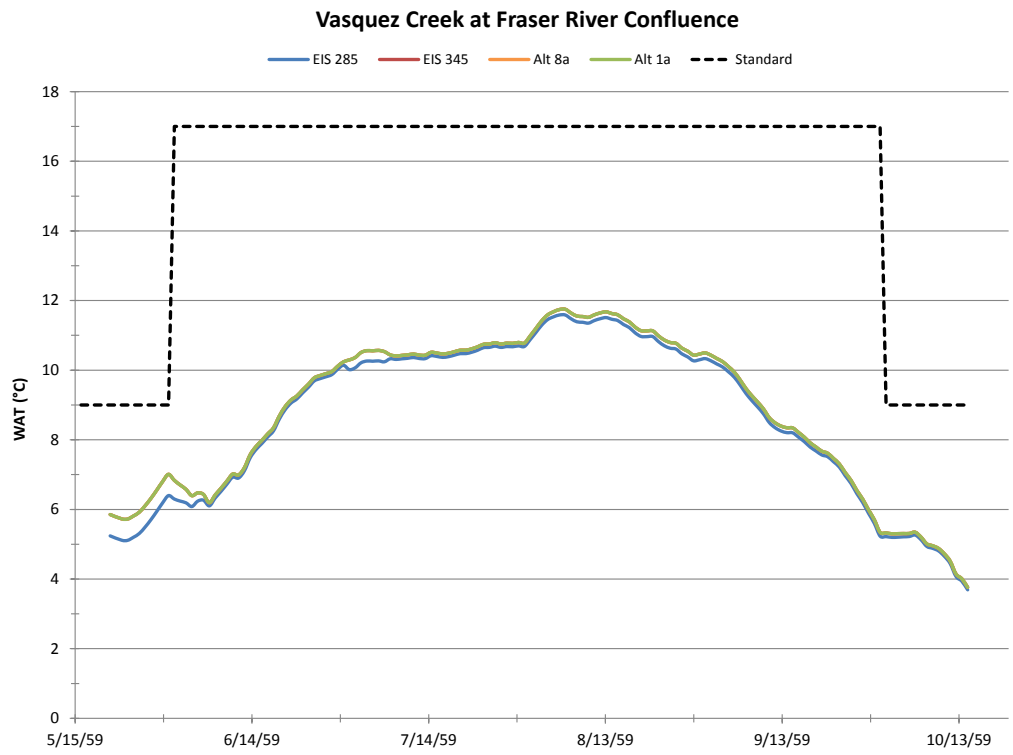

Figure 33. 1959 WATs, Vasquez Creek at the Fraser River confluence.

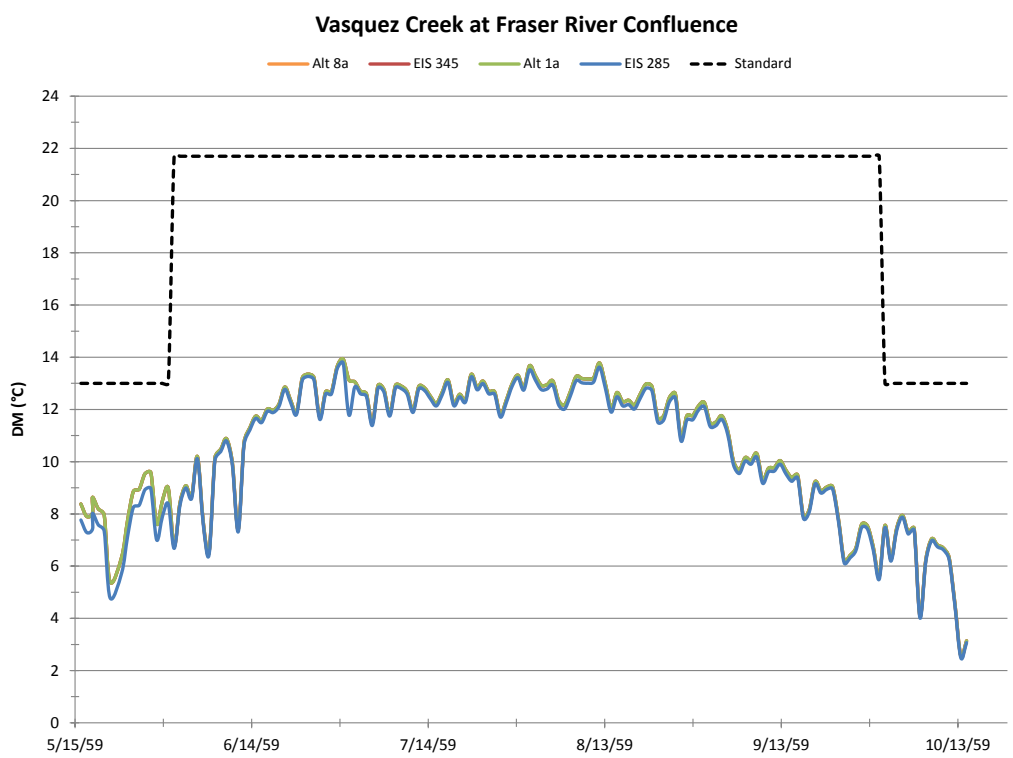

Figure 34. 1959 DMs, Vasquez Creek at the Fraser River confluence.

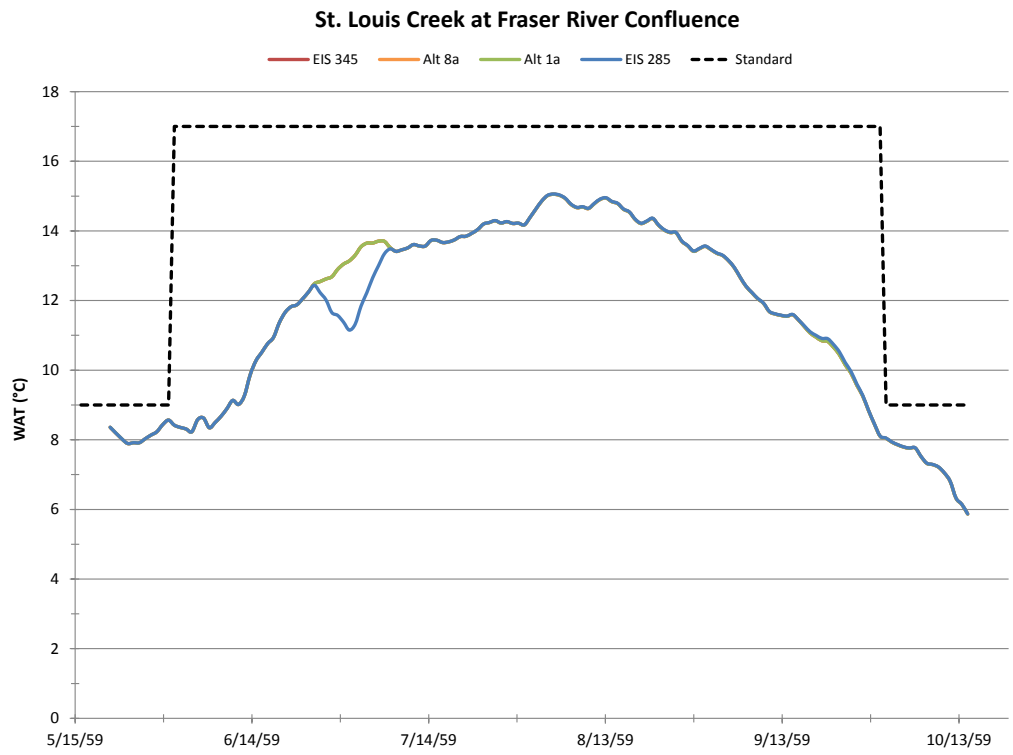

Figure 35. 1959 WATs, St. Louis Creek at the Fraser River confluence.

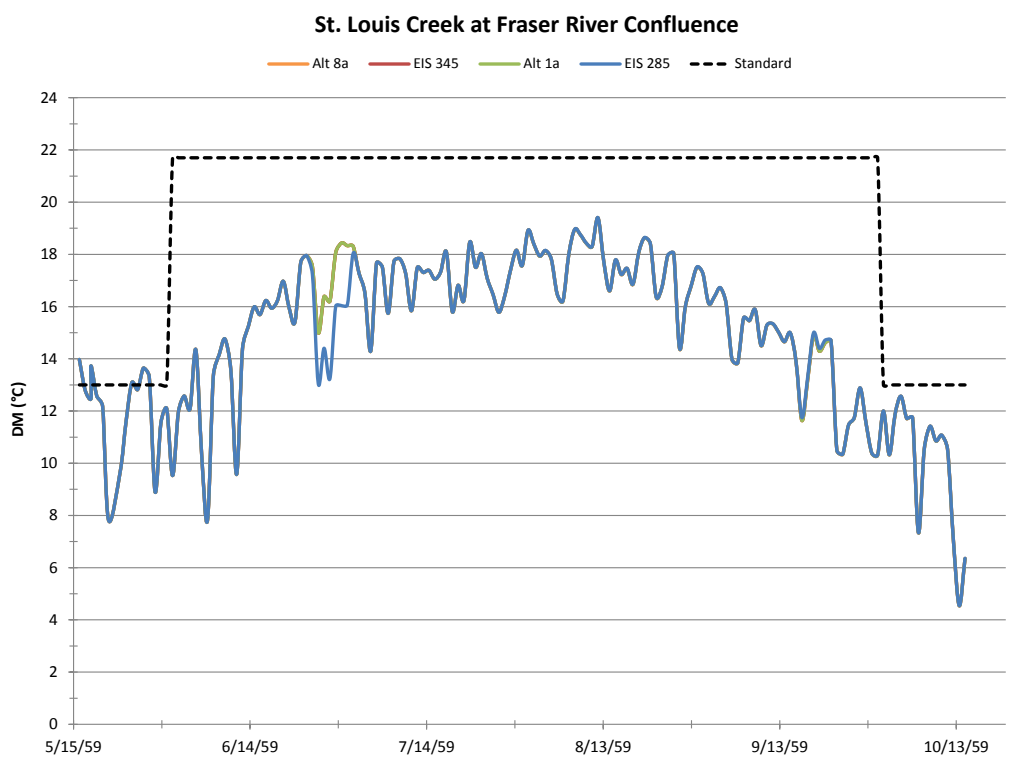

Figure 36. 1959 DMs, St. Louis Creek at the Fraser River confluence.

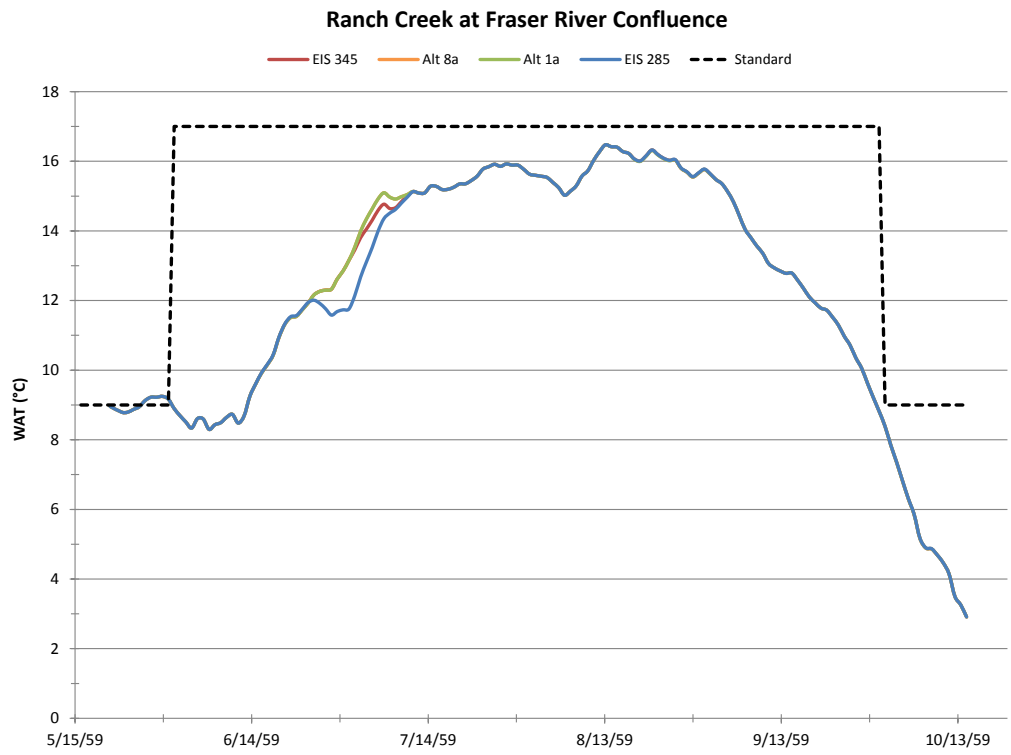

Figure 37. 1959 WATs, Ranch Creek at the Fraser River confluence.

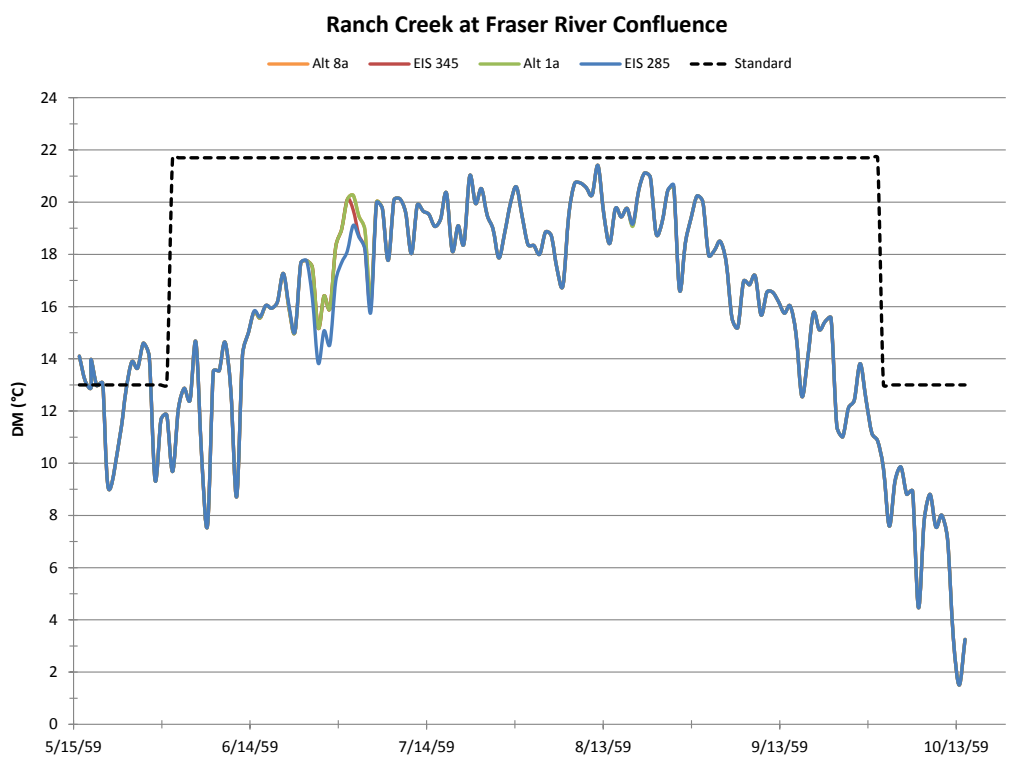

Figure 38. 1959 DMs, Ranch Creek at the Fraser River confluence.

Table 12. Summary of WAT and DM exceedances, 1959 flow scenario year.

1959	Rendezvous Bridge				Below Crooked Creek				Colorado River Confluence			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	13.66	14.02	14.02	14.02	16.11	16.10	16.10	16.10	20.36	20.21	20.20	20.21
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	18	25	26	26
August	0	0	0	0	0	0	0	0	19	18	18	18
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	18.77	20.26	20.26	20.26	21.47	21.53	21.70	21.70	25.18	24.90	25.65	25.65
# of Days Above Standard:												
May	1	4	4	4	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	1	2	3	3
August	0	0	0	0	0	0	0	0	6	3	3	3
September	0	0	0	0	0	0	0	0	0	0	0	0
October	1	3	3	3	0	0	0	0	0	0	0	0

1959	Vasquez Creek				St. Louis Creek				Ranch Creek			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	11.59	11.75	11.75	11.75	15.06	15.05	15.05	15.05	16.47	16.47	16.47	16.47
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	5	5	5	5
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	13.78	13.93	13.93	13.93	19.41	19.40	19.40	19.40	21.41	21.41	21.41	21.41
# of Days Above Standard:												
May	0	0	0	0	5	5	5	5	8	8	8	8
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0

Table 13. EIS 345 and Alt 1a WAT and DM increases relative to EIS 285, 1959 flow scenario year.

1959	Rendezvous Bridge		Below Crooked Creek		Colorado River Confluence	
	EIS 345	Alt 1a	EIS 345	Alt 1a	EIS 345	Alt 1a
Largest WAT Increase (°C)	1.25	1.25	1.65	1.72	2.53	2.75
Avg. WAT Increase (°C):						
May	0.47	0.47	0.04	0.04	0.03	0.03
June	0.47	0.47	0.12	0.12	0.17	0.17
July	0.71	0.71	0.27	0.33	0.53	0.66
August	0.34	0.34	0.06	0.06	-0.05	-0.05
September	0.48	0.48	0.36	0.36	-0.12	-0.11
October	0.59	0.59	0.42	0.42	0.17	0.17
Largest DM Increase (°C)	6.79	6.79	3.65	3.65	5.51	5.51
Avg. DM Increase (°C):						
May	0.74	0.74	0.02	0.02	0.03	0.03
June	0.84	0.84	0.27	0.27	0.33	0.33
July	1.27	1.27	0.26	0.32	0.30	0.48
August	0.58	0.58	0.16	0.16	-0.12	-0.12
September	0.83	0.83	0.51	0.51	-0.19	-0.19
October	0.90	0.90	0.52	0.52	0.11	0.11

Table 14. Alt 1a WAT and DM increases relative to EIS 345, 1959 flow scenario year.

1959	Rendezvous Bridge	Below Crooked Creek	Colorado River Confluence
Largest WAT Increase (°C)	0.00	0.27	0.56
Avg. WAT Increase (°C):			
May	0.00	0.00	0.00
June	0.00	0.00	0.00
July	0.00	0.06	0.13
August	0.00	0.00	0.00
September	0.00	0.00	0.00
October	0.00	0.00	0.00
Largest DM Increase (°C)	0.00	0.76	1.66
Avg. DM Increase (°C):			
May	0.00	0.00	0.00
June	0.00	0.00	0.00
July	0.00	0.07	0.17
August	0.00	0.00	0.00
September	0.00	0.00	0.00
October	0.00	0.00	0.00

1963 Scenario Year

Hydrology

For several dates in 1963 under scenarios EIS 345, Alt 1a and Alt 8a, corresponding PACSM simulation data showed low flows in the mainstem Fraser River between the Fraser at Winter Park gage (USGS Gage 09024000) and the Hammond No. 1 Ditch diversion. These low flows caused the ADYN portion of the dynamic temperature model to stop running. It was therefore necessary to add a small amount of flow to scenarios EIS 345, Alt 1a and Alt 8a in certain locations and for certain dates to allow the ADYN model to run. Through trial and error, it was found that an additional 1 cfs (flows increased from approximately 3.7 cfs to 4.7 cfs) added to the upstream boundary from September 16 to October 15 and 1-3 cfs added to St. Louis Creek from the end of June to mid-July was sufficient to allow the ADYN model to run. For St. Louis Creek, the low flows that required additional flow ranged from 1.2 cfs to 5.5 cfs. Similar to the 1948 and 1959 scenario year runs, adding this small amount of flow changed temperatures by less than 0.1°C.

Discharges at the three focus locations are shown in Figure 39 - Figure 41. In all three figures Alt 1a and Alt 8a are the same as EIS 345. According to the PACSM/point flow model simulations, the differences in flow between EIS 345 and both Alt 1a and Alt 8a are minimal. In fact, flows are different only for a couple of days and the difference in flows are typically 0.01 cfs. Overall, the annual virgin flow for the Fraser River below Crooked Creek in 1963 was only 58% of average and followed a very wet year, 1962 (140% of average annual). The virgin flow in May, June, July and August was 65%, 37%, 35% and 82% of the monthly average, respectively.

In 1963 the Moffat Project would cause no reduction of Fraser River flows (this is the difference between EIS 345 and Alt 1a). For cumulative conditions, there are flow reductions during June through mid-October (this is the difference between EIS 285 and Alt 1a).

In the previous year, 1962, Gross Reservoir would fill under EIS 285, EIS 345 and Alt 1a. Contents would decline during the winter months prior to the spring runoff in 1963 because the supply is being used to meet customer demand. Neither the existing Gross Reservoir with EIS 285 or EIS 345, nor the Gross Reservoir enlargement with Alt 1a would fill in 1963. As a result, between EIS 345 and Alt 1a there is no difference in Fraser River flows. The difference in Fraser River basin flows between EIS 285 and Alt 1a is mostly during June through mid-September and is due to higher demands of entities within the Fraser River basin (e.g., municipal and snowmaking demands), and due to reductions in U.S. Forest Service bypass flows because Denver Water customers would be on restrictions. The large spike in flow on June 16 was due to a large rain event that translated into large gains in all of the scenarios.

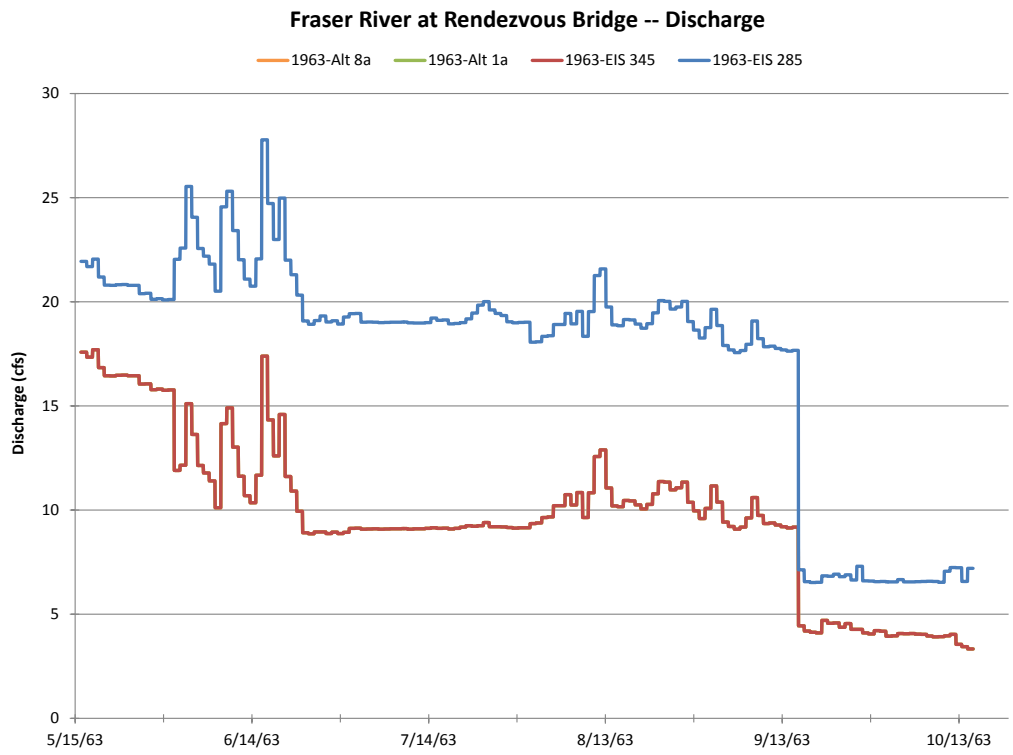

Figure 39. Discharge in the Fraser River at Rendezvous Bridge, 1963.

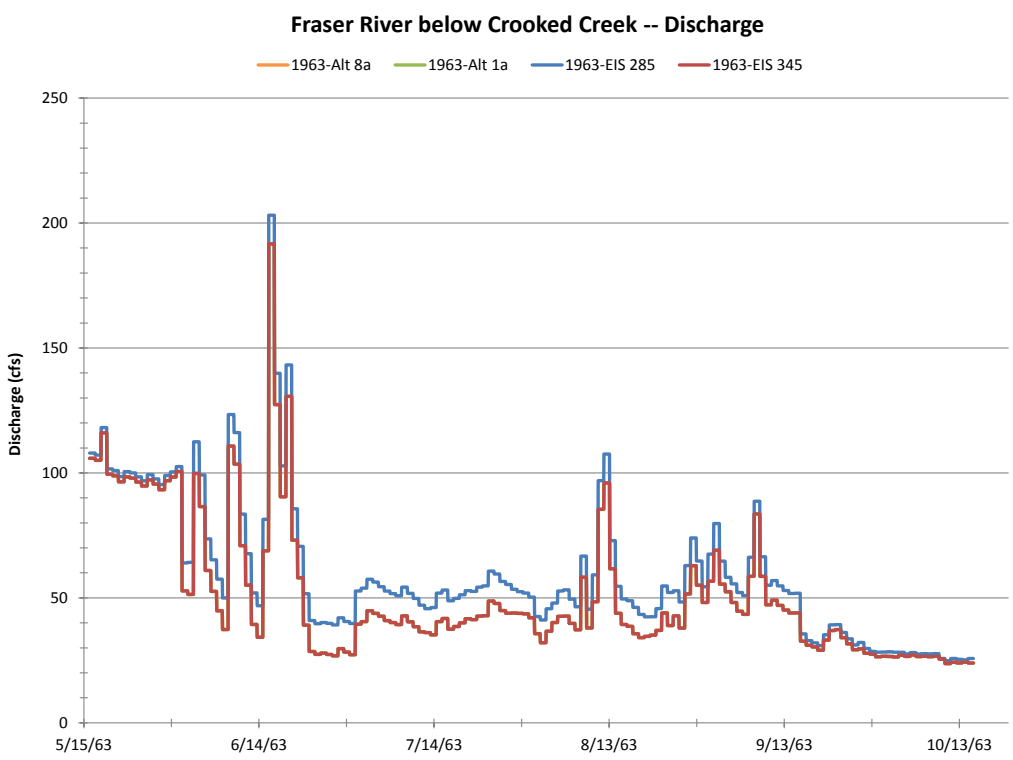

Figure 40. Discharge in the Fraser River below Crooked Creek, 1963.

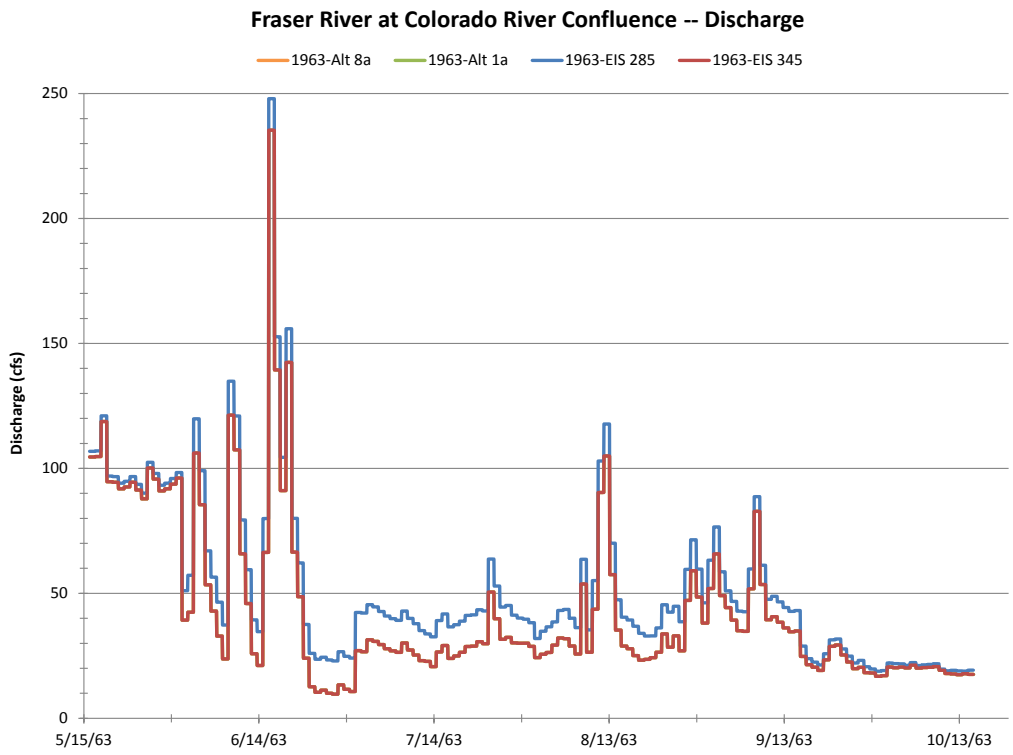

Figure 41. Discharge in the Fraser River at the Colorado River confluence, 1963.

Temperatures

Figure 42 - Figure 44 show the simulated hourly temperatures for the three focus locations. As with the hydrographs, Alt 1a and Alt 8a are the same as EIS 345. For the Fraser River at Rendezvous Bridge, the greatest differences in temperature between EIS 285 and the other three scenarios occur here. Temperatures are warmer with the EIS 345 (and Alt 1a and Alt 8a) scenario for every day of the simulation. The average difference in temperature is 1.10°C and the maximum difference is 4.48°C. The largest temperature differences occur in June, July and August. For the Fraser River below Crooked Creek, temperatures are fairly similar between the scenarios. The average difference in temperature is 0.15°C and the maximum difference is 1.58°C. The greatest differences in temperature occur in September and October. For the Fraser River at the Colorado River confluence, temperatures are fairly similar between the scenarios with the exception of the last week of June. Here, with all scenarios, flows drop substantially compared to the previous two weeks (Figure 41) and flows under EIS 345, Alt 1a and Alt 8a are 50% less than flows under EIS285. The average difference in temperature is 0.25°C and the maximum difference is 3.48°C.

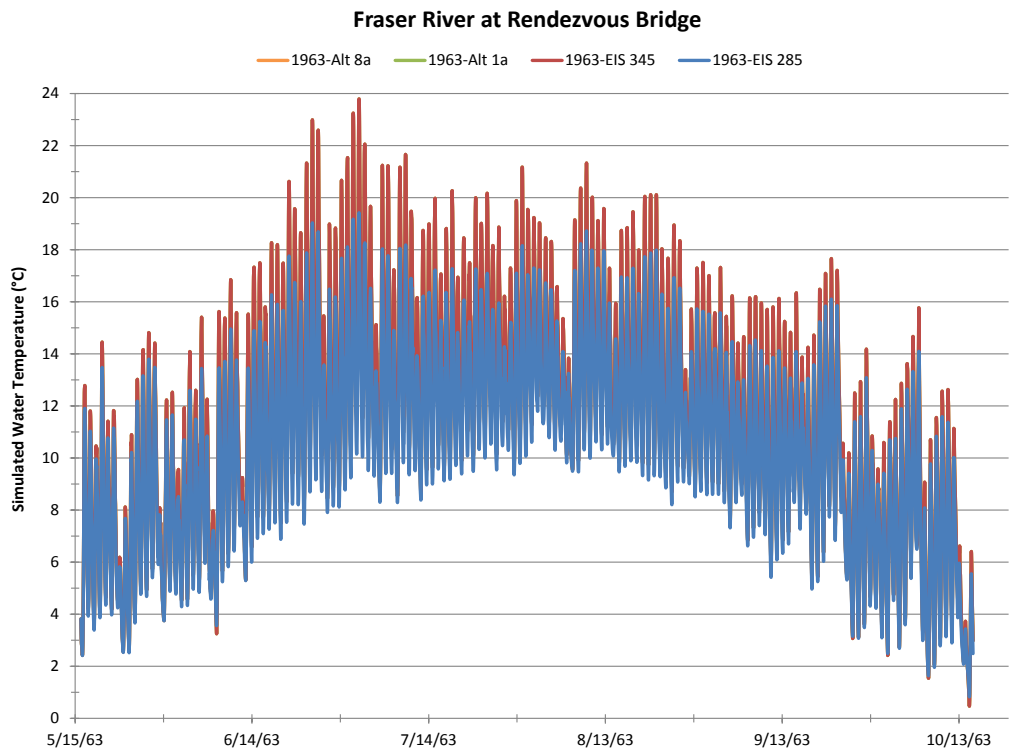

Figure 42. Simulated hourly temperatures in the Fraser River at Rendezvous Bridge, 1963.

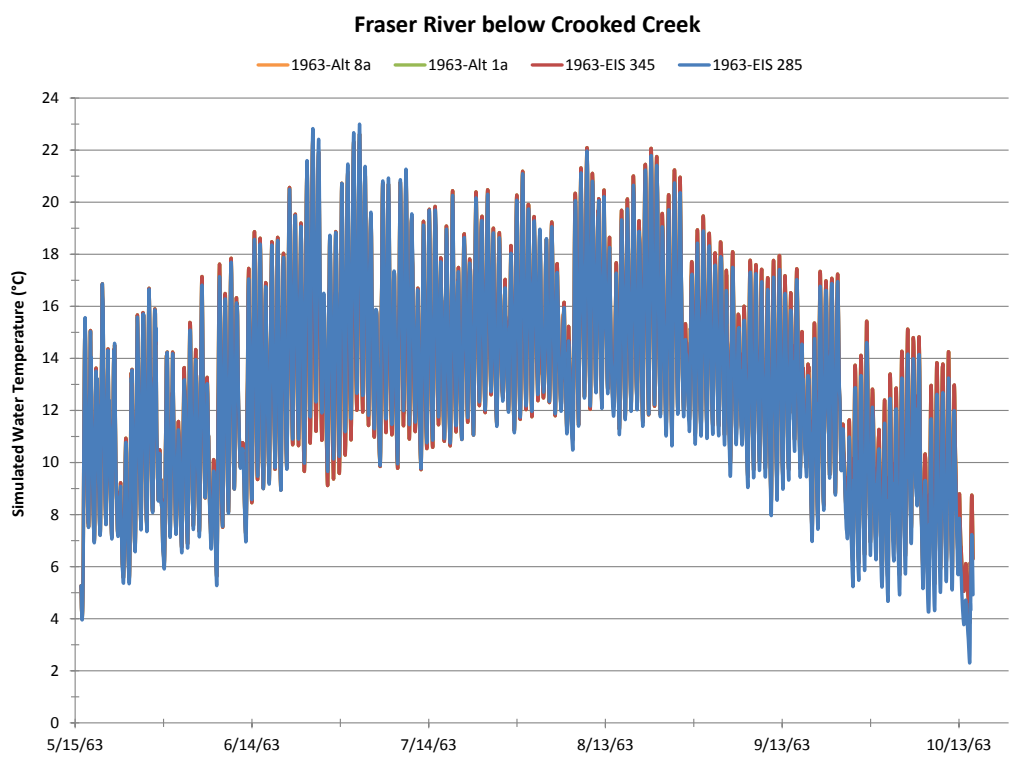

Figure 43. Simulated hourly temperatures in the Fraser River below Crooked Creek, 1963.

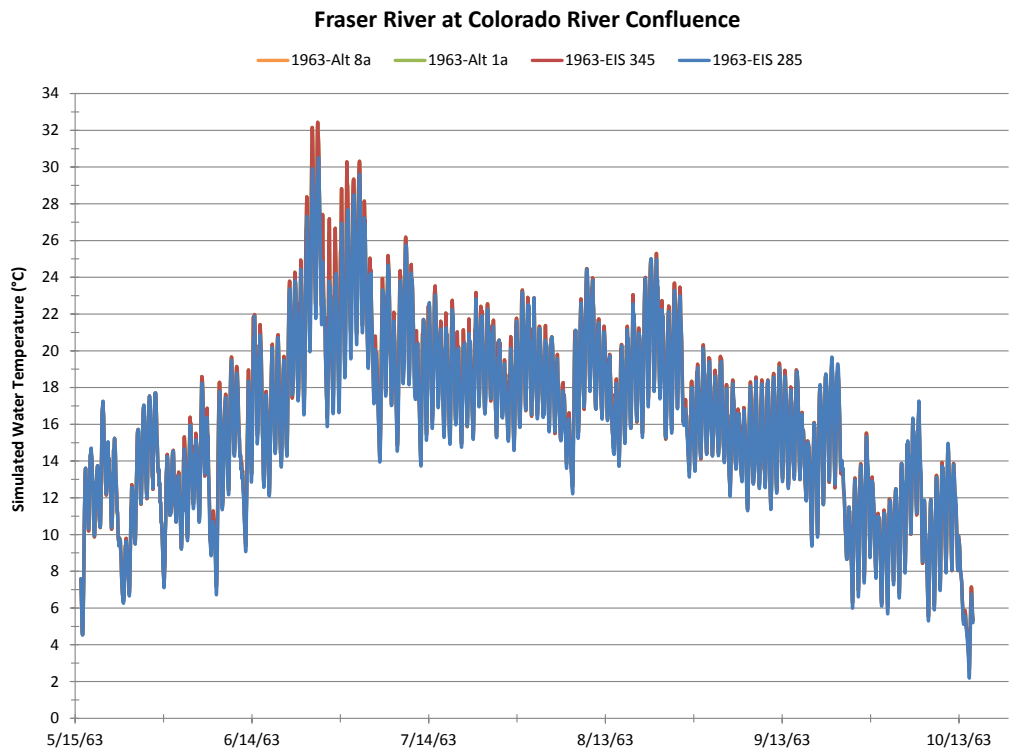

Figure 44. Simulated hourly temperatures in the Fraser River at the Colorado River confluence, 1963.

WATs and DMs

Fraser River at Rendezvous Bridge

Weekly Average Temperature (WAT) (Figure 45)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 46)

- EIS 285: The DM standard is exceeded for 4 days in May and 2 days in October, for a total of 6 days.
- EIS 345: The DM standard is exceeded for 4 days in May, 2 days in June, 3 days in July and 3 days in October, for a total of 12 days.
- Alt 1a: The DM standard is exceeded for 4 days in May, 2 days in June, 3 days in July and 3 days in October, for a total of 12 days. Therefore, with Alt 1a the DM standard is exceeded 6 more days compared to current conditions; none of the days are attributable to the Moffat Project.

Table A - 9 provides the temperatures and days for which exceedances occur. The May and October exceedances could possibly be considered exemptions.

Fraser River below Crooked Creek

Weekly Average Temperature (WAT) (Figure 47)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 48)

There are no exceedances of the DM standard for any of the four streamflow scenarios.

Fraser River at the Colorado River Confluence

Weekly Average Temperature (WAT) (Figure 49)

- EIS 285: The WAT standard is exceeded for 8 days in June, 31 days in July and 20 days in August, for a total of 59 days.
- EIS 345: The WAT standard is exceeded for 8 days in June, 31 days in July and 25 days in August, for a total of 64 days.
- Alt 1a: The WAT standard is exceeded for 8 days in June, 31 days in July and 25 days in August, for a total of 64 days. Therefore, with Alt 1a the WAT standard is exceeded 5 more days compared to current conditions; none of the days are attributable to the Moffat Project.

Table A - 10 provides the temperatures and days for which exceedances occur.

Daily Maximum (DM) (Figure 50)

- EIS 285: The DM standard is exceeded for 8 days in June, 8 days in July and 3 days in August, for a total of 19 days.
- EIS 345: The DM standard is exceeded for 10 days in June, 8 days in July and 5 days in August, for a total of 23 days.
- Alt 1a: The DM standard is exceeded for 10 days in June, 8 days in July and 5 days in August, for a total of 23 days. Therefore, with Alt 1a the DM standard is exceeded 4 more days compared to current conditions; none of the days are attributable to the Moffat Project.

Table A - 10 provides the temperatures and days for which exceedances occur.

Vasquez Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 51)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 52)

There are no exceedances of the DM standard for any of the four streamflow scenarios.

St. Louis Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 53)

- EIS 285: The WAT standard is exceeded for 1 day in May.
- EIS 345: The WAT standard is exceeded for 1 day in May.
- Alt 1a: The WAT standard is exceeded for 1 day in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Daily Maximum (DM) (Figure 54)

- EIS 285: The DM standard is exceeded for 7 days in May.
- EIS 345: The DM standard is exceeded for 7 days in May.
- Alt 1a: The DM standard is exceeded for 7 days in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Table A - 11 provides the temperatures and days for which exceedances occur. These could possibly be considered exemptions since they fall within the shoulder-season.

Ranch Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 55)

- EIS 285: The WAT standard is exceeded for 10 days in May.
- EIS 345: The WAT standard is exceeded for 10 days in May.
- Alt 1a: The WAT standard is exceeded for 10 days in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Daily Maximum (DM) (Figure 56)

- EIS 285: The DM standard is exceeded for 13 days in May.
- EIS 345: The DM standard is exceeded for 13 days in May.
- Alt 1a: The DM standard is exceeded for 13 days in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Table A - 12 provides the temperatures and days for which exceedances occur. The exceedances could possibly be considered exemptions since they fall within the shoulder-season.

Table 15 summarizes all exceedances for all locations. Table 16 summarizes the predicted increase in water temperature due to EIS 345 and Alt 1a (cumulative effects, plus Moffat Project) relative to EIS 285 (current conditions). Note that the increases for EIS 345 and Alt 1a are the same. In general, the stream temperatures will be higher in the Fraser River compared to current conditions. On average, the increase in WAT ranges from 0.01 to 1.7^{o}C, with the largest WAT increase at Rendezvous Bridge (2.12°C on July 4). On average, the increase in DM ranges from 0.01 to 2.7^{o}C, with the largest DM increase at Rendezvous Bridge (4.36°C on July 2). Note that for the Fraser River below Crooked Creek, the average

June and July WATs for EIS 345 and Alt 1a are slightly less than those for EIS 285 even though the flows are lower.

Summary for the Fraser River Mainstem

For 1963, the model simulates temperatures that have exceedances under current conditions (EIS 285) at Rendezvous Bridge, none below the confluence with Crooked Creek and temperature exceedances again at the confluence with the Colorado River. With Alt 1a (cumulative effects with the Moffat Project), there will be additional temperature exceedances at the same two locations. However, none of the exceedances at the two locations are attributable to the Moffat Project.

Summary for the Fraser River Tributaries

In Vasquez Creek, there are no WAT or DM exceedances identified for any of the four streamflow scenarios. In St. Louis Creek, there are exceedances of the WAT and DM standard under current and future conditions but the number of exceedances is the same for all four scenarios. In Ranch Creek, there are exceedances of the WAT and DM standard under current and future conditions but the number of exceedances is the same for all four scenarios.

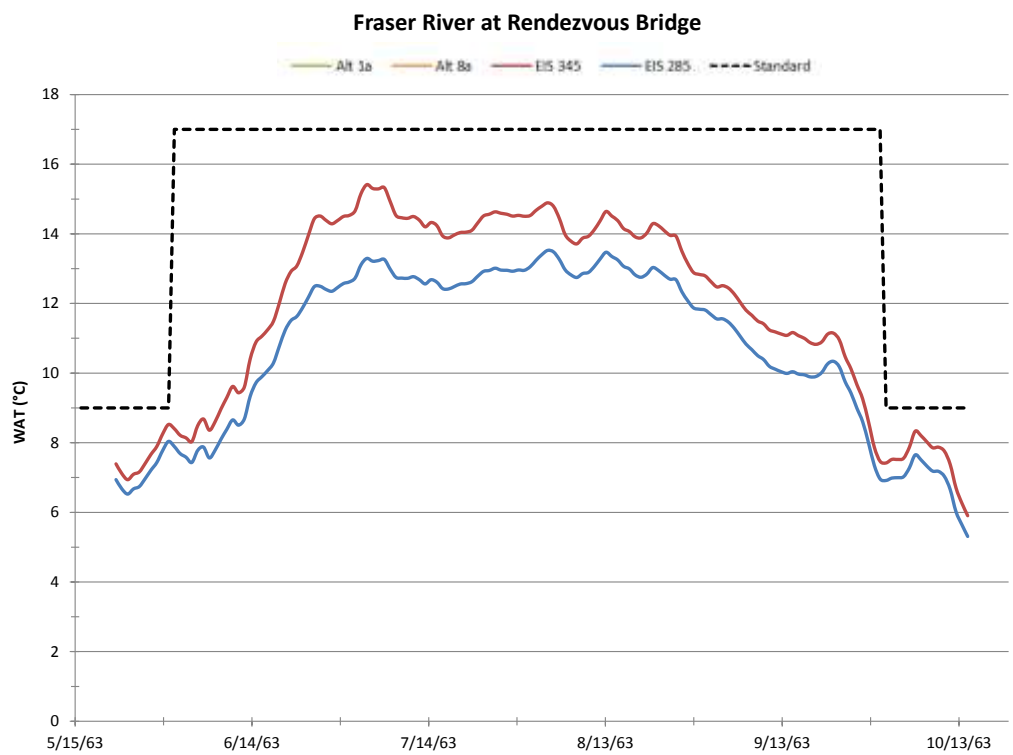

Figure 45. 1963 WATs, Fraser River at Rendezvous Bridge.

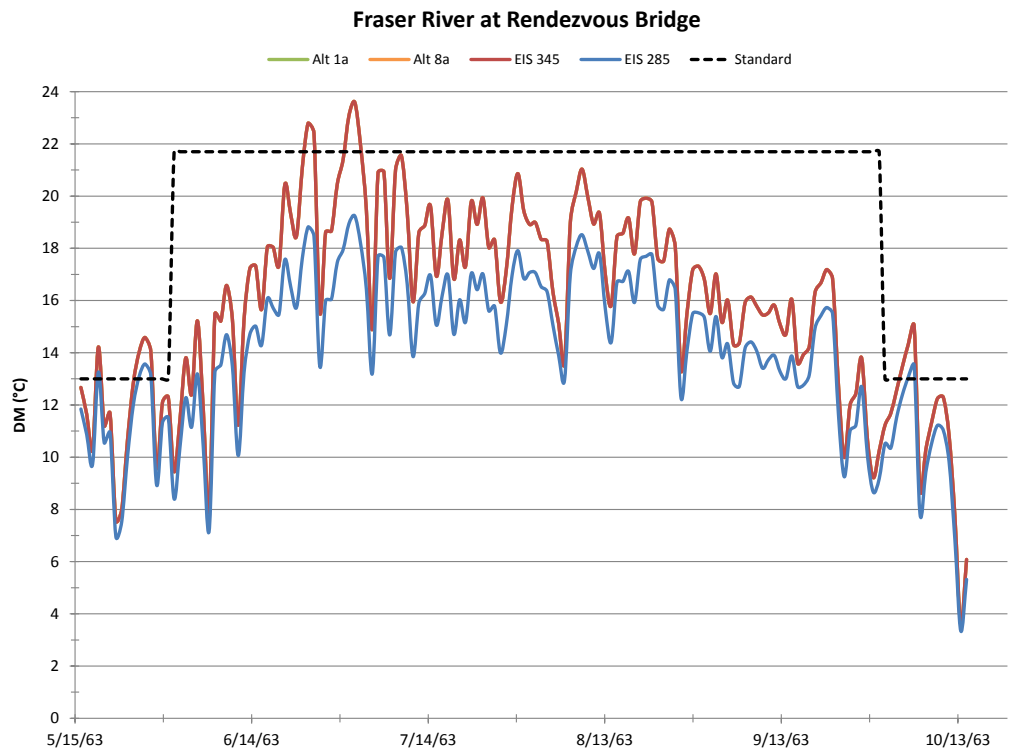

Figure 46. 1963 DMs, Fraser River at Rendezvous Bridge.

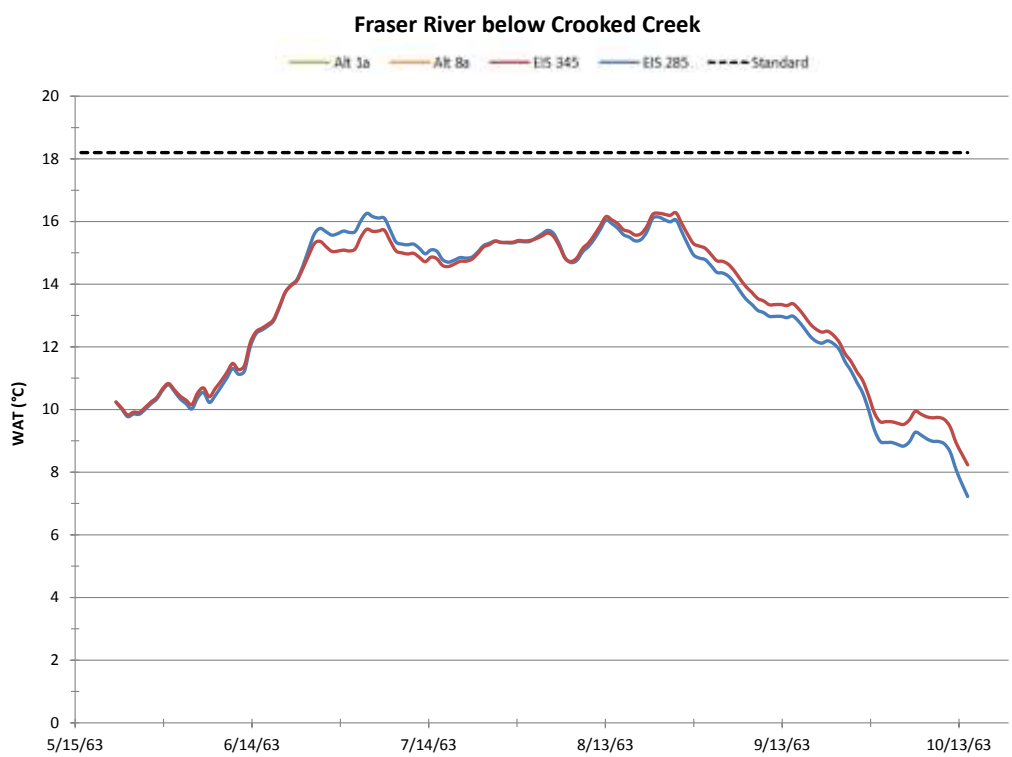

Figure 47. 1963 WATs, Fraser River below Crooked Creek.

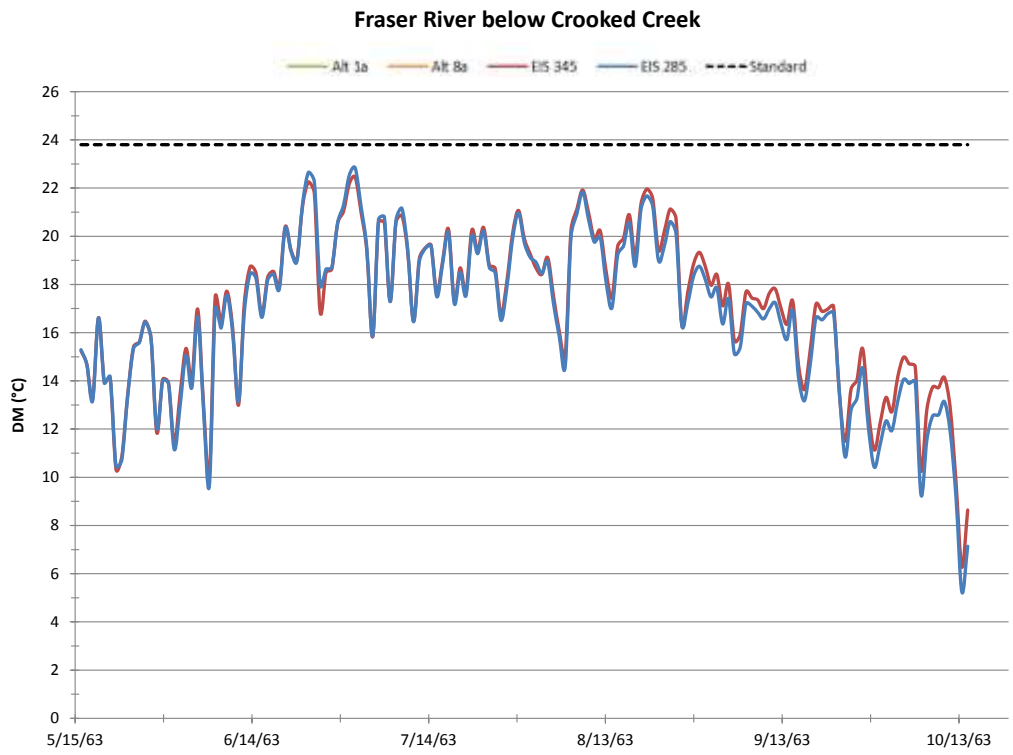

Figure 48. 1963 DMs, Fraser River below Crooked Creek.

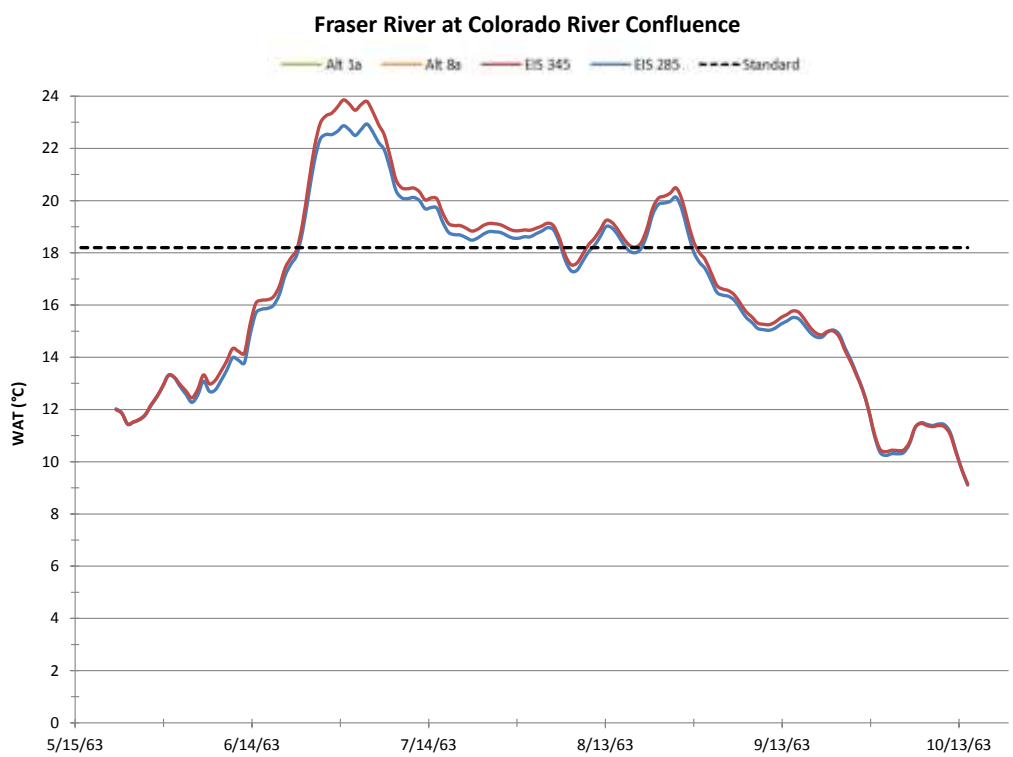

Figure 49. 1963 WATs, Fraser River at the Colorado River confluence.

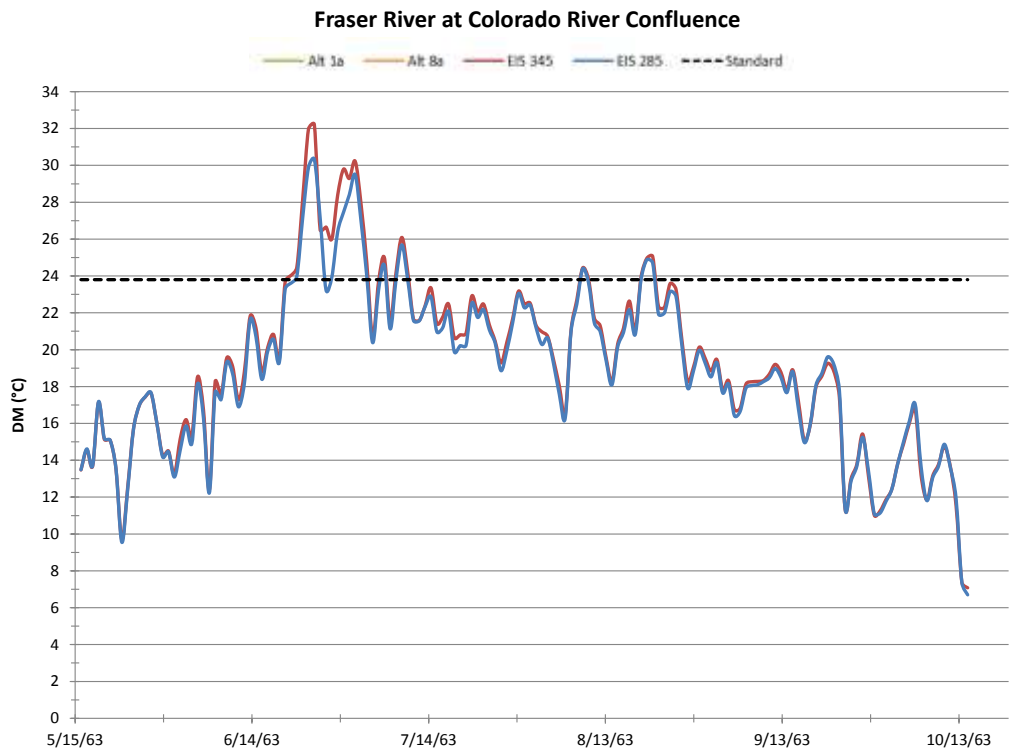

Figure 50. 1963 DMs, Fraser River at the Colorado River confluence.

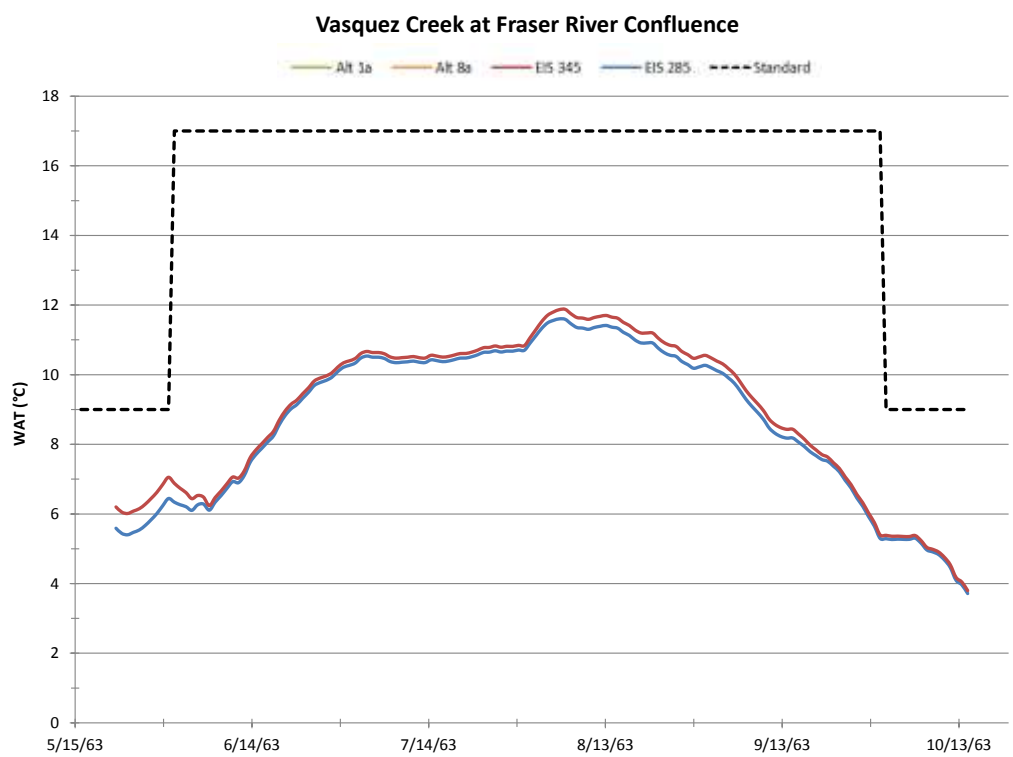

Figure 51. 1963 WATs, Vasquez Creek at the Fraser River confluence.

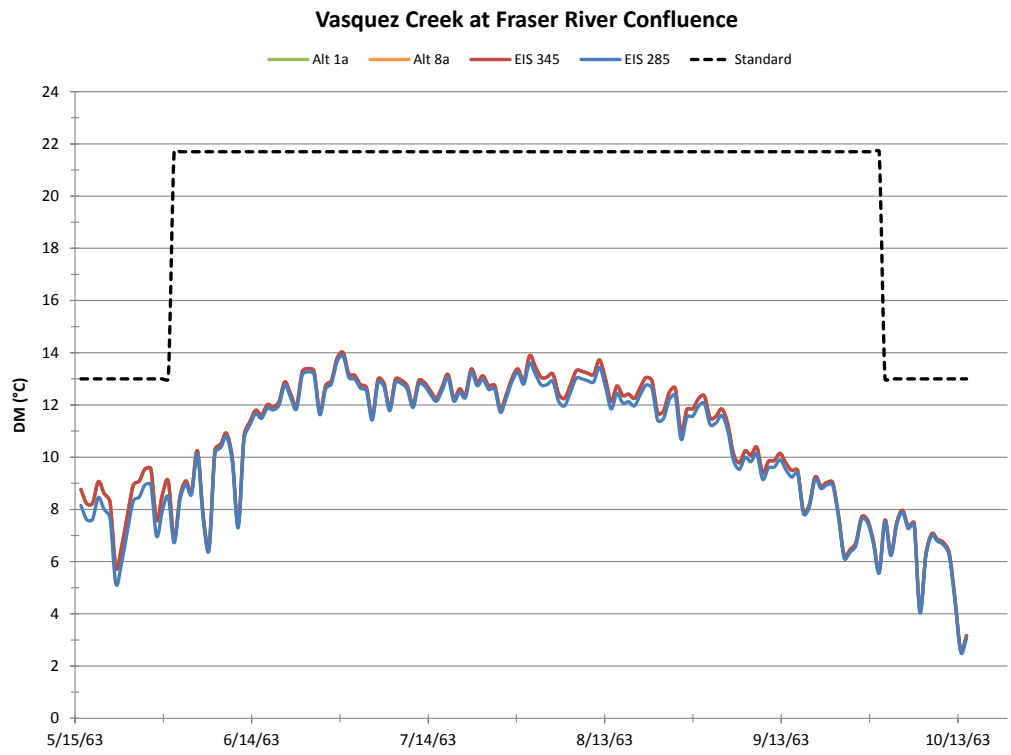

Figure 52. 1963 DMs, Vasquez Creek at the Fraser River confluence.

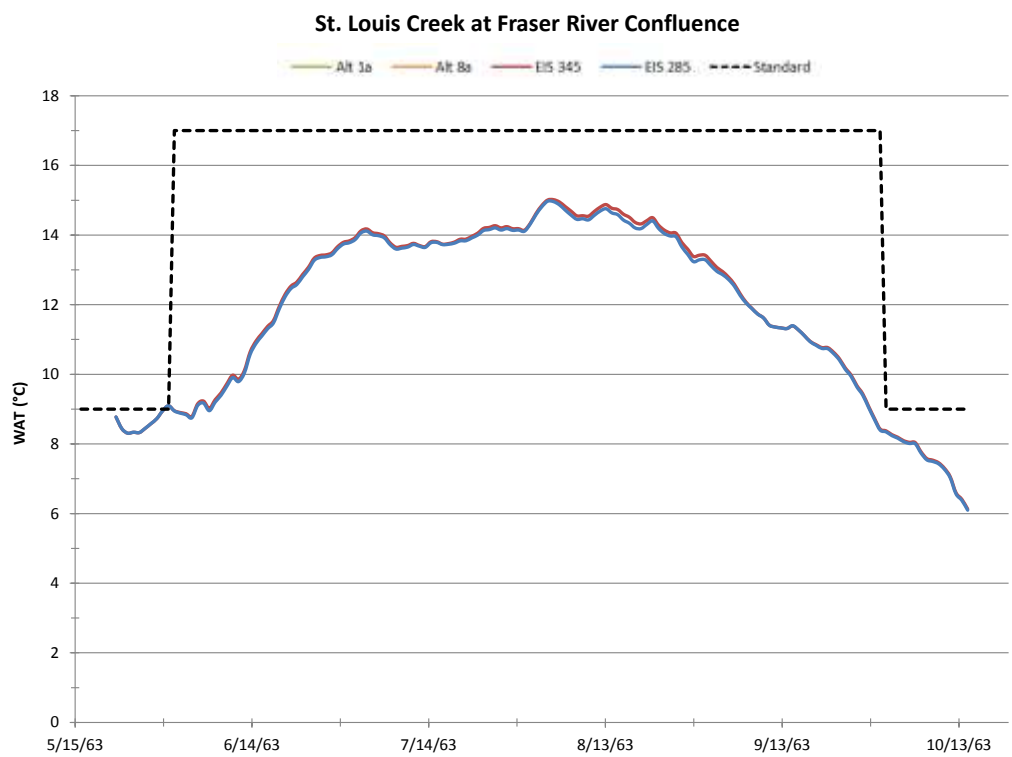

Figure 53. 1963 WATs, St. Louis Creek at the Fraser River confluence.

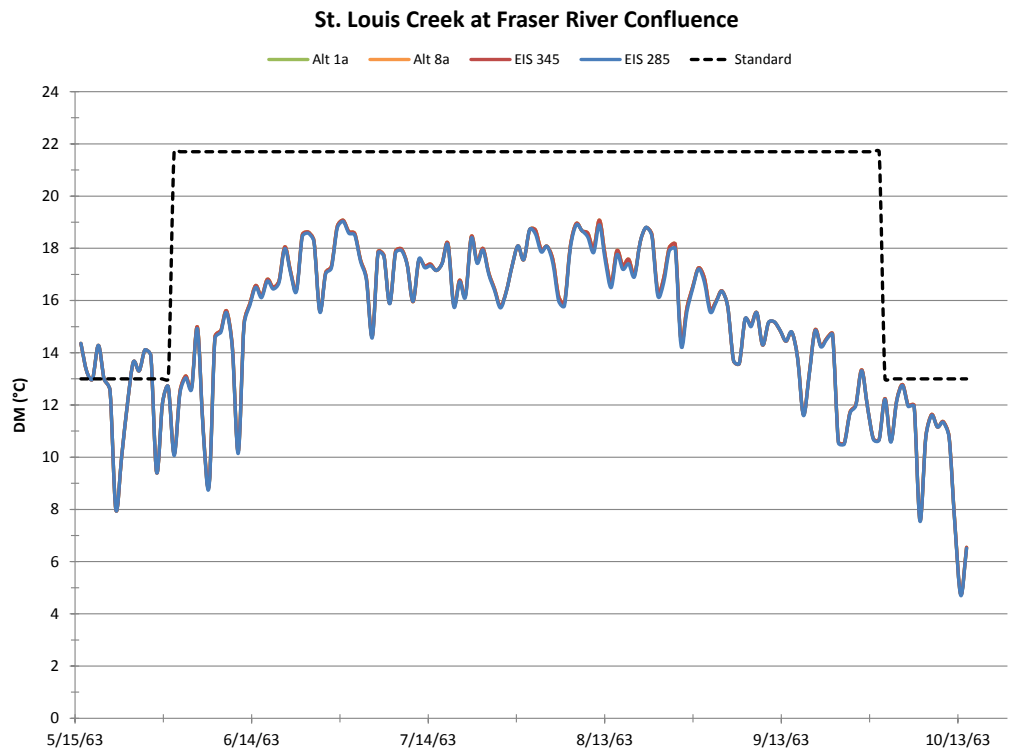

Figure 54. 1963 DMs, St. Louis Creek at the Fraser River confluence.

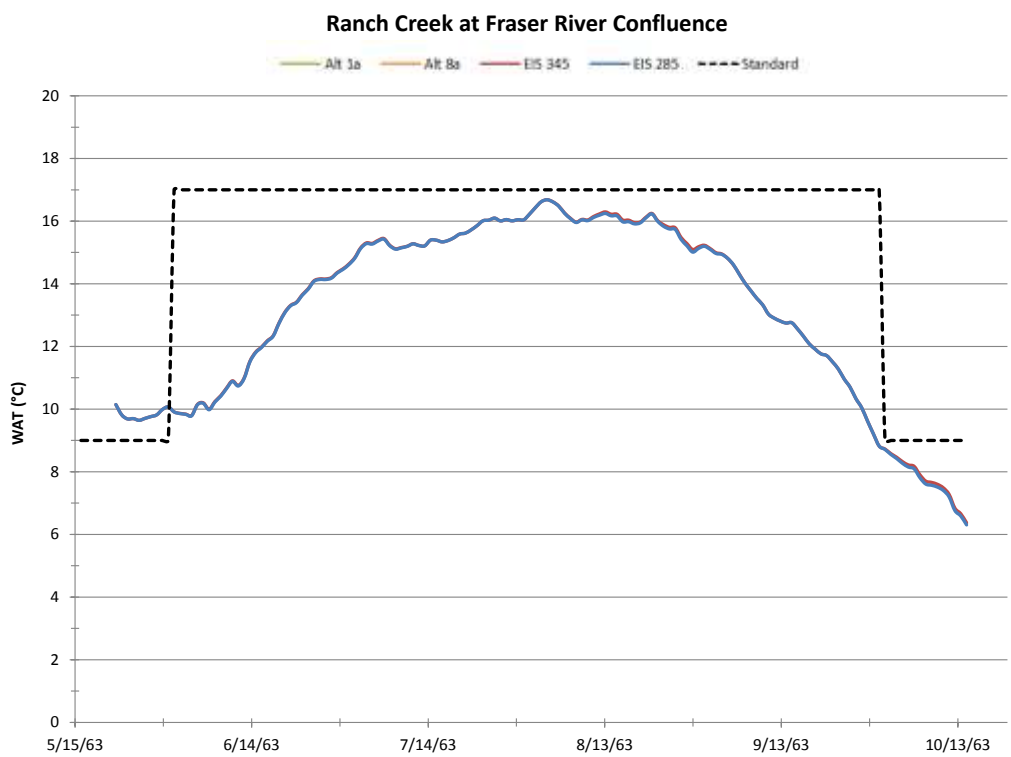

Figure 55. 1963 WATs, Ranch Creek at the Fraser River confluence.

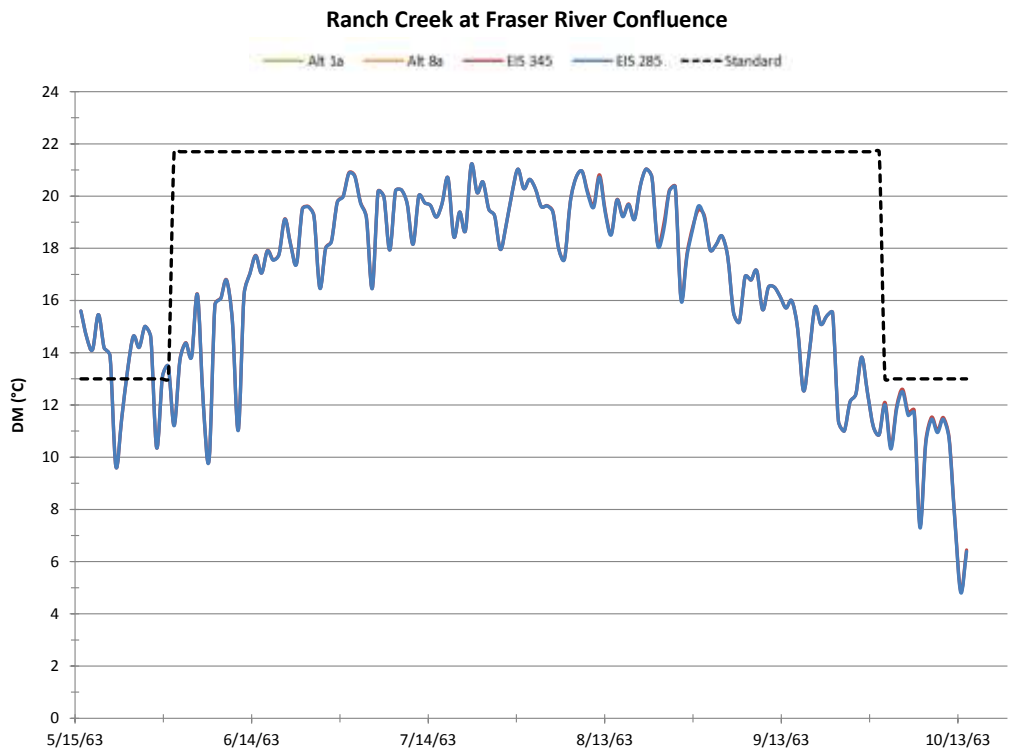

Figure 56. 1963 DMs, Ranch Creek at the Fraser River confluence.

Table 15. Summary of WAT and DM exceedances, 1963 flow scenario year.

1963	Rendezvous Bridge				Below Crooked Creek				Colorado River Confluence			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	13.53	15.41	15.41	15.41	16.26	16.28	16.28	16.28	22.94	23.86	23.86	23.86
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	8	8	8	8
July	0	0	0	0	0	0	0	0	31	31	31	31
August	0	0	0	0	0	0	0	0	20	25	25	25
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	19.24	23.60	23.60	23.60	22.84	22.45	22.45	22.45	30.33	32.22	32.22	32.22
# of Days Above Standard:												
May	4	4	4	4	0	0	0	0	0	0	0	0
June	0	2	2	2	0	0	0	0	8	10	10	10
July	0	3	3	3	0	0	0	0	8	8	8	8
August	0	0	0	0	0	0	0	0	3	5	5	5
September	0	0	0	0	0	0	0	0	0	0	0	0
October	2	3	3	3	0	0	0	0	0	0	0	0

1963	Vasquez Creek				St. Louis Creek				Ranch Creek			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	11.60	11.88	11.88	11.88	14.97	15.02	15.02	15.02	16.68	16.68	16.68	16.68
# of Days Above Standard:												
May	0	0	0	0	1	1	1	1	10	10	10	10
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	13.88	14.01	14.01	14.01	19.03	19.08	19.08	19.08	21.21	21.21	21.21	21.21
# of Days Above Standard:												
May	0	0	0	0	7	7	7	7	13	13	13	13
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0

Table 16. EIS 345 and Alt 1a WAT and DM increases relative to EIS 285, 1963 flow scenario year.

1963	Rendezvous Bridge		Below Crooked Creek		Colorado River Confluence	
	EIS 345	Alt 1a	EIS 345	Alt 1a	EIS 345	Alt 1a
Largest WAT Increase (°C)	2.12	2.12	1.01	1.01	0.99	0.99
Avg. WAT Increase (°C):						
May	0.45	0.45	0.05	0.05	0.01	0.01
June	1.21	1.21	-0.03	-0.03	0.38	0.38
July	1.71	1.71	-0.22	-0.22	0.45	0.45
August	1.16	1.16	0.13	0.13	0.26	0.26
September	0.90	0.90	0.38	0.38	0.14	0.14
October	0.63	0.63	0.76	0.76	0.02	0.02
Largest DM Increase (°C)	4.36	4.36	1.50	1.50	3.41	3.41
Avg. DM Increase (°C):						
May	0.76	0.76	0.01	0.01	0.01	0.01
June	2.19	2.19	0.09	0.09	0.77	0.77
July	2.72	2.72	0.03	0.03	0.43	0.43
August	1.73	1.73	0.31	0.31	0.27	0.27
September	1.39	1.39	0.54	0.54	0.08	0.08
October	0.98	0.98	0.99	0.99	-0.04	-0.04

1978 Scenario Year

Hydrology

For several dates in 1978 under scenarios EIS 345, Alt 1a and Alt 8a, corresponding PACSM simulation data showed low flows in the mainstem Fraser River between the Fraser at Winter Park gage (USGS Gage 09024000) and the Hammond No. 1 Ditch diversion. These low flows caused the ADYN portion of the dynamic temperature model to stop running. It was therefore necessary to add a small amount of flow to scenarios EIS 345, Alt 1a and Alt 8a in certain locations and for certain dates to allow the ADYN model to run. Through trial and error, it was found that an additional 1 cfs (flows increased from approximately 3.3 cfs to 4.3 cfs) added to the upstream boundary from September 16 to October 15 was sufficient to allow the ADYN model to run. As with the previous scenario years, adding this small amount of flow changed temperatures by less than 0.1°C.

Discharges at the three focus locations are shown in Figure 57 - Figure 59. In all three figures Alt 1a and Alt 8a are the same as EIS 345. According to the PACSM/point flow model simulations, the differences in flow between EIS 345 and both Alt 1a and Alt 8a are minimal. In fact, flows are different only for a couple of days and the difference in flows are typically 0.01 cfs. Overall, the annual virgin flow for the Fraser River below Crooked Creek in 1978 was 110% of average and followed a very dry year, 1977 (55% of average annual). The virgin flow in May, June, July and August was 96%, 130%, 118% and 86% of the monthly average, respectively.

In 1978 the Moffat Project would cause no reduction of Fraser River flows (this is the difference between EIS 345 and Alt 1a). For cumulative conditions, there are flow reductions mainly in late June through early September (this is the difference between EIS 285 and Alt 1a).

In the previous year, 1977, Gross Reservoir does not fill under EIS 285, EIS 345 or Alt 1a. With EIS 345, Gross Reservoir begins the runoff season in 1978 with slightly less contents than EIS 285. Neither the existing Gross Reservoir in EIS 345 nor the Gross Reservoir enlargement in Alt 1a would fill in 1978. As a result, between EIS 345 and Alt 1a there is no difference in Fraser River flows. The difference in Fraser River basin flows between EIS 285 and Alt 1a is mostly during the first two weeks of July, with smaller reductions through early September due to higher demands of entities within the Fraser River basin (e.g., municipal and snowmaking demands), and due to reductions in U.S. Forest Service bypass flows because Denver Water customers are on restrictions.

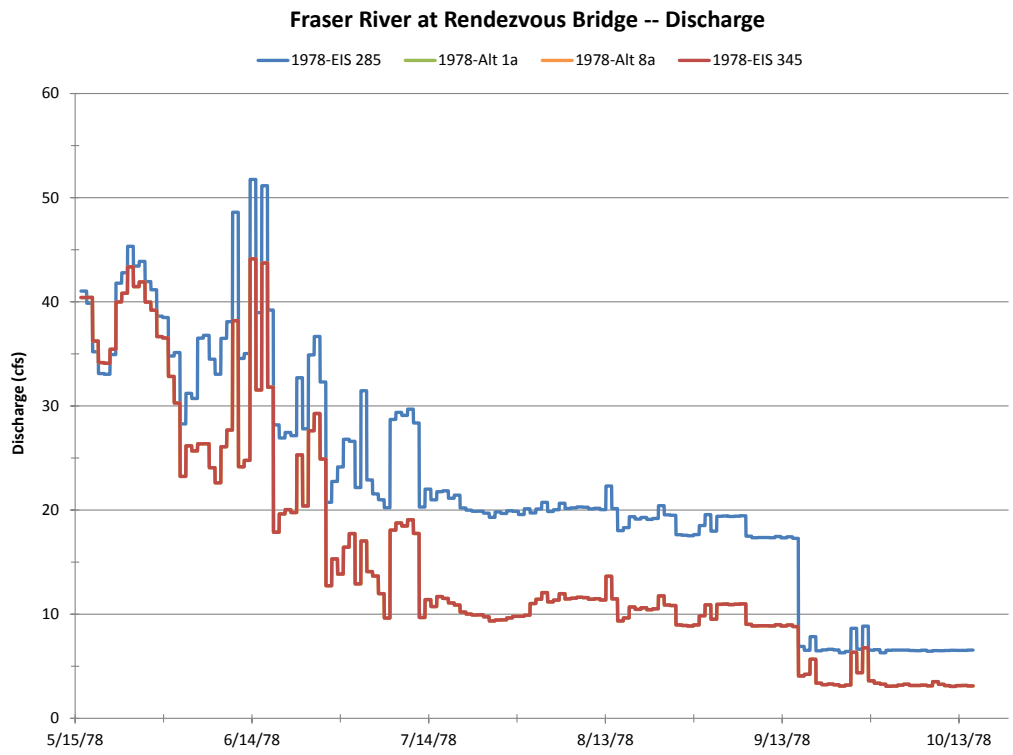

Figure 57. Discharge in the Fraser River at Rendezvous Bridge, 1978.

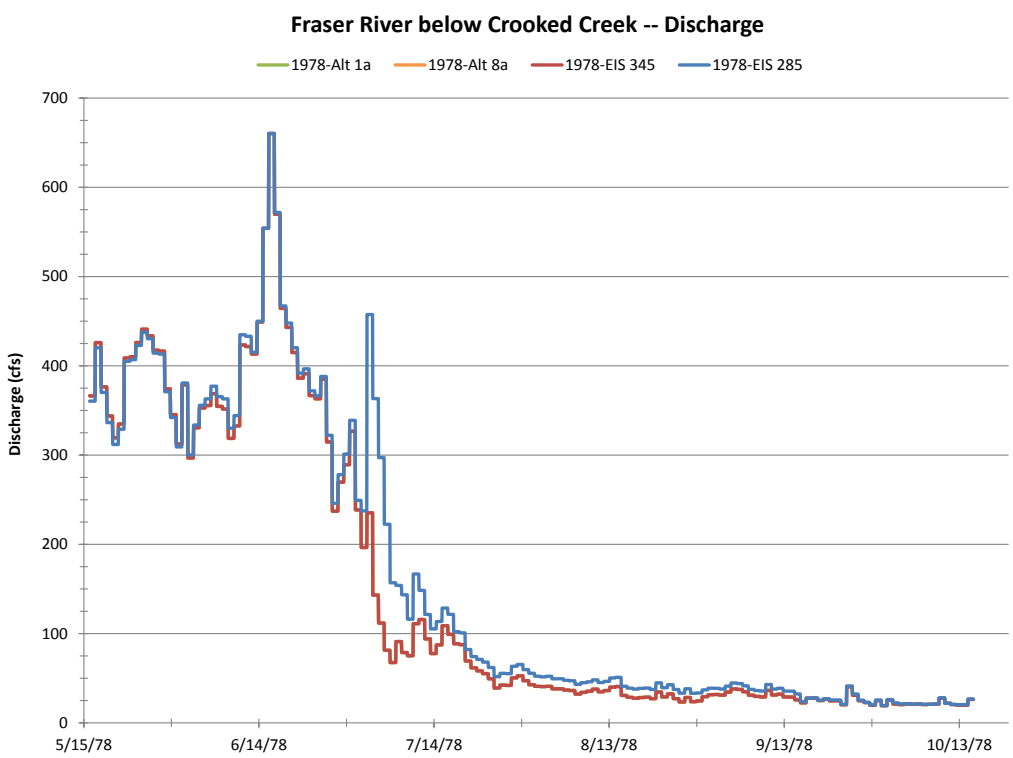

Figure 58. Discharge in the Fraser River below Crooked Creek, 1978.

