Hot Water and Low Flow: The Summer of 2015 in the Snoqualmie River Watershed

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Hot Water and Low Flow: The Summer of 2015 in the Snoqualmie River Watershed

Prepared for:

Snoqualmie Watershed Forum

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EXECUTIVE SUMMARY

The Snoqualmie Watershed Forum is committed to protecting and restoring the health of the Snoqualmie watershed to enhance and preserve its cultural and natural resources. Therefore, they requested this technical memorandum to summarize temperature data collected throughout the Snoqualmie River watershed during the warm-dry summer of 2015. The purpose is to inform the Snoqualmie Watershed Forum as well as partner organizations and interest groups about the unique river conditions observed in that year. This technical memorandum reports observed temperature trends across the mainstem Snoqualmie River and its tributaries, and discusses trends in the context of relevant data sets.

The Snoqualmie River watershed is an important area for aquatic habitats, agriculture, aesthetics, and recreational opportunities. The watershed supports several salmon and trout species, including Chinook salmon and Steelhead trout, which are listed under the Endangered Species Act. Historic and ongoing degradation have negatively impacted habitat quality and quantity throughout the watershed altering the health of the ecosystem and the viability of its related species. Additionally, several regional pressures including population growth, climate change, and various land uses place Snoqualmie River cultural and natural resources at risk.

The summer of 2015 had record low flows and high air temperatures which provided a unique opportunity to evaluate the status and trends of water temperatures in the Snoqualmie River. In an effort to capture these unique water conditions, the Snoqualmie Watershed Forum in partnership with King County Water and Land Resources strategically deployed 27 thermistors across the Snoqualmie River and its primary tributaries. Continuous water temperature was collected from June 30th to September 30th at 17 mainstem and 10 tributary locations. Water temperature time-series were summarized for the 7-day average of daily maximum temperatures and the 7-day average of daily minimum temperatures, and compared to Washington State water quality standards as well as air temperature and stream flow at representative locations. Additionally, 2015 Snoqualmie water temperatures were compared to two additional data sets including 2006 water temperature time-series collected by the Washington State Department of Ecology and multi-year water temperature time-series collected by King County.

Snoqualmie River water temperatures during the summer of 2015 were considerably high across all of the selected sample sites with many of the sites having 7-day average of daily maximum temperatures consistently above state standards for designated uses. Record low flows were ubiquitous across all sample sites and throughout the Snoqualmie River watershed during the summer of 2015, likely contributing to the observed high water temperatures. Water temperatures tended to increase from an upstream to downstream direction; however, there were noticeable differences from this pattern in areas where the valley walls narrowed and potential groundwater expression occurred. Additionally, the observed water temperature ranges appeared to decrease at sample sites within the

groundwater gaining reach of the Snoqualmie River below the falls (between the Raging and Tolt Rivers).

Water temperatures across primary tributaries were also quite warm with 7-day average of daily maximum temperatures at all of the sites (excluding Harris and Ames Creeks) consistently exceeding state standards. Several large tributaries (Tolt, Raging, and Cherry) were well within the range of temperatures observed in the mainstem Snoqualmie while many of the smaller tributaries (Harris, Ames, Tokul, Griffin, and Patterson) were noticeably cooler than the mainstem. While the 7-day average of daily maximum temperatures of the Tolt River was within the observed ranges of mainstem temperatures, the minimum temperatures in the Tolt were several degrees lower than the mainstem and may have influenced observed mainstem temperatures. The Raging River was the warmest tributary with 7-day average of daily maximum temperatures at times exceeding the mainstem Snoqualmie; however, a low percentage of flow contribution resulted in minimal influence on mainstem temperatures.

The North Fork of the Snoqualmie was right around the state standard and the South Fork was consistently above the state standard. The Middle Fork was not only much higher than the state standard but also significantly warmer than both the North and South Forks. Additionally, temperatures observed in the Middle Fork were well within the upper range of observed temperatures across the mainstem Snoqualmie. The North and South Forks on the other hand were consistently below temperatures observed in the mainstem. The Middle Fork was not only significantly warmer than both of the other forks but contributed the majority of the flow during the sampled period.

Comparisons with 2006 Washington State Department of Ecology and U.S. Geological Survey data indicated that 2015 displayed significantly warmer air temperatures and lower flows than both 2006 and the historical average. The onset of low flows observed in 2015 occurred much earlier than 2006 and the historical record, with low flow occurring as early as June in 2015 compared to the more typical August-September. Water temperatures reflected these differences in air temperature and flow with 2015 having consistently warmer mainstem Snoqualmie temperatures compared to 2006. Additionally, tributary water temperatures in 2015 were consistently warmer than the 2006 water temperature time-series.

Water temperature comparisons with King County continuous gauges were available for five sample sites (Cherry, Tuck, Harris, Griffin, and Patterson). Flows across these tributaries were consistently lower in 2015 compared to previously gauged years. Additionally, water temperatures from 2015 were consistently warmer than previous years. Across all sites that were comparable to King County gauging stations, the highest daily temperatures observed in 2015 exceeded all previously gauged years with the exception of Griffin Creek.

Salmonids in the Snoqualmie River watershed were subjected to both acute lethal and sub-lethal temperatures during the warm-dry summer of 2015. The impacts of these warm temperatures likely affected both juvenile salmonids rearing in the watershed over the

summer as well as the adults that were holding or which returned later in the year. During June and July, temperatures in the mainstem Snoqualmie intermittently rose above the 1-day maximum temperature standards for both acute lethal effects and migratory barriers. While the acute 1-day maximum temperatures were sporadic in the mainstem, the 7-day average of daily maximum temperature thresholds for core summer habitat as well as spawning, rearing and migration habitats were surpassed for the majority of the summer. Many of the Snoqualmie tributaries experienced exceedances for the core summer habitat thresholds and some of the larger tributaries (Cherry, Tolt, and Raging) exceeded 1-day maximum temperature thresholds. While the mainstem and major tributaries experienced water temperatures well above state thresholds, there were several, smaller tributaries that remained at or below the threshold for acute lethal effects. These colder tributaries as well as areas of groundwater exchange maintain cooler waters, which may have the potential to provide refuge for salmonids during warmer water condition.

The warm river conditions observed in 2015 emphasize the value of addressing water temperature issues in the Snoqualmie River watershed. With warm temperatures occurring throughout the Snoqualmie watershed, it will be important to focus on both site- and basin- level scales when prioritizing strategies to mitigate current conditions and to build watershed resiliency for future climate conditions. This study highlights the need to consider factors like spatial and temporal variation in temperature regimes, tributary and groundwater influences, and daily patterns in thermal fluctuations when addressing temperature issues and impacts on salmonids. Potential actions may include headwater and tributary riparian restoration, instream flow augmentation or reduced withdrawals, improved recharge and groundwater exchange, and improved floodplain, tributary, and riparian connectivity. Additional studies such as the influence of tributaries and groundwater, salmonid responses to temperature, spatial and temporal variation in water temperatures, and others are needed to better understand and develop management strategies.

The low flow and high temperature conditions observed in 2015 may provide useful insight into the likely impacts of climate change on the Snoqualmie River watershed. The ability of Snoqualmie River and its tributaries to continue supporting salmonid populations will inherently be tied to the degree to which these water bodies can be resilient to climate change. Building resiliency may require expanded emphasis on protecting and restoring cold-water refugia such as tributary confluences, headwaters, and groundwater recharge zones. Supporting floodplain processes, watershed storage, and instream flows may also be essential to build resiliency. At a minimum, it will be necessary to increase conservation and restoration efforts at a magnitude and scale comparable to the degree and urgency of apparent temperature and flow issues.

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1.0 INTRODUCTION

Across western Washington, the winter of 2014-15 was much warmer than is typical, resulting in extremely low snowpack across the west slope of the Cascade Range. As a result, snowmelt-driven flow peaks were largely absent in the spring and by early May 2015, many rivers were exhibiting near record low flows for the time of year. With minimal snow in the mountains, summer flows were likely to be very low until the onset of fall rains. Additionally, climate models forecasted a warm and dry summer. In an effort to capture this extreme event of very low flows coupled with high air temperatures, the Snoqualmie Watershed Forum and King County funded a study to monitor the status and trends of water temperature throughout the Snoqualmie River and its tributaries. This information would provide useful insight into questions such as: 1) To what extent were water temperatures at levels that were stressful or lethal to salmonids? 2) Do the tributaries and mainstem Snoqualmie respond similarly to extreme temperature events? 3) How do water temperatures and flows in 2015 compare to past years? 4) Can cooler areas of the river and tributaries be detected to help identify potential cold water refugia?

The Snoqualmie River watershed has been home to the Snoqualmie and Tulalip Tribes for millennia and is part of the Treaty-Reserved usual and accustomed fishing and hunting area of the Tulalip Tribes. The watershed drains nearly 700mi^2 from the crest of the Cascade Mountains down to the confluence with the Skykomish River near Monroe, to create the Snohomish River. The watershed is primarily in King County, with a small portion of the lower extents in Snohomish County. The three main forks of the Snoqualmie (North Fork, Middle Fork, and South Fork) meet near the city of North Bend and combine to form the mainstem Snoqualmie River before flowing past the city of Snoqualmie. At approximately river mile 38.5 the Snoqualmie drops 268ft over Snoqualmie Falls and continues flowing northward past Fall City, unincorporated agricultural areas, and the cities of Carnation and Duvall. The upper Snoqualmie watershed lies within the Mount Baker Snoqualmie National Forest and upland sub-drainages throughout the watershed are dominated by forests in public and private ownership. After forestry, agriculture and unincorporated rural residential areas are the most prevalent land uses, with incorporated cities representing just 2% of overall watershed area.

The Snoqualmie River watershed is an important area for aquatic habitats, domestic water supply uses, forestry, agricultural, and recreational activities (e.g., swimming, rafting, tubing, fishing and wildlife viewing). Additionally, the Snoqualmie has many residential, commercial, and industrial uses. The lower valley floor has over 14,000 acres designated as an Agricultural Production District, of which roughly 9,500 acres are actively farmed, supporting numerous agricultural uses including livestock, vegetables, pastures, fruits/berries, nurseries, row crops, dairies, and others.

The Snoqualmie River watershed supports wild populations of chinook (*Oncorhynchus tshawytscha*), chum (*Oncorhynchus keta*), coho (*Oncorhynchus kisutch*), and pink salmon (*Oncorhynchus gorbuscha*); steelhead trout (*Oncorhynchus mykiss*), rainbow (*Oncorhynchus mykiss*), brook (*Salvelinus fontinalis*), and cutthroat trout (*Oncorhynchus clarki*). Though rarely seen in the Snoqualmie, the watershed is also in the range of native char, e.g., Dolly

Varden (*Salvelinus malma*) and bull trout (*Salvelinus confluentus*). Chinook, bull trout, and steelhead trout are listed as threatened under the Endangered Species Act with Chinook and bull trout recovery strategies outlined in the Snohomish River Basin Salmon Conservation Plan (SBSRF 2005). Anadromous salmonid spawning within the mainstem Snoqualmie River occurs below the falls throughout the alluvial deposits below the confluences of the Tolt River, Raging River and Tokul Creek. Anadromous salmonid spawning also occurs across many of the Snoqualmie tributaries below the Falls including Cherry Creek, Tuck Creek, Harris Creek, Tolt River, Griffin Creek, Patterson Creek, Raging River, and Tokul Creek. Across the Snoqualmie tributaries, Chinook and steelhead spawning is primarily concentrated in the Raging and Tolt Rivers. Resident salmonid spawning also occurs above the falls throughout the tributaries and three forks of the Snoqualmie River.

Prior to European settlement, much of the Snoqualmie floodplain upstream of Duvall and downstream of the falls was forested. The riparian corridor was dominated by large numbers of hardwoods; however, very large cedar and spruce were frequent along these corridors (Collins and Sheikh 2002). While nearly 70% of the watershed is still forested (NOAA CCAP 2011 data), the lower portion of the Snoqualmie mainstem has only a fraction of its historic forest cover. Areas of forest cover in the floodplains below the falls are estimated to be at around 16% of pre-European settlement (Collins and Sheikh 2002). Additionally, while the historic floodplain featured many oxbows and wetlands (Collins and Sheikh 2002), many of these wetland features have either been disconnected or no longer exist due to conversion of the floodplain from a forested condition to one dominated by agricultural uses. Urban development pressures and land-use conversions have negatively impacted habitat quality and quantity throughout the Snoqualmie River watershed (Haring 2002). Specifically, salmonid habitat degradation has occurred due to fish passage barriers, floodplain modification, loss of wetlands, altered channel conditions including large woody debris removal, and altered riparian functions and conditions (Haring 2002). Additionally, the Snoqualmie is known to be impaired for water temperature and currently has a Total Maximum Daily Load (TMDL) aimed to protect aquatic life uses including core summer salmonid habitat as well as salmonid spawning, rearing, and migration (WA Ecology 2011).

The watershed has a temperate marine climate characteristic of warm, dry summers and cool, mild, wet winters (WA Ecology 2011). Precipitation falls unevenly across the watershed primarily in the higher elevations. Snowmelt runoff contributes to stream flows in May and June and low flows generally occur from August to September when snowmelt runoff and precipitation are minimal. These low flow periods can be critical for salmonids influencing their migration, spawning, and rearing. Summer low flow and high water temperatures are commonly co-occurring and can result in salmonid migration barriers, prolonged thermal stress, acute lethality, and increase susceptibility to pathogens. In 1979, in an effort to halt further water withdrawals for out-of-stream uses, an Instream Resources Protection Program established low flow targets for the mainstem of the Snoqualmie River (WAC 173-507) as well as several tributary basins, effectively precluding issuance of most new water rights.

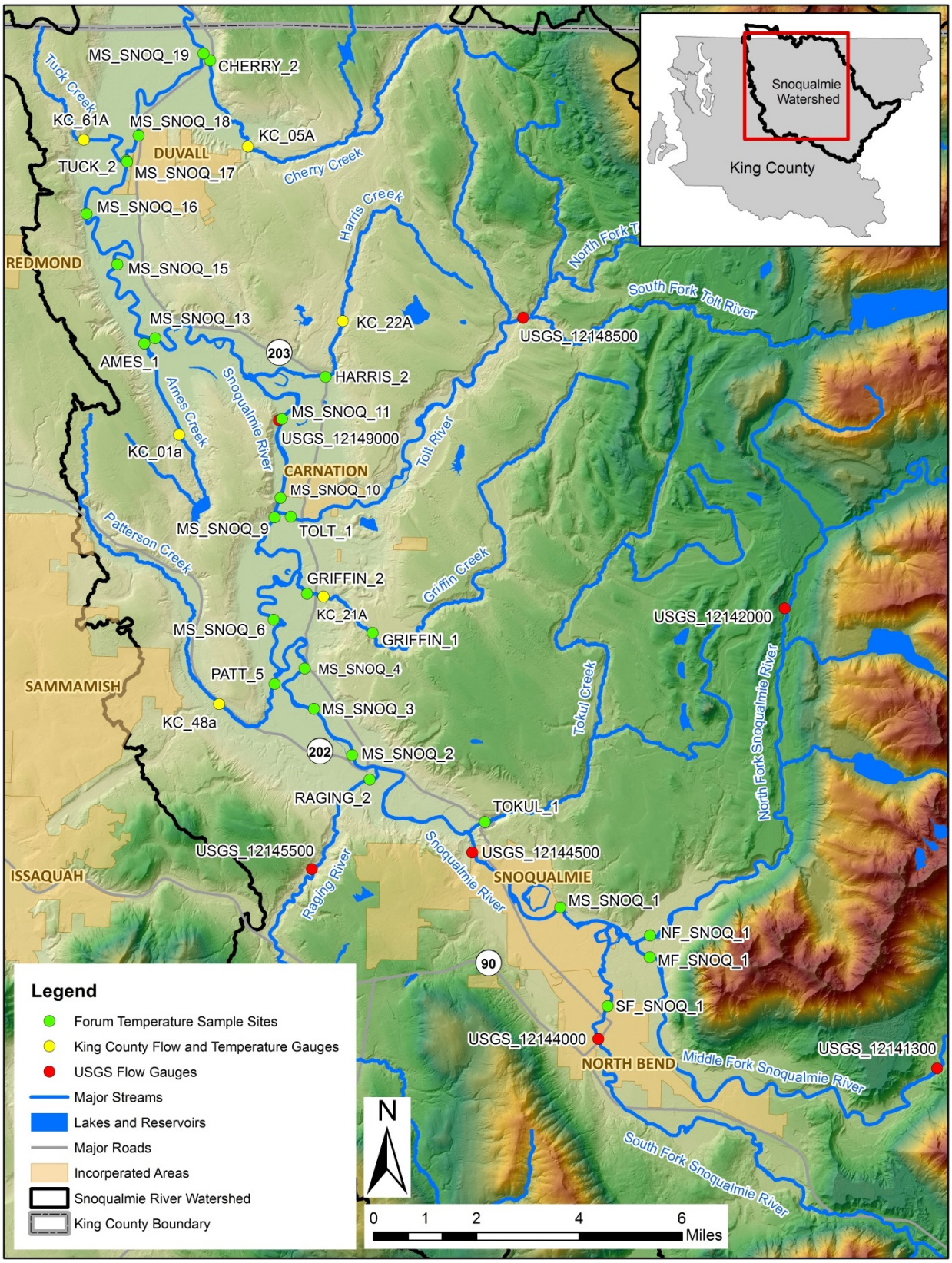
2.0 METHODS

2.1 Site Selection

Sample sites were selected throughout the Snoqualmie River watershed including the three forks of the upper Snoqualmie, major tributaries, and several mainstem Snoqualmie locations downstream to the King County/Snohomish County line. Geomorphology of the Snoqualmie River floodplain was used as a primary filter to evaluate potential mainstem and tributary sample locations. Geomorphology can influence how shallow groundwater expresses itself as surface water and groundwater is typically cooler than the surface water during summer months. Areas where colder water enters the system can have physiological and ecological significance for fishes serving as thermal refugia (Torgersen et al. 2012). Potential river reaches where groundwater expression may occur include areas where the floodplain width narrows on either bank creating pinch points, as well as areas downstream of large wetland complexes, and within alluvial reaches. Mainstem Snoqualmie sample sites were selected by using remote sensing LiDAR (Light Detection and Ranging) to identify the areas of narrowing in the floodplain. Additionally, several thermistors were placed in tributaries to measure how the temperature changes as it flows off the hills and across the floodplain. When possible, thermistors were placed near US. Geological Survey (USGS) and King County gauging stations for later comparisons with flow and water temperature. Once the approximate locations of the sites were selected, refinements were made based on availability of safe access to the waterway. While most sites were located at public access points, there were a few key areas in the Snoqualmie Valley where such locations are sparse. Through outreach to local farmers, we were grateful to secure access to the waterway through several private properties.

Water temperature in the Snoqualmie River was subsequently monitored across twenty seven sites including 17 mainstem and 10 tributary locations (Figure 1). The mainstem sites include one site above the Snoqualmie Falls, and 13 sites below the falls extending past Duvall and nearly to the county line. All three forks of the Snoqualmie (North, Middle, and South) were monitored as well as primary tributaries included Cherry Creek, Tuck Creek, Ames Creek, Harris Creek, Tolt River, Griffin Creek, Patterson Creek, Raging River, and Tokul Creek. Details of site-specific locations are further described in Table 1 in section 2.2.

Figure 1. Map of Snoqualmie River temperature study sites including USGS and King County gauging stations.



2.2 Thermistor Deployment and Periodic Downloads

Water temperature was monitored using HOBO Pendant Thermistors (Model# UA-002-64) with 64KB of rewritable memory. Thermistors were launched using the Onset HOBOware software and set to record temperature in Celsius on 15 minute intervals. Thermistors were calibrated using a combination of a chilled (refrigerated) and room temperature bath tests. Thermistors were placed in each bath and allowed to equilibrate for at least 3 hours. The temperatures of the baths were recorded after the equilibration period and compared with the downloaded thermistor readings. None of the thermistors recorded temperatures that deviated beyond the range of variability noted by Onset (±0.53°C).

Calibrated thermistors were deployed at the 27 sites in the Snoqualmie River on June 29th/30th and stayed in the water until September 29th/30th (Table 1), with occasional data downloads during that period. The thermistors were weighed down with bolts and nuts and secured with 40lb-test monofilament to riparian vegetation, bridges, logs, and other suitable secure points. To ensure the thermistors were retrievable at potentially higher late-summer flows, the thermistors were placed in the water no further than ~10ft from the bank. Water temperature at the time of thermistor deployment was recorded with an YSI temperature probe (Model #63). Thermistors were visited monthly to download temperature data, verify thermistor status (e.g., recording, shut-down, or missing), and to re-deploy any necessary replacement thermistors. Stream temperature was concurrently recorded at the time of monthly downloads with the YSI temperature probe to verify thermistor measurements.

Table 1. Snoqualmie River temperature study site locations.

Site ID	Approximate River Mile	Location
NF_SNOQ_1	0.3	North Fork Snoqualmie River near 428th Ave. S.E., Snoqualmie, WA
MF_SNOQ_1	0.4	Middle Fork Snoqualmie River near 428th Ave. S.E., Snoqualmie, WA
SF_SNOQ_1	2.1	South Fork Snoqualmie River downstream of Highway 202, Snoqualmie, WA
MS_SNOQ_1	40.8	Snoqualmie River near SE Reinig Rd., Snoqualmie, WA
MS_SNOQ_2	33.9	Snoqualmie River downstream of Raging River confluence, Fall City, WA
MS_SNOQ_3	32.6	Snoqualmie River near Carlson Restoration Site, Fall City, WA
MS_SNOQ_4	31.3	Snoqualmie River near Neal Rd. Boat Launch, Fall City, WA
MS_SNOQ_6	28.2	Snoqualmie River downstream of Patterson Creek, Carnation, WA
MS_SNOQ_9	23.8	Snoqualmie River near N.E. Tolt Hill Rd., Carnation, WA
MS_SNOQ_10	23.4	Snoqualmie River near Tolt MacDonald Park, Carnation, WA
MS_SNOQ_11	21.8	Snoqualmie River near Chinook Bend, Carnation, WA
MS_SNOQ_13	16.6	Snoqualmie River upstream of Ames Creek, Carnation, WA
MS_SNOQ_15	13.8	Snoqualmie River near N.E. 124th St., Duvall, WA
MS_SNOQ_16	11.2	Snoqualmie River near N.E. 138th St., Duvall, WA
MS_SNOQ_17	9.5	Snoqualmie River upstream of Tuck Creek, Duvall, WA
MS_SNOQ_18	8.9	Snoqualmie River near Taylor Boat Launch, Duvall, WA
MS_SNOQ_19	6.0	Snoqualmie River downstream of Cherry Creek, Duvall, WA
TOKUL_1	0.4	Tokul Creek near WDFW hatchery, Fall City, WA
RAGING_2	0.4	Raging River near S.E. 44th Pl. Dike Rd., Fall, City, WA
PATT_5	0.5	Patterson Creek near S.E. 24th St., Fall City, WA
GRIFFIN_1	2.4	Griffin Creek near King County routine water quality site, Carnation, WA
GRIFFIN_2	0.7	Griffin Creek near Highway 203, Carnation, WA
TOLT_1	0.3	Tolt River near Highway 203, Carnation, WA
HARRIS_2	1.8	Harris Creek near Highway 203, Carnation, WA
AMES_1	0.2	Ames Creek near 100th St., Carnation, WA
TUCK_1	0.04	Tuck Creek near West Snoqualmie River Rd. N.E., Duvall, WA
CHERRY_2	0.2	Cherry Creek near Duvall-Monroe Rd., Duvall, WA

2.3 Data Analyses and Comparisons

2.3.1 State Temperature Standards

Analyses and comparisons for the 2015 Snoqualmie temperature study were based on Washington State water temperature standards, as defined in the WAC (WAC 173-201a). Different parts of the Snoqualmie River support different aquatic life uses for salmonids. For example, salmonids require cool water during spawning and incubation, and species like coho salmon and steelhead spend one or more summers rearing in streams before migrating to the ocean. Thus, certain waters that are considered to be critical for salmon spawning and rearing have a different standard for temperature than other areas where spawning is unlikely to occur. Table 2 lists the temperature standards for aquatic life uses that apply to one or more water bodies in the Snoqualmie River watershed. The water bodies to which each category applies are listed in the third column. Tributaries to waters of a particular use designation are subject to the same standards as the receiving water, unless otherwise specified in the WAC.

The temperature standards outlined in Table 2 are computed as the 7-day average of the daily maximum temperatures (7-DADMAX), i.e., the arithmetic average of seven consecutive measures of daily maximum temperatures. The use of the 7-DADMAX instead of an instantaneous temperature maximum is intended to reflect that most aquatic organisms can tolerate a short period of high temperature, whereas persistently exposure to warm water is more likely to cause harm. If a water body is naturally warmer than or within 0.3°C of the criterion for that water body, human caused increases (considered cumulatively) must not increase that temperature by more than 0.3°C. Additional limits on human-caused temperature changes are described in the WAC.