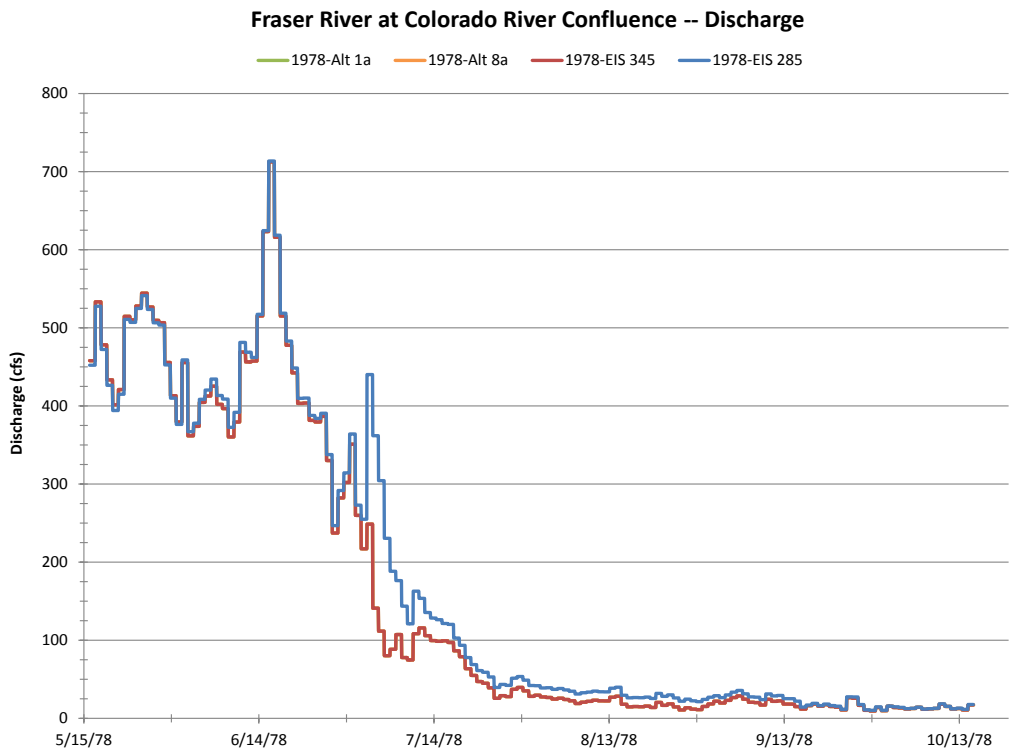

Figure 59. Discharge in the Fraser River at the Colorado River confluence, 1978.

Temperatures

Figure 60 - Figure 62 show the simulated hourly temperatures for the three focus locations. As with the hydrographs, Alt 1a and Alt 8a are the same as EIS 345. The greatest differences in temperature between EIS 285 and EIS 345 occur at the Rendezvous Bridge location. Temperatures are warmer with the EIS 345 (and Alt 1a and Alt 8a) scenario for every day of the simulation. The average difference in temperature is 0.85°C and the maximum difference is 3.30°C. The largest temperature differences occur in July, August and September. For the Fraser River below Crooked Creek, temperatures are very similar between the scenarios until July 1. The decrease in flow with EIS 345, Alt 1a and Alt 8a seen in Figure 58 around July 1 corresponds to the elevated temperatures at the same time shown in Figure 61. Temperatures are again similar for the remainder of July and through August. During September and October there are larger differences in temperature between the scenarios. The average difference in temperature is 0.29°C and the maximum difference is 2.72°C. Similar patterns were observed in the Fraser River at the Colorado River confluence, with the large change in temperature around July 1. Unlike the Crooked Creek location, temperatures are fairly similar in September and October. The average difference in temperature between the scenarios is 0.27°C and the maximum difference is 4.12°C.

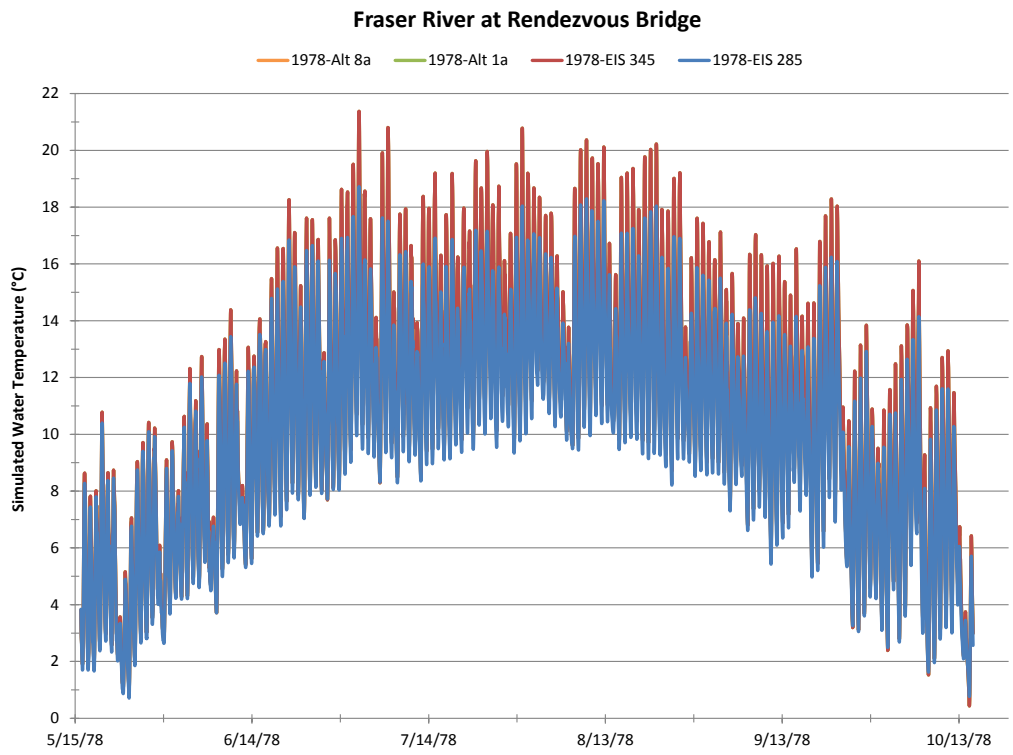

Figure 60. Simulated hourly temperatures in the Fraser River at Rendezvous Bridge, 1978.

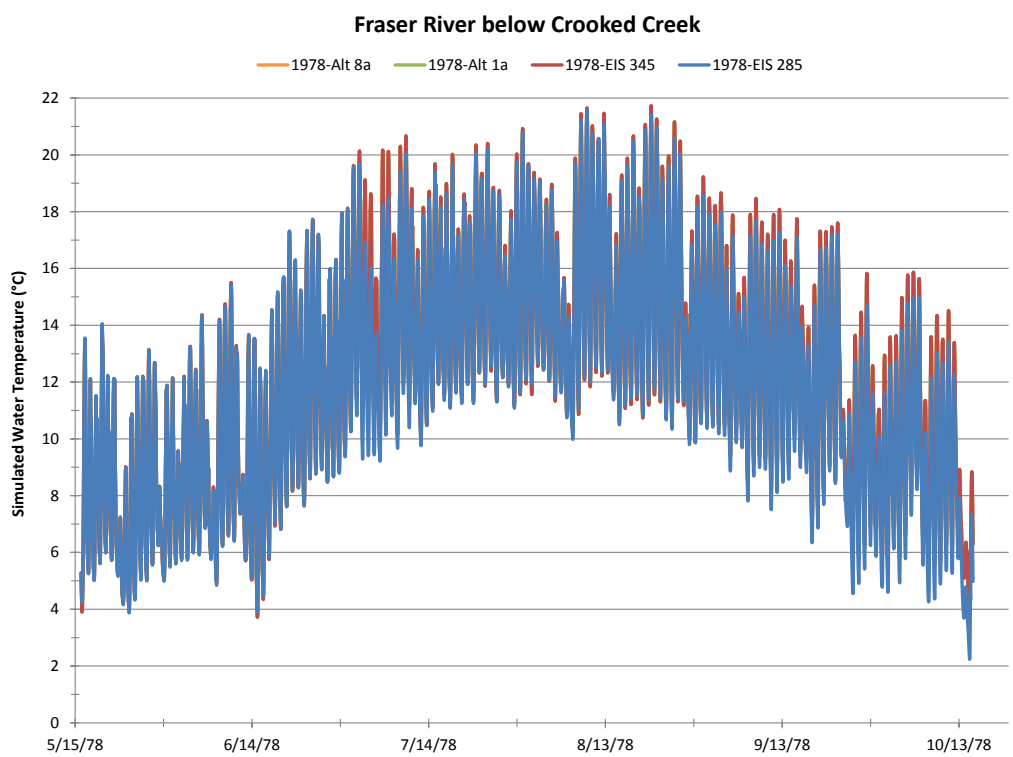

Figure 61. Simulated hourly temperatures in the Fraser River below Crooked Creek, 1978.

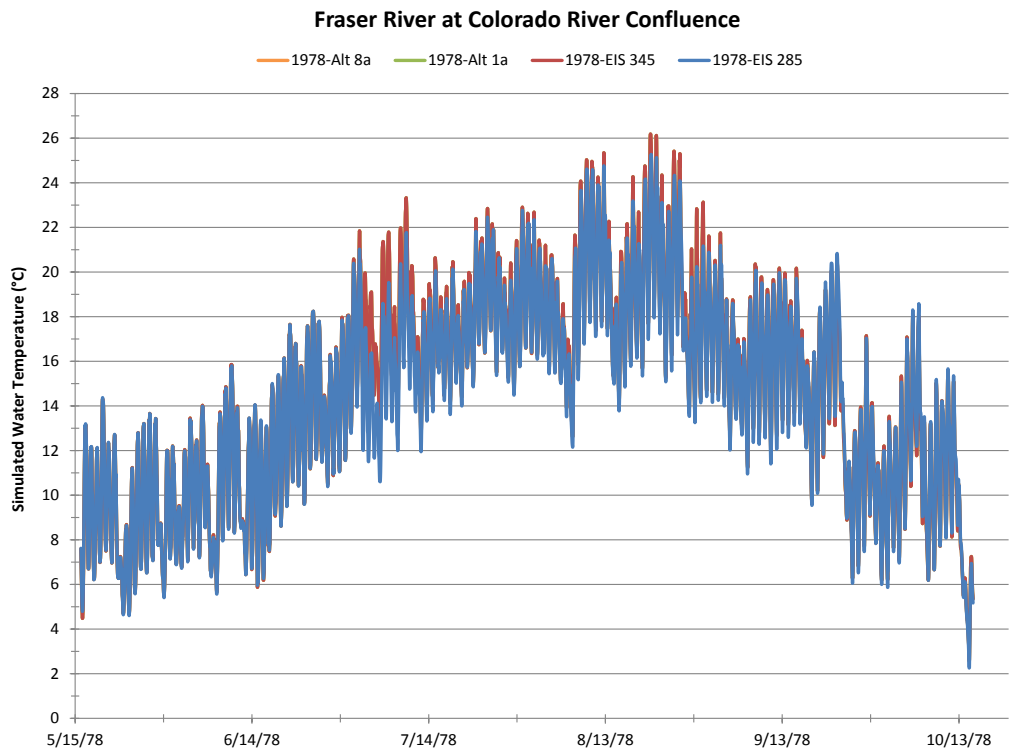

Figure 62. Simulated hourly temperatures in the Fraser River at the Colorado River confluence, 1978.

WATs and DMs

Fraser River at Rendezvous Bridge

Weekly Average Temperature (WAT) (Figure 63)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 64)

- EIS 285: The DM standard is exceeded for 2 days in October.
- EIS 345: The DM standard is exceeded for 3 days in October.
- Alt 1a: The DM standard is exceeded for 3 days in October. Therefore, with Alt 1a the DM standard is exceeded 1 more day compared to current conditions; this day is not attributable to the Moffat Project.

Table A - 13 provides the temperatures and days for which exceedances occur. These days are within the winter shoulder-season and could possibly be considered exemptions.

Fraser River below Crooked Creek

Weekly Average Temperature (WAT) (Figure 65)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 66)

There are no exceedances of the DM standard for any of the four streamflow scenarios.

Fraser River at the Colorado River Confluence

Weekly Average Temperature (WAT) (Figure 67)

- EIS 285: The WAT standard is exceeded for 6 days in July and 27 days in August, for a total of 33 days.
- EIS 345: The WAT standard is exceeded for 7 days in July, 28 days in August and 1 day in September, for a total of 36 days.
- Alt 1a: The WAT standard is exceeded for 7 days in July, 28 days in August and 1 day in September, for a total of 36 days. Therefore, with Alt 1a the WAT standard is exceeded 3 additional days compared to current conditions; these days are not attributable to the Moffat Project.

Table A - 14 provides the temperatures and days for which exceedances occur.

Daily Maximum (DM) (Figure 68)

- EIS 285: The DM standard is exceeded for 8 days in August.
- EIS 345: The DM standard is exceeded for 12 days in August.
- Alt 1a: The DM standard is exceeded for 12 days in August. Therefore, with Alt 1a the DM standard is exceeded 4 more days compared to current conditions; none of the days are attributable to the Moffat Project.

Table A - 14 provides the temperatures and days for which exceedances occur.

Vasquez Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 69)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 70)

There are no exceedances of the DM standard for any of the four streamflow scenarios.

St. Louis Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 71)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 72)

- EIS 285: The DM standard is exceeded for 2 days in May.
- EIS 345: The DM standard is exceeded for 2 days in May.
- Alt 1a: The DM standard is exceeded for 2 days in May. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Table A - 15 provides the temperatures and days for which exceedances occur. These could possibly be considered exemptions since they fall within the shoulder-season.

Ranch Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 73)

- EIS 285: The WAT standard is exceeded for 1 day in May and 3 days in October, for a total of 4 days.
- EIS 345: The WAT standard is exceeded for 1 day in May and 3 days in October, for a total of 4 days.
- Alt 1a: The WAT standard is exceeded for 1 day in May and 3 days in October, for a total of 4 days. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Daily Maximum (DM) (Figure 74)

- EIS 285: The DM standard is exceeded for 4 days in May and 4 days in October, for a total of 8 days.
- EIS 345: The DM standard is exceeded for 4 days in May and 4 days in October, for a total of 8 days.
- Alt 1a: The DM standard is exceeded for 4 days in May and 4 days in October, for a total of 8 days. Therefore, with Alt 1a there is no change in exceedances compared to current conditions.

Table A - 16 provides the temperatures and days for which exceedances occur. The exceedances could possibly be considered exemptions since they fall within the shoulder-season.

Table 17 summarizes all exceedances for all locations. Table 18 summarizes the predicted increase in water temperature due to EIS 345 and Alt 1a (cumulative effects, plus Moffat Project) relative to EIS 285 (current conditions). Note that the EIS 345 and Alt 1a increases are the same. In general, the stream temperatures will be higher in the Fraser River compared to current conditions. On average, the increase in WAT ranges from 0.01 to 1.2^{o}C, with the largest WAT increase at the Colorado River confluence (2.24°C on July 12). On average, the increase in DM ranges from 0.01 to 2.0^{o}C, with the largest DM increase at Rendezvous Bridge (3.13°C on July 7). Note that for the Fraser River at the Colorado River confluence, the average October WATs and DMs for EIS 345 and Alt 1a are slightly less than those for EIS 285 because the flows are slightly higher.

Summary for the Fraser River Mainstem

For 1978, the model simulates temperatures that have exceedances under current conditions (EIS 285) at Rendezvous Bridge, none below the confluence with Crooked Creek and temperature exceedances again at the confluence with the Colorado River. With Alt 1a (cumulative effects with the Moffat Project), there will be additional temperature exceedances at the same two locations. However, none of the exceedances at the two locations are attributable to the Moffat Project.

Summary for the Fraser River Tributaries

In Vasquez Creek, there are no WAT or DM exceedances identified for any of the four streamflow scenarios. In St. Louis Creek, there are exceedances of the DM standard under current and future conditions but the number of exceedances is the same for all four scenarios. In Ranch Creek, there are exceedances of the WAT standard under current and future conditions but the number of exceedances is the same for all four scenarios. There are also exceedances of the DM standard in Ranch Creek under current and future conditions but the number of exceedances is the same for all four scenarios.

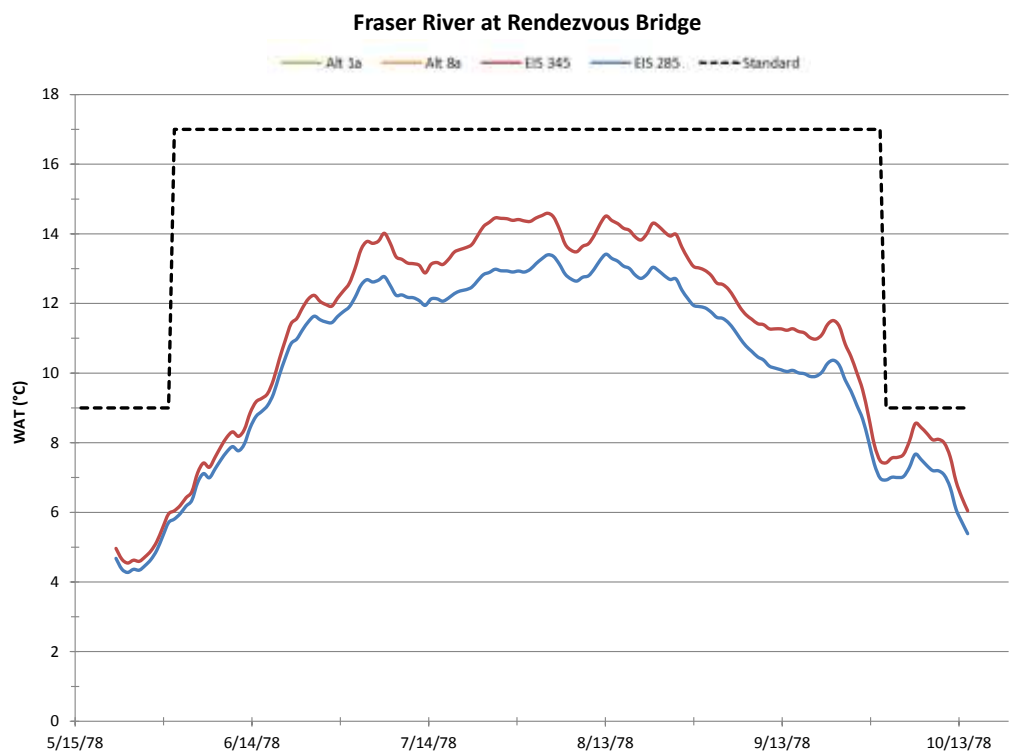

Figure 63. 1978 WATs, Fraser River at Rendezvous Bridge.

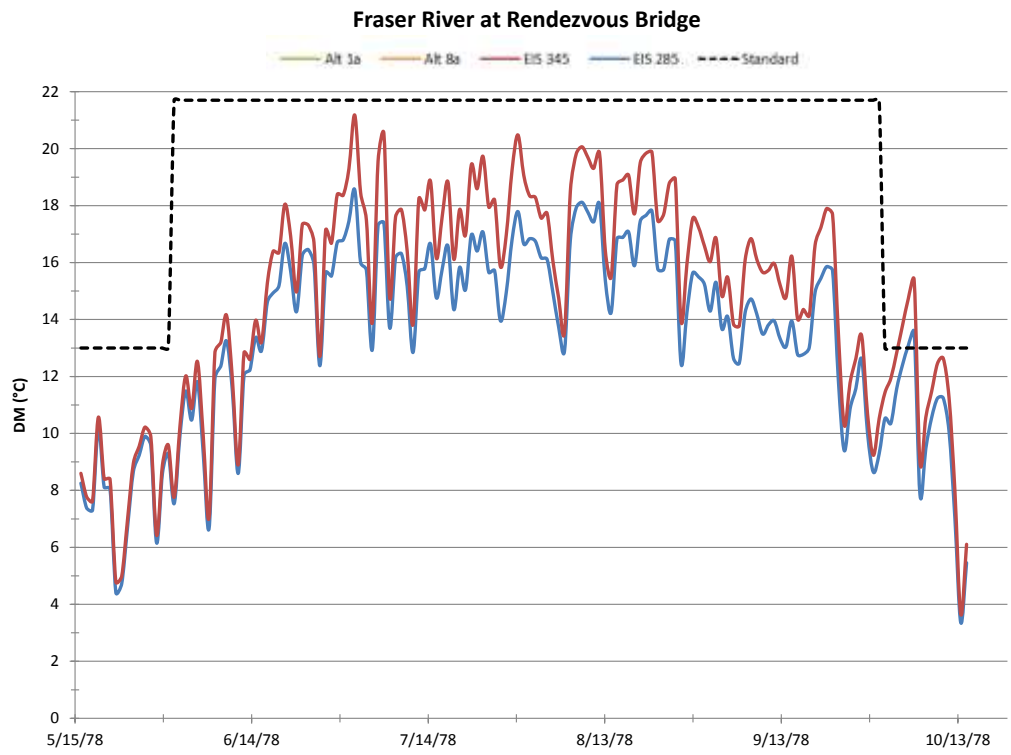

Figure 64. 1978 DMs, Fraser River at Rendezvous Bridge.

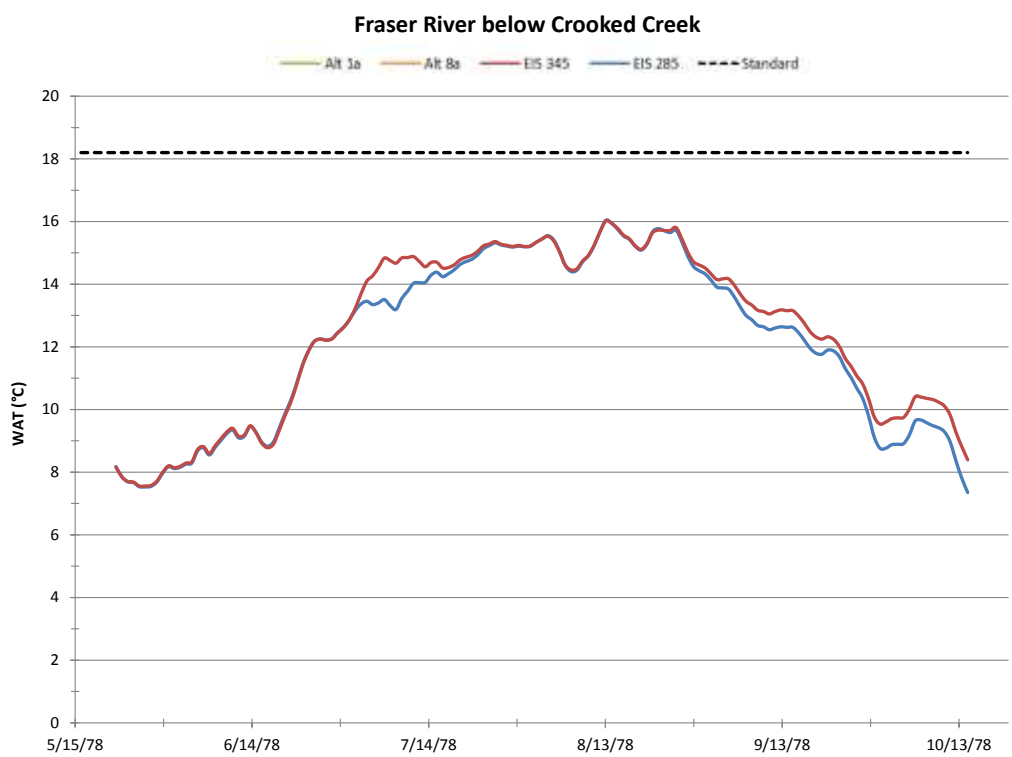

Figure 65. 1978 WATs, Fraser River below Crooked Creek.

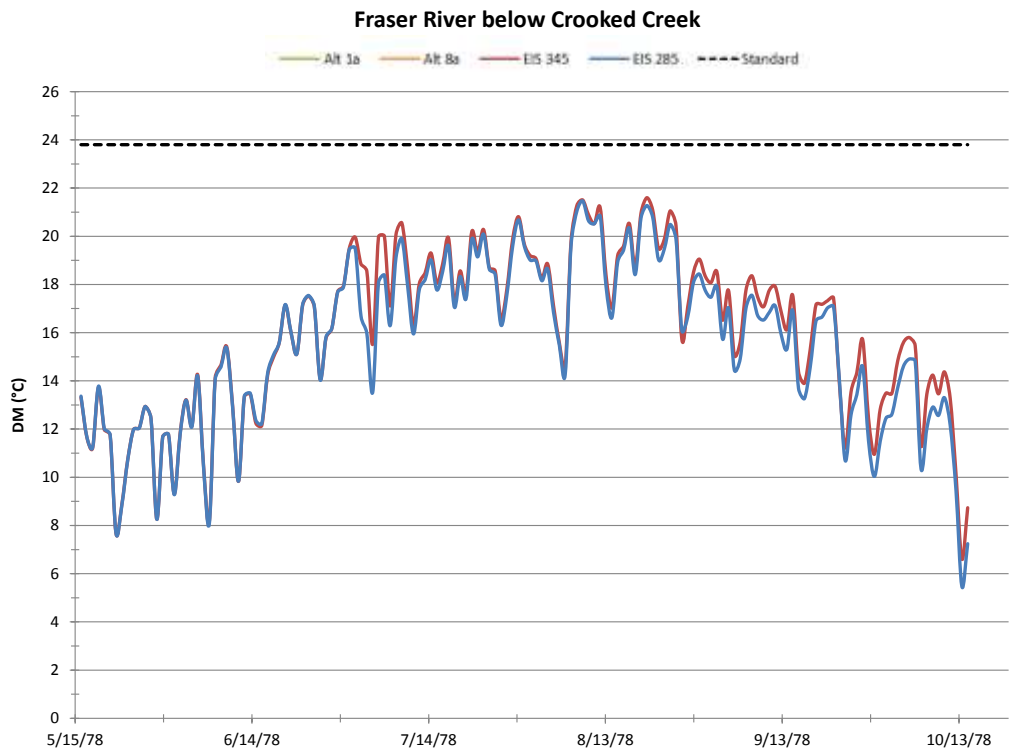

Figure 66. 1978 DMs, Fraser River below Crooked Creek.

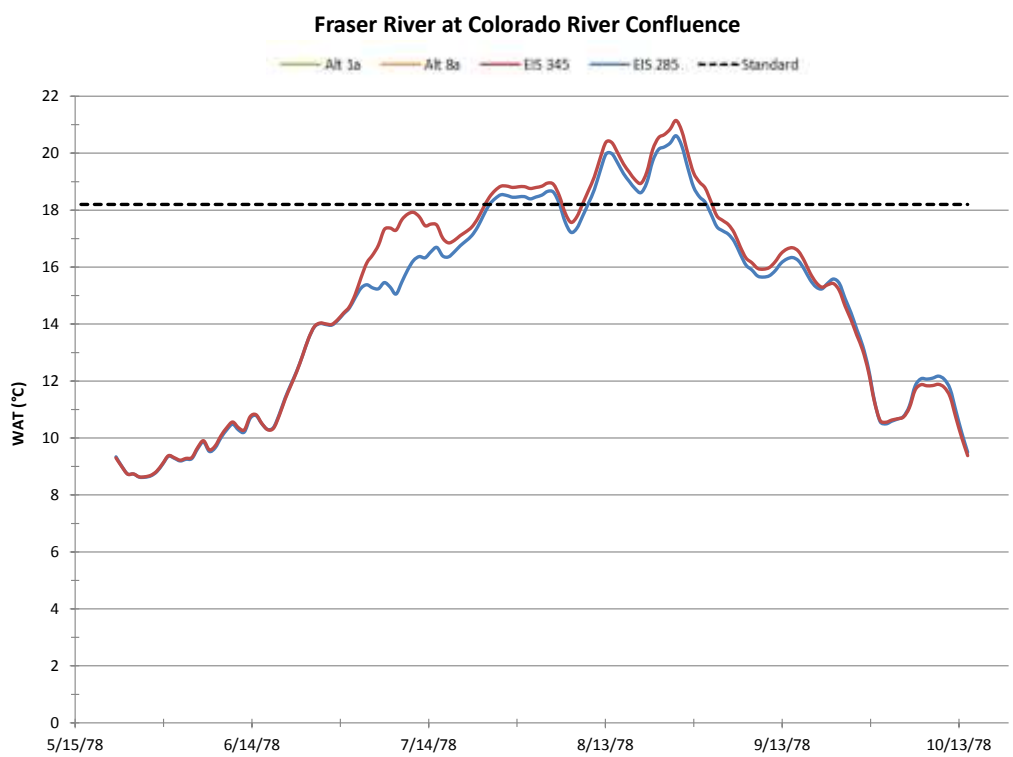

Figure 67. 1978 WATs, Fraser River at the Colorado River confluence.

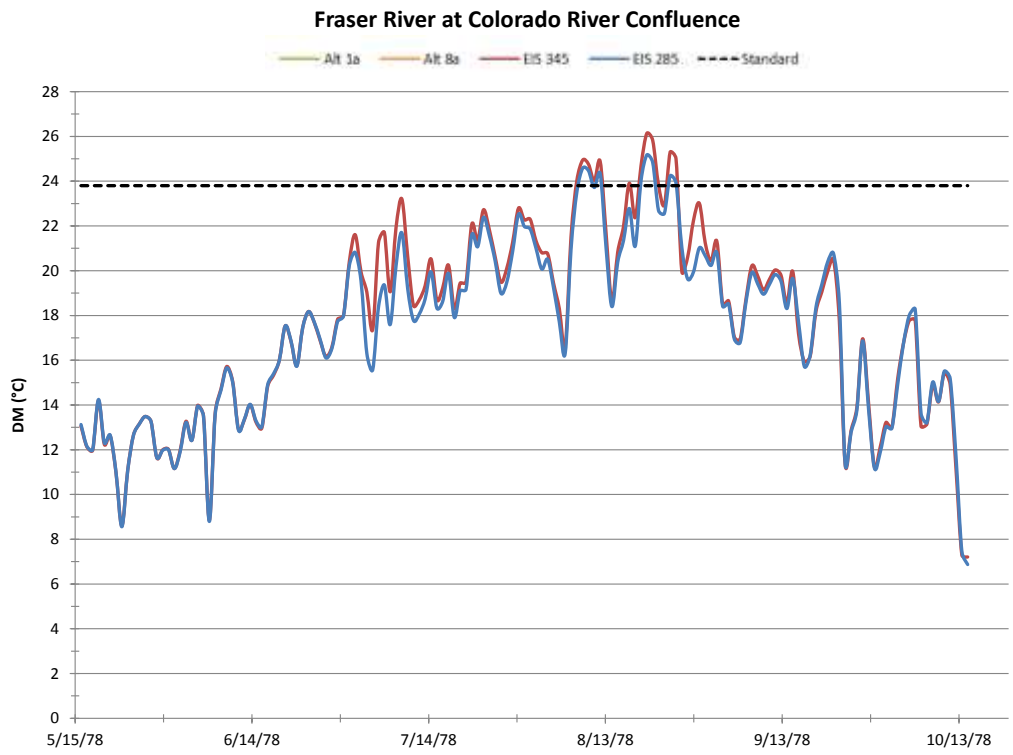

Figure 68. 1978 DMs, Fraser River at the Colorado River confluence.

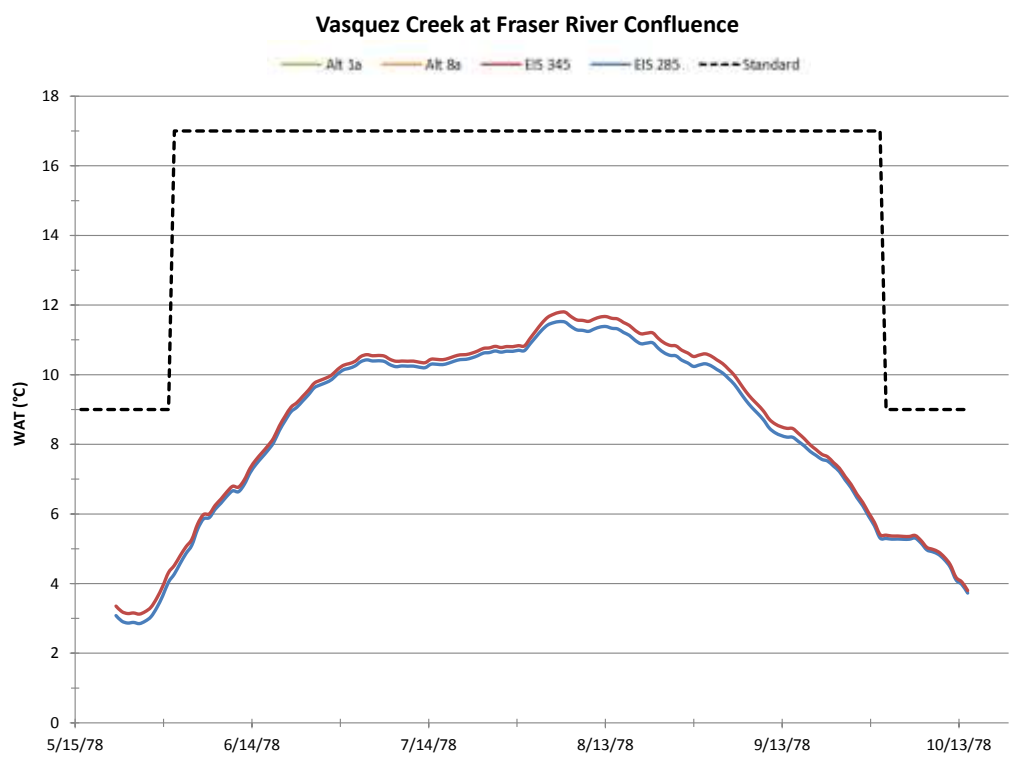

Figure 69. 1978 WATs, Vasquez Creek at the Fraser River confluence.

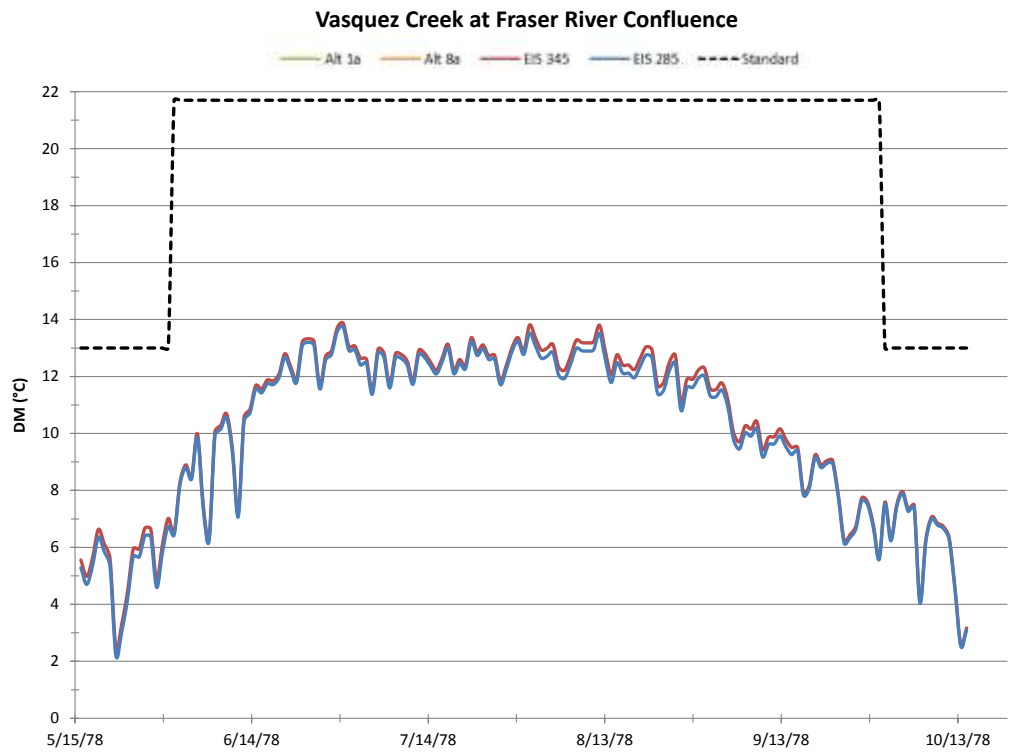

Figure 70. 1978 DMs, Vasquez Creek at the Fraser River confluence.

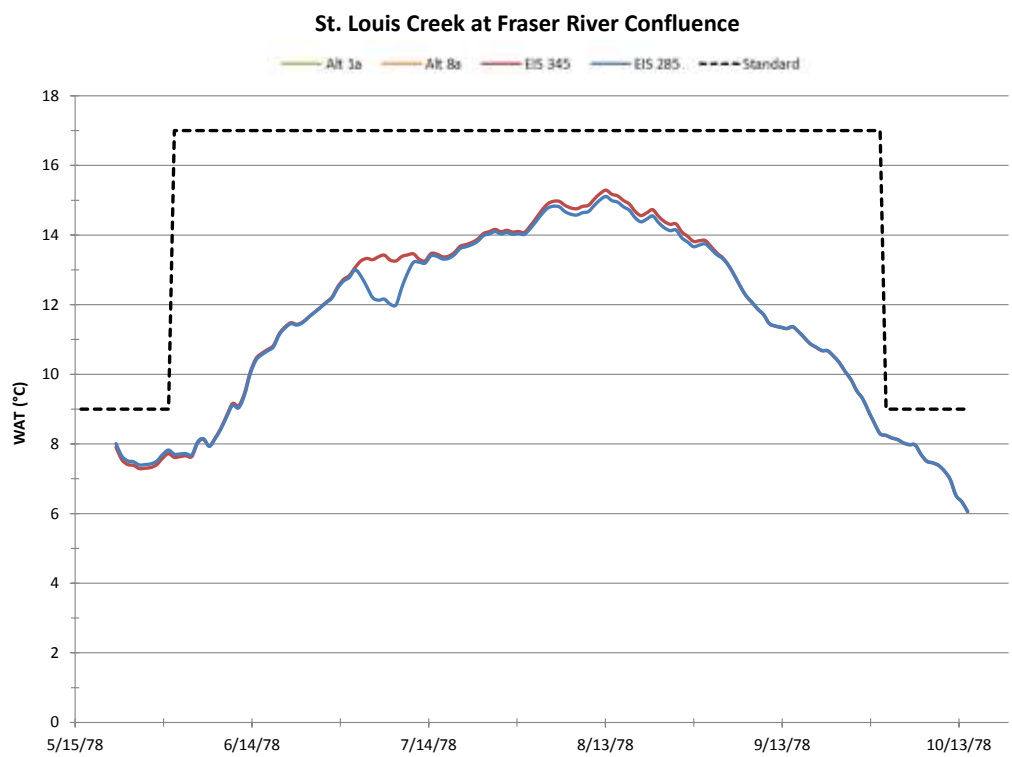

Figure 71. 1978 WATs, St. Louis Creek at the Fraser River confluence.

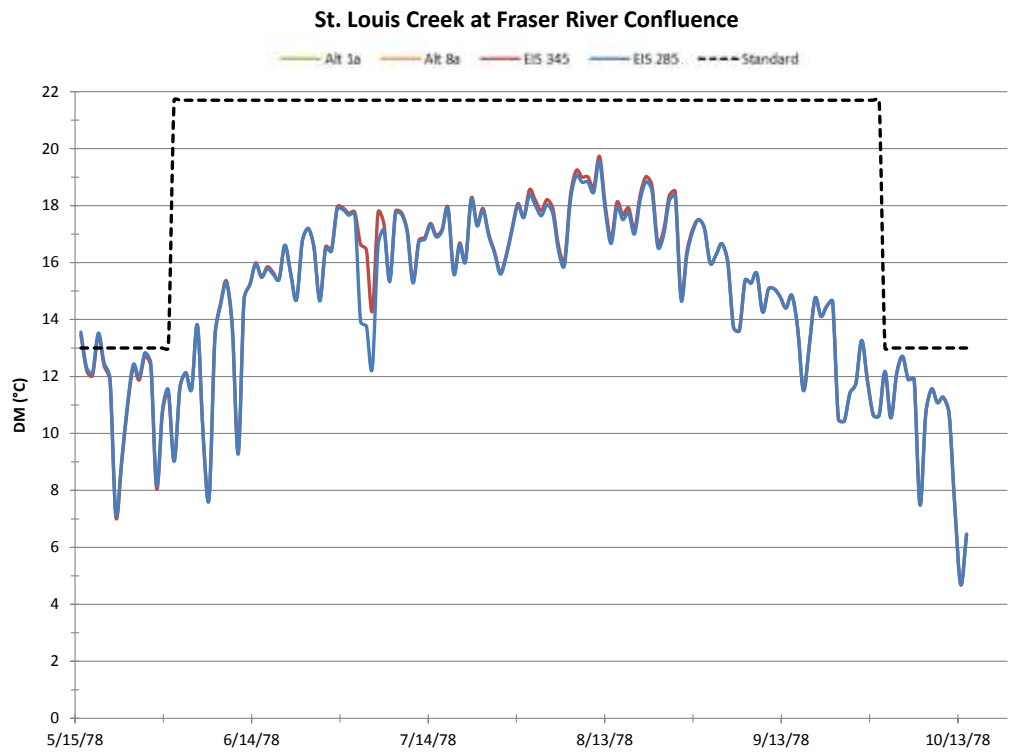

Figure 72. 1978 DMs, St. Louis Creek at the Fraser River confluence.

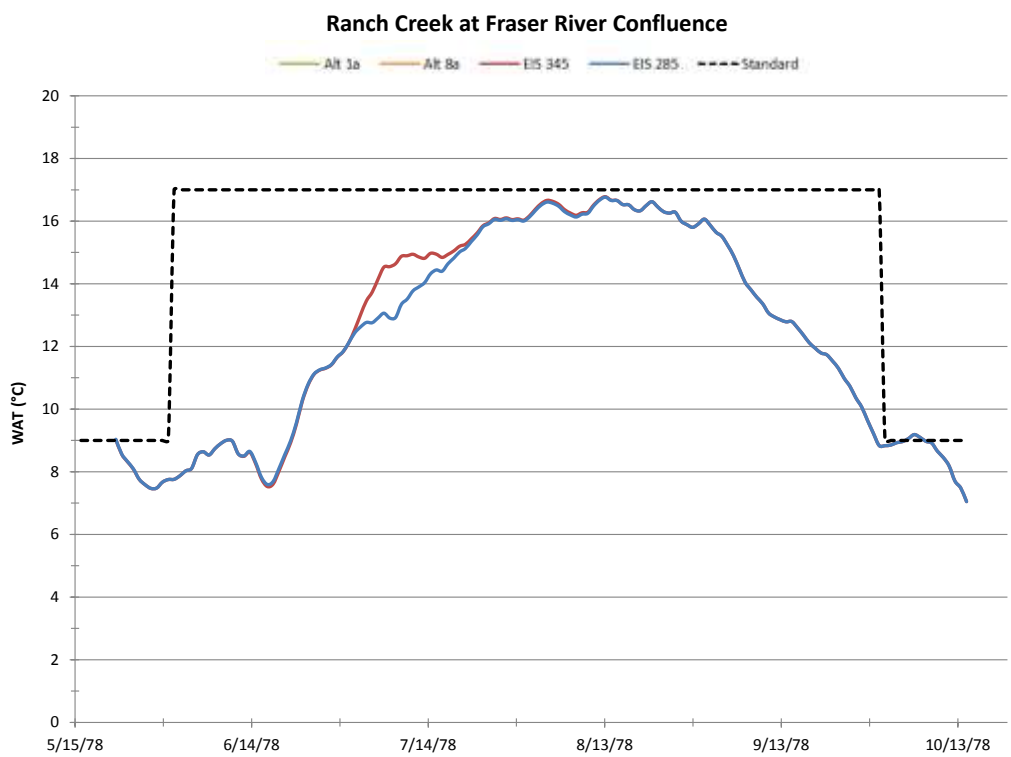

Figure 73. 1978 WATs, Ranch Creek at the Fraser River confluence.

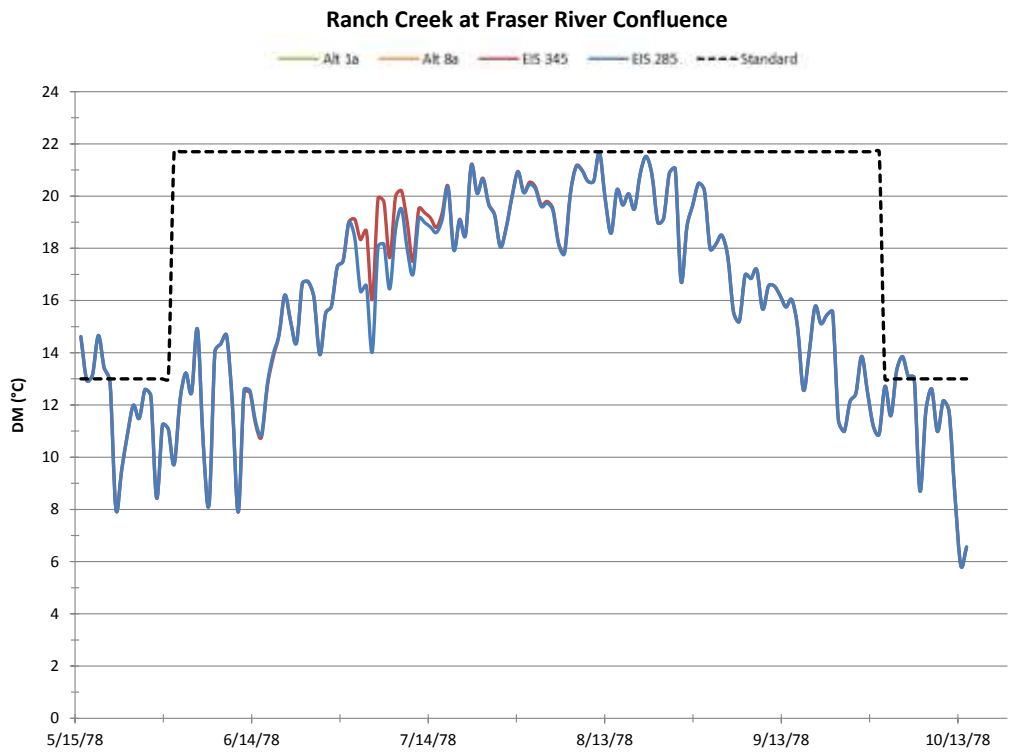

Figure 74. 1978 DMs, Ranch Creek at the Fraser River confluence.

Table 17. Summary of WAT and DM exceedances, 1978 flow scenario year.

1978	Rendezvous Bridge				Below Crooked Creek				Colorado River Confluence			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	13.42	14.59	14.59	14.59	16.04	16.02	16.02	16.02	20.61	21.15	21.15	21.15
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	6	7	7	7
August	0	0	0	0	0	0	0	0	27	28	28	28
September	0	0	0	0	0	0	0	0	0	1	1	1
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	18.55	21.18	21.18	21.18	21.47	21.60	21.60	21.60	25.18	26.14	26.14	26.14
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	8	12	12	12
September	0	0	0	0	0	0	0	0	0	0	0	0
October	2	3	3	3	0	0	0	0	0	0	0	0

1978	Vasquez Creek				St. Louis Creek				Ranch Creek			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	11.53	11.80	11.80	11.80	15.11	15.29	15.29	15.29	16.77	16.78	16.78	16.78
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	1	1	1	1
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	3	3	3	3
Max DM (°C)	13.74	13.88	13.88	13.88	19.55	19.73	19.73	19.73	21.66	21.66	21.66	21.66
# of Days Above Standard:												
May	0	0	0	0	2	2	2	2	4	4	4	4
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	4	4	4	4

Table 18. EIS 345 and Alt 1a WAT and DM increases relative to EIS 285, 1978 flow scenario year.

1978	Rendezvous Bridge		Below Crooked Creek		Colorado River Confluence	
	EIS 345	Alt 1a	EIS 345	Alt 1a	EIS 345	Alt 1a
Largest WAT Increase (°C)	1.51	1.51	1.48	1.48	2.24	2.24
Avg. WAT Increase (°C):						
May	0.26	0.26	0.02	0.02	0.01	0.01
June	0.43	0.43	0.00	0.00	0.03	0.03
July	1.17	1.17	0.45	0.45	0.82	0.82
August	1.11	1.11	0.03	0.03	0.40	0.40
September	1.00	1.00	0.45	0.45	0.15	0.15
October	0.77	0.77	0.85	0.85	-0.15	-0.15
Largest DM Increase (°C)	3.13	3.13	2.58	2.58	2.88	2.88
Avg. DM Increase (°C):						
May	0.31	0.31	0.00	0.00	-0.01	-0.01
June	0.81	0.81	0.00	0.00	0.01	0.01
July	2.03	2.03	0.60	0.60	0.83	0.83
August	1.67	1.67	0.28	0.28	0.68	0.68
September	1.51	1.51	0.72	0.72	0.08	0.08
October	1.16	1.16	1.06	1.06	-0.09	-0.09

1987 Scenario Year

Hydrology

For several dates in 1987 under scenarios EIS 345, Alt 1a and Alt 8a, corresponding PACSM simulation data showed low flows in the mainstem Fraser River between the Fraser at Winter Park gage (USGS Gage 09024000) and the Hammond No. 1 Ditch diversion. These low flows caused the ADYN portion of the dynamic temperature model to stop running. It was therefore necessary to add a small amount of flow to scenarios EIS 345, Alt 1a and Alt 8a in certain locations and for certain dates to allow the ADYN model to run. Through trial and error, it was found that an additional 1-4 cfs added to St. Louis Creek for half of the days in July was sufficient to allow the ADYN model to run. The low flows that required additional flow ranged from 1.7 cfs to 4.1 cfs. It was also necessary to add 2 cfs to the upstream boundary for October 12 and 13 (flows increased from 4 cfs to 6 cfs). As with the previous scenario years, adding this small amount of flow changed temperatures by less than 0.1°C.

Discharges at the three focus locations are shown in Figure 75 - Figure 77. According to the PACSM/point flow model simulations, the differences in flow between Alt 1a and Alt 8a are minimal except for a few dates. Overall, the annual virgin flow for the Fraser River below Crooked Creek in 1987 was 75% of average and followed an above average year, 1986 (122% of average annual). The virgin flow in May, June, July and August was 90%, 57%, 48% and 74% of the monthly average, respectively.

In 1987 the Moffat Project would mainly cause a large reduction of Fraser River flows from mid-May through the first few days of June (this is the difference between EIS 345 and Alt 1a). For cumulative conditions, there are flow reductions mainly from mid-May through the first few days of June, with smaller flow reductions continuing to near the end of July (this is the difference between EIS 285 and Alt 1a). The difference in Fraser River basin flows between EIS 285 and the other two scenarios is also due to higher demands of entities within the Fraser River basin (e.g., municipal and snowmaking demands).

In the previous year, 1986, Gross Reservoir would fill under EIS 285, EIS 345 and Alt 1a. Contents would decline during the winter months prior to the spring runoff in 1986. With EIS 345, Gross Reservoir actually begins the runoff season in 1987 with slightly more contents than EIS 285. Consequently, it takes a couple extra days to fill Gross Reservoir with EIS 285 (May 16) as compared to EIS 345 (May 14). Gross Reservoir enlargement also would fill with Alt 1a. By mid to late July after Gross Reservoir would fill, the flow in the Fraser River is similar for all three scenarios.

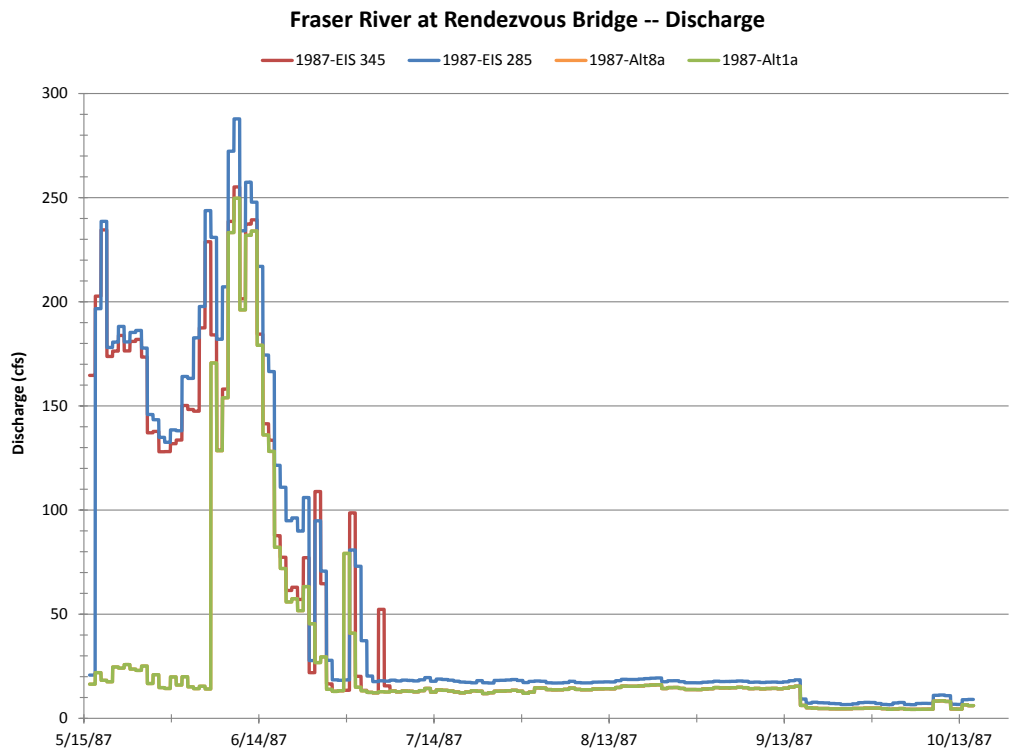

Figure 75. Discharge in the Fraser River at Rendezvous Bridge, 1987.

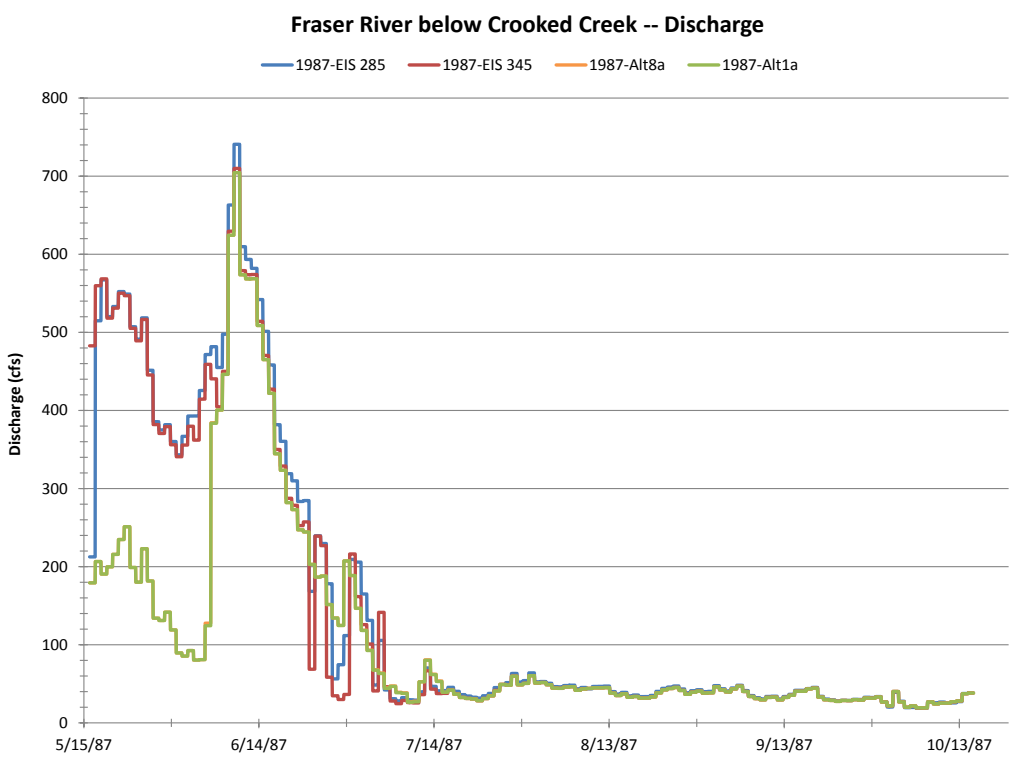

Figure 76. Discharge in the Fraser River below Crooked Creek, 1987.

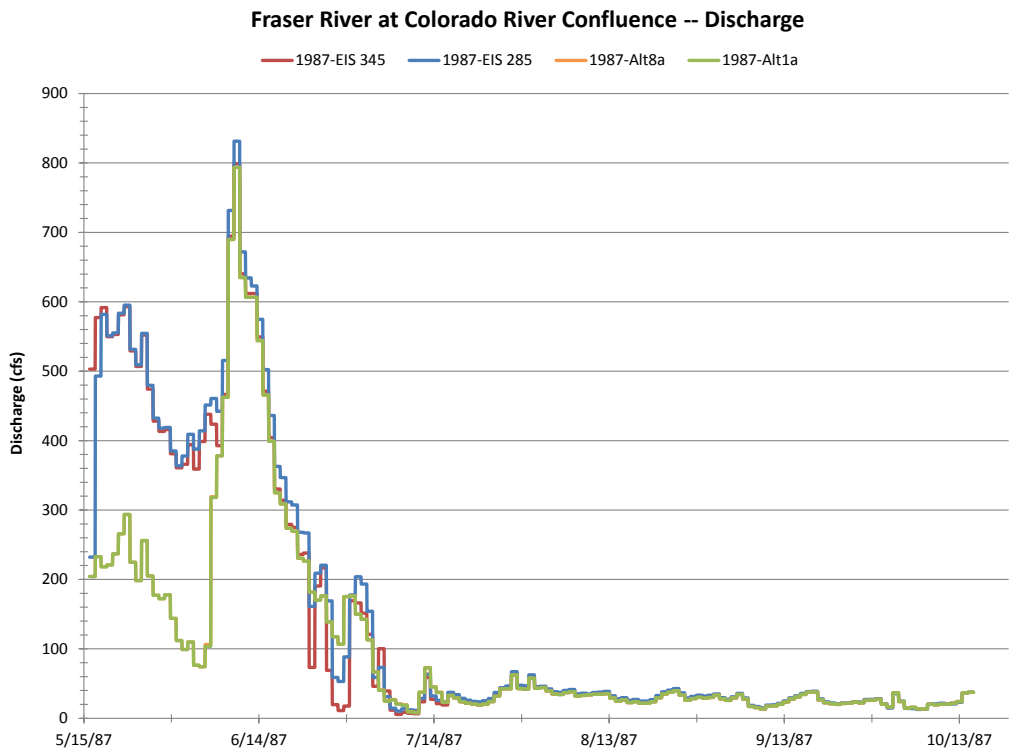

Figure 77. Discharge in the Fraser River at the Colorado River confluence, 1987.

Temperatures

Figure 78 - Figure 80 show the simulated hourly temperatures for the three focus locations. Because there are only small differences in flow between Alt 1a and Alt 8a, the simulated temperatures are also the same. For the Fraser River at Rendezvous Bridge, temperatures are warmer with the EIS 345 scenario compared to EIS 285 for nearly every day of the simulation. The average difference in temperature is 0.62°C and the maximum difference is 5.10°C. Temperatures are also warmer under Alt 1a compared to EIS 285. The average difference in temperature is 1.07°C and the maximum difference is 9.24°C. Comparing EIS 345 to Alt 1a, temperatures differ only from mid-May to July. During this time, the average difference in temperature is 1.33°C and the maximum difference is 7.24°C. It is apparent from Figure 78 that the lower flows observed under Alt 1a in May and June translate to warmer temperatures. For the Fraser River below Crooked Creek, similar temperature profiles were observed as for the Rendezvous Bridge location except that the temperature differences between scenarios are smaller. Between EIS 285 and EIS 345, the average difference in temperature is 0.23°C and the maximum difference is 1.48°C. Between EIS 285 and Alt 1a, the average difference in temperature is 0.64°C and the maximum difference is 5.12°C. Comparing EIS 345 to Alt 1a, temperatures differ only from mid-May to July. During this time, the average difference in temperature is 1.03°C and the maximum difference is 4.52°C. It is again apparent from Figure 79 that the lower flows observed under Alt 1a in May and June translate to warmer temperatures. For the Fraser River at the Colorado River

confluence (Figure 80), the average difference in temperature between EIS 285 and EIS 345 is 0.11°C and the maximum difference is 6.69°C. Between EIS 285 and Alt 1a, the average difference in temperature is 0.46°C and the maximum difference is 6.77°C. Comparing EIS 345 to Alt 1a, temperatures differ only from mid-May to July. During this time, the average difference in temperature is 0.84°C and the maximum difference is 6.57°C. Maximum temperatures under EIS 345 and Alta 1a are actually slightly cooler than those under EIS 285 from August through mid-October.

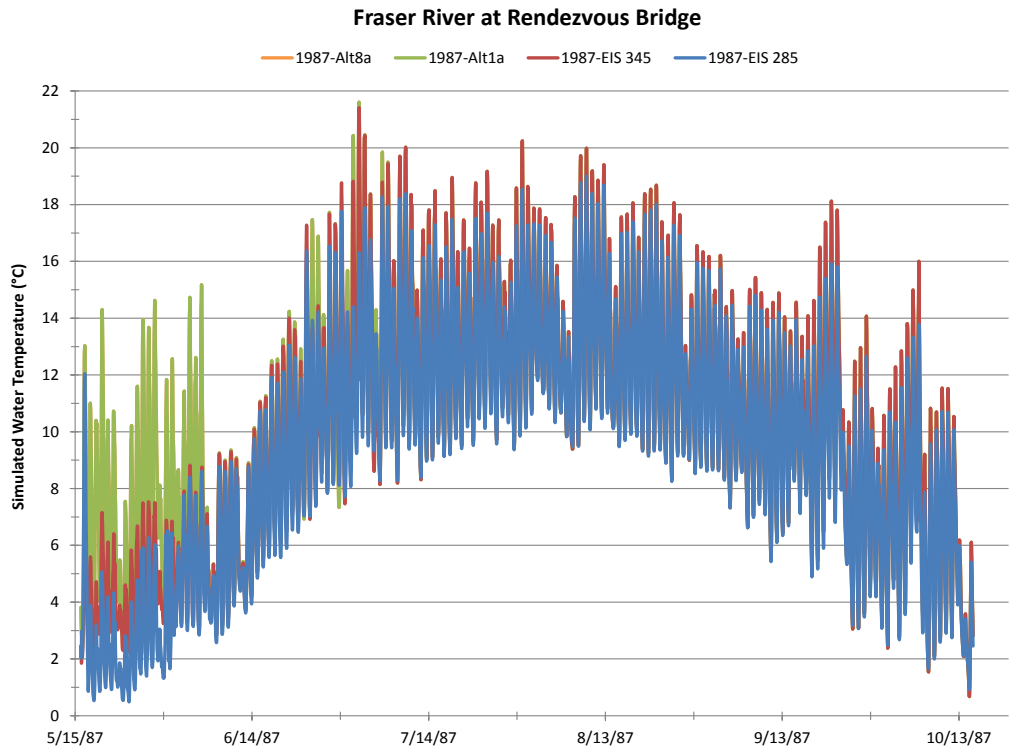

Figure 78. Simulated hourly temperatures in the Fraser River at Rendezvous Bridge, 1987.

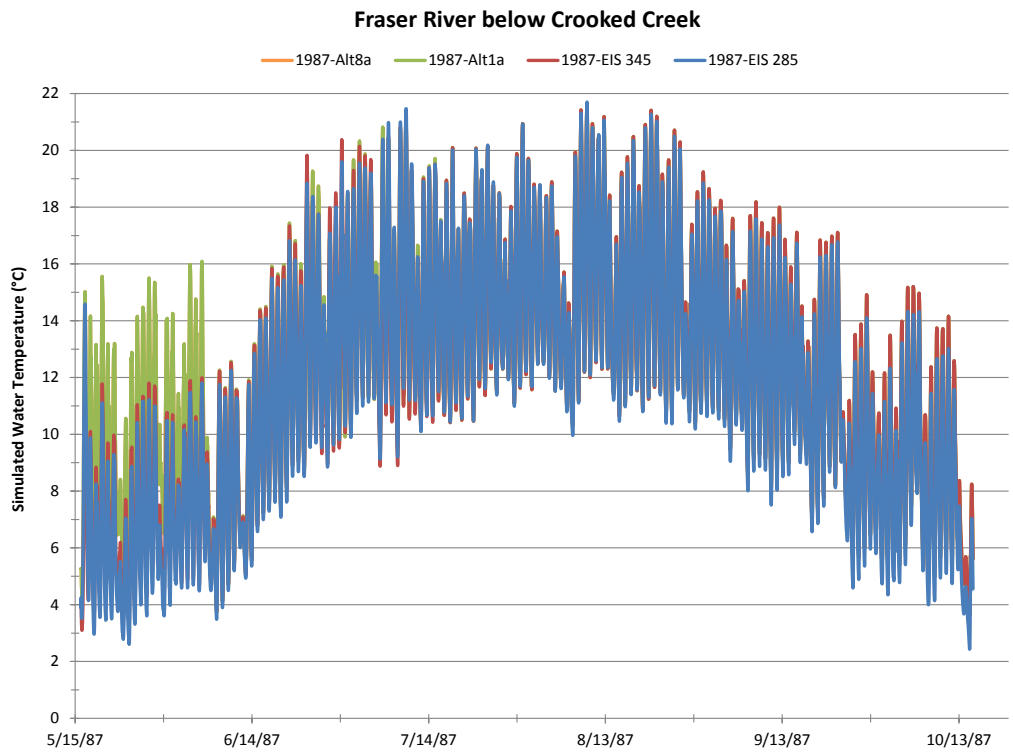

Figure 79. Simulated hourly temperatures in the Fraser River below Crooked Creek, 1987.

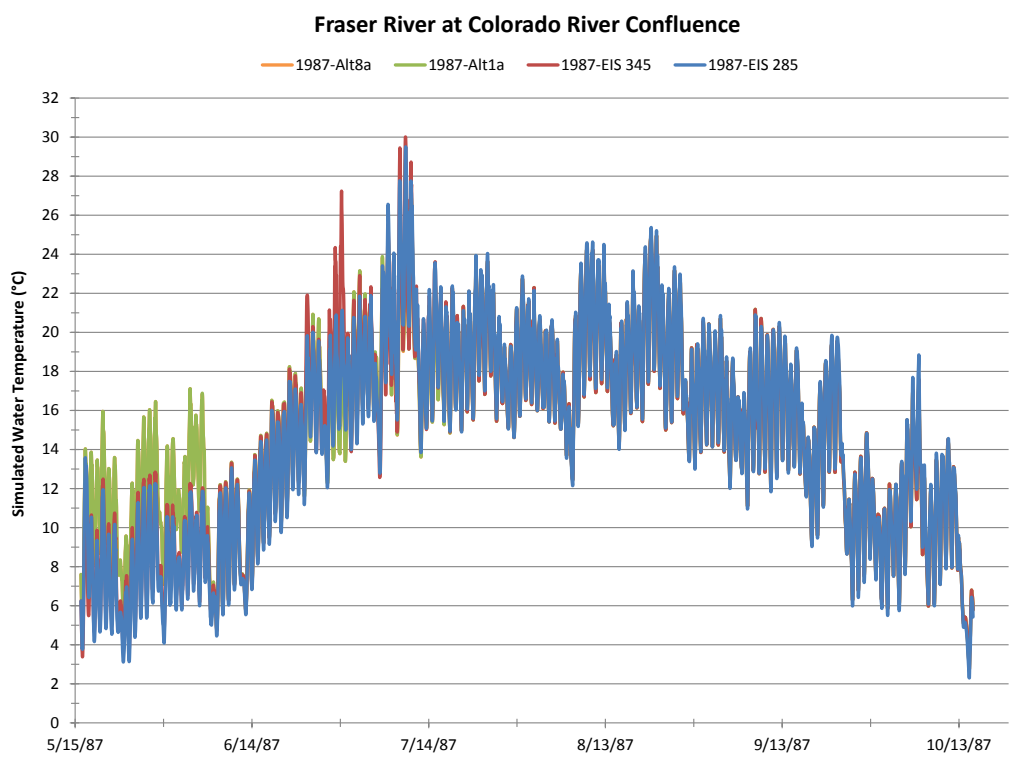

Figure 80. Simulated hourly temperatures in the Fraser River at the Colorado River confluence, 1987.

WATs and DMs

Fraser River at Rendezvous Bridge

Weekly Average Temperature (WAT) (Figure 81)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 82)

- EIS 285: The DM standard is exceeded for 2 days in October.
- EIS 345: The DM standard is exceeded for 3 days in October.
- Alt 1a: The DM standard is exceeded for 4 days in May and 3 days in October, for a total of 7 days. Therefore, with Alt 1a the DM standard is exceeded 5 more days compared to current conditions; 4 of the additional days are attributable to the Moffat Project.

Table A - 17 provides the temperatures and days for which exceedances occur. The exceedances are within the winter shoulder-season and could possibly be considered exemptions.

Fraser River below Crooked Creek

Weekly Average Temperature (WAT) (Figure 83)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 84)

There are no exceedances of the DM standard for any of the four streamflow scenarios.

Fraser River at the Colorado River Confluence

Weekly Average Temperature (WAT) (Figure 85)

- EIS 285: The WAT standard is exceeded for 25 days in July and 24 days in August, for a total of 49 days.
- EIS 345: The WAT standard is exceeded for 1 day in June, 31 days in July and 24 days in August, for a total of 56 days.
- Alt 1a: The WAT standard is exceeded for 26 days in July and 24 days in August, for a total of 50 days. Therefore, with Alt 1a the WAT standard is exceeded 1 additional day compared to current conditions. The Moffat Project would decrease exceedances by 6 days as compared to full use of the existing system.

Table A - 18 provides the temperatures and days for which exceedances occur.

Daily Maximum (DM) (Figure 86)

- EIS 285: The DM standard is exceeded for 5 days in July and 6 days in August, for a total of 11 days.

- EIS 345: The DM standard is exceeded for 2 days in June, 5 days in July and 6 days in August, for a total of 13 days.
- Alt 1a: The DM standard is exceeded for 4 days in July and 6 days in August, for a total of 10 days. Therefore, with Alt 1a the DM standard is exceeded 1 less day compared to current conditions. The Moffat Project would decrease exceedances by 3 days as compared to full use of the existing system.

Table A - 18 provides the temperatures and days for which exceedances occur.

Vasquez Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 87)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 88)

There are no exceedances of the DM standard for any of the four streamflow scenarios.

St. Louis Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 89)

There are no exceedances of the WAT standard for any of the four streamflow scenarios.

Daily Maximum (DM) (Figure 90)

- EIS 285: The DM standard is exceeded for 1 day in May.
- EIS 345: The DM standard is not exceeded.
- Alt 1a: The DM standard is exceeded for 5 days in May. Therefore, with Alt 1a the DM standard is exceeded on 4 more days compared to current conditions. With the Moffat Project there are 5 days of additional exceedances as compared to full use of the existing system.

Table A - 19 provides the temperatures and days for which exceedances occur. These could possibly be considered exemptions since they fall within the shoulder-season.

Ranch Creek at the Fraser River Confluence

Weekly Average Temperature (WAT) (Figure 91)

- EIS 285: The WAT standard is not exceeded.
- EIS 345: The WAT standard is not exceeded.
- Alt 1a: The WAT standard is exceeded for 5 days in May. Therefore, with Alt 1a the WAT standard is exceeded 5 more days compared to current conditions, which are attributable to the Moffat Project.

Daily Maximum (DM) (Figure 92)

- EIS 285: The DM standard is exceeded for 1 day in May and 2 days in October, for a total of 3 days.
- EIS 345: The DM standard is exceeded for 2 days in October.
- Alt 1a: The DM standard is exceeded for 9 days in May and 2 days in October, for a total of 11 days. Therefore, with Alt 1a the DM standard is exceeded 8 more days compared to current conditions. With the Moffat Project there are 9 days of additional exceedances as compared to full use of the existing system.

Table A - 20 provides the temperatures and days for which exceedances occur. The exceedances could possibly be considered exemptions since they fall within the shoulder-season.

Table 19 summarizes all exceedances for all locations. Table 20 summarizes the predicted increase in water temperature due to EIS 345 and Alt 1a (cumulative effects, plus Moffat Project) relative to EIS 285 (current conditions). In general, the stream temperatures will be higher in the Fraser River compared to current conditions. On average, the increase in WAT ranges from 0.04 to 4.6^{o}C, with the largest WAT increase at Rendezvous Bridge (5.07°C on May 31). On average, the increase in DM ranges from 0.04 to 6.3^{o}C, with the largest DM increase at Rendezvous Bridge (9.15°C on May 19). Note that for the Fraser River at the Colorado River confluence, the average July, August, September and October WATs and DMs for EIS 345 and Alt 1a are slightly less than those for EIS 285 because the flows are slightly higher. This is due to slightly more carry-over storage in Gross Reservoir in EIS 345 and Alt 1a, which then fills sooner compared to EIS 285. This operation is needed to meet the higher customer demands in Denver Water's north system and reduce the risk of running out of water in the subsequent year for EIS 345 and Alt 1a. The average July WATs for EIS 345 and Alt 1a are slightly less than those for EIS 285 for the Fraser River below Crooked Creek.

Table 21 summarizes the predicted increase in water temperature due to the Moffat Project, i.e., Alt 1a WAT and DM increases relative to EIS 345. In general, the predicted increase in stream temperatures attributable to the Moffat Project diversions occurs in May, June and July. Note that for the Fraser River at the Colorado River confluence in July the Alt 1a WATs and DMs are less than those for EIS 345.

Summary for the Fraser River Mainstem

For 1987, the model simulates temperatures that have exceedances under current conditions (EIS 285) at Rendezvous Bridge, none below the confluence with Crooked Creek and temperature exceedances again at the confluence with the Colorado River. With Alt 1a (cumulative effects with the Moffat Project), there will be additional temperature exceedances at the Rendezvous Bridge location. The DM standard is exceeded 5 more days compared to current conditions and 4 more days compared to full use of the existing system. With Alt 1a there will overall be fewer temperature exceedances for the Fraser River at the Colorado River confluence. There would be 1 additional day of WAT exceedances compared to current conditions but 6 fewer days of exceedances compared to full use of the existing system. There would be 1 less DM exceedance compared to current conditions and 3 fewer exceedances compared to full use of the existing system.

Summary for the Fraser River Tributaries

In Vasquez Creek, there are no WAT or DM exceedances identified for any of the four streamflow scenarios. In St. Louis Creek, there are exceedances of the DM standard under current and future conditions. With Alt 1a the DM standard is exceeded 4 more days compared to current conditions and 5 more days compared to full use of the existing system. In Ranch Creek, there are exceedances of the WAT standard under future conditions. With Alt 1a the WAT standard is exceeded 5 more days compared to current conditions and 5 more days compared to full use of the existing system. There are also exceedances of the DM standard in Ranch Creek under current and future conditions. With Alt 1a the DM standard is exceeded 8 more days compared to current conditions and 9 more days compared to full use of the existing system.

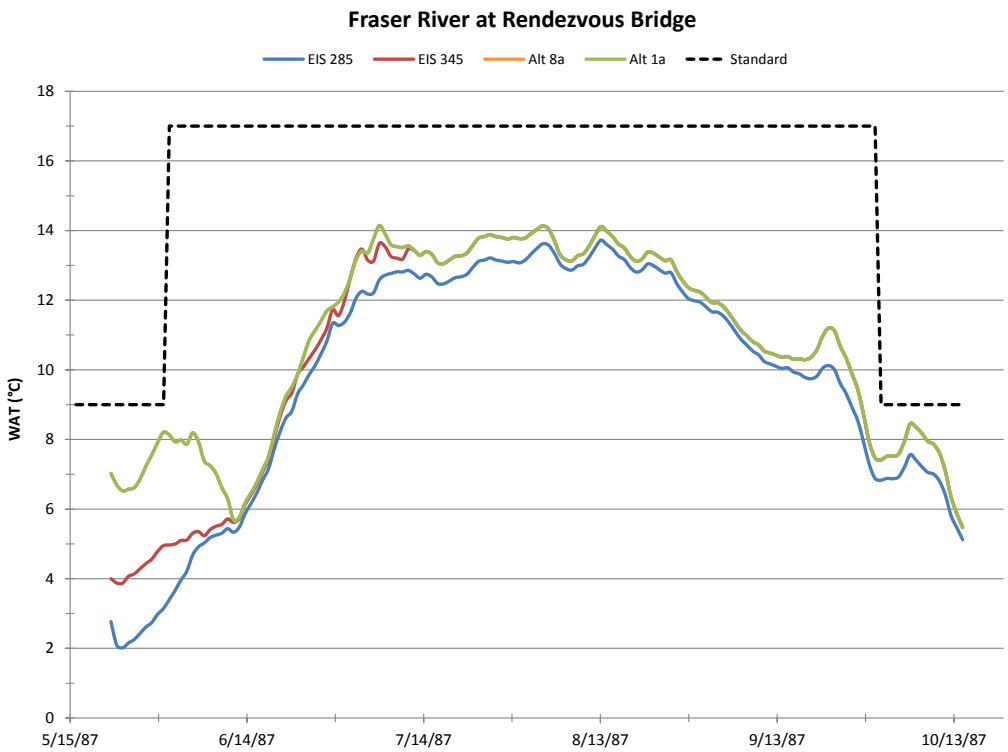

Figure 81. 1987 WATs, Fraser River at Rendezvous Bridge.

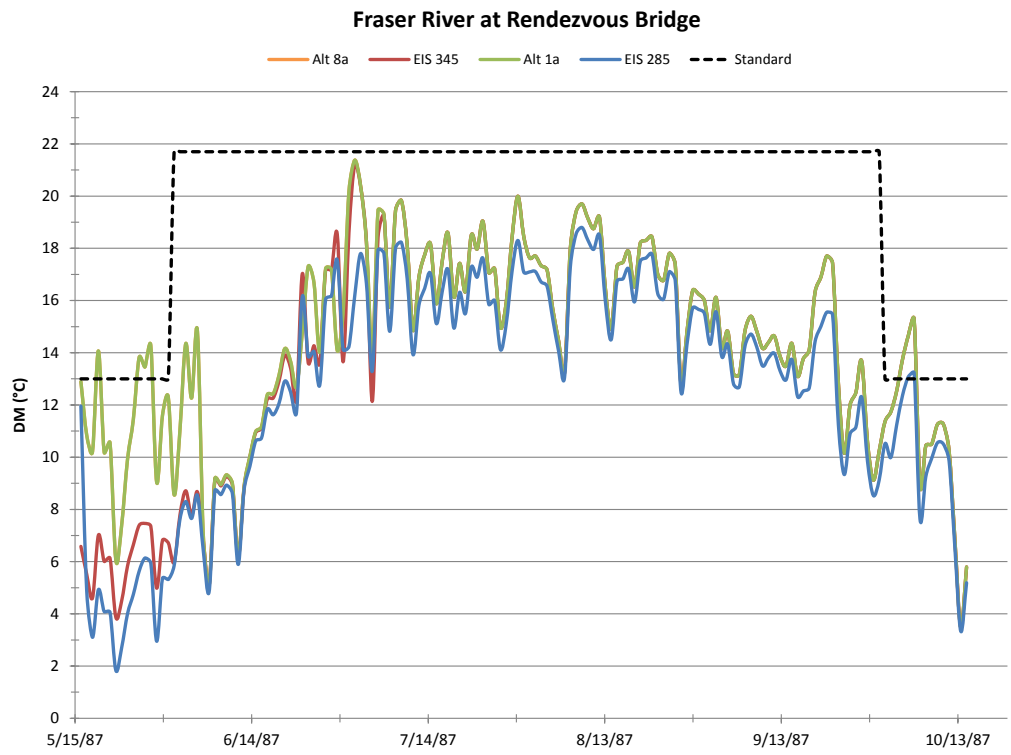

Figure 82. 1987 DMs, Fraser River at Rendezvous Bridge.

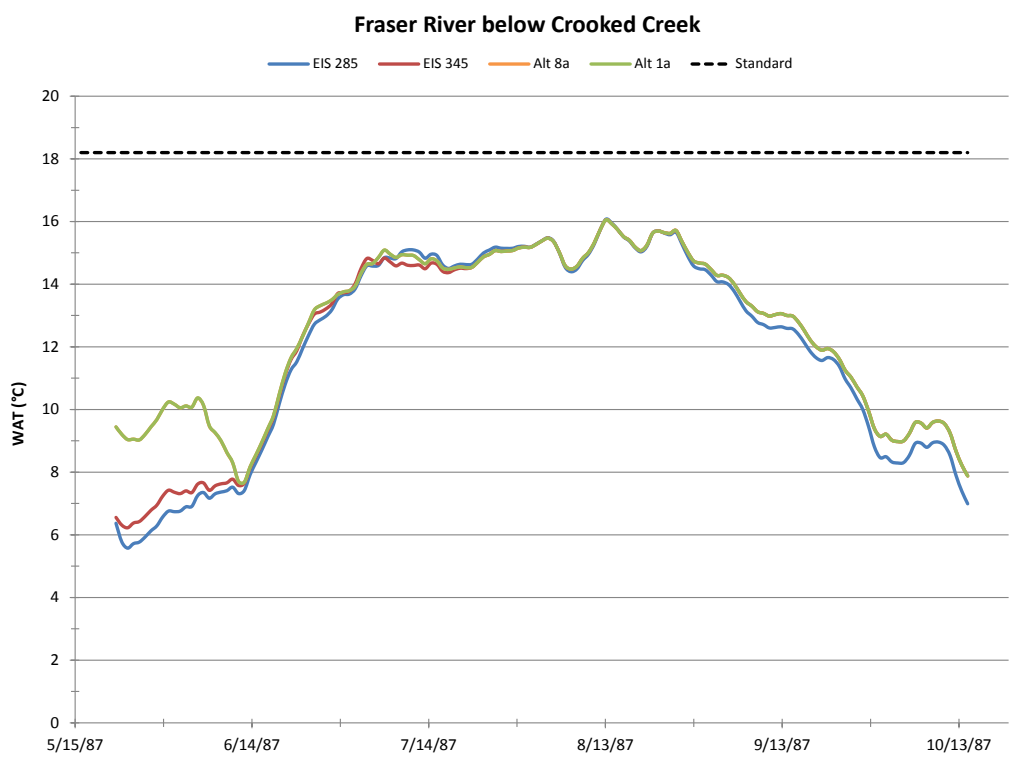

Figure 83. 1987 WATs, Fraser River below Crooked Creek.