As outlined in Table 2, the Washington State Department of Ecology (WA Ecology) has established 7-DADMAX thresholds where water temperatures should not exceed 16°C in core summer habitats or 17.5°C in areas of salmonid spawning, rearing and migration. In addition to the temperature standards listed in Table 2, WA Ecology has designated supplemental spawning and incubation criteria for water temperature in certain areas where salmonid spawning and egg development occurs. These criteria apply when the standard temperature criteria are insufficient. In these tributaries and mainstem reaches, the 7-DADMAX criterion is 13°C during the specified periods. These reaches are primarily in areas where the default criterion would be 16°C, and include portions of the Snoqualmie mainstem within Chinook spawning areas, lower portions of the Tolt River (including segments of each fork), and reaches in Cherry Creek, Patterson Creek, Griffin Creek and the Raging River. Additionally, WA Ecology has set a 1 day max temperature (1-DMAX) of 23°C to avoid acute lethal effects and a 1 DMAX temperature of 22°C to avoid barriers to migration.

Table 2. WA Ecology Snoqualmie River water quality temperature standards.

Aquatic Life Uses	Standards	Snoqualmie Waters
Char spawning and rearing. The key identifying characteristics of this use are spawning or early juvenile rearing by native char (bull trout and Dolly Varden), or use by other aquatic species similarly dependent on such cold water. Other common characteristic aquatic life uses for waters in this category include summer foraging and migration of native char; and spawning, rearing, and migration by other salmonid species.	**Temperature** (7-DADMax) 12°C.	North Fork Snoqualmie above and including Sunday Creek (at RM 17). Includes all tributaries above the junction. Middle Fork Snoqualmie above and including Dingford Creek (at RM 26). Includes all tributaries above the junction. Middle Fork Snoqualmie's tributaries at longitude -121.5629 and latitude 47.5389 North Fork Tolt above and including tributary at longitude -121.7775 and latitude 47.7183 (at RM 4). Includes all tributaries above the junction. South Fork Tolt above and including tributary at longitude -121.7392 and latitude 47.6925. Includes all tributaries above the junction. South Fork Tolt's unnamed tributaries at -121.7856 and latitude 47.6889. North Fork Creek (at North Fork Tolt RM 1) and unnamed creek at Longitude -121.8231 and latitude 47.7409 (Sec. 18 T26N R8E). All tributaries above junction. Cripple Creek (at Middle Fork Snoqualmie RM 24) and all tributaries. Pratt River (at Middle Fork Snoqualmie RM 16) and all tributaries. Taylor River (at Middle Fork Snoqualmie RM 20) and all tributaries.

Core summer salmonid habitat. The key identifying characteristics of this use are summer (June 15 - September 15) salmonid spawning or emergence, or adult holding; use as important summer rearing habitat by one or more salmonids; or foraging by adult and subadult native char. Other common characteristic aquatic life uses for waters in this category include spawning outside of the summer season, rearing, and migration by salmonids.	**Temperature** (7-DADMax) 16°C.	Cherry Creek and tributaries from mouth to headwaters. Snoqualmie River and tributaries from and including Harris Creek to west boundary of Twin Falls State Park on South Fork (RM 9.1) South Fork Snoqualmie from west boundary of Twin Falls State Park (RM 9.1) to headwaters. Middle Fork Snoqualmie from mouth to Dingford Creek (RM 26). North Fork Snoqualmie from mouth to Sunday Creek (RM 17). South Fork Tolt and tributaries from mouth to west boundary of T26N-R9E-Sec31 (RM 6.9). South Fork Tolt and tributaries from west boundary of T26N-R9ESec31 (RM 6.9) to headwaters, except for waters specifically listed in Table 602 as Char spawning and rearing. Tributaries to all waters designated Core summer salmonid habitat, or as Extraordinary primary contact for recreation. All lakes and all feeder streams to lakes, where reservoirs with a mean detention time greater than fifteen days are treated as lakes for use designation. All surface waters not listed in Table 602 lying within national forests, national parks and/or wilderness areas.
Salmonid spawning, rearing, and migration. The key identifying characteristic of this use is salmon or trout spawning and emergence that only occurs outside of the summer season (September 16 - June 14). Other common characteristic aquatic life uses for waters in this category include rearing and migration by salmonids.	**Temperature** (7-DADMax) 17.5°C.	Snoqualmie River from mouth to junction with Harris Creek (RM 21.3). All other surface waters.

2.3.2 Temperature Time-Series

Temperature time-series across sites were plotted against the Washington State temperature standards for aquatic designated uses. Time-series were plotted on an extended period (6/10/15-9/30/15) to show the transitions in designated uses and for ease of comparison to data series discussed in section 3.3. To aid in interpretation of water temperature results, the Snoqualmie River time-series were plotted with daily discharge as well as air temperature from the nearest city. Air temperature data for all of the respective cities in the study area were compiled from weather underground (http://www.wunderground.com/), and discharge data was compiled from a combination of USGS and King County hydrologic gauging stations. Gauges used for comparison in this study and the respective sample sites are included in Table 3.

Table 3. U.S. Geological Survey and King County hydrologic gauges used for comparison with 2015 Snoqualmie temperature sample sites.

Discharge Gauge	Location	Related Sample sites
USGS 12142000	North Fork Snoqualmie River near Snoqualmie Falls, WA	NF_SNOQ_1
USGS 12141300	Middle Fork Snoqualmie River near Tanner WA	MF_SNOQ_1
USGS 12144000	South Fork Snoqualmie River at North Bend , WA	SF_SNOQ_1
USGS 12144500	Snoqualmie River near Snoqualmie, WA	MS_SNOQ_1, 2, 3, 4
USGS 12149000	Snoqualmie River near Carnation, WA	MS_SNOQ_6, 9, 10, 11, 13, 15, 16, 17, 18, 19
USGS 12145500	Raging River near Fall City, WA	RAGING_2
USGS 12148500	Tolt River near Carnation, WA	TOLT_1
KC-48a	Patterson Creek downstream of 292nd Ave SE, Fall City , WA	PATT_5
KC-21a	Griffin Creek upstream of Highway 203, Carnation, WA	GRIFFIN_1, 2
KC-22a	Harris Creek near NE 108th St., Carnation, WA	HARRIS_2
KC-01a*	Ames Creek near W. Snoqualmie Valley Rd. NE., Carnation, WA	AMES_1
KC-61a	Tuck Creek near W. Snoqualmie Valley Rd. NE., Duvall ,WA	TUCK_1
KC-05a	Cherry Creek near NE Cherry Valley Rd., Duvall , WA	CHERRY_2

*Data only for 2008-2011; used for comparison of previously collected data mentioned in discussion sections.

2.3.3 Data Series Comparisons

2015 Snoqualmie River temperature results were compared with two data sets to further interpret trends and determine relative conditions. One data set included water temperature time-series collected by WA Ecology as part of the 2006 Snoqualmie

Temperature Total Maximum Daily Load (TMDL) efforts and the other data set included multi-year water temperature time-series collected at various King County gauging stations. WA Ecology TMDL time-series data were available for all of the tributaries; however, we focused on the King County water temperature time-series when available for comparison across multiple years. Water temperatures among the data sets were additionally compared with flows from the closest USGS or King County gauges. Temperature time-series across the mainstem Snoqualmie, as well as several primary tributaries including Ames Creek, Tolt River, Patterson Creek, Raging River, Tokul Creek, and the North, Middle, and South Forks of the upper Snoqualmie were compared with WA Ecology TMDL water temperature time-series. The remaining sampled tributaries including Tuck Creek, Cherry Creek, Griffin Creek, and Harris Creek were compared to the multi-year water temperature time-series collected from King County gauging stations.

Several other agencies and interest groups collected temperature data throughout the Snoqualmie River watershed in 2015. Some of these data sets include Tolt River monitoring conducted by the City of Seattle, mainstem Snoqualmie temperature monitoring conducted by the Snoqualmie Tribe, tributary monitoring by the Wild Fish Conservancy, as well as extensive monitoring throughout the Snoqualmie watershed by the U.S. Forest Service and National Marine Fisheries Service. While the included results and discussion do not provide comparison across all data sets, it may be useful to consider these resources for future analyses.

3.0 RESULTS AND DISCUSSION

3.1 Thermistor performance and Replacements

Monthly thermistor downloads and concurrent YSI readings confirmed that the HOBO Pendant Thermistors (Model# UA-002-64) performed well in recording ambient water temperature across the selected Snoqualmie sample sites (Figure 2). Across the 27 sample sites, thermistors went missing at four locations, one thermistor shut off due to shock, and two thermistors were out of water for a period of time. When missing, thermistors were replaced at select locations. None of the thermistors placed on private properties went missing. Details of all sample sites where thermistors did not capture the entire sample season can be found in Table 4.

Figure 2. YSI water temperature check in the Snoqualmie near NE Tolt Hill Road.

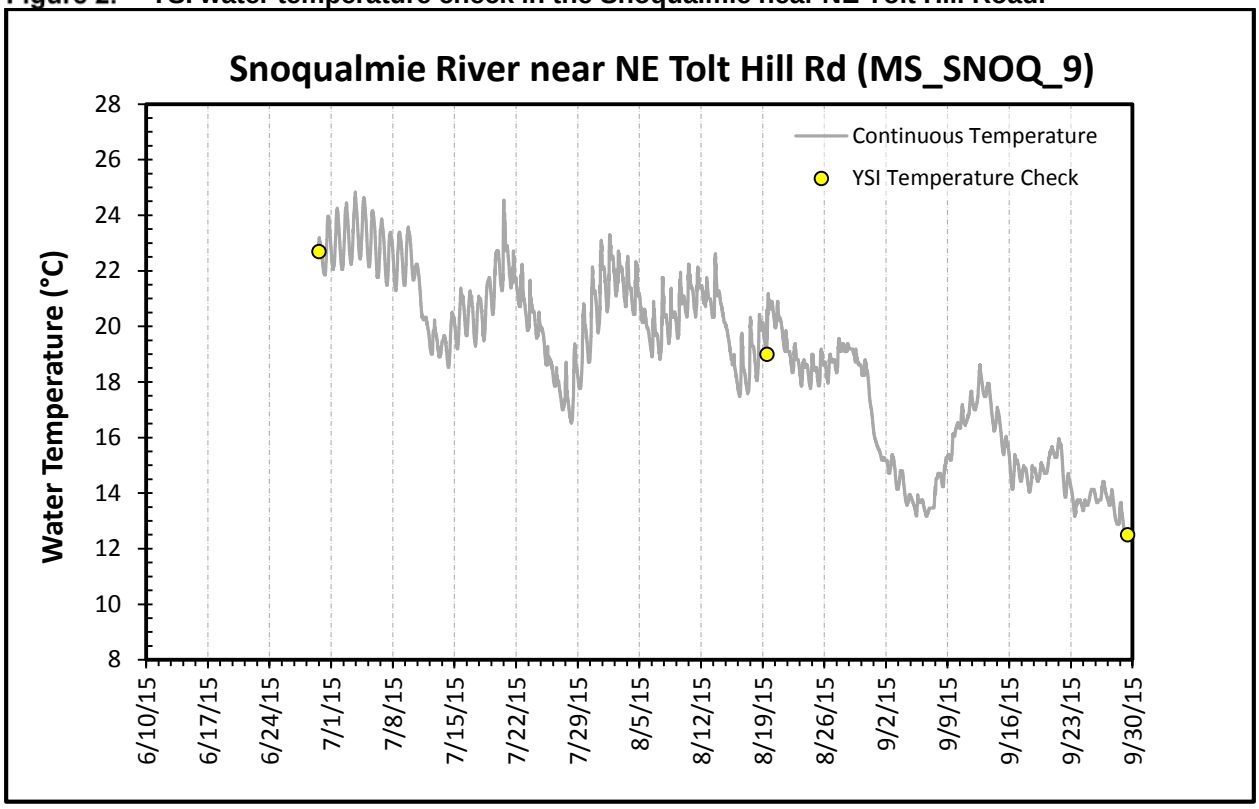


Table 4. Sample sites with incomplete time-series.

Site ID	Location	Notes
SF_SNOQ_1	South Fork Snoqualmie River downstream of Highway 202, Snoqualmie, WA	Thermistor shut off on 6/4/15 due to shock
MS_SNOQ_1	Snoqualmie River near SE Reinig Rd., Snoqualmie, WA	Thermistor missing on 8/19/15 and replacement missing on 9/30/15
MS_SNOQ_4	Snoqualmie River near Neal Rd. Boat Launch, Fall City, WA	Thermistor was likely out of water from 8/9/15 to 8/13/15
MS_SNOQ_6	Snoqualmie River downstream of Patterson Creek, Carnation, WA	Thermistor was likely out of water from 8/6/15 to 8/14/15
MS_SNOQ_17	Snoqualmie River upstream of Tuck Creek, Duvall, WA	Thermistor was pulled on 8/28/15 due to high flows
MS_SNOQ_18	Taylor Boat Launch, Duvall, WA	Thermistor missing on 8/20/15 and subsequently replaced. Replacement successfully retrieved on 9/30/15
AMES_1	Ames Creek near 100th St., Carnation, WA	Thermistor missing on 9/30/15
PATT_5	Patterson Creek near S.E. 24th St., Fall City, WA	Thermistor missing on 8/20/15 and replacement missing on 9/30/15

3.2 Snoqualmie River Temperature Time-Series and Trends

3.2.1 Time-series Examples

The Snoqualmie River temperature time-series were summarized across the sample period (7/1/15 – 9/30/15) for the 7-day average of daily maximum temperatures (7-DADMAX) and the 7-day average of daily minimum temperatures (7-DADMIN). Additionally, water temperature results were plotted with daily discharge and air temperature, as described in Section 2.3.2. Example panels from a mainstem and tributary site can be found in Figure 3 and Figure 4, respectively. Data for all other sample sites can be found in Appendix A.

Figure 3. Snoqualmie River temperature time-series downstream of the Raging River. Top panel includes daily average air temperature and discharge and the bottom panel includes continuous water temperature, 7-day maximum daily average, 7-day minimum daily average, and the WA state 7-day maximum daily average standard.

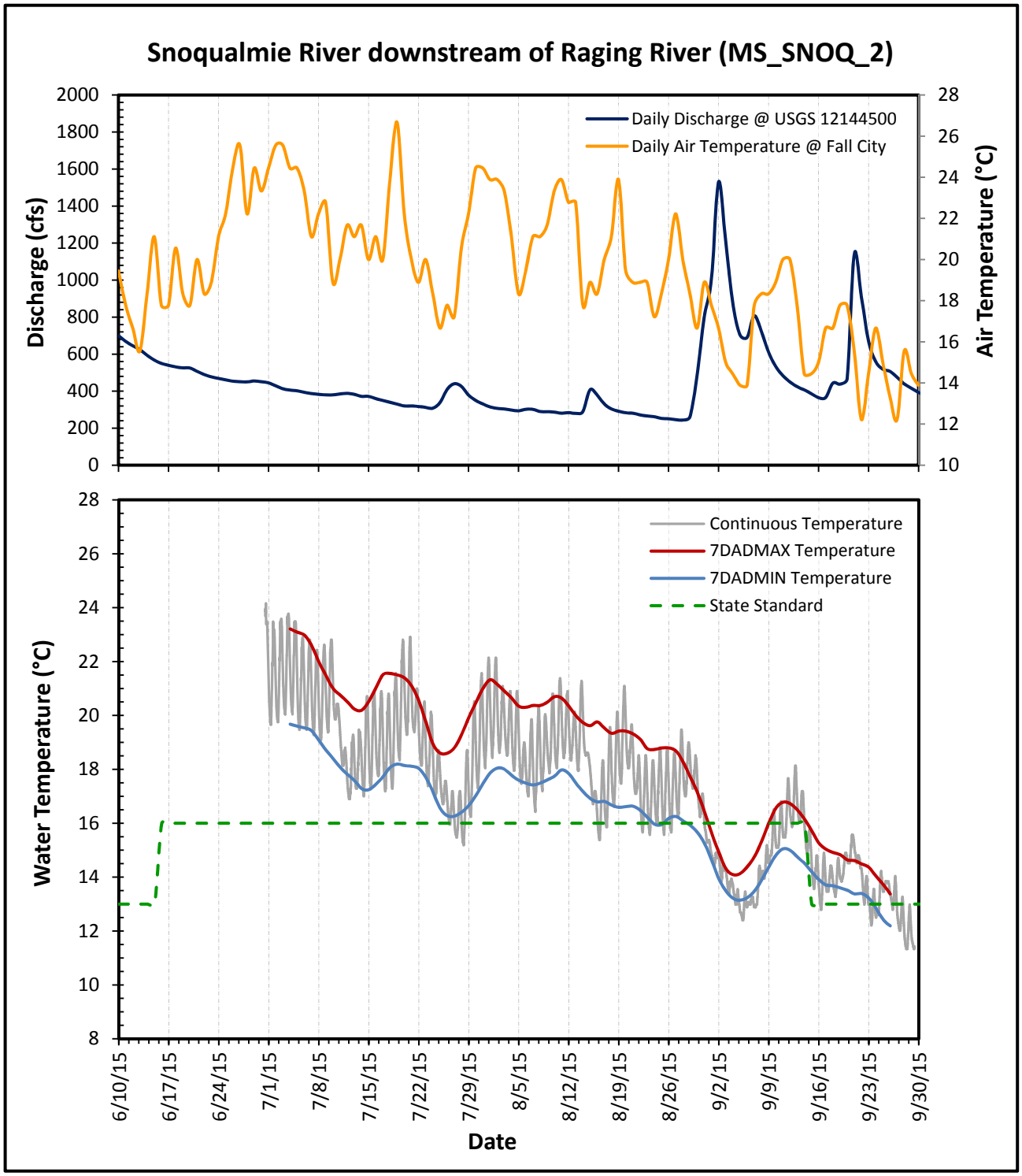
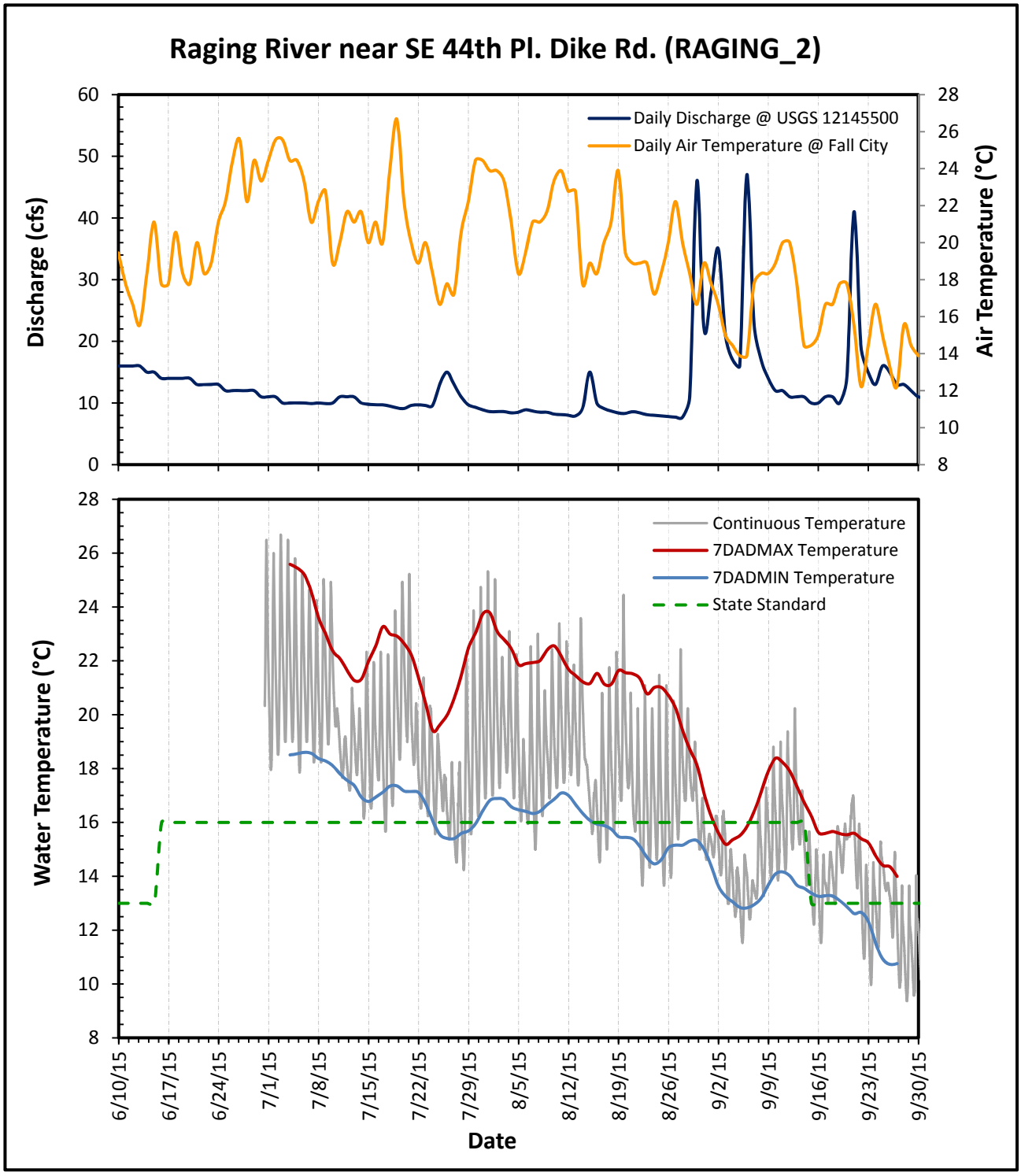


Figure 4. Raging River temperature time-series.
Top panel includes daily average air temperature and discharge and the bottom panel includes continuous water temperature, 7-day maximum daily average, 7-day minimum daily average, and the WA state 7-day maximum daily average standard.



3.2.2 Temperature Trends

3.2.2.1 Mainstem

Water temperatures in the Snoqualmie River during the summer of 2015 were quite high across all of the selected sample sites (Appendix A). Observed temperatures in the mainstem Snoqualmie, the Middle Fork of the Snoqualmie, and several tributaries (Raging, Tolt, Cherry, Patterson, Tuck, and Griffin) were consistently above state standards for designated uses, often by several degrees Celsius (1 degree Celsius is equal to 1.8 degrees Fahrenheit). Specifically, the 7-DADMAX for all mainstem sites below the three forks were above state standards for the entire sampled period, aside from the first half of September (Figure 5 & 6; Appendix A). It should be noted that the state standard shifts at the confluence of Harris Creek where designated uses change from core summer salmonid habitat (upstream of Harris Creek) to spawning, rearing, and migration habitats (downstream of Harris).

Figure 5. Mainstem Snoqualmie temperature time-series from above the falls downstream to Harris Creek. Site number 1 is furthest upstream and 11 is furthest downstream.

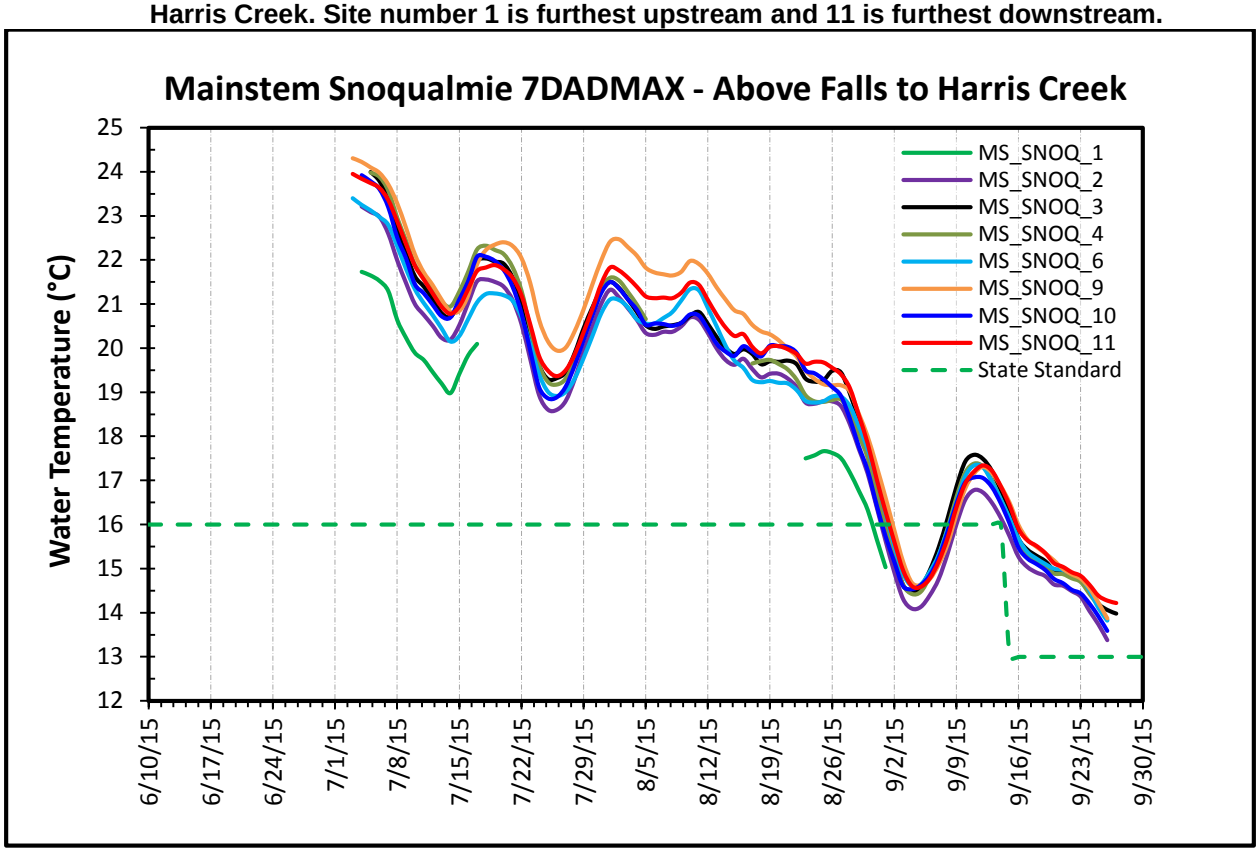
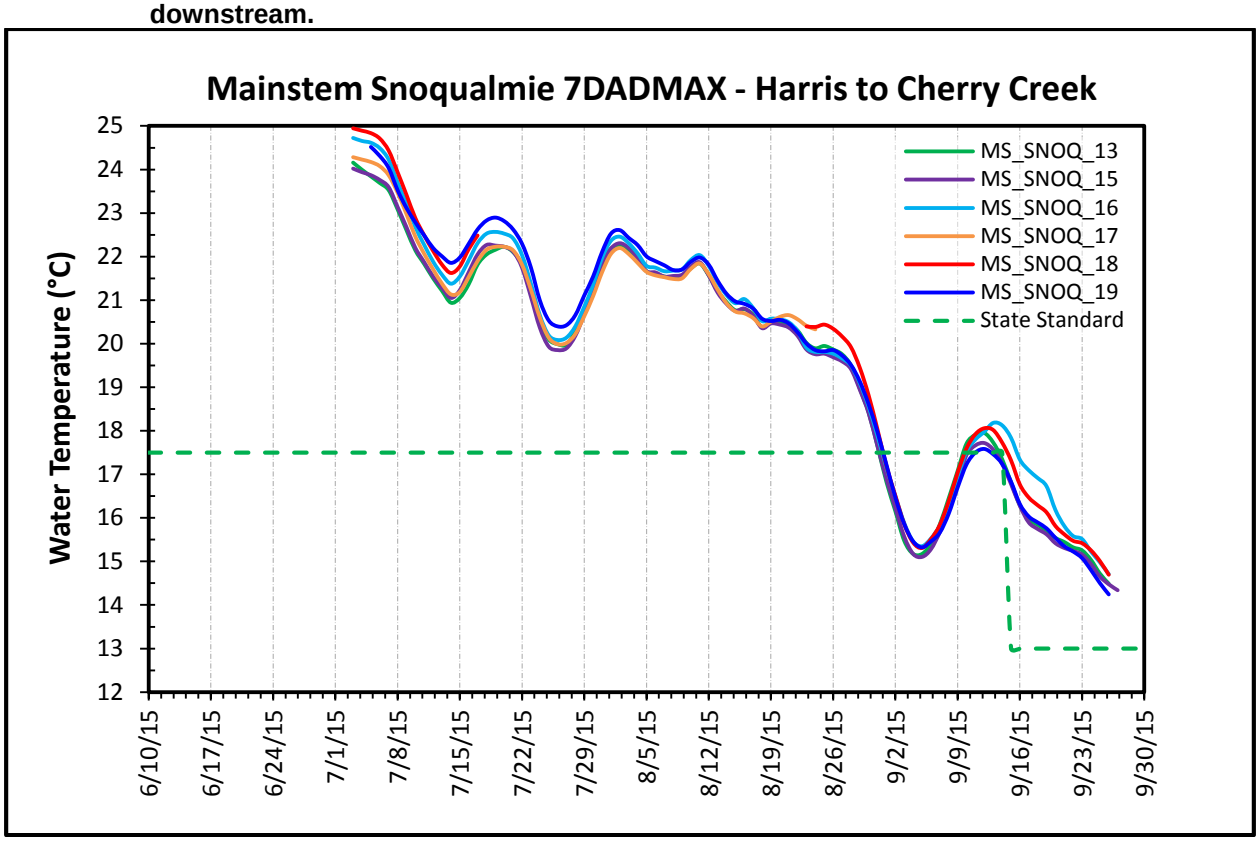


Figure 6. Mainstem Snoqualmie temperature time-series from Harris Creek downstream to the Cherry Creek confluence. Site number 13 is furthest upstream and 19 is furthest downstream.



Several factors influence water temperature in the Snoqualmie River including stream depth, discharge, air temperature, solar radiation, tributaries, and groundwater (Adams and Sullivan 1989). Record low flows were ubiquitous across all sample sites and throughout the Snoqualmie River watershed during the summer of 2015 (e.g., Figure 7; further discussed in section 3.3.1). Low flows likely contributed to the observed high water temperatures since decreased depth increases the effects of solar radiation and minimizes the ability to buffer air temperatures. For example, observed water temperatures mostly tracked air temperatures across sample sites, especially during the lowest flow periods prior to September storm events (e.g., Figure 8; Appendix A). Low flows may have also contributed to the difference between day and night temperature fluctuations for parts of the sample season. The temperature range across sites was considerably greater during the period before the September storm events compared to the period during and after (e.g., Figure 9). Many tributary sites, which carry a small fraction of the flow in the mainstem, expressed broader daily temperature ranges than most mainstem sites. These collective results support the influence of low flows on water temperature and highlight the relative sensitivity of water temperature to air temperature and solar radiation during low flow periods.

Figure 7. Flow in mainstem Snoqualmie at USGS 12149000 near Carnation, WA in 2015 and across 1929-2015.

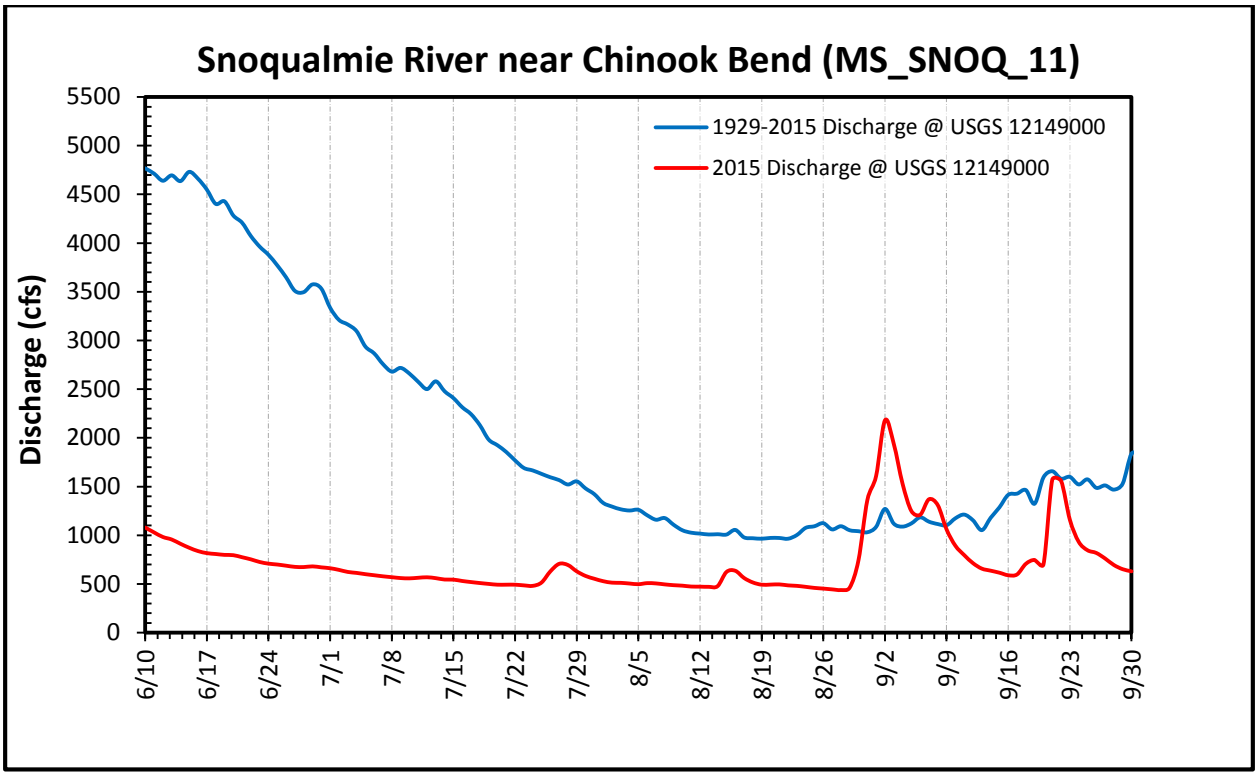


Figure 8. Mainstem Snoqualmie continuous water temperature downstream of Raging River and daily average air temperature in Fall City.

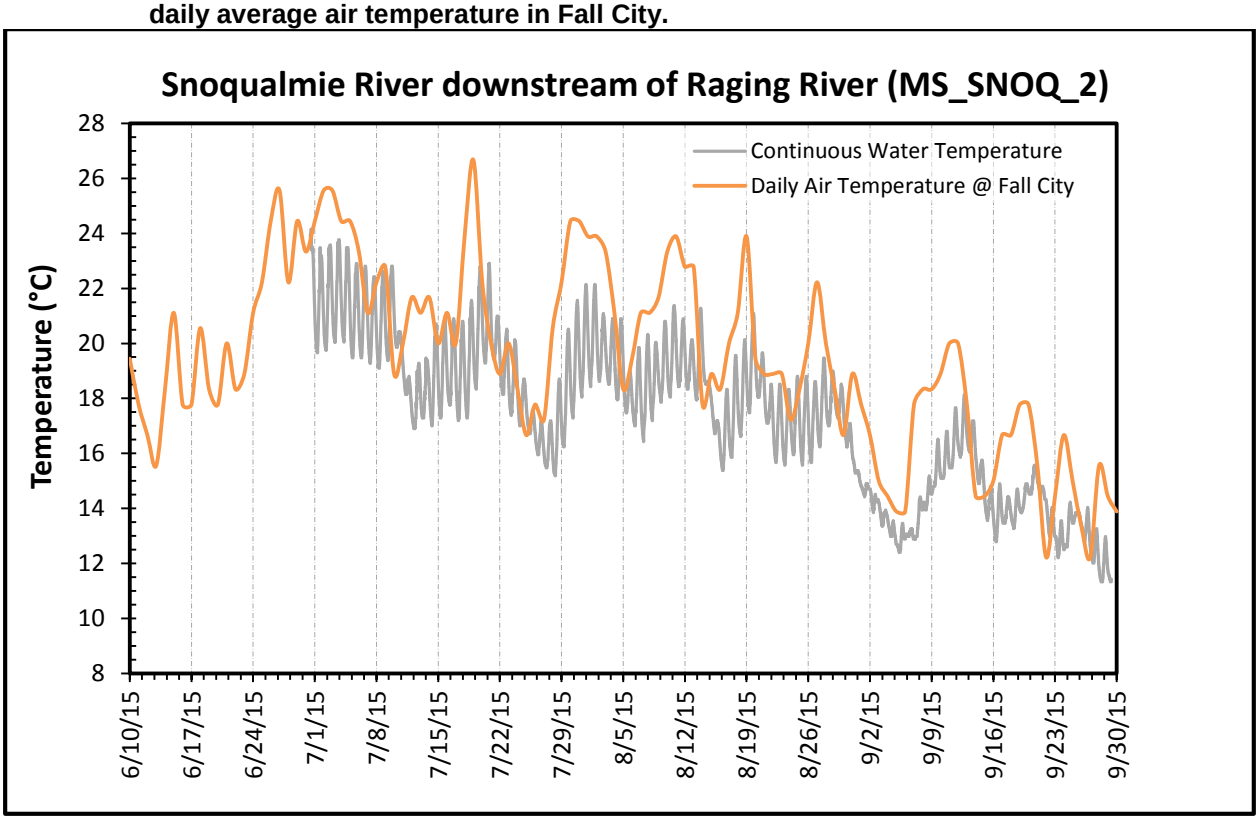
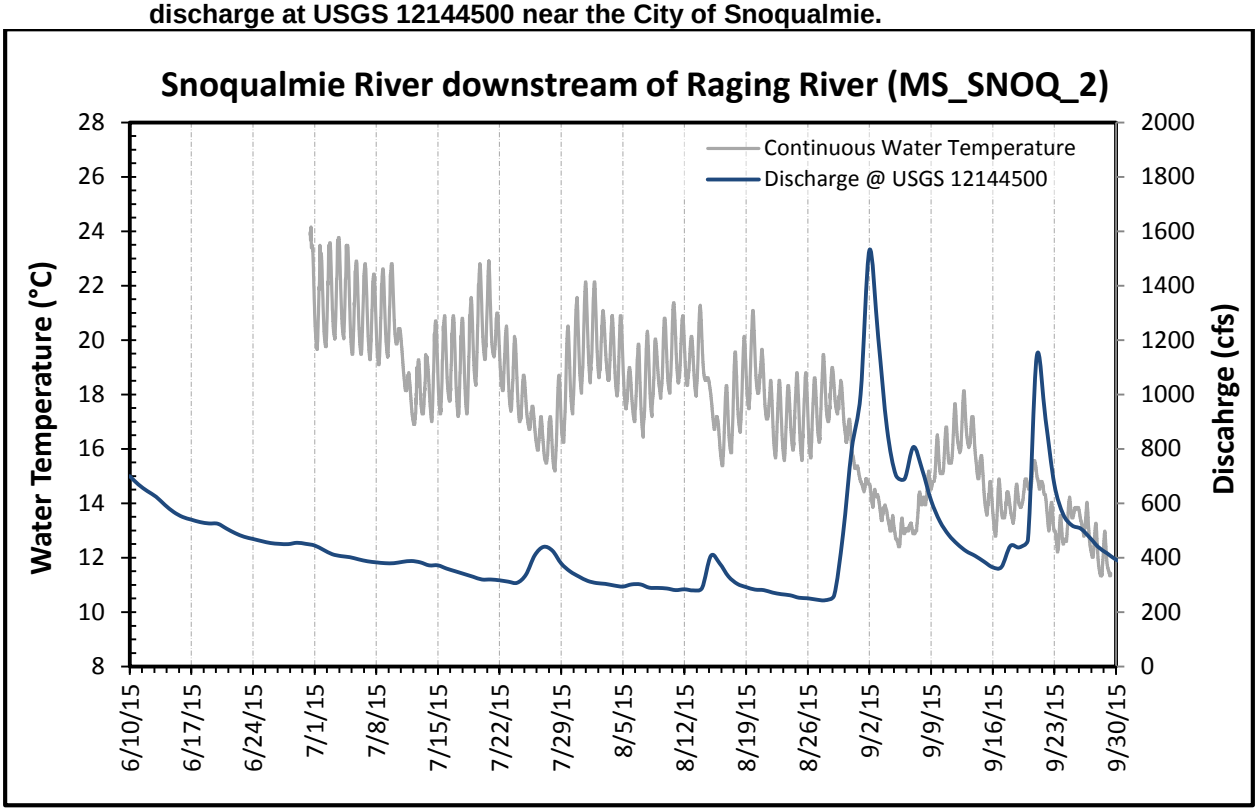


Figure 9. Mainstem Snoqualmie continuous water temperature downstream of Raging River and discharge at USGS 12144500 near the City of Snoqualmie.



Observed water temperature in the Snoqualmie generally increased from upstream to downstream. This increase in water temperature can be observed by comparing three sites going from below Snoqualmie Falls (MS_SNOQ_2) to mid-watershed (MS_SNOQ_11) to downstream of the confluence with Cherry Creek (MS_SNOQ_19) (Figure 10). Among these three sample sites, an upstream to downstream increase in water temperature was consistent across the 2015 sample period with water temperature 7-DADMAX gaining on average 1.28°C (2.30°F) and up to 2.07°C (3.73°F). However, there was variation in this upstream to downstream increasing trend among several individual sample sites. For example, MS_SNOQ_17 (Snoqualmie River upstream of Tuck Creek) was cooler than MS_SNOQ_16 from July to mid-August, despite being downstream (Figure 11). This variation could reflect the presence of groundwater inputs. At a broader scale the Snoqualmie appears to be a gaining reach (augmented with groundwater) between the falls and Carnation, where it transitions to a losing reach (discharges to groundwater) down to Monroe (WA Ecology 2011). However, at a finer scale, there may be groundwater inputs in areas downstream of Carnation where the valley/floodplain constricts (e.g., Figure 11). The relative exchanges between groundwater and surface waters likely occur in areas where the valley walls narrow creating constriction points for upwelling as well as in areas such as alluvial fans and bedrock outcrops where substrate differences influence exchange rates and gradients. For example, the Snoqualmie River around MS_SNOQ_16 and MS_SNOQ_4 pushes up against the valley wall resulting in a narrowed floodplain. In both of these reaches there is a noticeable decrease in temperature from upstream to downstream sample sites (Figure 11 & 12). Patterson Creek may have influenced the observed decrease in temperature from MS_SNOQ_4 to MS_SNOQ_6; however, this influence is likely minimal since Patterson only contributed around 2% of the flow during the summer of 2015.

Figure 10. Mainstem Snoqualmie 7DADMAX temperature time-series across three select sites.

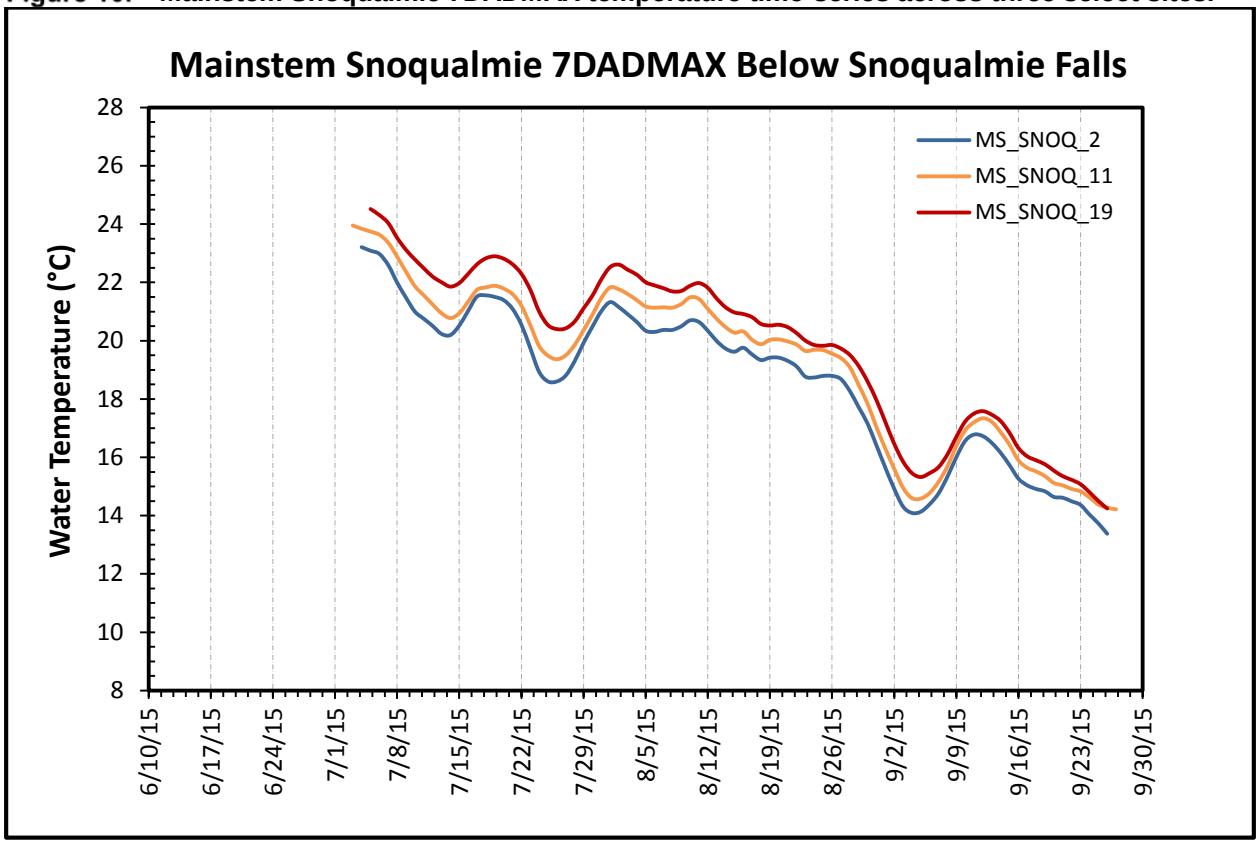


Figure 11. Mainstem Snoqualmie 7DADMAX temperature time-series across two select sites in a constrained section of the floodplain near Duvall.