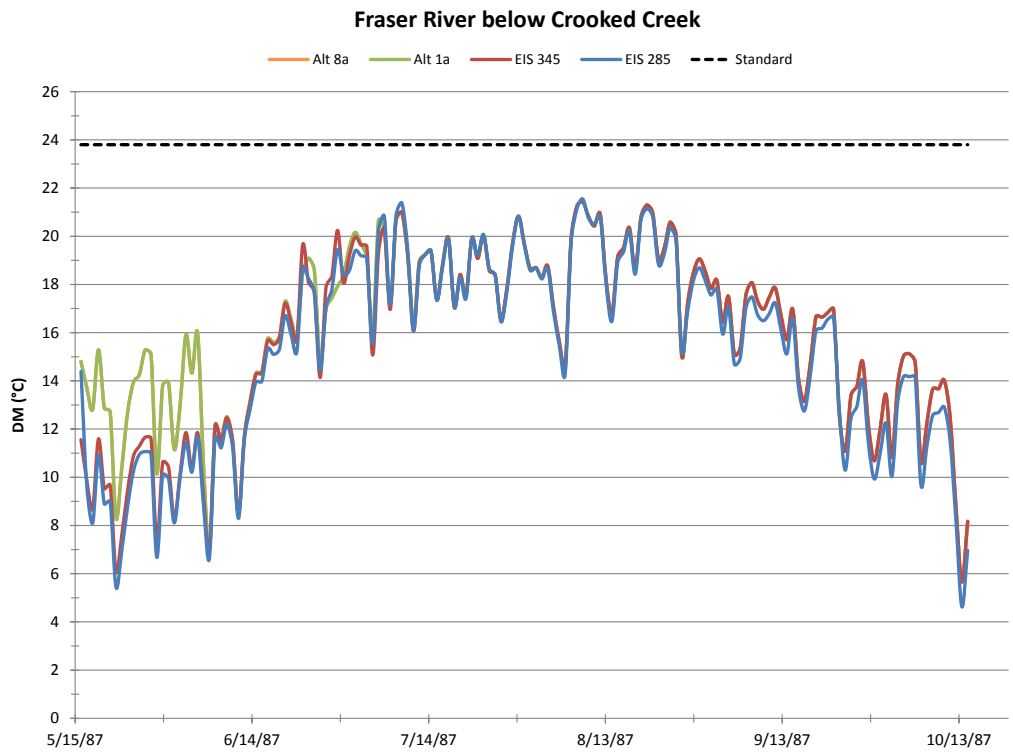

Figure 84. 1987 DMs, Fraser River below Crooked Creek.

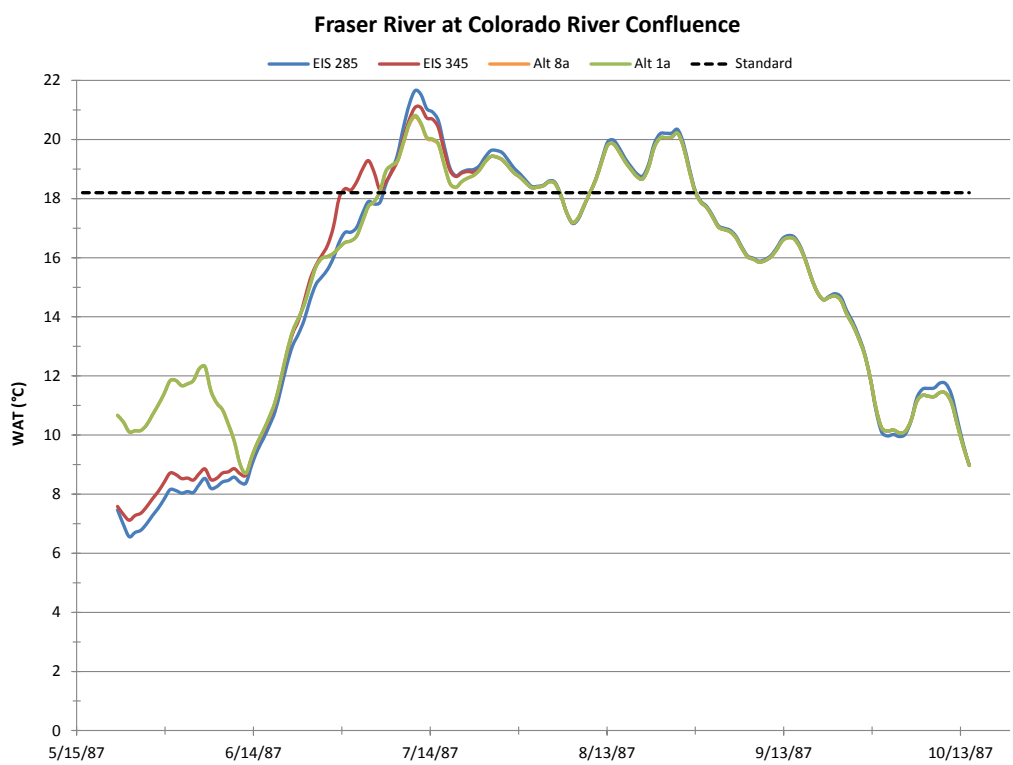

Figure 85. 1987 WATs, Fraser River at the Colorado River confluence.

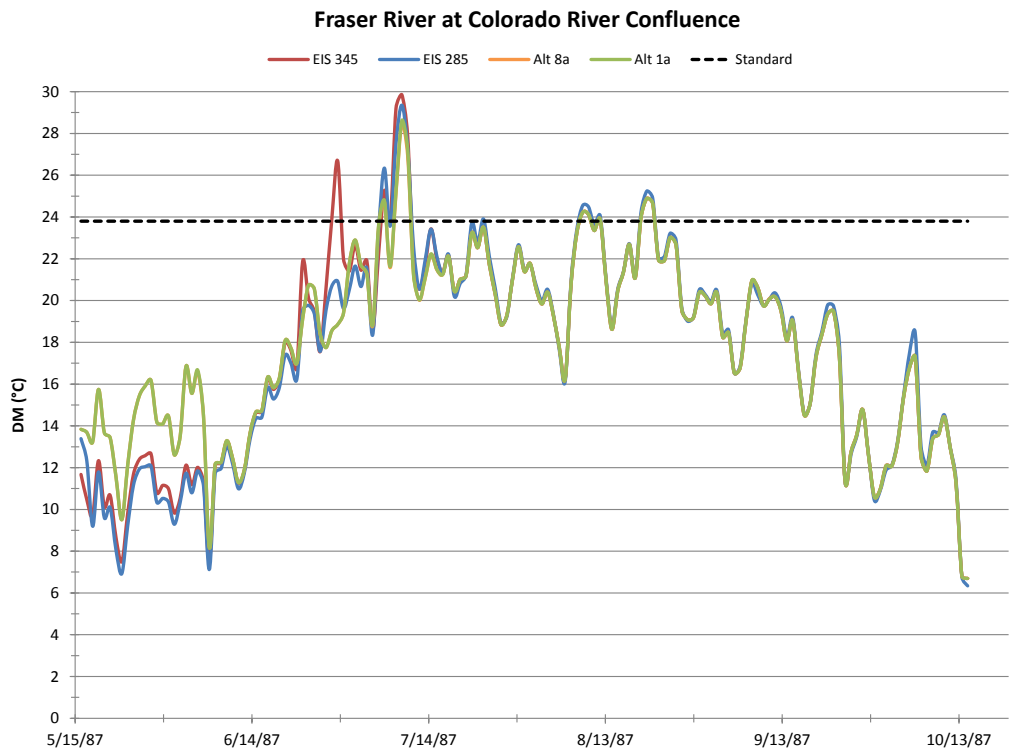

Figure 86. 1987 DMs, Fraser River at the Colorado River confluence.

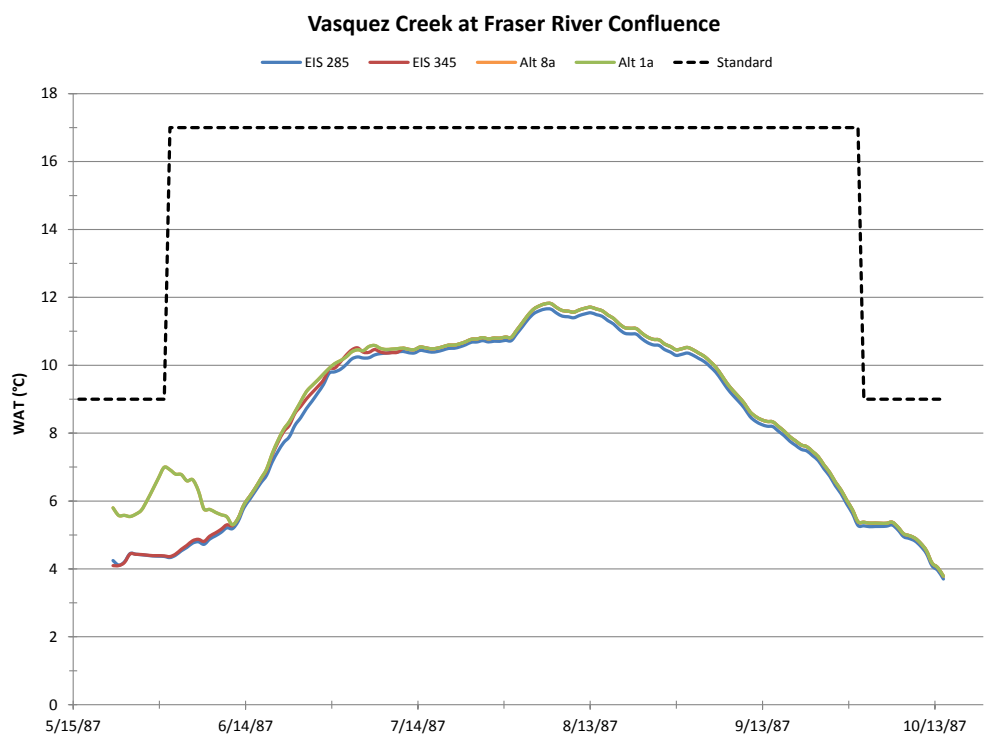

Figure 87. 1987 WATs, Vasquez Creek at the Fraser River confluence.

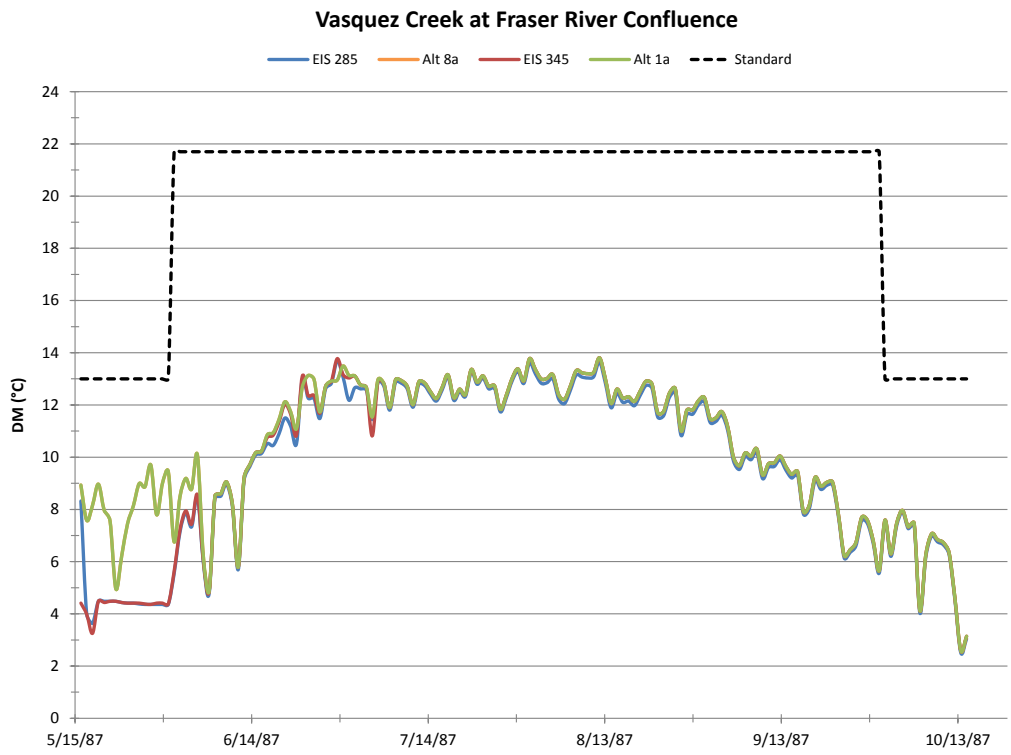

Figure 88. 1987 DMs, Vasquez Creek at the Fraser River confluence.

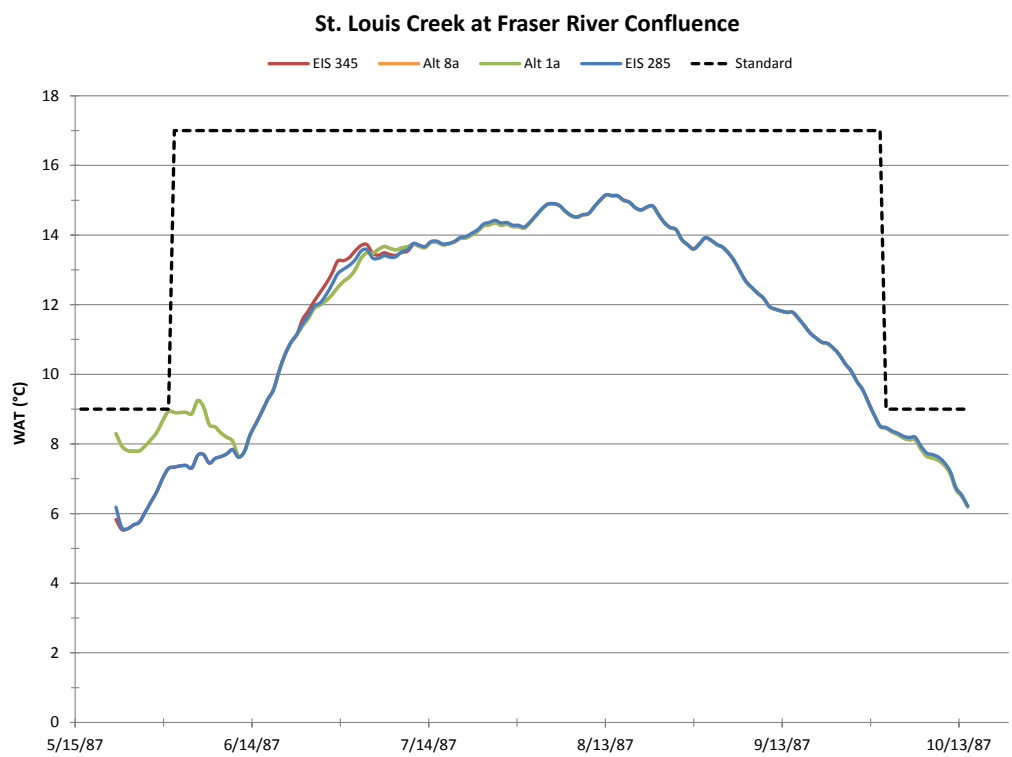

Figure 89. 1987 WATs, St. Louis Creek at the Fraser River confluence.

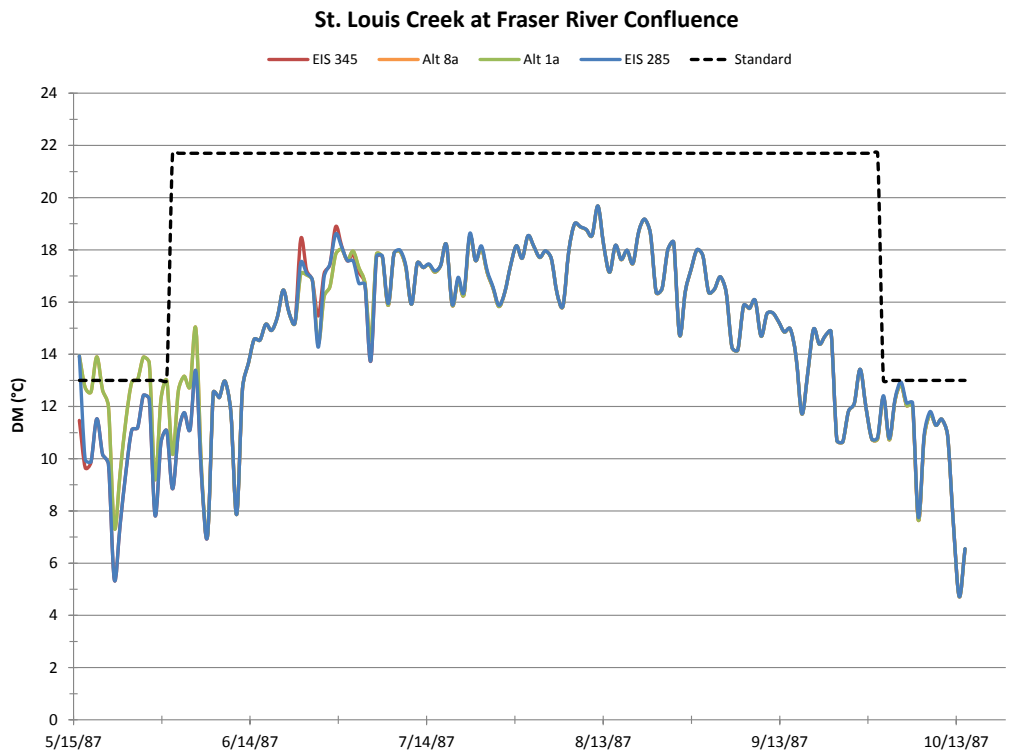

Figure 90. 1987 DMs, St. Louis Creek at the Fraser River confluence.

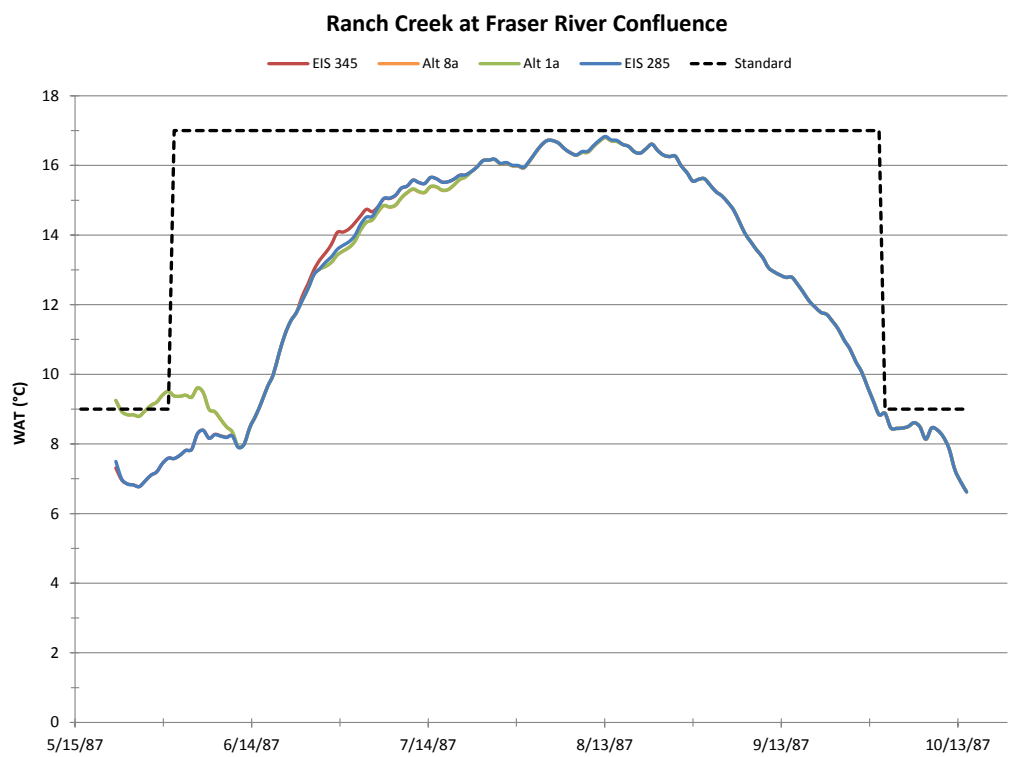

Figure 91. 1987 WATs, Ranch Creek at the Fraser River confluence.

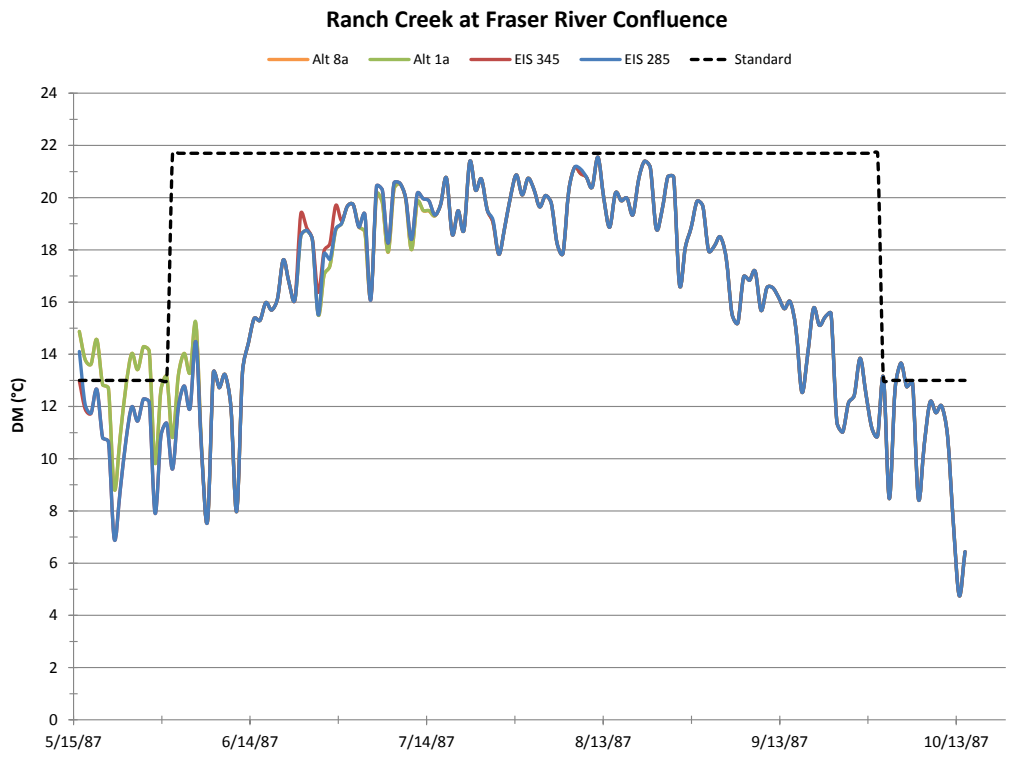

Figure 92. 1987 DMs, Ranch Creek at the Fraser River confluence.

Table 19. Summary of WAT and DM exceedances, 1987 flow scenario year.

1987	Rendezvous Bridge				Below Crooked Creek				Colorado River Confluence			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	13.72	14.13	14.14	14.15	16.08	16.05	16.05	16.05	21.65	21.09	20.82	20.77
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	1	0	0
July	0	0	0	0	0	0	0	0	25	31	26	26
August	0	0	0	0	0	0	0	0	24	24	24	24
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	18.80	21.19	21.38	21.38	21.55	21.44	21.43	21.43	29.35	29.86	28.62	28.49
# of Days Above Standard:												
May	0	0	4	4	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	2	0	0
July	0	0	0	0	0	0	0	0	5	5	4	4
August	0	0	0	0	0	0	0	0	6	6	6	6
September	0	0	0	0	0	0	0	0	0	0	0	0
October	2	3	3	3	0	0	0	0	0	0	0	0

1987	Vasquez Creek				St. Louis Creek				Ranch Creek			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
Max WAT (°C)	11.66	11.82	11.82	11.82	15.16	15.15	15.15	15.15	16.83	16.81	16.81	16.81
# of Days Above Standard:												
May	0	0	0	0	0	0	0	0	0	0	5	5
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0
Max DM (°C)	13.69	13.81	13.81	13.81	19.68	19.68	19.68	19.68	21.55	21.55	21.55	21.55
# of Days Above Standard:												
May	0	0	0	0	1	0	5	5	1	0	9	9
June	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	2	2	2	2

Table 20. EIS 345 and Alt 1a WAT and DM increases relative to EIS 285, 1987 flow scenario year.

1987	Rendezvous Bridge		Below Crooked Creek		Colorado River Confluence	
	EIS 345	Alt 1a	EIS 345	Alt 1a	EIS 345	Alt 1a
Largest WAT Increase (°C)	1.91	5.07	0.89	3.48	1.54	3.92
Avg. WAT Increase (°C):						
May	1.78	4.60	0.60	3.35	0.50	3.45
June	0.48	1.41	0.30	1.10	0.50	1.36
July	0.71	0.80	-0.12	-0.04	0.08	-0.31
August	0.36	0.36	0.04	0.04	-0.07	-0.07
September	0.53	0.53	0.35	0.35	-0.04	-0.04
October	0.71	0.71	0.71	0.71	-0.10	-0.10
Largest DM Increase (°C)	5.00	9.15	1.21	4.72	5.77	5.11
Avg. DM Increase (°C):						
May	1.24	6.28	0.37	3.63	0.26	3.27
June	0.44	1.30	0.31	0.91	0.76	0.94
July	1.38	1.53	0.00	0.09	0.04	-0.29
August	0.61	0.61	0.16	0.16	-0.13	-0.13
September	0.95	0.95	0.53	0.53	-0.07	-0.07
October	0.99	0.99	0.94	0.94	-0.19	-0.19

Table 21. Alt 1a WAT and DM increases relative to EIS 345, 1987 flow scenario year.

1987	Rendezvous Bridge	Below Crooked Creek	Colorado River Confluence
Largest WAT Increase (°C)	3.26	2.90	3.55
Avg. WAT Increase (°C):			
May	2.82	2.75	2.95
June	0.94	0.80	0.86
July	0.10	0.07	-0.39
August	0.00	0.00	0.00
September	0.00	0.00	0.00
October	0.00	0.00	0.00
Largest DM Increase (°C)	7.06	4.14	4.73
Avg. DM Increase (°C):			
May	5.04	3.26	3.01
June	0.87	0.60	0.19
July	0.16	0.10	-0.33
August	0.00	0.00	0.00
September	0.00	0.00	0.00
October	0.00	0.00	0.00

SUMMARY

The Fraser River dynamic water temperature model was used to simulate hourly stream temperatures in the Fraser River and its tributaries under four different streamflow scenarios:

- EIS 285 – Current Conditions - Streamflow conditions associated with Denver Water's existing system and an average demand of 285,000 AF/yr.
- EIS 345 – Full Use of the Existing System - Future streamflow conditions associated with Denver Water's existing system and Denver Water's demand has grown to an average of 345,000 AF/yr, plus other reasonably foreseeable future actions (RFFAs) are assumed to have occurred.
- Alternative 1a – Cumulative Effects with Moffat Project - Future streamflow conditions associated with Denver Water's proposed 72,000-AF enlargement of Gross Reservoir, a future average demand of 363,000 AF/yr and the same RFFAs assumed in EIS 345. The only differences between Alt 1a and EIS 345 are the proposed increase in reservoir storage and an increase in demand of 18,000 AF/yr.
- Alternative 8a – Cumulative Effects with Smaller Gross Reservoir Enlargement - Future streamflow conditions associated with a proposed 52,000-AF enlargement of Gross Reservoir, 5,000 AF of storage in gravel pits along the South Platte River, a future average demand of 363,000 AF/yr and the same RFFAs assumed in EIS 345. The only difference between Alt 1a and Alt 8a is a smaller reservoir expansion and slightly less diversion from the West Slope through the Moffat Tunnel. The temperature model results for Alt 1a and Alt 8a are exactly the same, therefore only Alt 1a is discussed in this summary.

The temperature model was run for the five years and months proposed by CDPHE: May 16 to October 15 of 1948, 1959, 1963, 1978 and 1987. These years were selected because they represent the critical conditions under which cumulative flow effects are greatest and temperature impacts are most likely to occur. These months were selected because these are the months when temperature exceedances have occurred in the Fraser River basin. Meteorological data from 2007 were used for each model simulation because it was one of the warmest years in 63 years of temperature record (1948-2010). Both of these factors (the five selected years and 2007 meteorological data) may cause this analysis to overestimate the impacts of the various streamflow scenarios.

The modeling results focus on three locations on the mainstem of the Fraser River and three tributaries:

- Fraser River below Vasquez Creek at Rendezvous Bridge
- Fraser River downstream of Crooked Creek
- Fraser River at the Colorado River confluence
- Vasquez Creek
- St. Louis Creek
- Ranch Creek

In the Fraser River basin, the following reaches are currently on Colorado's Section 303(d) List of Impaired Waters with a State-assigned low priority:

- Mainstem of the Fraser River from Hammond Ditch (just downstream of the Town of Fraser) to the Colorado River
- Ranch Creek

WAT and DM exceedances are summarized by location in the tables that follow. Within a year, differences in exceedances between the four streamflow scenarios are highlighted. Note that there are no exceedances for any year or any streamflow scenario for the Fraser River below Crooked Creek or Vasquez Creek. The other four locations are discussed below in more detail. Although the model results show the absolute magnitude of temperature change, this discussion of results focuses on the relative change and how that relates to the number of temperature standard exceedances.

Fraser River Downstream of Vasquez Creek at Rendezvous Bridge (Table 22)

Weekly Average Temperature (WAT)

There are no exceedances of the WAT standard at this location throughout the five years for any of the four streamflow scenarios.

Daily Maximum (DM)

- EIS 285: The DM standard is exceeded a total of 12 days throughout the five years.
- EIS 345: The DM standard is exceeded a total of 28 days throughout the five years.
- Alt 1a: With Alt 1a, the DM standard is exceeded a total of 32 days. Therefore, with Alt 1a the DM standard is exceeded 20 additional days compared to current conditions; 4 of the additional days are attributable to the Moffat Project.

Fraser River at the Colorado River Confluence (Table 23)

Weekly Average Temperature (WAT)

- EIS 285: The WAT standard is exceeded a total of 206 days throughout the five years.
- EIS 345: The WAT standard is exceeded a total of 236 days throughout the five years.
- Alt 1a: The WAT standard is exceeded a total of 231 days throughout the five years. Therefore, with Alt 1a the WAT standard is exceeded 25 additional days compared to current conditions. The Moffat Project would decrease the number of exceedances by 5 days as compared to full use of the existing system.

Daily Maximum (DM)

- EIS 285: The DM standard is exceeded a total of 47 days throughout the five years.
- EIS 345: The DM standard is exceeded a total of 56 days throughout the five years.

- Alt 1a: The DM standard is exceeded a total of 54 days throughout the five years. Therefore, with Alt 1a the DM standard is exceeded 7 additional days compared to current conditions. The Moffat Project would decrease the number of exceedances by 2 days as compared to full use of the existing system.

Overall Summary for the Fraser River Mainstem – The mainstem of the Fraser River from Hammond Ditch (just downstream of the Town of Fraser) to the confluence with the Colorado River is on the 303(d) List of Impaired Waters with a State-assigned low priority. The model identifies temperature exceedances under current conditions near the Town of Fraser (Rendezvous Bridge), none near the confluence with Crooked Creek and temperature exceedances again at the confluence with the Colorado River. With Alt 1a, under future, cumulative conditions, there will be additional temperature exceedances at both locations. However, 20% of the exceedances (4 days out of 20 days) at Rendezvous Bridge are attributable to the Moffat Project and none of the exceedances at the confluence with the Colorado River are attributable to the Moffat Project (Table 24).

Based on the simulated conditions, the additional diversions associated with the Moffat Project do not contribute to violations of the summertime (June-September) stream temperature standards. The Moffat Project does contribute to DM temperature standard violations in the Fraser River at Rendezvous Bridge in the month of May (4 days out of the 5 years simulated).

St. Louis Creek at the Fraser River Confluence (Table 25)

Weekly Average Temperature (WAT)

The WAT standard is exceeded for 1 day throughout the five years under all streamflow scenarios. Therefore, with Alt 1a there is no change in exceedances of the WAT standard.

Daily Maximum (DM)

- EIS 285: The DM standard is exceeded a total of 17 days throughout the five years.
- EIS 345: The DM standard is exceeded a total of 16 days throughout the five years.
- Alt 1a: The DM standard is exceeded a total of 21 days throughout the five years. Therefore, with Alt 1a the DM standard is exceeded 4 additional days compared to current conditions. With the Moffat Project there are 5 days of additional exceedances as compared to full use of the existing system.

Ranch Creek at the Fraser River Confluence (Table 26)

Weekly Average Temperature (WAT)

- EIS 285: The WAT standard is exceeded a total of 19 days throughout the five years.
- EIS 345: The WAT standard is exceeded a total of 19 days throughout the five years.

- Alt 1a: The WAT standard is exceeded a total of 24 days throughout the five years. Therefore, with Alt 1a the WAT standard is exceeded 5 additional days compared to current conditions; these 5 additional days are attributable to the Moffat Project.

Daily Maximum (DM)

- EIS 285: The DM standard is exceeded a total of 36 days throughout the five years.
- EIS 345: The DM standard is exceeded a total of 35 days throughout the five years.
- Alt 1a: The DM standard is exceeded a total of 45 days throughout the five years. Therefore, with Alt 1a the DM standard is exceeded 9 additional days compared to current conditions. With the Moffat Project there are 10 days of additional exceedances as compared to full use of the existing system.

Overall Summary for Fraser River Tributaries – There are no WAT or DM exceedances identified in any of the five years for any of the four streamflow scenarios on Vasquez Creek. There are exceedances of the DM standard in St. Louis Creek under current and future conditions. With Alt 1a the DM standard is exceeded 4 more days compared to current conditions. With the Moffat Project there are 5 days of additional exceedances as compared to full use of the existing system. There are exceedances of both the WAT and DM standard in Ranch Creek under current and future conditions. With Alt 1a the WAT standard is exceeded 5 additional days compared to current conditions and the days are attributable to the Moffat Project. With Alt 1a the DM standard is exceeded 9 more days compared to current conditions. With the Moffat Project there are 10 days of additional exceedances as compared to full use of the existing system (Table 24).

Based on the simulated conditions, the additional diversions associated with the Moffat Project do contribute to DM and WAT temperature standard exceedences in St. Louis and Ranch creeks. These exceedences occur in the month of May (St. Louis Creek: 5 days of DM standard exceedances and Ranch Creek: 10 days of DM and 5 days of WAT standard exceedances).

Future Data/Monitoring Needs

Dynamic (mechanistic) models require substantial hydrology, channel geometry, water temperature and meteorology data at various locations in the streams to be modeled. The data limitations and uncertainties associated with the Fraser River model are discussed in the section on “Model Development”. The following suggestions are provided for future data collection efforts that may be considered for a cooperative effort such as Learning by Doing, which could consider using the model to support decisions and designs for environmental enhancement projects in the Fraser River basin.

- **Hydrology** – Hourly hydrologic data, rather than daily data, would improve the performance of the model. On a daily basis, streams exhibit a gradual ramping up or down of flow, which would be reflected in hourly flow data. Also, since flow can be an important predictor of water temperature, hourly flow data would likely result in better estimates of stream temperatures.

- **Cross-section Geometry** – Ideally, cross-sections would be measured at regular intervals throughout the reach to be modeled. Instead, cross-section data were limited to a few discreet locations. It was necessary to take the existing cross-section data and extrapolate to sections of the Fraser River that needed geometry data in order for the ADYN model to run. For example, no cross-section data were available for the canyon-bound stretch of river, a distance of approximately 6 miles. Additional cross-section data would likely improve the performance of the model, but would also require re-calibration and re-validation of the model before it could be applied to other flow scenario years.
- **Water Temperature** – Temperature loggers should continue monitoring temperatures on Vasquez, St. Louis and Ranch creeks. It would be helpful if loggers were in place and recording temperature by mid-May; however, we recognize the difficulties in installing loggers during the runoff season when flows can be high and dangerous. Additional loggers in Elk, Crooked, Strawberry and Tenmile creeks would improve stream temperature predictions in the Fraser River, as well as provide data that indicate whether those creeks are experiencing high temperatures. In order to maximize model performance, loggers should be placed in the tributaries near the confluence with the Fraser River.
- **Meteorology** – The Tabernash weather station is centrally located within the modeled reach and can provide all of the required meteorological data except for solar radiation and cloud cover. Solar radiation data came from Northern Water's weather station near Windy Gap and cloud cover data came from a weather station in Kremmling. Model performance could potentially be improved if those data came from a location within the modeled reach.
- **Water Temperature Modeling and Model Selection** – A single reach water temperature model such as SSTEMP could be used to validate specific dates for tributary water temperatures and help refine the empirical models. For future model applications in other rivers, we recommend selecting a different dynamic water temperature model better suited to mountain stream systems such as SNTEMP. The RMS models are better suited to larger rivers and are difficult to apply to small, high mountain systems. In addition, RMS models are not well suited to model tributary streams in conjunction with mainstems as a single model domain.

Table 22. Summary of exceedances for the Fraser River at Rendezvous Bridge. Differences in exceedances between streamflow scenarios for a given year are highlighted in blue.

	1948				1959				1963				1978				1987			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
# of Days Above WAT Standard:																				
May																				
June																				
July	None				None				None				None				None			
August																				
September																				
October																				
# of Days Above DM Standard:																				
May	0	0	0	0	1	4	4	4	4	4	4	4	0	0	0	0	0	0	4	4
June	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	3	3	3	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	3	3	3	1	3	3	3	2	3	3	3	2	3	3	3	2	3	3	3
Total	**0**	**3**	**3**	**3**	**2**	**7**	**7**	**7**	**6**	**12**	**12**	**12**	**2**	**3**	**3**	**3**	**2**	**3**	**7**	**7**

Table 23. Summary of exceedances for the Fraser River at the Colorado River confluence. Differences in exceedances between streamflow scenarios for a given year are highlighted in blue.

	1948				1959				1963				1978				1987			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
# of Days Above WAT Standard:																				
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	8	8	8	8	0	0	0	0	0	1	0	0
July	8	17	17	17	18	25	26	26	31	31	31	31	6	7	7	7	25	31	26	26
August	20	20	20	20	19	18	18	18	20	25	25	25	27	28	28	28	24	24	24	24
September	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**28**	**37**	**37**	**37**	**37**	**43**	**44**	**44**	**59**	**64**	**64**	**64**	**33**	**36**	**36**	**36**	**49**	**56**	**50**	**50**
# of Days Above DM Standard:																				
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	8	10	10	10	0	0	0	0	0	2	0	0
July	0	1	1	1	1	2	3	3	8	8	8	8	0	0	0	0	5	5	4	4
August	2	2	2	2	6	3	3	3	3	5	5	5	8	12	12	12	6	6	6	6
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**2**	**3**	**3**	**3**	**7**	**5**	**6**	**6**	**19**	**23**	**23**	**23**	**8**	**12**	**12**	**12**	**11**	**13**	**10**	**10**

Table 24. Overall summary of temperature exceedances.

	Standard	Cumulative Effect with Moffat Project[1]	Effect Attributable to Moffat Project[2]
FRASER RIVER			
At Rendezvous Bridge	WAT	0	0
	DM	20 days (May, June, July, Oct)	4 days (May)
Below Crooked Creek	WAT	0	0
	DM	0	0
At Colorado River Confluence	WAT	25 days (July, Aug)	0
	DM	7 days (July, Aug)	0
TRIBUTARIES			
Vasquez Creek	WAT	0	0
	DM	0	0
St. Louis Creek	WAT	0	0
	DM	4 days (May)	5 days (May)
Ranch Creek	WAT	5 days (May)	5 days (May)
	DM	9 days (May)	10 days (May)

[1] Additional days of temperature exceedances compared to current conditions (Alt. 1a compared to EIS 285).

[2] Additional days of temperature exceedances attributable to the Moffat Project compared to Full Use of the Existing System (Alt. 1a compared to EIS 345).

If the shoulder season months (May and October) are eliminated, there would be one day of temperature exceedance in July on the Fraser River main stem and no exceedances in the tributaries attributable to the Moffat Project.

Table 25. Summary of exceedances for St. Louis Creek at the Fraser River confluence. Differences in exceedances between streamflow scenarios for a given year are highlighted in blue.

	1948				1959				1963				1978				1987			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
# of Days Above WAT Standard:																				
May									1	1	1	1								
June									0	0	0	0								
July			None				None		0	0	0	0			None				None	
August									0	0	0	0								
September									0	0	0	0								
October									0	0	0	0								
Total									**1**	**1**	**1**	**1**								
# of Days Above DM Standard:																				
May	2	2	2	2	5	5	5	5	7	7	7	7	2	2	2	2	1	0	5	5
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**2**	**2**	**2**	**2**	**5**	**5**	**5**	**5**	**7**	**7**	**7**	**7**	**2**	**2**	**2**	**2**	**1**	**0**	**5**	**5**

Table 26. Summary of exceedances for Ranch Creek at the Fraser River confluence. Differences in exceedances between streamflow scenarios for a given year are highlighted in blue.

	1948				1959				1963				1978				1987			
	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a	EIS 285	EIS 345	Alt 1a	Alt 8a
# of Days Above WAT Standard:																				
May					5	5	5	5	10	10	10	10	1	1	1	1	0	0	5	5
June					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July			None		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October					0	0	0	0	0	0	0	0	3	3	3	3	0	0	0	0
Total					**5**	**5**	**5**	**5**	**10**	**10**	**10**	**10**	**4**	**4**	**4**	**4**	**0**	**0**	**5**	**5**
# of Days Above DM Standard:																				
May	4	4	5	5	8	8	8	8	13	13	13	13	4	4	4	4	1	0	9	9
June	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	2	2	2	2
Total	**4**	**4**	**5**	**5**	**8**	**8**	**8**	**8**	**13**	**13**	**13**	**13**	**8**	**8**	**8**	**8**	**3**	**2**	**11**	**11**

EVALUATION OF THE MOFFAT PROJECT ON THE COLORADO RIVER DOWNSTREAM FROM THE FRASER RIVER

The original scope of work for the Fraser River water temperature model had an option for modeling the impacts of the Moffat Project on the Colorado River downstream from the Fraser River confluence. This option would require either the use of the existing Colorado River water temperature model (Hydros Consulting Inc. 2011) or construction of a new model. During the review of the Fraser River water temperature results another option was developed. This option was to use the existing Colorado River water temperature results instead of conducting any additional modeling. This third option was selected as the approach to be used for evaluation of the Moffat Project on the Colorado River. The following section describes the basis for selection of this option.

Justification for Using Colorado River Model Results

As part of the Windy Gap Firming Project (WGFP) EIS, water temperatures in the Colorado River were modeled using a dynamic water temperature model in a manner similar to that for the Fraser River (Hydros Consulting Inc. 2011). Three scenarios were modeled:

- Alternative 2 – Increased diversions from the Colorado River at Windy Gap and construction of a new 90,000-AF Chimney Hollow Reservoir (Alt2)
- No Action – Continuation of operations under existing agreements for conveyance of Windy Gap water (NA)
- Existing Conditions (EC)

The Fraser River was considered a major tributary inflow to the Colorado River and thus flows and temperatures at its confluence with the Colorado River were modeled as part of the WGFP dynamic water temperature model. The Colorado River water temperature model includes inflow and water temperature for the Fraser River. The WGFP model used a regression equation to predict hourly water temperatures from the Fraser River at the confluence with the Colorado River. The WGFP hydrology for cumulative conditions included the Moffat Project. The meteorology data for all WGFP simulations were from 2007, the same year used in the Fraser River water temperature model simulations.

The Fraser River water temperature model predicted hourly water temperatures at the confluence with the Colorado River for several alternatives. These predicted hourly temperatures for the Fraser River showed that the Moffat Project (Alt1a) does not produce any additional exceedences of the water temperature standards than cumulative effects without the Moffat Project (EIS 345) at the confluence of the Fraser and Colorado rivers.

1987 was a common simulation year for both the Fraser River water temperature model and the Colorado River water temperature model. Therefore, it was possible to compare simulated water temperatures from the two models at the Fraser River confluence with the Colorado River. Figure 93 compares modeled discharges under the proposed project streamflow scenario. That is, the Fraser River model shows simulated temperatures under Alt 1a (cumulative effects with the Moffat Project), while the Colorado River model shows cumulative effects simulated temperatures, in which the Moffat Project was considered one of the reasonably foreseeable future actions. While there are some differences in discharge the overall trend is similar. The largest differences in flow occur from June to mid-July. This translates into differences in simulated water temperature, which are apparent in Figure 94. The greatest differences in simulated temperature occur at times in July when simulated flows under the Fraser River model are particularly low.

The differences in simulated temperatures are most likely due to the differences in modeled discharges. For the Colorado River model, hydrologic data came from the Windy Gap Firming Project Hydrologic Model (described in Thompson 2011), whereas for the Fraser River model, data came from Denver Water's PACSM model.

Temperatures simulated from the Fraser River model are warmer than those simulated from the Colorado River model and exceedances of both the DM and WAT standard were predicted with the Fraser River model. Yet none of the exceedances were attributable to the Moffat Project (see Table 24).

These factors, such as the common meteorology year, the inclusion of the Moffat Project in the WGFP cumulative effects analysis and no differences in water temperature standard exceedences between EIS 345 and Alt 1a in the Fraser River model, all support the use of the existing WGFP water temperature model for evaluation of the Moffat Project on the Colorado River. The Fraser River model results at the confluence with the Colorado River and the WGFP model downstream from the Fraser River show similar seasonal patterns in water temperatures for the common year of 1987 (Figure 95-Figure 102). Therefore, the use of the WGFP water temperature results for cumulative effects should represent the expected changes in the Colorado River with the Moffat Project. While the simulation years are different, with the exception of 1987, both models include years with warmer than normal temperatures. The WGFP model therefore sufficiently incorporates any effects due to the Moffat Project.

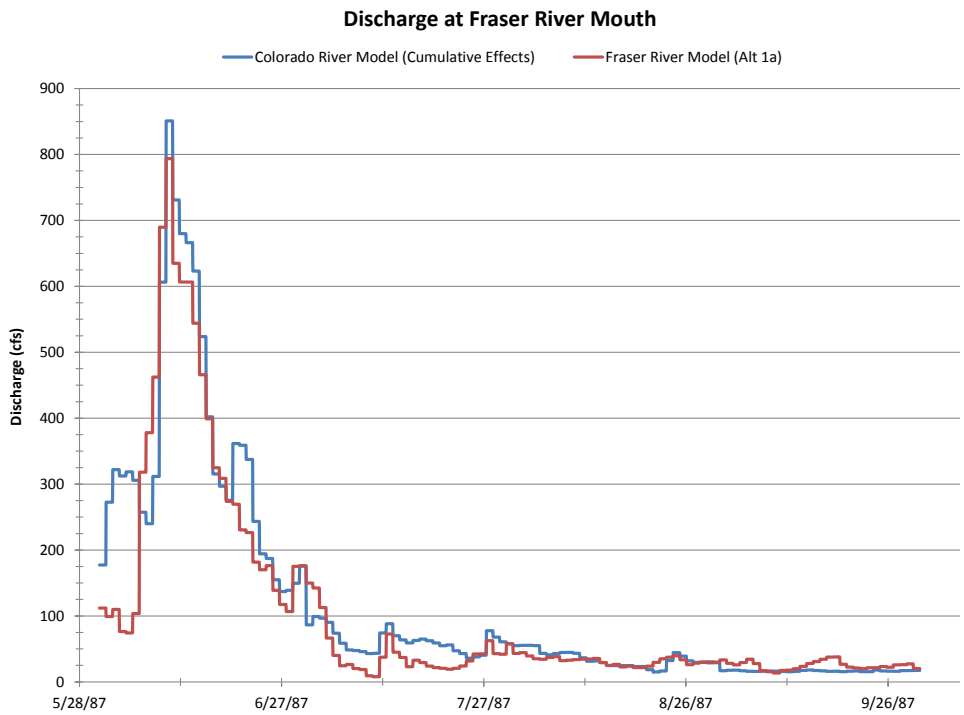

Figure 93. Comparison of discharge at the Fraser River mouth in 1987 under the proposed project streamflow scenario using two water temperature models.

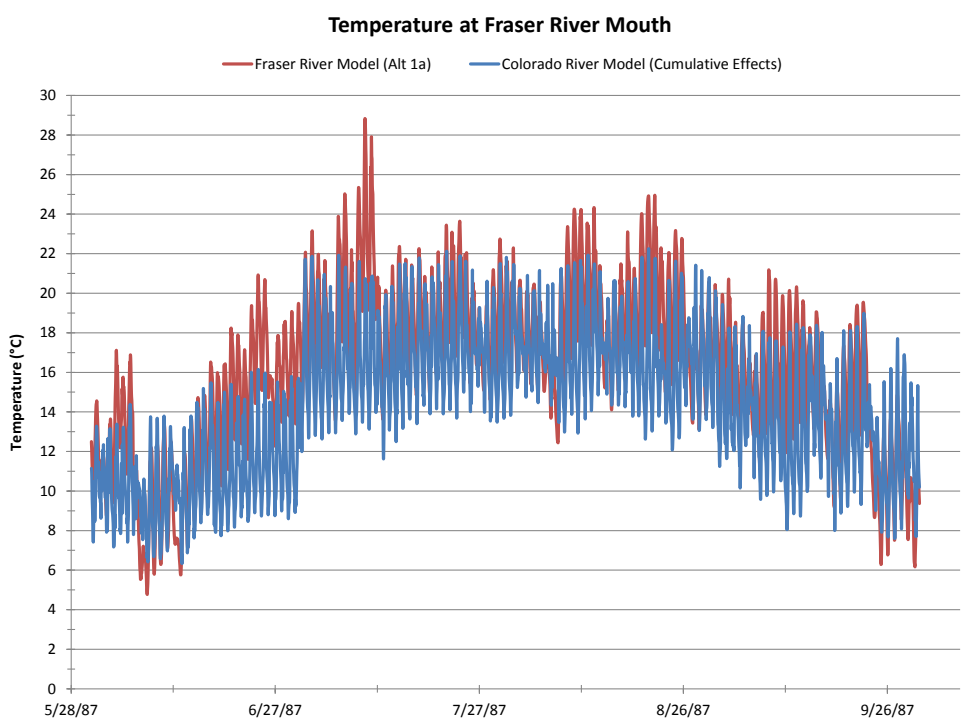

Figure 94. Comparison of temperature at the Fraser River mouth in 1987 under the proposed project streamflow scenario using two water temperature models.

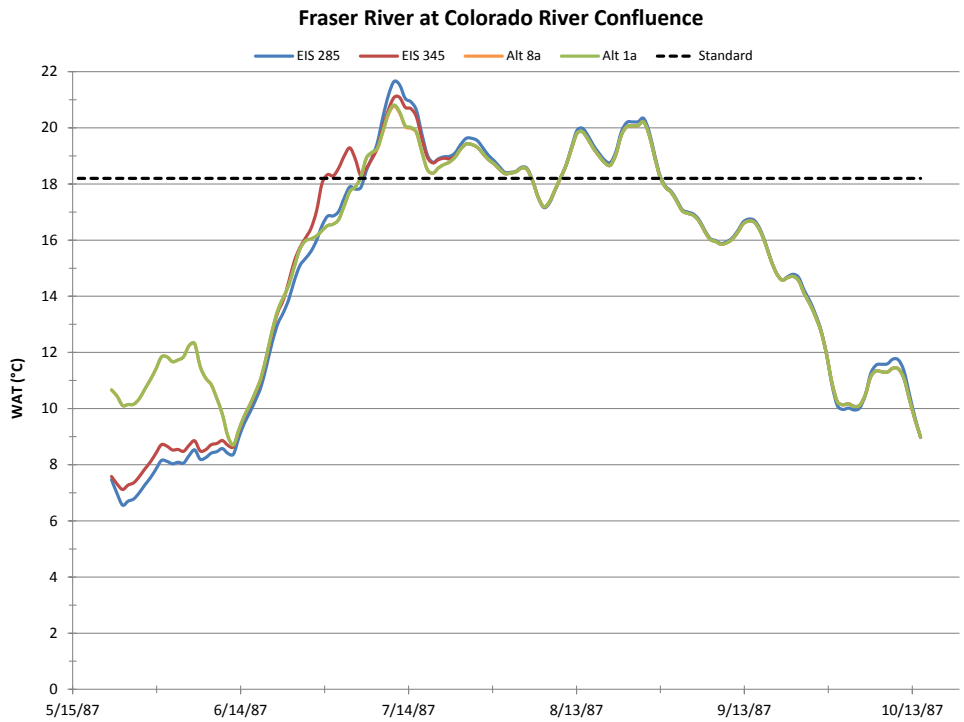

Figure 95. 1987 WATs, Fraser River at the Colorado River confluence.

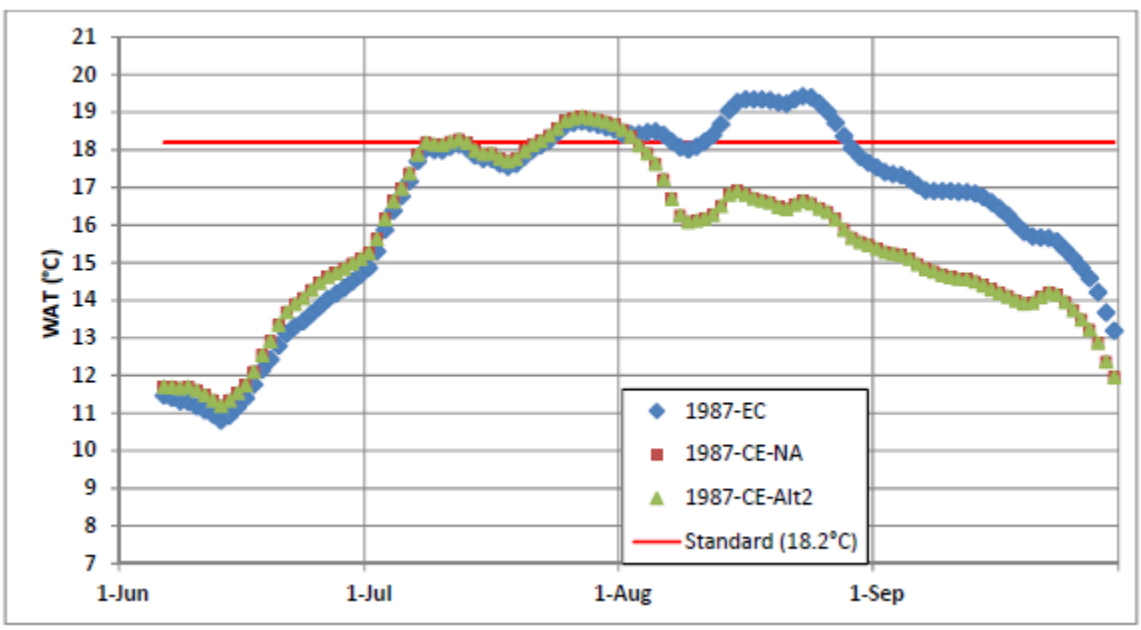

Figure 96. 1987 cumulative effects WATs for the Colorado River below Windy Gap Dam (Figure 179 in Hydros Consulting Inc. 2011). Note: EC=Existing Conditions, CE-NA= Cumulative effects No Action, CE-Alt2=cumulative effects preferred alternative.

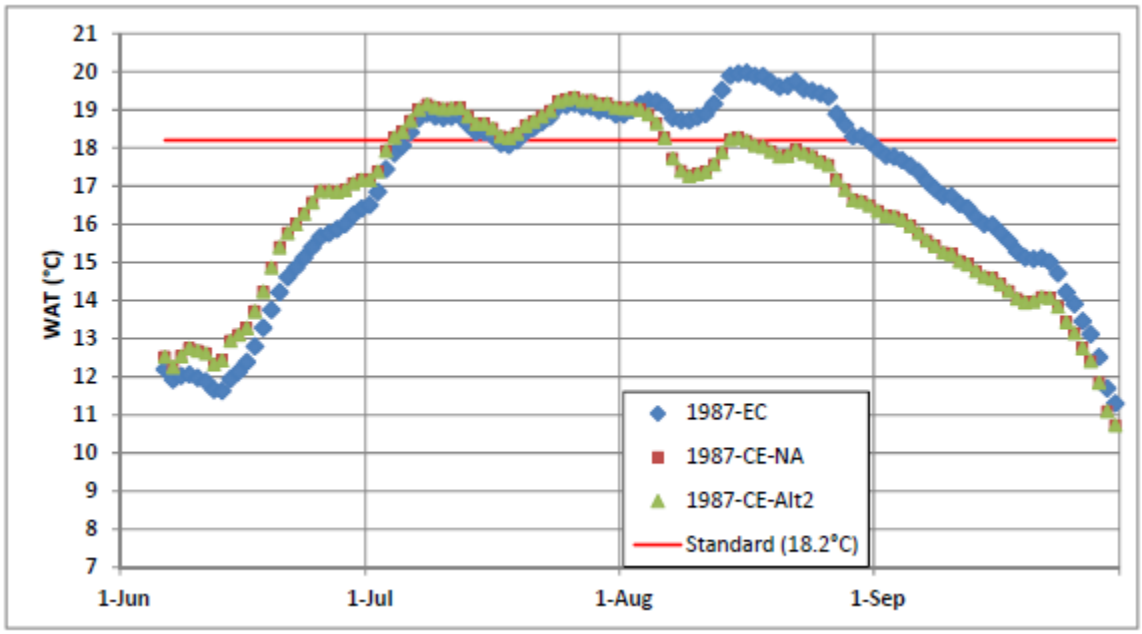

Figure 97. 1987 cumulative effects WATs for the Colorado River above the Hot Sulphur Springs water treatment plant (Figure 180 in Hydros Consulting Inc. 2011).

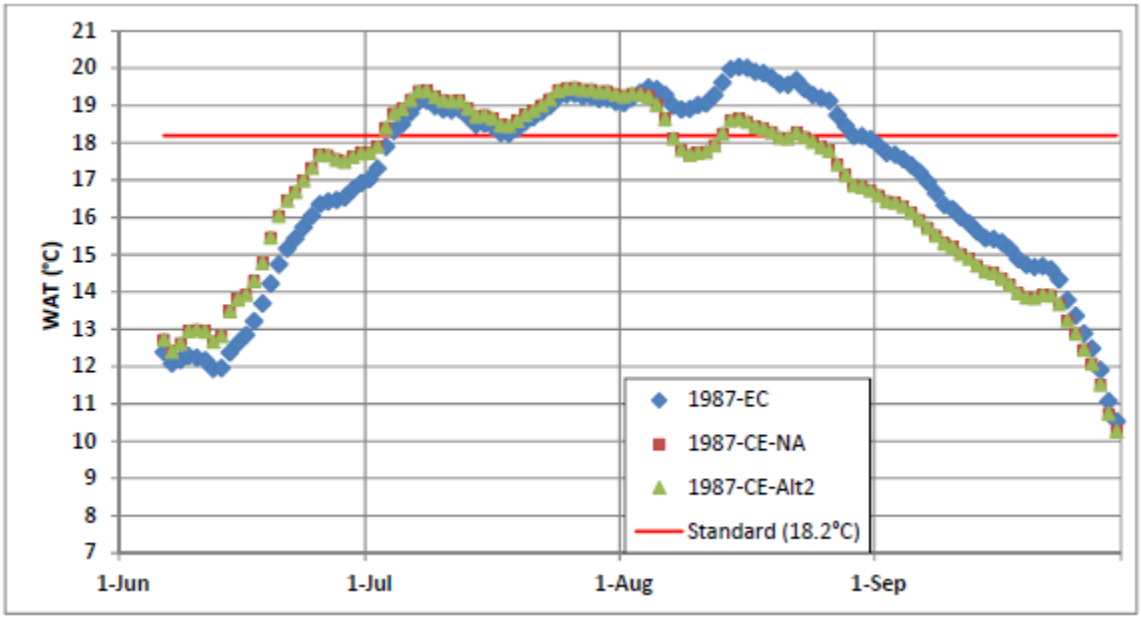

Figure 98. 1987 cumulative effects WATs for the Colorado River upstream of the confluence with the Williams Fork (Figure 181 in Hydros Consulting Inc. 2011).

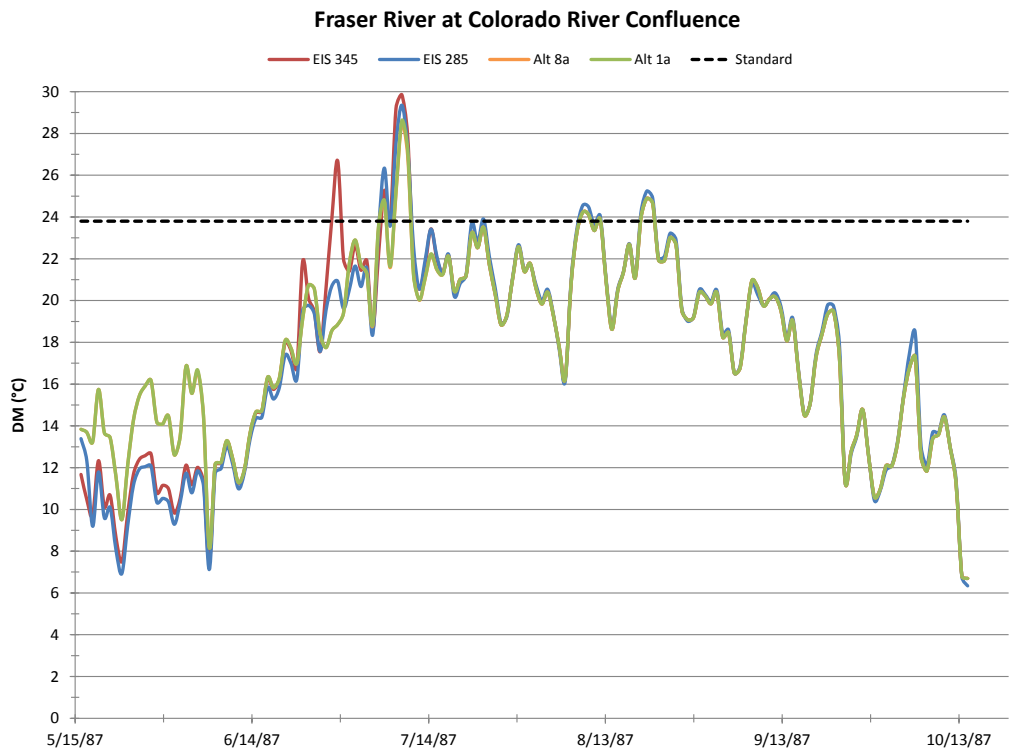

Figure 99. 1987 DMs, Fraser River at the Colorado River confluence.

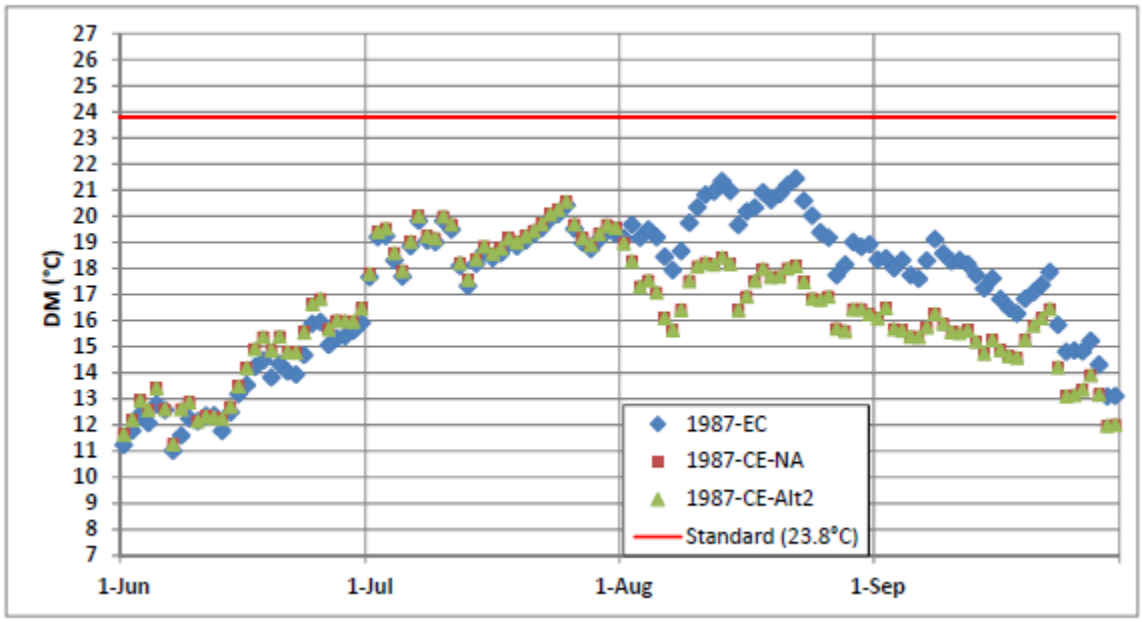

Figure 100. 1987 cumulative effects DMs for the Colorado River below Windy Gap Dam (Figure 182 in Hydros Consulting Inc. 2011).

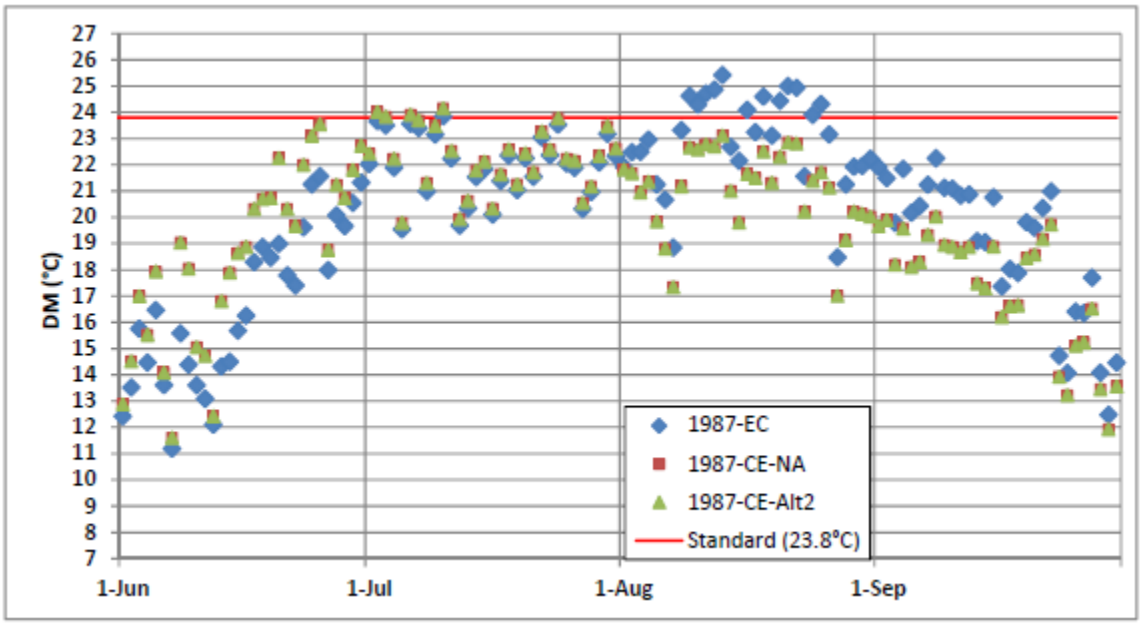

Figure 101. 1987 cumulative effects DMs for the Colorado River above the Hot Sulphur Springs water treatment plant (Figure 183 in Hydros Consulting Inc. 2011).

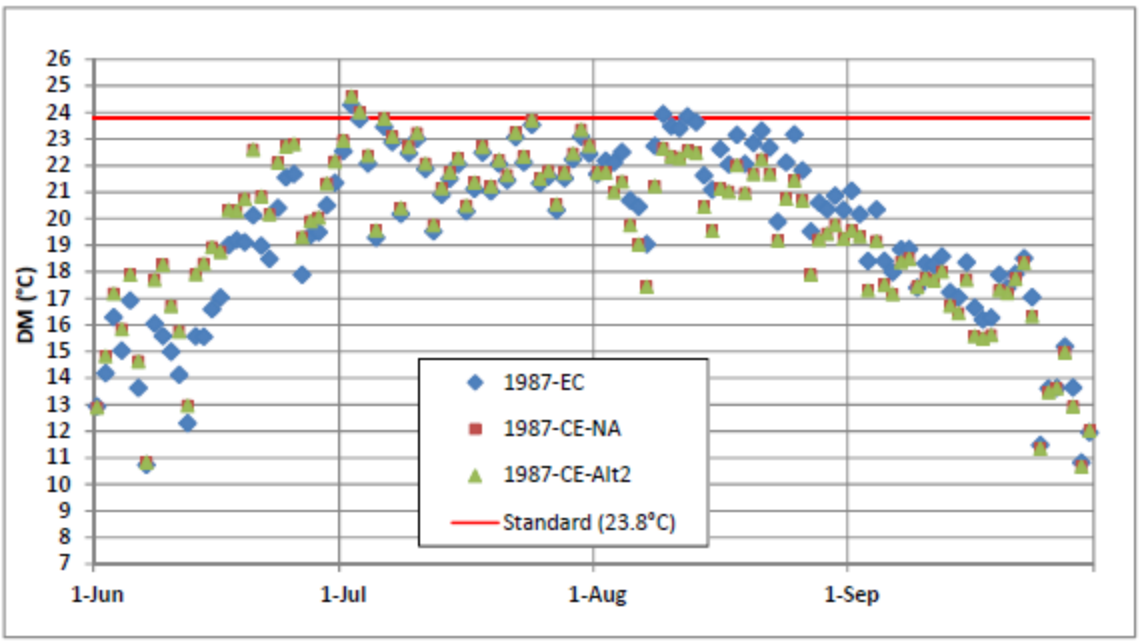

Figure 102. 1987 cumulative effects DMs for the Colorado River upstream of the confluence with the Williams Fork (Figure 184 in Hydros Consulting Inc. 2011).

Colorado River Cumulative Effects

As part of the WGFP EIS, cumulative effects were simulated for 1975, 1979, 1986, 1987 and 1988 using 2007 meteorology (Hydros Consulting Inc. 2011). Cumulative effects include reasonably foreseeable future actions that are anticipated to occur regardless of the action (or No Action) alternative that is chosen. The Moffat Project was included as one of the reasonably foreseeable future actions. The following paragraphs summarize the results of the simulations for 1975, 1979, 1986, 1987 and 1988. These five years represent the only years in the 15-year simulated daily hydrology focus period that were expected to exhibit possible increased river temperatures due to the proposed alternative. Cumulative effects were simulated for the No Action scenario and Alt2 (the proposed action alternative) and were also compared to Existing Conditions. Results focused on three locations: the Colorado River one mile downstream of Windy Gap Dam (WGD), upstream of the town of Hot Sulphur Springs (HSU) and upstream of the confluence with the Williams Fork (WFU).

1975 Cumulative Effects

1975 was an average year, with virgin annual flows ranking 23rd out of the 47 years of hydrology simulated for the WGFP. In June, pumping from Windy Gap Reservoir was greater under Existing Conditions than for Alt2 and No Action. Alt2 had the highest levels of pumping in July. Pumping from Windy Gap Reservoir and river flows were greater under Alt2 and No Action compared to existing conditions in August and September due to 5412 releases planned from Granby Reservoir. The “5412” release is the amount of water released from Granby Reservoir to comply with the U.S. Fish and Wildlife Service’s Upper Colorado River Recovery Program. This release of water is half of the water users’ obligation to release 10,825 acre-feet of water for the Recovery Program. The greatest flow differences and resultant temperature effects occurred below Windy Gap Reservoir in July. During this time, increased temperatures were simulated at WGD, HSU and WFU under Alt2 relative to both Existing Conditions and No Action. As a result, increased temperature exceedances were simulated for Alt2 compared to Existing Conditions and No Action at all three locations in July. In August, Alt2 and No Action simulated temperatures were lower than Existing Conditions due to 5412 releases from Granby Reservoir. Consequently, there were fewer exceedances with these two alternatives as compared to Existing Conditions. There were no acute exceedances simulated at WGD for any scenario and there were no exceedances in June or September for any scenario or location. Overall, planned releases from Granby Reservoir served to cool river temperatures in this scenario year.

1979 Cumulative Effects

1979 was an average to wetter year, with virgin annual flows ranking 14th out of the 47 years. In June, pumping from Windy Gap Reservoir was greater under Existing Conditions than for Alt2 and No Action (pumping rates and flows were similar for Alt2 and No Action in 1979). However, due to larger inflows, flows below Windy Gap Reservoir were also higher under Existing Conditions. In July, pumping was greater under Alt2 and No Action compared to Existing Conditions and flows below the reservoir were

correspondingly lower. During this time, increased temperatures were simulated at WGD, HSU and WFU under Alt2 and No Action relative to Existing Conditions. As a result, increased temperature exceedances were simulated for Alt2 and No Action compared to Existing Conditions. In August and September, planned 5412 releases from Granby Reservoir resulted in larger flows under Alt2 and No Action compared to Existing Conditions. As a result, Alt2 and No Action simulated temperatures were lower than Existing Conditions and there were fewer exceedances with these two scenarios as compared to Existing Conditions. There were no acute exceedances simulated at WGD for any scenario and there were no exceedances in June or September for any scenario or location. Overall, planned releases from Granby Reservoir served to cool river temperatures in this scenario year.

1986 Cumulative Effects

1986 was a wet year, with virgin annual flows ranking 4th out of the 47 years. Under Existing Conditions, no pumping from Windy Gap Reservoir occurred for the four-month period. The No Action scenario had higher amounts of pumping than Alt2 in July but less pumping in August. Due to high flows for this year, differences in pumping between scenarios did not cause large differences in flow downstream of Windy Gap Reservoir. Increases in flow in August and September from 5412 releases from Granby Reservoir under Alt2 and No Action had little effect on flows in August and slightly more effect in September. Differences in simulated temperatures between the scenarios occurred primarily in August and September but there were no temperature exceedances in any month for any scenario or location. Overall, in spite of pumping differences between scenarios comparable to those simulated for 1975 and 1979, temperature patterns were similar between scenarios because 1986 was a wet year.

1987 Cumulative Effects

1987 was an average to drier year, with virgin annual flows ranking 42nd out of the 47 years. In June, pumping from Windy Gap Reservoir was greater under Alt2 and No Action compared to Existing Conditions (pumping rates were identical for Alt2 and No Action), which resulted in larger flows downstream of the reservoir under Existing Conditions. Pumping did not occur for any scenario in July, August or September. This translated into very similar flows downstream of the reservoir in July between the scenarios. Flows were greater for Alt2 and No Action compared to Existing Conditions in August and September due to releases from Granby Reservoir. Increased temperatures were simulated in June under Alt2 and No Action and were a consequence of greater pumping from Windy Gap Reservoir. However, these increases did not result in any temperature exceedances in June. In July, temperatures under Alt2 and No Action were slightly warmer than those under Existing Conditions. This resulted in a few more temperature exceedances. In August and September, decreased temperatures under Alt2 and No Action are indicative of the cooling effect of releases from Granby Reservoir. This cooling effect resulted in fewer exceedances of both the acute and chronic temperature standards under Alt2 and No Action in August. There were no exceedances for any scenario in September. Also, there were no acute exceedances simulated at WGD for any scenario or month. Overall, planned releases from Granby Reservoir served to cool river temperatures in this scenario year.

1988 Cumulative Effects

1998 was an average year, with virgin annual flows ranking 34th out of the 47 years. Pumping from Windy Gap Reservoir occurred only in June under Alt2 and in July under No Action (and this was a much smaller amount compared to June). Therefore, the primary differences in flow downstream of the reservoir are in June, when flows under Alt2 are less than for Existing Conditions or No Action. Flows in July are similar for all three scenarios. In August and September, flows were greater under Alt2 and No Action due to 5412 releases from Granby Reservoir. As to be expected, simulated temperatures were warmer in June for Alt2 compared to Existing Conditions and No Action, although the temperature standards were never exceeded. The chronic temperature standard was exceeded in July at HSU and WFU but the number of exceedances was the same across scenarios; the acute standard was not exceeded in July. Temperatures under Alt2 and No Action were cooler in August and September compared to Existing Conditions due to Granby Reservoir releases. This translated into fewer exceedances in August. There were no exceedances in September for any scenario or location. Also, there were no acute exceedances simulated at WGD or WFU for any scenario or month. Overall, planned releases from Granby Reservoir served to cool river temperatures in this scenario year.

Cumulative Effects Summary

In general, simulated increased temperatures due to cumulative effects, which included the Moffat Project, for Alt2 resulted in a greater number of exceedances of both acute and chronic standards in July, compared to Existing Conditions. However, in August, due to 5412 releases from Granby Reservoir, the cumulative effects showed fewer exceedances for Alt2 in August compared to Existing Conditions. The net effect at all locations simulated on the Colorado River is that there are fewer or equal numbers of temperature exceedances. There are no exceedances under any scenario in June and September. Table 27 summarizes the number of temperature standard exceedances at each location for Existing Conditions and Alt2.

For the Colorado River below Windy Gap Dam, the net effect was fewer chronic standard exceedances for Alt2 compared to Existing Conditions. The acute standard was never exceeded at this location for any scenario. For the Colorado River upstream of Hot Sulphur Springs, the net effect was fewer chronic and acute standard exceedances for Alt2 compared to Existing Conditions. For the Colorado River upstream of Williams Fork, the net effect was fewer chronic standard exceedances and three additional days of acute standard exceedances for Alt2 compared to Existing Conditions over the five years.

Table 27. Cumulative effects summary of exceedances.

	1975		1979		1986		1987		1988	
	EC	Alt2	EC	Alt2	EC	Alt2	EC	Alt2	EC	Alt2
# of Days Above WAT Standard:										
WGD -- 1 mile downstream of Windy Gap Dam	14	0	6	11	0	0	31	11	11	0
HSU -- Upstream of Hot Sulphur Springs	23	16	25	18	0	0	53	31	33	12
WFU -- Upstream of Confluence with Williams Fork	25	28	34	34	0	0	54	40	36	15
# of Days Above DM Standard:										
WGD -- 1 mile downstream of Windy Gap Dam	0	0	0	0	0	0	0	0	0	0
HSU -- Upstream of Hot Sulphur Springs	3	3	1	3	0	0	11	3	4	0
WFU -- Upstream of Confluence with Williams Fork	0	1	0	2	0	0	2	2	0	0

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APPENDIX A

Detailed Temperature Comparisons for Days of DM and WAT Exceedances

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***For all tables, temperatures highlighted in green indicate where the standard was not exceeded.**

Table A - 1. Fraser River at Rendezvous Bridge, 1948.

1948	Rendezvous Bridge					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	0	3	3	3				
Temperature (°C) on:								
4-Oct	11.85	13.26	13.26	13.26		1.41	1.41	0.00
5-Oct	12.25	13.79	13.79	13.79		1.54	1.54	0.00
6-Oct	12.59	14.26	14.26	14.26		1.67	1.67	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 2. Fraser River at the Colorado River confluence, 1948.*

1948	Colorado River Confluence					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	28	37	37	37				
Temperature (°C) on:								
4-Jul	17.16	18.34	18.53	18.53		1.19	1.37	0.19
5-Jul	17.52	18.64	18.79	18.79		1.12	1.28	0.16
6-Jul	17.76	18.79	18.89	18.89		1.04	1.14	0.10
7-Jul	18.17	18.96	19.00	19.00		0.79	0.83	0.04
8-Jul	18.17	18.65	18.66	18.66		0.48	0.49	0.01
12-Jul	18.14	18.26	18.26	18.26		0.12	0.12	0.00
13-Jul	18.15	18.27	18.27	18.27		0.12	0.12	0.00
15-Jul	18.12	18.25	18.25	18.25		0.13	0.13	0.00
16-Jul	18.22	18.33	18.33	18.33		0.12	0.12	0.00
24-Jul	18.19	18.28	18.28	18.28		0.09	0.09	0.00
25-Jul	18.41	18.48	18.49	18.49		0.07	0.07	0.00
26-Jul	18.50	18.57	18.57	18.57		0.07	0.07	0.00
27-Jul	18.58	18.64	18.64	18.64		0.07	0.07	0.00
28-Jul	18.53	18.60	18.60	18.60		0.07	0.08	0.00
29-Jul	18.45	18.53	18.53	18.53		0.08	0.08	0.00
30-Jul	18.44	18.52	18.52	18.52		0.09	0.09	0.00
31-Jul	18.42	18.50	18.50	18.50		0.08	0.09	0.00
1-Aug	18.32	18.41	18.41	18.41		0.09	0.09	0.00
2-Aug	18.36	18.43	18.43	18.43		0.07	0.07	0.00
3-Aug	18.39	18.44	18.44	18.44		0.05	0.05	0.00
4-Aug	18.44	18.47	18.47	18.47		0.03	0.03	0.00
5-Aug	18.33	18.34	18.34	18.34		0.01	0.01	0.00
13-Aug	18.62	18.63	18.63	18.63		0.01	0.01	0.00
14-Aug	19.23	19.19	19.20	19.20		-0.03	-0.03	0.00
15-Aug	19.30	19.25	19.25	19.25		-0.05	-0.05	0.00
16-Aug	19.06	19.01	19.01	19.01		-0.05	-0.05	0.00
17-Aug	18.76	18.72	18.72	18.72		-0.04	-0.04	0.00
18-Aug	18.54	18.50	18.50	18.50		-0.04	-0.04	0.00
19-Aug	18.32	18.28	18.28	18.28		-0.04	-0.04	0.00
21-Aug	18.47	18.43	18.43	18.43		-0.04	-0.04	0.00
22-Aug	19.14	19.08	19.08	19.08		-0.06	-0.06	0.00
23-Aug	19.52	19.43	19.43	19.43		-0.09	-0.09	0.00
24-Aug	19.58	19.48	19.48	19.48		-0.10	-0.09	0.00
25-Aug	19.65	19.56	19.56	19.56		-0.09	-0.09	0.00
26-Aug	19.73	19.65	19.66	19.66		-0.08	-0.08	0.00
27-Aug	19.27	19.21	19.21	19.21		-0.07	-0.06	0.00
28-Aug	18.52	18.48	18.48	18.48		-0.04	-0.03	0.00
WAT Standard	18.20	18.20	18.20	18.20				
# of DM Exceedances	2	3	3	3				
Temperature (°C) on:								
2-Jul	22.96	24.58	24.61	24.61		1.62	1.65	0.03
21-Aug	24.31	23.99	23.99	23.99		-0.32	-0.32	0.00
22-Aug	24.21	23.97	23.98	23.98		-0.24	-0.23	0.01
DM Standard	23.80	23.80	23.80	23.80				

*Four of the WAT exceedances may not be fully realized under actual conditions because they are well within the model error. The days of interest are July 12, 13, 15 and 24. For these days, EIS 345 and Alt 1a exceed the standard whereas EIS 285 does not. Yet the maximum difference in temperature is at most 0.13°C.

Table A - 3. St. Louis Creek at the Fraser River confluence, 1948.

1948	St. Louis Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	2	2	2	2				
Temperature (°C) on:								
16-May	14.14	14.14	14.14	14.14		0.00	0.00	0.00
19-May	13.55	13.55	13.55	13.55		0.00	0.00	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 4. Ranch Creek at the Fraser River confluence, 1948.

1948	Ranch Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	4	4	5	5				
Temperature (°C) on:								
16-May	15.55	15.55	15.55	15.55		0.00	0.00	0.00
17-May	14.20	14.20	14.20	14.20		0.00	0.00	0.00
18-May	13.26	13.26	13.26	13.26		0.00	0.00	0.00
19-May	13.79	13.79	13.79	13.79		0.00	0.00	0.00
27-May	10.67	11.69	13.14	13.14		1.02	2.47	1.45
DM Standard	13.00	13.00	13.00	13.00				

Table A - 5. Fraser River at Rendezvous Bridge, 1959.

1959	Rendezvous Bridge					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	2	7	7	7				
Temperature (°C) on:								
19-May	12.56	13.51	13.51	13.51		0.95	0.95	0.00
26-May	12.87	13.80	13.80	13.80		0.93	0.93	0.00
27-May	13.55	14.57	14.57	14.57		1.02	1.02	0.00
28-May	12.95	13.79	13.79	13.79		0.84	0.84	0.00
4-Oct	12.11	13.26	13.26	13.26		1.15	1.15	0.00
5-Oct	12.61	13.87	13.87	13.87		1.26	1.26	0.00
6-Oct	13.08	14.53	14.53	14.53		1.45	1.45	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 6. Fraser River at the Colorado River confluence, 1959.*

1959	Colorado River Confluence					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	37	43	44	44				
Temperature (°C) on:								
4-Jul	15.59	17.86	18.28	18.28		2.27	2.69	0.42
5-Jul	16.14	18.21	18.72	18.72		2.07	2.58	0.51
6-Jul	16.72	18.59	19.13	19.13		1.87	2.41	0.54
7-Jul	17.52	19.04	19.59	19.59		1.52	2.08	0.56
8-Jul	17.96	18.88	19.44	19.44		0.92	1.48	0.56
9-Jul	18.17	18.55	19.02	19.02		0.38	0.85	0.47
10-Jul	18.62	18.74	19.05	19.05		0.13	0.43	0.30
11-Jul	19.03	19.07	19.22	19.22		0.05	0.19	0.14
12-Jul	19.35	19.35	19.40	19.40		0.00	0.05	0.05
13-Jul	19.42	19.39	19.41	19.41		-0.03	-0.01	0.02
14-Jul	19.25	19.23	19.23	19.23		-0.02	-0.01	0.01
15-Jul	19.40	19.39	19.39	19.39		-0.01	-0.01	0.00
16-Jul	19.43	19.41	19.41	19.41		-0.02	-0.02	0.00
17-Jul	18.86	18.87	18.87	18.87		0.01	0.01	0.00
18-Jul	18.44	18.47	18.47	18.47		0.03	0.03	0.00
19-Jul	18.33	18.37	18.37	18.37		0.04	0.04	0.00
20-Jul	18.30	18.34	18.34	18.34		0.04	0.04	0.00
21-Jul	18.195	18.23	18.23	18.23		0.03	0.03	0.00
23-Jul	18.19	18.22	18.22	18.22		0.02	0.02	0.00
24-Jul	18.50	18.50	18.50	18.50		0.01	0.01	0.00
25-Jul	18.73	18.72	18.72	18.72		-0.01	-0.01	0.00
26-Jul	18.77	18.76	18.76	18.76		0.00	0.00	0.00
27-Jul	18.77	18.76	18.76	18.76		-0.01	-0.01	0.00
28-Jul	18.67	18.68	18.68	18.68		0.00	0.00	0.00
29-Jul	18.56	18.58	18.58	18.58		0.01	0.01	0.00
30-Jul	18.39	18.42	18.42	18.42		0.03	0.03	0.00
12-Aug	18.42	18.42	18.42	18.42		-0.01	-0.01	0.00
13-Aug	19.07	19.04	19.04	19.04		-0.03	-0.03	0.00
14-Aug	19.67	19.60	19.60	19.60		-0.07	-0.07	0.00
15-Aug	19.72	19.63	19.63	19.63		-0.09	-0.09	0.00
16-Aug	19.43	19.34	19.34	19.34		-0.09	-0.09	0.00
17-Aug	19.06	18.98	18.98	18.98		-0.08	-0.08	0.00
18-Aug	18.80	18.72	18.72	18.72		-0.07	-0.07	0.00
19-Aug	18.56	18.49	18.49	18.49		-0.07	-0.07	0.00
20-Aug	18.43	18.36	18.36	18.36		-0.07	-0.07	-0.01
21-Aug	18.74	18.67	18.66	18.66		-0.07	-0.08	-0.01
22-Aug	19.44	19.35	19.34	19.34		-0.10	-0.11	-0.01
23-Aug	19.86	19.73	19.72	19.72		-0.13	-0.14	-0.01
24-Aug	19.98	19.83	19.83	19.83		-0.15	-0.15	-0.01
25-Aug	20.12	19.98	19.97	19.97		-0.14	-0.15	-0.01
26-Aug	20.36	20.21	20.20	20.20		-0.15	-0.15	0.00
27-Aug	19.99	19.84	19.84	19.84		-0.14	-0.15	0.00
28-Aug	19.26	19.15	19.15	19.15		-0.12	-0.12	0.00
29-Aug	18.58	18.49	18.49	18.49		-0.09	-0.09	0.00
30-Aug	18.202	18.14	18.14	18.14		-0.06	-0.07	0.00
WAT Standard	18.20	18.20	18.20	18.20				
# of DM Exceedances	7	5	6	6				
Temperature (°C) on:								
2-Jul	21.29	24.50	25.65	25.65		3.21	4.36	1.15
3-Jul	21.22	22.31	23.97	23.97		1.09	2.75	1.66
10-Jul	25.18	24.90	24.91	24.91		-0.28	-0.27	0.01
10-Aug	24.30	24.05	24.05	24.05		-0.25	-0.25	0.00
11-Aug	23.95	23.71	23.71	23.71		-0.24	-0.24	0.00
13-Aug	23.86	23.69	23.69	23.69		-0.17	-0.17	0.00
21-Aug	24.68	24.35	24.35	24.35		-0.33	-0.33	0.00
22-Aug	24.72	24.46	24.46	24.46		-0.26	-0.26	0.00
25-Aug	23.83	23.60	23.60	23.60		-0.23	-0.23	0.00
DM Standard	23.80	23.80	23.80	23.80				

*Five of the WAT exceedances may not be fully realized under actual conditions because they are well within the model error. The days of interest are July 4, July 9, July 21, July 23 and August 30. For these days, the maximum difference in temperature between flow scenarios is at most 0.42°C. Three of the DM exceedances may also not be fully realized. The days of interest are August 11, 13 and 25. EIS 285 exceeds the standard whereas EIS 345 and Alt 1a do not, yet the maximum difference in temperature is only 0.24°C.

Table A - 7. St. Louis Creek at the Fraser River confluence, 1959.

1959	St. Louis Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	5	5	5	5				
Temperature (°C) on:								
16-May	13.98	13.98	13.98	13.98		0.00	0.00	0.00
19-May	13.73	13.73	13.73	13.73		0.00	0.00	0.00
25-May	13.09	13.08	13.08	13.08		0.00	0.00	0.00
27-May	13.65	13.65	13.65	13.65		0.00	0.00	0.00
28-May	13.31	13.31	13.31	13.31		0.00	0.00	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 8. Ranch Creek at the Fraser River confluence, 1959.

1959	Ranch Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	5	5	5	5				
Temperature (°C) on:								
27-May	9.12	9.12	9.12	9.12		0.00	0.00	0.00
28-May	9.22	9.22	9.22	9.22		0.00	0.00	0.00
29-May	9.22	9.22	9.22	9.22		0.00	0.00	0.00
30-May	9.25	9.25	9.25	9.25		0.00	0.00	0.00
31-May	9.17	9.17	9.17	9.17		0.00	0.00	0.00
WAT Standard	9.00	9.00	9.00	9.00				
# of DM Exceedances	8	8	8	8				
Temperature (°C) on:								
16-May	14.10	14.10	14.10	14.10		0.00	0.00	0.00
17-May	13.16	13.16	13.16	13.16		0.00	0.00	0.00
19-May	13.98	13.98	13.98	13.98		0.00	0.00	0.00
21-May	13.07	13.07	13.07	13.07		0.00	0.00	0.00
25-May	13.88	13.88	13.88	13.88		0.00	0.00	0.00
26-May	13.65	13.65	13.65	13.65		0.00	0.00	0.00
27-May	14.60	14.60	14.60	14.60		0.00	0.00	0.00
28-May	14.07	14.07	14.07	14.07		0.00	0.00	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 9. Fraser River at Rendezvous Bridge, 1963.

1963	Rendezvous Bridge					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	6	12	12	12				
Temperature (°C) on:								
19-May	13.26	14.22	14.22	14.22		0.96	0.96	0.00
26-May	13.09	14.03	14.03	14.03		0.94	0.94	0.00
27-May	13.57	14.59	14.59	14.59		1.02	1.02	0.00
28-May	13.14	14.06	14.06	14.06		0.92	0.92	0.00
24-Jun	18.82	22.80	22.80	22.80		3.98	3.98	0.00
25-Jun	18.47	22.42	22.42	22.42		3.95	3.95	0.00
1-Jul	18.94	23.08	23.08	23.08		4.14	4.14	0.00
2-Jul	19.24	23.60	23.60	23.60		4.36	4.36	0.00
3-Jul	18.18	21.94	21.94	21.94		3.76	3.76	0.00
4-Oct	12.40	13.48	13.48	13.48		1.08	1.08	0.00
5-Oct	13.07	14.33	14.33	14.33		1.26	1.26	0.00
6-Oct	13.52	15.03	15.03	15.03		1.51	1.51	0.00
DM Standard (Oct-May)	13.00	13.00	13.00	13.00				
DM Standard (Jun-Sep)	21.70	21.70	21.70	21.70				

Table A - 10. Fraser River at the Colorado River confluence, 1963.*

1963	Colorado River Confluence					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	59	64	64	64				
Temperature (°C) on:								
23-Jun	18.84	19.15	19.15	19.15		0.30	0.30	0.00
24-Jun	20.19	20.61	20.61	20.61		0.42	0.42	0.00
25-Jun	21.49	22.02	22.02	22.02		0.53	0.53	0.00
26-Jun	22.35	22.95	22.95	22.95		0.60	0.60	0.00
27-Jun	22.53	23.25	23.25	23.25		0.72	0.72	0.00
28-Jun	22.53	23.35	23.35	23.35		0.82	0.82	0.00
29-Jun	22.66	23.60	23.60	23.60		0.94	0.94	0.00
30-Jun	22.87	23.86	23.86	23.86		0.99	0.99	0.00
1-Jul	22.72	23.70	23.70	23.70		0.98	0.98	0.00
2-Jul	22.50	23.46	23.46	23.46		0.97	0.97	0.00
3-Jul	22.72	23.68	23.68	23.68		0.96	0.96	0.00
4-Jul	22.94	23.80	23.80	23.80		0.86	0.86	0.00
5-Jul	22.64	23.41	23.41	23.41		0.78	0.78	0.00
6-Jul	22.23	22.92	22.92	22.92		0.69	0.69	0.00
7-Jul	21.94	22.51	22.51	22.51		0.57	0.57	0.00
8-Jul	21.21	21.68	21.68	21.68		0.47	0.47	0.00
9-Jul	20.38	20.80	20.80	20.80		0.41	0.41	0.00
10-Jul	20.11	20.49	20.49	20.49		0.38	0.38	0.00
11-Jul	20.08	20.46	20.46	20.46		0.38	0.38	0.00
12-Jul	20.12	20.48	20.48	20.48		0.36	0.36	0.00
13-Jul	20.01	20.34	20.34	20.34		0.34	0.34	0.00
14-Jul	19.69	20.03	20.03	20.03		0.34	0.34	0.00
15-Jul	19.74	20.10	20.10	20.10		0.37	0.37	0.00
16-Jul	19.71	20.07	20.07	20.07		0.36	0.36	0.00
17-Jul	19.18	19.53	19.53	19.53		0.35	0.35	0.00
18-Jul	18.79	19.13	19.13	19.13		0.34	0.34	0.00
19-Jul	18.70	19.05	19.05	19.05		0.35	0.35	0.00
20-Jul	18.68	19.05	19.05	19.05		0.36	0.36	0.00
21-Jul	18.58	18.95	18.95	18.95		0.36	0.36	0.00
22-Jul	18.49	18.83	18.83	18.83		0.35	0.35	0.00
23-Jul	18.57	18.90	18.90	18.90		0.33	0.33	0.00
24-Jul	18.72	19.05	19.05	19.05		0.33	0.33	0.00
25-Jul	18.82	19.13	19.13	19.13		0.31	0.31	0.00
26-Jul	18.80	19.11	19.11	19.11		0.31	0.31	0.00
27-Jul	18.78	19.07	19.07	19.07		0.29	0.29	0.00
28-Jul	18.66	18.96	18.96	18.96		0.30	0.30	0.00
29-Jul	18.57	18.86	18.86	18.86		0.29	0.29	0.00
30-Jul	18.56	18.84	18.84	18.84		0.28	0.28	0.00
31-Jul	18.62	18.88	18.88	18.88		0.26	0.26	0.00
1-Aug	18.62	18.87	18.87	18.87		0.25	0.25	0.00
2-Aug	18.73	18.94	18.94	18.94		0.21	0.21	0.00
3-Aug	18.84	19.03	19.03	19.03		0.19	0.19	0.00
4-Aug	18.96	19.14	19.14	19.14		0.17	0.17	0.00
5-Aug	18.88	19.04	19.04	19.04		0.16	0.16	0.00

Table A – 10 continued.

1963	Colorado River Confluence					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
Temperature (°C) on:								
6-Aug	18.41	18.57	18.57	18.57		0.16	0.16	0.00
11-Aug	18.04	18.31	18.31	18.31		0.28	0.28	0.00
12-Aug	18.28	18.55	18.55	18.55		0.27	0.27	0.00
13-Aug	18.62	18.88	18.88	18.88		0.26	0.26	0.00
14-Aug	19.01	19.24	19.24	19.24		0.24	0.24	0.00
15-Aug	18.96	19.17	19.17	19.17		0.21	0.21	0.00
16-Aug	18.69	18.90	18.90	18.90		0.21	0.21	0.00
17-Aug	18.33	18.55	18.55	18.55		0.23	0.23	0.00
18-Aug	18.07	18.29	18.29	18.29		0.22	0.22	0.00
19-Aug	18.01	18.22	18.22	18.22		0.21	0.21	0.00
20-Aug	18.16	18.38	18.38	18.38		0.22	0.22	0.00
21-Aug	18.68	18.92	18.92	18.92		0.24	0.24	0.00
22-Aug	19.47	19.71	19.71	19.71		0.24	0.24	0.00
23-Aug	19.86	20.09	20.09	20.09		0.24	0.24	0.00
24-Aug	19.91	20.17	20.17	20.17		0.26	0.26	0.00
25-Aug	19.97	20.29	20.29	20.29		0.32	0.32	0.00
26-Aug	20.14	20.49	20.49	20.49		0.36	0.36	0.00
27-Aug	19.67	20.05	20.05	20.05		0.38	0.38	0.00
28-Aug	18.83	19.22	19.22	19.22		0.39	0.39	0.00
29-Aug	18.05	18.44	18.44	18.44		0.39	0.39	0.00
WAT Standard	18.20	18.20	18.20	18.20				
# of DM Exceedances	19	23	23	23				
Temperature (°C) on:								
21-Jun	23.61	24.03	24.03	24.03		0.42	0.42	0.00
22-Jun	23.97	24.47	24.47	24.47		0.50	0.50	0.00
23-Jun	27.15	28.15	28.15	28.15		1.00	1.00	0.00
24-Jun	29.89	31.98	31.98	31.98		2.09	2.09	0.00
25-Jun	30.33	32.22	32.22	32.22		1.89	1.89	0.00
26-Jun	26.41	26.50	26.50	26.50		0.09	0.09	0.00
27-Jun	23.25	26.66	26.66	26.66		3.41	3.41	0.00
28-Jun	23.93	26.01	26.01	26.01		2.08	2.08	0.00
29-Jun	26.39	28.38	28.38	28.38		1.99	1.99	0.00
30-Jun	27.45	29.79	29.79	29.79		2.34	2.34	0.00
1-Jul	28.41	29.29	29.29	29.29		0.88	0.88	0.00
2-Jul	29.50	30.23	30.23	30.23		0.73	0.73	0.00
3-Jul	26.99	27.93	27.93	27.93		0.94	0.94	0.00
4-Jul	23.97	24.68	24.68	24.68		0.71	0.71	0.00
7-Jul	24.58	25.00	25.00	25.00		0.42	0.42	0.00
9-Jul	23.80	24.17	24.17	24.17		0.37	0.37	0.00
10-Jul	25.69	26.09	26.09	26.09		0.40	0.40	0.00
11-Jul	23.81	24.23	24.23	24.23		0.42	0.42	0.00
10-Aug	24.39	24.44	24.44	24.44		0.05	0.05	0.00
11-Aug	23.64	23.84	23.84	23.84		0.20	0.20	0.00
20-Aug	23.79	23.93	23.93	23.93		0.14	0.14	0.00
21-Aug	24.89	24.96	24.96	24.96		0.07	0.07	0.00
22-Aug	24.71	25.06	25.06	25.06		0.35	0.35	0.00
DM Standard	23.80	23.80	23.80	23.80				

*Five of the WAT exceedances may not be fully realized under actual conditions because they are well within the model error. The days of interest are August 11, 18-20 and 29. For these days, EIS 345 and Alt 1a exceed the standard whereas EIS 285 does not. Yet the maximum difference in temperature is at most 0.39°C. Three of the DM exceedances may also not be fully realized. The days of interest are June 21, August 11 and August 20. In these days, EIS 345 and Alt 1a exceed the standard whereas EIS 285 does not, yet the maximum difference in temperature is at most 0.42°C.

Table A - 11. St. Louis Creek at the Fraser River confluence, 1963.

1963	St. Louis Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	1	1	1	1				
Temperature (°C) on:								
31-May	9.10	9.10	9.10	9.10		0.00	0.00	0.00
WAT Standard	9.00	9.00	9.00	9.00				
# of DM Exceedances	7	7	7	7				
Temperature (°C) on:								
16-May	14.36	14.36	14.36	14.36		0.00	0.00	0.00
17-May	13.29	13.28	13.28	13.28		-0.01	-0.01	0.00
19-May	14.29	14.28	14.28	14.28		-0.01	-0.01	0.00
25-May	13.65	13.64	13.64	13.64		-0.01	-0.01	0.00
26-May	13.31	13.31	13.31	13.31		0.00	0.00	0.00
27-May	14.12	14.12	14.12	14.12		0.00	0.00	0.00
28-May	13.89	13.89	13.89	13.89		0.00	0.00	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 12. Ranch Creek at the Fraser River confluence, 1963.

1963	Ranch Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	10	10	10	10				
Temperature (°C) on:								
22-May	10.15	10.15	10.15	10.15		0.00	0.00	0.00
23-May	9.82	9.82	9.82	9.82		0.00	0.00	0.00
24-May	9.69	9.69	9.69	9.69		0.00	0.00	0.00
25-May	9.70	9.70	9.70	9.70		0.00	0.00	0.00
26-May	9.64	9.64	9.64	9.64		0.00	0.00	0.00
27-May	9.70	9.70	9.70	9.70		0.00	0.00	0.00
28-May	9.76	9.76	9.76	9.76		0.00	0.00	0.00
29-May	9.82	9.82	9.82	9.82		0.00	0.00	0.00
30-May	9.99	9.99	9.99	9.99		0.00	0.00	0.00
31-May	10.07	10.07	10.07	10.07		0.00	0.00	0.00
WAT Standard	9.00	9.00	9.00	9.00				
# of DM Exceedances	13	13	13	13				
Temperature (°C) on:								
16-May	15.60	15.60	15.60	15.60		0.00	0.00	0.00
17-May	14.59	14.59	14.59	14.59		0.00	0.00	0.00
18-May	14.12	14.12	14.12	14.12		0.00	0.00	0.00
19-May	15.46	15.46	15.46	15.46		0.00	0.00	0.00
20-May	14.18	14.18	14.18	14.18		0.00	0.00	0.00
21-May	13.88	13.88	13.88	13.88		0.00	0.00	0.00
24-May	13.31	13.31	13.31	13.31		0.00	0.00	0.00
25-May	14.63	14.63	14.63	14.63		0.00	0.00	0.00
26-May	14.21	14.21	14.21	14.21		0.00	0.00	0.00
27-May	15.01	15.01	15.01	15.01		0.00	0.00	0.00
28-May	14.58	14.58	14.58	14.58		0.00	0.00	0.00
30-May	13.09	13.09	13.09	13.09		0.00	0.00	0.00
31-May	13.48	13.48	13.48	13.48		0.00	0.00	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 13. Fraser River at Rendezvous Bridge, 1978.

1978	Rendezvous Bridge					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	2	3	3	3				
Temperature (°C) on:								
4-Oct	12.41	13.79	13.79	13.79		1.38	1.38	0.00
5-Oct	13.09	14.73	14.73	14.73		1.64	1.64	0.00
6-Oct	13.56	15.39	15.39	15.39		1.83	1.83	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 14. Fraser River at the Colorado River confluence, 1978.*

1978	Colorado River Confluence					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	33	36	36	36				
Temperature (°C) on:								
25-Jul	18.19	18.45	18.45	18.45		0.26	0.26	0.00
26-Jul	18.41	18.69	18.69	18.69		0.29	0.29	0.00
27-Jul	18.54	18.84	18.84	18.84		0.30	0.30	0.00
28-Jul	18.51	18.84	18.84	18.84		0.33	0.33	0.00
29-Jul	18.45	18.80	18.80	18.80		0.34	0.34	0.00
30-Jul	18.47	18.82	18.82	18.82		0.35	0.35	0.00
31-Jul	18.48	18.83	18.83	18.83		0.35	0.35	0.00
1-Aug	18.40	18.76	18.76	18.76		0.36	0.36	0.00
2-Aug	18.46	18.80	18.80	18.80		0.33	0.33	0.00
3-Aug	18.53	18.84	18.84	18.84		0.31	0.31	0.00
4-Aug	18.66	18.95	18.95	18.95		0.29	0.29	0.00
5-Aug	18.63	18.91	18.91	18.91		0.28	0.28	0.00
6-Aug	18.22	18.50	18.50	18.50		0.28	0.28	0.00
10-Aug	17.79	18.22	18.22	18.22		0.43	0.43	0.00
11-Aug	18.24	18.69	18.69	18.69		0.45	0.45	0.00
12-Aug	18.72	19.17	19.17	19.17		0.45	0.45	0.00
13-Aug	19.38	19.82	19.82	19.82		0.44	0.44	0.00
14-Aug	19.97	20.39	20.39	20.39		0.42	0.42	0.00
15-Aug	19.98	20.37	20.37	20.37		0.39	0.39	0.00
16-Aug	19.65	20.01	20.01	20.01		0.36	0.36	0.00
17-Aug	19.28	19.62	19.62	19.62		0.34	0.34	0.00
18-Aug	19.01	19.33	19.33	19.33		0.32	0.32	0.00
19-Aug	18.75	19.06	19.06	19.06		0.31	0.31	0.00
20-Aug	18.62	18.94	18.94	18.94		0.33	0.33	0.00
21-Aug	18.97	19.34	19.34	19.34		0.37	0.37	0.00
22-Aug	19.72	20.12	20.12	20.12		0.40	0.40	0.00
23-Aug	20.13	20.54	20.54	20.54		0.41	0.41	0.00
24-Aug	20.22	20.65	20.65	20.65		0.43	0.43	0.00
25-Aug	20.36	20.85	20.85	20.85		0.49	0.49	0.00
26-Aug	20.61	21.15	21.15	21.15		0.54	0.54	0.00
27-Aug	20.25	20.77	20.77	20.77		0.52	0.52	0.00
28-Aug	19.50	20.01	20.01	20.01		0.51	0.51	0.00
29-Aug	18.82	19.32	19.32	19.32		0.50	0.50	0.00
30-Aug	18.47	18.99	18.99	18.99		0.52	0.52	0.00
31-Aug	18.28	18.78	18.78	18.78		0.50	0.50	0.00
1-Sep	17.86	18.30	18.30	18.30		0.44	0.44	0.00
WAT Standard	18.20	18.20	18.20	18.20				
# of DM Exceedances	8	12	12	12				
Temperature (°C) on:								
9-Aug	23.51	24.02	24.02	24.02		0.51	0.51	0.00
10-Aug	24.58	24.94	24.94	24.94		0.36	0.36	0.00
11-Aug	24.47	24.76	24.76	24.76		0.29	0.29	0.00
12-Aug	23.72	24.02	24.02	24.02		0.30	0.30	0.00
13-Aug	24.34	24.88	24.88	24.88		0.54	0.54	0.00
18-Aug	22.78	23.91	23.91	23.91		1.13	1.13	0.00
20-Aug	24.02	24.68	24.68	24.68		0.66	0.66	0.00
21-Aug	25.18	26.14	26.14	26.14		0.96	0.96	0.00
22-Aug	24.84	25.83	25.83	25.83		0.99	0.99	0.00
23-Aug	22.70	23.83	23.83	23.83		1.13	1.13	0.00
25-Aug	24.24	25.31	25.31	25.31		1.07	1.07	0.00
26-Aug	23.92	25.00	25.00	25.00		1.08	1.08	0.00
DM Standard	23.80	23.80	23.80	23.80				

*Three of the WAT exceedances may not be fully realized under actual conditions because they are well within the model error. The days of interest are July 25, August 10 and September 1. For these days, EIS 345 and Alt 1a exceed the standard whereas EIS 285 does not. Yet the maximum difference in temperature is at most 0.44°C. Two of the DM exceedances may also not be fully realized. The days of interest are August 9 and 12. In these days, EIS 345 and Alt 1a exceed the standard whereas EIS 285 does not, yet the maximum difference in temperature is 0.51°C.

Table A - 15. St. Louis Creek at the Fraser River confluence, 1978.

1978	St. Louis Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	2	2	2	2				
Temperature (°C) on:								
16-May	13.56	13.46	13.46	13.46		-0.10	-0.10	0.00
19-May	13.53	13.42	13.42	13.42		-0.11	-0.11	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 16. Ranch Creek at the Fraser River confluence, 1978.

1978	Ranch Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	4	4	4	4				
Temperature (°C) on:								
22-May	9.04	9.02	9.02	9.02		-0.02	-0.02	0.00
5-Oct	9.06	9.06	9.06	9.06		0.00	0.00	0.00
6-Oct	9.19	9.19	9.19	9.19		0.00	0.00	0.00
7-Oct	9.10	9.10	9.10	9.10		0.00	0.00	0.00
WAT Standard	9.00	9.00	9.00	9.00				
# of DM Exceedances	8	8	8	8				
Temperature (°C) on:								
16-May	14.63	14.60	14.60	14.60		-0.03	-0.03	0.00
18-May	13.16	13.16	13.16	13.16		0.00	0.00	0.00
19-May	14.67	14.64	14.64	14.64		-0.03	-0.03	0.00
20-May	13.43	13.40	13.40	13.40		-0.03	-0.03	0.00
3-Oct	13.32	13.32	13.32	13.32		0.00	0.00	0.00
4-Oct	13.85	13.85	13.85	13.85		0.00	0.00	0.00
5-Oct	13.09	13.09	13.09	13.09		0.00	0.00	0.00
6-Oct	13.05	13.05	13.05	13.05		0.00	0.00	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 17. Fraser River at Rendezvous Bridge, 1987.

1987	Rendezvous Bridge					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	2	3	7	7				
Temperature (°C) on:								
19-May	4.92	7.01	14.07	14.07		2.09	9.15	7.06
26-May	5.63	7.39	13.82	13.82		1.76	8.19	6.43
27-May	6.14	7.46	13.45	13.45		1.32	7.31	5.99
28-May	5.93	7.35	14.27	14.27		1.42	8.34	6.92
4-Oct	12.36	13.74	13.74	13.74		1.38	1.38	0.00
5-Oct	13.08	14.66	14.66	14.66		1.58	1.58	0.00
6-Oct	13.23	15.29	15.29	15.29		2.06	2.06	0.00
DM Standard	13.00	13.00	13.00	13.00				

Table A - 18. Fraser River at the Colorado River confluence, 1987.*

1987	Colorado River Confluence					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	49	56	50	50				
Temperature (°C) on:								
30-Jun	16.86	18.34	16.52	16.52		1.48	-0.34	-1.82
1-Jul	16.86	18.29	16.57	16.57		1.42	-0.29	-1.72
2-Jul	17.03	18.57	16.74	16.74		1.54	-0.29	-1.83
3-Jul	17.51	19.00	17.23	17.23		1.49	-0.28	-1.77
4-Jul	17.90	19.29	17.74	17.74		1.39	-0.16	-1.55
5-Jul	17.82	18.88	17.90	17.90		1.07	0.09	-0.98
6-Jul	17.88	18.29	18.26	18.26		0.41	0.38	-0.03
7-Jul	18.49	18.57	18.94	18.94		0.08	0.45	0.37
8-Jul	18.95	18.90	19.13	19.13		-0.05	0.19	0.24
9-Jul	19.49	19.30	19.29	19.29		-0.20	-0.20	-0.01
10-Jul	20.41	20.04	19.91	19.91		-0.37	-0.50	-0.13
11-Jul	21.18	20.67	20.54	20.54		-0.52	-0.64	-0.13
12-Jul	21.65	21.09	20.82	20.82		-0.57	-0.84	-0.27
13-Jul	21.53	21.08	20.56	20.56		-0.45	-0.96	-0.52
14-Jul	21.05	20.73	20.08	20.08		-0.32	-0.97	-0.65
15-Jul	20.93	20.69	20.02	20.02		-0.24	-0.91	-0.67
16-Jul	20.64	20.40	19.86	19.86		-0.24	-0.78	-0.54
17-Jul	19.78	19.62	19.15	19.15		-0.16	-0.63	-0.47
18-Jul	19.03	18.95	18.52	18.52		-0.08	-0.51	-0.43
19-Jul	18.77	18.75	18.39	18.39		-0.02	-0.38	-0.36
20-Jul	18.90	18.87	18.58	18.58		-0.03	-0.32	-0.29
21-Jul	18.97	18.92	18.70	18.70		-0.05	-0.27	-0.22
22-Jul	18.98	18.90	18.78	18.78		-0.09	-0.20	-0.11
23-Jul	19.11	18.99	18.95	18.95		-0.12	-0.15	-0.03
24-Jul	19.40	19.25	19.24	19.24		-0.16	-0.16	-0.01
25-Jul	19.63	19.43	19.43	19.43		-0.20	-0.20	0.00
26-Jul	19.63	19.40	19.41	19.41		-0.22	-0.22	0.00
27-Jul	19.55	19.30	19.31	19.31		-0.24	-0.24	0.01
28-Jul	19.29	19.09	19.09	19.09		-0.21	-0.20	0.00
29-Jul	19.03	18.86	18.87	18.87		-0.16	-0.16	0.00
30-Jul	18.84	18.72	18.73	18.73		-0.12	-0.11	0.00
31-Jul	18.61	18.53	18.53	18.53		-0.09	-0.08	0.01
1-Aug	18.41	18.37	18.37	18.37		-0.05	-0.04	0.00
2-Aug	18.42	18.39	18.39	18.39		-0.03	-0.03	0.00
3-Aug	18.46	18.44	18.44	18.44		-0.02	-0.02	0.00
4-Aug	18.60	18.57	18.57	18.57		-0.03	-0.03	0.00
5-Aug	18.55	18.52	18.52	18.52		-0.04	-0.04	0.00
11-Aug	18.21	18.21	18.21	18.21		0.00	0.00	0.00
12-Aug	18.67	18.65	18.65	18.65		-0.03	-0.03	0.00
13-Aug	19.31	19.25	19.25	19.25		-0.06	-0.06	0.00
14-Aug	19.91	19.81	19.81	19.81		-0.11	-0.10	0.00
15-Aug	19.98	19.85	19.85	19.85		-0.13	-0.13	0.00
16-Aug	19.72	19.59	19.59	19.59		-0.13	-0.13	0.00
17-Aug	19.37	19.25	19.25	19.25		-0.11	-0.11	0.00
18-Aug	19.09	18.99	18.99	18.99		-0.09	-0.09	0.00
19-Aug	18.85	18.75	18.76	18.76		-0.09	-0.09	0.00
20-Aug	18.76	18.67	18.67	18.67		-0.09	-0.09	0.00
21-Aug	19.14	19.05	19.05	19.05		-0.10	-0.10	0.00
22-Aug	19.86	19.74	19.74	19.74		-0.12	-0.12	0.00
23-Aug	20.19	20.05	20.05	20.05		-0.15	-0.15	0.00
24-Aug	20.21	20.06	20.06	20.06		-0.15	-0.15	0.00
25-Aug	20.22	20.08	20.08	20.08		-0.14	-0.14	0.00
26-Aug	20.34	20.21	20.21	20.21		-0.13	-0.13	0.00
27-Aug	19.87	19.76	19.76	19.76		-0.11	-0.11	0.00
28-Aug	19.05	18.96	18.96	18.96		-0.08	-0.08	0.00
29-Aug	18.29	18.24	18.24	18.24		-0.05	-0.05	0.00
WAT Standard	18.20	18.20	18.20	18.20				

Table A – 18 cont.

1987	Colorado River Confluence					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of DM Exceedances	11	13	10	10				
Temperature (°C) on:								
28-Jun	20.69	23.91	18.55	18.55		3.22	-2.14	-5.36
29-Jun	20.92	26.69	18.85	18.85		5.77	-2.07	-7.84
7-Jul	26.34	25.26	24.80	24.80		-1.08	-1.54	-0.46
8-Jul	23.57	23.81	21.63	21.63		0.24	-1.94	-2.18
9-Jul	27.52	29.21	25.23	25.23		1.69	-2.29	-3.98
10-Jul	29.35	29.86	28.62	28.62		0.51	-0.73	-1.24
11-Jul	27.34	27.89	27.21	27.21		0.55	-0.13	-0.68
24-Jul	23.90	23.51	23.51	23.51		-0.39	-0.39	0.00
10-Aug	24.55	24.22	24.22	24.22		-0.33	-0.33	0.00
11-Aug	24.49	24.12	24.12	24.12		-0.37	-0.37	0.00
13-Aug	24.07	23.90	23.90	23.90		-0.17	-0.17	0.00
20-Aug	24.22	23.97	23.97	23.97		-0.25	-0.25	0.00
21-Aug	25.24	24.89	24.89	24.89		-0.35	-0.35	0.00
22-Aug	24.90	24.65	24.65	24.65		-0.25	-0.25	0.00
DM Standard	23.80	23.80	23.80	23.80				

*One of the WAT exceedances may not be fully realized under actual conditions because it is well within the model error. The day of interest is July 6. For this day, EIS 345 and Alt 1a exceed the standard whereas EIS 285 does not. Yet the maximum difference in temperature is 0.41°C. Two of the DM exceedances may also not be fully realized. The days of interest are July 8 and 24. On July 8, EIS 345 exceeds the standard by only 0.01°C. On July 24, EIS 285 exceeds the standard whereas EIS 345 and Alt 1a do not, yet the difference in temperature is 0.39°C.

Table A - 19. St. Louis Creek at the Fraser River confluence, 1987.

1987	St. Louis Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	0	0				
# of DM Exceedances	1	0	5	5				
Temperature (°C) on:								
16-May	13.94	11.47	13.94	13.94		-2.47	0.00	2.47
19-May	11.53	11.53	13.90	13.90		0.00	2.37	2.37
26-May	11.19	11.18	13.04	13.04		-0.01	1.85	1.86
27-May	12.44	12.43	13.90	13.90		-0.01	1.46	1.47
28-May	12.28	12.28	13.67	13.67		0.00	1.39	1.39
DM Standard	13.00	13.00	13.00	13.00				

Table A - 20. Ranch Creek at the Fraser River confluence, 1987.

1987	Ranch Creek					Change in Temp. Between:		
	EIS 285	EIS 345	Alt 1a	Alt 8a		285 & 345	285 & Alt 1a	345 & Alt 1a
# of WAT Exceedances	0	0	5	5				
Temperature (°C) on:								
22-May	7.50	7.31	9.25	9.25		-0.19	1.75	1.94
28-May	7.10	7.10	9.11	9.11		0.00	2.01	2.01
29-May	7.20	7.20	9.20	9.20		0.00	2.00	2.01
30-May	7.44	7.44	9.40	9.40		0.00	1.96	1.96
31-May	7.59	7.59	9.51	9.51		0.00	1.92	1.92
WAT Standard	9.00	9.00	9.00	9.00				
# of DM Exceedances	3	2	11	11				
Temperature (°C) on:								
16-May	14.11	12.98	14.88	14.88		-1.13	0.77	1.90
17-May	12.08	11.90	13.80	13.80		-0.18	1.72	1.90
18-May	11.74	11.73	13.62	13.62		-0.01	1.88	1.89
19-May	12.66	12.66	14.56	14.56		0.00	1.90	1.90
25-May	11.99	11.99	14.03	14.03		0.00	2.04	2.04
26-May	11.44	11.44	13.41	13.41		0.00	1.97	1.97
27-May	12.29	12.29	14.29	14.29		0.00	2.00	2.00
28-May	12.15	12.15	14.11	14.11		0.00	1.96	1.96
31-May	11.36	11.36	13.14	13.14		0.00	1.78	1.78
1-Oct	13.12	13.12	13.12	13.12		0.00	0.00	0.00
4-Oct	13.67	13.67	13.67	13.67		0.00	0.00	0.00
DM Standard	13.00	13.00	13.00	13.00				

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Appendix B3 – Antidegradation Review for Temperature Impacts

Final Report

Antidegradation Review for Temperature Impacts on the Fraser River

Moffat Collection System Project

Section 401 Certification Review

Prepared by:

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February 11, 2015

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EXECUTIVE SUMMARY

The Moffat Collection System Project (Moffat Project or Project) is a water supply project proposed by Denver Water to develop 18,000 acre-feet per year (AF/yr) of new firm yield for its customers. Denver Water proposes to enlarge its existing Gross Reservoir by 72,000 AF to a total storage capacity of 113,811 AF. Water from the Fraser River, Williams Fork River and South Boulder Creek would be diverted and delivered during average and wet years via the Moffat Tunnel and South Boulder Creek to Gross Reservoir. There would be no additional diversions in dry years associated with the Moffat Project because Denver Water already can divert the maximum amount physically and legally available with its existing water rights and facilities.

In the Fraser River basin, two reaches are currently on the State of Colorado's Section 303(d) List of Impaired Waters for water temperature: the mainstem Fraser River downstream of the Hammond Ditch to the Colorado River and Ranch Creek. Further reductions in flow associated with the Moffat Project could cause or contribute to additional exceedances of temperature standards. To support the Section 401 Certification review for the Moffat Project, a dynamic water temperature model for the Fraser River was subsequently developed that simulated hourly water temperatures under different flow years and scenarios (Miller Ecological Consultants, Inc. 2015a).

An antidegradation review was completed for the Moffat Project to evaluate the potential for the cumulative effects of flow reduction to cause significant temperature impacts in the Fraser River, defined as a loss of more than 15% of the assimilative capacity. River temperatures simulated from the Fraser River dynamic water temperature model were used to calculate the Daily Maximum (DM), a metric used for the acute temperature standard, and the Weekly Average Temperature (WAT), a metric used for the chronic temperature standard. Five scenario years (1948, 1959, 1963, 1978 and 1987) were evaluated from mid-May to mid-October. The years were selected because for some months they represent the critical conditions under which cumulative flow effects are greatest and temperature impacts are most likely to occur as defined by CDPHE. Critical conditions were characterized as months in which the flow reduction from current conditions (EIS 285) to future, cumulative effects with the Moffat Project (Alt 1a) was greater than 10% and Alt 1a flows were less than the median of the 45-year dataset for that month. The review focused on two locations on the mainstem Fraser River: at Rendezvous Bridge, in which the Tier I temperature standard is applicable, and below the Granby Sanitation District, where the Tier II standard is applied.

DMs and WATs were assessed against an assimilative capacity threshold that was produced according to a methodology developed collaboratively with CDPHE. Predicted increases in temperature that exceeded 15% of assimilative capacity were tallied as "excursions" and are considered to have a potentially significant impact on water quality. To understand when Moffat Project operations would potentially contribute to the excursions, excursion counts for EIS 345 (cumulative conditions without the Moffat Project in operation) and Alt 1a (cumulative conditions with the Moffat Project) were compared.

The modeling results for the five scenario years indicate that increases in water temperature in excess of the 15% available assimilative capacity will occur in the future under cumulative conditions at both locations in the Fraser River. The focus of the antidegradation review is on cumulative effects, but the review was also used to understand the Moffat Project's contribution to the simulated temperature increases.

- At Rendezvous Bridge, DM and WAT excursions occur in all months (June through September) in all five years. The number of days simulated to have stream temperature increases greater than 15% of the assimilative capacity ranged from 38 to 103 days for DMs and 13 to 94 days for WATs (out of the 122 days between June 1 through September 30), depending on the year. The Moffat Project would contribute to only a small portion of the DM and WAT excursions, primarily in June and to a very limited extent in July for WAT excursions. The increases in temperature resulting in excursions do not result in exceedances of the DM or WAT standards, except for 5 days above the DM standard for the 1963 simulation (2% of the time). There were no days above the WAT standard in any of the five years.

- Further downstream below the Granby Sanitation District, DM and WAT excursions occur in May through August, but much less frequently than upstream at Rendezvous Bridge. The number of days simulated to have stream temperature increases greater than 15% of the assimilative capacity ranged from 9 to 24 days for DMs and 15 to 59 days for WATs (out of the 153 days between May 16 through October 15), depending on the year. The Moffat Project would contribute to only a small portion of the DM and WAT excursions, primarily in May and June and to a very limited extent in July. The increases in temperature resulting in excursions that would also result in exceedances of the temperature standards would occur 1% of the time for DM and 4% of the time for WAT standards.

The five scenario years were selected from a 45-year dataset. To provide context for these years, the results were extrapolated to the 45-year dataset to understand the likelihood of the temperature excursions predicted in the five years occurring in the future. The following tables summarize the findings.

Excursions Generalized to the 45-Year Study Period
Fraser River at Rendezvous Bridge
June through September

Conditions	DM Threshold Exceeded	WAT Threshold Exceeded
Cumulative Conditions	43% of time	28% of time
Attributable to the Moffat Project	0.9% of time	2% of time

Excursions Generalized to the 45-Year Study Period
Fraser River below Granby Sanitation District
Mid-May through mid-October

Conditions	DM Threshold Exceeded	WAT Threshold Exceeded
Cumulative Conditions	5% of time	12% of time
Attributable to the Moffat Project	1% of time	1% of time

Denver Water has made mitigation and enhancement commitments to address stream temperature problems. These commitments include additional real-time monitoring in the Fraser River, Ranch Creek and Colorado River, operational responses such as bypass of up to 250 acre-feet of water and additional environmental protection measures to restore and enhance the aquatic environment in Grand County.

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INTRODUCTION

The Moffat Collection System Project (herein referred to as the Moffat Project or Project) is a water supply project proposed by Denver Water to develop 18,000 acre-feet per year (AF/yr) of new firm yield for its customers. Denver Water proposes to enlarge its existing Gross Reservoir by 72,000 AF to a total storage capacity of 113,811 AF. Water from the Fraser River, Williams Fork River and South Boulder Creek would be diverted and delivered during average and wet years via the Moffat Tunnel and South Boulder Creek to Gross Reservoir. There would be no additional diversions in dry years because Denver Water already can divert the maximum amount physically and legally available with its existing water rights and facilities.

Concerns were raised by Colorado Department of Public Health and Environment (CDPHE) and U.S. Environmental Protection Agency (EPA) during their review of the Preliminary Final EIS that segments of the Fraser River basin are currently listed as impaired for temperature. In the Fraser River basin, two reaches are currently on the State of Colorado's Section 303(d) List of Impaired Waters: the mainstem Fraser River downstream of the Hammond Ditch to the Colorado River and Ranch Creek. St. Louis Creek has had some temperature exceedances but is not currently on the 303(d) list. Further reductions in flow associated with the Moffat Project could cause or contribute to additional exceedances of temperature standards. Both CDPHE and EPA recommended developing a dynamic (mechanistic) model that could predict daily stream temperatures under a range of flow conditions to evaluate the cumulative and Project-related effects. A dynamic water temperature model for the Fraser River was subsequently developed that simulated hourly water temperatures under different flow years and scenarios (Miller Ecological Consultants, Inc. 2015a). Key components of the model are summarized below.

Streamflow Conditions: The objective of modeling water temperature in the Fraser River was to assess the potential effects of four streamflow scenarios for the Moffat Project. The four streamflow scenarios are:

- EIS 285 – Current Conditions - Streamflow conditions associated with Denver Water's existing system and an average demand of 285,000 acre-feet per year (AF/yr).
- EIS 345 – Full Use of the Existing System - Future streamflow conditions associated with Denver Water's existing system and Denver Water's demand has grown to an average of 345,000 AF/yr, plus other reasonably foreseeable future actions (RFFAs) are assumed to have occurred.
- Alternative 1a (Alt 1a) – Cumulative Effects with Moffat Project - Future streamflow conditions associated with Denver Water's proposed 72,000-AF enlargement of Gross Reservoir, a future average demand of 363,000 AF/yr and the same RFFAs assumed in EIS 345. The only differences between Alt 1a and EIS 345 are the proposed increase in reservoir storage and an increase in demand of 18,000 AF/yr.
- Alternative 8a (Alt 8a) – Cumulative Effects with Smaller Gross Reservoir Enlargement - Future streamflow conditions associated with a proposed 52,000-AF enlargement of Gross Reservoir,

5,000 AF of storage in gravel pits along the South Platte River, a future average demand of 363,000 AF/yr and the same RFFAs assumed in EIS 345. The only difference between Alt 1a and Alt 8a is a smaller reservoir expansion and slightly less diversion from the West Slope through the Moffat Tunnel.

Scenario Years: The temperature model simulated hourly temperatures for the five years and months proposed by CDPHE: May 16 to October 15 of 1948, 1959, 1963, 1978 and 1987. These years were selected because they represent the critical conditions under which cumulative flow effects are greatest and temperature impacts are most likely to occur. These months were selected because these are the months when temperature exceedances have occurred in the Fraser River basin.

Geographic Extent: The Fraser River was modeled from downstream of the Winter Park Water and Sanitation District to the Colorado River confluence (Figure 1). The modeling results focused on three locations on the mainstem:

- Fraser River below Vasquez Creek at Rendezvous Bridge
- Fraser River downstream of Crooked Creek
- Fraser River at the Colorado River confluence

Meteorological Data: Data from 2007 were used for each model simulation because 2007 was one of the warmest years in 63 years of temperature record (1948-2010). As air temperature is an important factor influencing river temperatures, using 2007 meteorological data, combined with the five selected years, may have caused the model to overestimate the temperatures, and therefore the impacts, of the various scenarios.

State Water Temperature Standards: CDPHE's Water Quality Control Division has established the following acute and chronic water temperature criteria for the Fraser River to protect against negative effects to aquatic life:

		Temperature Standard (°C)		
Stream Classification	**Applicable Months**	**Weekly Average Temp. (WAT) (Chronic)**	**Daily Maximum (DM) (Acute)**	**Location on Fraser River Where Applied**
Cold Stream Tier I	June – Sept.	17.0	21.7	Rendezvous Bridge
	Oct. - May	9.0	13.0	
Cold Stream Tier II	April – Oct.	18.2	23.8	Below Granby Sanitation District
	Nov. - March	9.0	13.0	

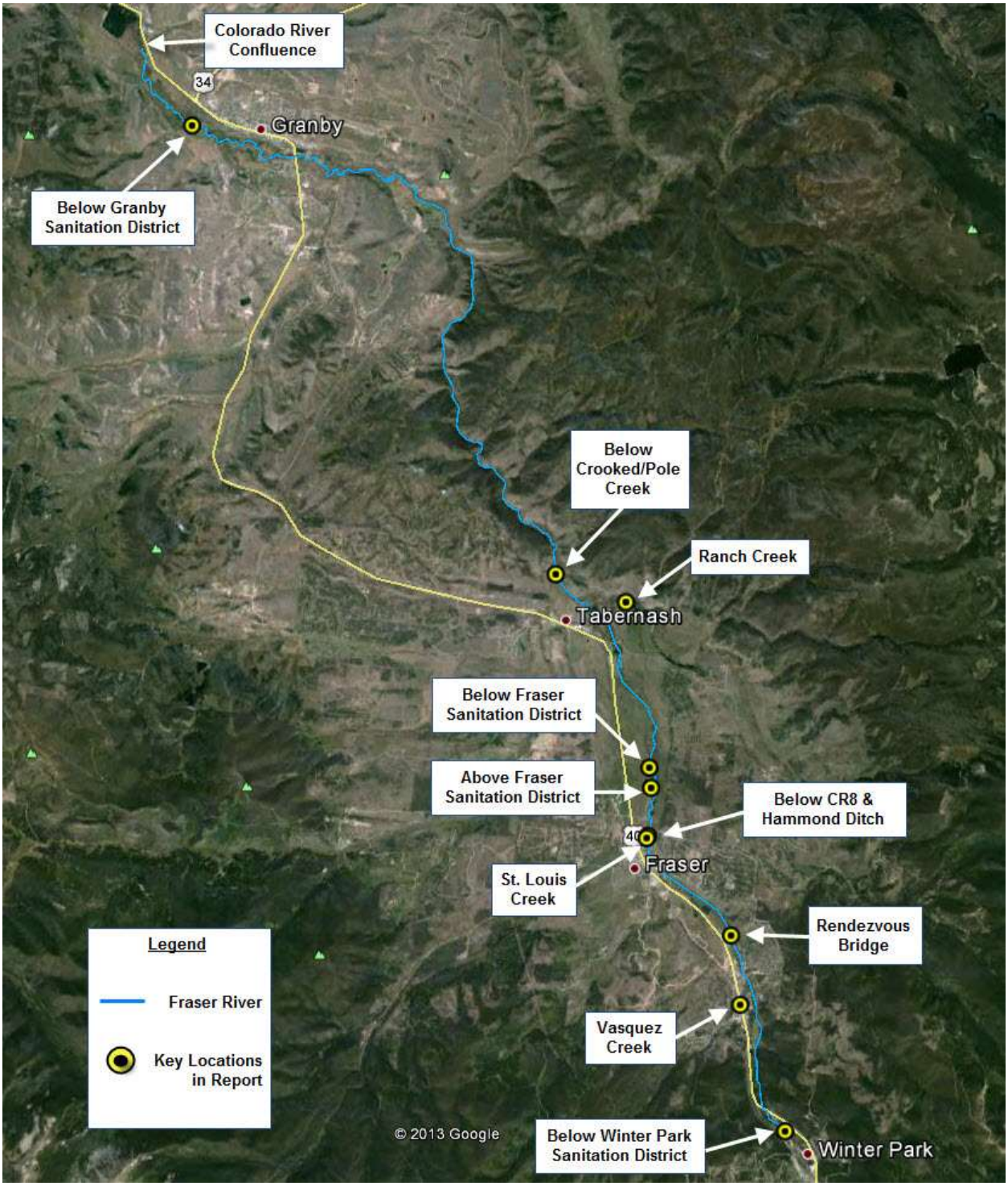

Figure 1. Fraser River study area.

For water projects that require 401 certification, such as the Moffat Project, CDPHE's Water Quality Control Division must evaluate cumulative impacts to water quality and the evaluation includes antidegradation review. The purpose of an antidegradation review is to assess the cumulative effects of flow reduction and its impact on temperature in the Fraser River. The significance of the temperature impacts depends on the extent to which the cumulative flow reductions will result in a loss of assimilative capacity (CDPHE 2014b). Simulated temperatures from the Fraser River dynamic water temperature model were used to assess antidegradation for 401 certification.

Characterization of Scenario Years and Extrapolation to the 45-Year Dataset

The five scenario years chosen to evaluate the potential for significant temperature impacts (1948, 1959, 1963, 1978 and 1987) were selected from a 45-year dataset. These years were selected because CDPHE determined that they represent the critical conditions under which cumulative flow effects are greatest and temperature impacts are most likely to occur. For that reason, it is important to contextualize the five selected years relative to the 45-year dataset to assess the likelihood of the temperature impacts predicted in these five years occurring in the future (both cumulative and Project-related). CDPHE developed two criteria for characterizing critical conditions (CDPHE 2014b). The following paragraphs describe the criteria and how they were used to characterize the scenario years (specifically, certain months within those years).

The first criterion was based on the assumption that cumulative impacts are most likely to be evident when flows are reduced by a large amount relative to current conditions (i.e., a large percent reduction in flow). For the Moffat Project, this change in flow is the difference between Alt 1a and EIS 285. Changes in flow were evaluated on a monthly basis, using PACSM data for the Fraser River below Crooked Creek. It was assumed that conditions in the Fraser River below Crooked Creek are representative of the river in general because it includes effects of all Denver Water operations. As is typical for snowmelt-driven streams, flows are high in June and decline to near base levels in September. Concordantly, most of the additional flow taken under Alt 1a occurs in June and July, when flows are highest (Figure 2). Further comparing the changes in flow on a monthly basis, a large flow reduction would be at least 10% (Table 1). Therefore, the first criterion for characterizing critical conditions was months in which the reduction in flow was greater than 10%. Figure 3 and Figure 4 display the monthly reduction in flow versus EIS 285 flows. For each month except October, at least two of the scenario years meet the criterion. In no months do all five years meet the criterion.

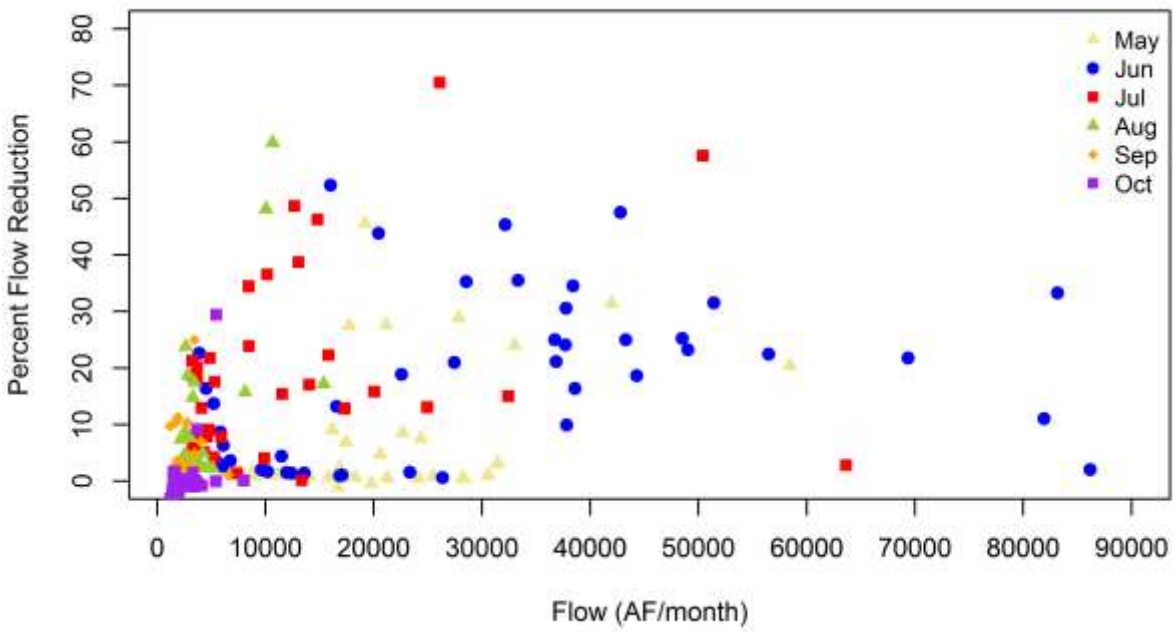

Figure 2. Percent flow reduction calculated for Alt 1a, relative to EIS 285, vs. monthly flow for EIS 285, Fraser River below Crooked Creek. Data are from PACSM output for WY1947-1991.

Table 1. Distribution of relative flow reductions in May through October for WY1947-1991.

Flow Reduction	May	June	July	August	September	October
<10%	38	17	23	37	41	44
10-20%	0	8	10	5	3	0
20-30%	5	10	5	1	1	1
30-40%	1	6	3	0	0	0
40-50%	1	3	2	1	0	0
>50%	0	1	2	1	0	0

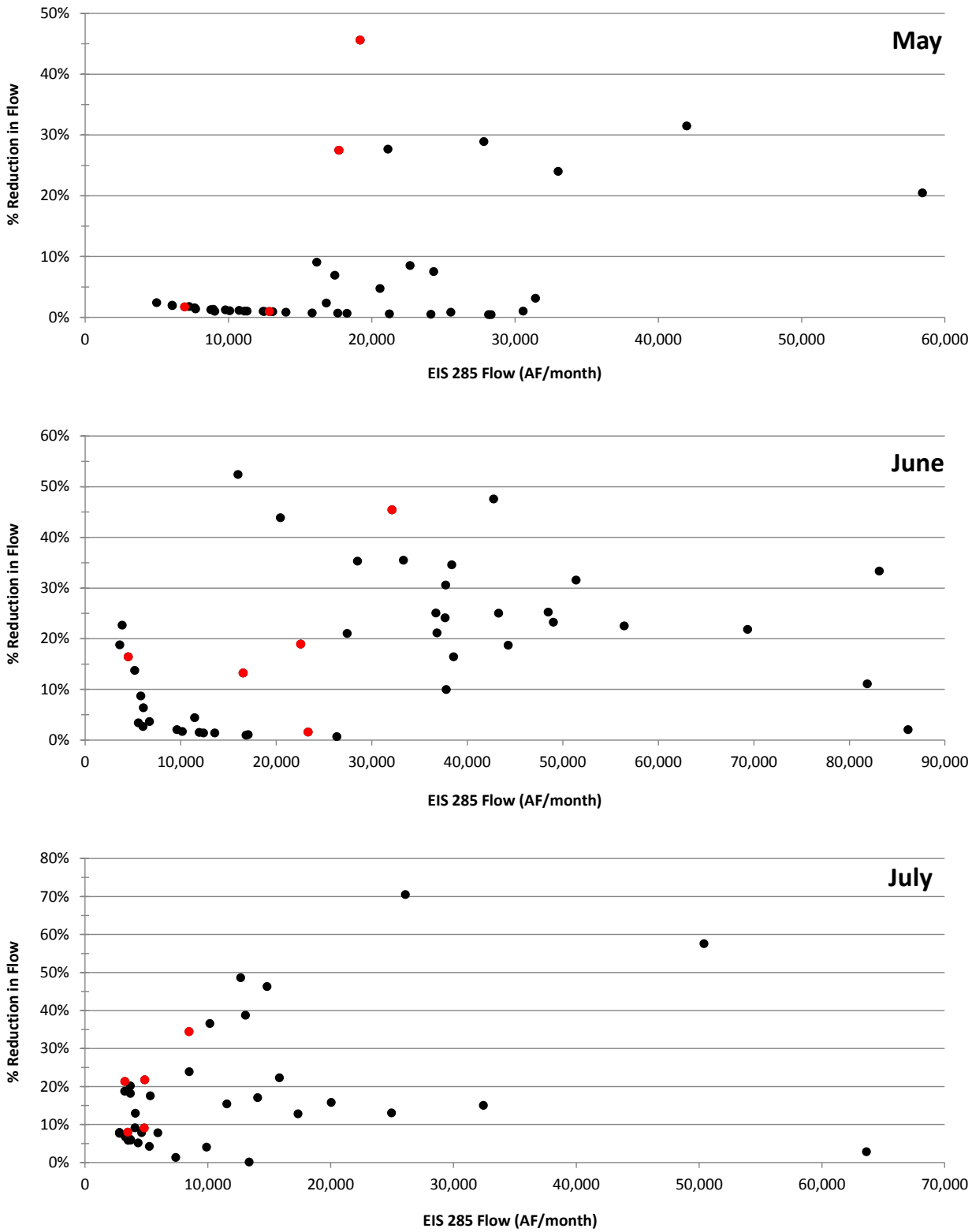

Figure 3. Percent reduction in flow vs. EIS 285 flows for May, June and July for the 45-year dataset. Scenario years are highlighted in red.

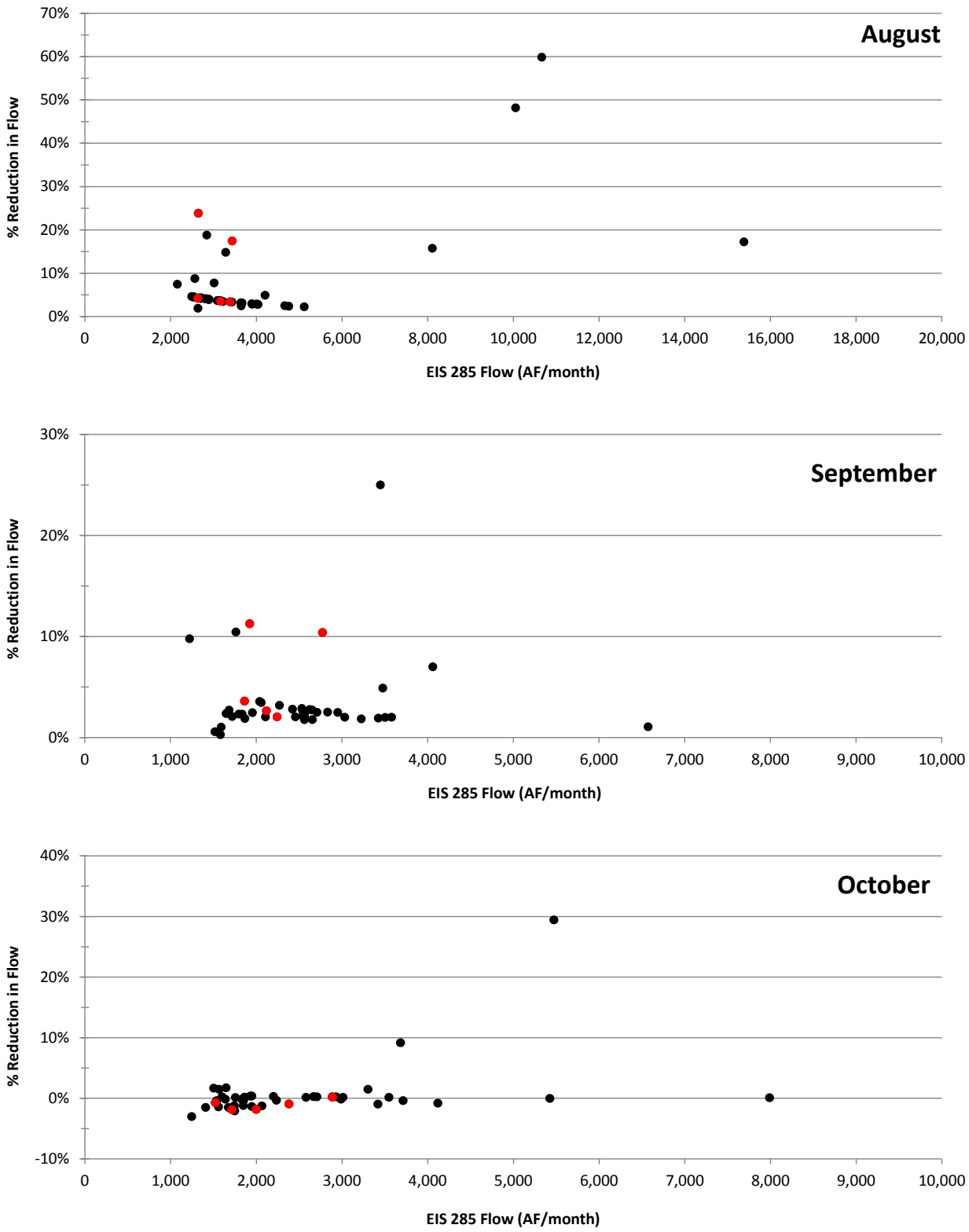

Figure 4. Percent reduction in flow vs. EIS 285 flows for August, September and October for the 45-year dataset. Scenario years are highlighted in red.

The second criterion, which is applied in tandem with the first criterion, is that the remaining flow (i.e., Alt 1a flows) should be low. The rationale for this criterion is that a water mass with less depth moves more slowly, resulting in more warming during the day. As a consequence, average temperatures could increase and the DM would also increase. Comparing Alt 1a flows on a monthly basis, there is a lot of variability in flow for May and June (Table 2). From July through October, flows tend to be less than 10,000 acre-feet (AF) per month. A fixed threshold for determining low flows therefore did not seem appropriate. Instead, the second criterion for characterizing critical conditions was months in which Alt 1a flows were less than the median of the 45-year dataset. Alt 1a flows for each month are displayed graphically in Figure 5 and Figure 6. For each month, at least two of the scenario years meet the criterion. In no months do all five years meet the criterion.

For each month, only a few years from the entire dataset met both criteria (Table 3). Specifically, in May and September, 2 years out of 45 met the criteria (4.4%). In June, 9 years out of 45 met the criteria (20%). In July, 7 years out of 45 met the criteria (15.6%). In August, 4 years out of 45 met the criteria (8.9%). Finally, in October, no years met the criteria.

The five scenario years met both criteria for at least two of the six months in which temperatures were simulated. For 1948 and 1987, the criteria were met in May and June. For 1959, the criteria were met in June and July. For 1963, the criteria were met in June, July and August. Finally, for 1978, the criteria were met in August and September. None of the five years represented critical conditions in October. Thus, in combination, the scenario years may serve to represent critical conditions as defined by CDPHE, yet no single year is representative of critical conditions for the entire six-month focus period. In total, 11 months out of the 30 months that were evaluated (6 months x 5 years) met both criteria.

Table 2. Alt 1a flows from May through October based on PACSM output for WY1947-1991.

Flow (AF/month)	May	June	July	August	September	October
<5000	1	4	22	41	44	43
5000-10000	11	7	13	3	1	2
10000-15000	11	7	3	1	0	0
15000-20000	10	5	3	0	0	0
20000-30000	9	10	3	0	0	0
>30000	3	12	1	0	0	0

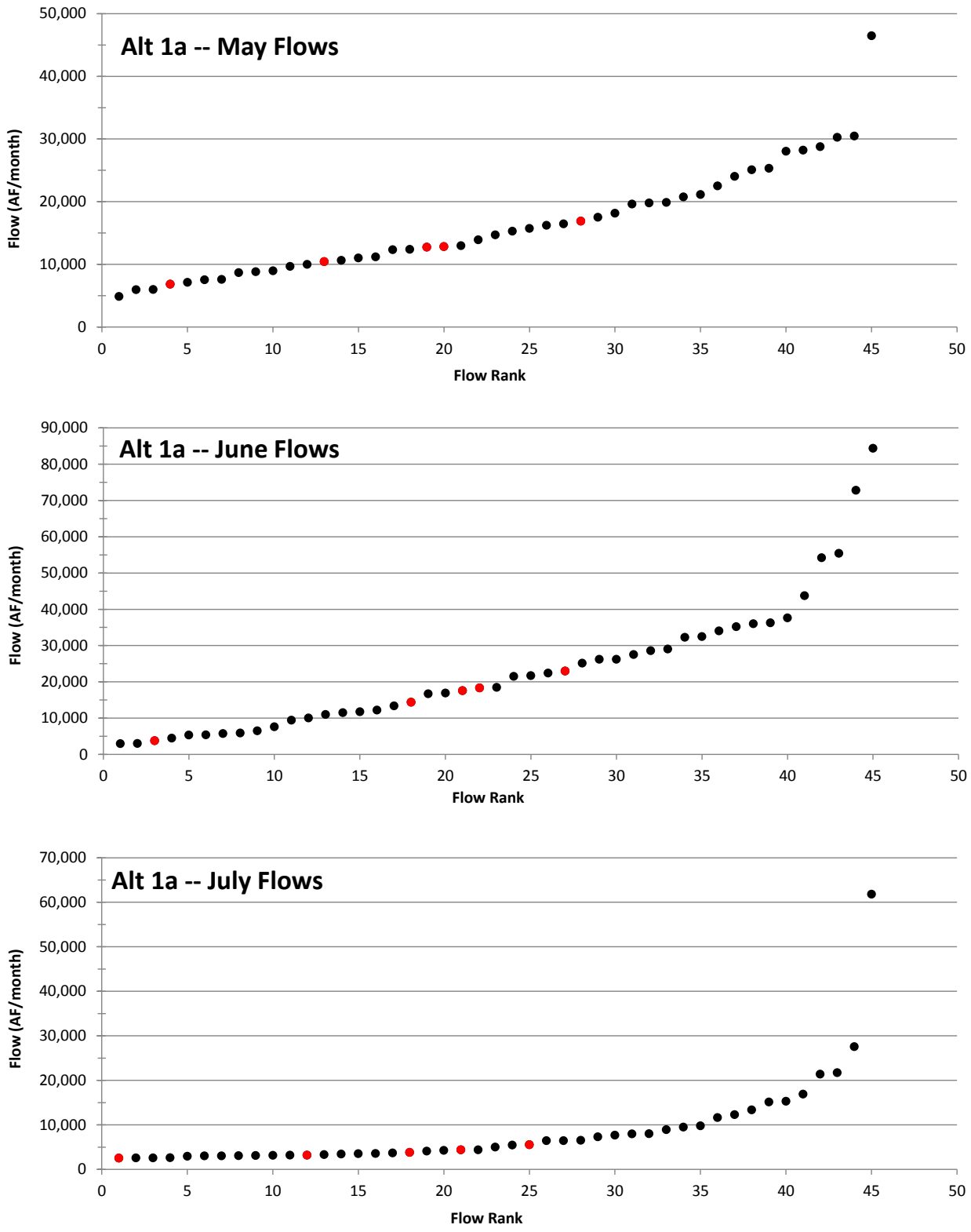

Figure 5. May, June and July Alt 1a flows for the 45-year dataset. Scenario years are highlighted in red.

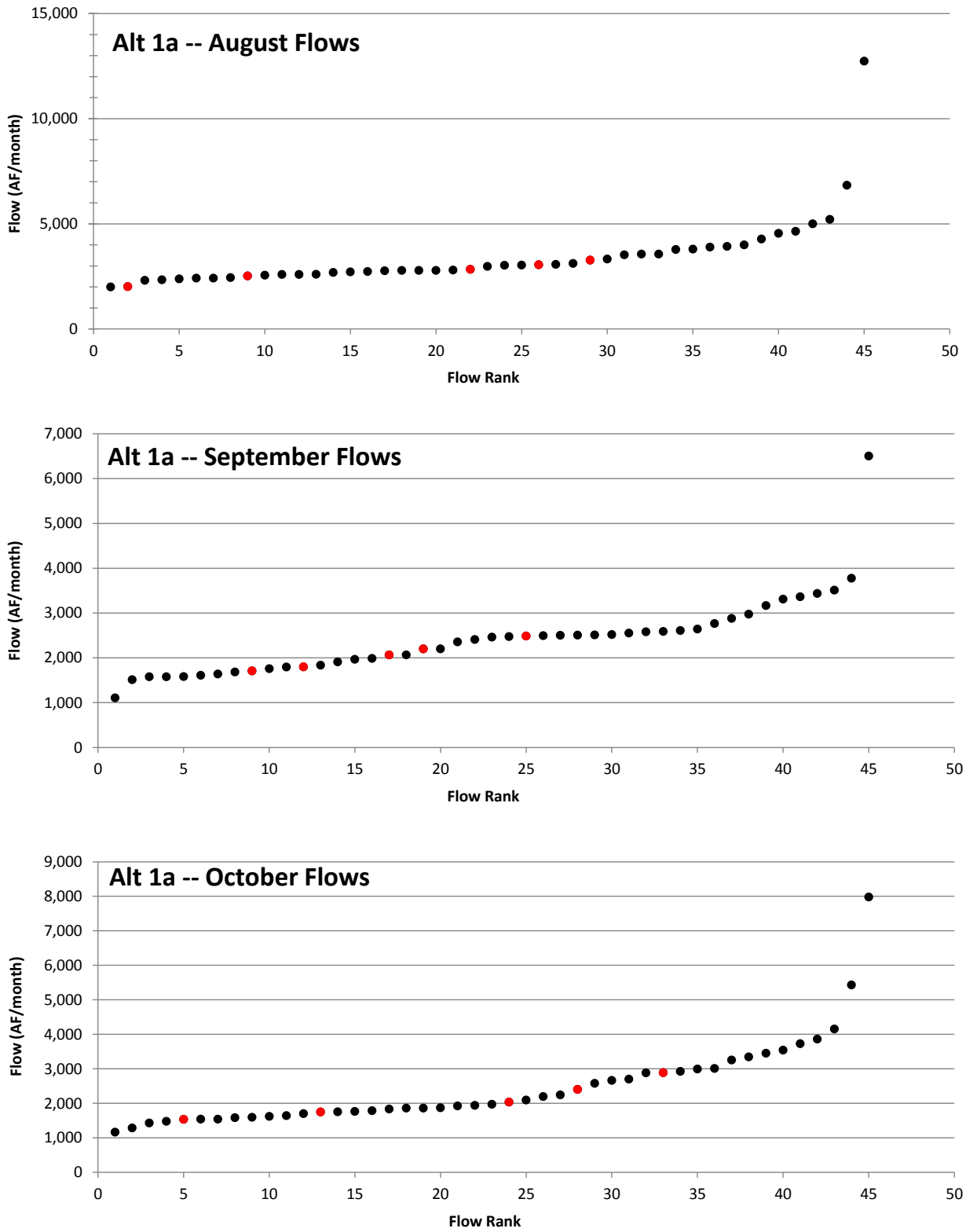

Figure 6. August, September and October Alt 1a flows for the 45-year dataset. Scenario years are highlighted in red.

Table 3. Count of years in which operation of Alt 1a causes a large percent reduction in monthly flow and Alt 1a flows are less than the median of the 45-year dataset for that month.

Month	Flow Reduction >=10%	Flow Reduction <10%	Median Alt 1a Flow (AF/month)	Years with Flow Reduction >=10% and Alt 1a Flow < Median
May	7	38	14704	2
June	28	17	18456	9
July	22	23	5015	7
August	8	37	2976	4
September	4	41	2462	2
October	1	44	1974	0

METHODS

Antidegradation review is comprised of the following analyses. The methodology was developed collaboratively with CDPHE (CDPHE 2013, 2014a and 2014b). More detail about the specific steps taken for each location can be found in the results section.

1) **Development of historical (observed) baseline conditions** based on historical temperature data. Historical baseline conditions were determined according to a methodology provided by CDPHE (2013). For each location, all available temperature data were compiled and the typical assessment metrics, the Daily Maximum (DM) and the Weekly Average Temperature (WAT), were calculated.[1] DMs and WATs were calculated with the CDPHE Temperature Analysis Program macro. Following the assessment methodology, the highest DM and WAT values were discarded on each ordinal day, as long as at least 3 years of data were available for that day. The result is a single DM and WAT value for each ordinal day. These DMs and WATs were then smoothed, eliminating day-to-day variability. The smoothed values are defined as the baseline.

2) **Development of current (modeled) baseline conditions** based on current conditions (EIS 285) temperatures simulated from the Fraser River water temperature model.

3) **Comparison of the baselines.** The two baselines are compared to determine which baseline is most appropriate for the antidegradation review. The historical baseline serves as a basis for qualitatively determining whether the modeled current conditions for each flow scenario year are representative of

[1] The Daily Maximum (DM) is defined by the Colorado WQCC as the highest 2-hour average water temperature. The DM is used for the acute standard with the exclusion of values concurrent with maximum daily air temperatures greater than the 90th percentile of historical daily temperature. The Weekly Average Temperature (WAT) is defined by the WQCC as the mathematical mean of multiple evenly-spaced daily temperatures over a 7-day consecutive period, with a minimum of three data points spaced evenly through the day. The WAT is used for the chronic standard with exclusion of values concurrent with maximum daily air temperatures greater than the 90th percentile of historical monthly temperature.

the historical baseline (CDPHE 2014a). For the locations that were assessed, the current (modeled) baseline was used for the antidegradation review.

4) **Development of the baseline available increment (BAI).** The remaining assimilative capacity, defined as the baseline available increment (BAI), is then calculated, which is the difference between the DM and WAT temperature standards and the baseline temperatures. If a predicted increase in temperature exceeds 15% of the BAI, then antidegradation review is necessary and the potential water quality impacts are considered significant.

5) **Development and evaluation of results.** The purpose of the antidegradation review is to evaluate the potential for cumulative effects of flow reduction to cause significant temperature impacts, defined as a loss of more than 15% of the assimilative capacity. Once baseline conditions and thresholds were established, stream temperatures predicted from the Fraser River water temperature model were compared to the BAI thresholds. Specifically, the changes in temperature between flow scenarios EIS 345, Alt 1a and Alt 8a to current conditions (EIS 285) were compared to the assimilative capacity thresholds. Results are presented as follows:

- Excursions – The number of days the simulated *cumulative* stream temperatures (Alt 1a) exceed the BAI threshold for DMs and WATs is counted. To understand when the Moffat Project is operating and potentially contributing to the excursions, the differences in excursion counts between EIS 345 and Alt 1a are also presented.

- Exceedances – The number of days the simulated *cumulative* stream temperatures (Alt 1a) exceed the DM and WAT standard. Similar to above, the exceedances attributable to Moffat Project diversions are also presented. The summary of exceedances gives further context as to when excursions of the assimilative capacity threshold occur.

These specific results are simulated for the five scenario years, 1948, 1959, 1963, 1978 and 1987. To provide a broader perspective regarding the likelihood of impacts occurring in the future (both cumulative and Project-related), the results from the scenario years are extrapolated to the 45-year dataset.

Antidegradation Assessment Locations: For the Moffat Project, it was decided to evaluate temperature impacts at two locations on the Fraser River: at Rendezvous Bridge, the downstream boundary of the Tier I temperature standard designation, and below the Granby Sanitation District (Tier II temperature standard at this location), approximately two miles upstream of the confluence with the Colorado River. The Rendezvous Bridge location is the same location that was a focus of the dynamic water temperature model report (Miller Ecological Consultants, Inc. 2015a). The location below the Granby Sanitation District was chosen because it was the closest location to the Colorado River confluence that had historical (observed) data. Note that this was not a focus location in the dynamic temperature model report.

RESULTS

Fraser River at Rendezvous Bridge

Development of Baseline Conditions

For the Fraser River at Rendezvous Bridge, 15-minute water temperature data were available from 2008 through 2013, although none of the years had a complete record of data from May 16 to October 15. First, DMs and WATs were calculated with the CDPHE Temperature Analysis Program macro. Any days that were missing more than 4 hours of temperature data were removed from further analysis. Following the assessment methodology, the highest DM and WAT were discarded on each ordinal day, as long as at least three years of data were available for that day. The single DM value for each day is shown in Figure 7. Missing data from 2012 influenced the DM values from June 25 to July 11, which were colder than expected. 2012 was a warm year for water temperature and was often the highest DM that was subsequently discarded. But for the data missing from June 25 to July 11, 2013 had the warmest DMs which were then discarded, leaving a much cooler DM to be used for the missing days (Figure 8). We felt that it was important to keep in the 2012 data, yet the missing data skewed the results since 2012 was a warm year. We decided to fill in the missing data for 2012 using the nearest downstream temperature logger from Rendezvous Bridge (at County Road 804) to estimate temperatures. We compared temperatures at the two locations for the week preceding the missing data and the week after the missing data and there were consistent differences in temperature from hour to hour. For example, during the warmest times of the day, temperatures at County Road 804 were about 2°C warmer than those at Rendezvous Bridge. During the coolest times of the day, temperatures at County Road 804 were about 1°C warmer. To fill in the missing data at Rendezvous Bridge, we then offset the temperatures from County Road 804 by approximately 1-2°C, depending on the time of day.

After filling in the missing data for 2012, we re-ran the temperature macro to calculate DMs and WATs. The highest DM and WAT for each day were then discarded as before. The revised single DM value for each day is shown in Figure 9.

A second anomaly with the data were the DM temperatures that were calculated prior to May 26. Several of these temperatures seemed warmer than normal for that time of year. For these days, only 2012 data were available (Figure 8). Knowing that 2012 was a warm year, these temperatures were likely warmer than one would expect for a more average year. Because of this lack of a complete data set, we eliminated all days prior to May 26 from further analysis.

The historical baseline DM values were then smoothed using the equation that was provided in the assessment methodology (CDPHE 2013). The best fit regression line to the data is shown in Figure 10. The R^2 is 0.85. Note that if we had not filled in the missing 2012 data, the highest possible R^2 would have been 0.65. The fit of the smoothed curve to the baseline DMs is shown in Figure 11.