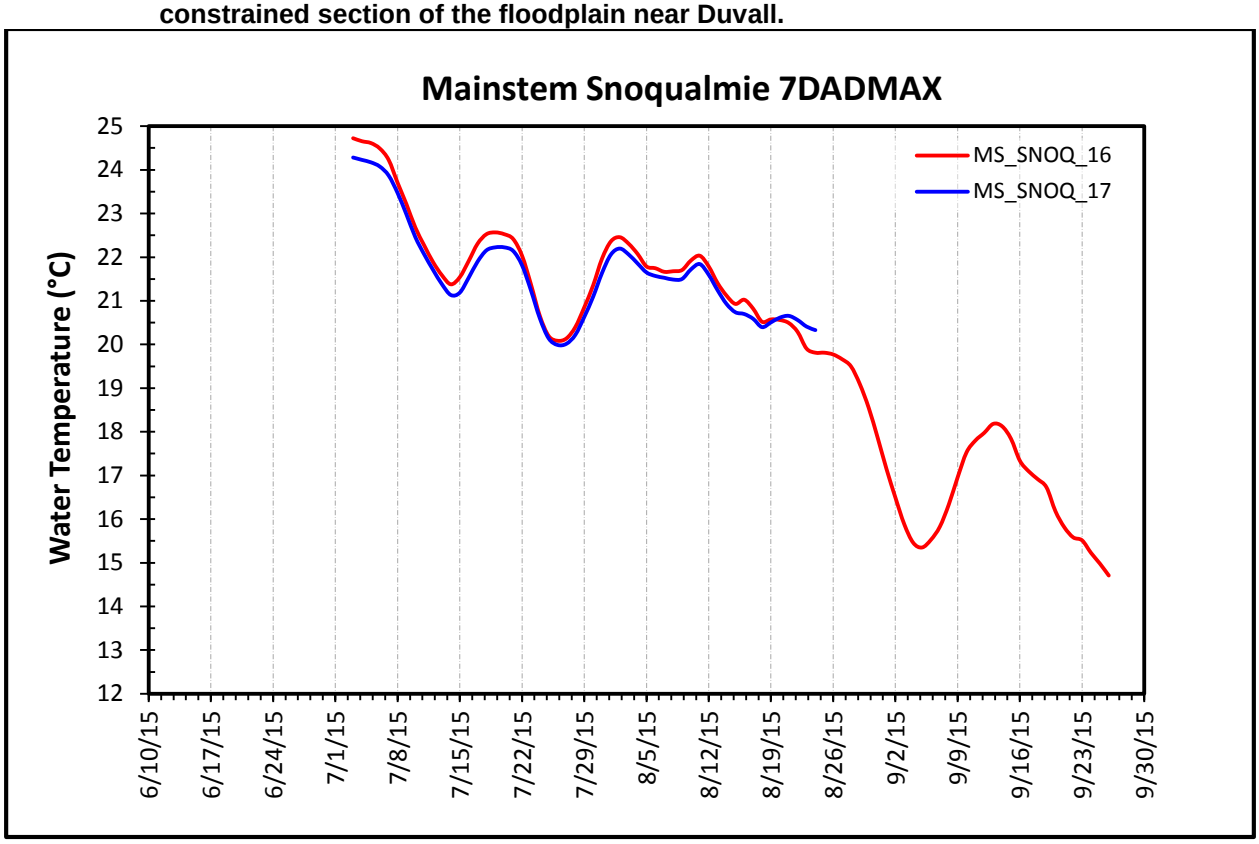
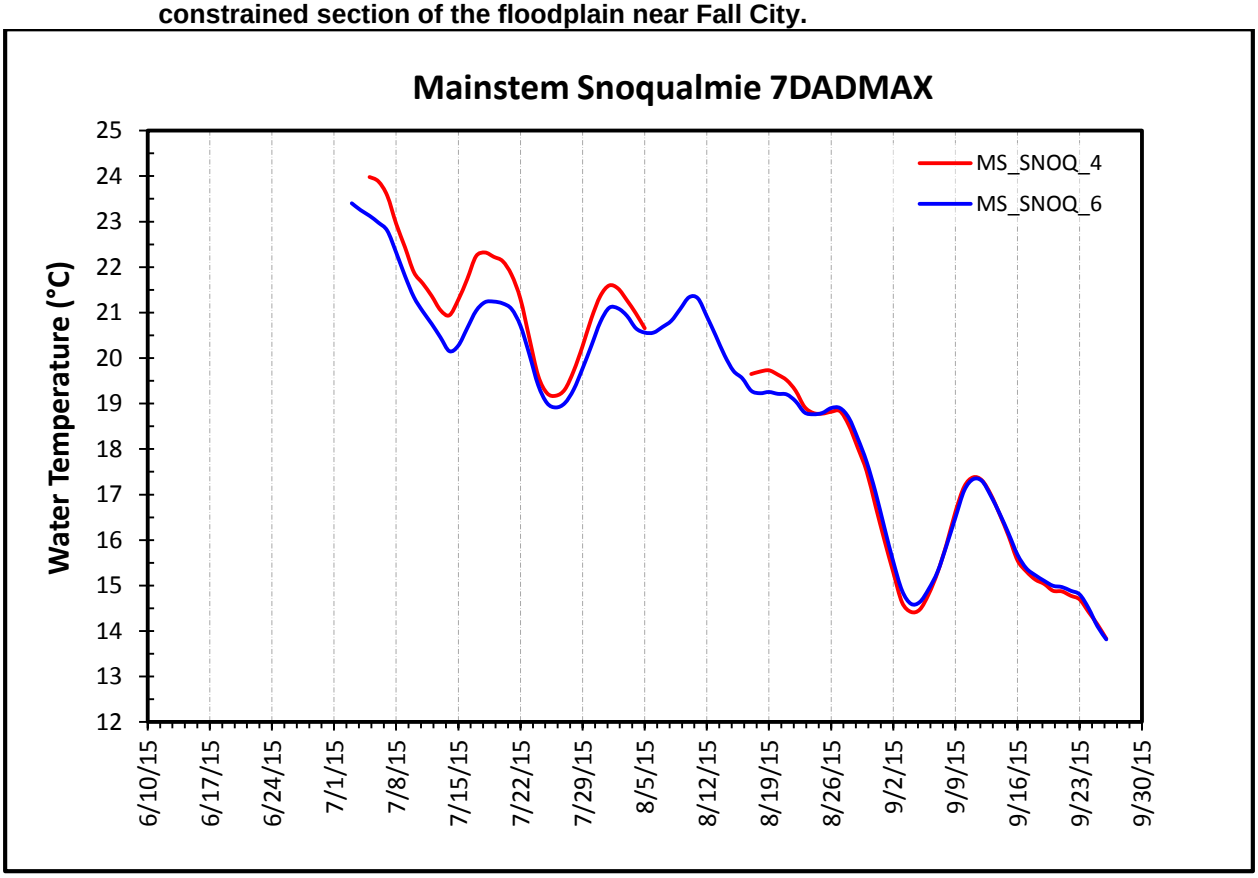
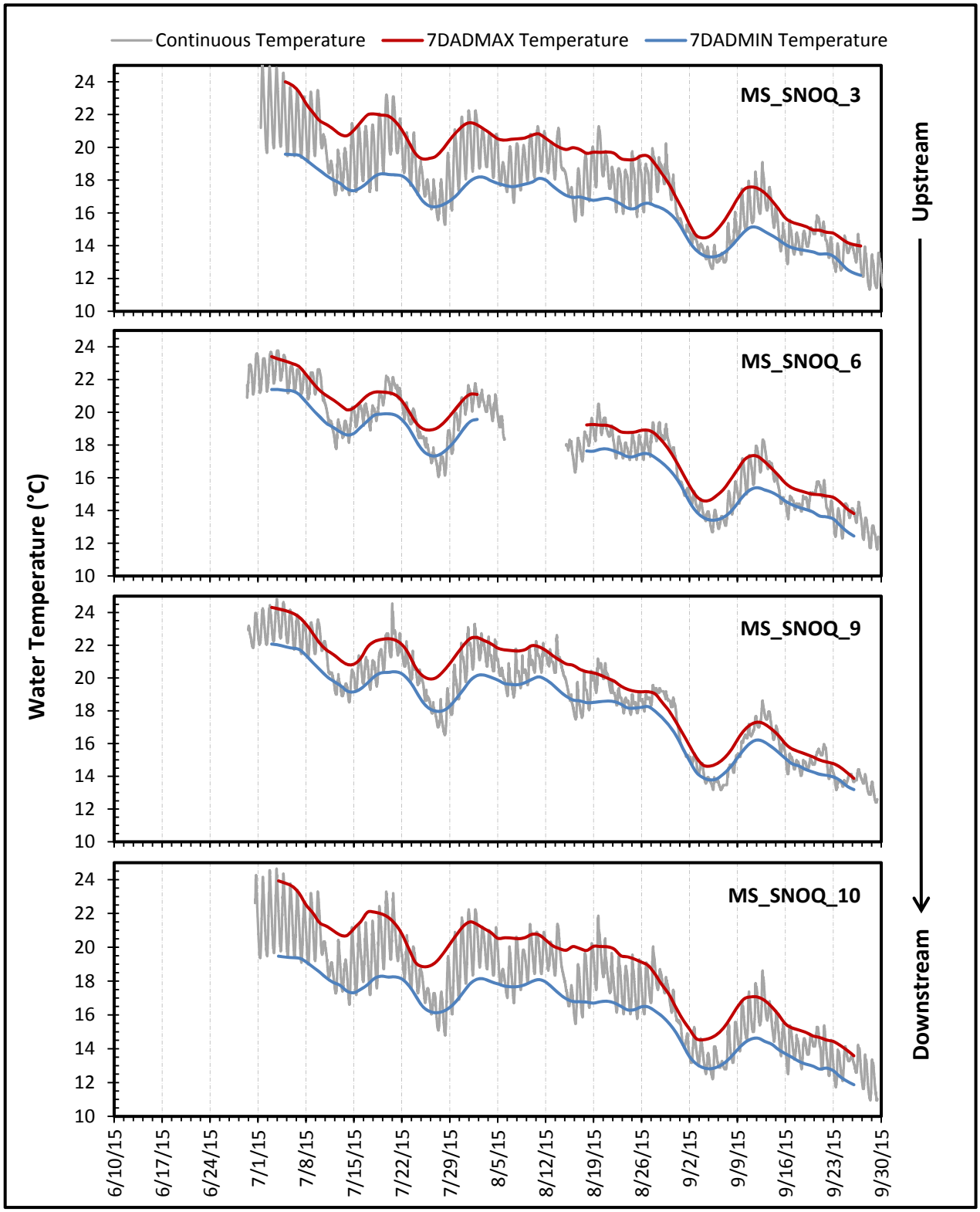


Figure 12. Mainstem Snoqualmie 7DADMAX temperature time-series across two select sites in a constrained section of the floodplain near Fall City.



The 2015 Snoqualmie River temperature time-series may further indicate the potential influence and contribution of groundwater exchange through comparison of temperature ranges across sites. For example, there appeared to be a decrease in water temperature range around MS_SNOQ_6 (downstream of Patterson Creek) and MS_SNOQ_9 (near NE Tolt Hill Road) compared to upstream (MS_SNOQ_3) and downstream (MS_SNOQ_10) sites (Figure 13). This pattern may support the gaining reach described by WA Ecology (2011) between the Raging and Tolt River, where groundwater inputs may decrease the temperature range observed in MS_SNOQ_6 and MS_SNOQ_9. However, it should be noted that the large temperature ranges observed near Tolt MacDonald Park were likely influenced by of the Tolt River plume, which runs along the right bank downstream of the confluence. The 2015 temperature time-series also appeared to show a relative upstream to downstream trend in decreasing water temperature daily ranges. This may have been a result of several factors including relatively warmer downstream water temperatures buffering daily fluctuations, potential buffering from groundwater and tributary inputs, the higher overall volume of water as the river progresses downstream, or other factors.

Figure 13. Mainstem Snoqualmie River temperature range comparison. Site number 3 is furthest upstream and site number 10 is furthest downstream.



3.2.2.2 Tributaries

Water temperatures across all of the primary tributaries aside from Harris Creek and Ames Creek were consistently above state standards, up until the end of August (Figure 14). Most tributaries were cooler than the 7-DADMAX temperature range observed across mainstem sample sites (Figure 15); however, the Raging River, Cherry Creek, Tuck Creek, and the Tolt River were well within mainstem temperature ranges (Figure 16). It should be noted that Cherry and Tuck Creek have extensive exposed floodplain upstream of the sample sites, which likely influenced these observed warmer temperatures. Kaje (2009) reported that tributaries had a major increase in temperature while crossing these portions of exposed floodplains. There appeared to be a pattern of larger tributaries (Tolt, Raging, and Cherry) having relatively higher temperatures with similar fluctuations, and many of the smaller tributaries (Harris, Ames, Tokul, Griffin, and Patterson) having lower temperatures with similar fluctuations. Tuck Creek did not align with either of these tributary groups showing greater fluctuations and falling within in the ranges of both smaller and larger tributaries. While the 7-DADMAX of the Tolt River was within the observed ranges of mainstem temperatures (Figure 16), the minimum temperatures in the Tolt were several degrees lower than the mainstem and may have subsequently influenced mainstem temperatures. For example, during the hottest 2015 periods in July and August, the Tolt appeared to decrease mainstem Snoqualmie 7-DADMIN temperatures (Figure 17 & Figure 18). The potential influence of the Tolt was also supported by a decrease in mainstem Snoqualmie temperature from the sample site upstream of the confluence (MS_SNOQ_9) to the sample site downstream (MS_SNOQ_10) (Figure 19). However, it should be noted that since the 2015 thermistor was likely within the plume of the Tolt, the decrease in mainstem temperature may not be fully representative if the mainstem cross section in that area is adequately mixed. The influence of the Tolt is supported by findings from WA Ecology (2011), who also showed the Tolt decreasing mainstem temperatures. The Tolt River contributes the most flow out of any tributary below Snoqualmie Falls, which likely results in the observable influence on mainstem temperatures. Specifically, on July 4th and August 2nd, 2015 the Tolt River contributed approximately 21% of the flows observed in the mainstem Snoqualmie near Carnation. The Raging River was the warmest tributary observed during 2015, with 7-DADMAX temperatures at times being greater than ranges observed in the mainstem (Figure 16). However, unlike the Tolt, the Raging River only contributed a small percentage of summer flow (approximately 3% in July and August) which likely resulted in a minimal influence on mainstem temperatures (Figure 17 & 18).

Figure 14. Temperature time-series for primary tributaries in the Snoqualmie River.

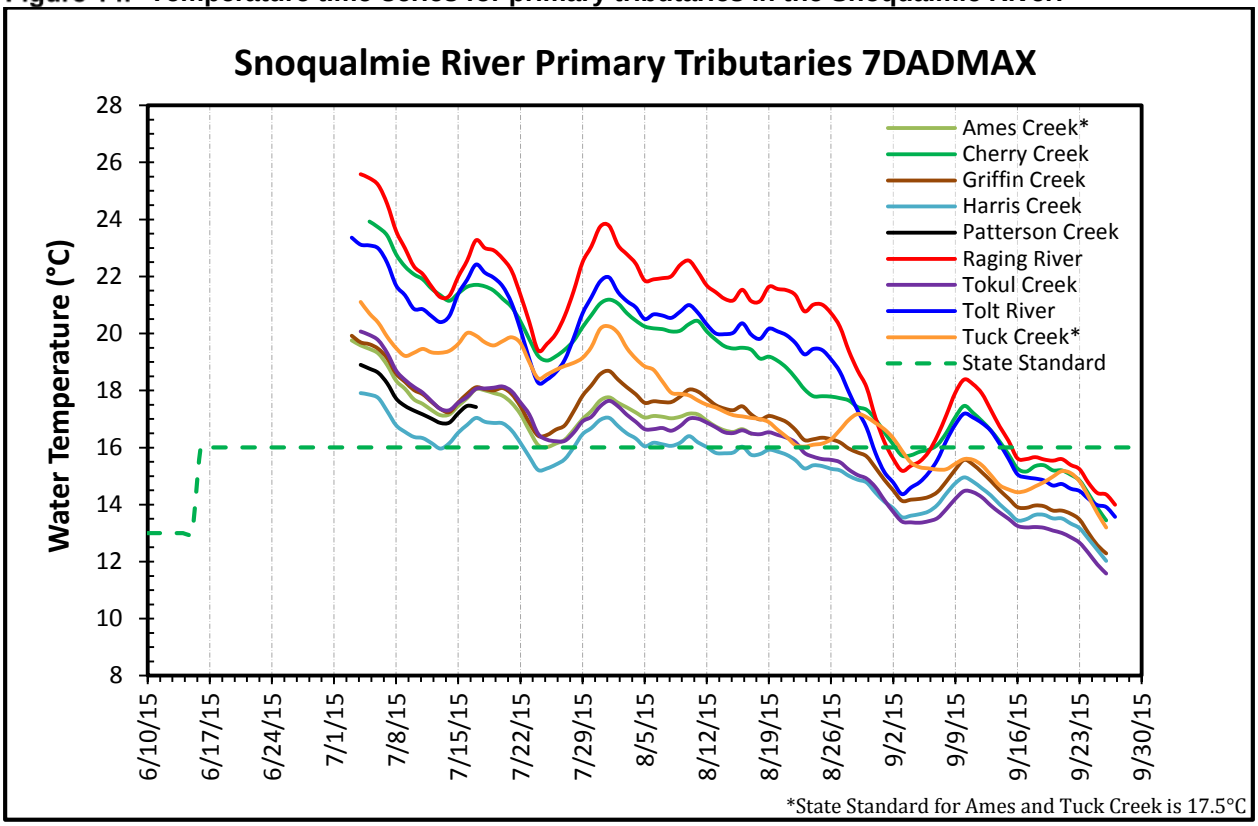


Figure 15. Temperature time-series for select cooler tributaries and the mainstem 7DADMAX range in the Snoqualmie River.

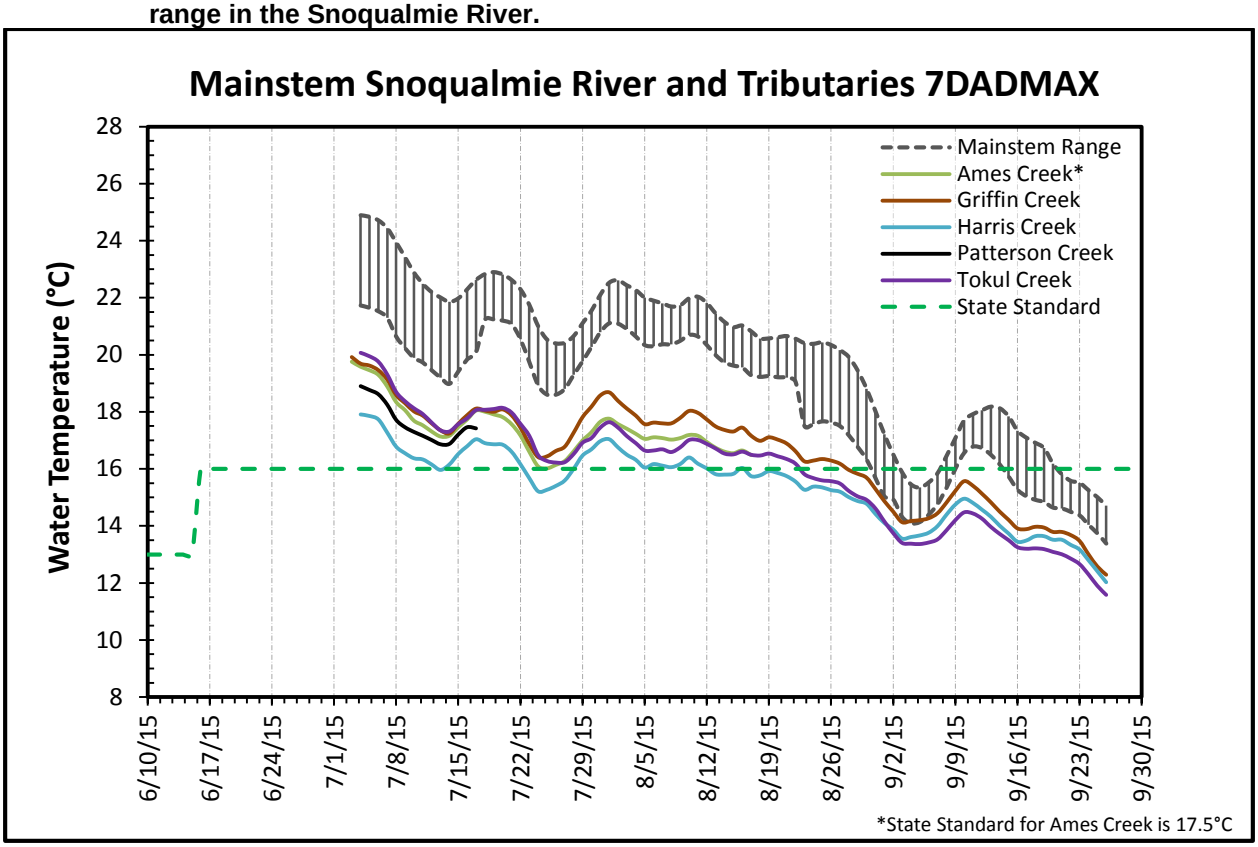


Figure 16. Temperature time-series for select warmer tributaries and the mainstem 7DADMAX range in the Snoqualmie River.

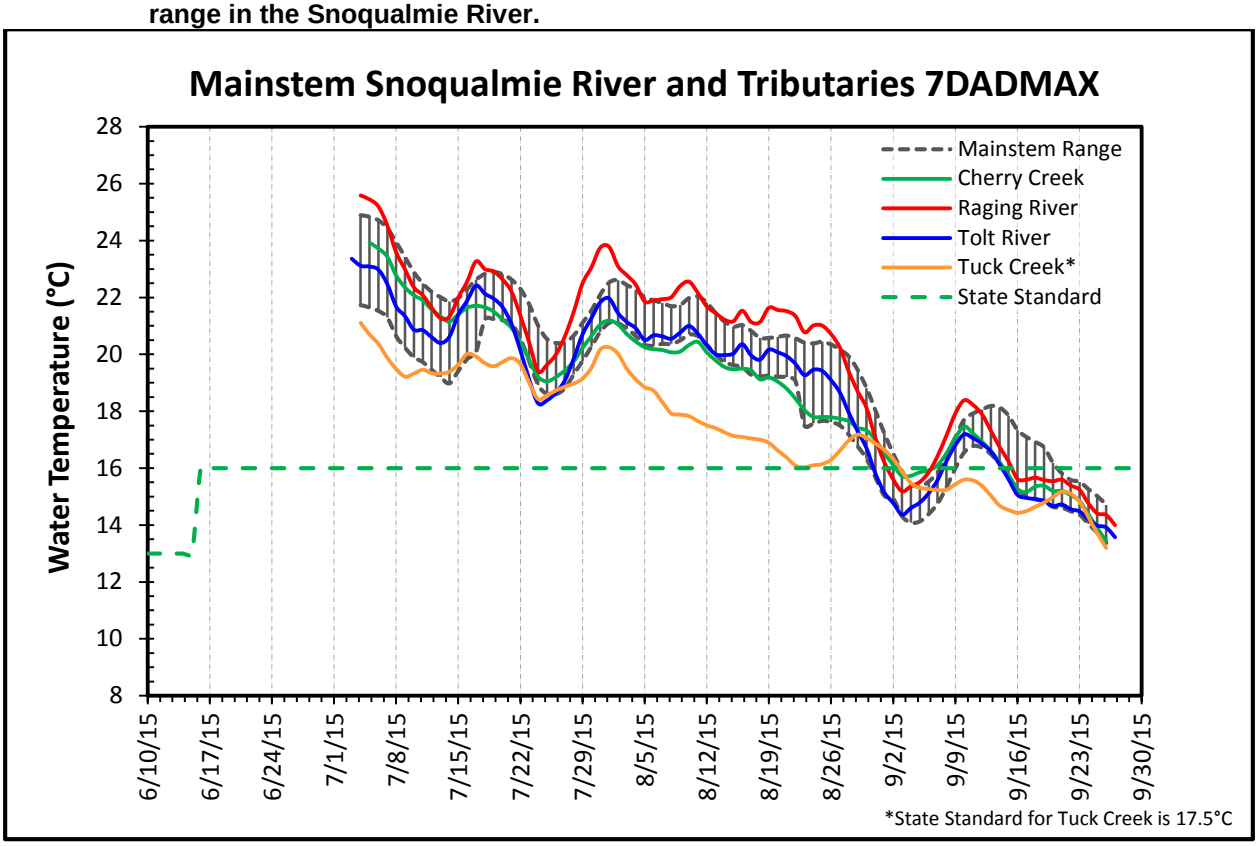


Figure 17. Longitudinal temperature time-series for the mainstem Snoqualmie River and select tributaries for July 4th, 2015.

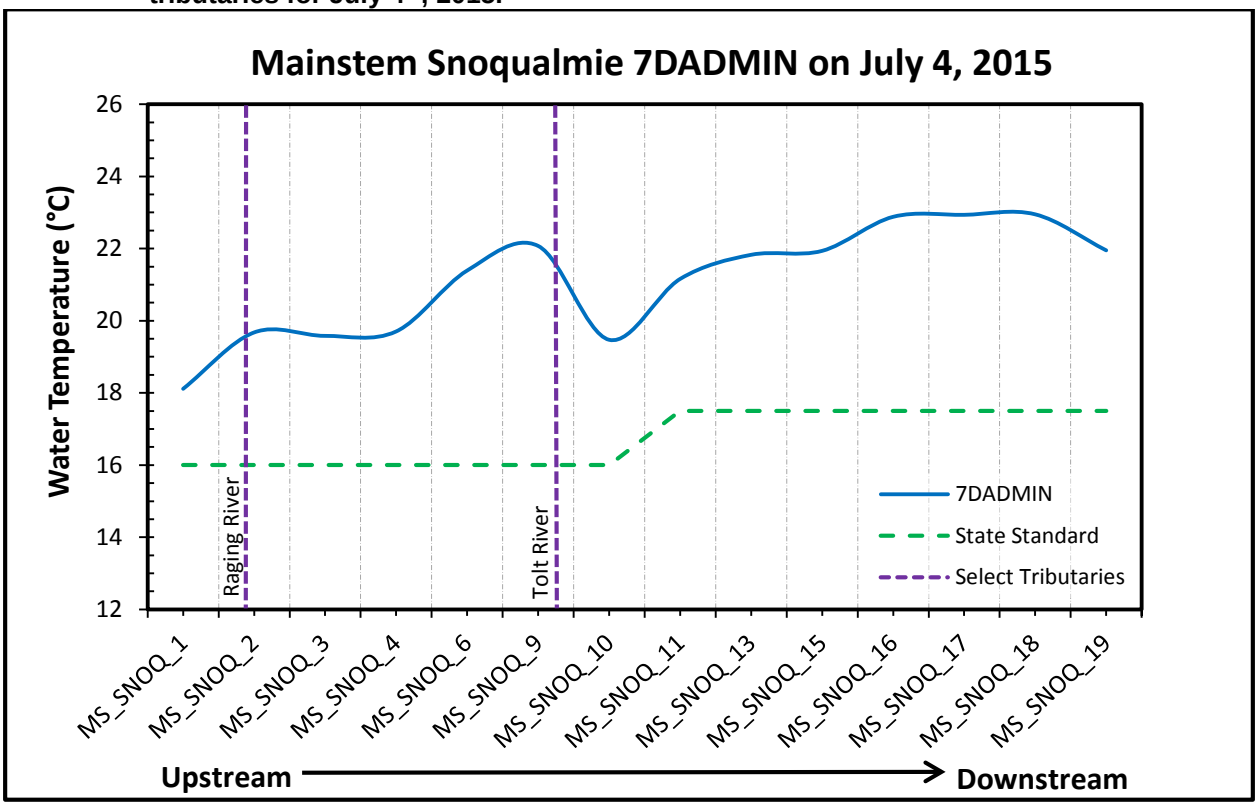


Figure 18. Longitudinal temperature time-series for the mainstem Snoqualmie River and select tributaries for August 2nd, 2015.

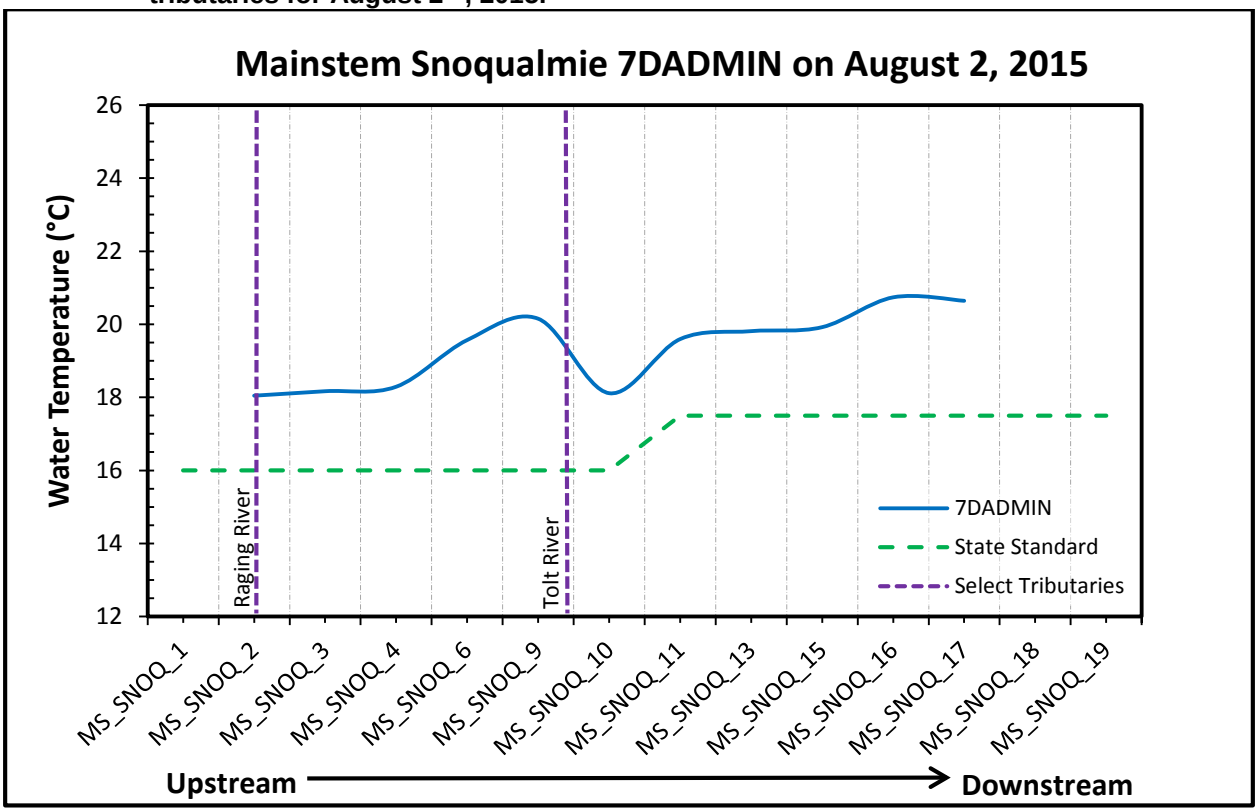
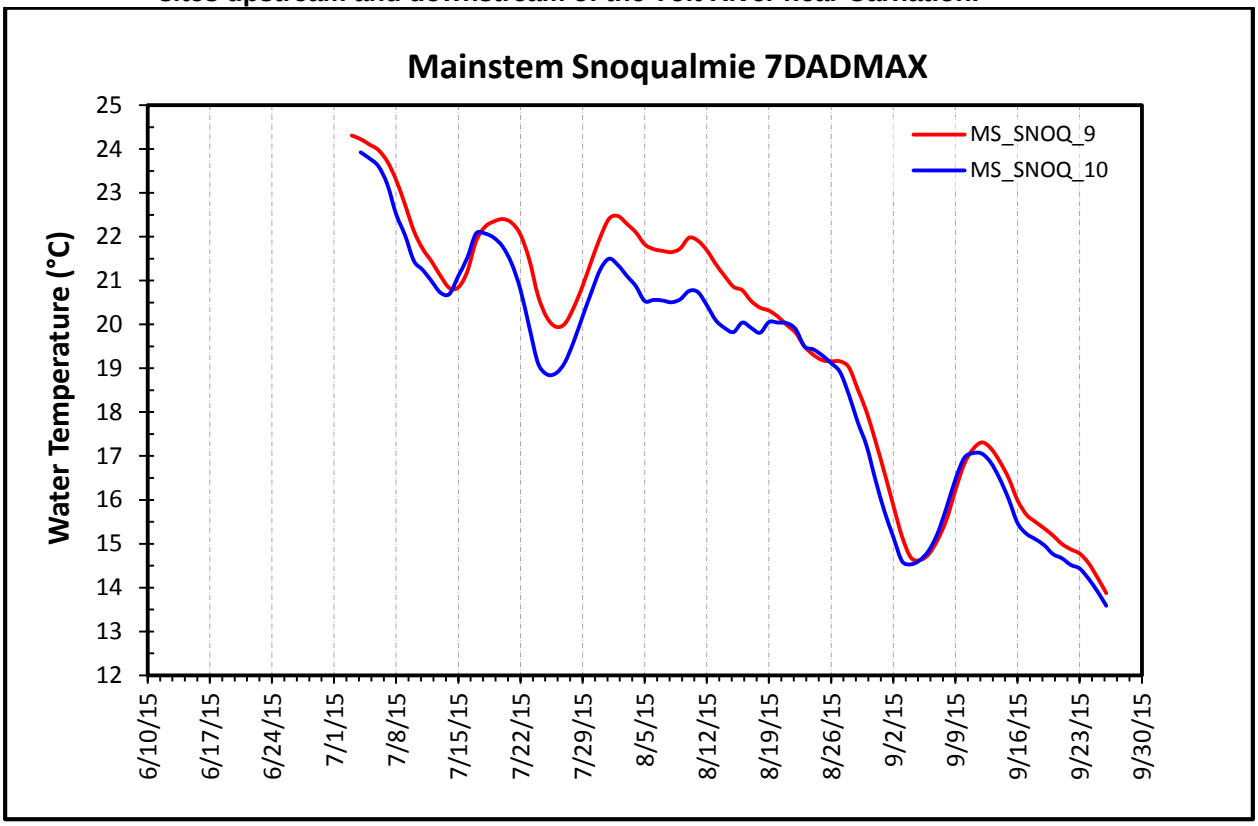


Figure 19. Mainstem Snoqualmie River 7DADMAX temperature time-series across two select sites upstream and downstream of the Tolt River near Carnation.



3.2.2.3 Above the Falls

Temperature time-series in the North Fork Snoqualmie were right around the state standard and the South Fork Snoqualmie was consistently above the state standard in July and August (Figure 20). The Middle Fork on the other hand was significantly warmer than the North and South Forks and much higher than the state standard throughout the majority of the summer, cooling in early September. Temperatures observed in the Middle Fork Snoqualmie were even within the upper range of 7-DADMAX temperatures observed across the mainstem Snoqualmie (Figure 21). The North and South Forks of the upper Snoqualmie were considerably cooler than the mainstem Snoqualmie throughout the 2015 summer period. These results were similar to findings from WA Ecology (2011), who also showed that North and South Fork temperatures were considerably cooler than the Middle Fork and mainstem Snoqualmie. However, while the North and South forks maintained relatively lower temperatures, the majority of the flow during the summer period of 2015 appeared to come from the Middle Fork (Figure 22), which is a significantly larger basin. Specifically, the Middle Fork Snoqualmie contributed on average 50.5% (with up to 61.6%) of the flow coming out of all three of the forks. The high Middle Fork temperatures and percent contribution likely influenced the high temperatures observed downstream. It's also worth noting that during late-August and early-September the Middle Fork dropped a considerable ~5°C while the North and South Forks only dropped ~3°C. A localized precipitation event could provide a possible explanation; however, discharge in the North and Middle Forks showed similar responses suggesting otherwise (Figure 22). It may be possible that temperatures in the Middle Fork are more sensitive to changes in flow compared to the other Forks, especially if there is a greater difference between air/precipitation temperatures and instream temperatures.

Figure 20. Temperature time-series of the North, Middle, and South Forks of the Snoqualmie River.

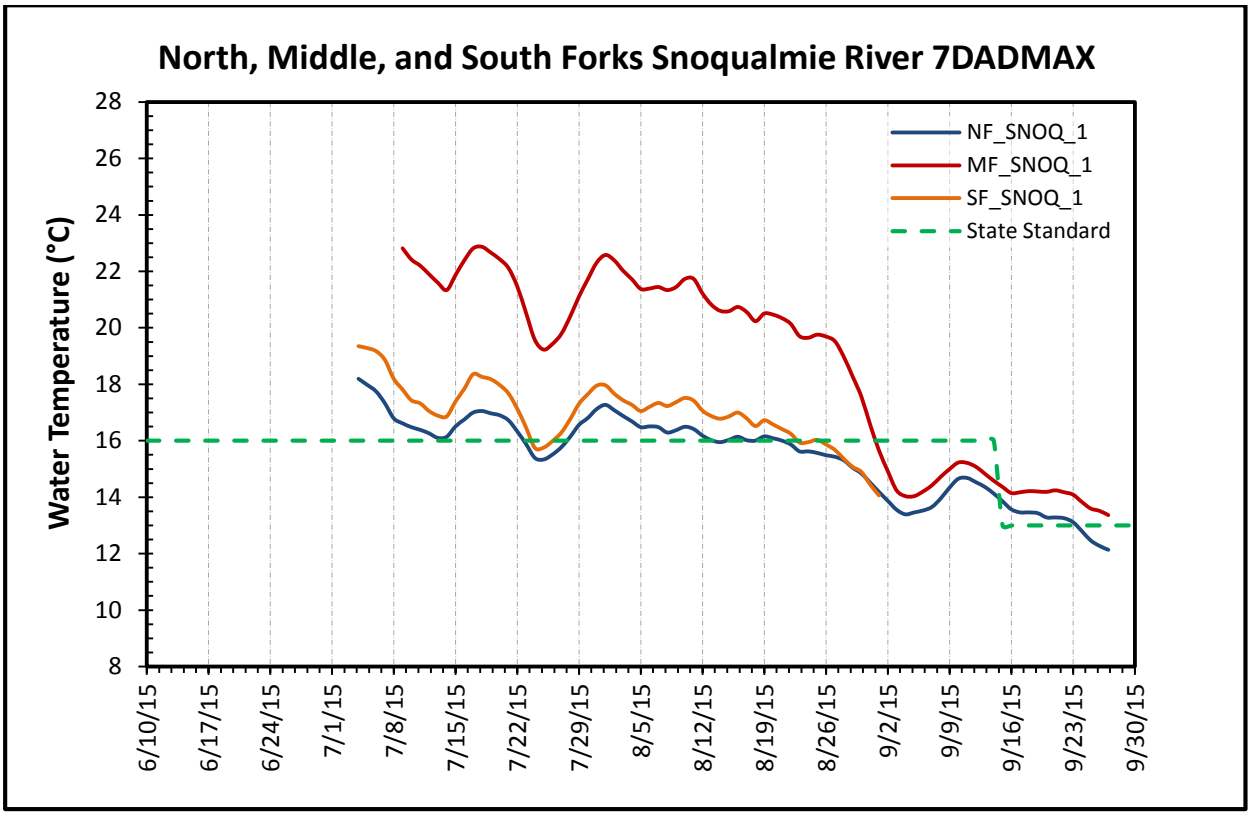


Figure 21. Temperature time-series of the three forks and the mainstem Snoquamie River 7DADMAX ranges.

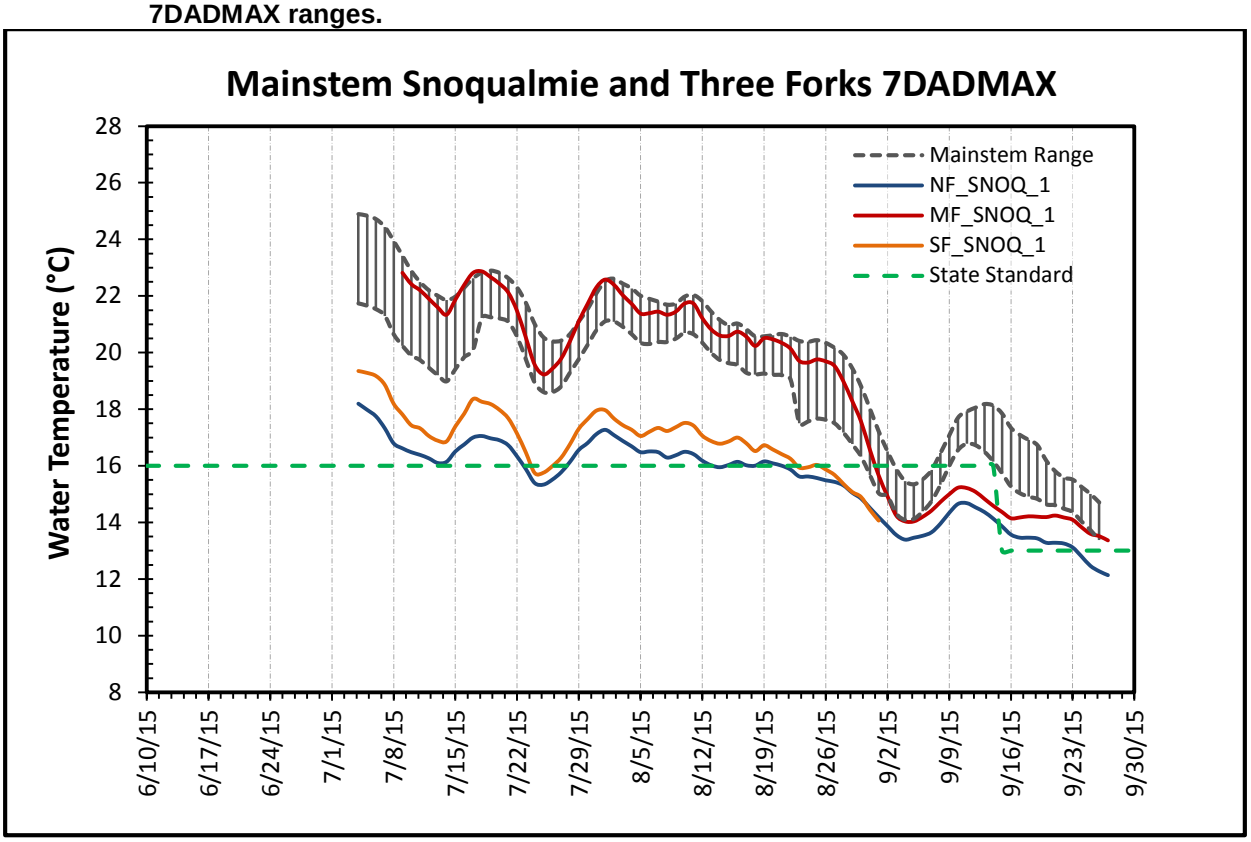
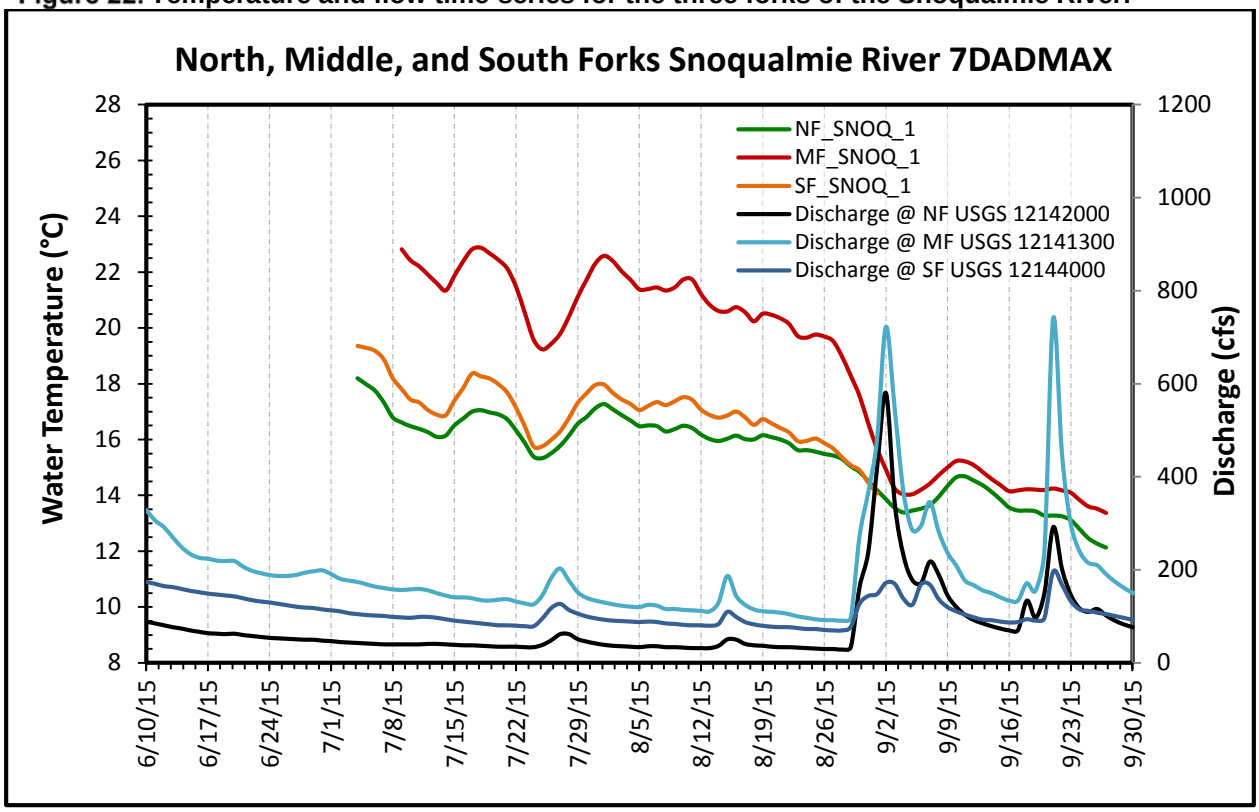


Figure 22. Temperature and flow time-series for the three forks of the Snoqualmie River.



3.3 Data Series Comparisons

Comparisons between water temperatures and respective flows across all sample sites can be found in Appendix B.

3.3.1 2006 WA Ecology TMDL

WA Ecology TMDL continuous temperature time-series were collected throughout the Snoqualmie River watershed from June to September in 2006. WA Ecology TMDL sites that were closest to our selected sample locations were chosen for comparisons. Flows in 2006 were generally lower than average daily flow observed in the extended USGS record; however, flows in 2015 across mainstem and tributary sites were significantly lower than all records from June through August (Figure 23, 24, 25, & 26). Summer low flows in the Snoqualmie generally occur from mid-August to mid-September, which were consistent with flows observed in 2006. The summer of 2015 on the other hand observed low flows much earlier than the extended USGS record, with low flow periods occurring as early as June.

Figure 23. Flow in mainstem Snoqualmie at USGS 12149000 near Carnation, WA in 2006, 2015, and across 1929-2015.

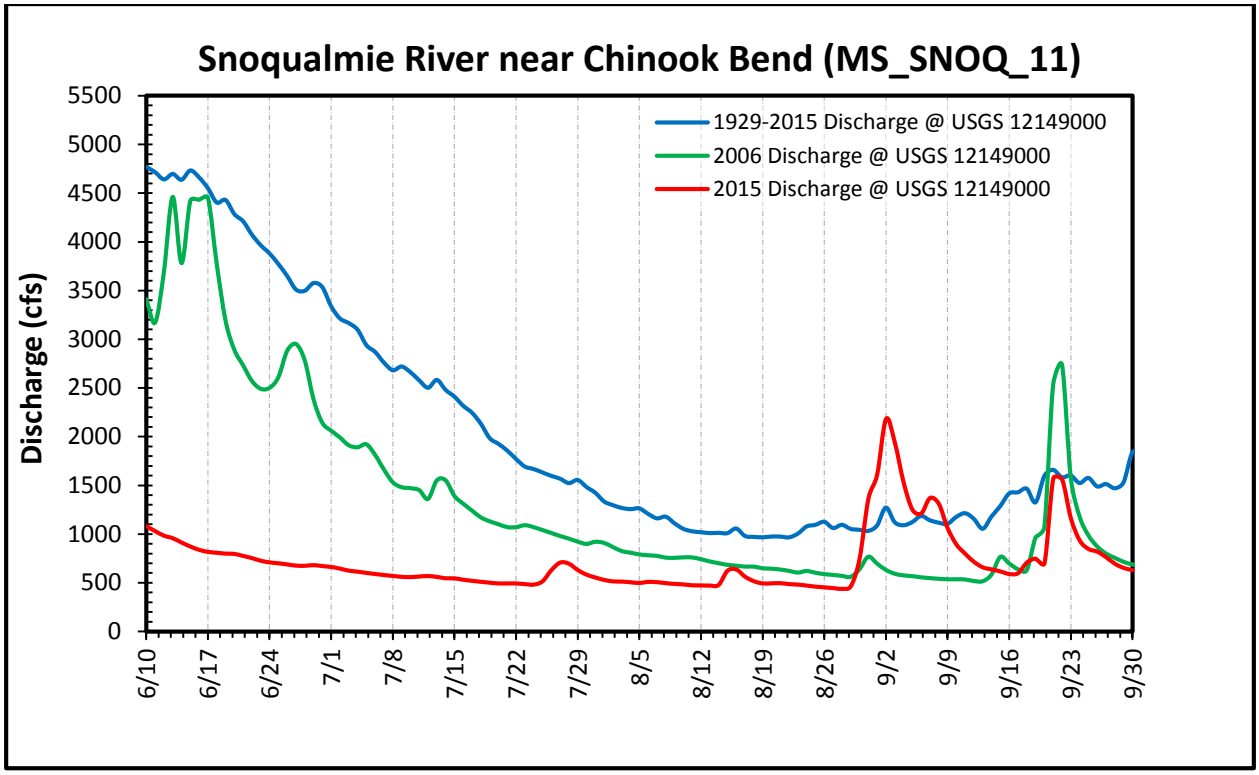


Figure 24. Flow in mainstem Snoqualmie at USGS 12145500 near Snoqualmie, WA in 2006, 2015, and across 1900-2015.

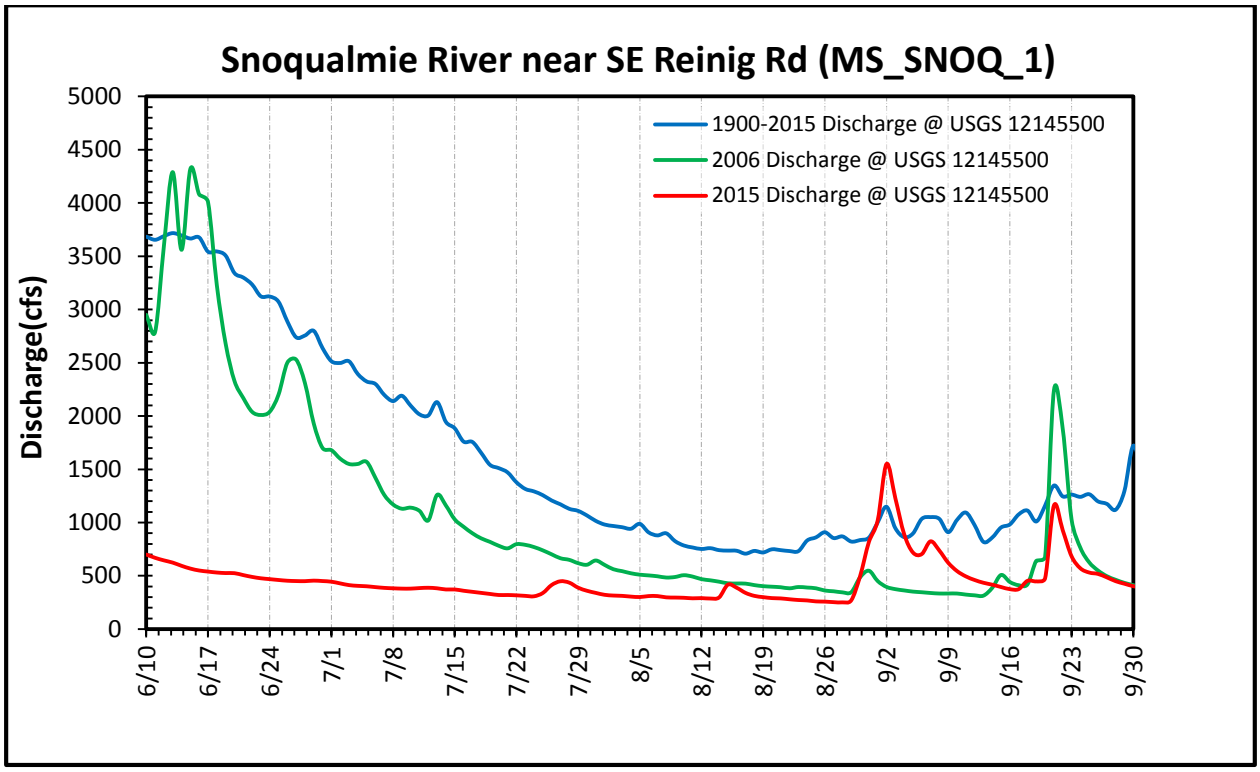


Figure 25. Flow in Raging River at USGS 12145500 near Fall City, WA in 2006, 2015, and across 1945-2014.