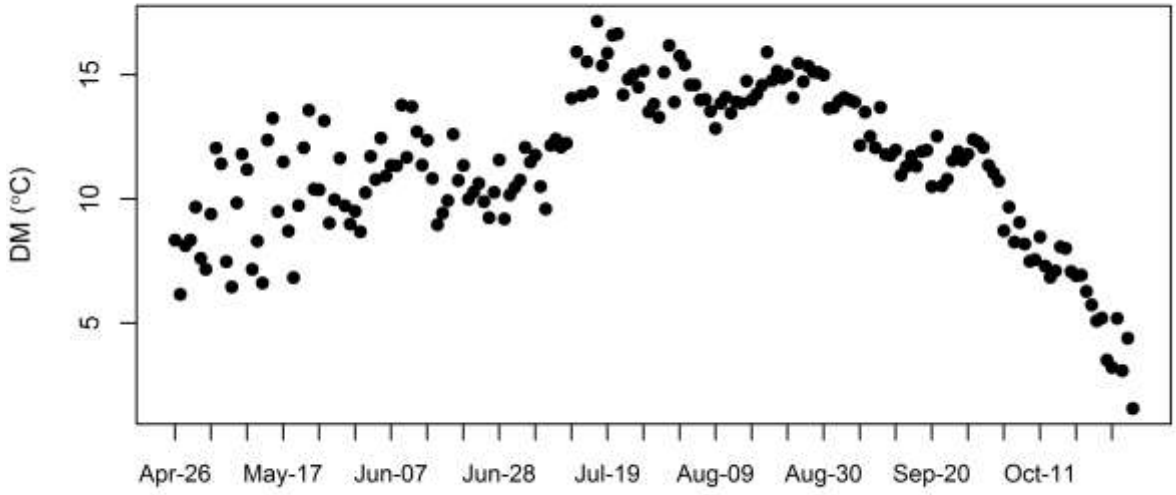

Figure 7. DMs used for each ordinal day for the Fraser River at Rendezvous Bridge.[2]

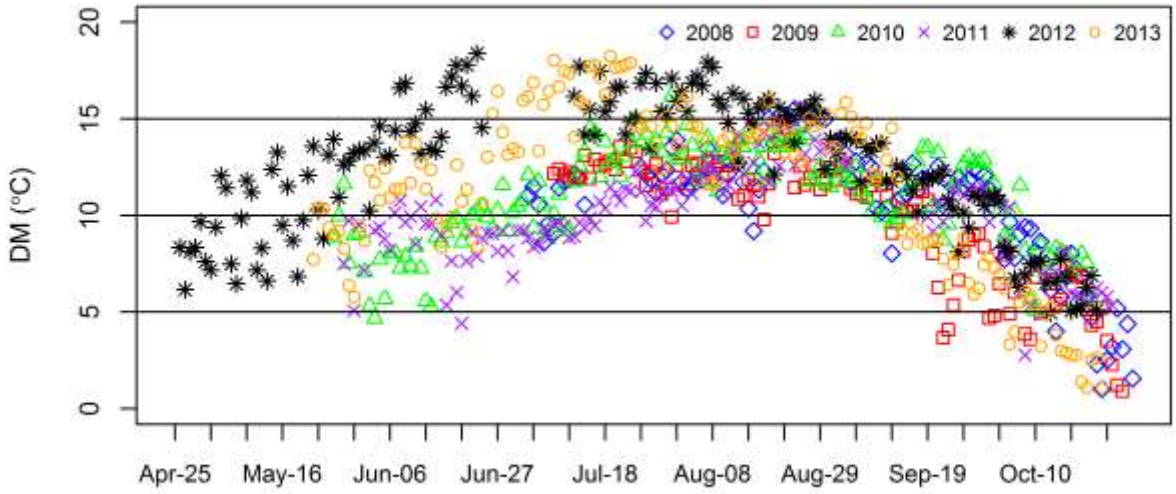

Figure 8. DM temperatures at the Rendezvous Bridge site, 2008-2013.

[2] The DMs used follows the CDPHE methodology of using the second-highest DM as long as at least three years of data were available for that day.

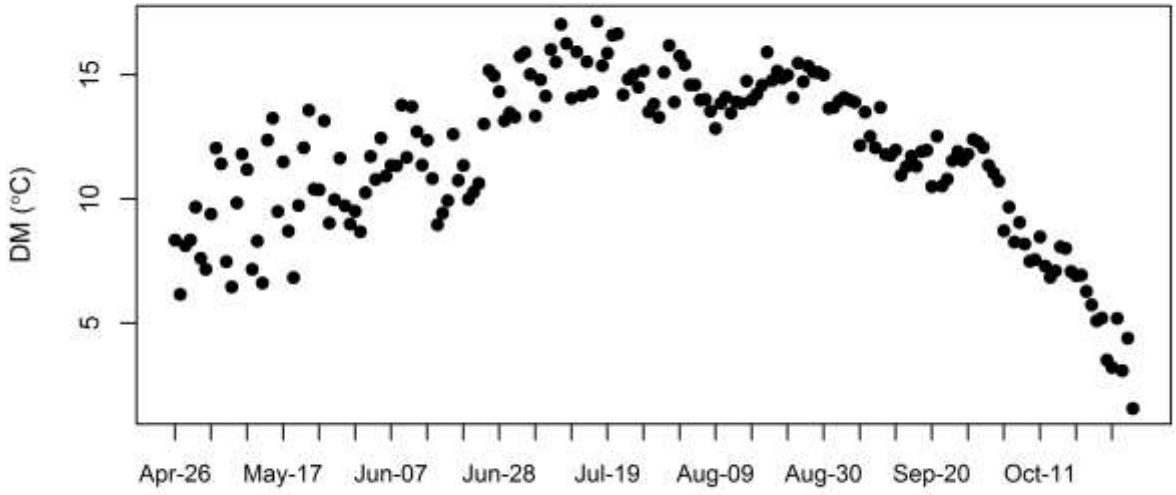

Figure 9. DMs used for each ordinal day for the Fraser River at Rendezvous Bridge. [2] **Missing 2012 data have been filled in.**

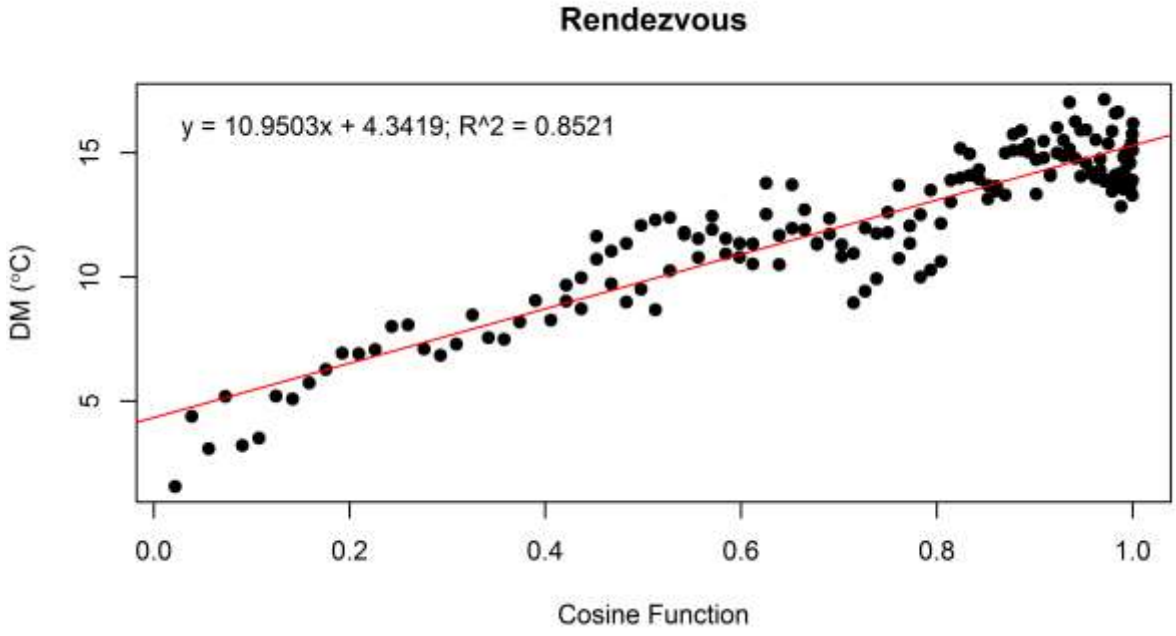

Figure 10. Regression analysis to determine the mean and amplitude of the harmonic function that characterizes the baseline DM, Fraser River at Rendezvous Bridge.

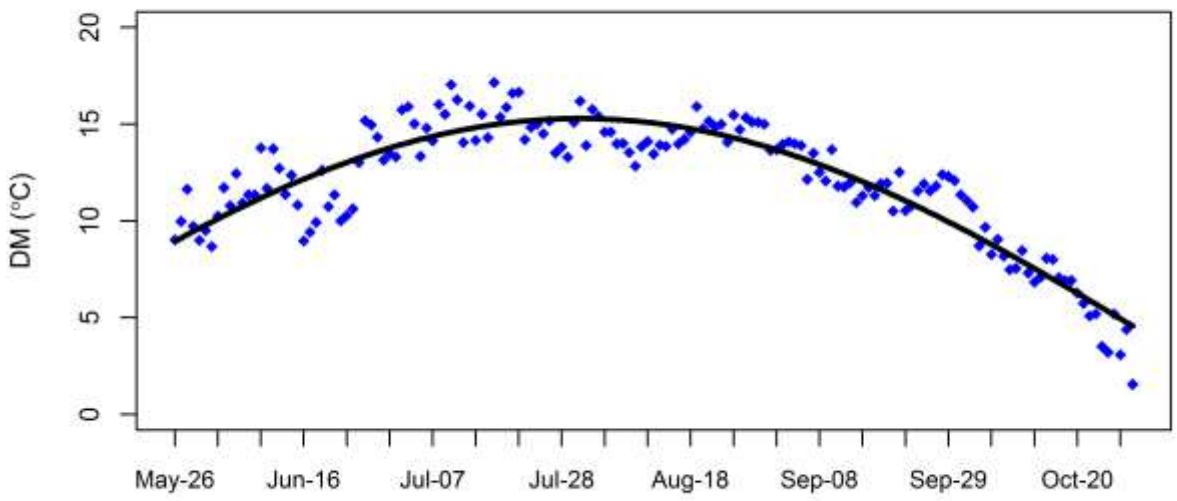

Figure 11. Fit of regression line to baseline DM values, Fraser River at Rendezvous Bridge.

The same methodology was used to develop smoothed historical baseline WAT values. The fit of the regression line to the data is shown in Figure 12. The R^2 is 0.93. The fit of the smoothed curve to the baseline WATs is shown in Figure 13.

Baseline DM and WAT curves based on current conditions for each scenario year were then developed and compared to the historical baseline curves (Figure 14 and Figure 15). For both DMs and WATs, the current conditions baselines tended to be warmer than the historical baselines from about mid-July through September. From June through mid-July there was more variability in the current conditions baselines, with some warmer than the historical baseline and others cooler. Warmer current conditions baselines are not unexpected, given the nature of the scenario years and meteorology that were chosen for model simulations. 2007 meteorological data were used for all simulations and 2007 was one of the warmest years on record. As was stated in the draft report for the Fraser River dynamic water temperature model (Miller Ecological Consultants, Inc. 2015a), the combination of the selected scenario years and "hot" meteorology may have resulted in overestimates of the impacts of the four streamflow scenarios. The result is that baseline temperatures are developed from warmer temperatures than historical conditions. Nevertheless, it was agreed upon to use current conditions baselines for the antidegradation analysis. The use of current conditions baselines means that all comparisons that are made are from temperatures that were simulated under the same set of meteorological conditions. This was deemed more appropriate than comparing simulated temperatures to a historical baseline that was developed under a different set of meteorological conditions.

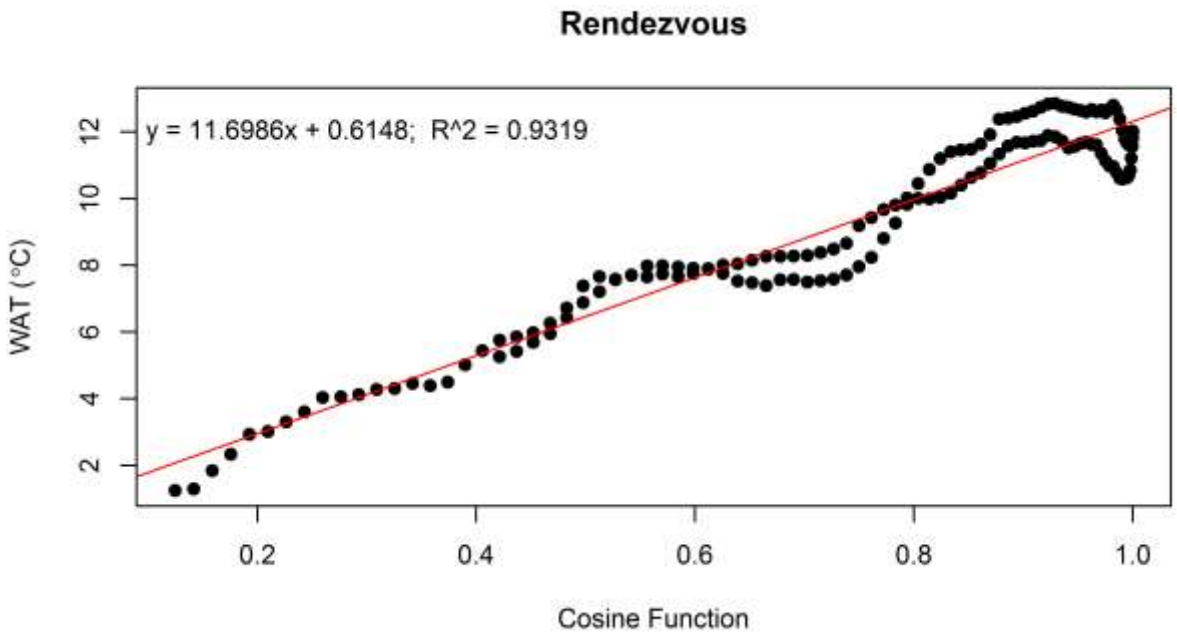

Figure 12. Regression analysis to determine the mean and amplitude of the harmonic function that characterizes the baseline WAT, Fraser River at Rendezvous Bridge.

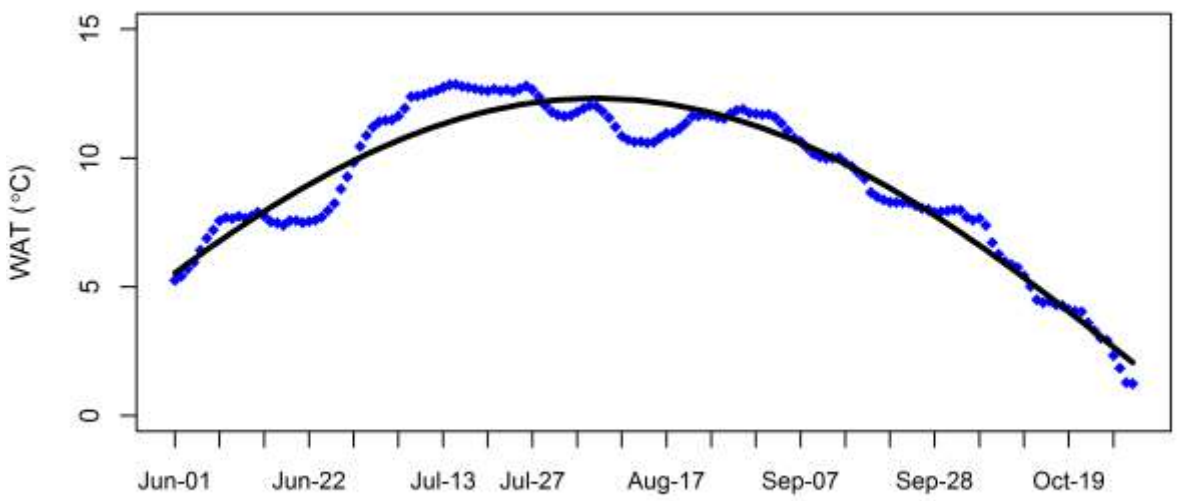

Figure 13. Fit of regression line to baseline WAT values, Fraser River at Rendezvous Bridge.

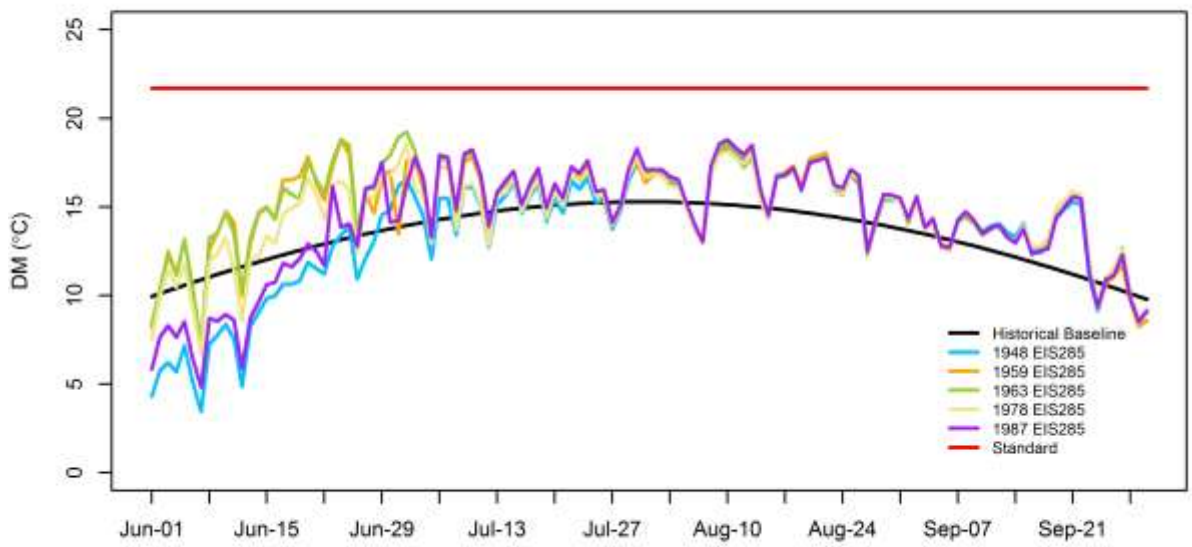

Figure 14. Comparison of scenario year baseline DM curves to the historical baseline DM curve, Fraser River at Rendezvous Bridge.

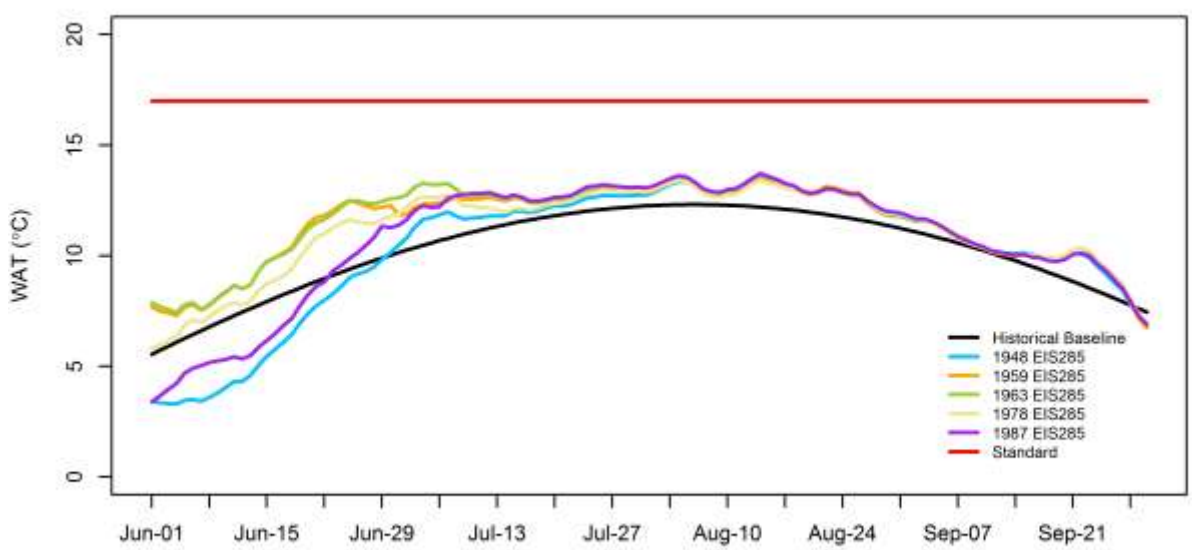

Figure 15. Comparison of scenario year baseline WAT curves to the historical baseline WAT curve, Fraser River at Rendezvous Bridge.

The BAI was then calculated, which was the difference between the standard (21.7°C for the DM and 17.0°C for the WAT for a Tier I stream) and the baseline values from the current conditions curves. The 15% assimilative capacity threshold curves are provided in the results section for each scenario year.

Comparisons of Simulated Temperatures to Daily Thresholds

The following figures compare the results of the model simulations for the years 1948, 1959, 1963, 1978 and 1987 to the 15% assimilative capacity thresholds. For each year, it is important to understand that the figures illustrate the *difference* in predicted temperatures between future flow scenarios (EIS 345, Alt 1a and Alt 8a) and current conditions (EIS 285). For example, all figures that compare Alt 1a to the thresholds are actually comparing the difference between Alt 1a and EIS 285 simulated temperatures to the thresholds. While the difference between Alt 1a and EIS 285 was the primary interest, we also included results that compare EIS 345 to EIS 285 and Alt 8a to EIS 285. The EIS 345 streamflow scenario is the cumulative conditions for all Reasonably Foreseeable Future Actions (RFFAs) without the Moffat Project in operation. The Alt1a streamflow scenario is all RFFAs plus operation of the Moffat Project. The comparison between the impacts of EIS 345 and Alt 1a therefore provides a direct evaluation of the impacts of Moffat Project operations. Additionally, results are presented only from June 1 to September 30 since these are the applicable months for the Tier I summer temperature standard.

1948 Scenario Year

DMs

Figure 16 shows the 15% assimilative capacity threshold. The threshold ranges from 0.51°C in mid-summer to 2.74°C in June. Figure 17 compares the number of excursions to the threshold based on current conditions. There are 27, 38 and 39 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Figure 18 further summarizes the number of excursions by month. The difference in excursions between EIS 345 and Alt 1a (excursions that are directly attributable to the Moffat Project operation) occurs in June, in which the project contributes an additional 12 excursions. Note that while there are 12 excursions attributed to operation of the Moffat Project, there are no DM temperature standard exceedances for 1948. As Figure 19 illustrates, the excursions that occur in June are well below the DM temperature standard, averaging approximately 12°C below the standard in early June and approximately 6°C below the standard from mid to late June. Excursions that are well below the temperature standard will be discussed later in this document, particularly as they relate to biological requirements for fish.

WATs

Figure 20 shows the 15% assimilative capacity threshold. The threshold ranges from 0.52°C in mid-summer to 2.06°C in early June. Figure 21 compares the number of excursions to the threshold based on current conditions. There are 2, 20 and 20 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Figure 22 further summarizes the number of excursions by month. The difference in excursions between EIS 345 and Alt 1a occurs primarily in June, in which the Moffat Project contributes an additional 17 excursions (plus one additional excursion in July). Note that while there are 18 excursions attributed to operation of the Moffat Project, there are no WAT temperature standard exceedances for 1948. As Figure 23 illustrates, the excursions that occur in June are well below the WAT temperature standard, average approximately 11°C below the standard in early June and approximately 6°C below the standard from mid to late June.

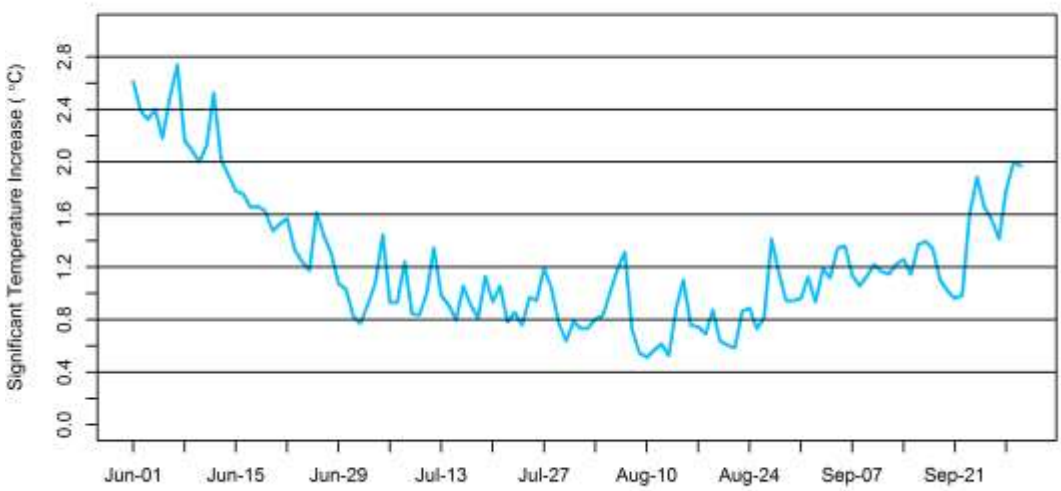

Figure 16. DM 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1948.

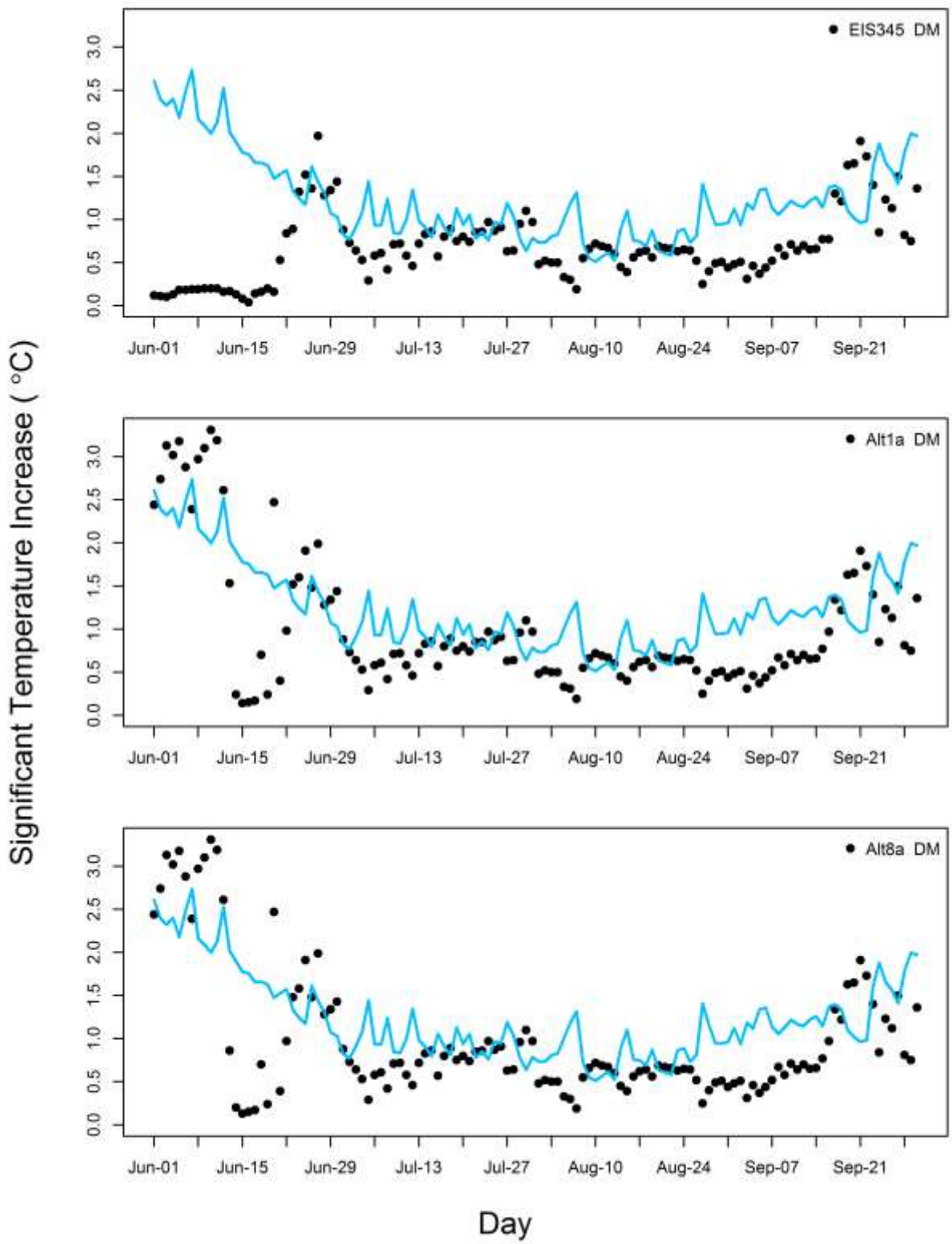

Figure 17. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1948.

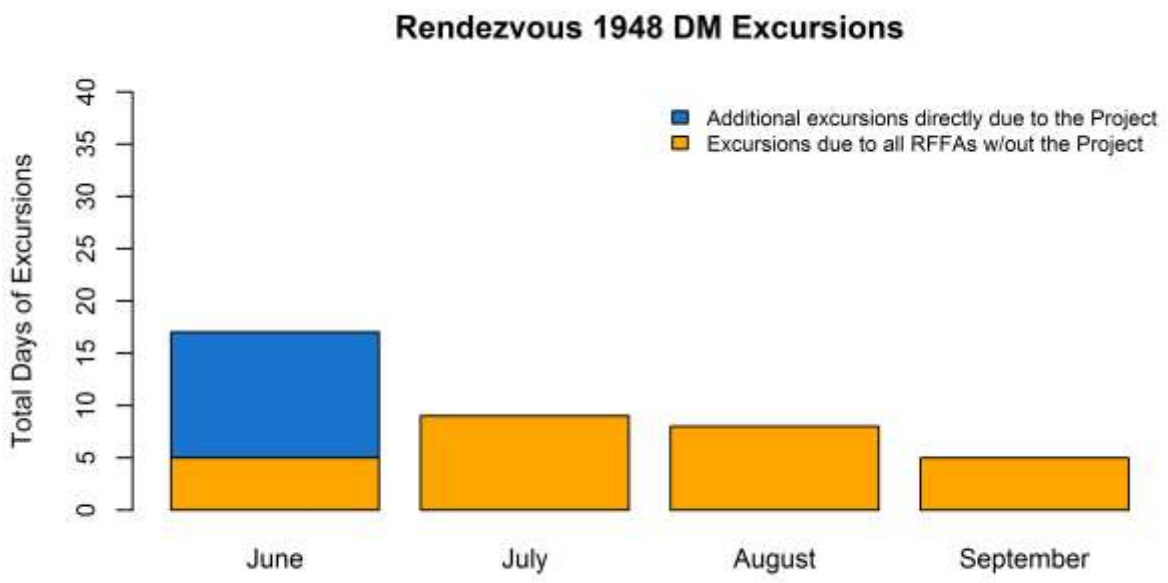

Figure 18. Summary of DM temperature excursions for 1948, Fraser River at Rendezvous Bridge.

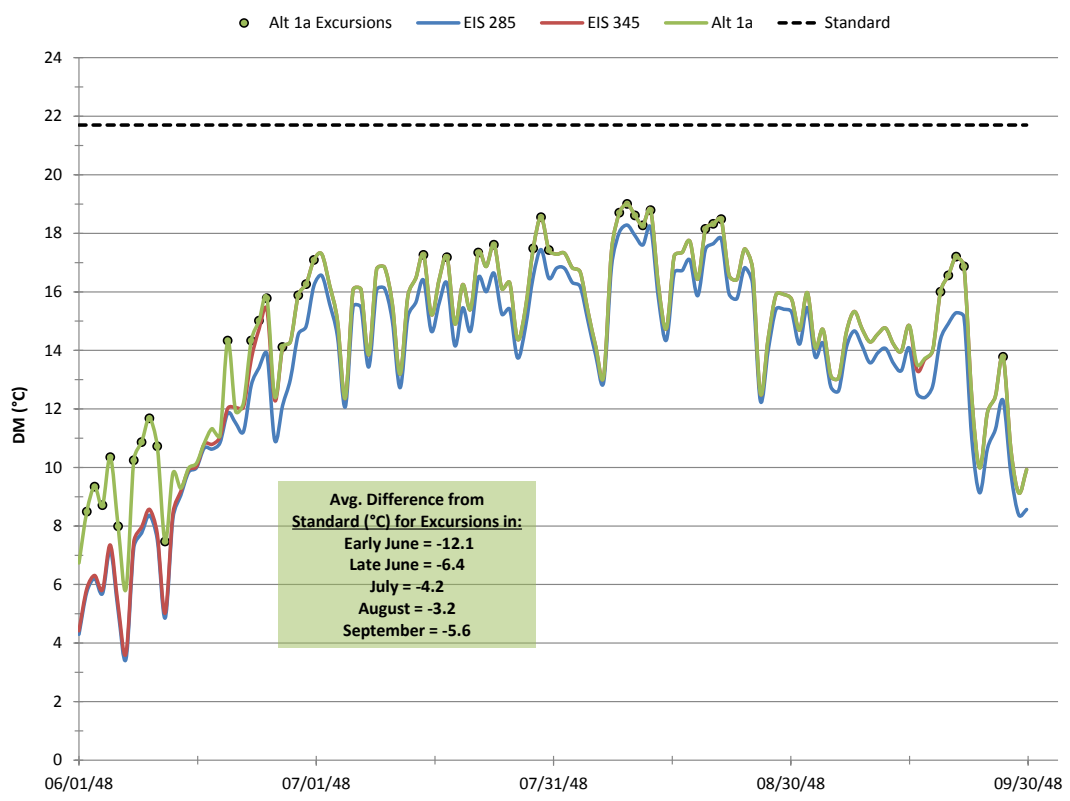

Figure 19. Alt 1a DM temperature excursions for 1948 (circles), compared to EIS 285, EIS 345 and the temperature standard.

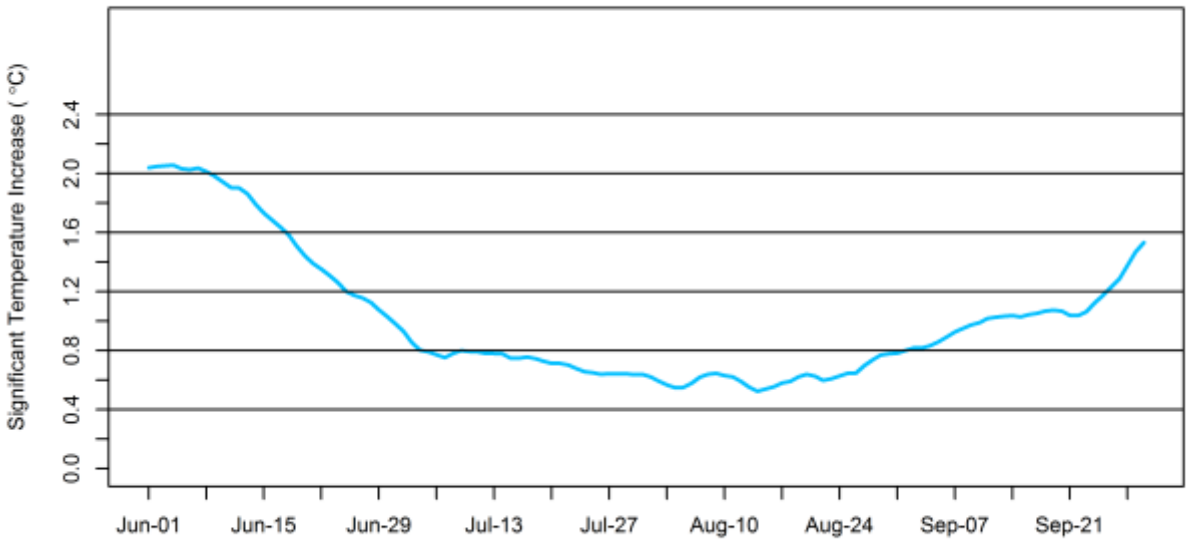

Figure 20. WAT 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1948.

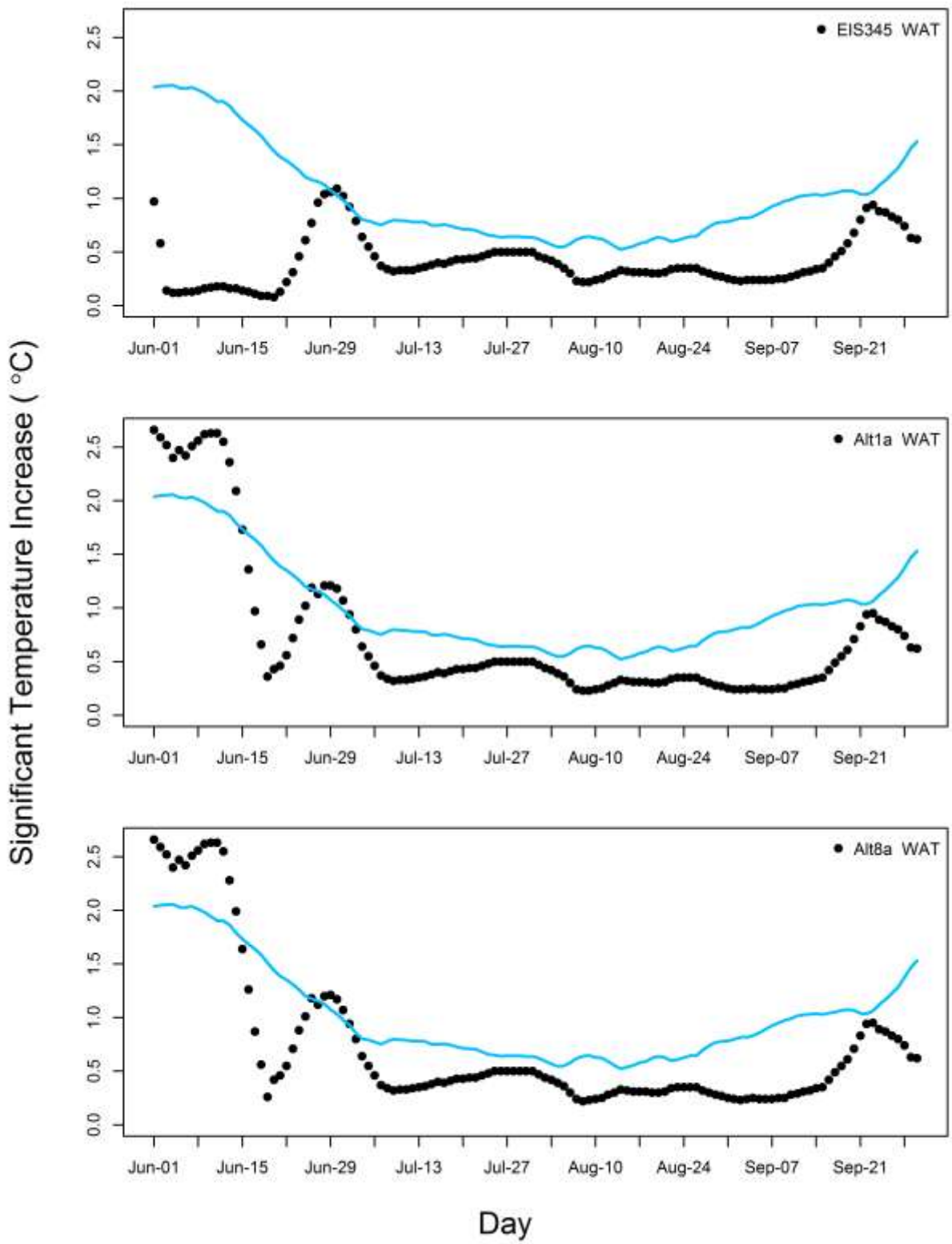

Figure 21. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1948.

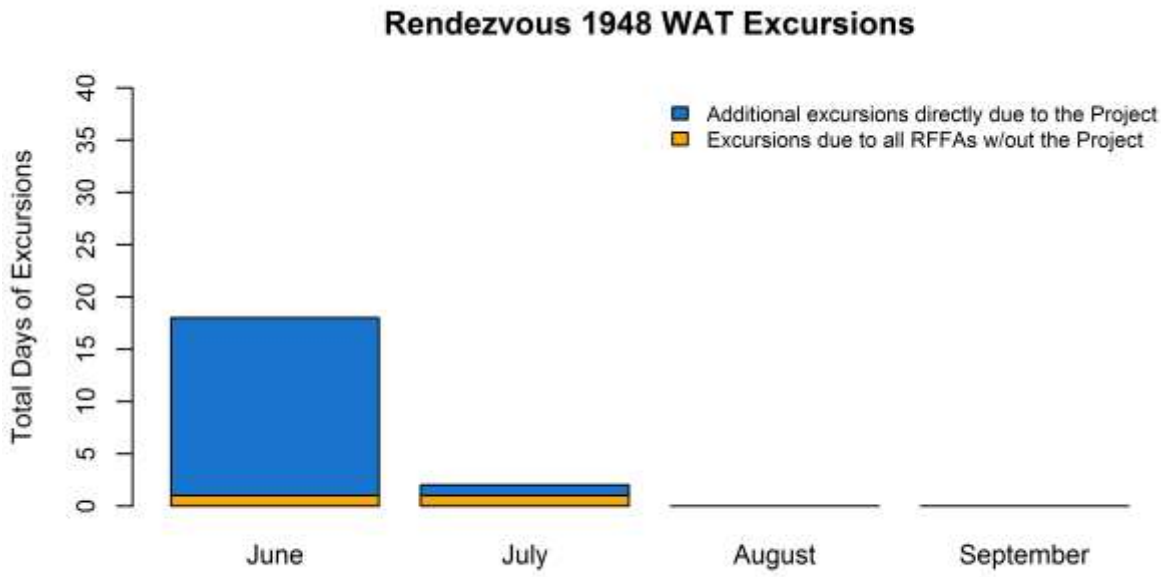

Figure 22. Summary of WAT temperature excursions for 1948, Fraser River at Rendezvous Bridge.

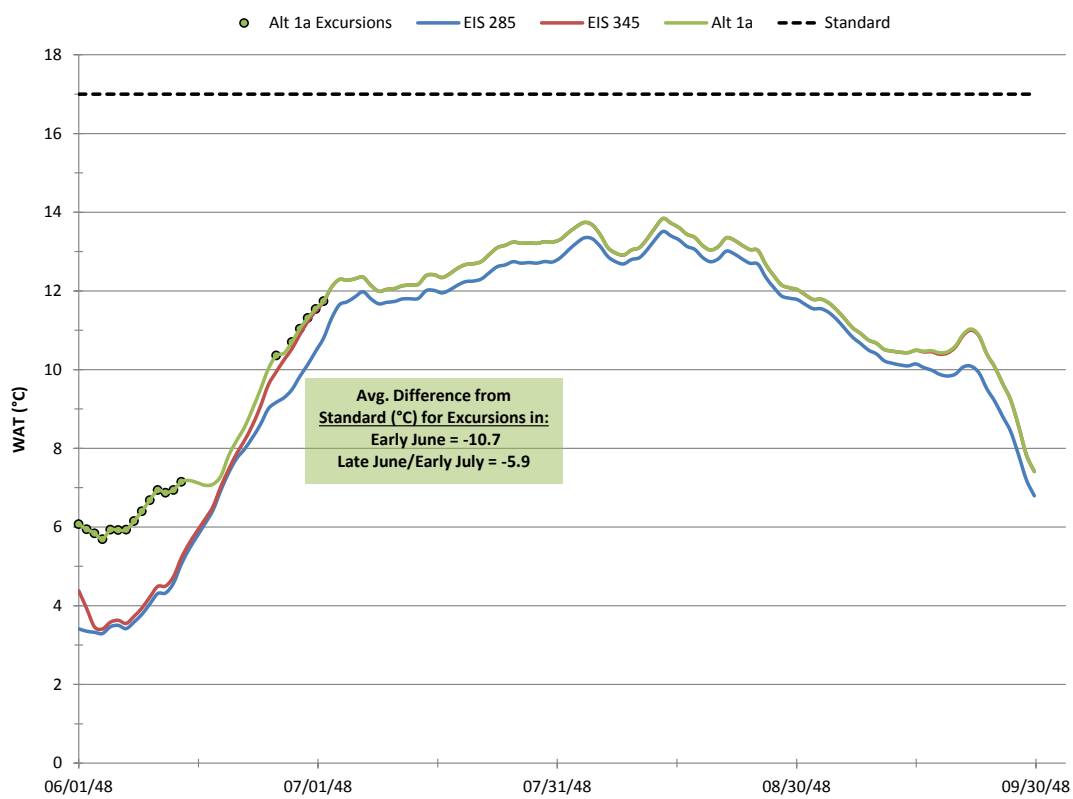

Figure 23. Alt 1a WAT temperature excursions for 1948 (circles), compared to EIS 285, EIS 345 and the temperature standard.

1959 Scenario Year

DMs

Figure 24 shows the 15% assimilative capacity threshold. The threshold ranges from 0.44°C to 2.20°C. Figure 25 compares the number of excursions to the threshold based on current conditions. There are 46, 46 and 46 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. Additionally, while there are a number of excursions due to RFFAs, there are no DM temperature standard exceedances for 1959. Figure 26 further summarizes the number of excursions by month.

WATs

Figure 27 shows the 15% assimilative capacity threshold. The threshold ranges from 0.50°C to 1.54°C. Figure 28 compares the number of excursions to the threshold based on current conditions. There are 13, 13 and 13 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. Additionally, while there are a number of excursions due to RFFAs, there are no WAT temperature standard exceedances for 1959. Figure 29 further summarizes the number of excursions by month.

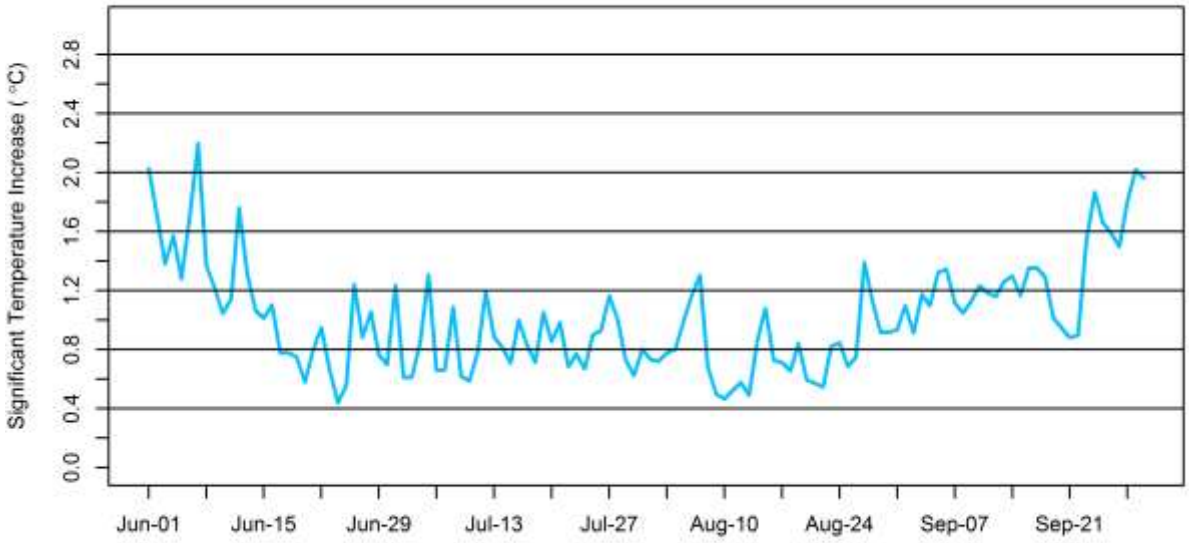

Figure 24. DM 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1959.

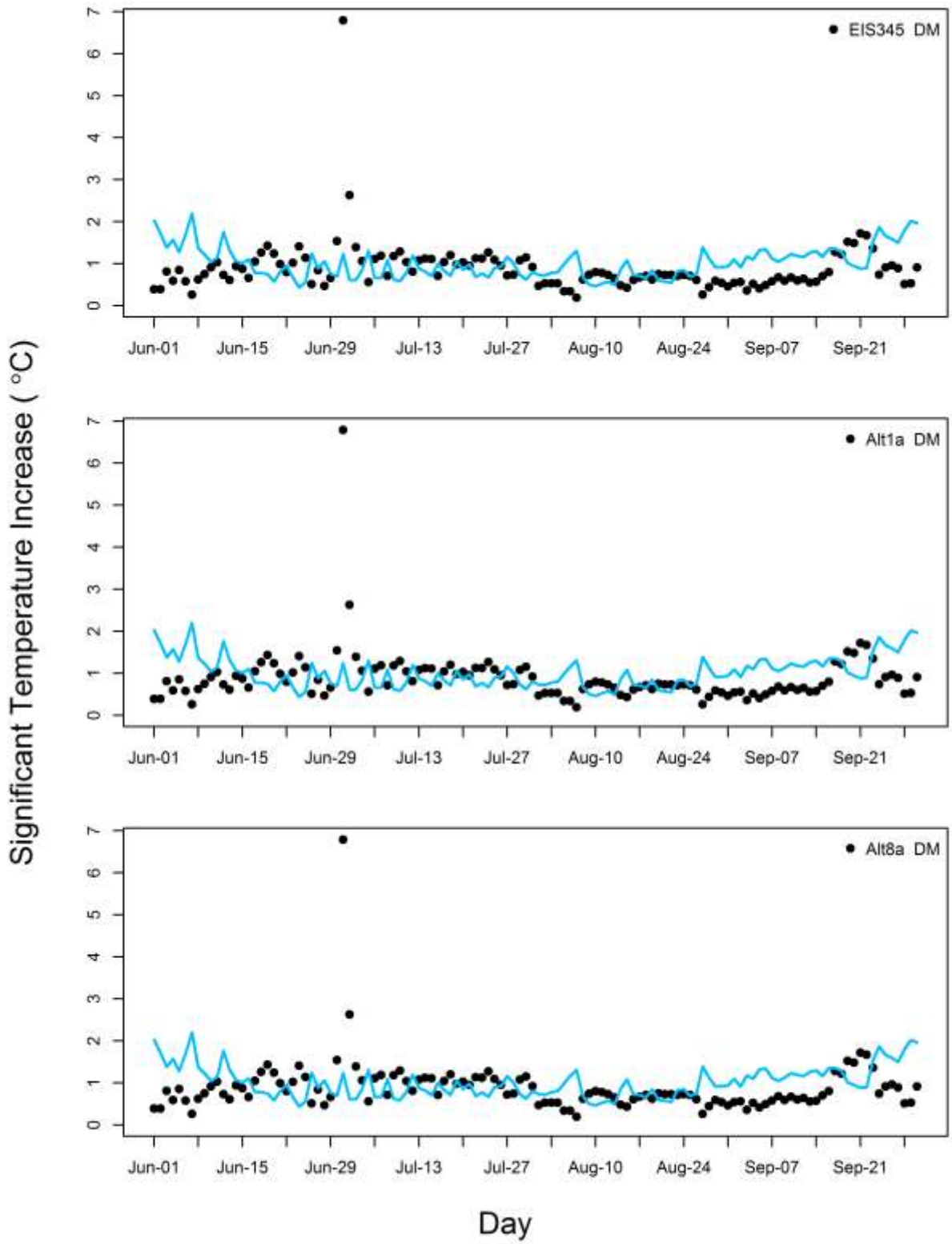

Figure 25. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1959.

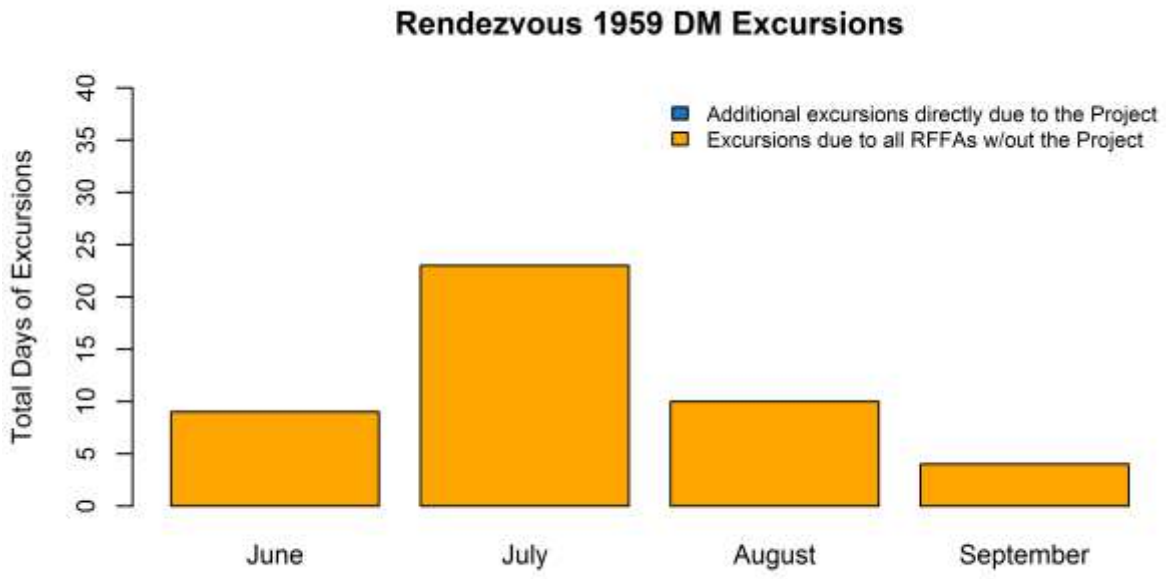

Figure 26. Summary of DM temperature excursions for 1959, Fraser River at Rendezvous Bridge.

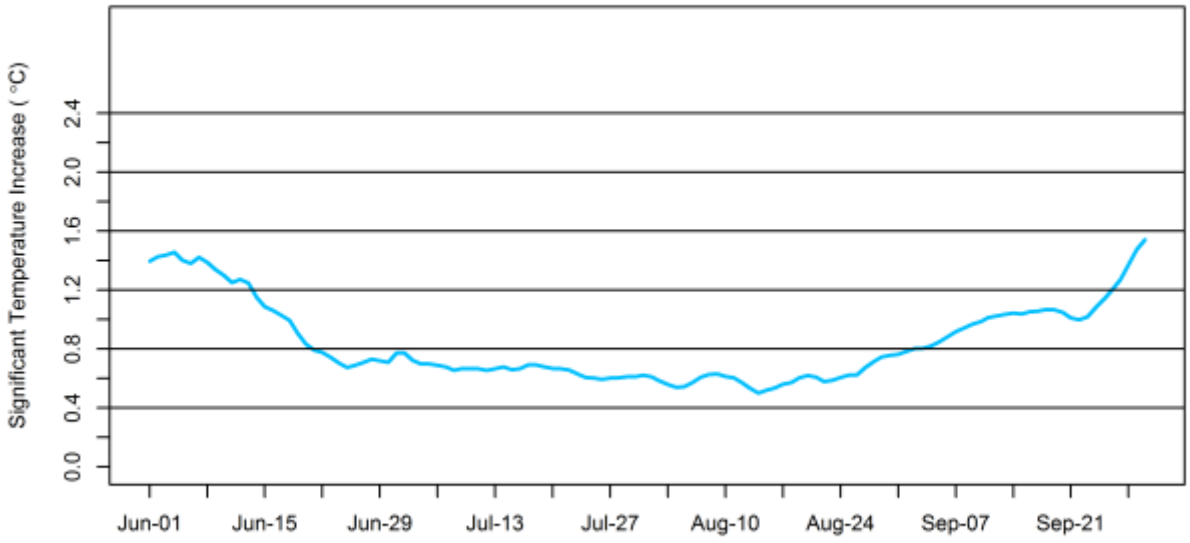

Figure 27. WAT 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1959.

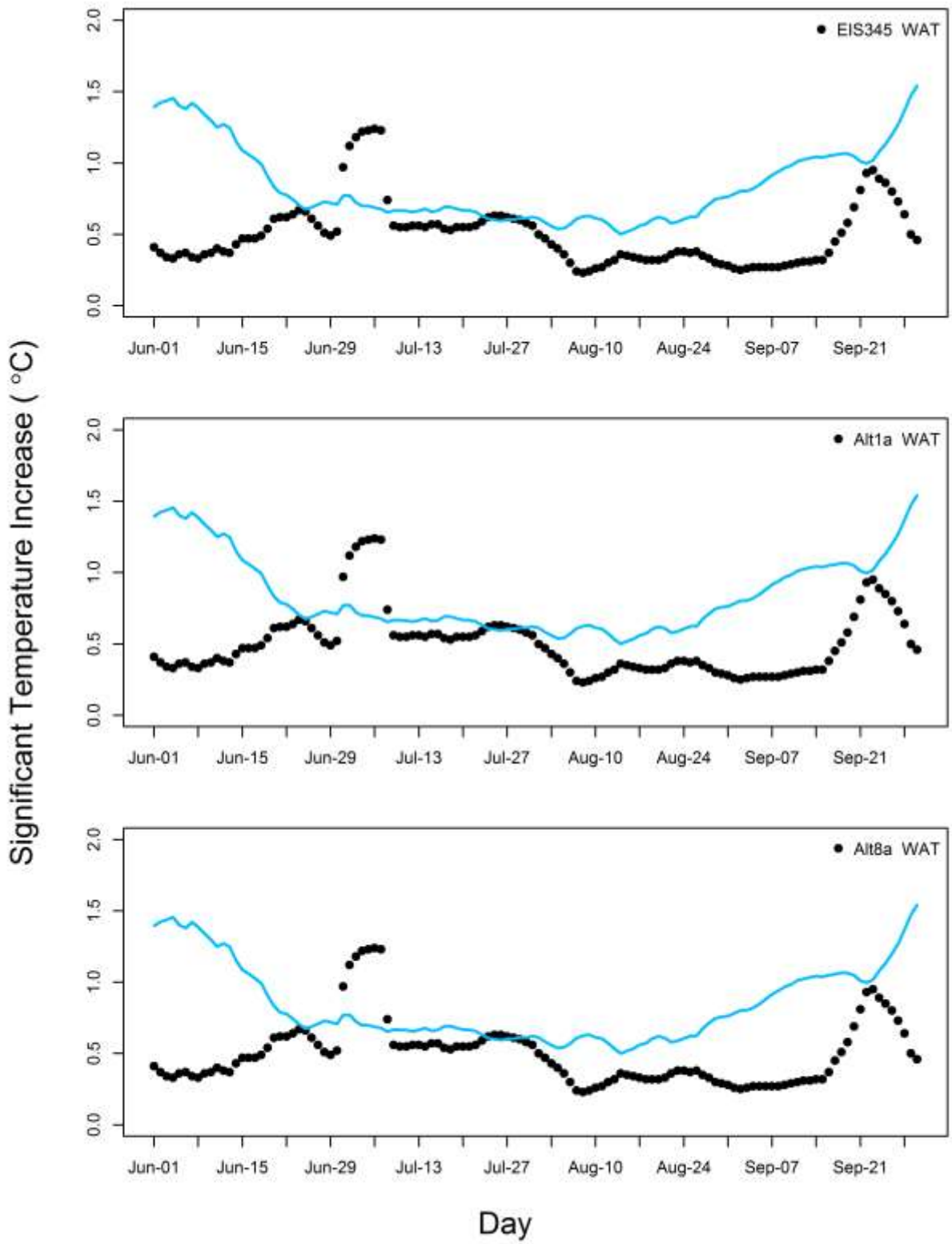

Figure 28. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1959.

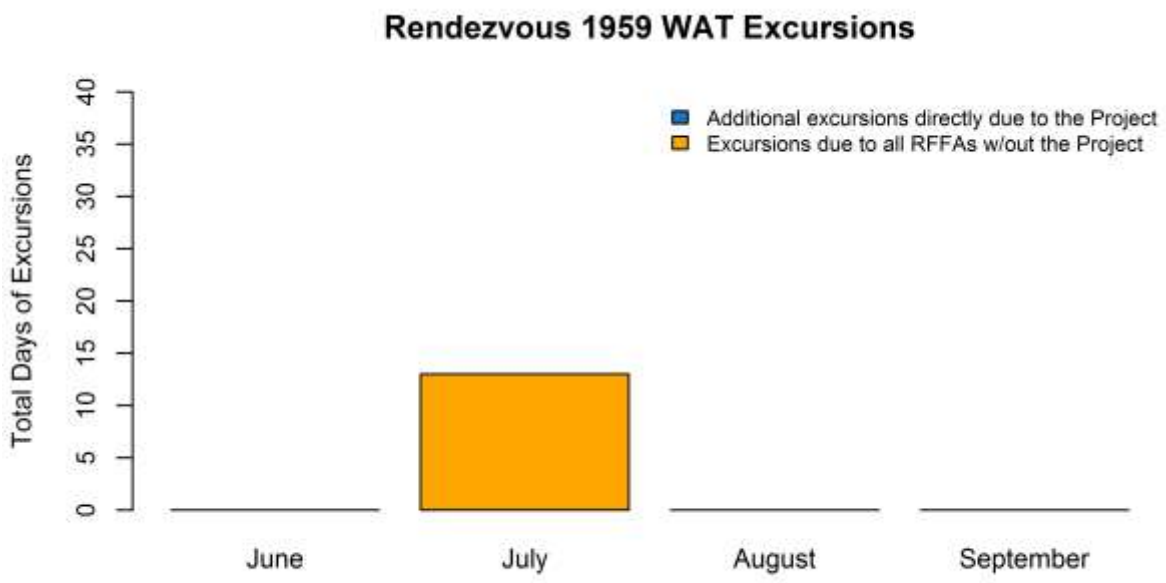

Figure 29. Summary of WAT temperature excursions for 1959, Fraser River at Rendezvous Bridge.

1963 Scenario Year

DMs

Figure 30 shows the 15% assimilative capacity threshold. The threshold ranges from 0.37°C to 2.18°C. Figure 31 compares the number of excursions to the threshold based on current conditions. There are 103, 103 and 103 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. In 1963, for cumulative conditions without the Moffat Project (all RFFAs), there are flow reductions during June through mid-October (this is the difference between EIS 285 and EIS 345). The Moffat Project would cause no reduction of Fraser River flows (this is the difference between EIS 345 and Alt 1a). For cumulative conditions, DM excursions are summarized by month in Figure 32 and DM standard exceedances are summarized by month in Figure 33. Note that there are excursions due to RFFAs in August and September even though there are not any exceedances.

WATs

Figure 34 shows the 15% assimilative capacity threshold. The threshold ranges from 0.52°C to 1.51°C. Figure 35 compares the number of excursions to the threshold based on current conditions. There are 94, 94 and 94 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. Additionally, while there are a number of excursions due to RFFAs, there are no WAT temperature standard exceedances for 1963. Figure 36 further summarizes the number of excursions by month.

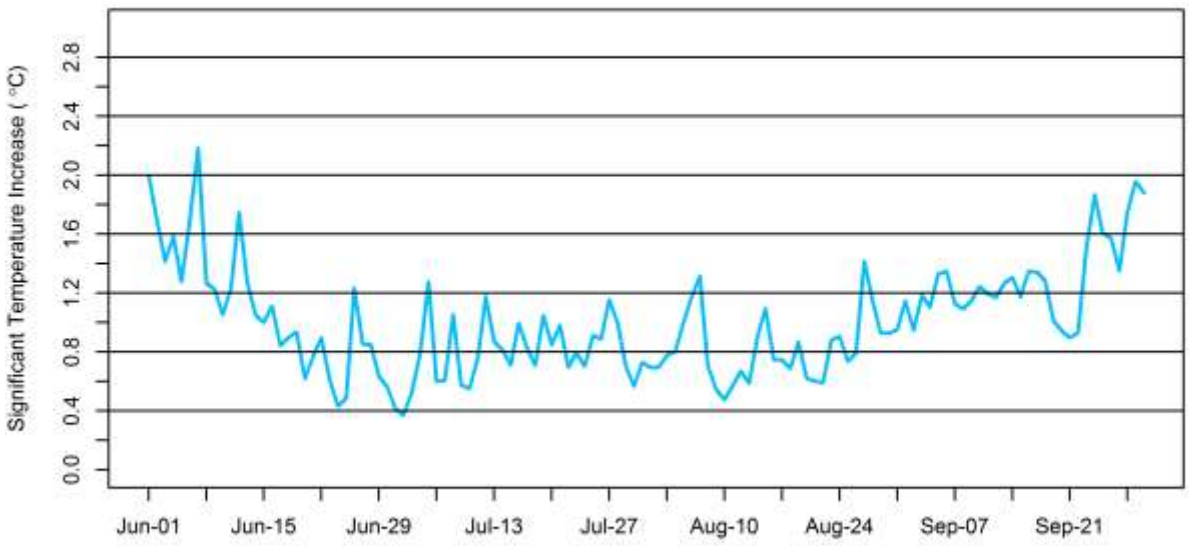

Figure 30. DM 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1963.

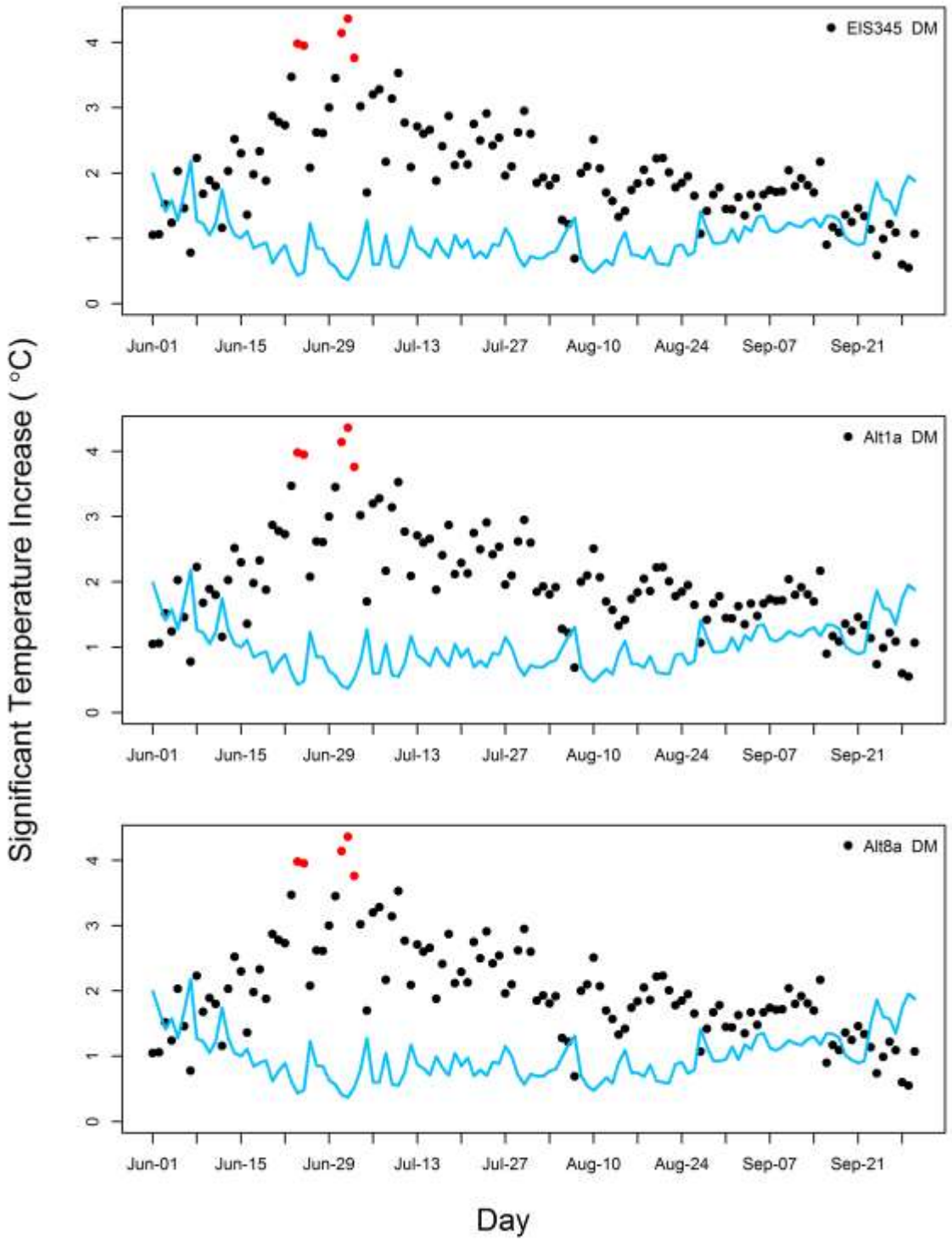

Figure 31. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1963.[3]

[3] Red dots indicate days which exceeded the temperature standard.

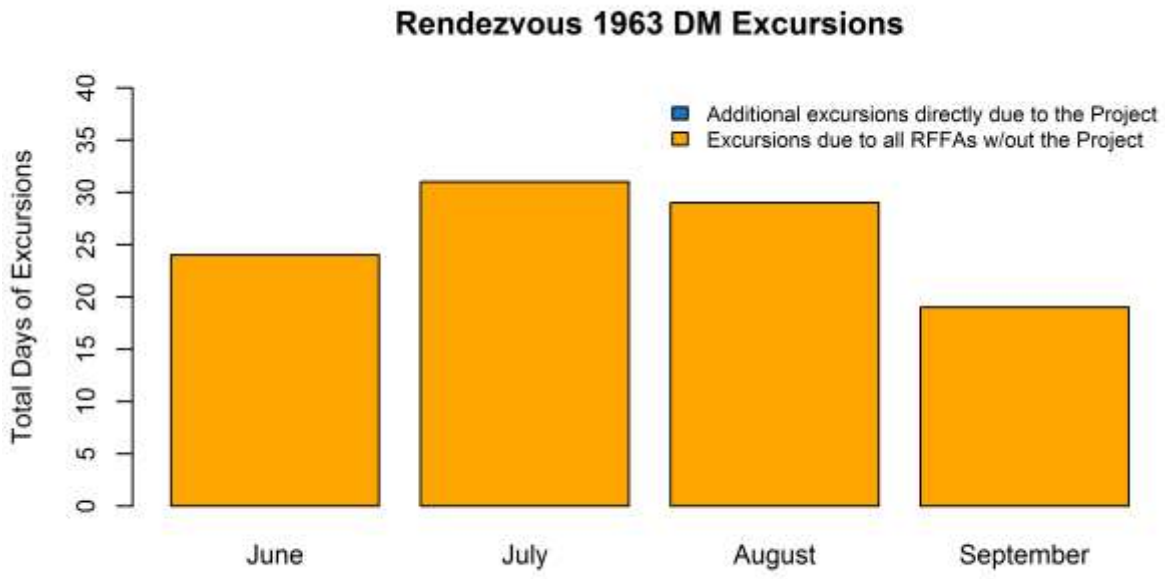

Figure 32. Summary of DM temperature excursions for 1963, Fraser River at Rendezvous Bridge.

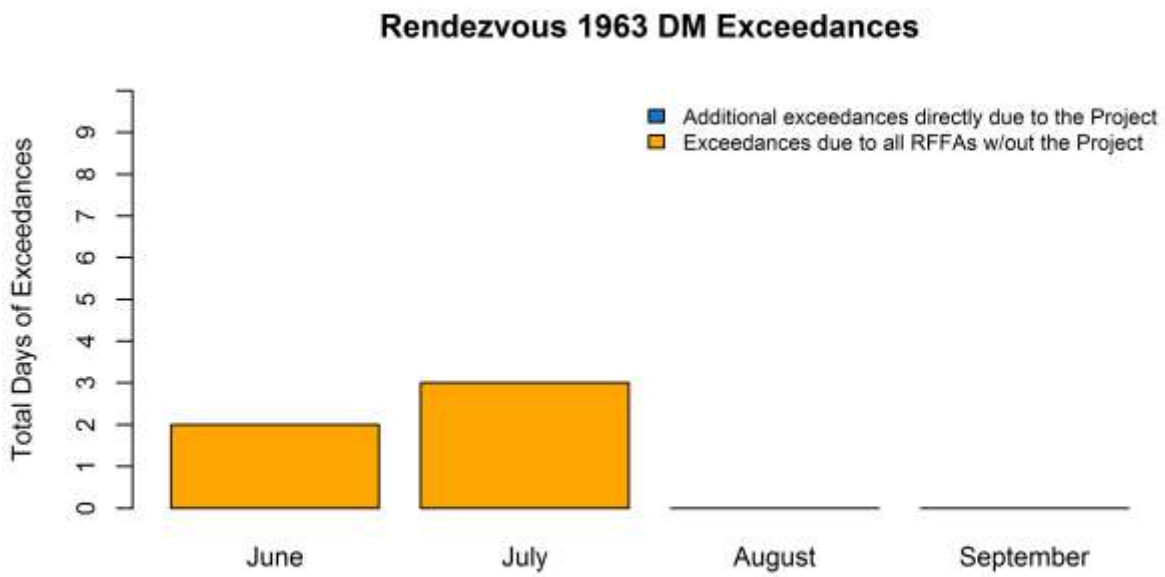

Figure 33. Total DM exceedances for 1963, Fraser River at Rendezvous Bridge.

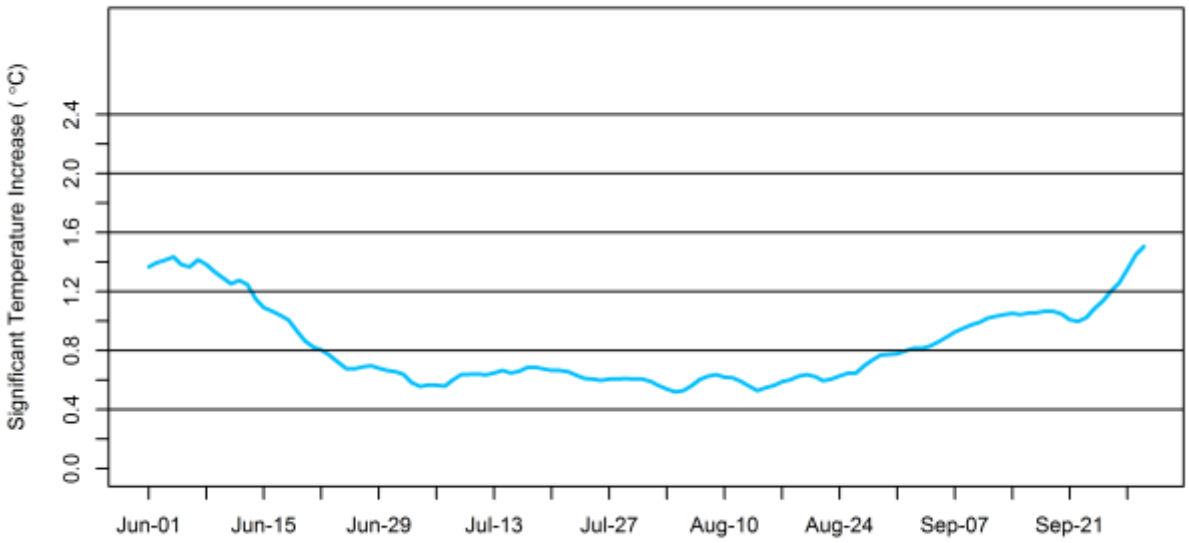

Figure 34. WAT 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1963.

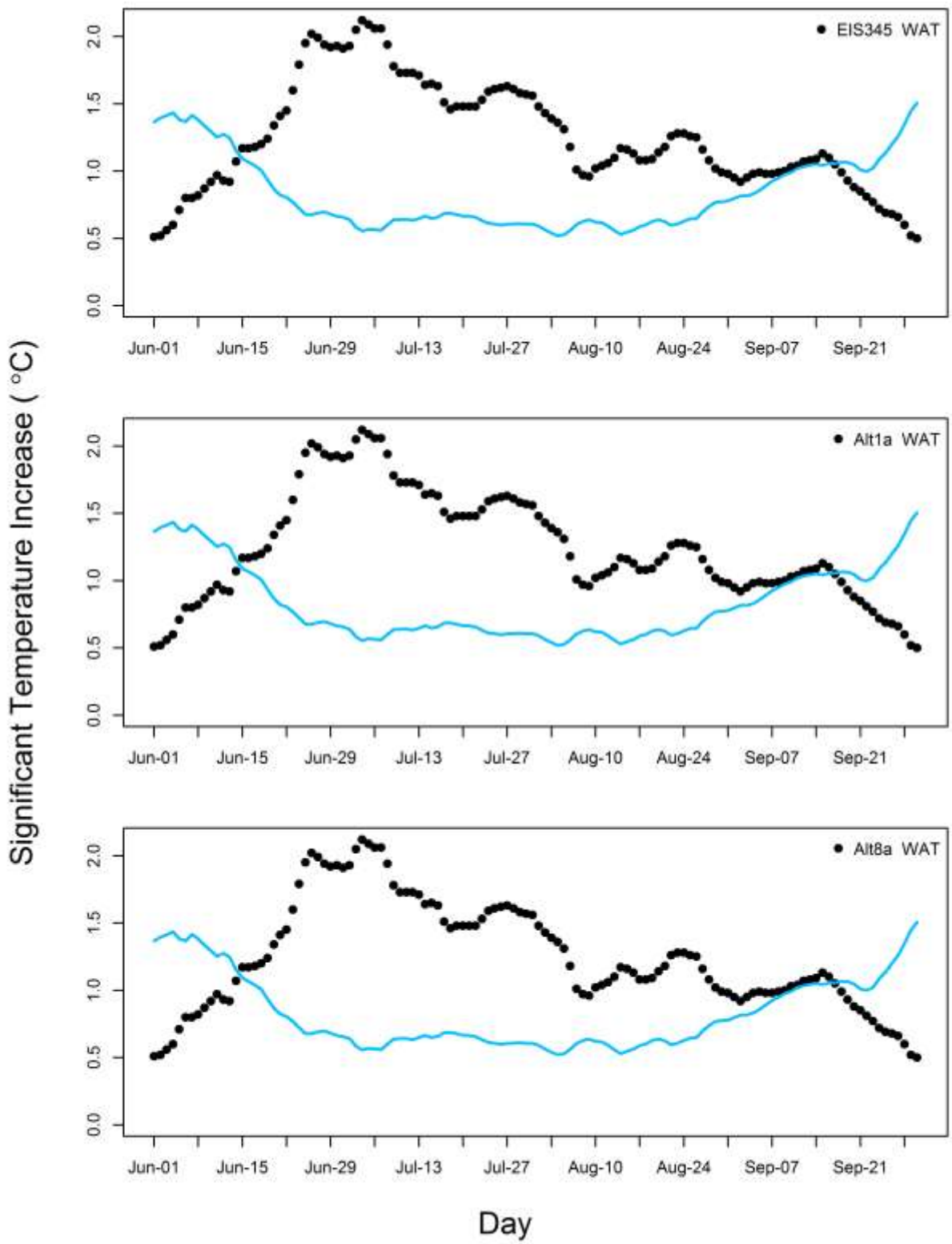

Figure 35. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1963.

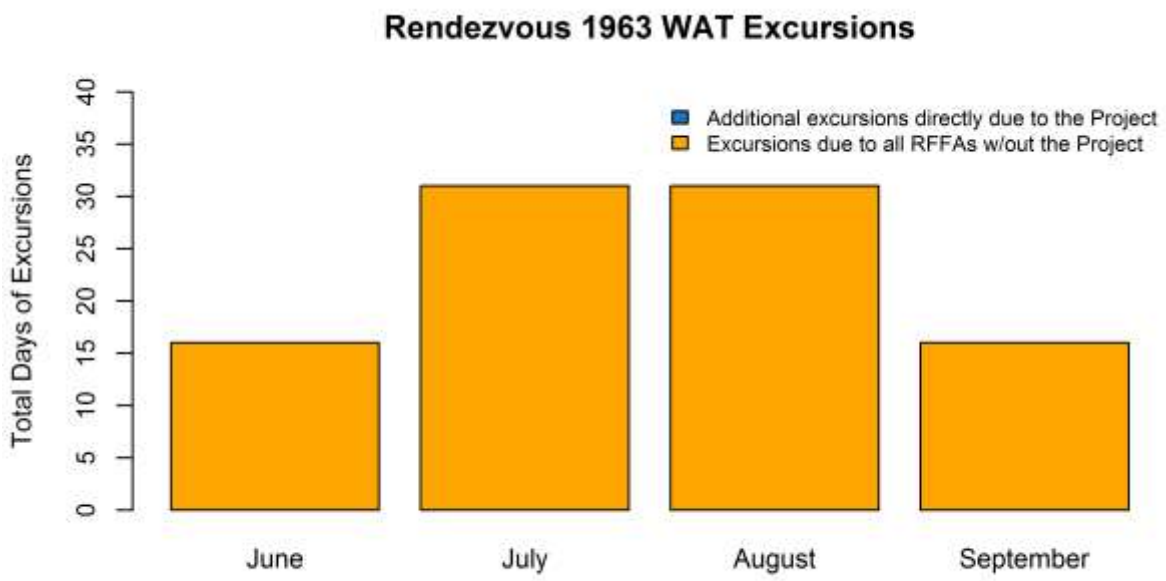

Figure 36. Summary of WAT temperature excursions for 1963, Fraser River at Rendezvous Bridge.

1978 Scenario Year

DMs

Figure 37 shows the 15% assimilative capacity threshold. The threshold ranges from 0.47°C to 2.25°C. Figure 38 compares the number of excursions to the threshold based on current conditions. There are 85, 85 and 85 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. In 1978, for cumulative conditions without the Moffat Project (all RFFAs), there are flow reductions mainly in late June through early September (this is the difference between EIS 285 and EIS 345). The Moffat Project would cause no reduction of Fraser River flows (this is the difference between EIS 345 and Alt 1a). Additionally, while there are a number of excursions due to RFFAs, there are no DM temperature standard exceedances for 1978. Figure 39 further summarizes the number of excursions by month.

WATs

Figure 40 shows the 15% assimilative capacity threshold. The threshold ranges from 0.54°C to 1.68°C. Figure 41 compares the number of excursions to the threshold based on current conditions. There are

80, 80 and 80 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. Additionally, while there are a number of excursions due to RFFAs, there are no WAT temperature standard exceedances for 1978. Figure 42 further summarizes the number of excursions by month.