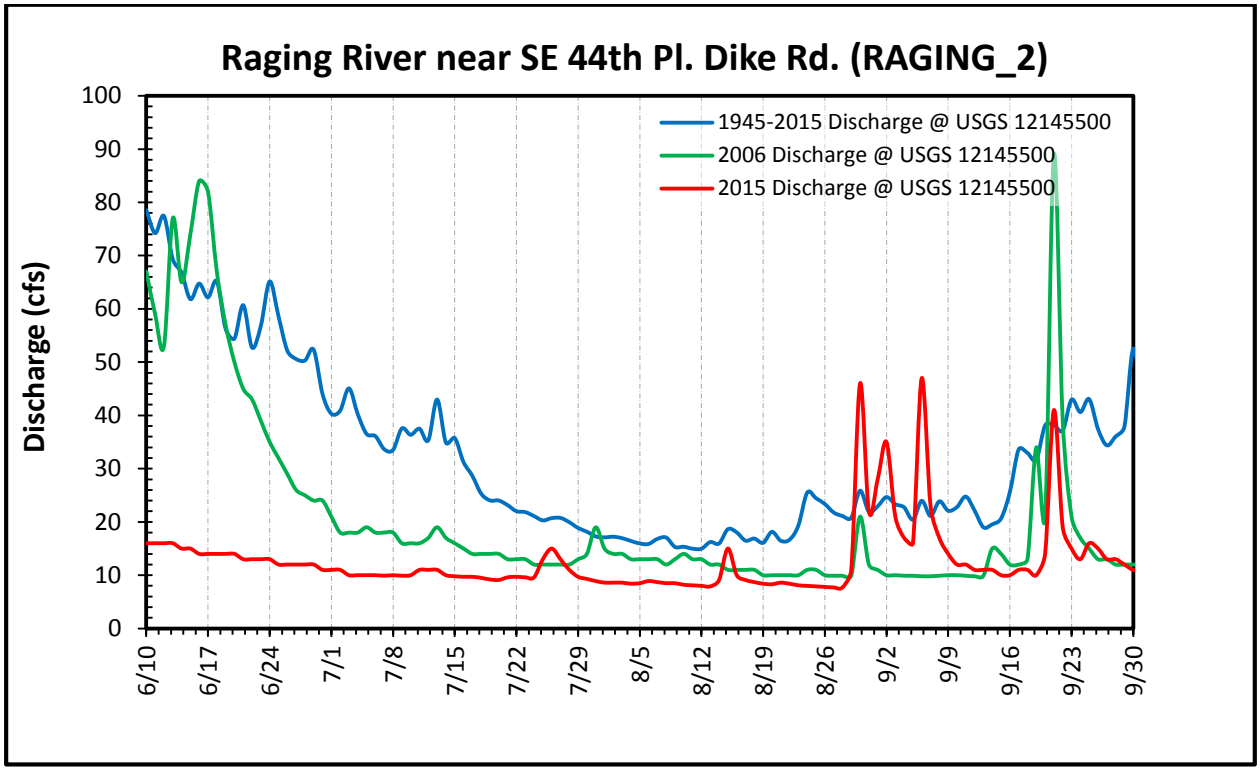
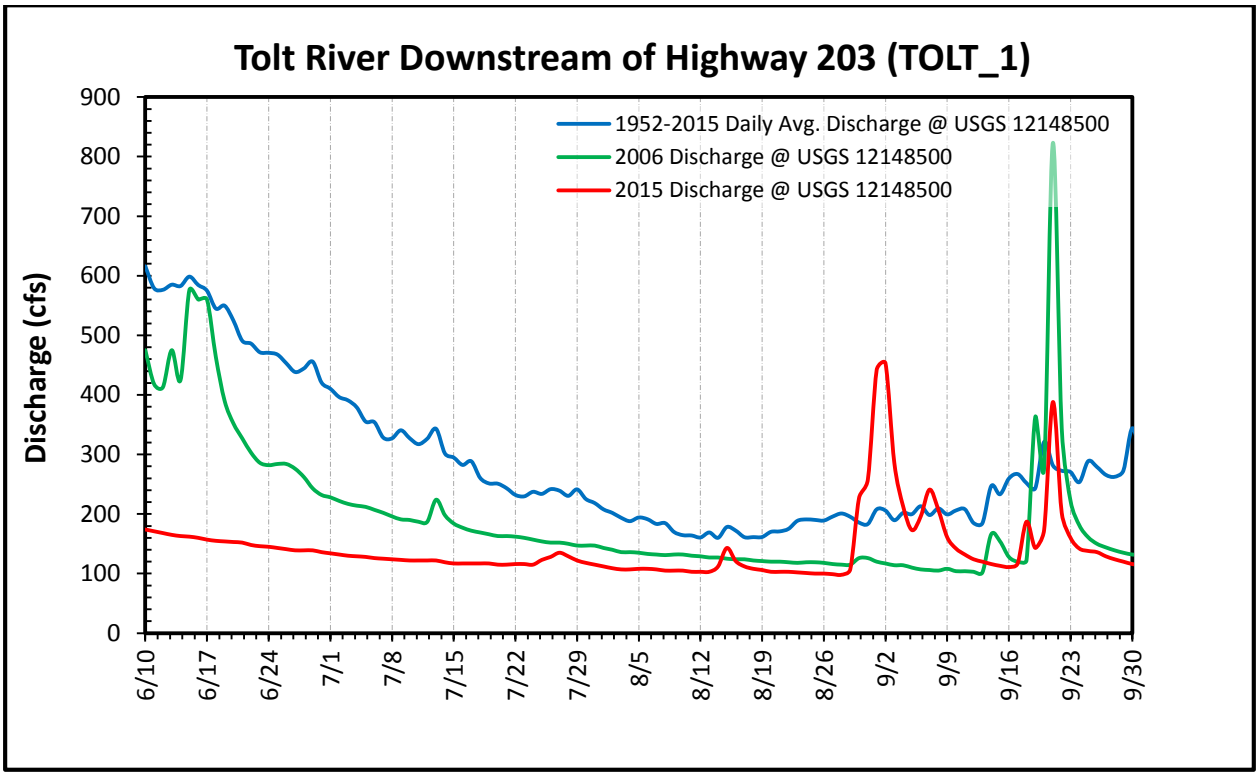
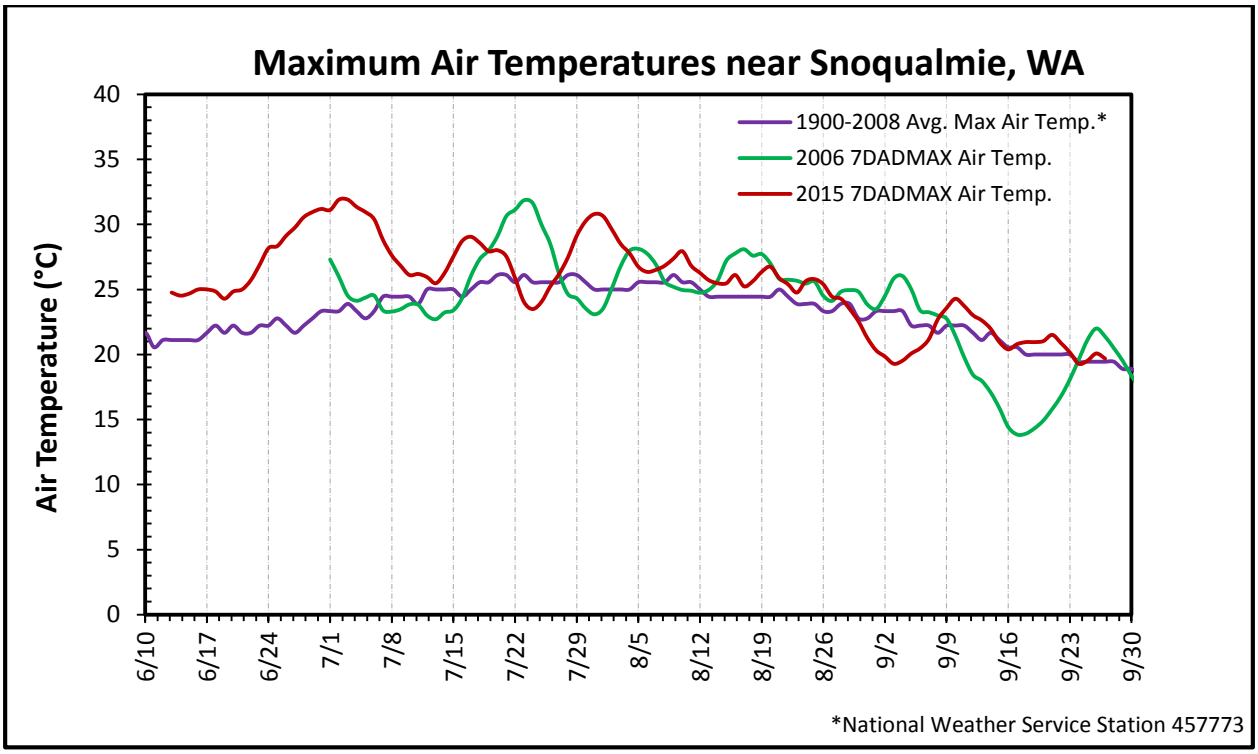


Figure 26. Flow in Tolt River at USGS 12148500 near Carnation, WA in 2006, 2015, and across 1952-2014.



Weather conditions in 2006 were generally warm with 7-DADMAX air temperatures fluctuating around the long-term maximum average (Figure 27). From July 1st to September 27th, 2006 had a 7-DADMAX air temperature above the long-term average maximum temperature a total of 56 out of the 89 days (63%). In comparison, 2015 displayed some of the warmest maximum average temperatures compared to 2006 and the long-term series. For example, from June 13th to September 27th, 2015 observed a 7-DADMAX air temperatures above the long-term average maximum temperature a total of 90 out of the 107 days (84%).

Figure 27. Maximum average air temperature near Snoqualmie, WA in 2006, 2015, and across 1900-2008.



Water temperatures from 2006 and 2015 reflected these aforementioned differences in flow and air temperature (Appendix B). 2015 featured consistently warmer water temperatures than 2006 in the mainstem Snoqualmie, with the exception of the end of July and early September (Figure 28; Appendix B). Similar patterns were observed across tributaries with 2015 water temperatures consistently exceeding 2006 time-series, aside from similar periods in the July and September (Figure 29; Appendix B). During 2006, the highest daily maximum stream temperatures occurred on July 24th and 25th (WA Ecology 2011). The highest daily maximum stream temperatures of 2015 occurred on July 1st to July 3rd. Across all sites that were comparable to 2006 WA Ecology TMDL data, the highest daily temperatures observed in 2015 exceeded all 2006 values with the exception of the North Fork Snoqualmie (Table 55). Additionally, the percent of days in which the 7-DADMAX water temperature of 2015 exceeded the 7-DADMAX of that respective day in 2006 ranged from 61.6% to 100%, with an average exceedance of 76.4% (Table 5).

Figure 28. Snoqualmie River 7DADMAX water temperature time-series and related flows in 2006 and 2015.

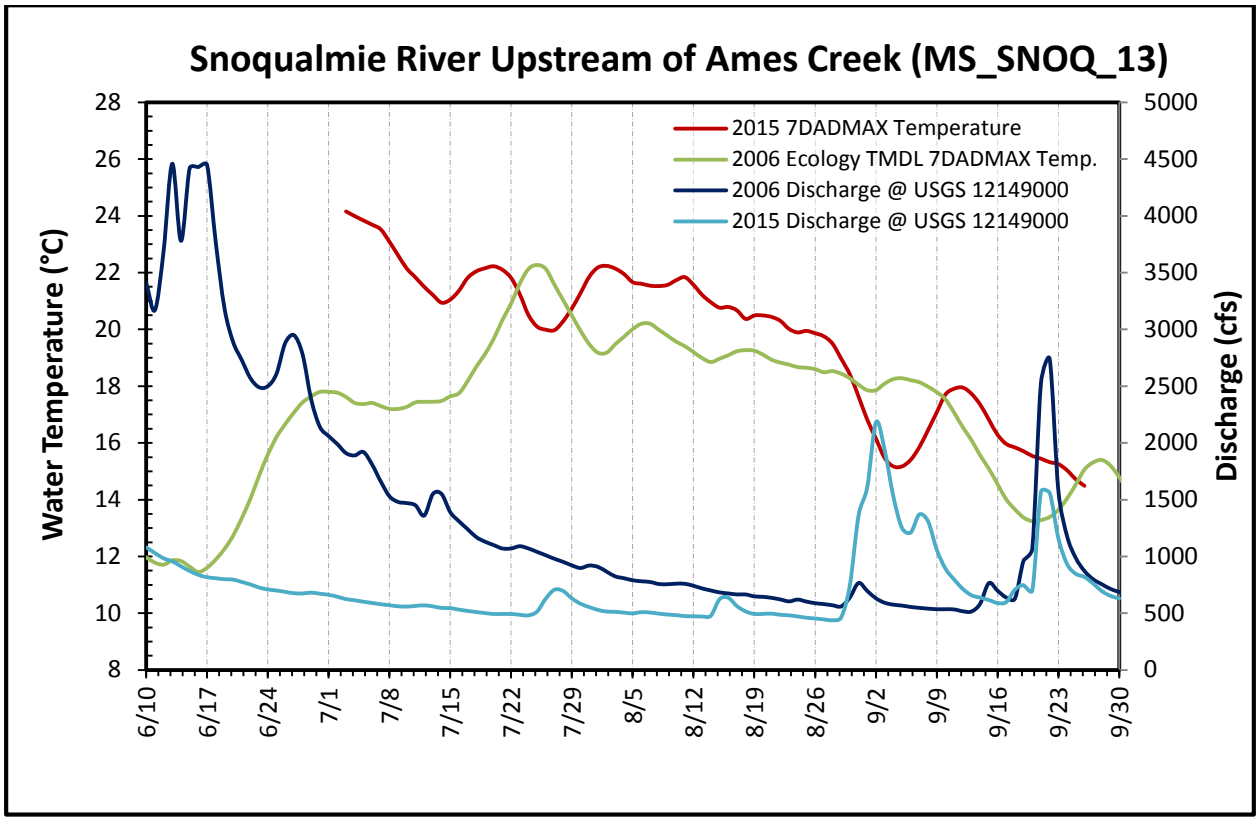


Figure 29. Raging River 7DADMAX water temperature time-series and related flows in 2006 and 2015.

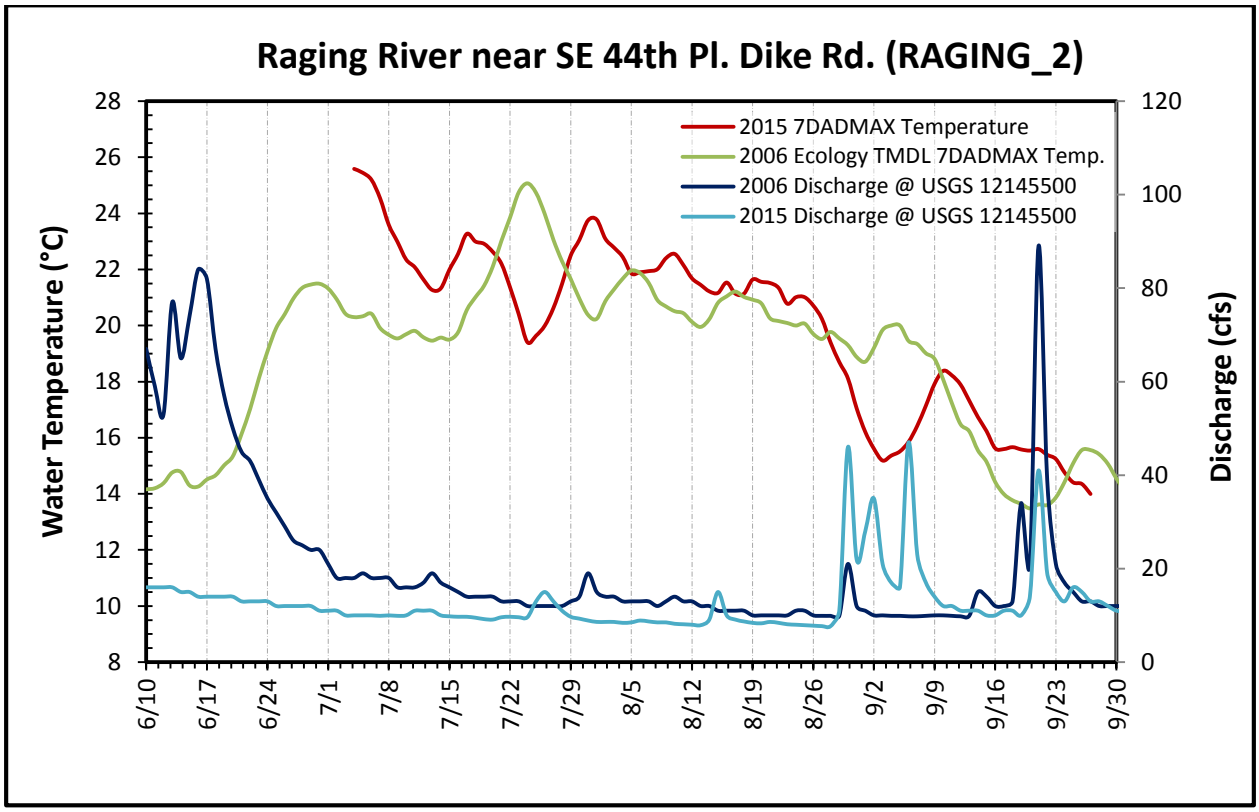


Table 5. Comparison of 2015 water temperature data with 2006 WA Ecology TMDL data.

	2015 (°C)		2006 TMDL (°C)		
Location	**Highest Daily Water Temp.**	**Highest 7DADMAX**	**Highest Daily Water Temp.**	**Highest 7DADMAX**	**% of Days 7DADMAX of 2015 > 7DADMAX of 2006**
MS_SNOQ_19	25.51	24.52	22.79	22.31	77.4%
MS_SNOQ_18	24.42	24.95	23.01	22.41	76.0%
MS_SNOQ_17	24.74	24.28	23.01	22.41	86.8%
MS_SNOQ_16	25.13	24.72	23.01	22.41	79.1%
MS_SNOQ_15	24.35	24.02	23.26	22.58	91.9%
AMES_1	20.23	19.76	17.84	12.36	100.0%
MS_SNOQ_13	24.45	24.16	22.74	22.27	80.2%
MS_SNOQ_11	24.35	23.95	21.87	21.40	72.6%
MS_SNOQ_10	24.64	23.93	21.92	21.23	74.7%
TOLT_1	24.16	23.36	23.10	22.00	73.6%
MS_SNOQ_2	24.84	24.31	21.92	21.23	79.8%
MS_SNOQ_6	23.77	23.40	22.66	21.85	61.6%
MS_SNOQ_4	24.55	23.98	22.29	21.60	65.5%
MS_SNOQ_3	25.13	23.99	22.29	21.60	78.8%
MS_SNOQ_2	24.16	23.21	21.36	20.75	75.3%
RAGING_2	26.68	25.59	26.39	25.07	69.8%
TOKUL_1	20.71	20.07	18.71	18.06	88.5%
MS_SNOQ_1	22.33	21.73	21.60	20.76	NA
NF_SNOQ_1	19.09	18.19	19.85	19.04	66.3%
MF_SNOQ_1	24.45	22.87	22.59	21.95	65.4%
SF_SNOQ_1	19.95	19.35	19.79	19.03	65.0%

3.3.2 King County Tributary Gauges

Extended water temperature time-series were available at 5 King County hydrologic gauging stations (Chery, Tuck, Harris, Griffin, and Patterson Creeks). Due to missing thermistors and an incomplete data-series, Patterson Creek was not used for multi-year comparison. The remaining 4 tributaries and gauging stations were used for extended comparison. Flows across these tributaries were considerably lower in 2015 compared to previously gauged years up to mid-August (Figure 30 & 31, Appendix B). Additionally, water temperatures from 2015 were consistently warmer than previous years in July and August (Figure 30 & 31; Appendix B). Across all sites that were comparable to King County gauging stations, the highest daily temperatures observed in 2015 exceeded all previous years with the exception of Griffin Creek (Table 6). Additionally, the percent of days in which the 7-DADMAX water temperature of 2015 exceeded the 7-DADMAX of that respective day across previous years ranged from 43.5% to 96.5%, with an average exceedance of 68.0% (Table 6).

Figure 30. Cherry Creek 7DADMAX water temperature time-series and flows in 2006 and across 2001-2014.

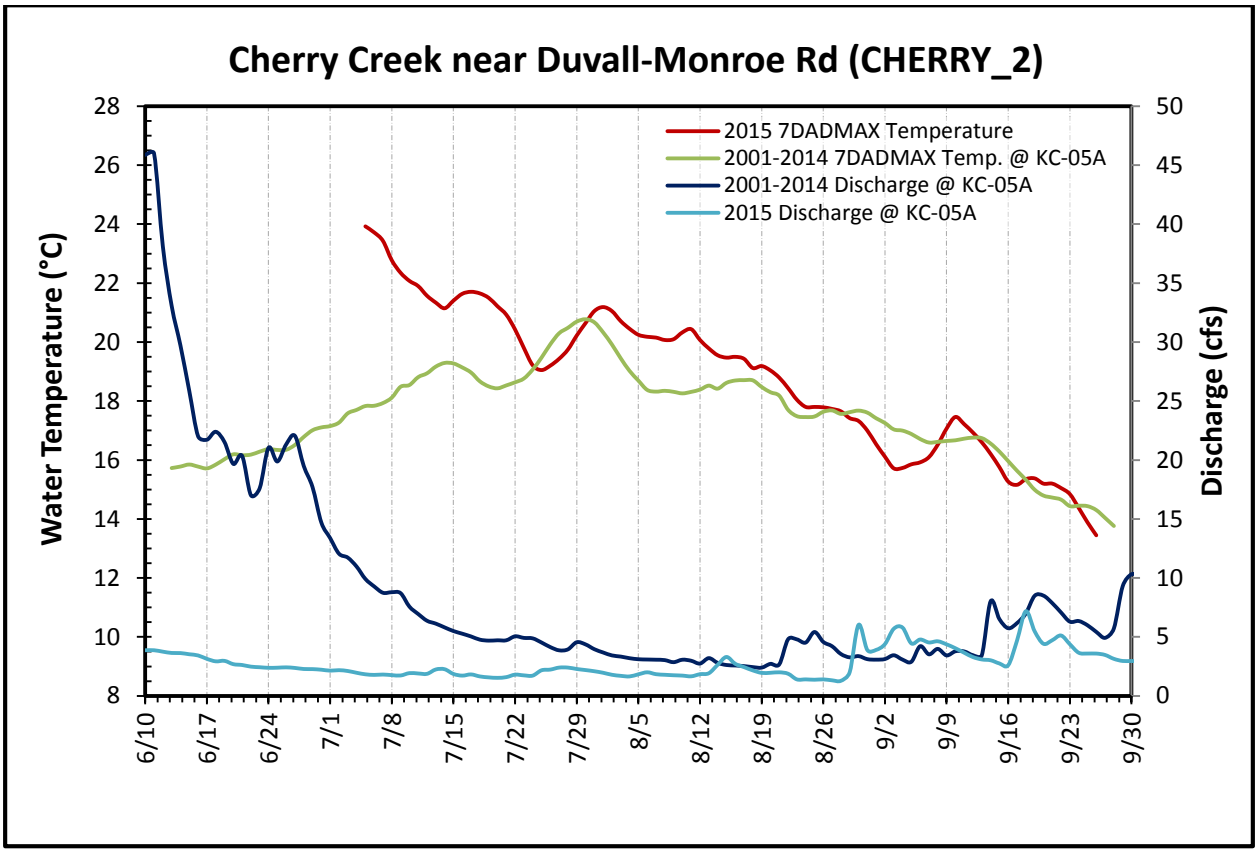


Figure 31. Griffin Creek 7DADMAX water temperature time-series and flows in 2006 and across 2001-2014.

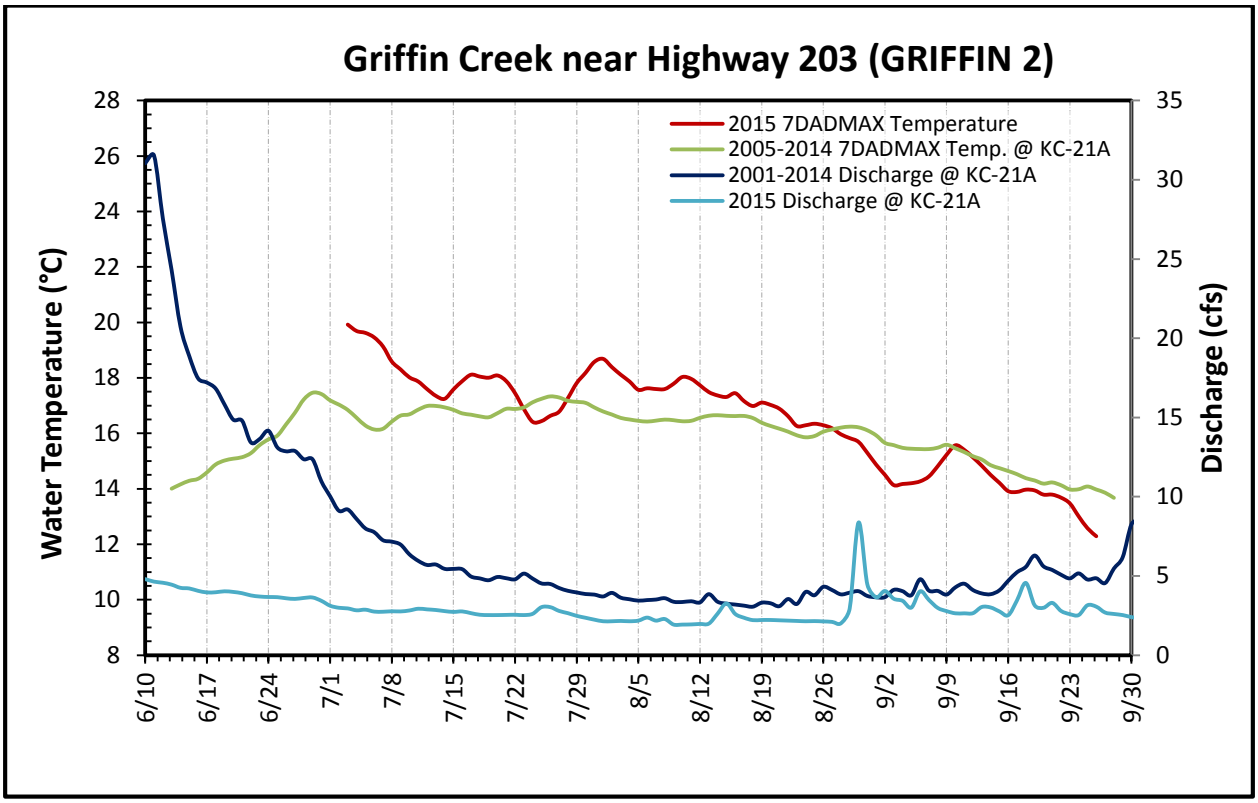


Table 6. Comparison of 2015 water temperature data with King County gauging stations.

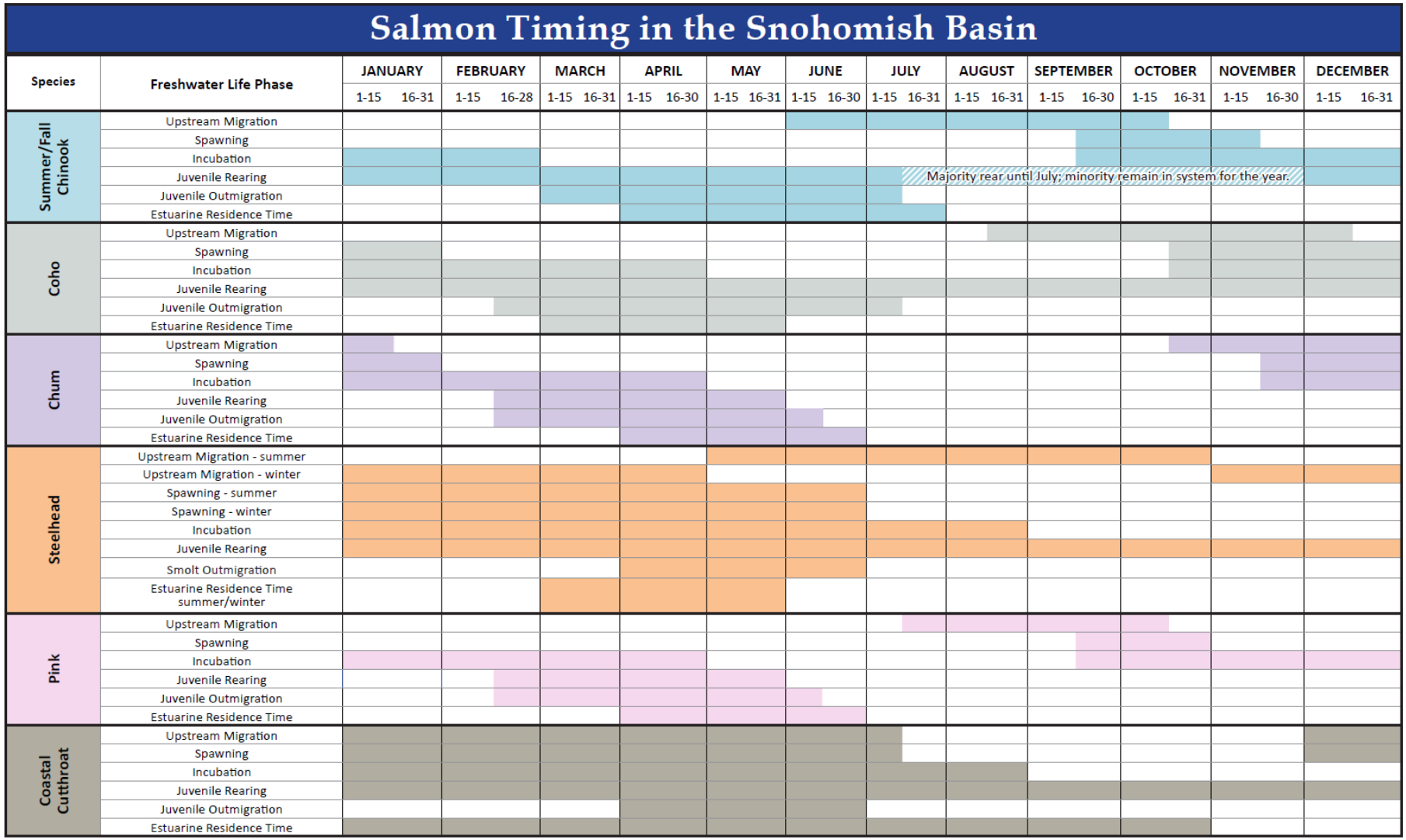
	2015 (°C)		Previous Years (°C)			
Location	**Highest Daily Water Temp.**	**Highest 7DADMAX**	**Date Range**	**Highest Daily Water Temp.**	**Highest 7DADMAX**	**% of Days 7DADMAX of 2015 > 7DADMAX of KC Gauge Record**
CHERRY_2	24.93	23.93	2001-2014	24.90	20.77	70.2%
TUCK_2	24.16	21.11	2008-2014	21.70	18.63	96.5%
HARRIS_2	18.43	17.91	2000-2014	17.33	16.56	43.5%
GRIFFIN_2	20.42	19.92	2005-2014	21.66	17.46	61.6%

3.4 Snoqualmie River Temperatures and Salmon Survival

The Snoqualmie Watershed Forum's interest in this temperature study came from a desire to understand temperature impacts to salmon. The summer of 2015 proved to be one of the warmest summers on record with some of the lowest water flows ever recorded. These conditions resulted in warm water temperatures throughout the Snoqualmie River watershed. Salmonids in the Snoqualmie River were subjected to these harsh environmental conditions which may have jeopardized their health and survival. This study was able to capture the extreme summer of 2015 which helps to build a greater understanding of the extent to which water temperatures can threaten salmonids in the Snoqualmie River. This is particularly relevant in light of climate change projections that suggest weather years like 2015 may become more common.

As stated in the introduction, there are many factors contributing to salmon habitat degradation in the Snoqualmie River. Impaired water quality, specifically warm water temperatures, pose an additional threat influencing salmonid health, development, migration, and survival. Higher water temperatures have a myriad of lethal and sub-lethal effects on salmonids at all life stages. For reference, Table 7 shows the timing of various salmonid freshwater life stages in the Snohomish River Basin.

Table 7. Salmonid freshwater life cycle timing in the Snohomish River Basin.



At their most extreme, high water temperatures are lethal to salmonids. A single daily peak temperature of 23-25°C can kill salmonids in a few seconds or hours (WA Ecology 2002). Even if water temperatures do not reach lethal levels, warmer temperatures (16 - 23°C) can cause significant sub-lethal effects such as increased susceptibility to disease, metabolic stress, developmental issues, and blockages to migration (i.e., salmon may refuse to swim through extremely warm waters), which can influence survival during spawning, development, and rearing. Adult salmonids are successful at migrating up rivers at temperatures of 15 °C and below. When the daily average temperatures exceed 15°C, migration is disrupted and when water temperatures reach a daily maximum of 21- 22°C, migration is blocked. When salmonids return to their natal streams, spawning success is impaired at temperatures above 12 - 13°C. When adults are able to spawn, eggs experience a higher rate of non-fertilization, abnormalities (e.g., odd number of eyes), or outright mortality at temperatures above 11°C. If eggs do hatch, juvenile salmonids face a host of sub-lethal effects caused by warmer temperatures such as altered growth rates and developmental disorders (e.g., twisted backbones or malformed tails and mouths). Juvenile salmonid development and rearing is interrupted when average water temperatures exceed 13 - 15°C or when maximum temperatures exceed 17-19°C. Higher water temperatures during development can alter fry emergence timing which can influence survival rates due to predation, disease, and starvation (Richter and Kolmes, 2005). Warmer water temperatures during rearing increase the rate of respiration in juvenile salmonids and increases the need for food and oxygen. Juvenile salmonids spend more time foraging in the open water, increasing metabolic demands and the chance for predation. These sub-lethal effects hinder juvenile salmonid health and growth influencing their life-cycle survival.

Based on the scientific literature and WA Ecology's thresholds, in 2015, Snoqualmie River salmonids were subjected to both acute and sub-lethal temperatures. The 7-DADMAX thresholds for core summer habitat and spawning, rearing, and migration habitats were surpassed for the majority of the summer (Figure 32). The 7-DADMAX did not go below the high temperature threshold until the onset of the late summer storms at the end of August and only dipped below those thresholds for a short period. In mid-September, the state temperature threshold changes to 13°C and mainstem temperatures remained warmer than that threshold during this study period. The beginning of the summer was significantly warmer than the late summer. During June and July, temperatures in the mainstem Snoqualmie intermittently rose above the 1-DMAX for both acute lethal effects and migration barriers (Figure 33). From the end of July to the end of September, water temperatures did not reach acute lethal temperatures; however, it wasn't until mid-August that water temperatures were below the 1-DMAX threshold for barriers to migration.

Figure 32. Mainstem Snoqualmie 7DADMAX range and WA Ecology thresholds for designated uses. State Standards after Sept. 15 specific for spawning and egg Incubation.

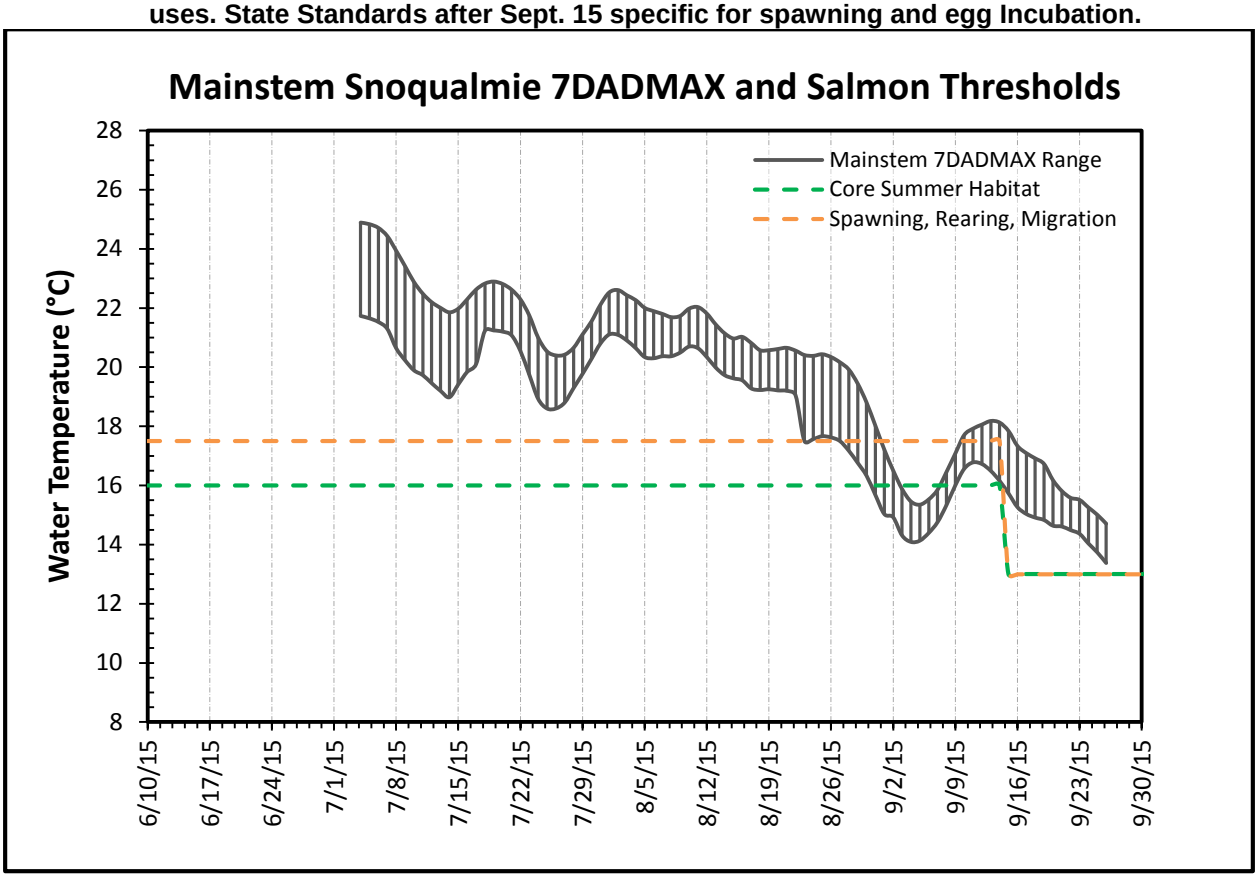
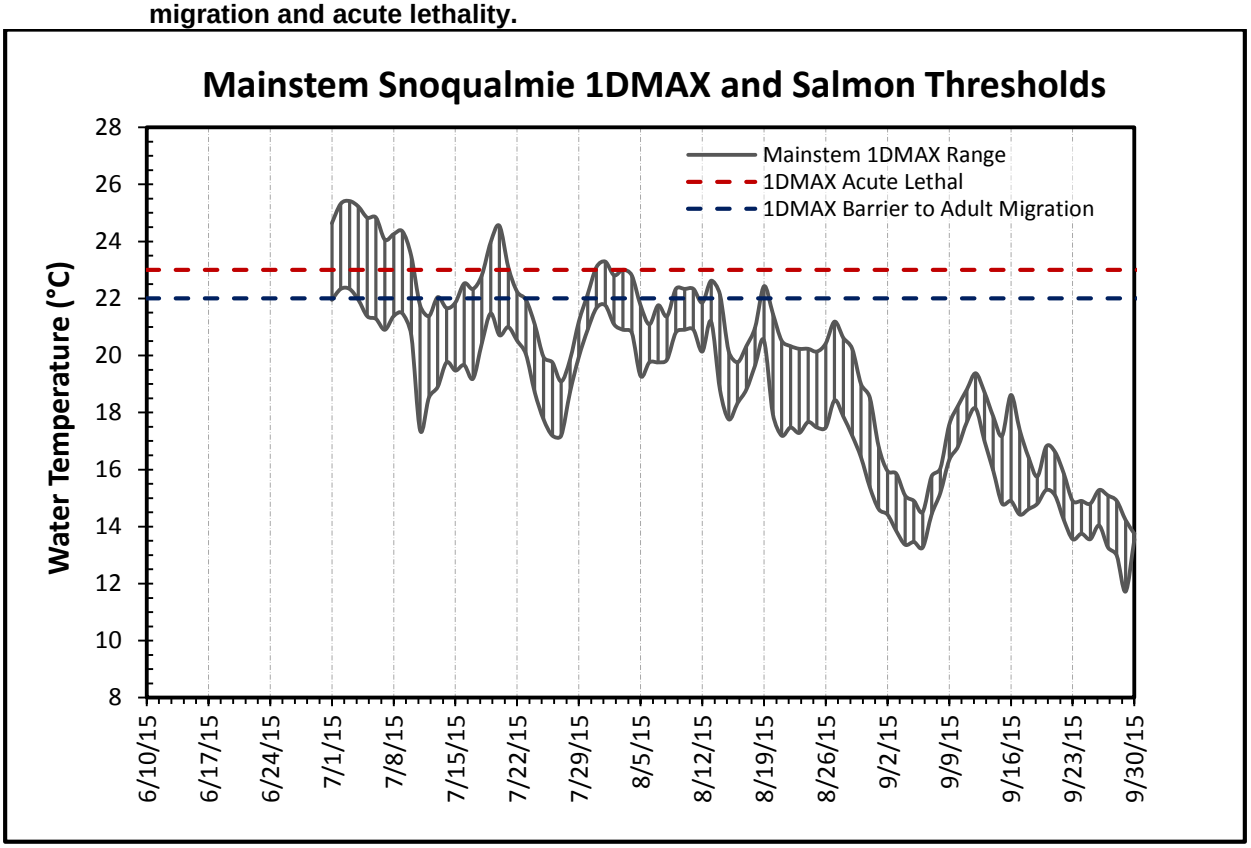
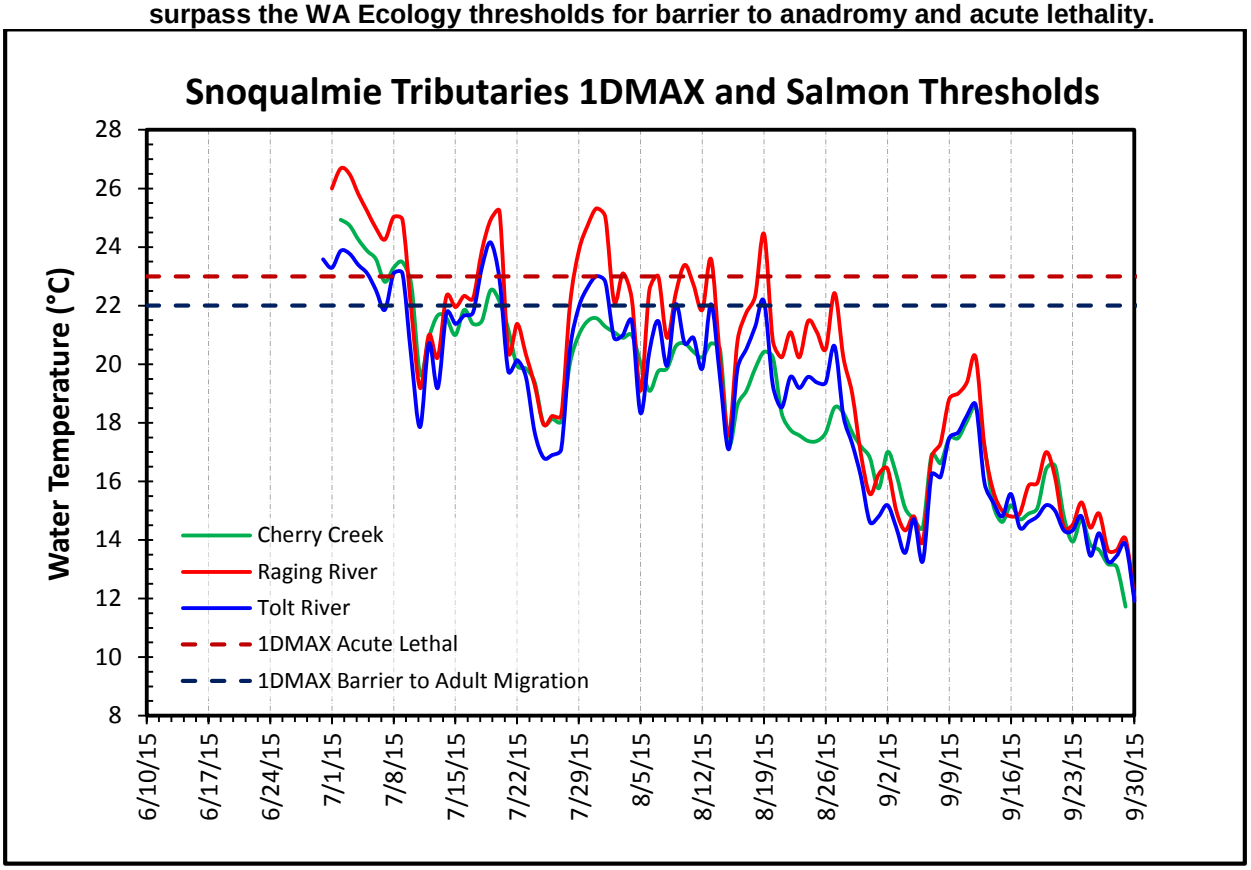


Figure 33. Mainstem Snoqualmie 1DMAX range and WA Ecology thresholds for barrier to migration and acute lethality.



Similar to the mainstem, many of the Snoqualmie tributaries experienced exceedances for core summer habitat thresholds (Figure14, Section 3.2.2.2). In addition to exceedance of the 7-DADMAX thresholds, some of the larger tributaries (Cherry Creek, Tolt River, and Raging River) exceeded 1-DMAX temperature thresholds for acute lethality and barriers to migration (Figure 34). As mentioned in the introduction, the Tolt and Raging Rivers are key spawning and rearing areas for threatened Chinook salmon. For a large portion of July, all three tributaries were frequently above the 1-DMAX threshold for acute lethal effects. In addition to the Raging River being well above the 23°C lethal standard, minimal flows resulted in the Raging flowing sub-surface near the confluence with the Snoqualmie, creating a physical barrier. While the Tolt had 1-DMAX temperatures that were potentially acute lethal and/or barriers to migration, continuous flow connection to the mainstem Snoqualmie and lower minimum temperatures (discussed in section 3.2.2.2) may have buffered conditions in the lower Tolt.

Figure 34. Snoqualmie tributaries downstream of Snoqualmie Falls with 1DMAX range that surpass the WA Ecology thresholds for barrier to anadromy and acute lethality.

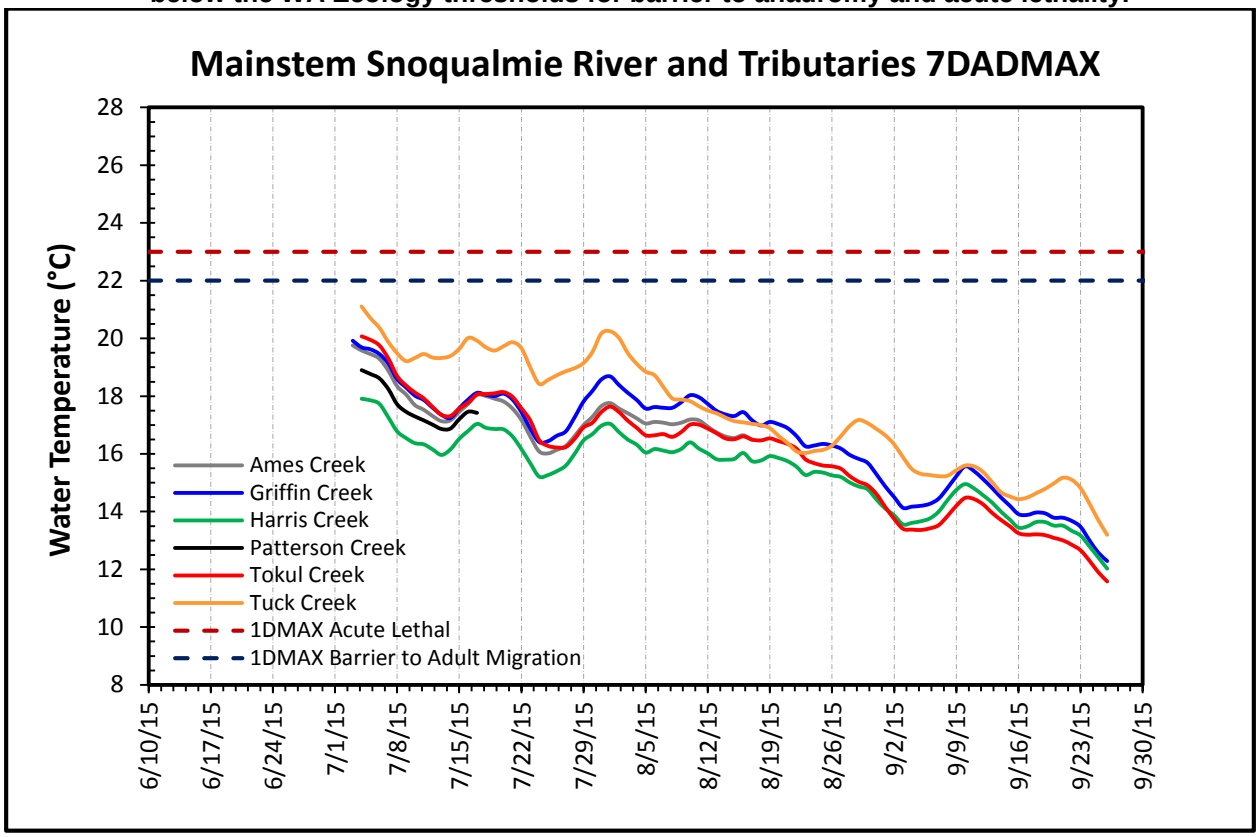


While the mainstem and major tributaries experienced water temperatures well above state thresholds, there were several, smaller tributaries that remained at or below the thresholds for acute lethality and barriers to migration (Figure 35). These colder tributaries as well as areas of groundwater exchange (discussed in section 3.2.2) create areas of cooler water which may provide refuge to salmonids from warmer water, helping to support physiological and ecological needs. However, it is not well understood how these small tributaries and groundwater areas are utilized by salmonids in the Snoqualmie

or how the spatial and temporal distribution of cold water refugia influence salmonid life histories.

Salmonids are known to detect and preferentially utilize even small differences in temperature. Our study revealed that the timing of the daily maximum temperature can differ noticeably by location. For example, on July 4, mainstem sites MS_SNOQ_4 (near Neal Rd. Boat Launch) and MS_SNOQ_6 (downstream of Patterson Creek), which are located just 2.5 river miles apart, had daily temperature peaks that differed by approximately two hours. On that same date, some mainstem sites began cooling down as early as 5:30 PM while the site with the latest maximum did not begin to cool until 9:30 PM. There was no clear longitudinal pattern to the timing of the daily maximum, i.e., the maximum was not progressively later further downstream. While all of the temperatures in question remained extremely warm, these differences in timing nevertheless provide fish with some opportunities to utilize 'temporal' thermal refuge areas to avoid the most harmful conditions (Torgersen et al. 2012).