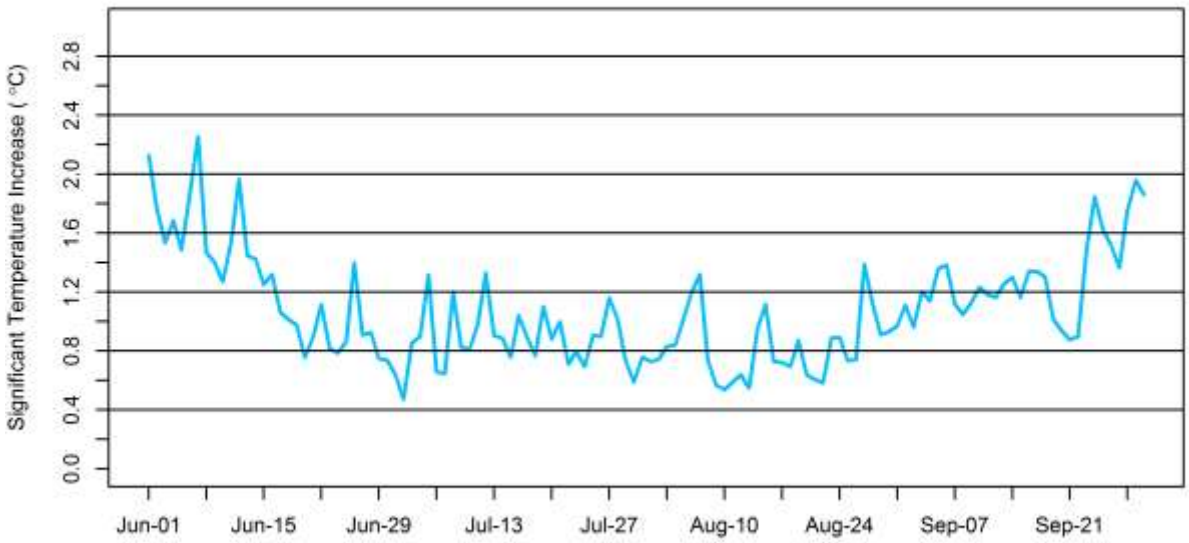

Figure 37. DM 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1978.

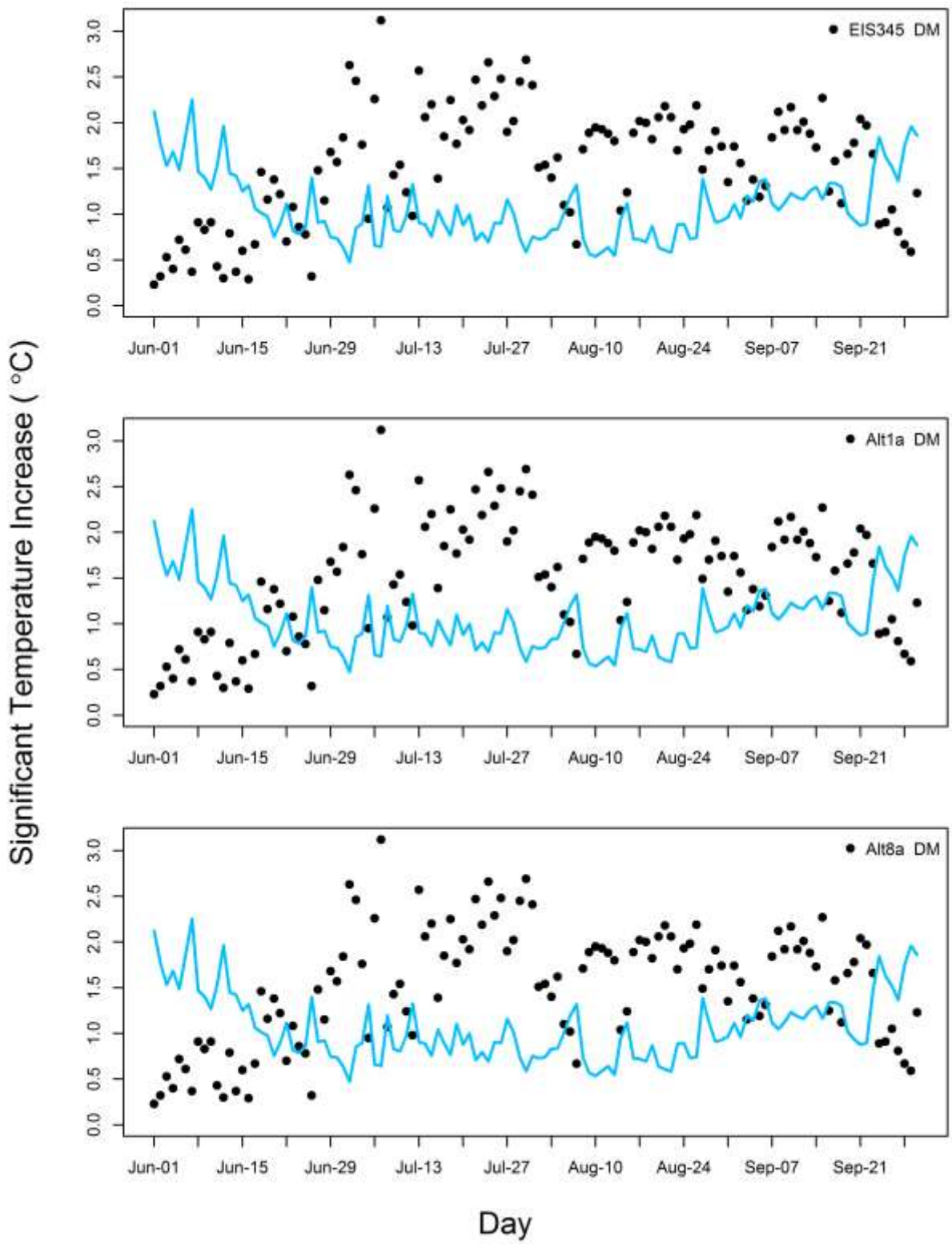

Figure 38. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1978.

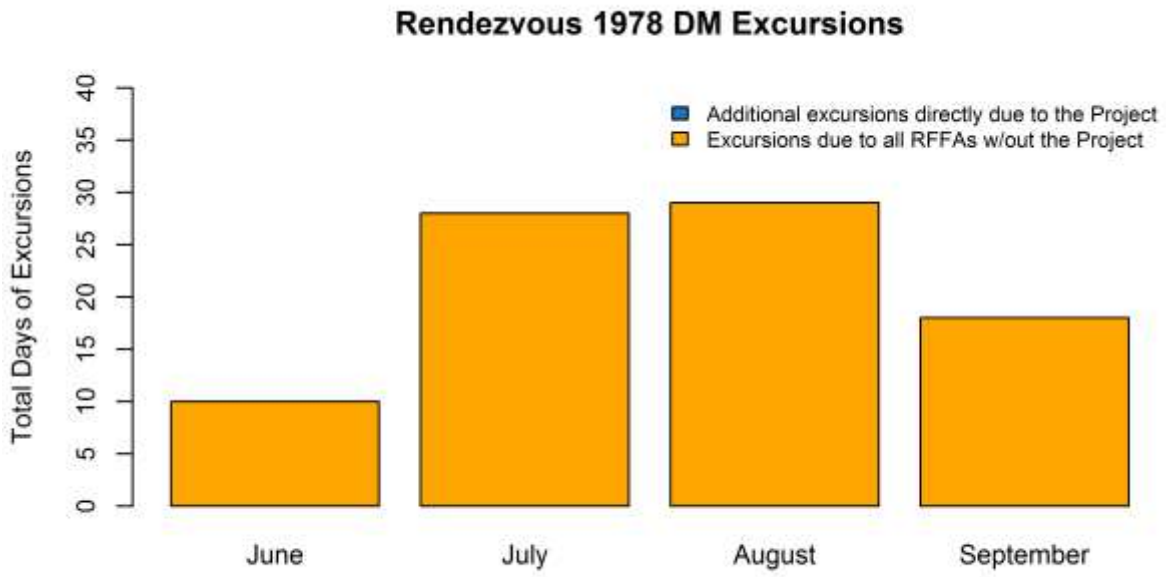

Figure 39. Summary of DM temperature excursions for 1978, Fraser River at Rendezvous Bridge.

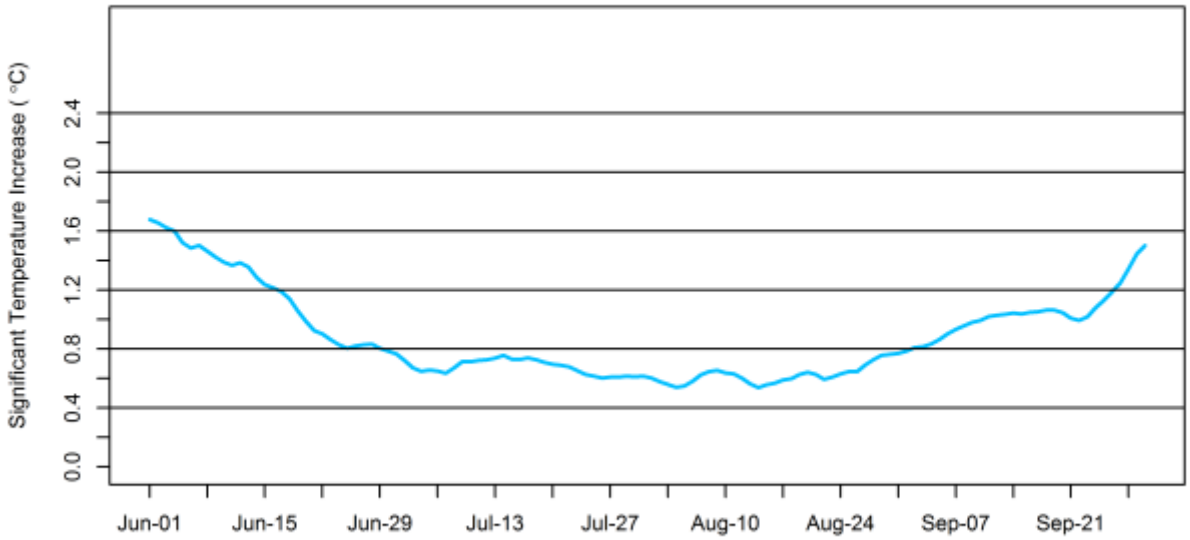

Figure 40. WAT 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1978.

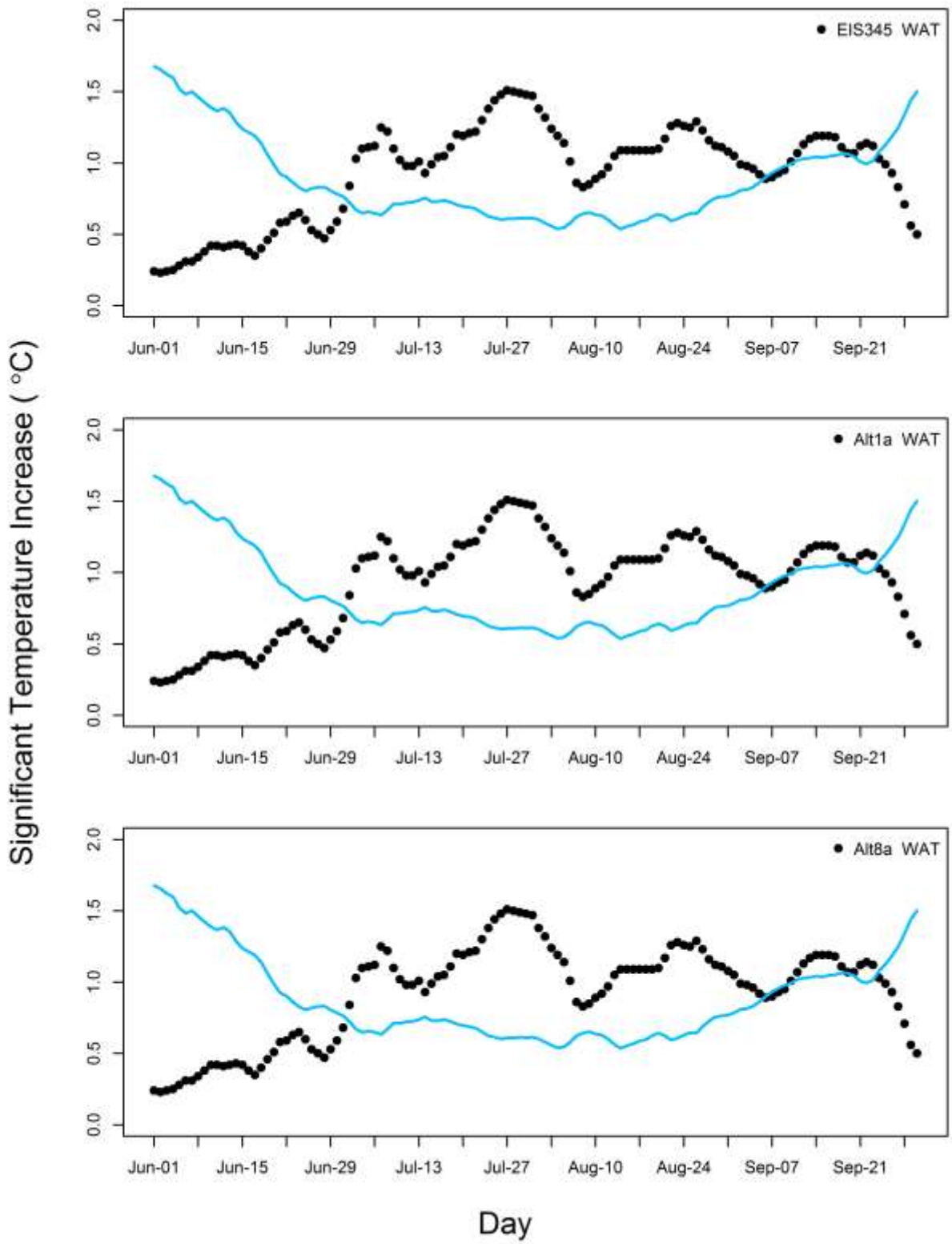

Figure 41. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1978.

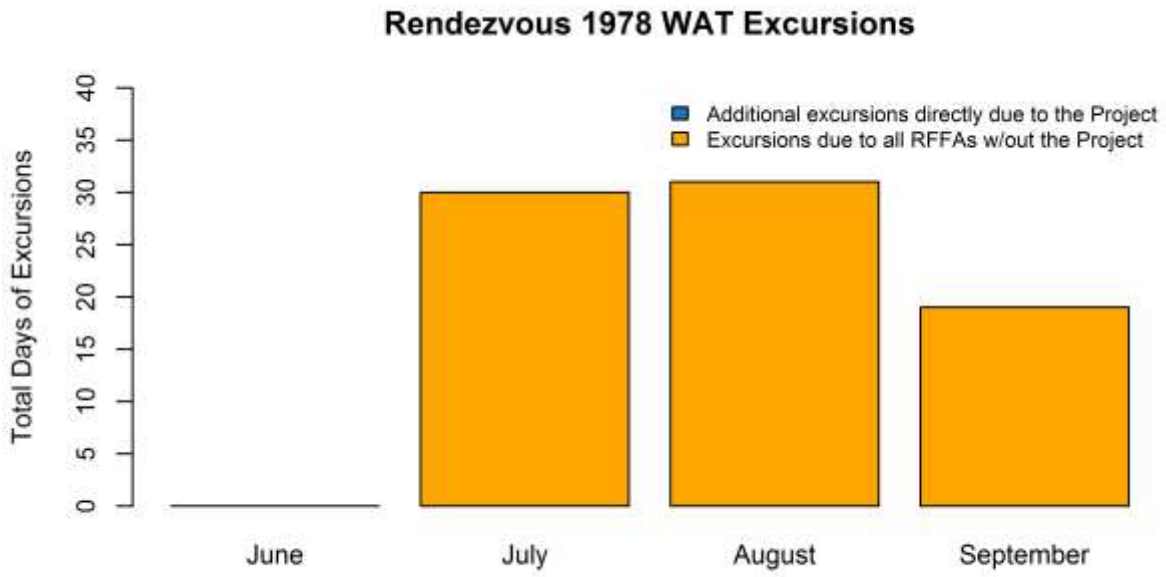

Figure 42. Summary of WAT temperature excursions for 1978, Fraser River at Rendezvous Bridge.

1987 Scenario Year

DMs

Figure 43 shows the 15% assimilative capacity threshold. The threshold ranges from 0.44°C to 2.53°C. Figure 44 compares the number of excursions to the threshold based on current conditions. There are 43, 50 and 50 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Figure 45 further summarizes the number of excursions by month. The difference in excursions between EIS 345 and Alt 1a (excursions that are directly attributable to the Moffat Project) occurs primarily in June, in which the project contributes an additional 6 excursions (plus one additional excursion in July). Note that while there are 7 excursions attributed to operation of the Moffat Project, there are no DM temperature standard exceedances for 1987. As Figure 46 illustrates, the excursions that occur in June are well below the DM temperature standard, averaging approximately 10°C below the standard in early June and approximately 5°C below the standard in late June.

WATs

Figure 47 shows the 15% assimilative capacity threshold. The threshold ranges from 0.49°C to 2.04°C. Figure 48 compares the number of excursions to the threshold based on current conditions. There are 26, 39 and 39 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Figure 49 further summarizes the number of excursions by month. The difference in excursions between EIS 345 and Alt 1a occurs in June and July, in which the operation of the Moffat Project contributes an additional 9 excursions in June and 4 in July. Note that while there are 13 excursions attributed to operation of the Moffat Project, there are no WAT temperature standard exceedances for 1987. As Figure 50 illustrates, the excursions that occur in June and July are below the WAT temperature standard, averaging approximately 9°C below the standard in June and approximately 3°C below the standard in July.

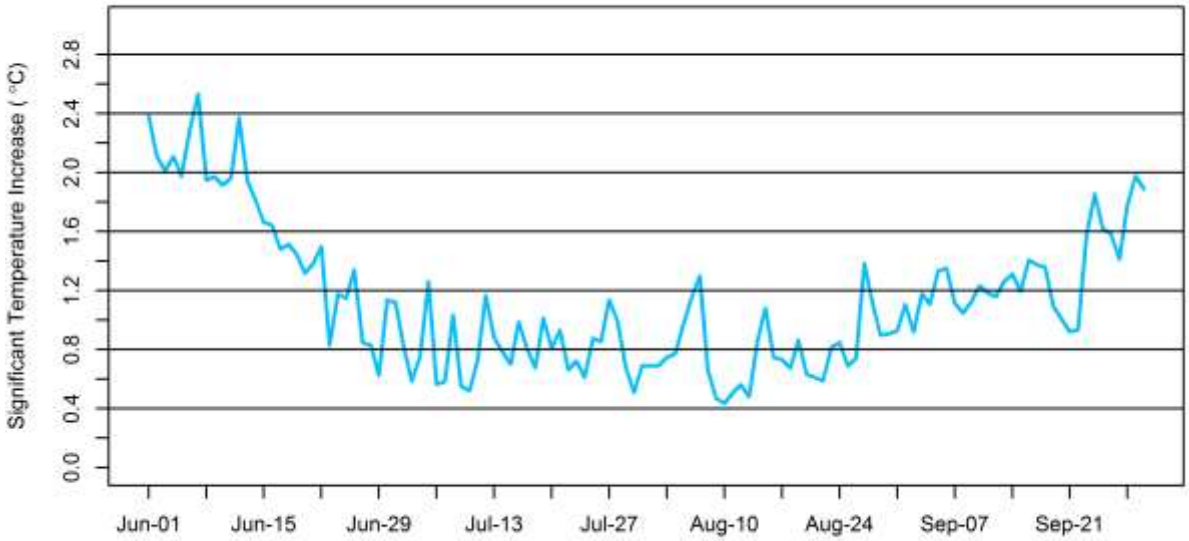

Figure 43. DM 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1987.

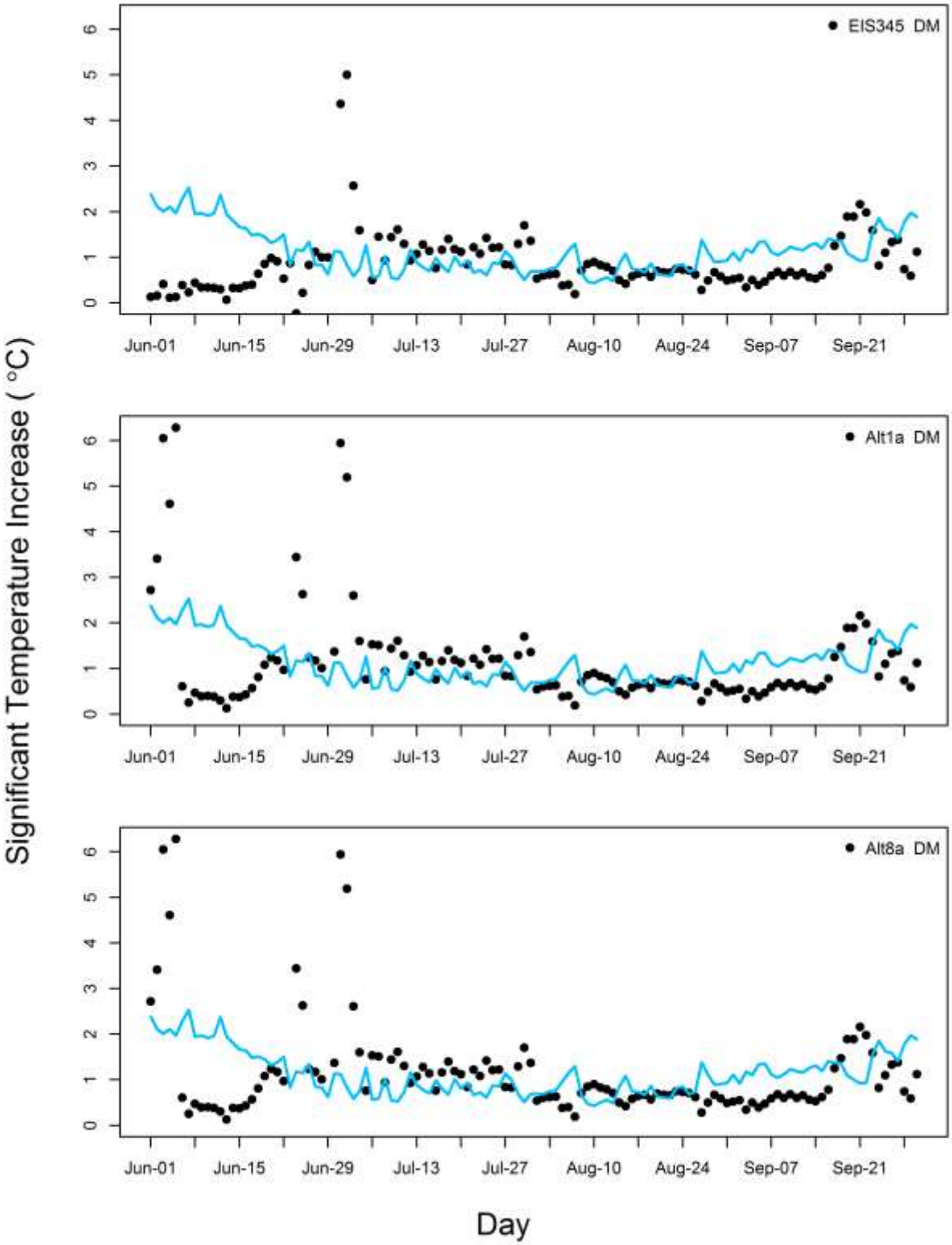

Figure 44. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1987.

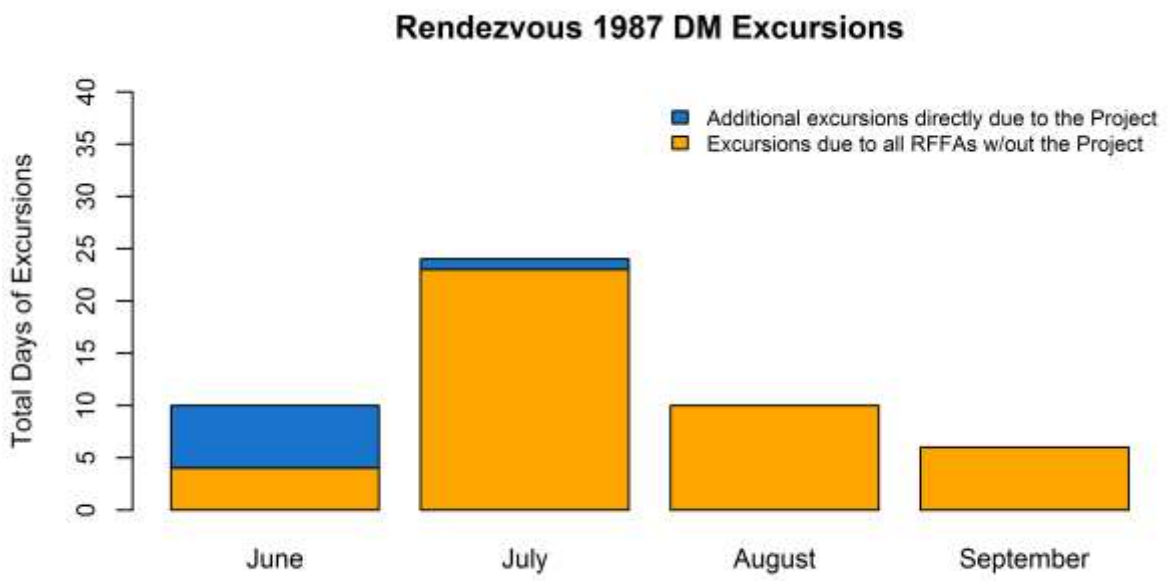

Figure 45. Summary of DM temperature excursions for 1987, Fraser River at Rendezvous Bridge.

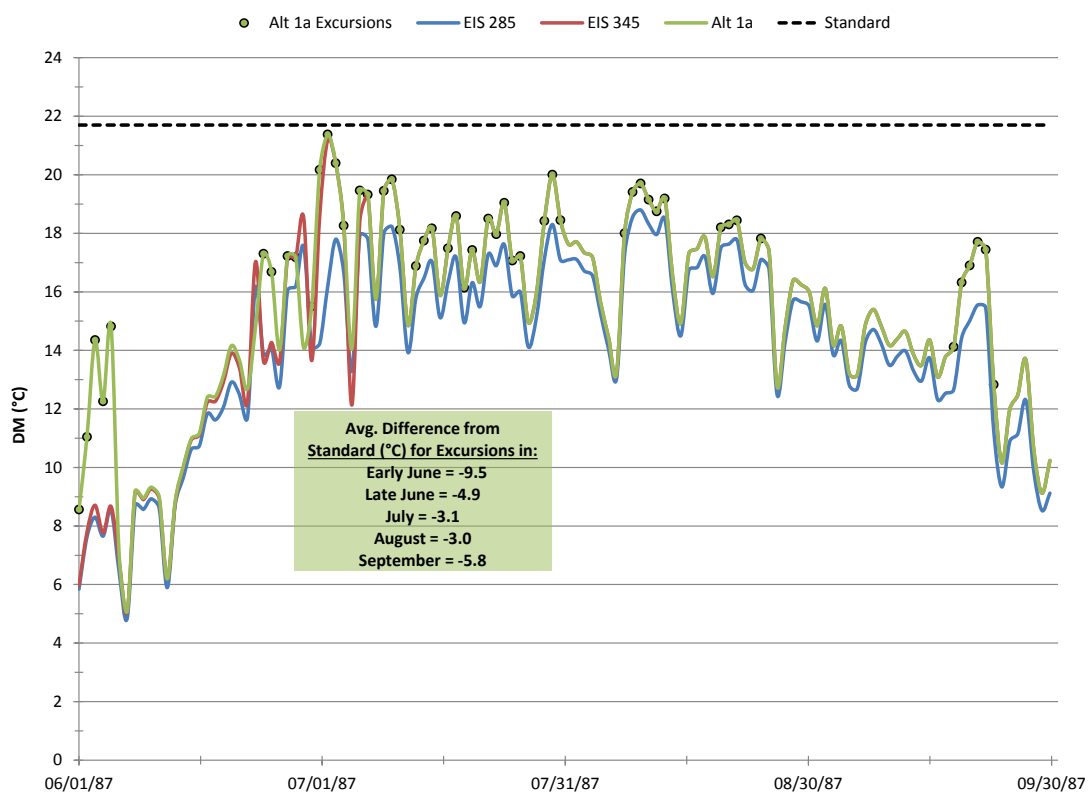

Figure 46. Alt 1a DM temperature excursions for 1987 (circles), compared to EIS 285, EIS 345 and the temperature standard.

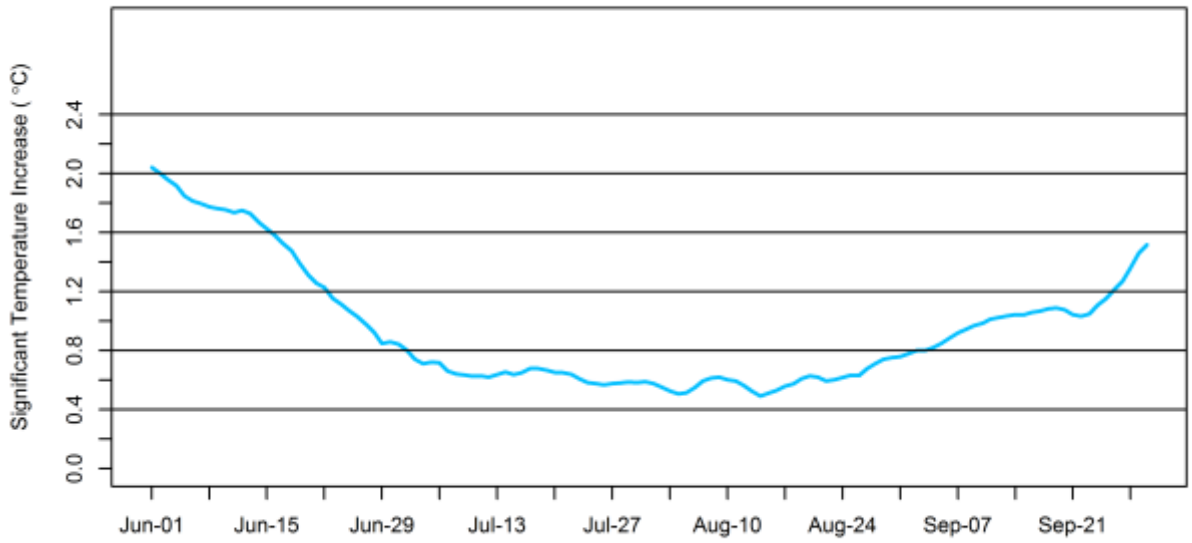

Figure 47. WAT 15% assimilative capacity threshold, Fraser River at Rendezvous Bridge, 1987.

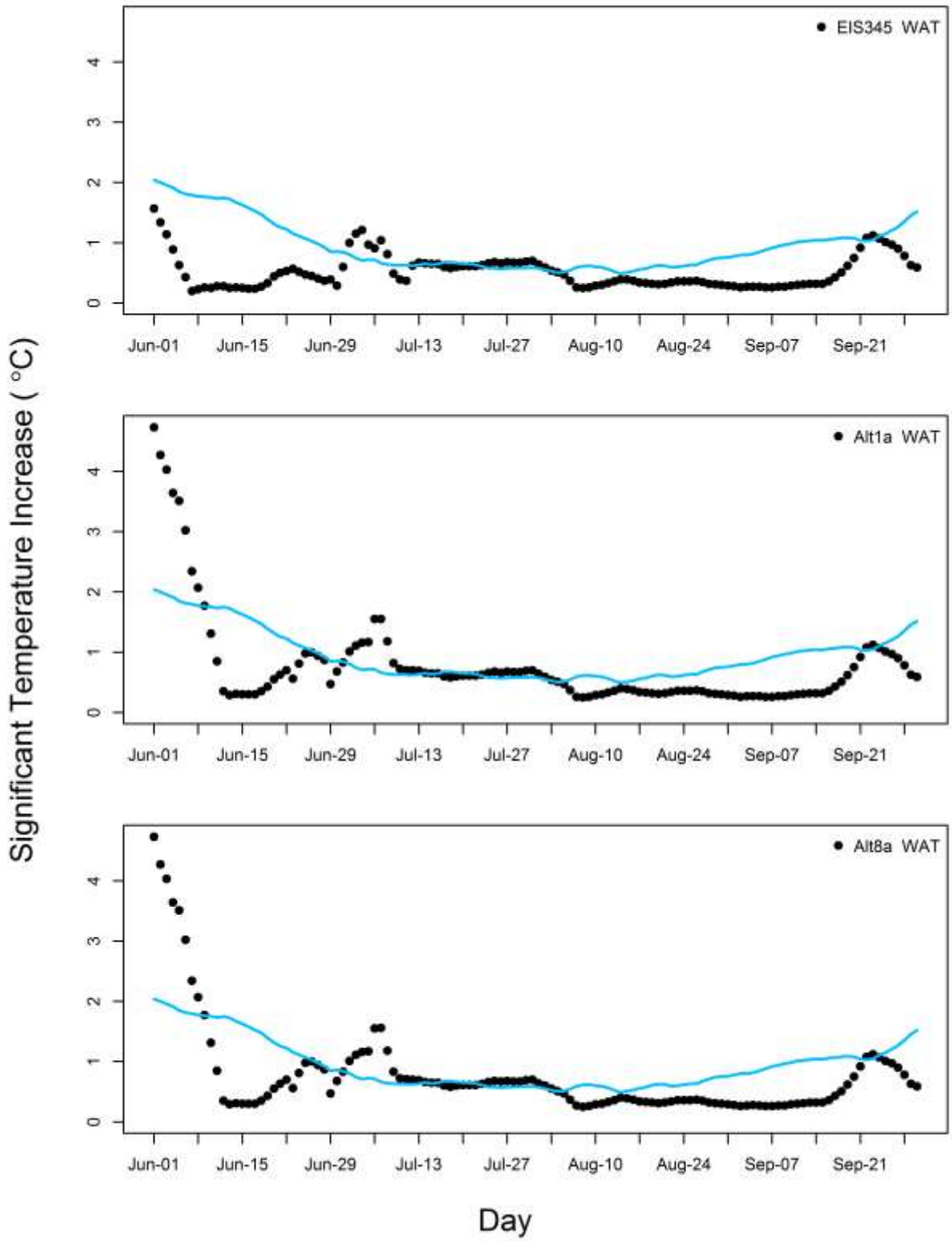

Figure 48. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River at Rendezvous Bridge, 1987.

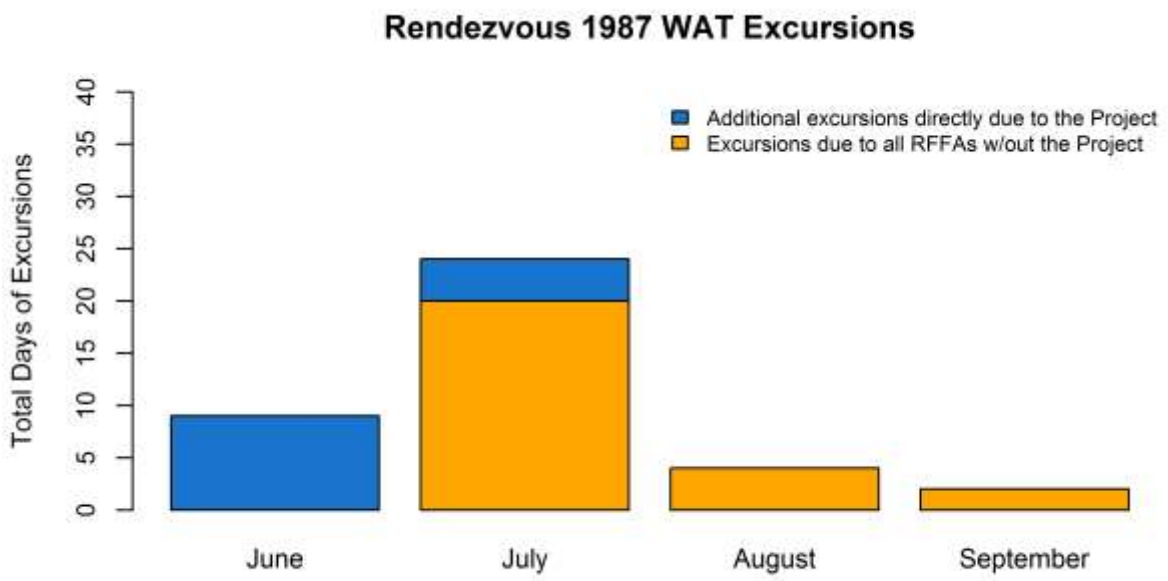

Figure 49. Summary of WAT temperature excursions for 1987, Fraser River at Rendezvous Bridge.

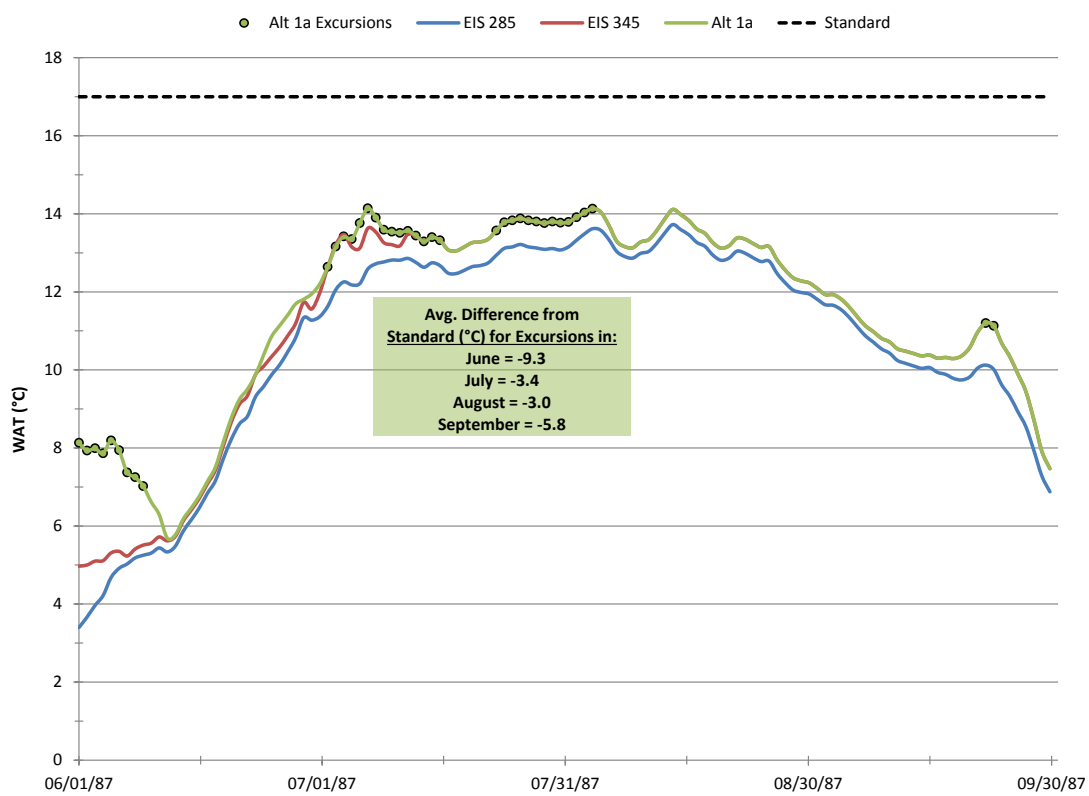

Figure 50. Alt 1a WAT temperature excursions for 1987 (circles), compared to EIS 285, EIS 345 and the temperature standard.

Summary of Scenario Year Results

Summaries of DM and WAT threshold excursions and temperature standard exceedances for all scenario years are provided in Table 4 and Table 5. DM and WAT excursions occur in all months (June through September) in all five years. The increases in temperature resulting in excursions do not result in exceedances of the DM or WAT standards, except for 5 days above the DM standard in the 1963 simulation (2% of the time). There were no days above the WAT standard in any of the five years.

The Moffat Project would contribute to only a small portion of the DM and WAT excursions, primarily in June and to a very limited extent in July for WAT excursions. The number of excursions is greater for Alt 1a than for EIS 345 in three months for DMs and four months for WATs. The differences in excursions between EIS 345 and Alt 1a are the differences that can be attributed to the operation of the Moffat Project. Therefore, for DMs, the operation of the Moffat Project contributes additional excursions in three of the 20 months that were evaluated. For WATs, the operation of the Moffat Project contributes additional excursions in four of the 20 months that were evaluated.

Table 4. Summary of excursions of the DM 15% assimilative capacity threshold (top) and exceedances of the temperature standard (bottom), Fraser River at Rendezvous Bridge. Months that met the critical conditions criteria are highlighted in blue.

	1948			1959			1963			1978			1987		
Month	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**
June	5	17	17	9	9	9	24	24	24	10	10	10	4	10	10
July	9	8	9	23	23	23	31	31	31	28	28	28	23	24	24
August	8	8	8	10	10	10	29	29	29	29	29	29	10	10	10
September	5	5	5	4	4	4	19	19	19	18	18	18	6	6	6
Totals	**27**	**38**	**39**	**46**	**46**	**46**	**103**	**103**	**103**	**85**	**85**	**85**	**43**	**50**	**50**

	1948				1959				1963				1978				1987			
Month	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**
Days Above DM Standard:																				
June	0	0	0	0	0	0	0	0	0	2	2	2	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	3	3	3	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**5**	**5**	**5**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Table 5. Summary of excursions of the WAT 15% assimilative capacity threshold (top) and exceedances of the temperature standard (bottom), Fraser River at Rendezvous Bridge. Months that met the critical conditions criteria are highlighted in blue.

	1948			1959			1963			1978			1987		
Month	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**
June	1	18	18	0	0	0	16	16	16	0	0	0	0	9	9
July	1	2	2	13	13	13	31	31	31	30	30	30	20	24	24
August	0	0	0	0	0	0	31	31	31	31	31	31	4	4	4
September	0	0	0	0	0	0	16	16	16	19	19	19	2	2	2
Totals	**2**	**20**	**20**	**13**	**13**	**13**	**94**	**94**	**94**	**80**	**80**	**80**	**26**	**39**	**39**

	1948				1959				1963				1978				1987			
Month	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**
Days Above WAT Standard:																				
June																				
July	None				None				None				None				None			
August																				
September																				

Generalization of Scenario Year Results to the 45-Year Dataset

The temperature impacts predicted from the scenario years should be extrapolated to the 45-year dataset to gain an understanding of how frequently those impacts are likely to occur in the future. To review, the scenario years were selected because CDPHE determined that they represent the critical conditions under which cumulative flow effects are greatest and temperature impacts are most likely to occur. Critical conditions were defined as months in which the flow reduction from EIS 285 to Alt 1a was greater than 10% and months in which Alt 1a flows were less than the median of the 45-year dataset. No scenario year met the critical conditions criteria for every month of the six-month focus period. In total, 11 months out of the 30 months that were evaluated (6 months x 5 years) met both criteria.

Table 6 summarizes the number of DM and WAT temperature excursions by month. When critical conditions are present (rows highlighted in blue), it is estimated that there will be temperature excursions due to all cumulative effects from June through September. Yet, temperature excursions are also predicted in years that were not defined as critical. We then decided to split the 45-year dataset into months that represent critical conditions (n = 22 from June-September; refer to Table 3) and those that do not represent critical conditions (n = 158). Using the results from the scenario years, we then totaled the number of excursions under critical conditions and extrapolated to the 45-year dataset and totaled the number of excursions under non-critical conditions and extrapolated to the 45-year dataset. We then added those numbers together to estimate the percent of the time the temperature threshold is expected to be exceeded. Results are detailed below.

DM Excursions

Of the 610 days in the 5-year simulation period (June-September (122 days) x 5 years), 274 days met the critical conditions criteria (45%), whereas 336 days did not meet the criteria (55%).

- **Cumulative Effects Including the Moffat Project:** In the 5-year simulation period, the DM assimilative capacity threshold is exceeded a total of 190 days (of 274 days) during the months that met the critical conditions criteria, which equates to 69% of the days. The DM assimilative capacity threshold is exceeded a total of 132 days (of 336 days) during the months that were not considered to represent critical conditions, which equates to 39% of the days. Given that critical conditions are expected in 22 months of the 45 years (180 months), we would expect the threshold to be exceeded 43% of the time from June through September:

$$(69\% \times (22/180)) + (39\% \times (158/180)) = 43\%$$

- **Effects Attributable to the Moffat Project:** In the 5-year simulation period, the DM assimilative capacity threshold is exceeded a total of 18 days (of 274 days) during the months that met the critical conditions criteria, which equates to 7% of the days. The DM assimilative capacity threshold is exceeded for 0 days (of 336 days) during the months that were not considered to represent critical conditions. Using the same logic as above, we would expect the threshold to

be exceeded 0.9% of the time from June through September due to operation of the Moffat Project:

$$(7\% \times (22/180)) + (0\% \times (158/180)) = 0.9\%$$

DM excursions directly due to operation of the Moffat Project are expected to occur primarily in June, but will likely be well below the temperature standard.

Table 6. Number of temperature excursions by month. Rows highlighted in blue are the scenario years that met the two flow criteria. Note the numbers in parentheses are the number of simulated excursions due to operation of the Moffat Project.

	% Reduction in Flow	Alt 1a Flow (AF/month)	# of DM Excursions	# of WAT Excursions
June				
1963	16.4	3,773	24 (0)	16 (0)
1959	13.2	14,364	9 (0)	0 (0)
1948	45.4	17,542	17 (12)	18 (17)
1987	18.9	18,302	10 (6)	9 (9)
1978	1.6	22,976	10 (0)	0 (0)
July				
1963	21.3	2,552	31 (0)	31 (0)
1959	21.8	3,813	23 (0)	13 (0)
1948	9.1	4,387	8 (0)	2 (1)
1978	34.5	5,551	28 (0)	30 (0)
1987	8.0	3,210	24 (1)	24 (4)
August				
1978	23.8	2,017	29 (0)	31 (0)
1963	17.4	2,838	29 (0)	31 (0)
1948	3.4	3,272	8 (0)	0 (0)
1959	3.5	3,056	10 (0)	0 (0)
1987	4.2	2,524	10 (0)	4 (0)
September				
1978	11.3	1,708	18 (0)	19 (0)
1948	3.6	1,797	5 (0)	0 (0)
1959	2.1	2,198	4 (0)	0 (0)
1963	10.4	2,487	19 (0)	16 (0)
1987	2.6	2,065	6 (0)	2 (0)

WAT Excursions

- **Cumulative Effects Including the Moffat Project:** In the 5-year simulation period, the WAT assimilative capacity threshold is exceeded a total of 168 days (of 274 days) during the months that met the critical conditions criteria, which equates to 61% of the days. The WAT assimilative capacity threshold is exceeded a total of 78 days (of 336 days) during the months that were not considered to represent critical conditions, which equates to 23% of the days. Given that critical conditions are expected in 22 months of the 45 years (180 months), we would expect the threshold to be exceeded 28% of the time from June through September:

$$(61\% \times (22/180)) + (23\% \times (158/180)) = 28\%$$

- **Effects Attributable to the Moffat Project:** In the 5-year simulation period, the WAT assimilative capacity threshold is exceeded a total of 26 days (of 274 days) during the months that met the critical conditions criteria, which equates to 9% of the days. The WAT assimilative capacity threshold is exceeded a total of 5 days (of 336 days) during the months that were not considered to represent critical conditions, which equates to 1% of the days. Using the same logic as above, we would expect the threshold to be exceeded 2% of the time from June through September due to operation of the Moffat Project:

$$(9\% \times (22/180)) + (1\% \times (158/180)) = 2\%$$

WAT excursions directly due to operation of the Moffat Project are expected to occur in June and July. Temperatures in June will likely be well below the temperature standard.

Note that with this methodology it is not possible to predict the number of excursions for a particular year. But, given the results presented above, we anticipate that years that contain months representative of critical conditions will have more excursions than years that do not have months that exhibit critical conditions. Of the 45 years in the complete dataset, 31 do not have any months that would be considered critical.

Biological Context for Temperature Excursions

The additional DM and WAT excursions that are directly attributable to the Moffat Project occur primarily in June. Yet, the temperatures at which excursions occur are well below the temperature standard. In early June, excursion temperatures for both DMs and WATs are approximately 10°C below the standard and in late June temperatures are approximately 6°C below the standard. It is important to consider how biologically significant these excursions are when the baseline temperatures that are used for comparison are cool. For example, in 1948 the DM temperatures in early June for Alt 1a in which excursions occur range from 7.5 to 11.7°C. In comparison, the DM temperatures for EIS 285 and EIS 345 during the same dates range from 4.9 to 8.6°C. These temperatures are colder than the lower limit for optimum temperature for some trout species and longnose sucker (Table 7). For WATs in 1948, temperatures in early June for Alt 1a in which excursions occur range from 5.7 to 7.2°C. In contrast, the

Table 7. Lower and upper optimum temperature limits for species expected to be present in Tier I and Tier II coldwater streams (Source: CDPHE unpublished data from temperature database 2004).

Species	Optimum Temperature*	
	Lower Limit (°C)	Upper Limit (°C)
Cutthroat trout	9.6	14
Cutthroat trout – spawning	7.4	10.5
Brook trout	11.7	16.4
Brook trout – spawning	5.8	9.6
Rainbow trout	13.7	18.8
Rainbow trout – spawning	6.8	12.8
Brown trout	11.6	16.1
Brown trout – spawning	4.5	11.5
Longnose sucker	10	13.1

* Optimum temperature is "derived from the species-specific performance over a range of temperatures and includes parameters such as growth rate, digestion rate, gross conversion efficiency, swimming performance, metabolic rate, cardiac rate, etc." (CDPHE 2011). The DM and WAT temperature standards were developed from these data. Insufficient data for mountain whitefish, mottled sculpin and Arctic grayling.

WAT temperatures for EIS 285 and EIS 345 during the same dates range from 3.3 to 5.2°C. The operation of the Moffat Project is predicted to increase water temperatures in some months. The increase in water temperature changes the temperature from lower than optimum temperature to within the optimum temperature range, in particular for cutthroat trout and spawning rainbow trout. The change in temperature does not follow the natural pattern; however, the slight warming may be biologically beneficial.

Meteorological Context for Scenario Years

The Fraser River dynamic water temperature model simulated hourly water temperatures for the five scenario years and all years used the same meteorological data from 2007, thus the primary difference between streamflow scenarios and scenario years was flow. 2007 was one of the hottest years on record, particularly for July and August. Indeed, 2007 was warmer than the 30-year average for nearly all of June through September (Figure 51). The choice of this year for the simulations was intentional because using a warm year is more likely to provide a defensible characterization of critical conditions than would an average year (CDPHE 2014b). As was stated in the report for the Fraser River dynamic water temperature model, the combination of the selected scenario years and "hot" meteorology may have resulted in overestimates of stream temperatures. The result is that baseline temperatures were developed from warmer temperatures, which resulted in less assimilative capacity. Consequently, it is easier for changes in flow to cause excursions.

We think it is important to further investigate the potential role that 2007 air temperatures play in estimating impacts from the Moffat Project. Figure 52 shows the assimilative capacity threshold, 2007 average daily air temperature and flow from mid-July to early September for scenario year 1948 for the Fraser River at Rendezvous Bridge, as well as Alt 1a DM excursions (black dots that are above the threshold line). During this period, the assimilative capacity threshold is a near mirror-image of 2007 average daily air temperature. Seeing that flows fluctuate very little during this time (bottom of Figure 52), the variability in the threshold is seemingly a reflection of air temperature, not differences in flows. Using a different set of air temperatures would therefore seem likely to produce a different assimilative capacity threshold. The degree to which the number of excursions would change is uncertain. Other examples from 1959 and 1987 are provided in Figure 53 and Figure 54, respectively.

Overall, we think the selection of 2007 air temperatures potentially has a significant role in determining temperature impacts from the Moffat Project. Since stream temperatures are largely controlled by air temperature (Miller Ecological Consultants, Inc. 2014), all of the analyses that have been undertaken, from the temperature model simulations to the antidegradation review, have been a reflection of the 2007 air temperature data. We caution against over-generalizing results to future years because all of the results are very specific to 2007 data. The similarity between future year daily air temperature patterns and the 2007 pattern of air temperature is unknown. The focus should be more on trends in the dataset and less on individual day values.

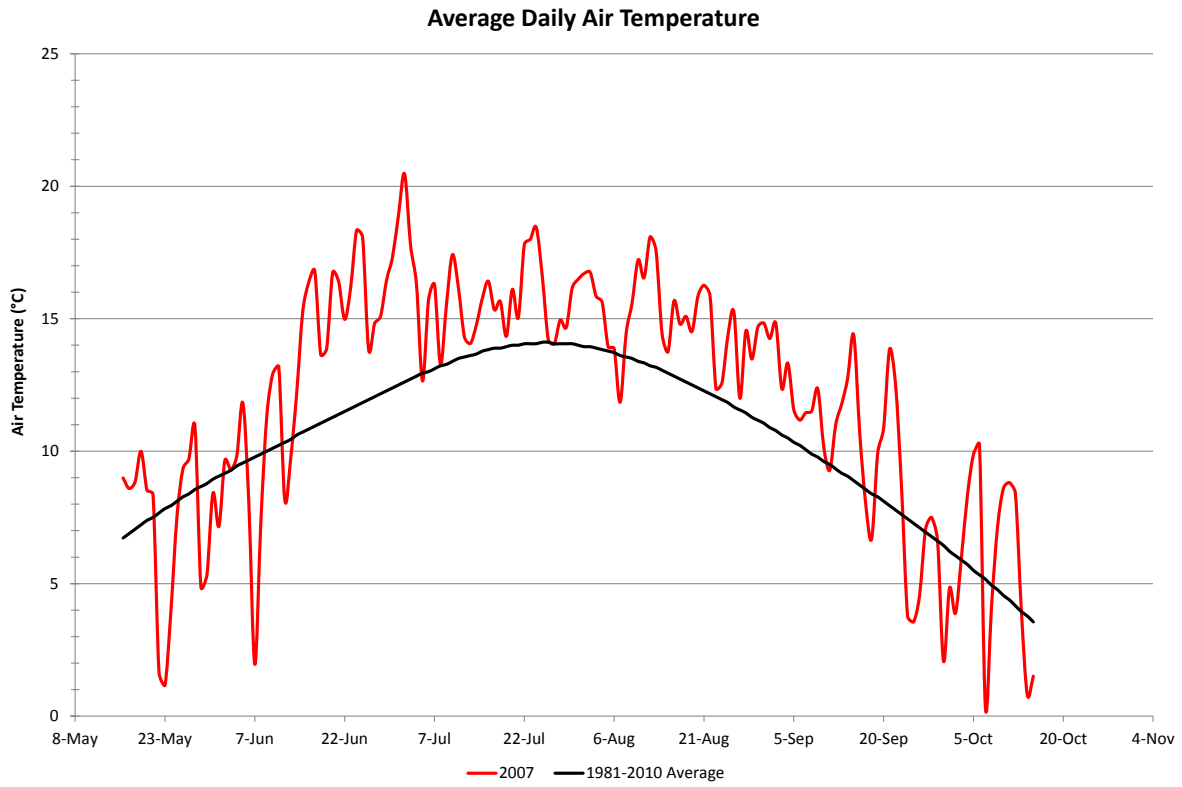

Figure 51. 2007 average daily air temperature at Tabernash compared to the 30-year average (1981-2010).

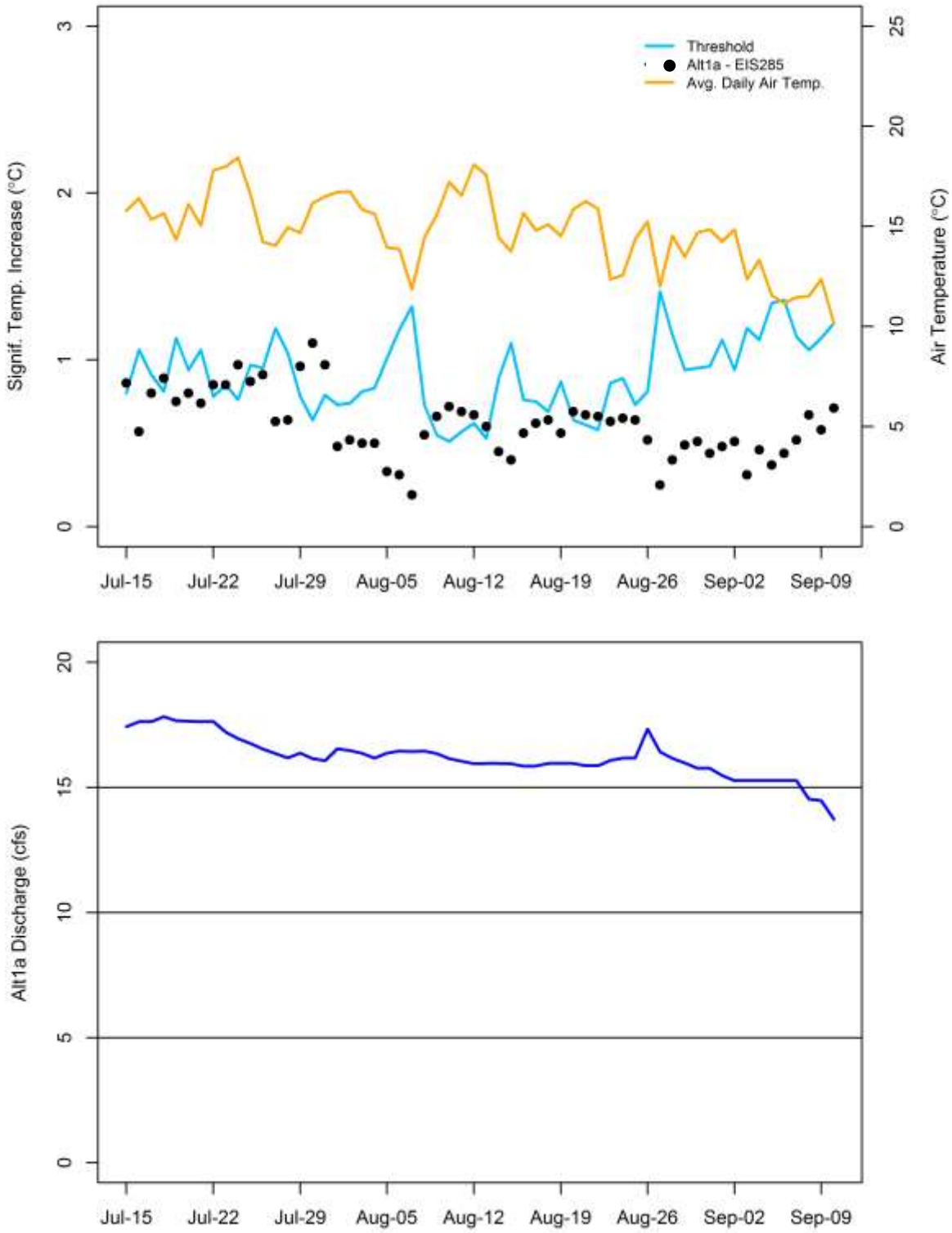

Figure 52. Comparison of the assimilative capacity threshold to 2007 average daily air temperature and Alt 1a flows, Fraser River at Rendezvous Bridge, 1948. Black dots above the blue threshold line indicate excursions.

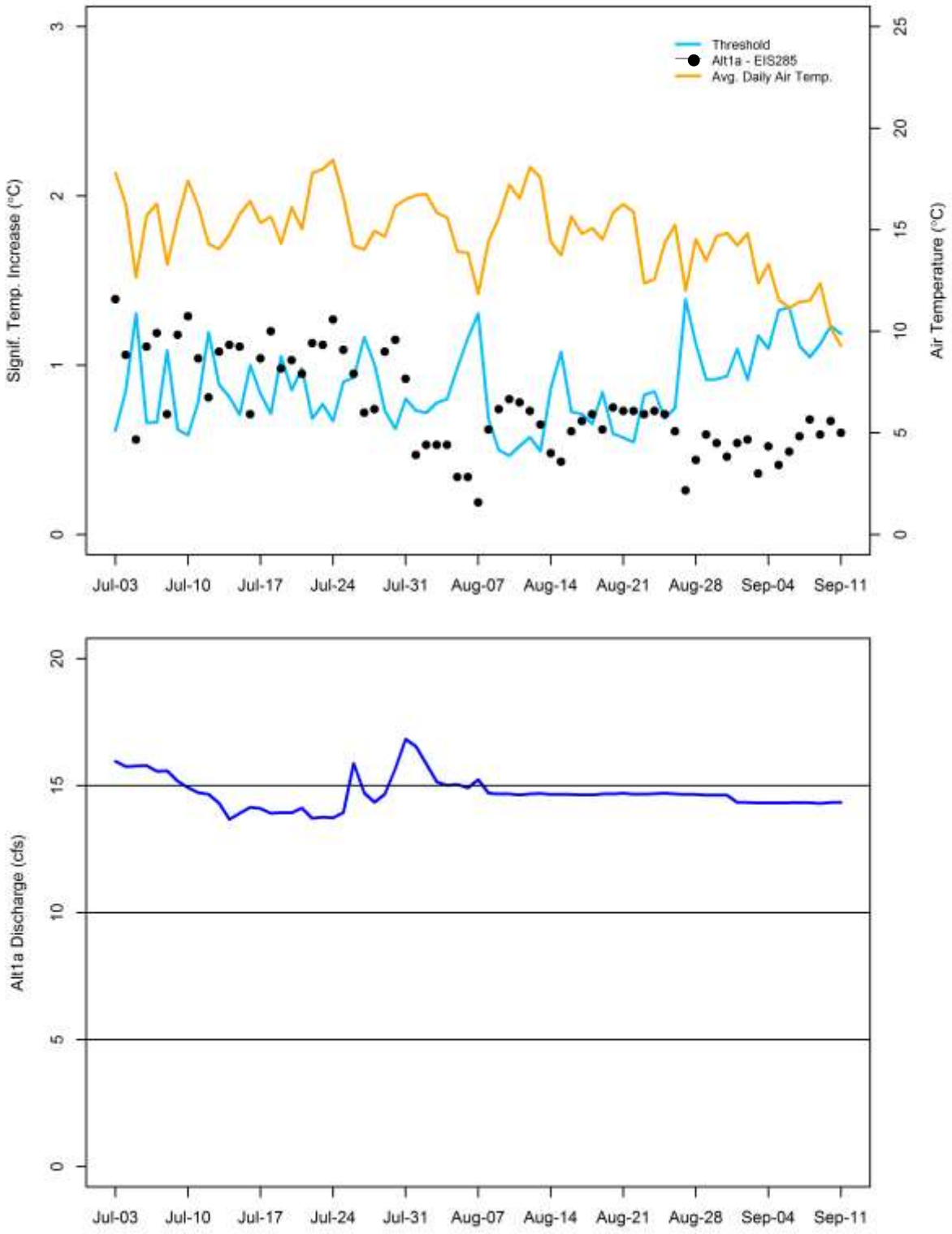

Figure 53. Comparison of the assimilative capacity threshold to 2007 average daily air temperature and Alt 1a flows, Fraser River at Rendezvous Bridge, 1959. Black dots above the blue threshold line indicate excursions.

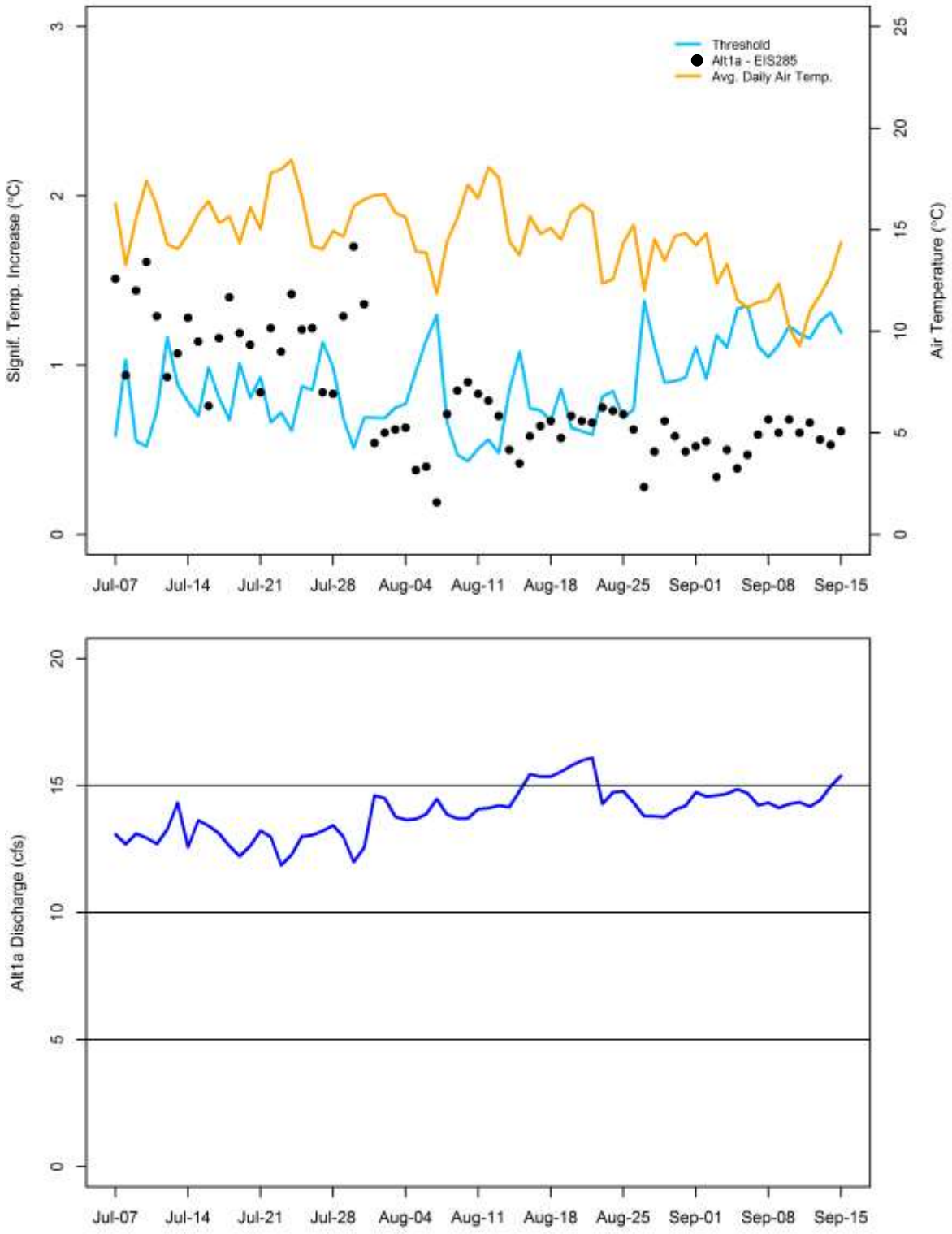

Figure 54. Comparison of the assimilative capacity threshold to 2007 average daily air temperature and Alt 1a flows, Fraser River at Rendezvous Bridge, 1987. Black dots above the blue threshold line indicate excursions.

Fraser River below the Granby Sanitation District

Development of Baseline Conditions

For the Fraser River below the Granby Sanitation District, 15-minute water temperature data were available from 2008 through 2013. With the exception of 2009 none of the years had a complete record of data from May 16 to October 15. First, DMs and WATs were calculated with the CDPHE Temperature Analysis Program macro. Any days that were missing more than 4 hours of temperature data were removed from further analysis. DMs for each year are shown in Figure 55. Following the assessment methodology, the highest DM and WAT were discarded on each ordinal day, as long as at least three years of data were available for that day. The single DM value for each day is shown in Figure 56. We only included days where the DM was consistently above zero, which was from March 24 to November 22. Although there were missing data for most years, this did not cause any problems with calculating a single DM or WAT value for each day, unlike the Rendezvous Bridge location. Therefore, we did not feel it was necessary to fill in any of the missing data.

The historical baseline DM values were then smoothed using the equation that was provided in the assessment methodology (CDPHE 2013). The best fit regression line to the data is shown in Figure 57. The R^2 is 0.93. The fit of the smoothed curve to the baseline DMs is shown in Figure 58.

The same methodology was used to develop smoothed historical baseline WAT values. The fit of the regression line to the data is shown in Figure 59. The R^2 is 0.97. The fit of the smoothed curve to the baseline WATs is shown in Figure 60.

Baseline DM and WAT curves based on current conditions for each scenario year were then developed and compared to the historical baseline curves (Figure 61 and Figure 62). For DMs, the current conditions curves tended to be cooler than the historical baseline curve until mid-June; then the curves are warmer than the historical baseline curve through October. 1963 had some particularly warm temperatures in late June and early July. For WATs, the same overall pattern was observed except that the 1963 curve was nearly always warmer than the historical baseline curve. Warmer current conditions baselines are not unexpected, given the nature of the scenario years and meteorology that were chosen for model simulations, as was discussed for the Fraser River at Rendezvous Bridge. Likewise, it was agreed upon to use current conditions baselines for the antidegradation analysis. The use of current conditions baselines means that all comparisons that are made are from temperatures that were simulated under the same set of meteorological conditions. This was deemed more appropriate than comparing simulated temperatures to a historical baseline that was developed under a different set of meteorological conditions.

The BAI was then calculated, which was the difference between the standard (23.8°C for the DM and 18.2°C for the WAT for a Tier II stream) and the baseline values from the current conditions curves. The 15% assimilative capacity threshold curves are provided in the results section for each scenario year.

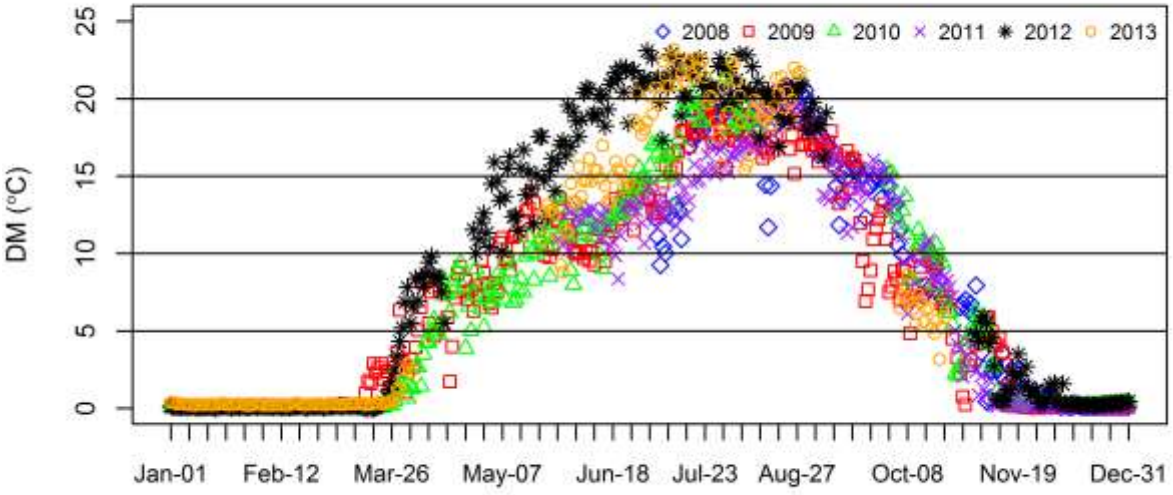

Figure 55. DM temperatures for the Fraser River below the Granby Sanitation District, 2008-2013.

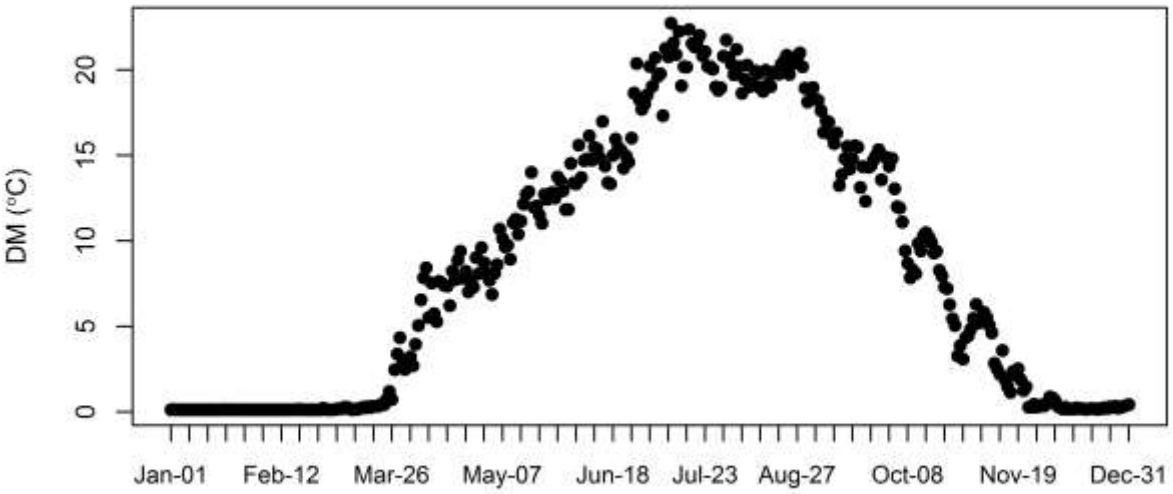

Figure 56. DMs used for each ordinal day for the Fraser River below the Granby Sanitation District.[2]

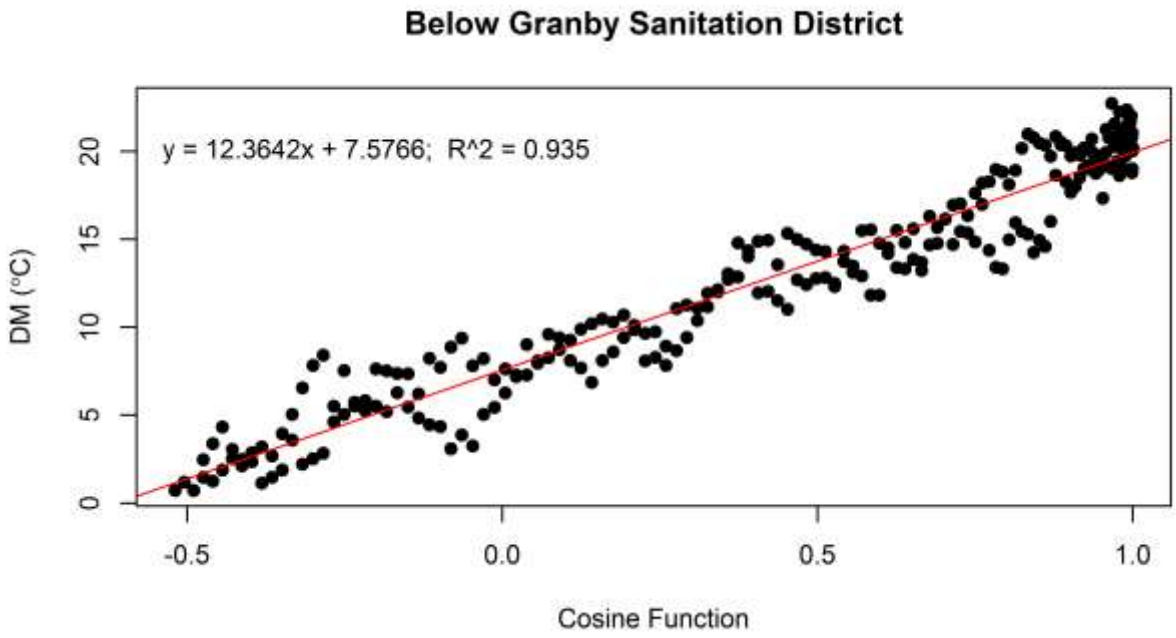

Figure 57. Regression analysis to determine the mean and amplitude of the harmonic function that characterizes the baseline DM, Fraser River below the Granby Sanitation District.

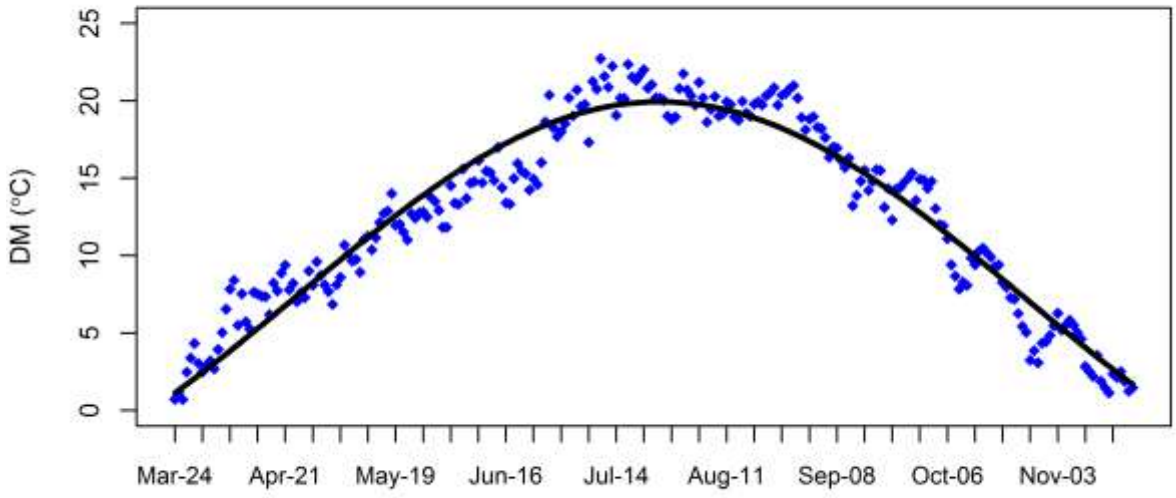

Figure 58. Fit of regression line to baseline DM values, Fraser River below the Granby Sanitation District.

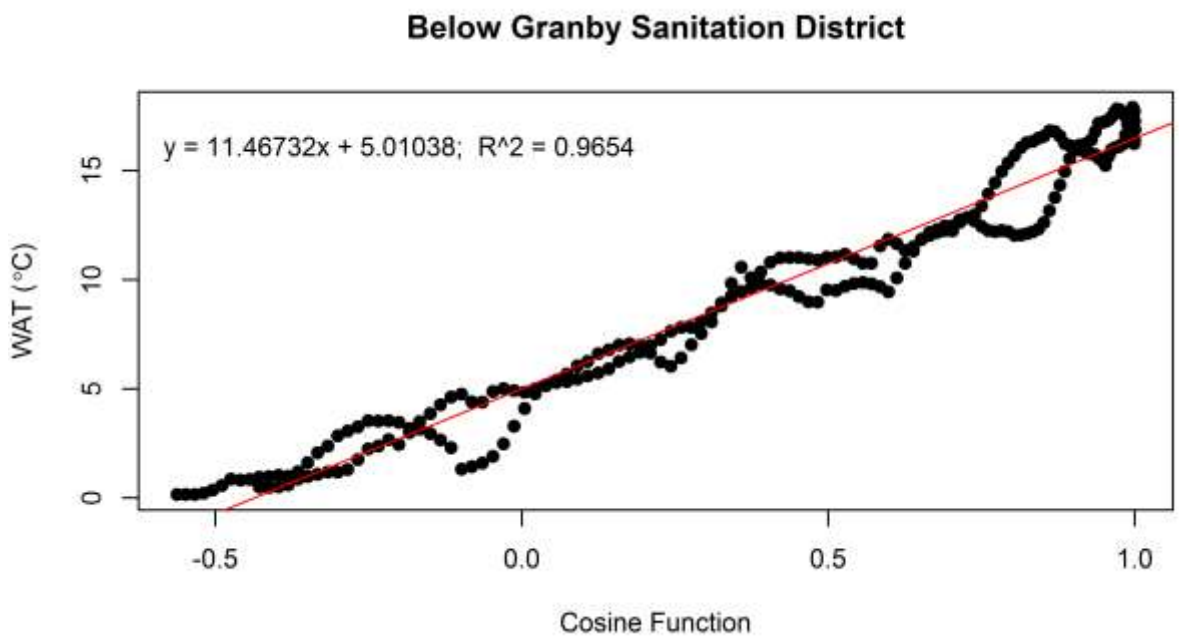

Figure 59. Regression analysis to determine the mean and amplitude of the harmonic function that characterizes the baseline WAT, Fraser River below the Granby Sanitation District.

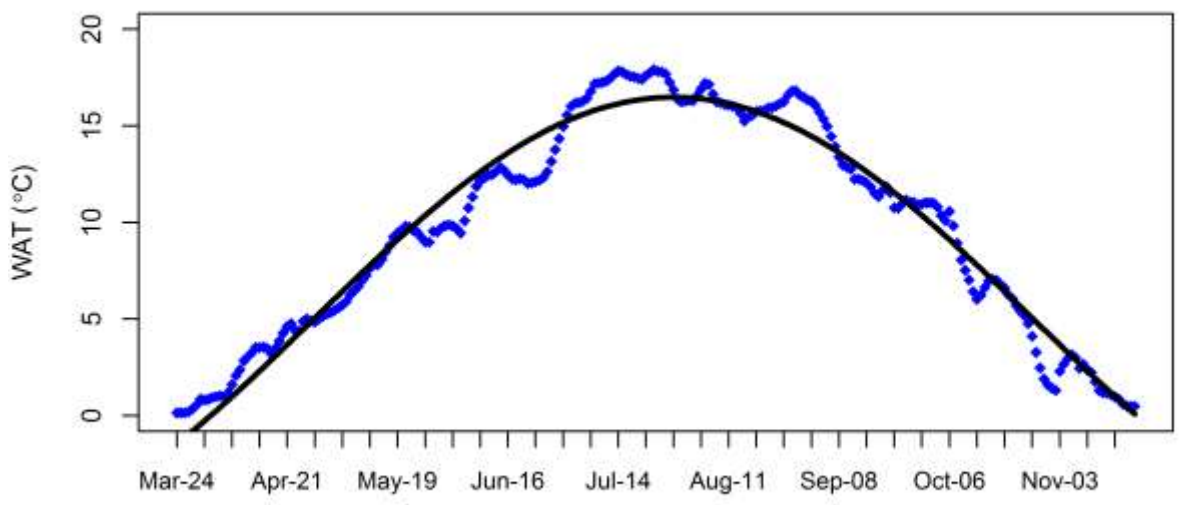

Figure 60. Fit of regression line to baseline WAT values, Fraser River below the Granby Sanitation District.

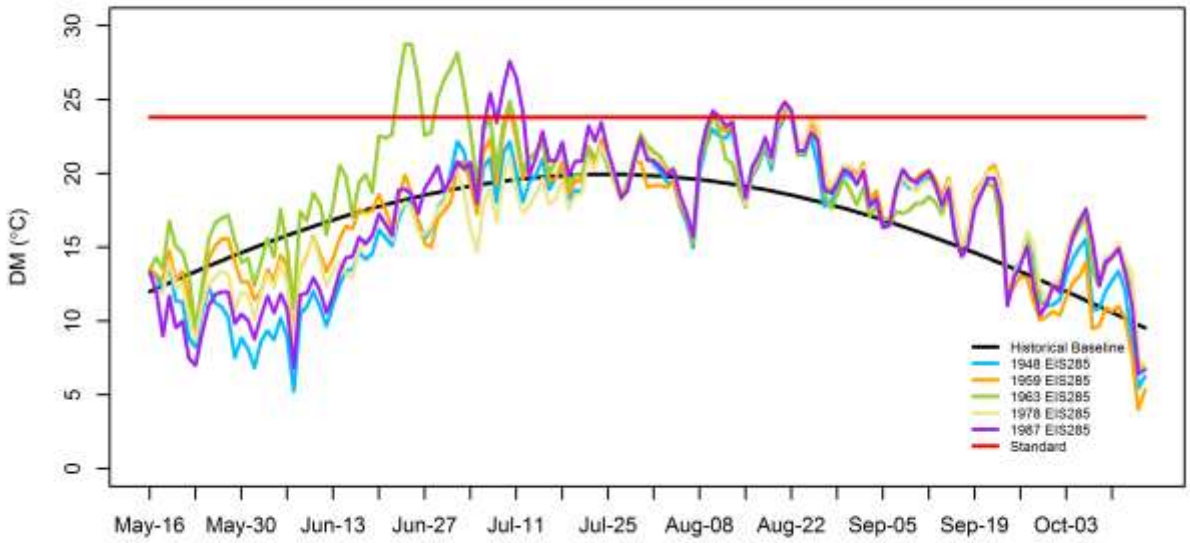

Figure 61. Comparison of scenario year baseline DM curves to the historical baseline DM curve, Fraser River below the Granby Sanitation District.

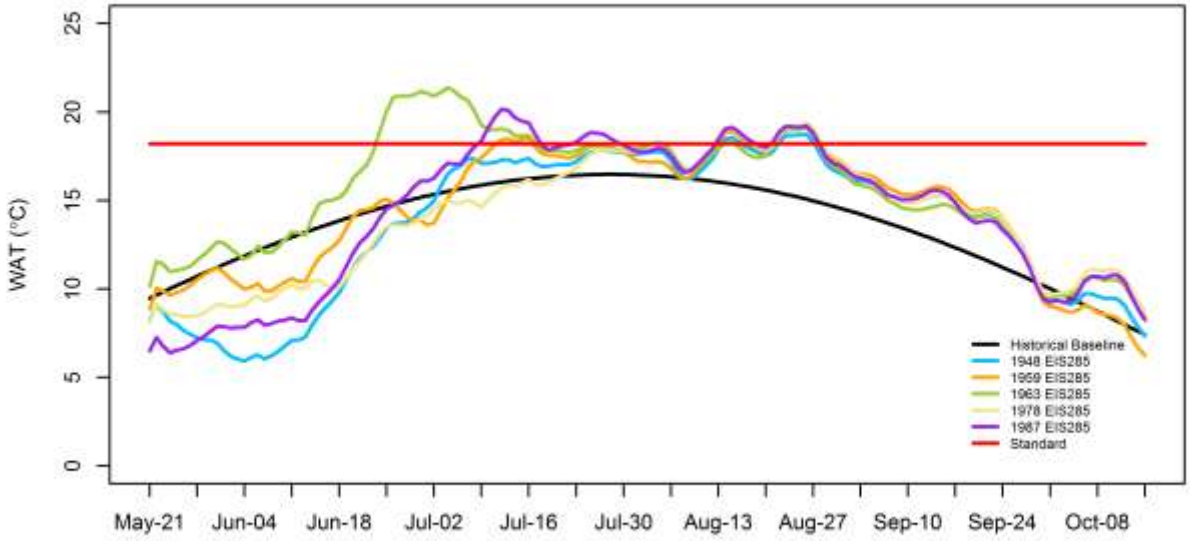

Figure 62. Comparison of scenario year baseline WAT curves to the historical baseline WAT curve, Fraser River below the Granby Sanitation District.

Comparisons of Simulated Temperatures to Daily Thresholds

The figures that follow compare the results of the model simulations for the years 1948, 1959, 1963, 1978 and 1987 to the daily thresholds. Again, it is important to understand that the figures illustrate the *difference* in predicted temperatures between future flow scenarios (EIS 345, Alt 1a and Alt 8a) and current conditions (EIS 285). While the difference between Alt 1a and EIS 285 was the primary interest, we also included results that compare EIS 345 to EIS 285 and Alt 8a to EIS 285. The difference in the results between EIS 345 and Alt1a provides a direct evaluation of the impacts of Moffat Project operations.

1948 Scenario Year

DMs

Figure 63 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 2.78°C. The threshold drops to zero because for many days under the EIS 285 flow scenario the predicted DM was above the temperature standard, which did not allow for any remaining assimilative capacity. This same pattern was observed for WATs and occurred in all scenario years. Figure 64 compares the number of excursions to the threshold based on current conditions. There are 6, 24 and 24 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Figure 65 further summarizes the number of excursions by month. The difference in excursions between EIS 345 and Alt 1a (excursions that are directly attributable to the Moffat Project) occurs in May and June, in which the Project contributes an additional 4 excursions in May and 14 excursions in June. Note that while there are 18 excursions attributed to operation of the Moffat Project, there are no DM temperature standard exceedances for 1948. As Figure 66 illustrates, the excursions that occur in May and June are well below the DM temperature standard, averaging approximately 11°C below the standard in May and early June and approximately 5°C below the standard in late June.

WATs

Figure 67 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 1.84°C. Figure 68 compares the number of excursions to the threshold based on current conditions. There are 11, 34 and 34 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Figure 69 further summarizes the number of excursions by month. The difference in excursions between EIS 345 and Alt 1a occurs in May and June, in which the Project contributes an additional 2 excursions in May and 21 excursions in June. Note that while there are 23 excursions attributed to operation of the Moffat Project, there are no WAT temperature standard exceedances for these months (Figure 70). As Figure 71 illustrates, the excursions that occur in May and June are well below the WAT temperature standard, averaging approximately 9°C below the standard in May, 8°C below the standard in early June and 3.5°C in late June.

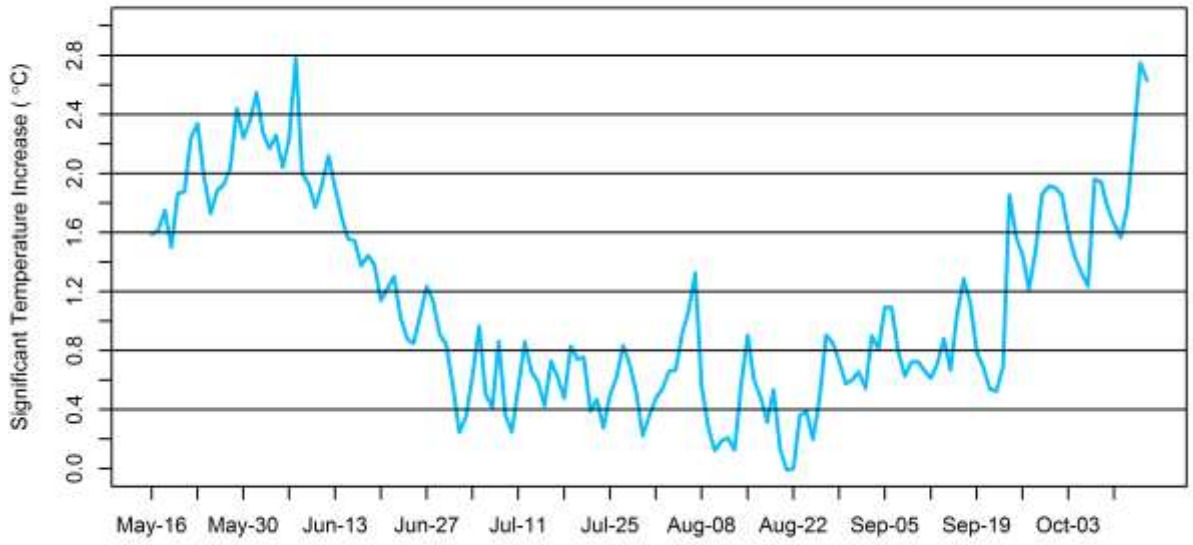

Figure 63. DM 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1948.

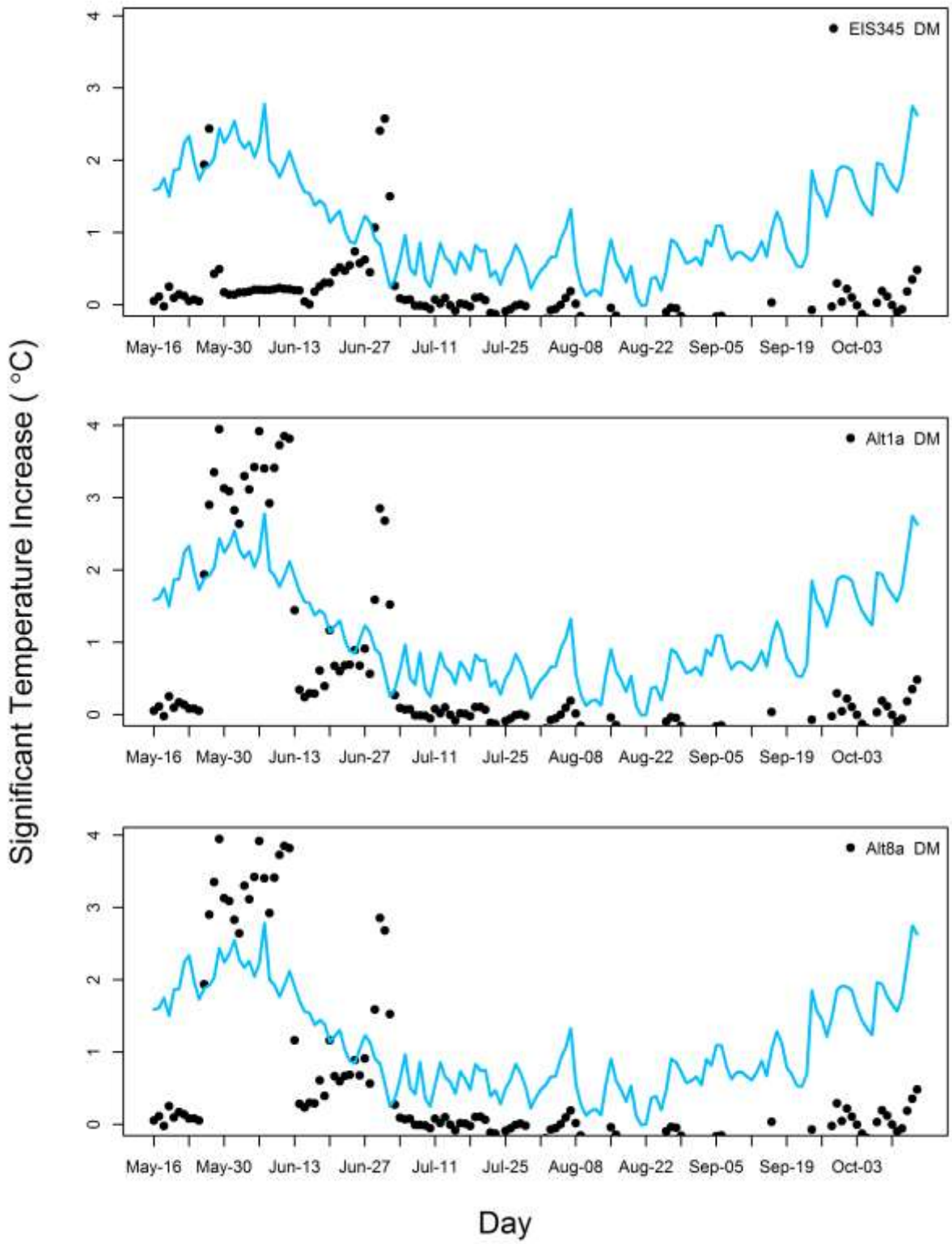

Figure 64. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1948.

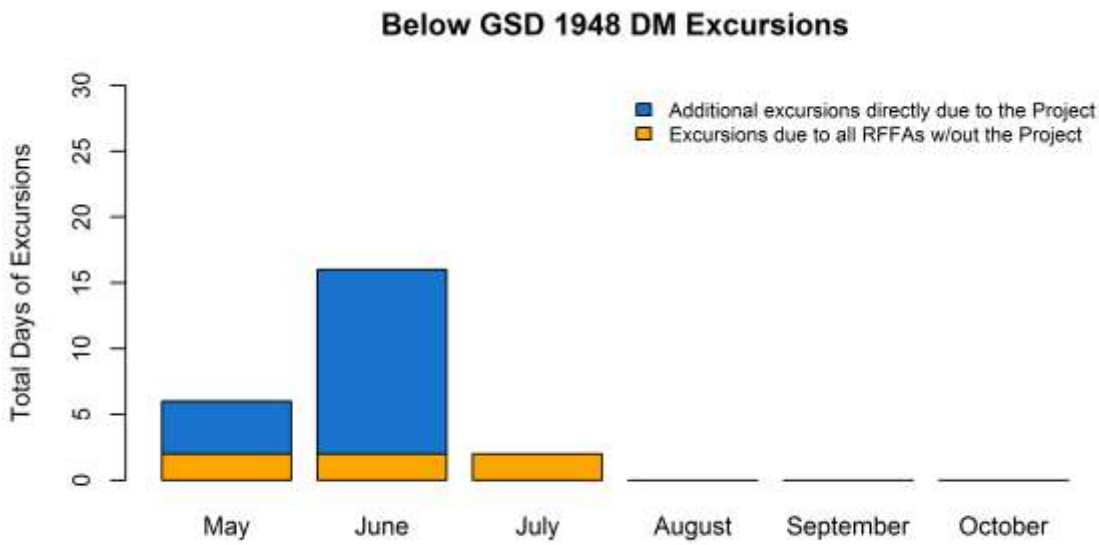

Figure 65. Summary of DM temperature excursions for 1948, Fraser River below the Granby Sanitation District.

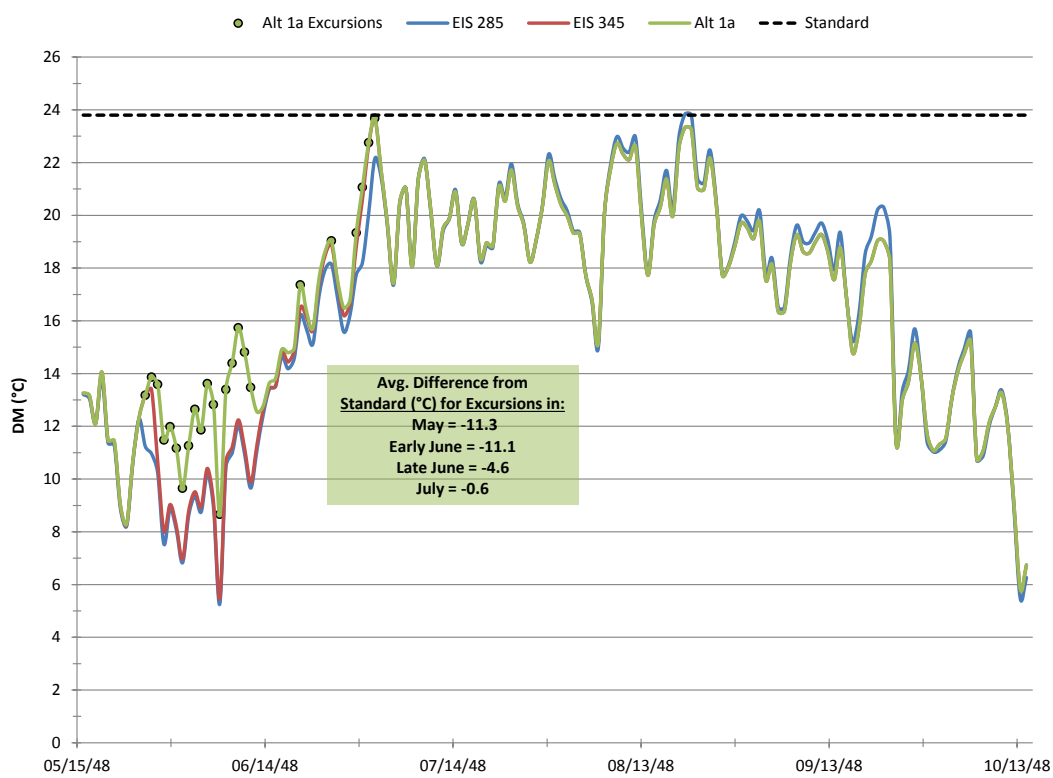

Figure 66. Alt 1a DM temperature excursions for 1948 (circles), compared to EIS 285, EIS 345 and the temperature standard.

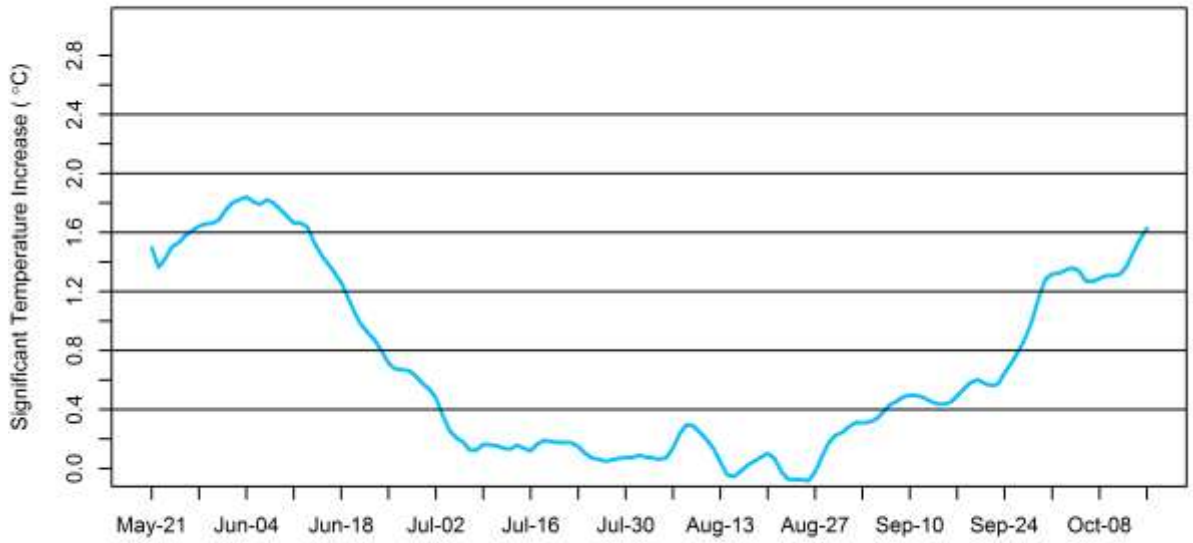

Figure 67. WAT 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1948.

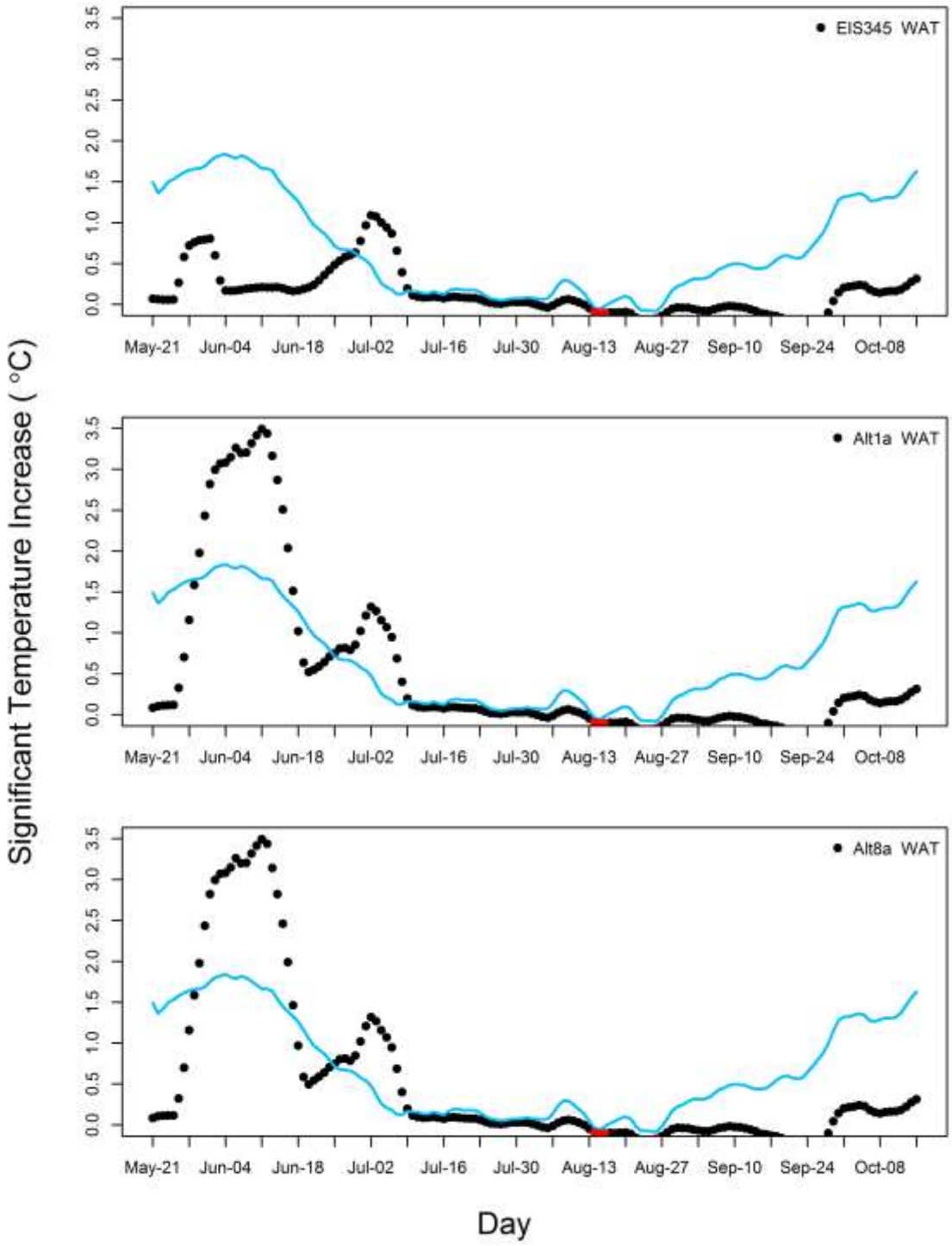

Figure 68. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1948.[4]

[4] Red dots indicate days which exceeded the temperature standard.

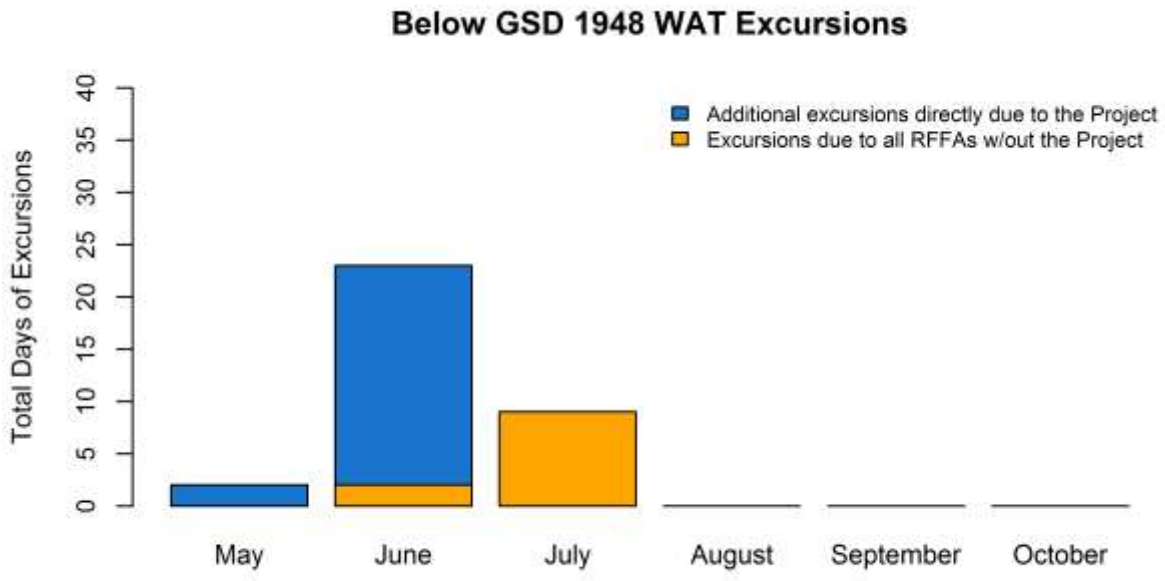

Figure 69. Summary of WAT temperature excursions for 1948, Fraser River below the Granby Sanitation District.

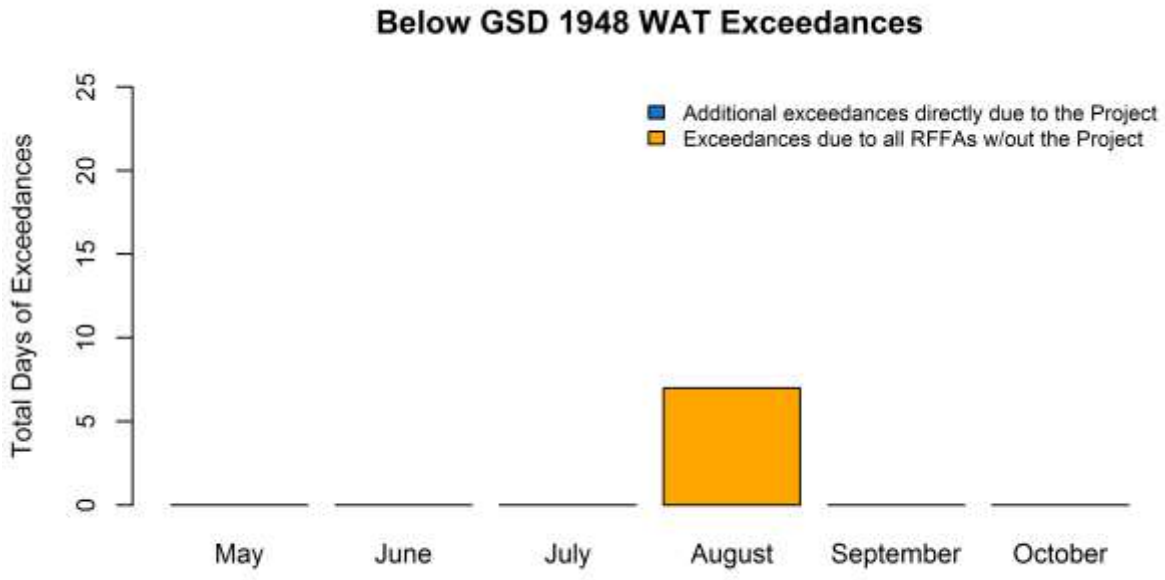

Figure 70. Total WAT standard exceedances for 1948, Fraser River below the Granby Sanitation District.

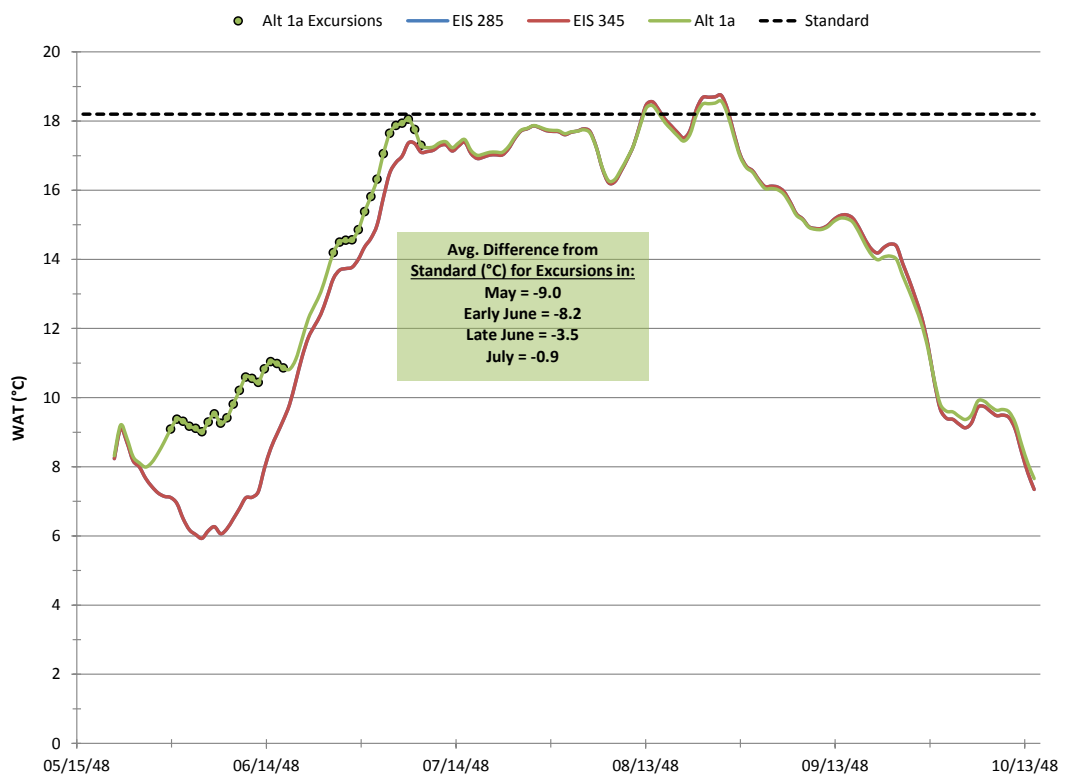

Figure 71. Alt 1a WAT temperature excursions for 1948 (circles), compared to EIS 285, EIS 345 and the temperature standard.

1959 Scenario Year

DMs

Figure 72 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 2.97°C. Figure 73 compares the number of excursions to the threshold based on current conditions. There are 8, 9 and 9 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Figure 74 further summarizes the number of excursions by month. The difference in excursions between EIS 345 and Alt 1a occurs in July, in which the operation of the Moffat Project contributes one additional excursion. DM temperature standard exceedances are summarized by month in Figure 75. Note that there are excursions due to RFFAs in June even though there are not any exceedances.

WATs

Figure 76 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 1.80°C. Figure 77 compares the number of excursions to the threshold based on current conditions. There are 13, 15 and 15 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Figure 78 further summarizes the number of excursions by month. The difference in excursions between EIS 345 and Alt 1a occurs in July, in which the operation of the Moffat Project contributes two additional excursions. WAT temperature standard exceedances are summarized by month in Figure 79. Note that there are excursions due to RFFAs in June even though there are not any exceedances.

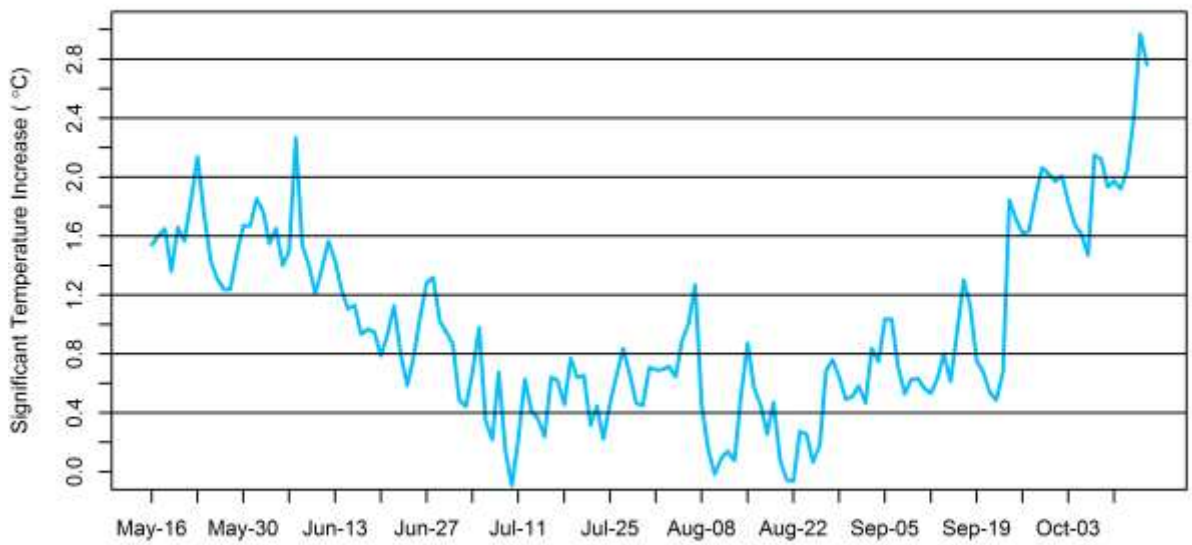

Figure 72. DM 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1959.

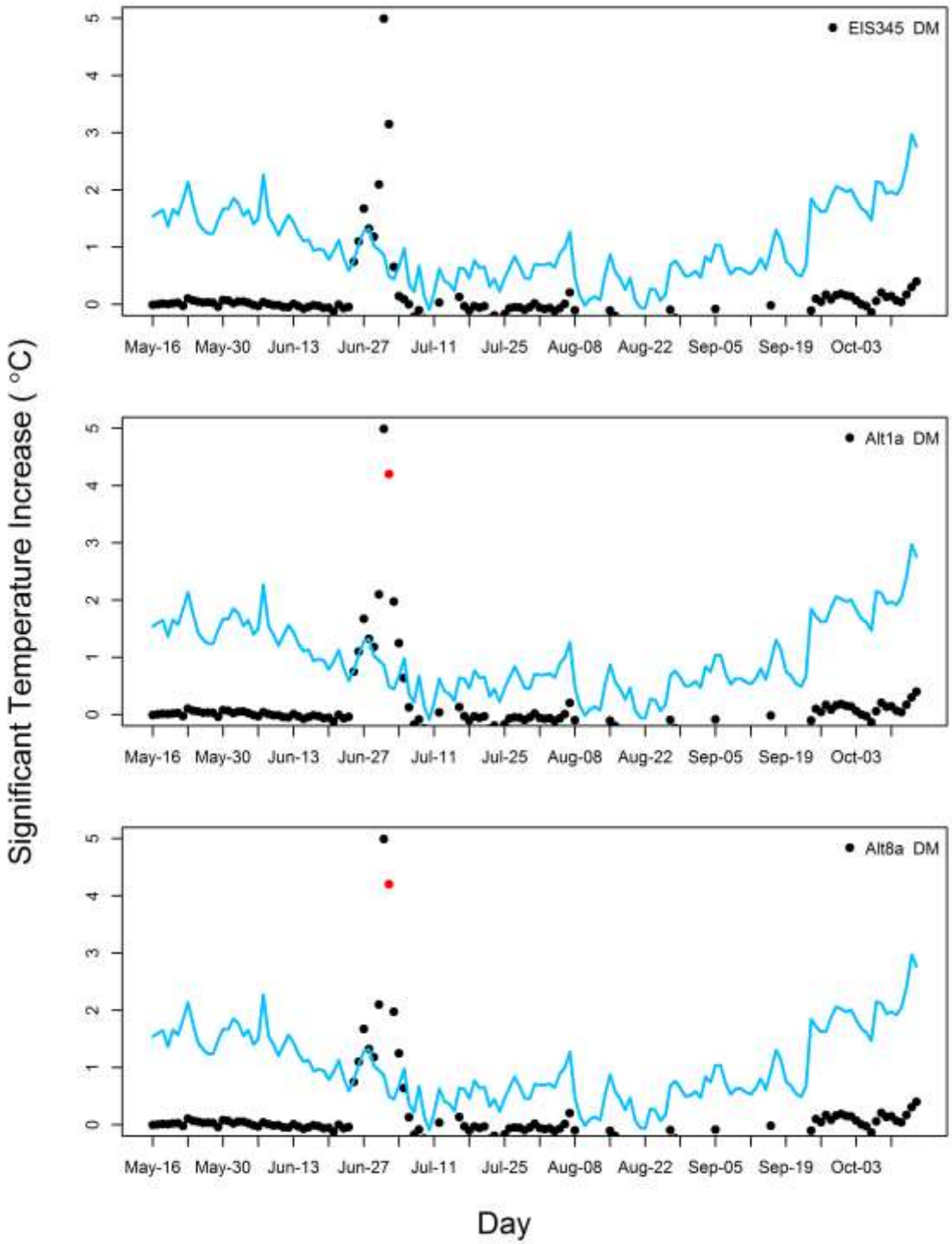

Figure 73. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1959.[5]

[5] Red dots indicate days which exceeded the temperature standard.

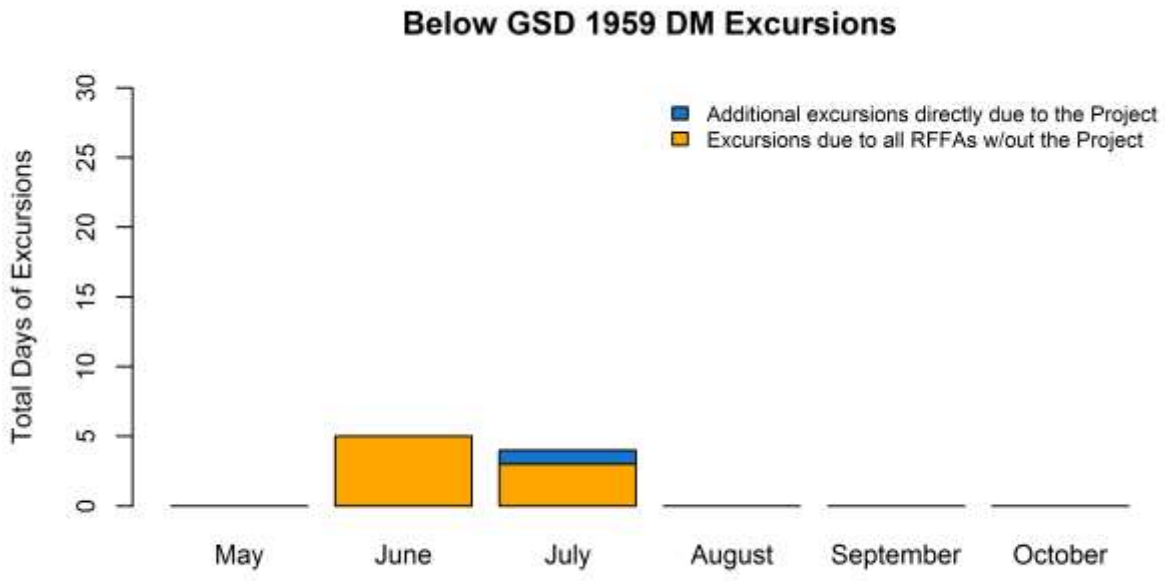

Figure 74. Summary of DM temperature excursions for 1959, Fraser River below the Granby Sanitation District.

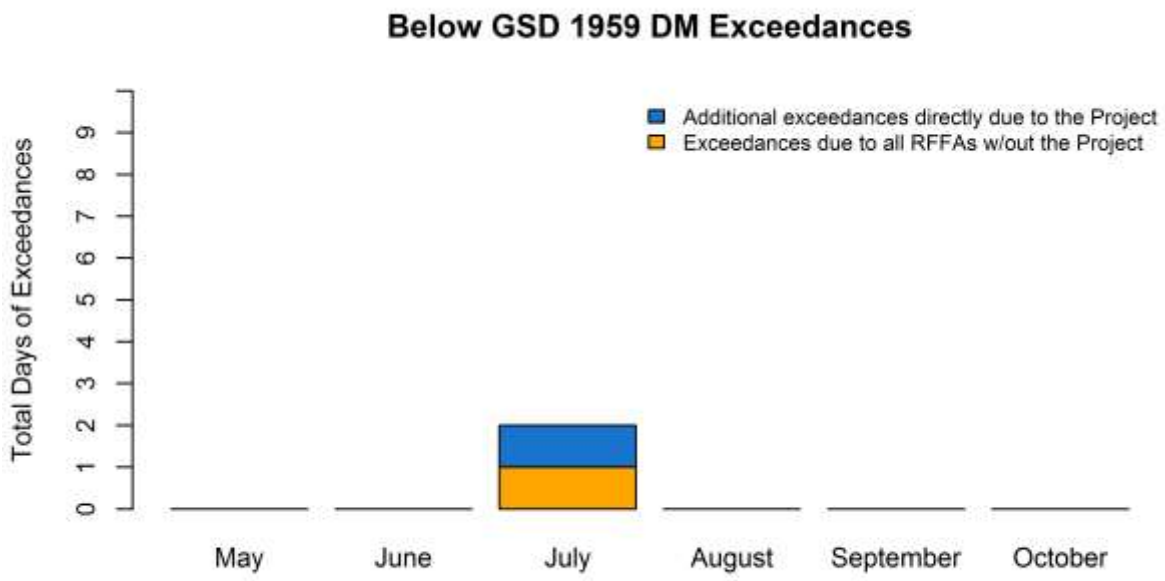

Figure 75. Total DM exceedances for 1959, Fraser River below the Granby Sanitation District.

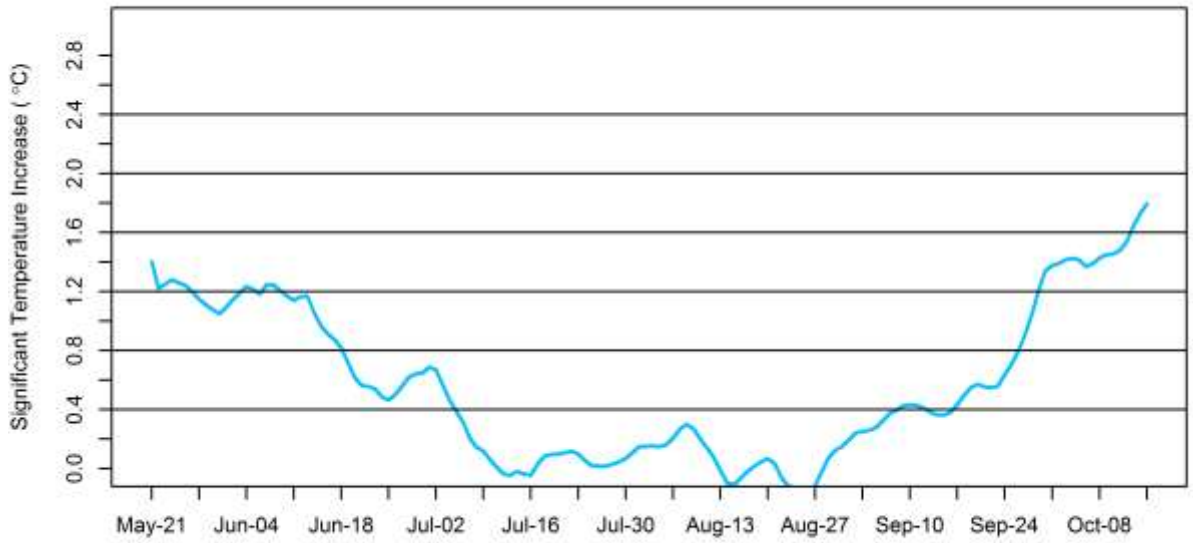

Figure 76. WAT 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1959.

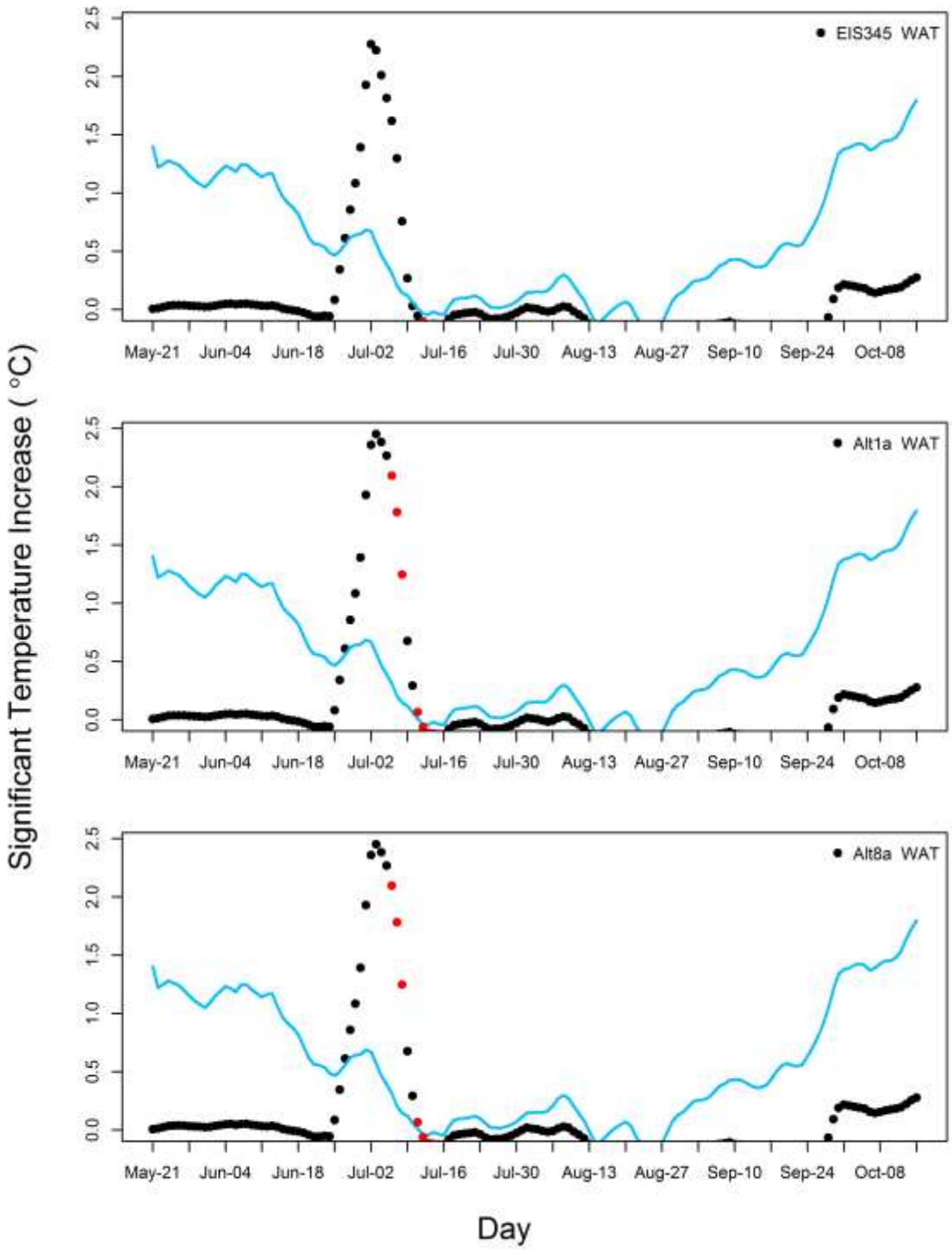

Figure 77. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1959.[6]

[6] Red dots indicate days which exceeded the temperature standard.

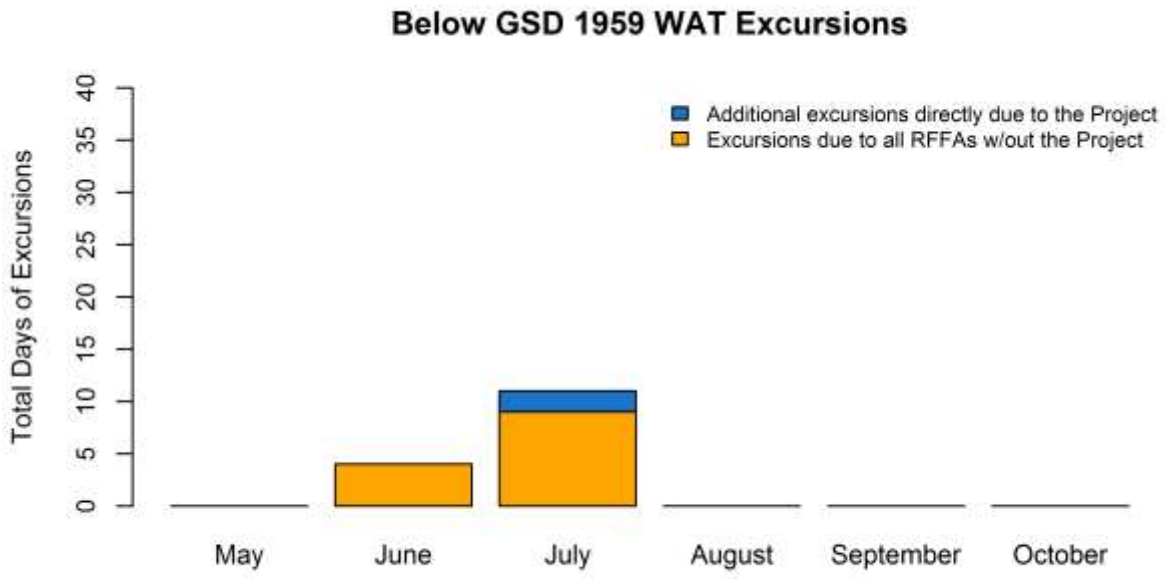

Figure 78. Summary of WAT temperature excursions for 1959, Fraser River below the Granby Sanitation District.

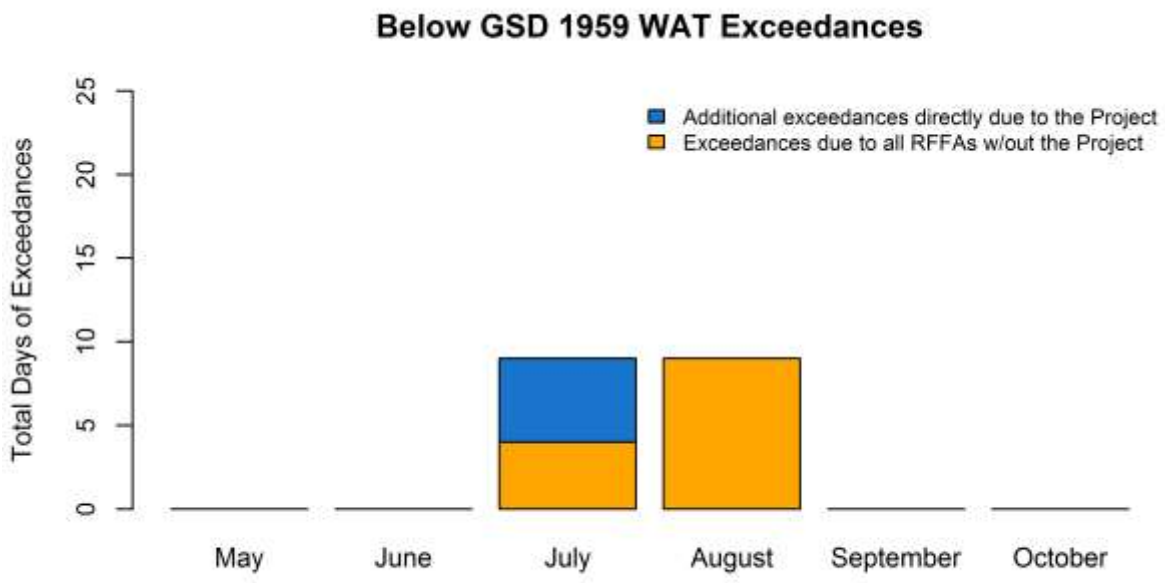

Figure 79. Total WAT exceedances for 1959, Fraser River below the Granby Sanitation District.

1963 Scenario Year

DMs

Figure 80 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 2.53°C. Figure 81 compares the number of excursions to the threshold based on current conditions. There are 11, 11 and 11 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. In 1963, for cumulative conditions without the Moffat Project (all RFFAs), there are flow reductions during June through mid-October (this is the difference between EIS 285 and EIS 345). The Moffat Project would cause no reduction of Fraser River flows (this is the difference between EIS 345 and Alt 1a). DM temperature excursions are summarized by month in Figure 82 and DM exceedances are summarized by month in Figure 83.

WATs

Figure 84 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 1.48°C. Figure 85 compares the number of excursions to the threshold based on current conditions. There are 59, 59 and 59 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. WAT temperature excursions are summarized by month in Figure 86 and WAT exceedances are summarized by month in Figure 87.

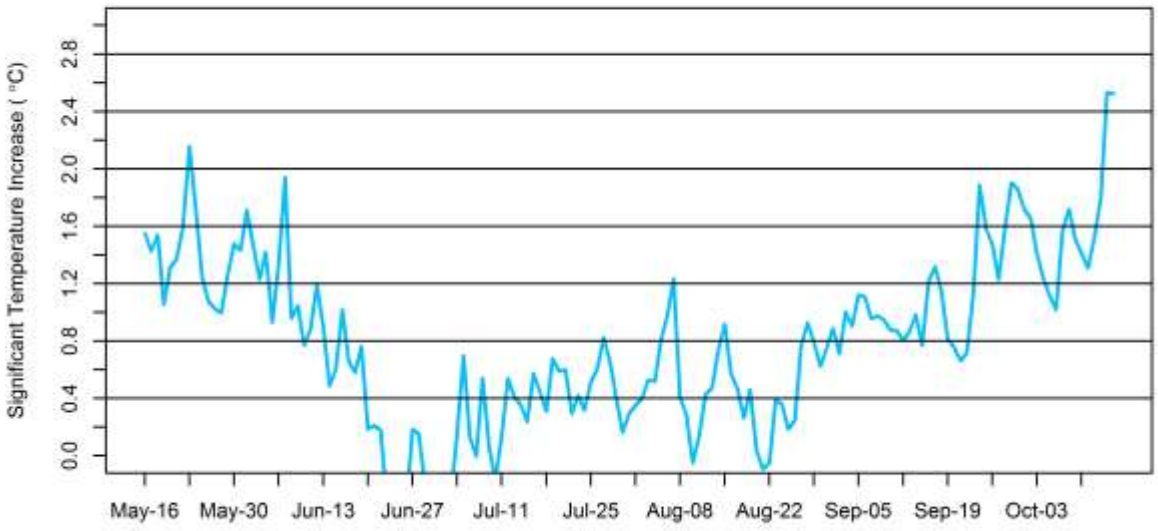

Figure 80. DM 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1963.

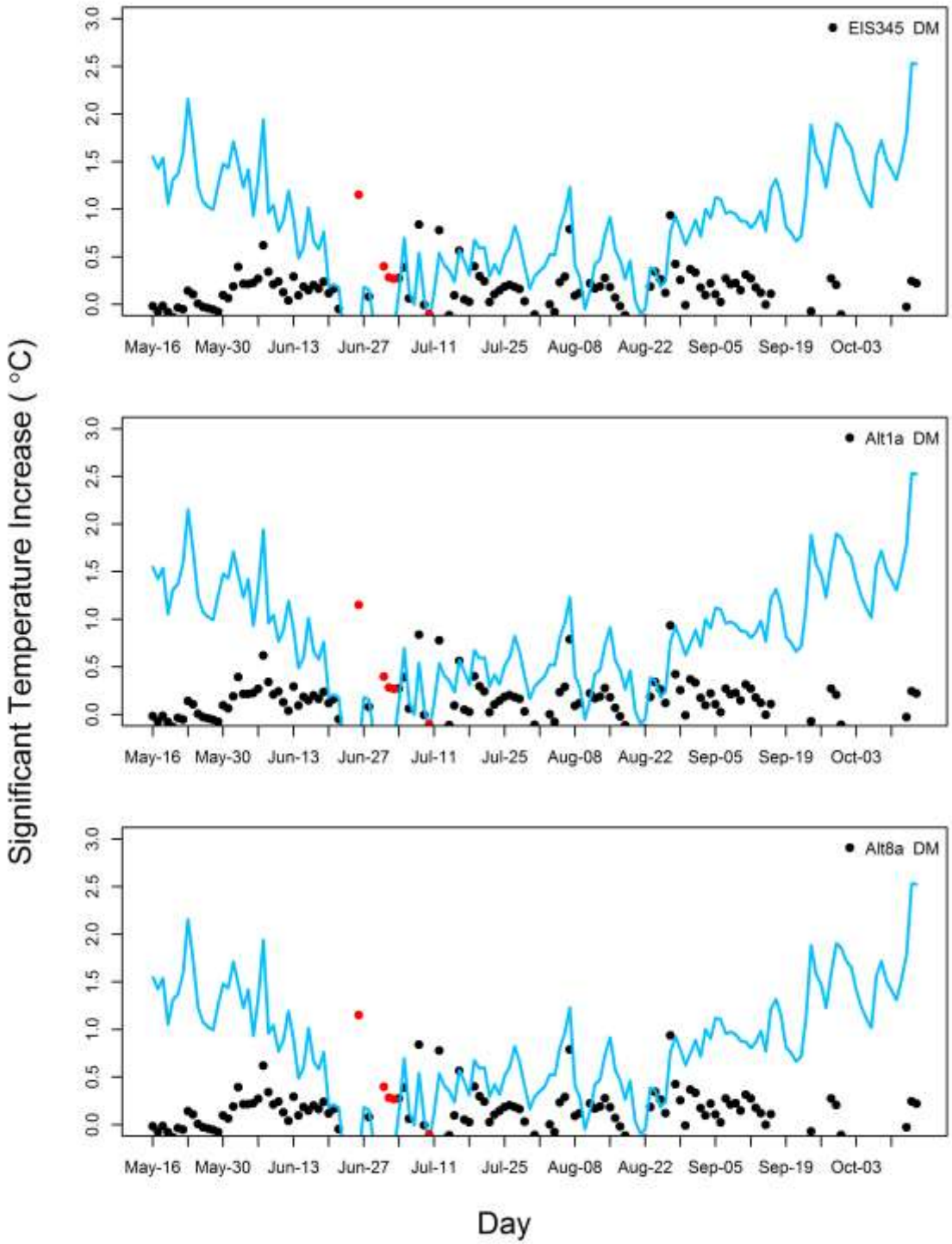

Figure 81. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1963.[7]

[7] Red dots indicate days which exceeded the temperature standard.

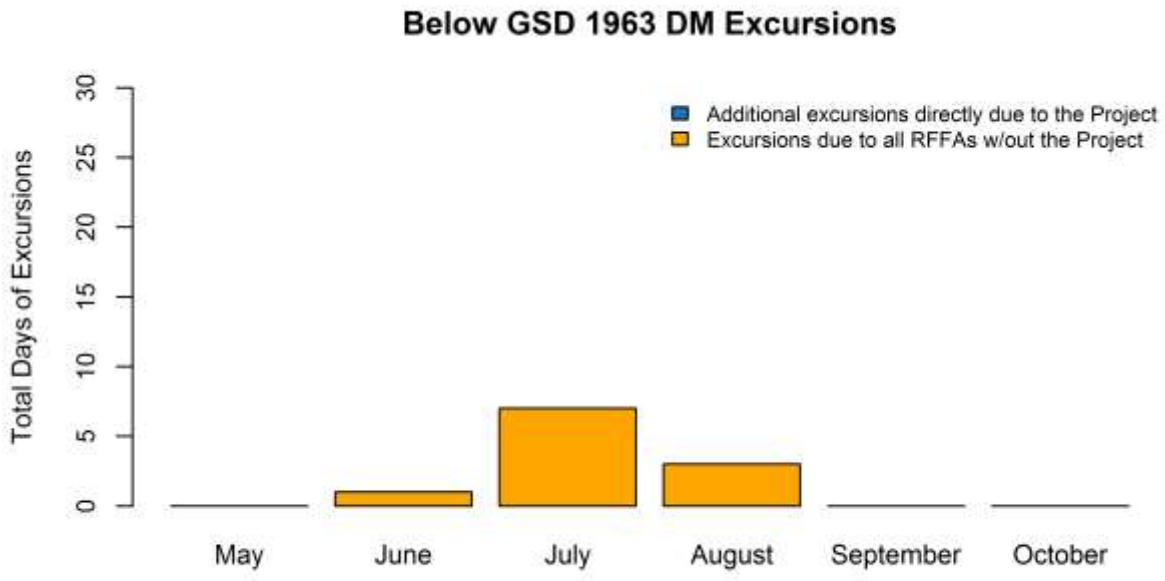

Figure 82. Summary of DM temperature excursions for 1963, Fraser River below the Granby Sanitation District.

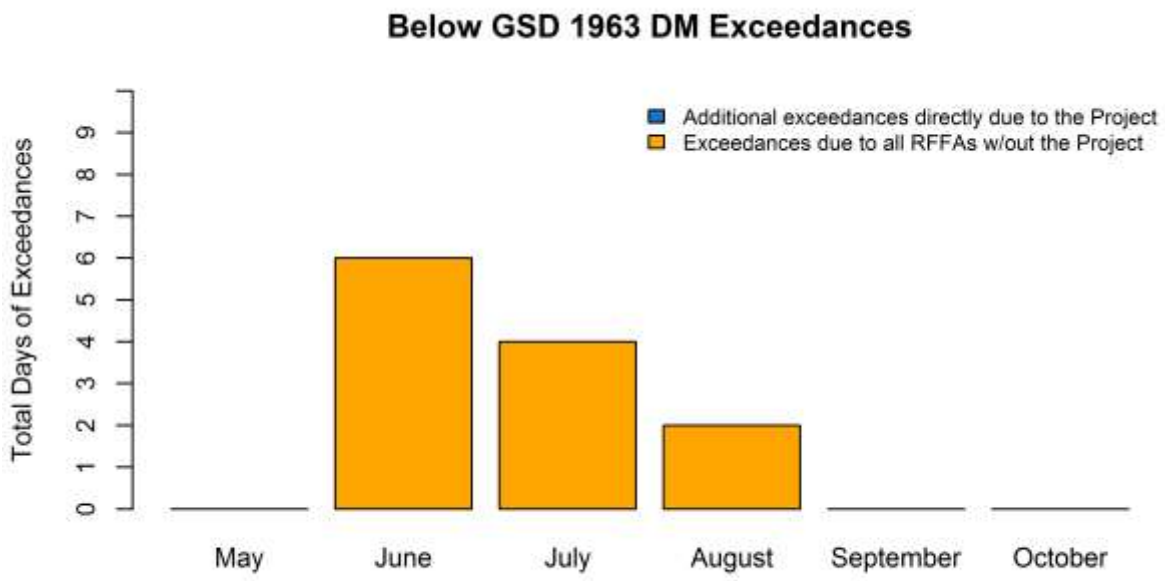

Figure 83. Total DM exceedances for 1963, Fraser River below the Granby Sanitation District.

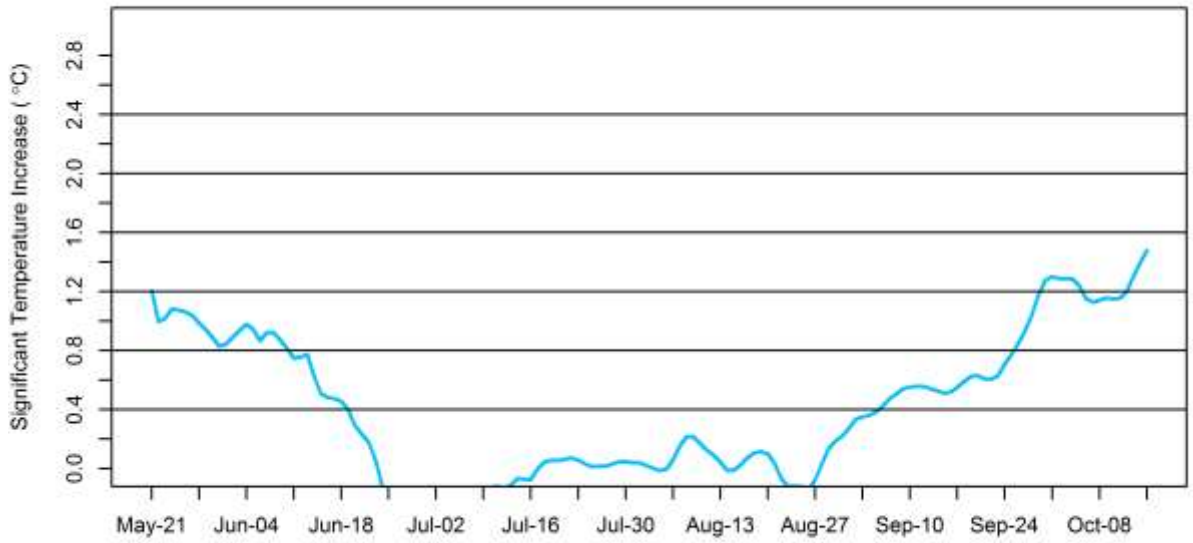

Figure 84. WAT 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1963.

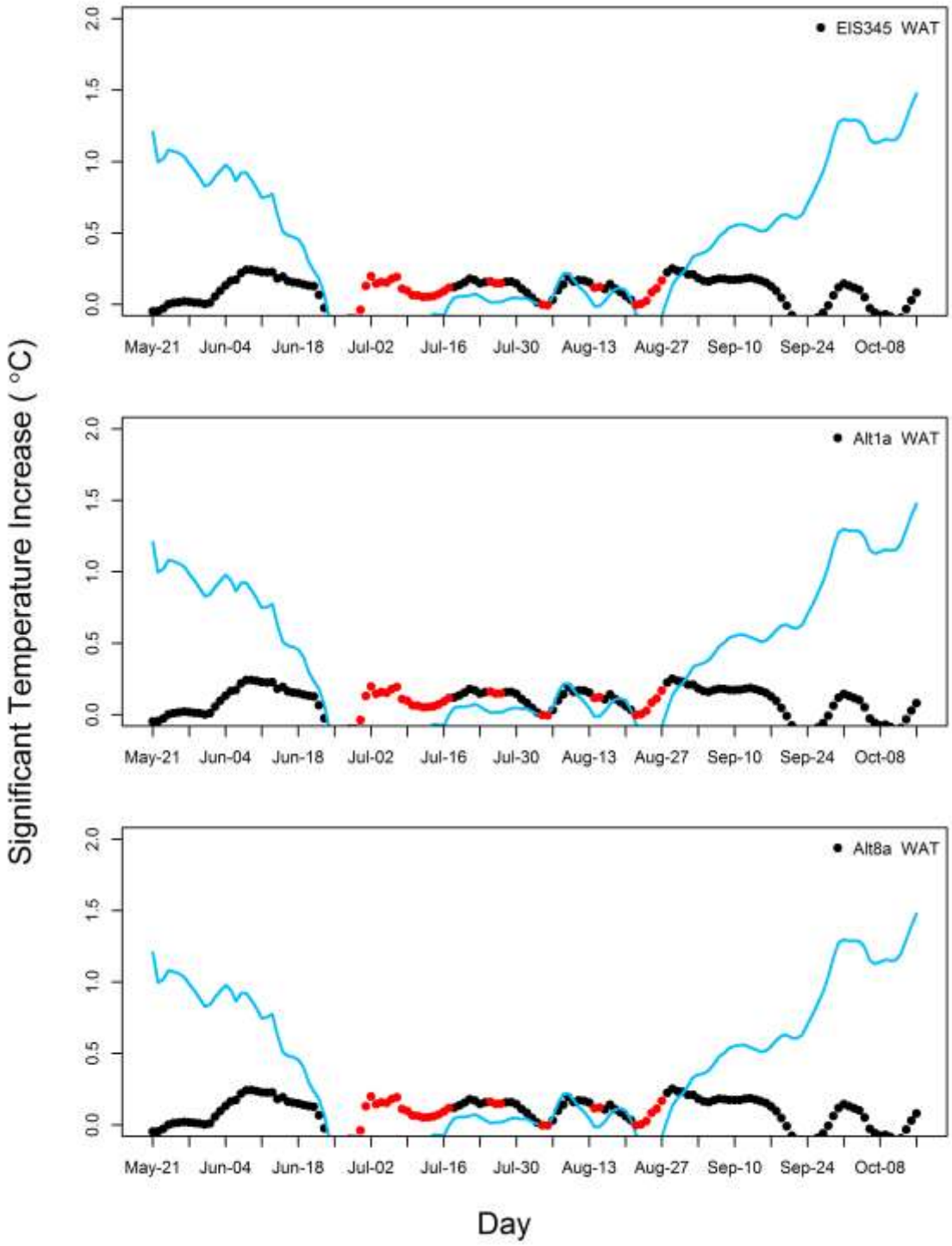

Figure 85. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1963.[8]

[8] Red dots indicate days which exceeded the temperature standard.

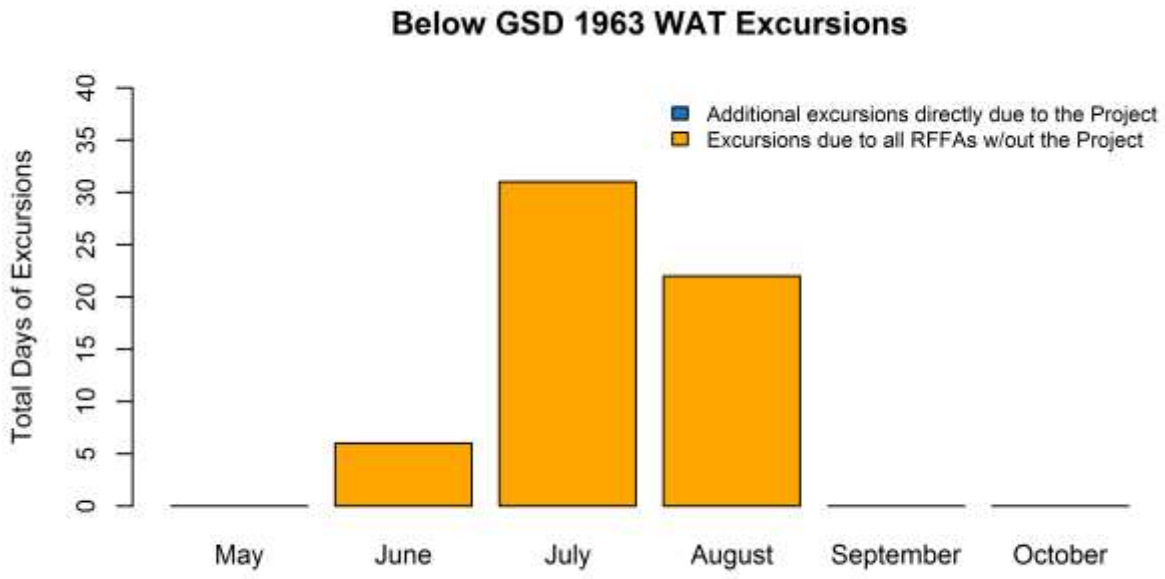

Figure 86. Summary of WAT temperature excursions for 1963, Fraser River below the Granby Sanitation District.

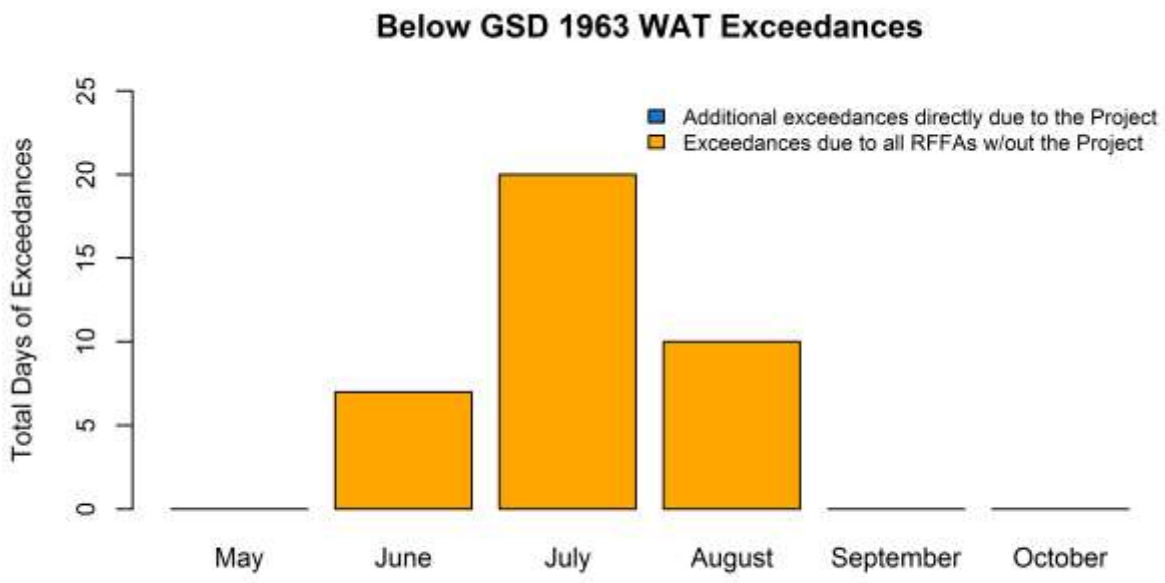

Figure 87. Total WAT exceedances for 1963, Fraser River below the Granby Sanitation District.

1978 Scenario Year

DMs

Figure 88 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 2.52°C. Figure 89 compares the number of excursions to the threshold based on current conditions. There are 10, 10 and 10 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. In 1978, for cumulative conditions without the Moffat Project (all RFFAs), there are flow reductions mainly in late June through early September (this is the difference between EIS 285 and EIS 345). The Moffat Project would cause no reduction of Fraser River flows (this is the difference between EIS 345 and Alt 1a). DM temperature excursions are summarized by month in Figure 90 and DM standard exceedances are summarized by month in Figure 91. Note that there are excursions due to RFFAs in July even though there are not any exceedances.

WATs

Figure 92 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 1.51°C. Figure 93 compares the number of excursions to the threshold based on current conditions. There are 51, 51 and 51 excursions for EIS 345, Alt 1a and Alt 8a, respectively. Note that there are no differences in temperature between the three future flow scenarios, thus the operation of the Moffat Project does not contribute any additional excursions above those from RFFAs. WAT temperature excursions are summarized by month in Figure 94 and WAT exceedances are summarized by month in Figure 95. Note that there are excursions due to RFFAs in July even though there are not any exceedances.

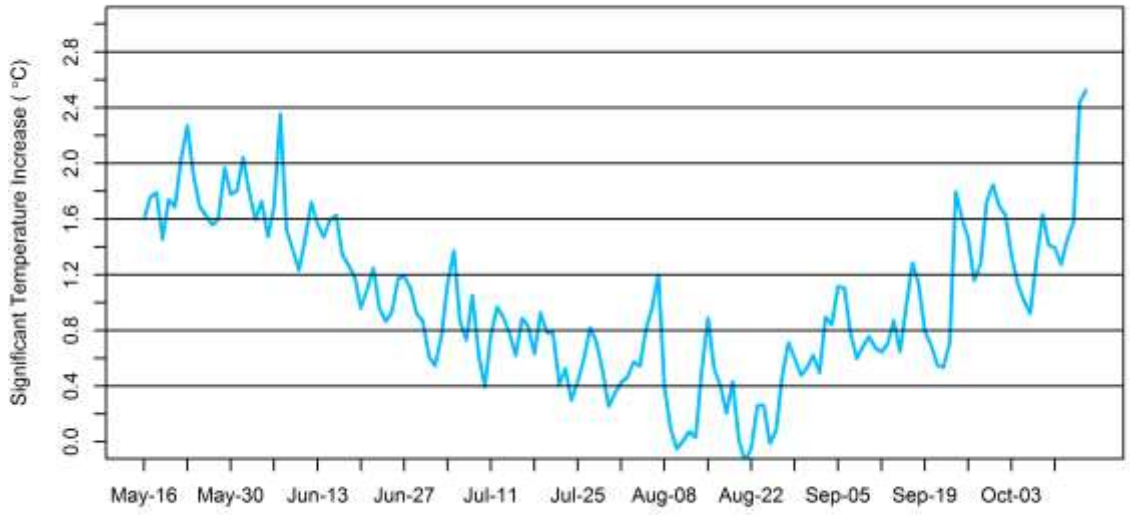

Figure 88. DM 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1978.

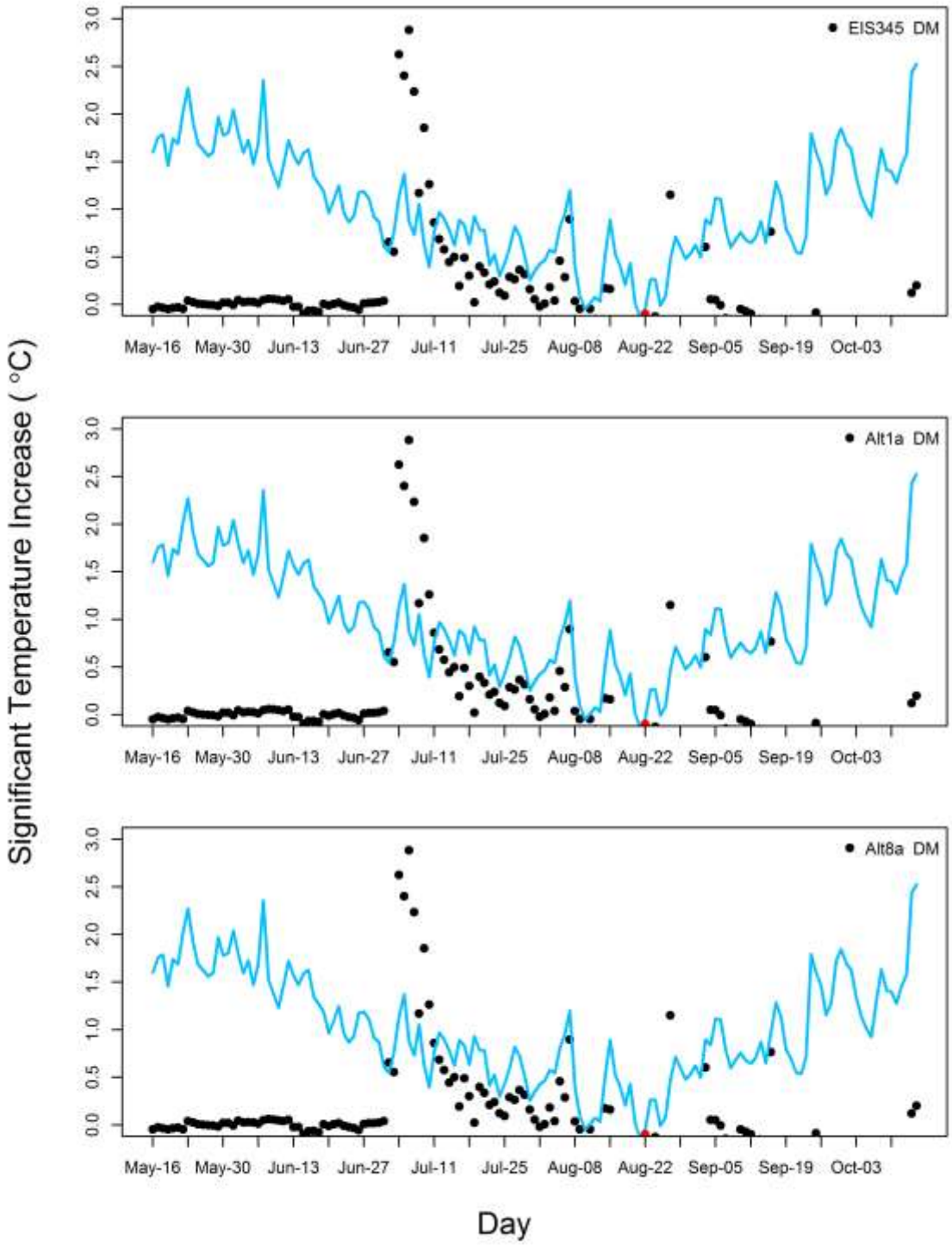

Figure 89. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1978.[9]

[9] Red dots indicate days which exceeded the temperature standard.

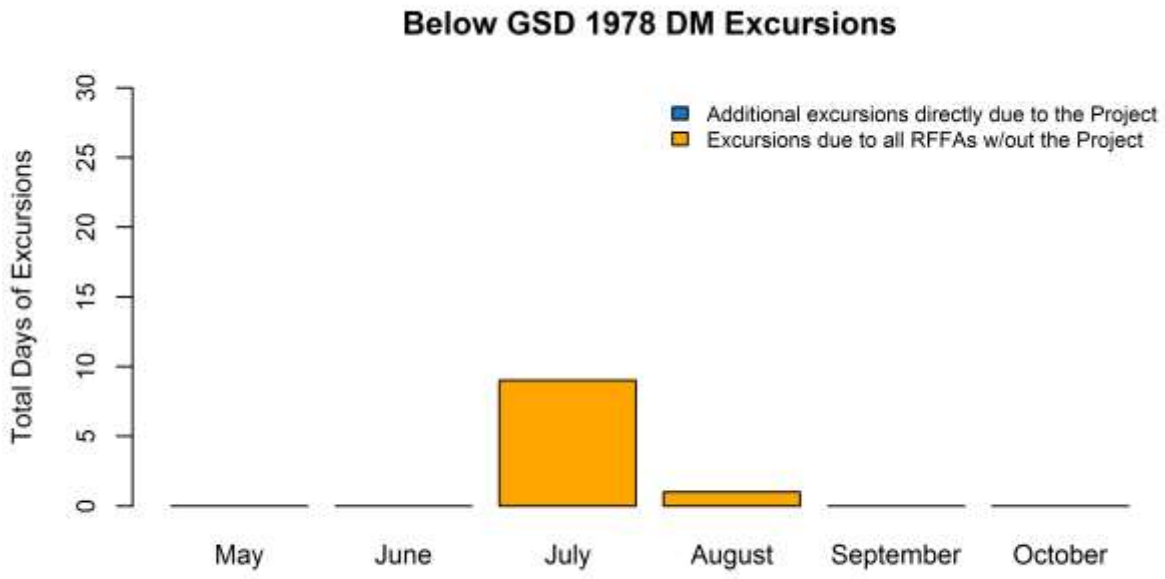

Figure 90. Summary of DM temperature excursions for 1978, Fraser River below the Granby Sanitation District.

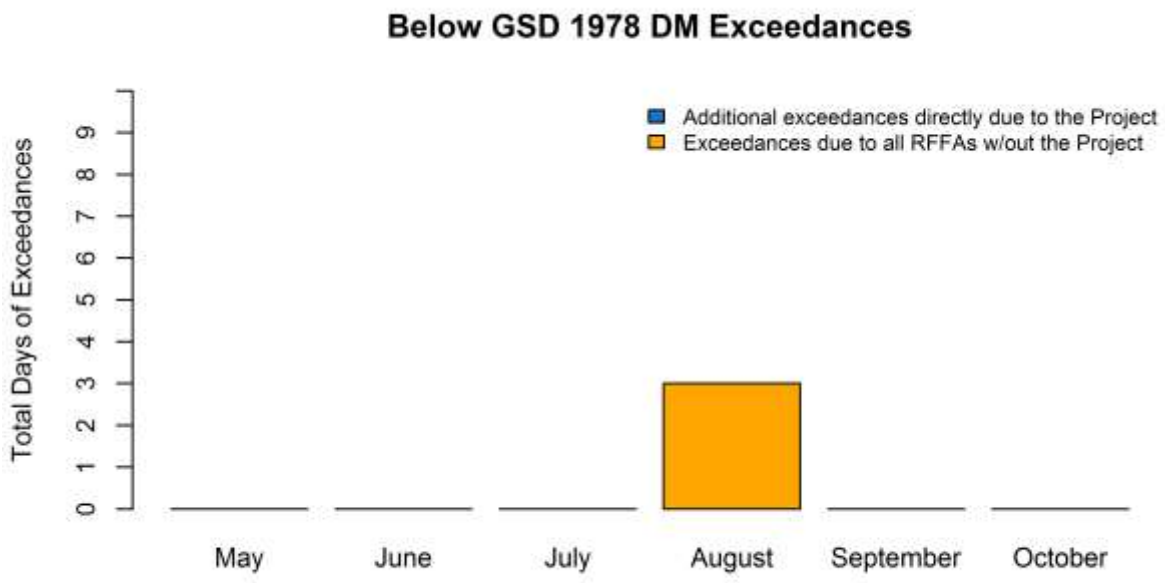

Figure 91. Total DM exceedances for 1978, Fraser River below the Granby Sanitation District.

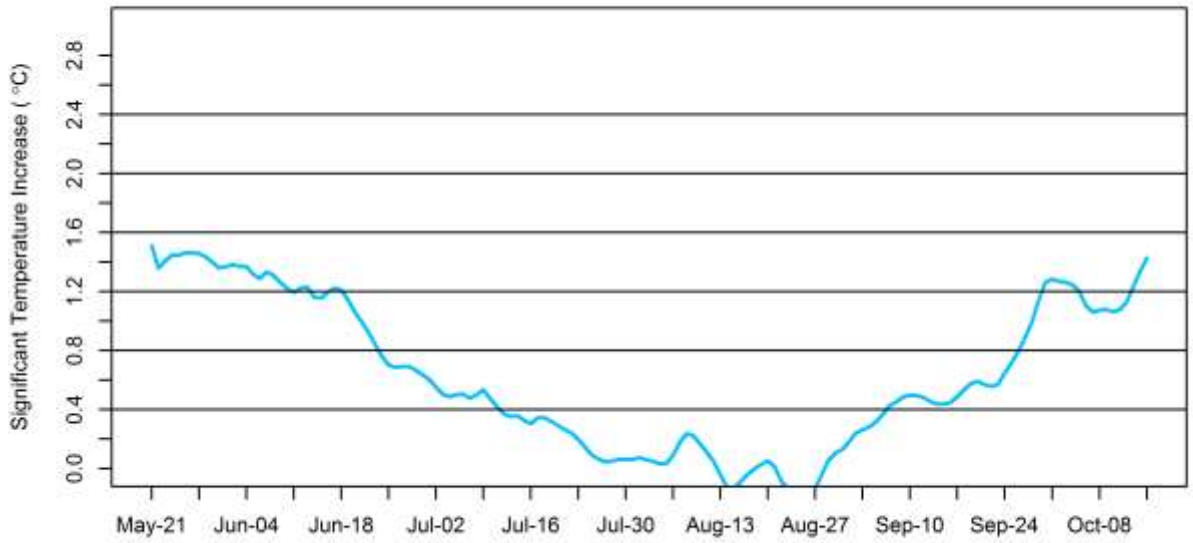

Figure 92. WAT 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1978.

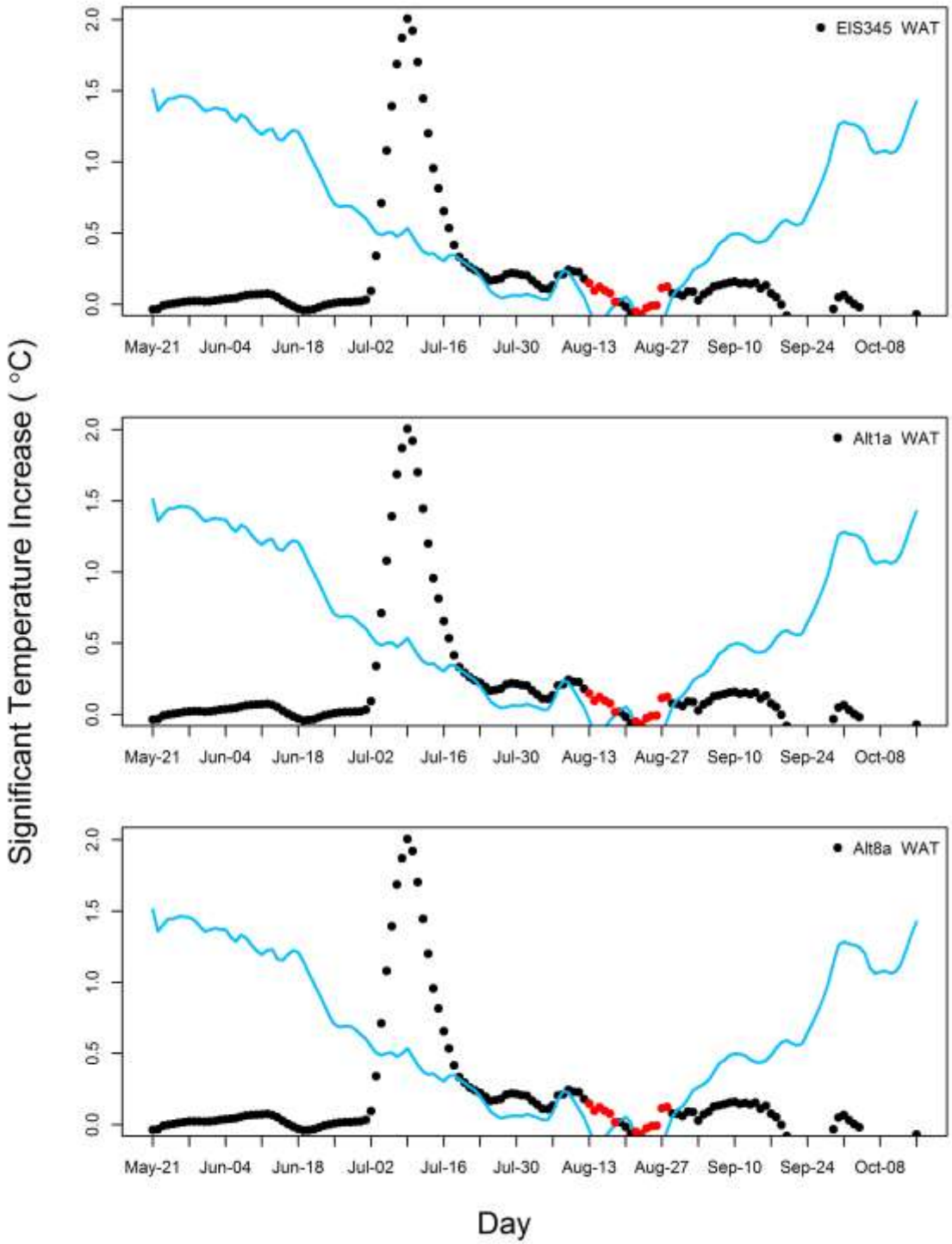

Figure 93. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1978.[10]

[10] Red dots indicate days which exceeded the temperature standard.

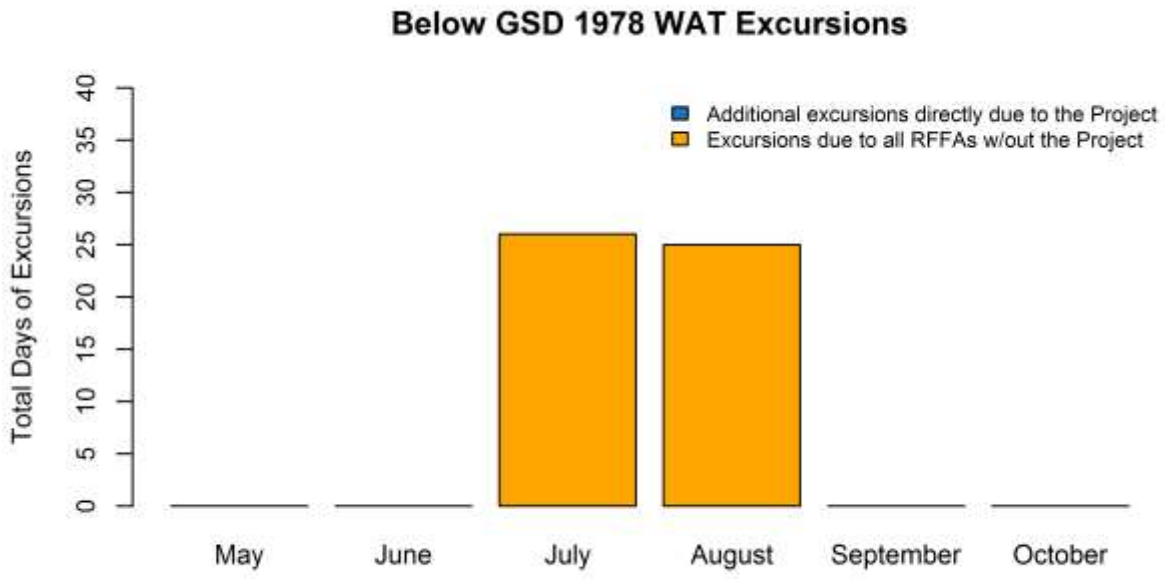

Figure 94. Summary of WAT temperature excursions for 1978, Fraser River below the Granby Sanitation District.

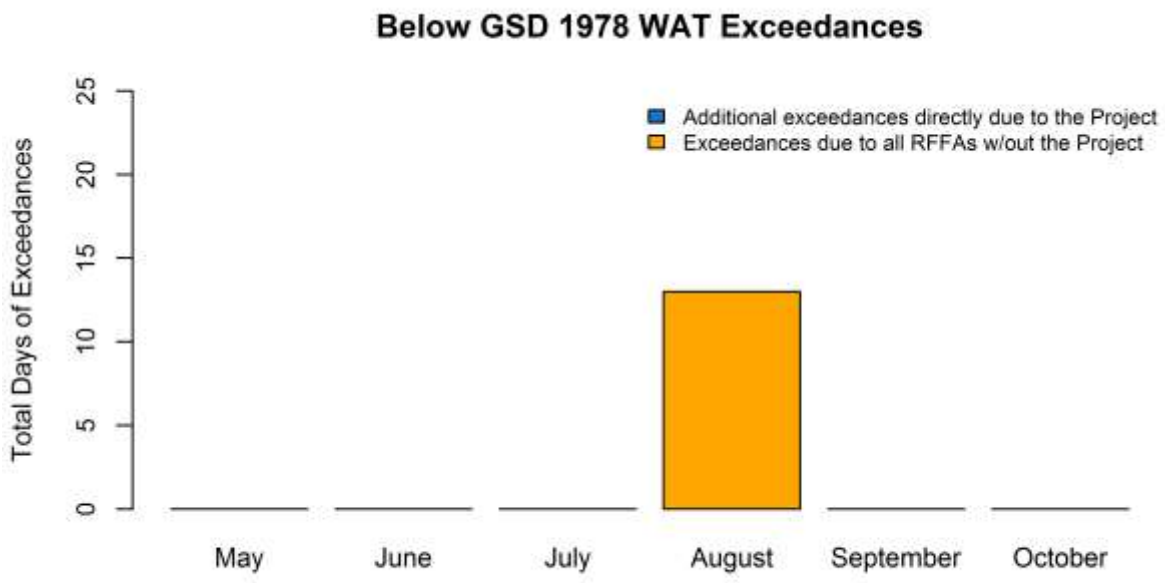

Figure 95. Total WAT exceedances for 1978, Fraser River below the Granby Sanitation District.

1987 Scenario Year

DMs

Figure 96 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 2.60°C. Figure 97 compares the number of excursions to the threshold based on current conditions. There are 8, 24 and 24 excursions for EIS 345, Alt 1a and Alt 8a, respectively. DM temperature excursions are summarized by month in Figure 98 and DM exceedances are summarized by month in Figure 99. The difference in excursions between EIS 345 and Alt 1a occurs in May and June, in which the Moffat Project contributes an additional 13 excursions in May and 3 excursions in June. Note that while there are 16 excursions attributed to operation of the Moffat Project, there are no DM temperature standard exceedances in May. As Figure 100 illustrates, the excursions that occur in May and June are well below the DM temperature standard, averaging approximately 10°C below the standard in May and early June and 4°C below the standard in late June.

WATs

Figure 101 shows the 15% assimilative capacity threshold. The threshold ranges from 0°C to 1.77°C. Figure 102 compares the number of excursions to the threshold based on current conditions. There are 12, 24 and 24 excursions for EIS 345, Alt 1a and Alt 8a, respectively. WAT temperature excursions are summarized by month in Figure 103 and WAT standard exceedances are summarized by month in Figure 104. The difference in excursions between EIS 345 and Alt 1a occurs in May, June and July, in which the Project contributes an additional 11 excursions in May, 5 additional excursions in June and 4 fewer excursions in July. Note that while there are 12 additional excursions attributed to operation of the Moffat Project, there are no WAT temperature standard exceedances for May and June. As Figure 105 illustrates, the excursions that occur in May and June are well below the WAT temperature standard, averaging approximately 8°C below the standard in May and early June and 3°C below the standard in late June.

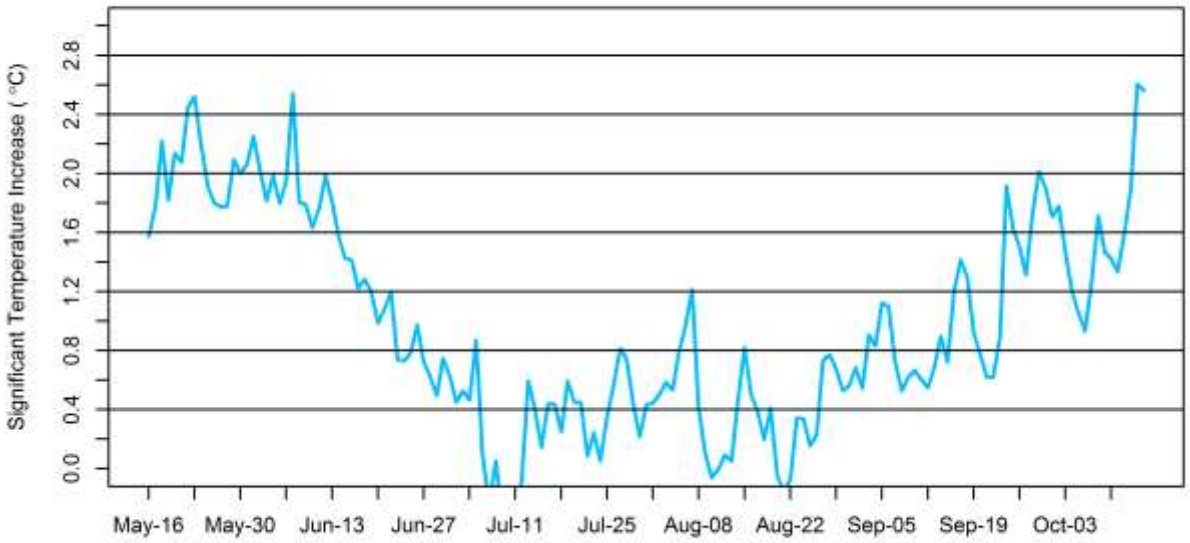

Figure 96. DM 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1987.

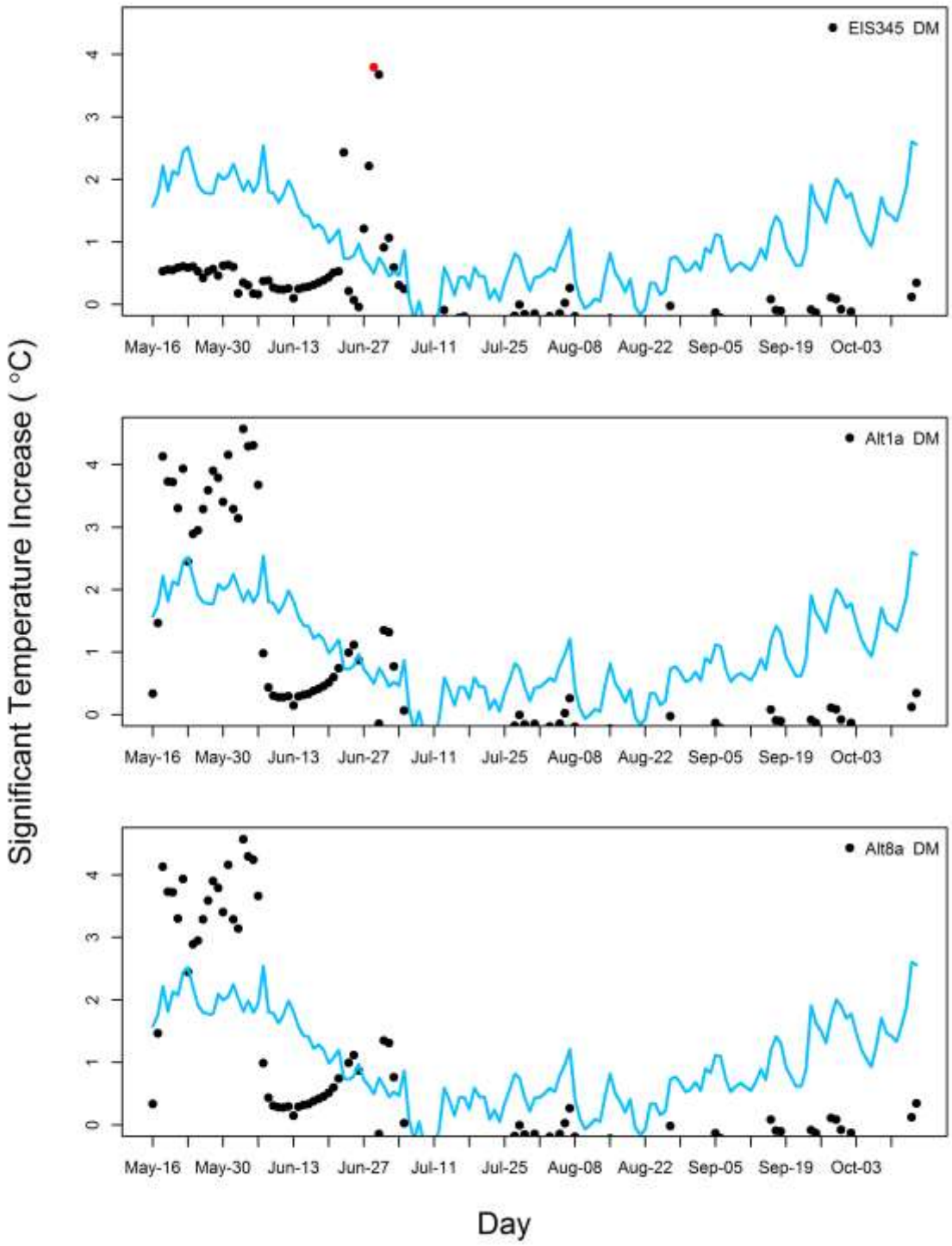

Figure 97. Comparison of flow scenario DM temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1987.[11]

[11] Red dots indicate days which exceeded the temperature standard.

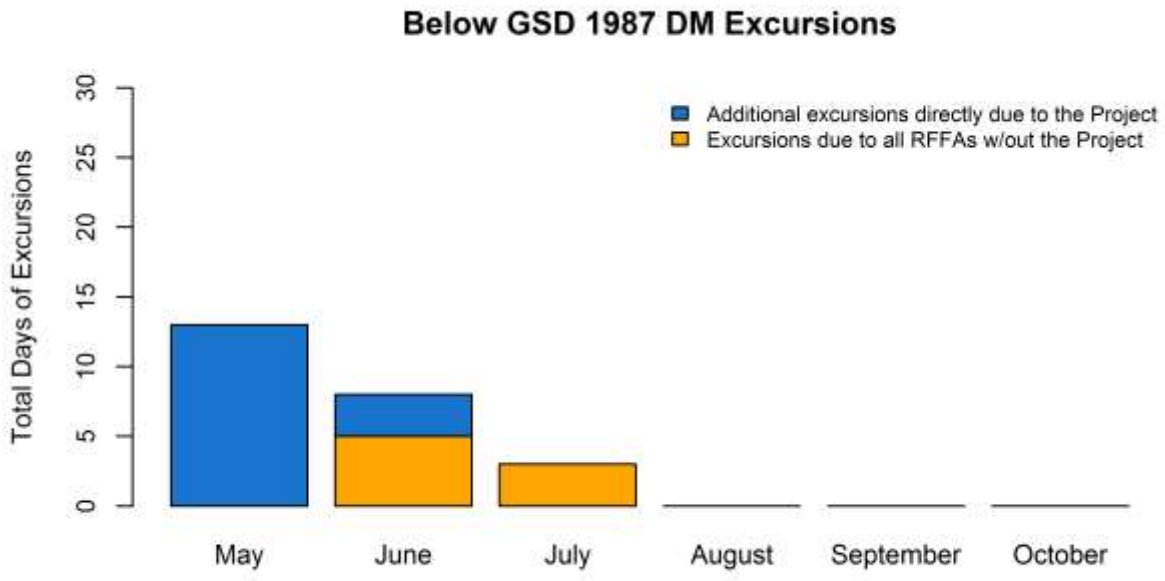

Figure 98. Summary of DM temperature excursions for 1987, Fraser River below the Granby Sanitation District.

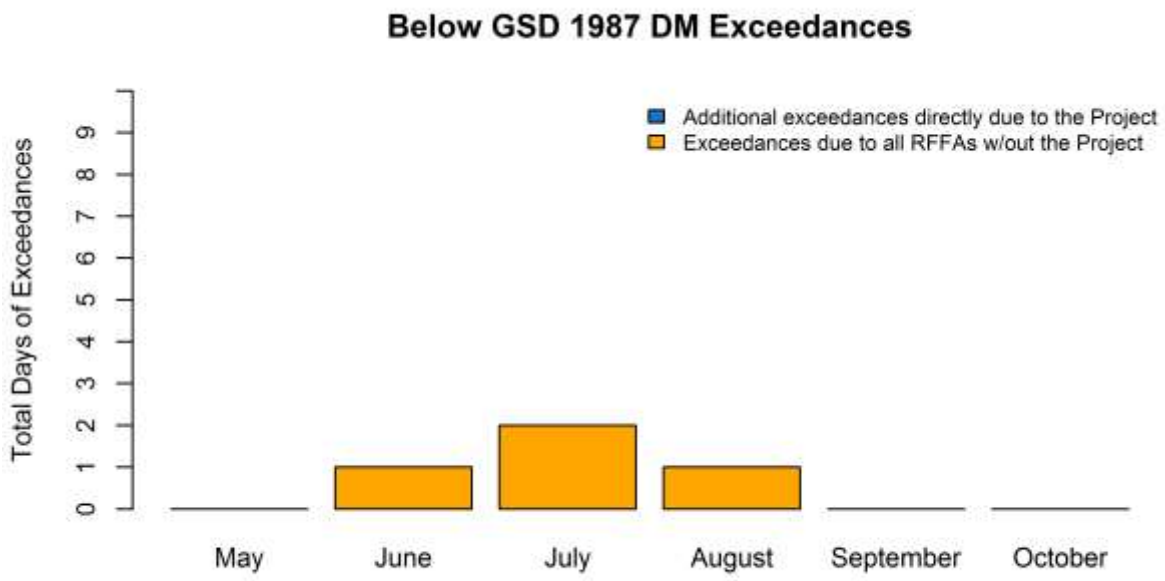

Figure 99. Total DM exceedances for 1987, Fraser River below the Granby Sanitation District.

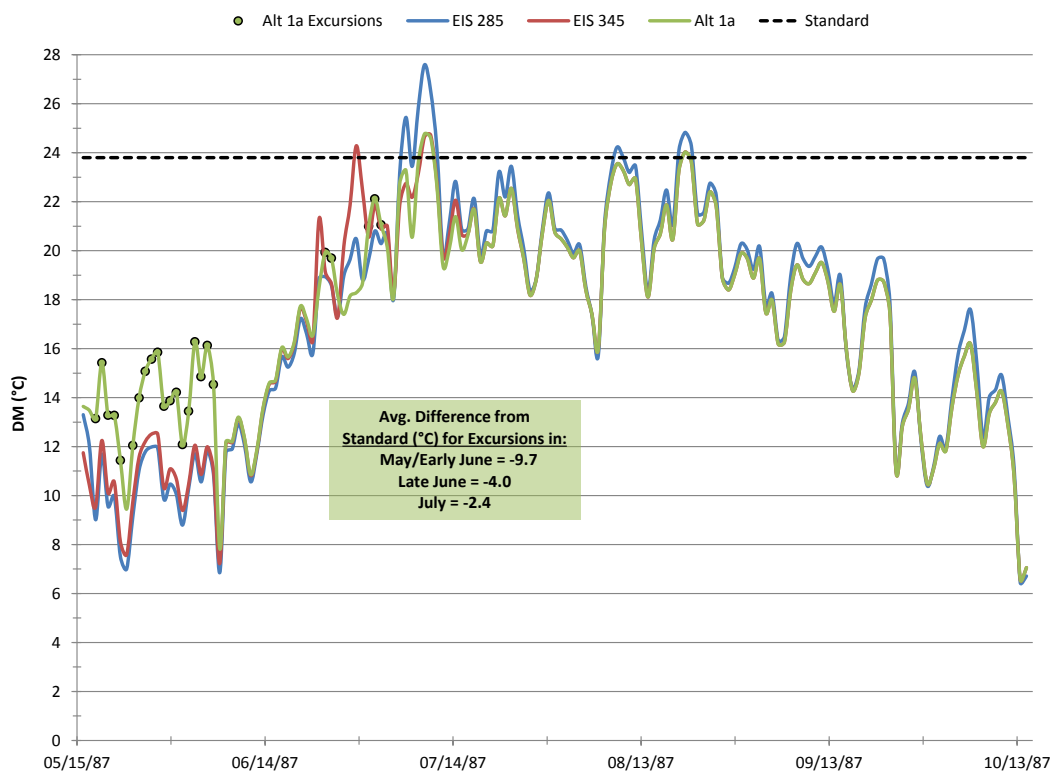

Figure 100. Alt 1a DM temperature excursions for 1987 (circles), compared to EIS 285, EIS 345 and the temperature standard.

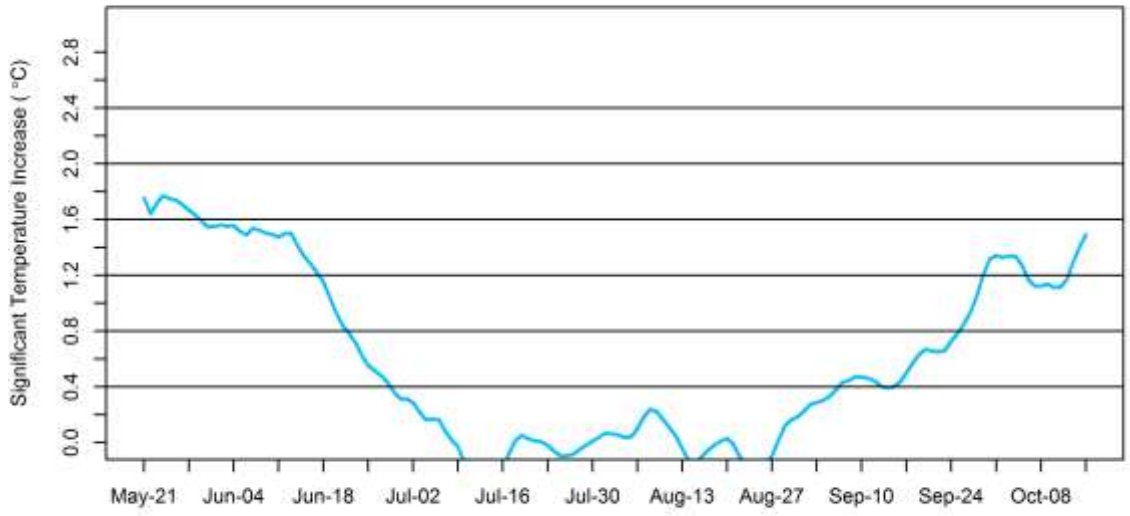

Figure 101. WAT 15% assimilative capacity threshold, Fraser River below the Granby Sanitation District, 1987.

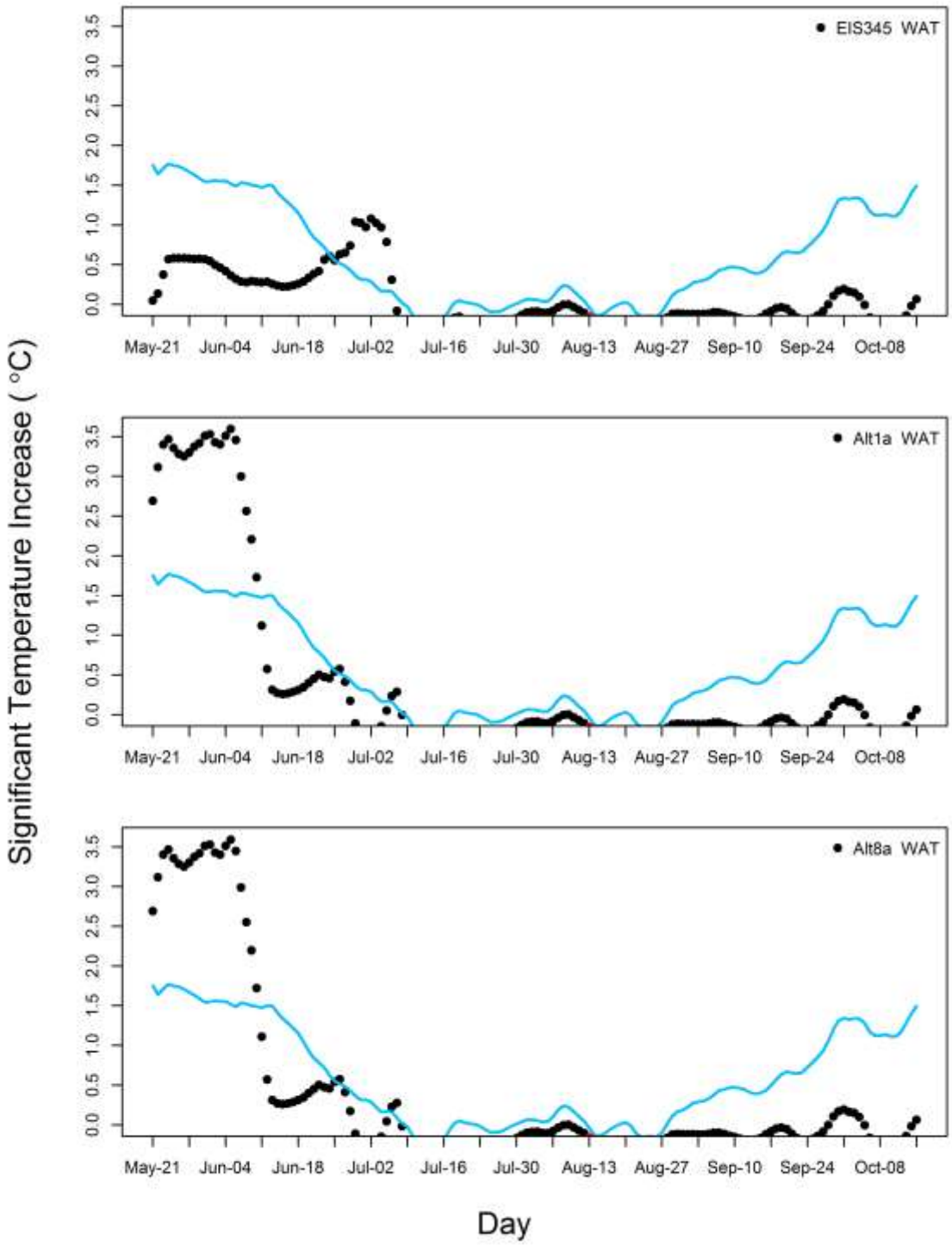

Figure 102. Comparison of flow scenario WAT temperature excursions to the 15% BAI threshold, Fraser River below the Granby Sanitation District, 1987.[12]

[12] Red dots indicate days which exceeded the temperature standard.

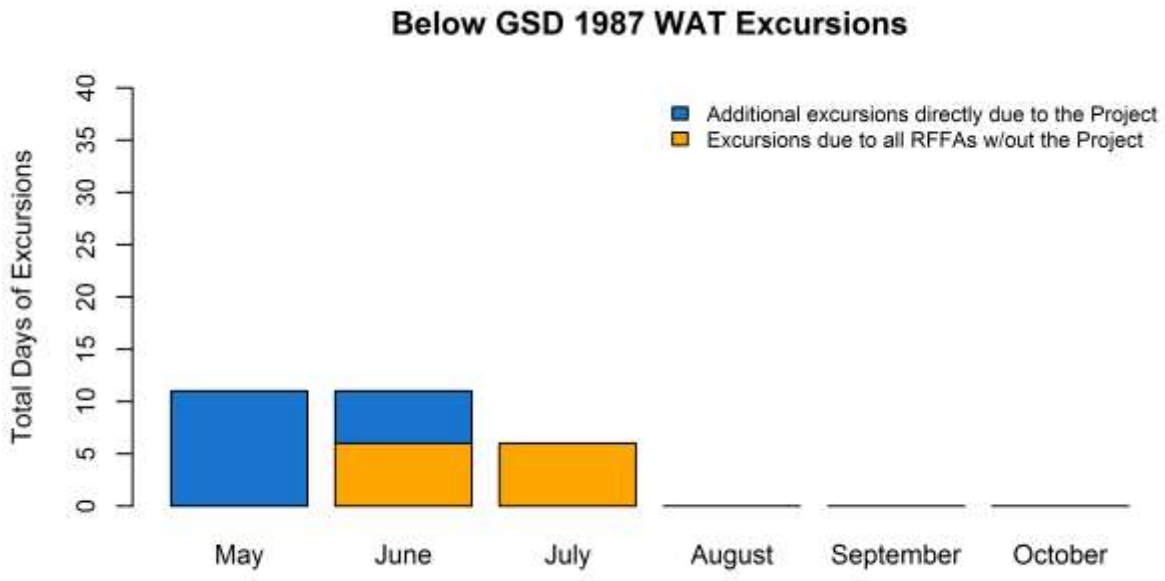

Figure 103. Summary of WAT temperature excursions for 1987, Fraser River below the Granby Sanitation District.

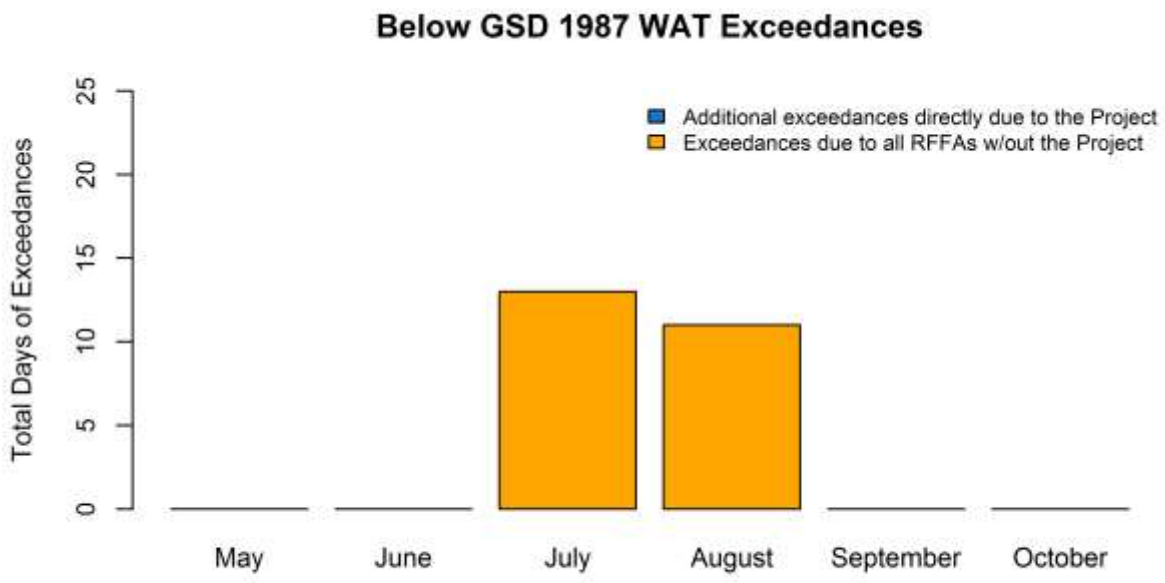

Figure 104. Total WAT exceedances for 1987, Fraser River below the Granby Sanitation District.

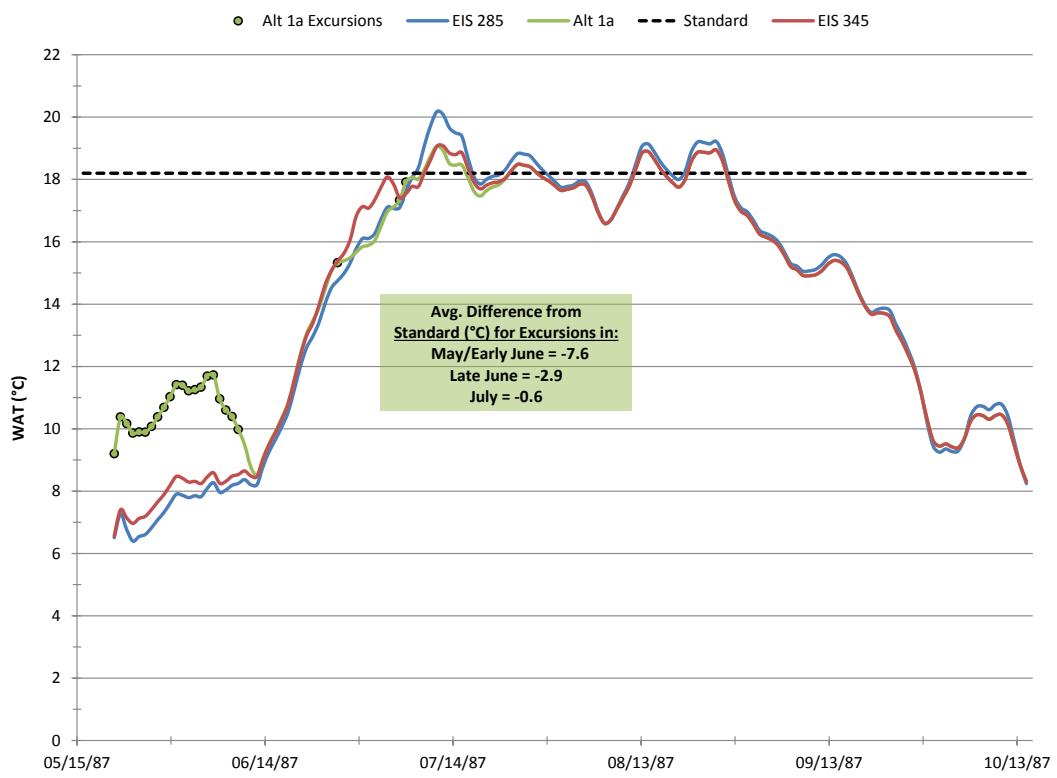

Figure 105. Alt 1a WAT temperature excursions for 1987 (circles), compared to EIS 285, EIS 345 and the temperature standard.

Summary of Scenario Year Results

Summaries of DM and WAT threshold excursions and temperature standard exceedances for all years are provided in Table 8 and Table 9. DM and WAT excursions occur in May through August. The increases in temperature resulting in excursions that would also result in exceedances of the temperature standards would occur approximately 1% of the time for DM (i.e., one day out of 78 excursions also resulted in an exceedance of the standard) and approximately 4% of the time for WAT standards (i.e., 7 days out of 183 excursions also resulted in an exceedance of the standard).

The Moffat Project would contribute to only a small portion of the DM and WAT excursions, primarily in May and June and to a very limited extent in July. The number of excursions is greater for Alt 1a than for EIS 345 in five months for both DMs and WATs. The differences in excursions between EIS 345 and Alt 1a are the differences that can be attributed to the operation of the Moffat Project. Therefore, for DMs and WATs, the Moffat Project contributes additional excursions in five of the 30 months that were evaluated.

Table 8. Summary of excursions of the DM 15% assimilative capacity threshold (top) and exceedances of the temperature standard (bottom), Fraser River below the Granby Sanitation District. Months that met the critical conditions criteria are highlighted in blue.[13]

	1948			1959			1963			1978			1987		
Month	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**
May	2	6	6	0	0	0	0	0	0	0	0	0	0	13	13
June	2	16	16	5	5	5	1	1	1	0	0	0	5	8	8
July	2	2	2	3	4	4	7	7	7	9	9	9	3	3	3
August	0	0	0	0	0	0	3	3	3	1	1	1	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**6**	**24**	**24**	**8**	**9**	**9**	**11**	**11**	**11**	**10**	**10**	**10**	**8**	**24**	**24**

	1948				1959				1963				1978				1987			
Month	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**
Days Above DM Standard:																				
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	6	6	6	6	0	0	0	0	0	1	0	0
July	0	0	0	0	1	1	2	2	5	4	4	4	0	0	0	0	5	2	2	2
August	1	0	0	0	3	0	0	0	3	2	2	2	4	3	3	3	5	1	1	1
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**1**	**0**	**0**	**0**	**4**	**1**	**2**	**2**	**14**	**12**	**12**	**12**	**4**	**3**	**3**	**3**	**10**	**4**	**3**	**3**

[13] It is possible to have a temperature exceedance that is not further considered to be a temperature excursion. There are days in which both EIS 285 and EIS 345 (or Alt 1a) temperatures exceed the standard, yet the EIS 345 (or Alt 1a) temperature is cooler than the EIS 285 temperature. These days therefore do not count as excursions.

Table 9. Summary of excursions of the WAT 15% assimilative capacity threshold (top) and exceedances of the temperature standard (bottom), Fraser River below the Granby Sanitation District. Months that met the critical conditions criteria are highlighted in blue.[14]

	1948			1959			1963			1978			1987		
Month	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**	**EIS345**	**Alt1a**	**Alt8a**
May	0	2	2	0	0	0	0	0	0	0	0	0	0	11	11
June	2	23	23	4	4	4	6	6	6	0	0	0	6	11	11
July	9	9	9	9	11	11	31	31	31	26	26	26	6	2	2
August	0	0	0	0	0	0	22	22	22	25	25	25	0	0	0
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Totals	**11**	**34**	**34**	**13**	**15**	**15**	**59**	**59**	**59**	**51**	**51**	**51**	**12**	**24**	**24**

	1948				1959				1963				1978				1987			
Month	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**	**EIS 285**	**EIS 345**	**Alt 1a**	**Alt 8a**
Days Above WAT Standard:																				
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	7	7	7	7	0	0	0	0	0	0	0	0
July	0	0	0	0	5	4	9	9	17	20	20	20	0	0	0	0	16	13	12	12
August	9	7	7	7	12	9	9	9	10	10	10	10	13	13	13	13	13	11	11	11
September	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	**9**	**7**	**7**	**7**	**17**	**13**	**18**	**18**	**34**	**37**	**37**	**37**	**13**	**13**	**13**	**13**	**29**	**24**	**23**	**23**

[14] It is possible to have a temperature exceedance that is not further considered to be a temperature excursion. There are days in which both EIS 285 and EIS 345 (or Alt 1a) temperatures exceed the standard, yet the EIS 345 (or Alt 1a) temperature is cooler than the EIS 285 temperature. These days therefore do not count as excursions.

Generalization of Scenario Year Results to the 45-Year Dataset

The temperature impacts predicted from the scenario years should be extrapolated to the 45-year dataset to gain an understanding of how frequently those impacts are likely to occur in the future. As with the Rendezvous Bridge location, we decided to split the 45-year dataset into months that represent critical conditions (n = 24 from May to October; refer to Table 3) and those that do not represent critical conditions (n = 246). Using the results from the scenario years, we then totaled the number of excursions under critical conditions and extrapolated to the 45-year dataset and totaled the number of excursions under non-critical conditions and extrapolated to the 45-year dataset. We then added those numbers together to estimate the percent of the time the temperature threshold is expected to be exceeded. Results are detailed below.

DM Excursions

Of the 765 days in the 5-year simulation period (May 16 to October 15 (153 days) x 5 years), 306 days met the critical conditions criteria (40%), whereas 459 days did not meet the criteria (60%).

- **Cumulative Effects Including the Moffat Project:** In the 5-year simulation period, the DM assimilative capacity threshold is exceeded a total of 64 days (of 306 days) during the months that met the critical conditions criteria, which equates to 21% of the days. The DM assimilative capacity threshold is exceeded a total of 14 days (of 459 days) during the months that were not considered to represent critical conditions, which equates to 3% of the days. Given that critical conditions are expected in 24 months of the 45 years (270 months), we would expect the threshold to be exceeded 5% of the time from mid-May through mid-October:

$$(21\% \times (24/270)) + (3\% \times (246/270)) = 5\%$$

- **Effects Attributable to the Moffat Project:** In the 5-year simulation period, the DM assimilative capacity threshold is exceeded a total of 35 days (of 306 days) during the months that met the critical conditions criteria, which equates to 11% of the days. The DM assimilative capacity threshold is exceeded for 0 days (of 459 days) during the months that were not considered to represent critical conditions. Using the same logic as above, we would expect the threshold to be exceeded 1% of the time from mid-May through mid-October due to operation of the Moffat Project:

$$(11\% \times (24/270)) + (0\% \times (246/270)) = 1\%$$

DM excursions directly due to operation of the Moffat Project are expected to occur primarily in May and June, but will likely be well below the temperature standard.

WAT Excursions

- **Cumulative Effects Including the Moffat Project:** In the 5-year simulation period, the WAT assimilative capacity threshold is exceeded a total of 146 days (of 306 days) during the months

that met the critical conditions criteria, which equates to 48% of the days. The WAT assimilative capacity threshold is exceeded a total of 37 days (of 459 days) during the months that were not considered to represent critical conditions, which equates to 8% of the days. Given that critical conditions are expected in 24 months of the 45 years (270 months), we would expect the threshold to be exceeded 12% of the time from mid-May through mid-October:

$$(48\% \times (24/270)) + (8\% \times (246/270)) = 12\%$$

- **Effects Attributable to the Moffat Project:** In the 5-year simulation period, the WAT assimilative capacity threshold is exceeded a total of 41 days (of 306 days) during the months that met the critical conditions criteria, which equates to 13% of the days. The WAT assimilative capacity threshold is exceeded for 0 days (of 459 days) during the months that were not considered to represent critical conditions. Using the same logic as above, we would expect the threshold to be exceeded 1% of the time from mid-May through mid-October due to operation of the Moffat Project:

$$(13\% \times (24/270)) + (0\% \times (246/270)) = 1\%$$

WAT excursions directly due to operation of the Moffat Project are expected to occur primarily in May and June, but will likely be well below the temperature standard.

Note that with this methodology it is not possible to predict the number of excursions for a particular year. But, given the results presented above, we anticipate that years that contain months representative of critical conditions will have more excursions than years that do not have months that exhibit critical conditions. Of the 45 years in the complete dataset, 31 do not have any months that would be considered critical.

Biological Context for Temperature Excursions

The additional DM and WAT excursions that are directly attributable to the Moffat Project occur primarily in May and June. Yet, the temperatures at which excursions occur are well below the temperature standard. In May and early June, excursion temperatures for DMs are approximately 10°C below the standard and WAT temperatures are approximately 8°C below the standard. In late June, temperatures are approximately 4°C below the standard for both DMs and WATs. It is important to consider how significant these excursions are when the baseline temperatures that are used for comparison are cool. For example, in 1948 the DM temperatures in May and early June for Alt 1a in which excursions occur range from 8.7 to 15.7°C (Figure 66). Meanwhile, the DM temperatures for EIS 285 and EIS 345 during the same dates range from 5.3 to 13.4°C. These temperatures are colder than the lower limit for optimum temperature for some trout species and longnose sucker (refer back to Table 7). For WATs in 1948, temperatures in May and early June for Alt 1a in which excursions occur range from 9.0 to 11.0°C (Figure 71). In contrast, the WAT temperatures for EIS 285 and EIS 345 during the same dates range from 5.9 to 9.3°C. The operation of the Moffat Project is predicted to increase

water temperatures in some months. The increase in water temperature changes the temperature from lower than optimum temperature to within the optimum temperature range, in particular for cutthroat trout and spawning rainbow trout. The change in temperature does not follow the natural pattern, however, the slight warming may be biologically beneficial.

Meteorological Context for Scenario Years

As was discussed previously, the choice to use 2007 meteorological data for the simulations was intentional. The use of "hot" meteorology may have resulted in overestimates of stream temperatures. The result is that baseline temperatures were developed from warmer temperatures, which resulted in less assimilative capacity. Consequently, it is easier for changes in flow to cause excursions. However, most of the excursions in the Fraser River below the Granby Sanitation District occur in May and June, when modeled baseline temperatures were actually cooler than the historical baseline (see Figure 61). The number of excursions is likely less influenced by air temperature and more influenced by large reductions in flow. For example, in 1948, in which 22 excursions were simulated in May and June, the change in flow between EIS 285 and Alt 1a was approximately 500 cfs (Figure 106). Overall, we think the selection of 2007 air temperatures potentially has a significant role in determining temperature impacts from the Moffat Project, but the effect is less apparent below the Granby Sanitation District compared to upstream at Rendezvous Bridge.

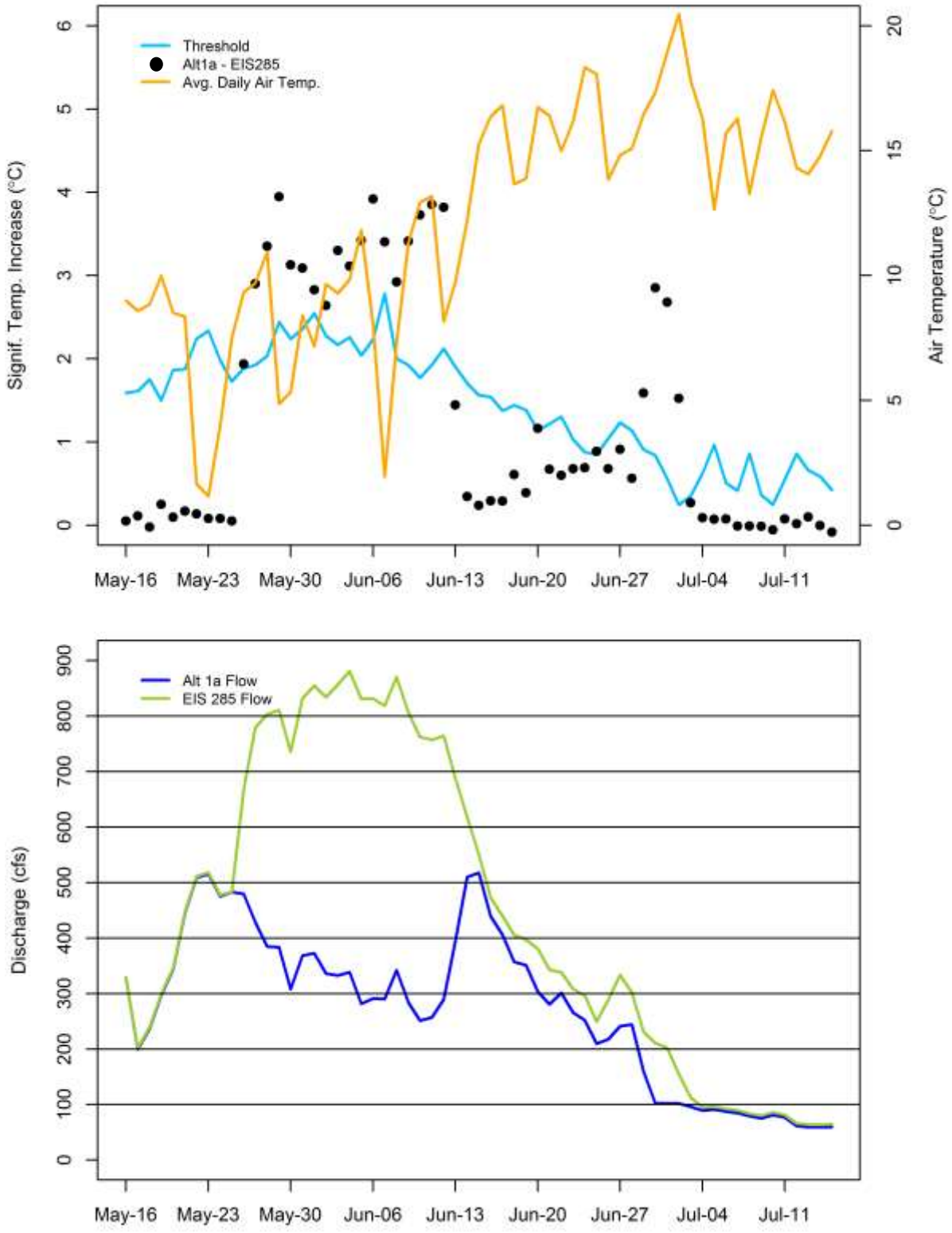

Figure 106. Comparison of the assimilative capacity threshold to 2007 average daily air temperature and Alt 1a and EIS 285 flows, Fraser River below the Granby Sanitation District, 1948. Black dots above the blue threshold line indicate excursions.

SUMMARY

An antidegradation review was completed for the Moffat Project to evaluate the potential for the cumulative effects of flow reduction to cause significant temperature impacts in the Fraser River, defined as a loss of more than 15% of the assimilative capacity. River temperatures simulated from a dynamic water temperature model were used to calculate the Daily Maximum (DM), a metric used for the acute temperature standard, and the Weekly Average Temperature (WAT), a metric used for the chronic temperature standard. Five scenario years were evaluated from mid-May to mid-October. The years were selected because for some months they represent the critical conditions under which cumulative flow effects are greatest and temperature impacts are most likely to occur as defined by CDPHE. The review focused on two locations on the mainstem Fraser River: at Rendezvous Bridge, in which the Tier I temperature standard is applicable, and below the Granby Sanitation District, where the Tier II standard is applied.

DMs and WATs were assessed against an assimilative capacity threshold that was produced according to a methodology developed collaboratively with CDPHE. Predicted increases in temperature that exceeded 15% of assimilative capacity were tallied as "excursions" and are considered to have a potentially significant impact on water quality. To understand when Moffat Project operations would potentially contribute to the excursions, excursion counts for EIS 345 (cumulative conditions without the Moffat Project in operation) and Alt 1a (cumulative conditions with the Moffat Project) were compared.

The cumulative effects of flow reduction are anticipated to cause significant temperature impacts as defined as the loss of more than 15% of the available assimilative capacity in the Fraser River. DM and WAT temperature excursions are summarized by location below. Excursions are further separated into two groups: those that are estimated to occur for months that represent critical conditions and those for months that do not represent critical conditions. The Moffat Project is predicted to directly contribute to temperature excursions, but in general, its contribution is relatively small compared to all cumulative effects.

Fraser River at Rendezvous Bridge

Excursions under Critical Conditions

Of the 610 days in the 5-year simulation period (June-September (122 days) x 5 years), 274 met the critical conditions criteria (45%).

<u>Daily Maximum (DM) Excursions</u>

- **Cumulative Effects Including the Moffat Project**: The DM assimilative capacity threshold is exceeded a total of 190 days of the 5-year simulation period that met the critical conditions criteria (274 days), which equates to 69% of the days.

- **Effects Attributable to the Moffat Project**: Of the 190 days of excursions, the Moffat Project directly contributes 18 days of excursions, which equates to 7% of the days in the 5-year simulation period that met the critical conditions criteria. The excursions directly due to operation of the Moffat Project occur in June. The temperatures at which excursions occur are well below the threshold of the Tier I water temperature standard.

Weekly Average Temperature (WAT) Excursions

- **Cumulative Effects Including the Moffat Project:** The WAT assimilative capacity threshold is exceeded a total of 168 days of the 5-year simulation period that met the critical conditions criteria (274 days), which equates to 61% of the days.
- **Effects Attributable to the Moffat Project**: Of the 168 days of excursions, the Moffat Project directly contributes 26 days of excursions, which equates to 9% of the days in the 5-year simulation period that met the critical conditions criteria. The excursions directly due to operation of the Moffat Project occur in June. The temperatures at which excursions occur are well below the threshold of the Tier I water temperature standard.

Excursions under Non-Critical Conditions

Of the 610 days in the 5-year simulation period (June-September (122 days) x 5 years), 336 did not meet the critical conditions criteria (55%).

Daily Maximum (DM) Excursions

- **Cumulative Effects Including the Moffat Project**: The DM assimilative capacity threshold is exceeded a total of 132 days of the 5-year simulation period that were not considered to represent critical conditions (336 days), which equates to 39% of the days.
- **Effects Attributable to the Moffat Project**: Of the 132 days of excursions, the Moffat Project does not directly contribute to any of the excursions.

Weekly Average Temperature (WAT) Excursions

- **Cumulative Effects Including the Moffat Project:** The WAT assimilative capacity threshold is exceeded a total of 78 days of the 5-year simulation period that were not considered to represent critical conditions (336 days), which equates to 23% of the days.
- **Effects Attributable to the Moffat Project**: Of the 78 days of excursions, the Moffat Project directly contributes 5 days of excursions, which equates to 1% of the days in the 5-year simulation period that were not considered to represent critical conditions. The excursions directly due to operation of the Moffat Project occur in July.

Excursions Generalized to the 45-Year Dataset

DM Excursions

- **Cumulative Effects Including the Moffat Project:** In the 5-year simulation period, the DM assimilative capacity threshold is exceeded a total of 190 days (of 274 days) during the months that met the critical conditions criteria, which equates to 69% of the days, and 132 days (of 336 days) during the months that were not considered to represent critical conditions, which equates to 39% of the days. Given that critical conditions are expected in 22 months of the 45 years (180 months), we would expect the threshold to be exceeded 43% of the time from June through September:

$$(69\% \times (22/180)) + (39\% \times (158/180)) = 43\%$$

- **Effects Attributable to the Moffat Project:** In the 5-year simulation period, the DM assimilative capacity threshold is exceeded a total of 18 days (of 274 days) during the months that met the critical conditions criteria, which equates to 7% of the days, and 0 days (of 336 days) during the months that were not considered to represent critical conditions. Using the same logic as above, we would expect the threshold to be exceeded 0.9% of the time from June through September due to operation of the Moffat Project:

$$(7\% \times (22/180)) + (0\% \times (158/180)) = 0.9\%$$

WAT Excursions

- **Cumulative Effects Including the Moffat Project:** In the 5-year simulation period, the WAT assimilative capacity threshold is exceeded a total of 168 days (of 274 days) during the months that met the critical conditions criteria, which equates to 61% of the days, and 78 days (of 336 days) during the months that were not considered to represent critical conditions, which equates to 23% of the days. Given that critical conditions are expected in 22 months of the 45 years (180 months), we would expect the threshold to be exceeded 28% of the time from June through September:

$$(61\% \times (22/180)) + (23\% \times (158/180)) = 28\%$$

- **Effects Attributable to the Moffat Project:** In the 5-year simulation period, the WAT assimilative capacity threshold is exceeded a total of 26 days (of 274 days) during the months that met the critical conditions criteria, which equates to 9% of the days, and 5 days (of 336 days) during the months that were not considered to represent critical conditions, which equates to 1% of the days. Using the same logic as above, we would expect the threshold to be exceeded 2% of the time from June through September due to operation of the Moffat Project:

$$(9\% \times (22/180)) + (1\% \times (158/180)) = 2\%$$

Fraser River below the Granby Sanitation District

Excursions under Critical Conditions

Of the 765 days in the 5-year simulation period (May 16 to Oct 15 (153 days) x 5 years), 306 met the critical conditions criteria (40%).

Daily Maximum (DM) Excursions

- **Cumulative Effects Including the Moffat Project**: The DM assimilative capacity threshold is exceeded a total of 64 days of the 5-year simulation period that met the critical conditions criteria (306 days), which equates to 21% of the days.
- **Effects Attributable to the Moffat Project**: Of the 64 days of excursions, the Moffat Project directly contributes 35 days of excursions, which equates to 11% of the days in the 5-year simulation period that met the critical conditions criteria. The excursions directly due to operation of the Moffat Project occur primarily in May and June. The temperatures at which excursions occur are well below the threshold of the Tier II water temperature standard.

Weekly Average Temperature (WAT) Excursions

- **Cumulative Effects Including the Moffat Project:** The WAT assimilative capacity threshold is exceeded a total of 146 days of the 5-year simulation period that met the critical conditions criteria (306 days), which equates to 48% of the days.
- **Effects Attributable to the Moffat Project**: Of the 146 days of excursions, the Moffat Project directly contributes 41 days of excursions, which equates to 13% of the days in the 5-year simulation period that met the critical conditions criteria. The excursions directly due to operation of the Moffat Project occur primarily in May and June. The temperatures at which excursions occur are well below the threshold of the Tier II water temperature standard.

Excursions under Non-Critical Conditions

Of the 765 days in the 5-year simulation period (May 16 to Oct 15 (153 days) x 5 years), 459 did not meet the critical conditions criteria (60%).

Daily Maximum (DM) Excursions

- **Cumulative Effects Including the Moffat Project**: The DM assimilative capacity threshold is exceeded a total of 14 days of the 5-year simulation period that were not considered to represent critical conditions (459 days), which equates to 3% of the days.
- **Effects Attributable to the Moffat Project**: Of the 14 days of excursions, the Moffat Project does not directly contribute to any of the excursions.

Weekly Average Temperature (WAT) Excursions

- **Cumulative Effects Including the Moffat Project:** The WAT assimilative capacity threshold is exceeded a total of 37 days of the 5-year simulation period that were not considered to represent critical conditions (459 days), which equates to 8% of the days.
- **Effects Attributable to the Moffat Project**: Of the 37 days of excursions, the Moffat Project does not directly contribute to any of the excursions.

Excursions Generalized to the 45-Year Dataset

DM Excursions

- **Cumulative Effects Including the Moffat Project:** In the 5-year simulation period, the DM assimilative capacity threshold is exceeded a total of 64 days (of 306 days) during the months that met the critical conditions criteria, which equates to 21% of the days, and 14 days (of 459 days) during the months that were not considered to represent critical conditions, which equates to 3% of the days. Given that critical conditions are expected in 24 months of the 45 years (270 months), we would expect the threshold to be exceeded 5% of the time from mid-May through mid-October:

$$(21\% \times (24/270)) + (3\% \times (246/270)) = 5\%$$

- **Effects Attributable to the Moffat Project:** In the 5-year simulation period, the DM assimilative capacity threshold is exceeded a total of 35 days (of 306 days) during the months that met the critical conditions criteria, which equates to 11% of the days, and 0 days (of 459 days) during the months that were not considered to represent critical conditions. Using the same logic as above, we would expect the threshold to be exceeded 1% of the time from mid-May through mid-October due to operation of the Moffat Project:

$$(11\% \times (24/270)) + (0\% \times (246/270)) = 1\%$$

WAT Excursions

- **Cumulative Effects Including the Moffat Project:** In the 5-year simulation period, the WAT assimilative capacity threshold is exceeded a total of 146 days (of 306 days) during the months that met the critical conditions criteria, which equates to 48% of the days, and 37 days (of 459 days) during the months that were not considered to represent critical conditions, which equates to 8% of the days. Given that critical conditions are expected in 24 months of the 45 years (270 months), we would expect the threshold to be exceeded 12% of the time from mid-May through mid-October:

$$(48\% \times (24/270)) + (8\% \times (246/270)) = 12\%$$

- **Effects Attributable to the Moffat Project:** In the 5-year simulation period, the WAT assimilative capacity threshold is exceeded a total of 41 days (of 306 days) during the months that met the critical conditions criteria, which equates to 13% of the days, and 0 days (of 459 days) during the months that were not considered to represent critical conditions. Using the same logic as above, we would expect the threshold to be exceeded 1% of the time from mid-May through mid-October due to operation of the Moffat Project:

$$(13\% \times (24/270)) + (0\% \times (246/270)) = 1\%$$

In summary, for the Fraser River at Rendezvous Bridge, temperature excursions are predicted to occur due to future, cumulative conditions in June, July, August and September. In general, the significant impacts are predicted to occur 28-43% of the time from June through September. The Moffat Project is predicted to directly contribute to excursions approximately 1-2% of the time, mostly in June; however, the temperatures are well below the threshold of the Tier I temperature standards at these times. The Moffat Project is not predicted to cause any temperature excursions in August or September. For the Fraser River below the Granby Sanitation District, temperature excursions are predicted to occur due to future, cumulative conditions from May through August. In general, the significant impacts are predicted to occur 5-12% of the time from mid-May to mid-October. The Moffat Project is predicted to directly contribute to 1% of the excursions, generally in May, June and July. However, temperatures in May and June are well below the threshold of the Tier II temperature standards during the times that excursions occur. The Moffat Project is not predicted to cause any temperature excursions in August, September or October.

EVALUATION OF THE MOFFAT PROJECT ON THE COLORADO RIVER DOWNSTREAM FROM THE FRASER RIVER

As detailed in the Fraser River water temperature model report, the original scope of work for the Fraser River water temperature model had an option for modeling the impacts of the Moffat Project on the Colorado River downstream from the Fraser River confluence. It was decided to use the existing Colorado River water temperature results (Hydros Consulting Inc. 2011) instead of conducting any additional modeling. Both models used a common meteorology year for temperature simulations and the Moffat Project was included in the Windy Gap Firming Project (WGFP) cumulative effects analysis. To support the 401 certification process for the WGFP, an antidegradation analysis was completed for the Colorado River from the Granby Reservoir Dam to just upstream of the confluence with the Williams Fork (Hydros Consulting Inc. 2014). Results from the analysis are summarized below.

The Colorado River from the Fraser River confluence to just upstream of the Williams Fork confluence was the key reach for assessment of antidegradation cumulative effects with the WGFP. Under cumulative effects, the Fraser River has decreased flow rates and increased water temperatures. This reach also contains Windy Gap Reservoir, from which additional diversions are the primary direct effect of the WGFP on the Colorado River. Five locations were evaluated for temperature impacts: 1 mile downstream of Windy Gap Dam, above Hot Sulphur Springs Water Treatment Plant, above Hot Sulphur Springs Resort, at the Lone Buck campground, and upstream of the confluence with the Williams Fork. All five locations are subject to the same major drivers for temperature changes under cumulative effects and all locations showed DM and WAT temperature excursions for four of the five years that were evaluated (the fifth year, 1986, was a wet year and did not show any temperature impacts). Excursions occurred in June and July (exact counts of days per month were not available). No temperature excursions were simulated in August or September due to the cooling effect of the 5412 releases. The 5412 release is the amount of water released from Granby Reservoir to comply with the U.S. Fish and Wildlife Service's Upper Colorado River Recovery Program. This release of water is half of the water users' obligation to release 10,825 acre-feet of water for the Recovery Program. The four years that had temperature impacts were the only dry to average years with increased Windy Gap diversions in the 15-year focus period. Therefore, temperature impacts could be expected in four out of 15 years. This corresponds to the approximate anticipated frequency of additional diversions from Windy Gap in dry and average years for the WGFP.

In summary, cumulative temperature impacts were simulated to increase the number of DM and WAT excursions at some locations in some years, but the overall effect was a net reduction in excursions, attributable to the 5412 releases.

SUMMARY OF MITIGATION AND ENHANCEMENT COMMITMENTS

Temperature Mitigation Measures

Proposed Mitigation for Section 404 Permit Condition

Denver Water will implement the following measures to address stream temperature problems in the Fraser and upper Colorado river basins.

1. *Temperature Mitigation Monitoring*. Commencing when acceptable regulatory approvals are received for the Moffat Project, Denver Water will monitor temperature at the locations listed below, which have been approved in Denver Water's *Fish and Wildlife Mitigation Plan*.
    a. **Fraser River below Crooked Creek near Tabernash (U.S. Geological Survey [USGS] gage #09033300)** - an existing real-time gaging and temperature station maintained by the USGS.

b. **Ranch Creek near Fraser, Colorado (USGS gage #09032000)** - an existing USGS gaging station. In 2014, Denver Water coordinated with the USGS to install a real-time temperature monitoring station on this gaging station.

c. **Ranch Creek below Meadow Creek (USGS gage #09033100)** - an existing USGS gaging station. In 2014, Denver Water coordinated with the USGS to reactivate this retired gage by installing real-time flow and temperature gages.

c. **Colorado River downstream of Windy Gap** - Denver Water will work with the Subdistrict to install, monitor and maintain two continuous, real-time temperature monitoring stations on the Colorado River at the Windy Gap gage and upstream of the Williams Fork River confluence.

2. *Temperature Mitigation Response***.** Denver Water will bypass up to 250 acre-feet (AF) of water, at a rate up to 4 cfs, to alleviate temperature problems.

   a. Mitigation Response Triggers. Bypass of the 250 AF will be triggered by the occurrence of any of the following temperature action levels during the period from July 15 to August 31, whether or not the Moffat Project is diverting water at the time the trigger occurs.

      1) Daily Maximum temperature of 21.2°C (70.2°F) at any of the Fraser River Basin gages and 23.8°C (74.8°F) at either of the Colorado River gages, based on the current acute standard.

      2) Maximum Weekly Average Temperature (MWAT) of 17°C (62.6°F) at any of the Fraser River Basin gages and 18.2°C (64.8°F) at either of the Colorado River gages, based on the current chronic standard.

   b. Mitigation Response Action. As stream temperature approaches a temperature action level after the Moffat Project is operational, the Learning by Doing (LBD) Technical Committee will determine which of Denver Water's facilities should bypass the 250 AF. (See below for more details on the LBD cooperative effort.) If agreement cannot be reached by the members of LBD, Colorado Parks and Wildlife (CPW) will decide. Any decision to implement a bypass must a) involve a location at which Denver Water is currently diverting, and b) determine there is sufficient streamflow available for bypass so as to make up to 250 AF available.

To understand the potential effectiveness of the 250 AF of bypass water, the Fraser River dynamic water temperature model was used to simulate stream temperature responses when an additional 4 cfs is bypassed through the Fraser River system for the month of August. Results indicated that the additional 4 cfs could cool stream temperatures somewhat, but would not totally alleviate temperature problems (Miller Ecological Consultants, Inc. 2015b).

Additional Actions for Elevated Stream Temperature

The Additional Actions describe commitments by Denver Water to assure the environment in Grand County is protected beyond purely mitigating impacts identified by the Corps in the Final EIS potentially

caused by the Moffat Project. These commitments will be incorporated as Section 404 Permit conditions for the Moffat Project and implemented through the LBD cooperative effort.

If Denver Water has already bypassed the 250 AF and the response triggers listed below occur, Denver Water will undertake the additional response actions described below.

A. **Additional Environmental Protection Response Triggers**. Additional Environmental Protections will be warranted by the occurrence of either of the following temperature response triggers during the period from July 15 to August 31 when the Moffat Project is diverting. (Refer to the next section on determining when diversions are Moffat Project diversions.)

   1) Any of the Fraser River Basin gages (USGS gages #09033300, 09032000 or 9033100) records a Daily Maximum temperature of 21.2°C (70.2°F).
   2) Any of the Fraser River Basin gages records an MWAT of 17°C (62.6°F).

B. **Additional Environmental Protection Actions**. Depending on where the Response Triggers occur, Denver Water will coordinate with LBD and implement either one or both of the following measures.

   1) Ranch Creek. At its Ranch Creek diversion, Denver Water will bypass an amount of water up to the natural inflow at the Ranch Creek diversion that will maintain the flow in Ranch Creek at the USGS gaging station near Fraser, Colorado (USGS gage #09032000) at 6 cfs (which is 2 cfs above the CWCB's in-stream flow right). This operation will continue until the temperature falls below the Response Trigger or Project Water is no longer being diverted.
   2) Fraser River. At its Fraser River and/or Jim Creek diversion(s), Denver Water will bypass an amount of water up to the combined natural inflow at the Fraser River and/or Jim Creek diversions that will maintain the flow in the Fraser River at the Winter Park USGS gage (#0902400) at 14 cfs (which is 6 cfs above the CWCB's in-stream flow right for the Fraser River at this location). This operation will continue until the temperature falls below the Response Trigger or Project Water is no longer being diverted. Denver Water will use reasonable efforts to provide the additional flows from the Jim Creek diversion to assure a flow in Jim Creek.

If after no more than 20 years of Moffat Project operation, the Additional Actions are determined by LBD and verified by the CDPHE to have a *de minimis* effect in reducing the stream temperature below the temperature response triggers at USGS gages #09032000, 09033300 or 09033100 when the Moffat Project is diverting, Denver Water will contribute $1 million to LBD for the exclusive purpose of designing and constructing projects to address stream temperature issues in the Fraser River Basin.

Determining When Diversions Are Moffat Project Diversions

When dealing with mitigation, enhancement measures and additional environmental protections, all intended to address the aquatic environment, it is important to distinguish between flow changes caused by diversions attributable to Denver Water's existing system and the incremental impacts caused by diversions related to operation of the Moffat Project, so that mitigation can be measured for regulatory compliance purposes. The following accounting procedure will be used to distinguish whether a flow change is being caused by the diversions for Denver Water's existing system (which is not subject to mitigation requirements) or by diversions for the Moffat Project.

After the Moffat Project is constructed, daily reservoir accounting will first credit the water diverted by Denver Water from the Williams Fork and Fraser river basins to fill the existing, "Old Water" capacity of Gross Reservoir, which is 41,811 AF. When the amount of Old Water in storage equals 41,811 AF, the next increment of water put into storage at Gross Reservoir from the Williams Fork and Fraser river basins will be counted as "Project Water." The Old Water is the first water stored in Gross Reservoir and the first water taken out of storage. Project Water does not include water stored from South Boulder Creek or flow-through water.[15]

Voluntary Enhancements for Aquatic Resources

In addition to the mitigation measures and additional environmental protections described above that address Moffat Project-related impacts, Denver Water has voluntarily entered into binding agreements with various stakeholders to provide significant resources to restore and enhance aquatic resources in Grand County. These enhancements are intended to address both current and future conditions of the aquatic environment without regard to causation.

Most of the enhancement resources to be provided by Denver Water under contracts are contingent upon the status of the Moffat Project. Some enhancement efforts can begin in the short term, upon Denver Water's receipt and acceptance of federal permits, while other resources will be available once the Moffat Project is operational. For purposes of clarifying how enhancements will work, it is assumed that the permitting process will be concluded late in 2015, and that the Moffat Project would become operational in 2021. Therefore, the period 2015-2021 is defined for illustrative purposes as the ***Interim***

[15]Flow-through water is water diverted and passed directly through Gross Reservoir to meet demand without being stored in the enlarged reservoir. Flow-through water is not considered Project Water because Denver Water could and would divert and pass through that water without the Moffat Project.

Period, and after 2021 is the ***Project Period***. When the Interim Period begins and ends and when the Project Period begins will change if issuance of permits or operation of the Moffat Project is delayed.

Colorado River Cooperative Agreement (CRCA)

In 2013, Denver Water, along with Grand County, Summit County, the River District and numerous other entities, signed the CRCA. The CRCA provides a framework for numerous actions to benefit water supply, water quality, recreation and the environment. Denver Water's resource commitments are contingent upon the issuance of permits necessary for the construction of the Moffat Project.

A. Learning by Doing Cooperative Effort

Under the CRCA, Denver Water has entered into the LBD Intergovernmental Agreement (IGA) with Grand County, the River District and Middle Park. The explicit purpose of LBD is to "maintain and, where reasonably possible, restore or enhance the condition of the aquatic environment in Grand County." The parties to LBD intend "to build and promote a stable, permanent relationship that respects the interests and legal responsibilities of the parties, while achieving the goals of the Cooperative Effort."

LBD is a unique and groundbreaking effort to manage an aquatic environment on a permanent cooperative basis. Importantly, LBD "will not seek a culprit for changes in the condition of the stream, but will provide a mechanism to identify issues of concern and focus available resources to address those issues." LBD will be implemented through the ongoing work of a management committee comprised of the parties to the LBD IGA, plus Northern Water, Colorado Parks and Wildlife and Trout Unlimited. All the parties to the LBD IGA have agreed to contribute resources on an ongoing basis. The most significant resources are those provided to Grand County by Denver Water under the CRCA, not the least of which is its ongoing permanent involvement in the LBD effort. The actions undertaken by LBD are to be coordinated with mitigation actions related to the Moffat Project, thereby increasing the effectiveness of both efforts.

B. Enhancement Resources Available During Interim Period

1. *LBD During Interim Period*.
    a. Denver Water Resources Provided. LBD will become effective upon Denver Water's acceptance of permits related to the Moffat Project. Under the CRCA, the following resources will become available to LBD during the Interim Period.
        1) $1.25 million for aquatic habitat improvements.
        2) $2 million for water quality projects, including but not limited to improvements to the capacity of wastewater treatment plants. Although this fund will be administered by Grand County and several sanitation districts, the projects should be coordinated through LBD.

3) As determined by Denver Water on a case-by-case basis, Denver Water will use the flexibility in its system and provide in-kind contributions of people, equipment and material to benefit LBD efforts.
4) Denver Water will undertake voluntary pilot projects using the environmental water described below that may become available in the Interim Period.

b. LBD Monitoring Program. In the IGA, the LBD parties specifically agreed to develop a stream monitoring plan to monitor conditions for the purposes of identifying and responding to potential changes to the environment; defining desired improvements and modifications; and measuring the effectiveness of actions taken. Monitoring will help identify the stressors that may cause impacts to the aquatic environment, regardless of causation, so the stressors can be addressed by LBD. This monitoring program is a voluntary effort as defined in the CRCA and is not part of the regulatory process.

1) *Defining Stream Conditions in Grand County*. A common database for the Fraser River Watershed should be established to better understand the relationship between hydrologic changes and impacts to the aquatic environment; the role of naturally-occurring conditions such as climate change, beetle kill, air temperature or wildfire; and the effectiveness of different management responses to address problem areas. An example of potential hydrologic changes is the increased diversions by Denver Water using its existing infrastructure, which will occur prior to Project operation. Using the common database, Denver Water and other parties in the Fraser Basin can participate in voluntary operational experiments to develop prescriptions for important stream reaches. Prescriptions might include operational actions, restoration projects and other voluntary efforts.

   The LBD parties have agreed to rely on the information contained in the Grand County Stream Management Plan (GCSMP) and to enhance the information in the Plan. The LBD Monitoring Plan will incorporate elements used during Phase 3B of the GCSMP. Monitoring under LBD "will be used to identify changes in the aquatic environment, identify critical stream reaches, assign priorities for action steps, evaluate the effectiveness of actions taken, and to modify and refine strategies for achieving goals of the Cooperative Effort." As members of the LBD management team, Denver Water and Grand County will advocate for the LBD Monitoring Plan to address the issues described below.

2) *Water Temperature***.** Monitoring water temperature will help improve the understanding of the relationship between water temperature at the mouth of tributaries and higher up in the watershed, and the thermal interactions among water flow, air temperature, shading and channel configuration.

   - LBD should expand the existing network of water temperature data loggers to other streams and locations in the Fraser River Basin where flow data is available. Temporary loggers should be placed near the mouth and at upstream locations in

streams experiencing temperature issues. The LBD Management Team will identify locations for additional data loggers and how long loggers remain in the field.

- Air temperature should be monitored at each water temperature data logger location and at a few general locations in the watershed.
- Data from the loggers would be used to determine where and how many real-time temperature monitoring stations LBD should deploy throughout the basin.

3) *Channel Stability and Sediment Transport*. Enhancement of the GCSMP described in the LBD IGA should include additional channel stability and sediment transport data and analysis, including the analysis used in the Moffat Project Final EIS, to develop valid prescriptions for specific stream reaches.

4) *Benthic Macroinvertebrate Monitoring***.** LBD should design and implement annual monitoring for macroinvertebrates, using Colorado's Multi-Metric Index or another agreed to methodology. Monitoring locations should represent, at a minimum, the four stream segments in the Fraser River Watershed defined in the CDPHE-WQCC's Standards and Classifications for the Upper Colorado River (5 CCR 1002-33). The purpose of the monitoring is to establish a baseline to identify priority stream reaches and test the effectiveness of management activities initiated by LBD.

5) *Riparian Areas and Wetland Monitoring***.** Denver Water will work with LBD to design and implement a mapping program for riparian vegetation in the Fraser River Watershed. Locations for the monitoring efforts will be determined by LBD, and should include, at a minimum, a species inventory and photo documentation.

c. Use of LBD Resources**.** The parties to LBD, including Denver Water, have committed to develop an annual operations plan to maximize the stream environmental benefits produced by the available resources, including the water and funding contributed by Denver Water. The plan will explore opportunities for coordinated operations of diversion structures and reservoir releases among all water users in Grand County, including Northern Water; the Subdistrict; Reclamation, Denver Water; Middle Park; River District; and in-county diversions for agricultural, municipal, industrial and others uses. The purpose of coordinated operations is to allow the water users to meet the supply requirements of their systems, while maximizing the effectiveness of LBD. It is anticipated that coordinated operations could greatly enhance the effectiveness of such activities. Denver Water and Grand County agree that some of these resources should be dedicated to the same issues addressed by the mitigation measures to leverage benefits to the stream environment.

1) *Temperature*. Helping to ameliorate temperature issues in the Fraser River Basin and the Colorado River is one of LBD's priorities. Using the data generated through the LBD Monitoring Plan described above, experimental voluntary responses (e.g., changes in diversions, increased shading and modified channel configurations) will be tested to define possible combinations of actions to address temperature issues. As part of voluntary pilot projects, Denver Water will release available water in excess of its needs when stream temperatures are measured within 1°C of the daily maximum acute temperature standard and when stream temperatures are measured at or above the MWAT chronic standard at agreed upon locations.
2) *Channel Stability*. Based on the supplemental data and analysis provided through the LBD Monitoring Plan, LBD should begin to develop prescriptions to address channel stability and sediment transport. As part of voluntary pilot projects, Denver Water will use water on a voluntary basis to test the prescription for flushing flows and to determine potential operational issues with releasing flushing flows. In addition, LBD should address sediment loading issues through mechanical means. For example, Denver Water has already proposed a joint effort with LBD to replace the culvert downstream of the Fraser River diversion structure with one that is more fish friendly and designed to reduce sediment into the Fraser River.

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