Figure 35. Snoqualmie tributaries downstream of Snoqualmie Falls with 1DMAX range that were below the WA Ecology thresholds for barrier to anadromy and acute lethality.



This study illuminates the potential impacts of water temperatures on salmonids during a particularly hot, low-flow season and highlights the potential significance of cold-water refugia across tributaries and areas of groundwater exchange. Conditions in 2015 indicate that sub-lethal and acute lethal water temperatures can occur throughout the Snoqualmie River watershed. The impacts of these warm temperatures likely affected both juvenile salmonids rearing in the river over the summer (e.g., coho, steelhead and stream-type

Chinook) or adults that were either holding or which returned later in the year. These impacts could affect many of the Snoqualmie salmonid populations and greatly impede their life-cycle viability. While the occurrence of warm water conditions were quite apparent throughout the Snoqualmie, the extent to which these conditions influenced juvenile and adult salmonids will likely not be fully known until we can evaluate the survival and productivity of returning adults in the future.

4.0 CONCLUSIONS

4.1.1 Implications for Snoqualmie River Salmonid Conservation

During the summer of 2015, high air temperatures and record low flows resulted in warm water temperatures throughout the Snoqualmie River watershed. Water temperatures were consistently above state standards for designated uses and resulted in stressful and potentially lethal conditions for salmonid populations. Warm, low-flow river conditions observed in 2015 emphasize the value of addressing water temperature issues, whether through conventional or innovative strategies. With warm temperatures occurring throughout the Snoqualmie watershed, it may be useful to consider site-specific efforts within a basin-wide context. Focusing on site- and basin-level scales may help to spatially prioritize strategies for mitigating current conditions and to build watershed resiliency for future climate conditions. For example, this may result in an increased emphasis on headwaters and smaller tributaries as compared to primarily the mainstem. Current efforts have been unable to ameliorate observed water temperature conditions, and it may be necessary to increase conservation and restoration efforts in the Snoqualmie at a magnitude and scale comparable to the degree and urgency of apparent temperature issues.

Results from this study highlight the need to consider factors like spatial and temporal variation in temperature regimes, tributary influences, areas of groundwater exchange, floodplain connectivity, as well as daily patterns in thermal fluctuations when addressing Snoqualmie River temperature issues and evaluating potential impacts on salmonid populations. Incorporating these factors into conservation and restoration strategies may help in supporting habitat conditions necessary to maintain viable salmonid populations over the long-term. Potential restoration actions may include headwater and tributary riparian restoration, instream flow augmentation or reduced withdrawals, improved recharge and groundwater exchange, and improved floodplain and riparian connectivity.

Areas like headwaters, tributaries, and groundwater upwelling zones may provide thermal refugia during warm events as well as thermal corridors between river reaches. The temperature time-series data in 2015 showed that tributaries and groundwater exchange zones can influence mainstem Snoqualmie temperature fluctuations and thermal extremes. Tributaries and groundwater exchange reaches may subsequently be ideal locations to focus cold-water conservation and restoration efforts. Hyporheic exchange (i.e., surface water mixing with shallow groundwater while flowing through substrate beneath and adjacent to channel) can reduce temperature maximums helping to support thermally-sensitive aquatic organisms. Actions that could help to enhance hyporheic and groundwater recharge and support cold-water refugia may include increasing mainstem and tributary channel complexity and restoring floodplain wetlands and connectivity. In order to improve hyporheic and groundwater exchange, it will be important to remove channel constraints such as levees and revetments (where public safety is not at risk) and supplement river conditions with instream structures such as log jams. Where appropriate, the construction and encouragement of log jams and boulder complexes will help stimulate vertical hyporheic and groundwater exchange, supporting cold-water refugia.

Low flows were ubiquitous across the Snoqualmie in the summer of 2015, and exacerbated high water temperatures by reducing the ability of the river to buffer air temperatures and solar radiation. These patterns emphasize the importance of maintaining summer flows, whether through increased recharge (e.g., restored wetland complexes), decreased withdrawals, or increased channel complexity and connectivity. Area such as the Middle Fork Snoqualmie and select tributaries highlight the importance of such instream flows, with observed water temperatures showing considerable response to changing in river flows. It will be critical to protect surface water instream flows, especially in the tributaries, as they influence mainstem temperatures and provide important temperature refuge for salmonids. As noted by Snoqualmie Watershed Forum staff, the newly formed Snoqualmie Watershed Improvement District may be well positioned to develop partnerships to help develop water banking and water right transfers among water right holders to meet the needs of the valley as well as provide a net gain in instream flows. In addition to organizing water rights in localized areas, Snoqualmie Watershed Forum staff emphasize that it will also be important to encourage WA Ecology to address illegal water withdrawals throughout the basin.

The prevalence of warm temperatures throughout the watershed supports the need for ongoing and continued riparian restoration. With riparian corridors helping to shade and influence river water temperatures, broad riparian restoration and forest retention is vital in the short-term and long-term to fully address Snoqualmie River temperature issues. It was apparent in 2015 that tributaries played a critical role in providing cooler water refuges for fish, even though the lower reaches had heavily degraded riparian conditions. It may be useful therefore for riparian restoration to be focused, in the near-term, on headwaters and throughout smaller tributaries to the mainstem. However, the long-term need for mainstem planting, particularly on the southern banks, is also critical for watershed-wide temperature issues since it will take decades for the plantings to become mature enough to affect temperatures.

To help accomplish riparian restoration, Snoqualmie Watershed Forum staff suggest that it may be necessary to compensate landowners versus relying on entirely voluntary donations of land. One way to do this is to purchase permanent conservation easements from private landowners in high priority areas. The easements would provide compensation to land owners and would support robust riparian plantings in critical reaches. It will be important to continue working with agricultural land owners in the basin; agriculture is a special and valuable land use in the Snoqualmie Valley and farms occupy some of the most critical riparian areas for restoring fish habitat and improving water quality. Closely working with the agricultural community will be imperative to develop a riparian buffer strategy that achieves meaningful gains in riparian condition while working thoughtfully through constraints unique to the agricultural landscape.

The conditions observed in 2015 may provide useful insight into the likely impacts of climate change on the Snoqualmie River watershed. Climate variability and potential future changes will affect the Puget Sound region through a suite of impacts that are likely to include increased warming, increased variability in precipitation patterns, and more frequent and intense rainfall (Mauger et al. 2015). Specific to the Snoqualmie River watershed, climate change forecasts predict that drainages are likely to shift from snow and rain-on-snow dominated to transitional and rain dominated drainages. With more

drainages shifting away from climatic and hydrologic regimes that support snowpack and spring snow-melt driven flows, flow and temperature conditions akin to those observed in 2015 are likely to be the norm rather than the exception.

Climate change impacts are expected to have a negative influence on salmonid populations through warmer stream temperatures, lower summer stream flows, and higher winter stream flows (Mauger et al. 2015). The stressful and potentially lethal conditions observed in 2015 highlight the need to plan for and mitigate potential climate change impacts. The ability of Snoqualmie River and its tributaries to continue supporting salmonid populations will inherently be tied to the degree to which these water bodies can be resilient to climate change. Integrating the information and patterns observed in 2015 into climate and hydrologic models will help to understand how conservation and restoration strategies may be able to mitigate impacts and build resiliency. Potential strategies to help build resiliency may include expanded emphasis on cold-water refugia such as tributary confluences, headwaters, and groundwater recharge zones, as well as accelerating the restoration of riparian condition, extent, and connectivity. Additionally, supporting floodplain processes, watershed storage, and instream flows may be essential to build resiliency. Through a proactive and integrated approach, protection and restoration efforts in the Snoqualmie River watershed can help to address climate change impacts, reduce associated risks, and promote adaptation.

4.1.2 Potential Future Evaluations

There are several studies that may help in further understanding water temperature and hydrology in the Snoqualmie River watershed. As mentioned in section 2.3.3, various other agencies and interest groups were collecting temperature data throughout the Snoqualmie River in 2015. Comparisons across these data sets will be useful to further understand temperature trends and conditions in the Snoqualmie as well as to evaluate potential future conditions.

Tributaries may have the potential to provide areas of cooler water and subsequent refuge from higher water temperatures. Our understanding of which tributaries provide cold water and how these interacts with mainstem temperatures and localized thermal regimes is relatively limited. Gaining a greater understanding of tributary influence and thermal regime impacts would be helpful to understand where salmonids might find refuge during hot weather years as well as helping to prioritize where riparian plantings may need to occur. Similarly, it may be useful to compare the 2015 temperature data against other data sets (e.g., land cover and surficial geology) to understand why some tributaries were cool, while others of similar size were not.

It would be useful to evaluate how groundwater is expressed in the Snoqualmie River watershed and the spatial arrangement of groundwater exchange zones. This may help to understand how groundwater influences the system and how exchange zones relate to different geomorphic and landscape features. Pairing the 2015 water temperature data series with various other efforts, such as the 2006 FLIR (forward looking infrared) data, may help to further evaluate gaining and losing reaches as well as groundwater exchange zones. Additional efforts such as longitudinal thermal profiling and groundwater

assessments may help to identify cold water refugia and develop restoration actions which support groundwater exchange.

Consideration of spatial and temporal variation in water temperatures may help understand how different areas of the Snoqualmie or its tributaries respond to climatic and hydrologic events. This information may inform localized variation among drainages and reaches, which could provide a framework for conservation and restoration prioritization. This information may highlight how strategies may differ among reaches or areas of the watershed.

With the Middle Fork Snoqualmie showing considerably warmer temperatures than both the North and South Forks, it would be useful to conduct an extensive temperature study within the Middle Fork to understand if observed conditions are natural or of anthropogenic influence. This information may help to further understand how temperature is regulated in the Snoqualmie and to what extent various conservation and restoration efforts may have in mitigating warmer temperatures.

Understanding how fish use the Snoqualmie River system and respond to warm temperature conditions is increasingly relevant. A potential study may include PIT (passive integrated transponder) tagging or radio tagging salmonids and evaluating movement patterns during summer months. This would help to better understand how fish distribute through the season and on a daily basis. Additionally, evaluating water column depth and body temperature from internal acoustic tags may help to evaluate how salmonids distribute across thermal regimes and whether species and life histories seek out thermal refugia. It may also be useful to overlay spawner and redd survey data on temperature profiles to determine any temperature-specific relationships.

Other evaluations may include running hydrologic models to understand the thermal diversity in the mainstem as well as performing a low flow assessment to understand the Snoqualmie aquifer. This could help in determining if the aquifer could supplement surface flow with cooler groundwater or if the aquifer could be used in late summer for out of stream uses, allowing more surface water to stay in the system.

5.0 REFERENCES

Adams, T.N. and K. Sullivan, 1989. The physics of forest stream heating: a simple model. Timber, Fish, and Wildlife. Washington State Department of Natural Resources, Olympia, WA. Report No TFW-WQ3-90-007.

Collins, B.D. and A.J. Sheikh. 2002. Mapping historical conditions in the Snoqualmie River valley (RM 0 – RM 40). Report to King County Department of Natural Resources. Department of Earth and Space Sciences, University of Washington.

Cook, B., P. Davies, K. Rutherford, and T. Walshe. 2004. Managing high in-stream temperatures using riparian vegetation. In River and Riparian Land Management Technical Guideline. 24pp.

Haring, D. 2002. Salmonid Habitat Limiting Factors Analysis – Snohomish River Watershed. WRIA 07. Washington State Conservation Commission Report, 331 pp.

Kaje, J. 2009. Snoqualmie Watershed Water Quality Synthesis Report. Prepared for the Snoqualmie Watershed Forum. King County Department of Natural Resources and Parks, Water and Land Resources Division. 180p.

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover. 2015. State of Knowledge: Climate Change in Puget Sound. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle. Doi:10.7915/CIG93777D

Richter, A. and S.A. Kolmes. 2005. Maximum temperature limits for Chinook, Coho, and chum salmon, and steelhead trout in the Pacific Northwest. Reviews in Fisheries Science 13(1): 23-49.

Snohomish Basin Salmon Recovery Forum (SBSRF). 2005. Snohomish River Basin Salmon Conservation Plan. Snohomish County Surface Water Management Division, Everett, WA.

Torgersen, C.E., J.L. Ebersole, and D.M. Keenan, 2012, Primer for Identifying Cold-Water Refuges to Protect and Restore Thermal Diversity in Riverine Landscapes: U.S. Environmental Protection Agency EPA 910-C-12-001, 91pp.

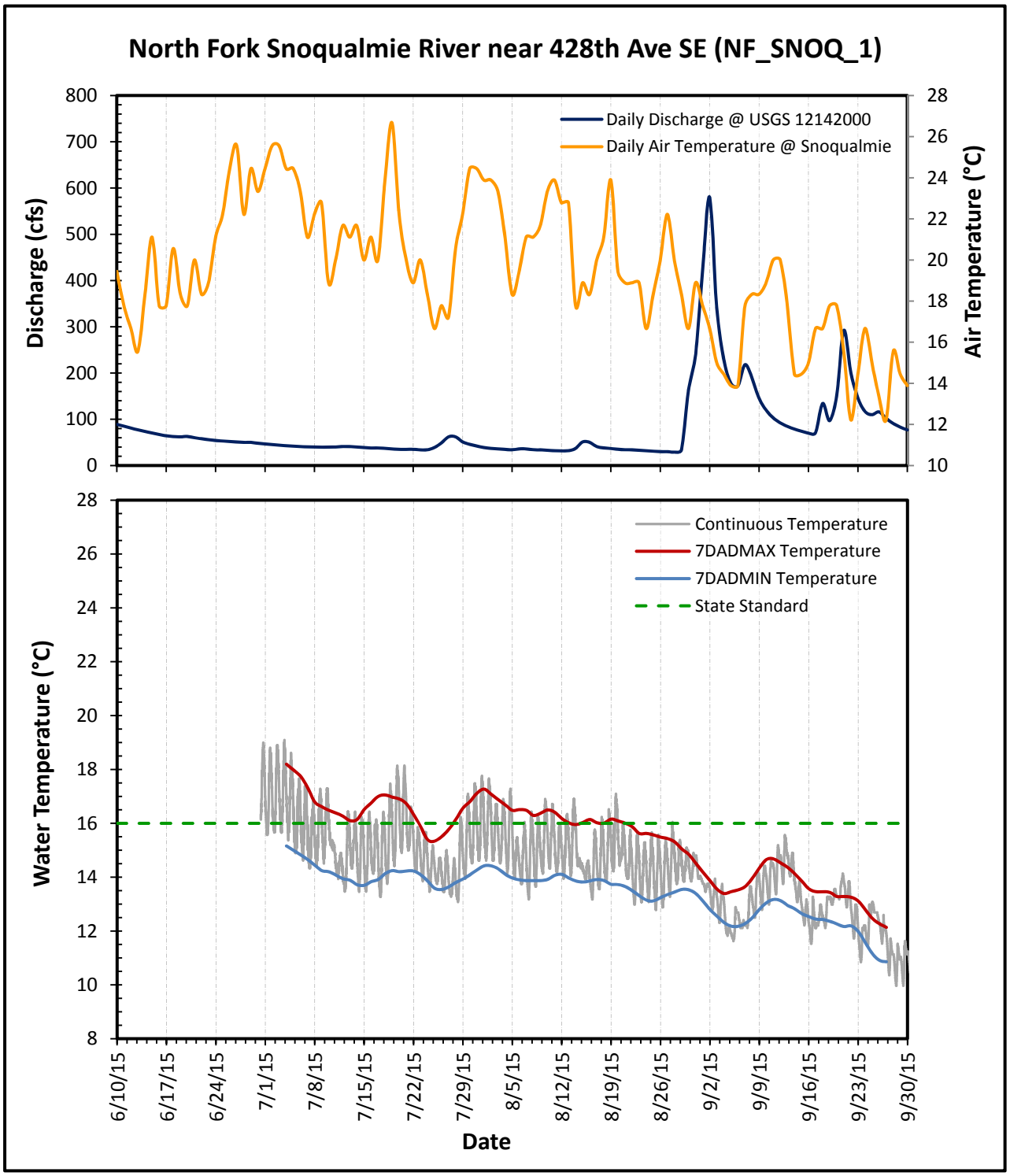
Washington Department of Ecology (WA Ecology). 2002. Evaluating Standards for Protecting Aquatic Life in Washington's Surface Water Quality Standards – Temperature Criteria. Prepared by Water Quality Program. Publication No. 00-10-070.

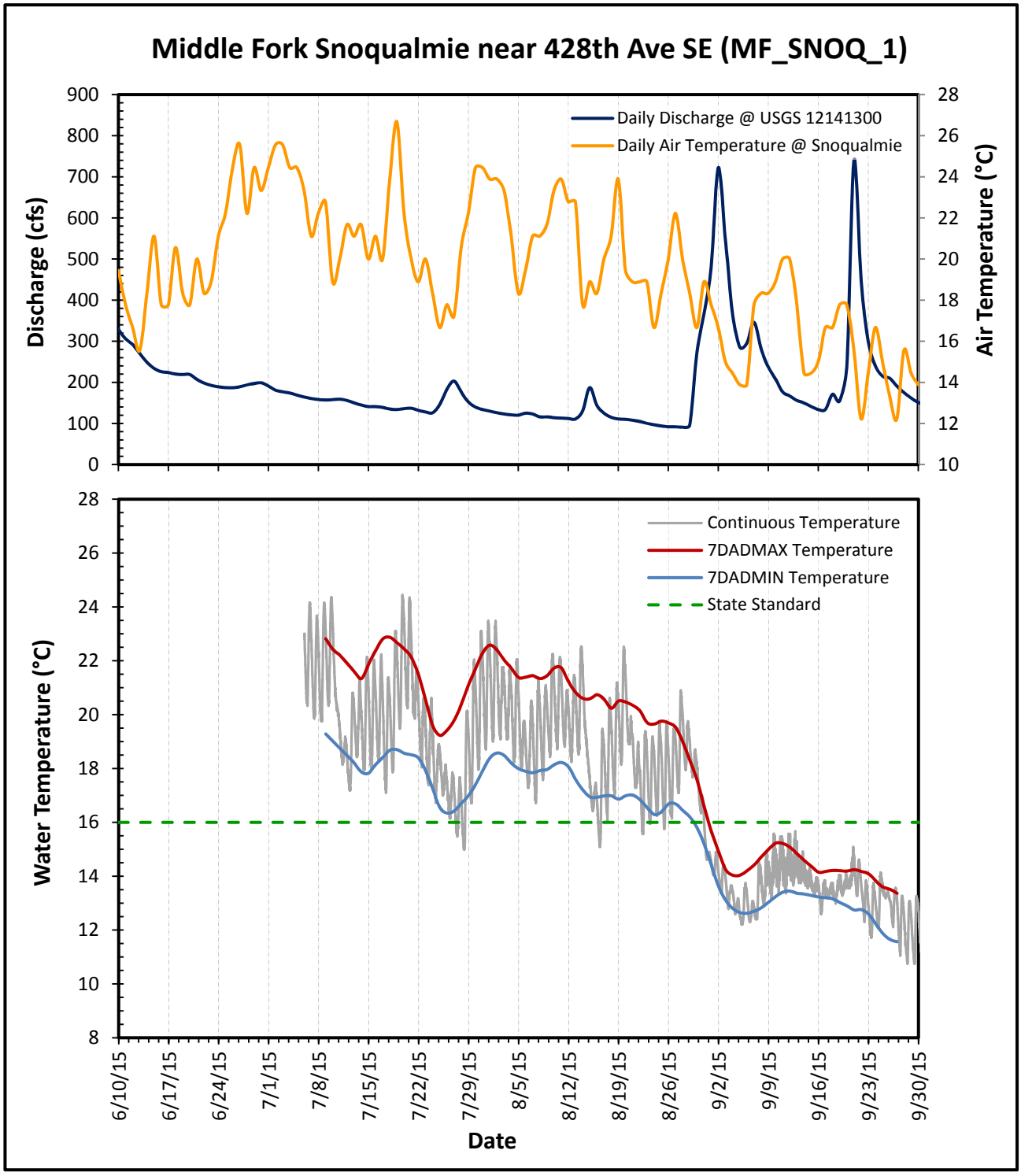
Washington Department of Ecology (WA Ecology). 2011. Snoqualmie River Basin Temperature Total Maximum Daily Load Water Quality Improvement Report and Implementation Plan. Prepared by Anita Stohr, James Kardouni, and Ralph Svrjcek. Publication No. 11-10-041.

6.0 APPENDICES

Appendix A. Temperature profiles across sampled sites.

Top panels including discharge and daily average air temperature at respective location. Bottom panels including continuous temperature, 7 day daily average maximum, 7day daily average minimum, and WA Ecology State standards.




Middle Fork Snoqualmie near 428th Ave SE (MF_SNOQ_1)
Daily Discharge @ USGS 12141300
Daily Air Temperature @ Snoqualmie
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
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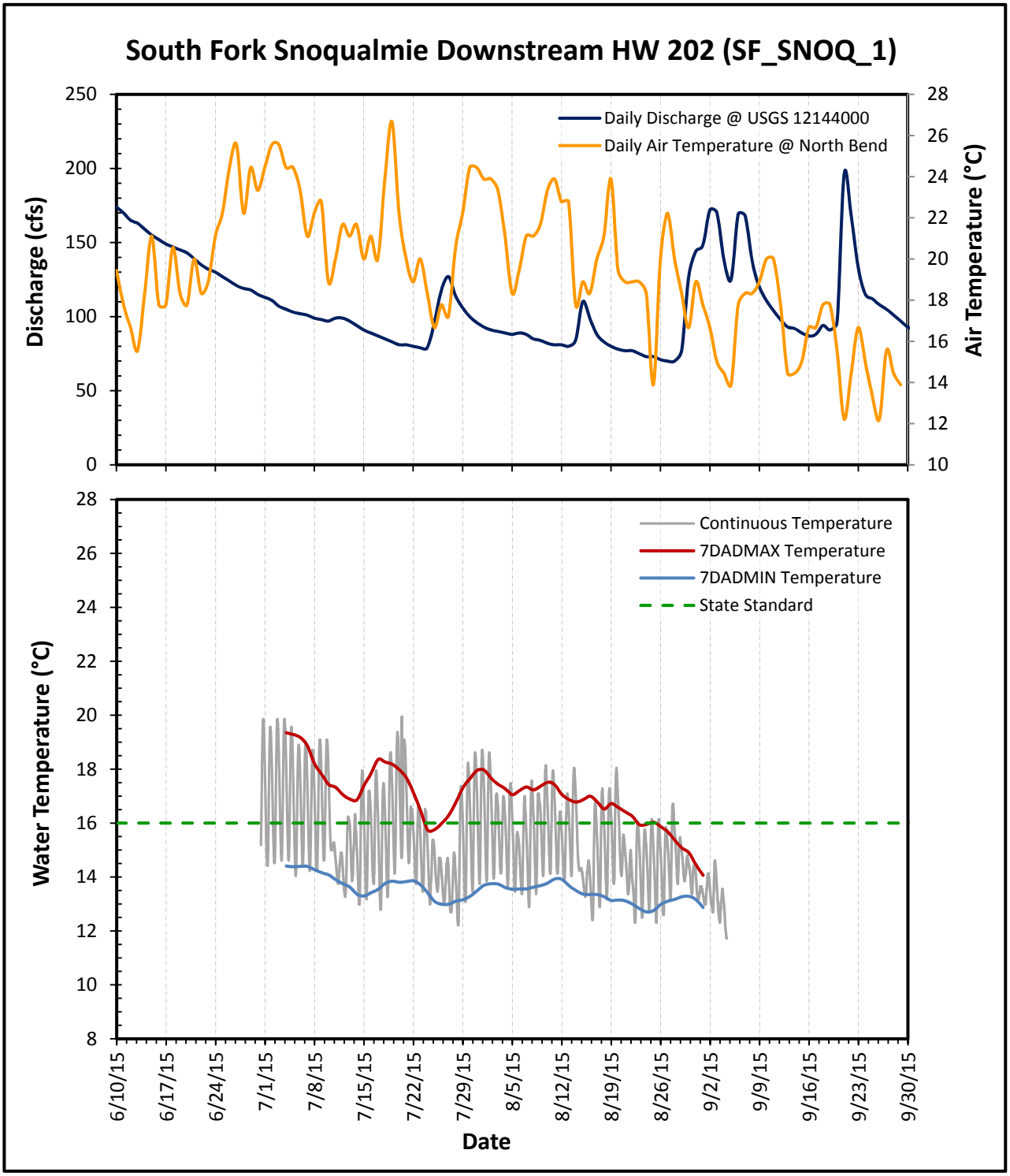
9/23/15
9/30/15


South Fork Snoqualmie Downstream HW 202 (SF_SNOQ_1)
Daily Discharge @ USGS 12144000
Daily Air Temperature @ North Bend
Discharge (cfs)
Air Temperature (°C)
250
200
150
100
50
0
28
26
24
22
20
18
16
14
12
10
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
28
26
24
22
20
18
16
14
12
10
8
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
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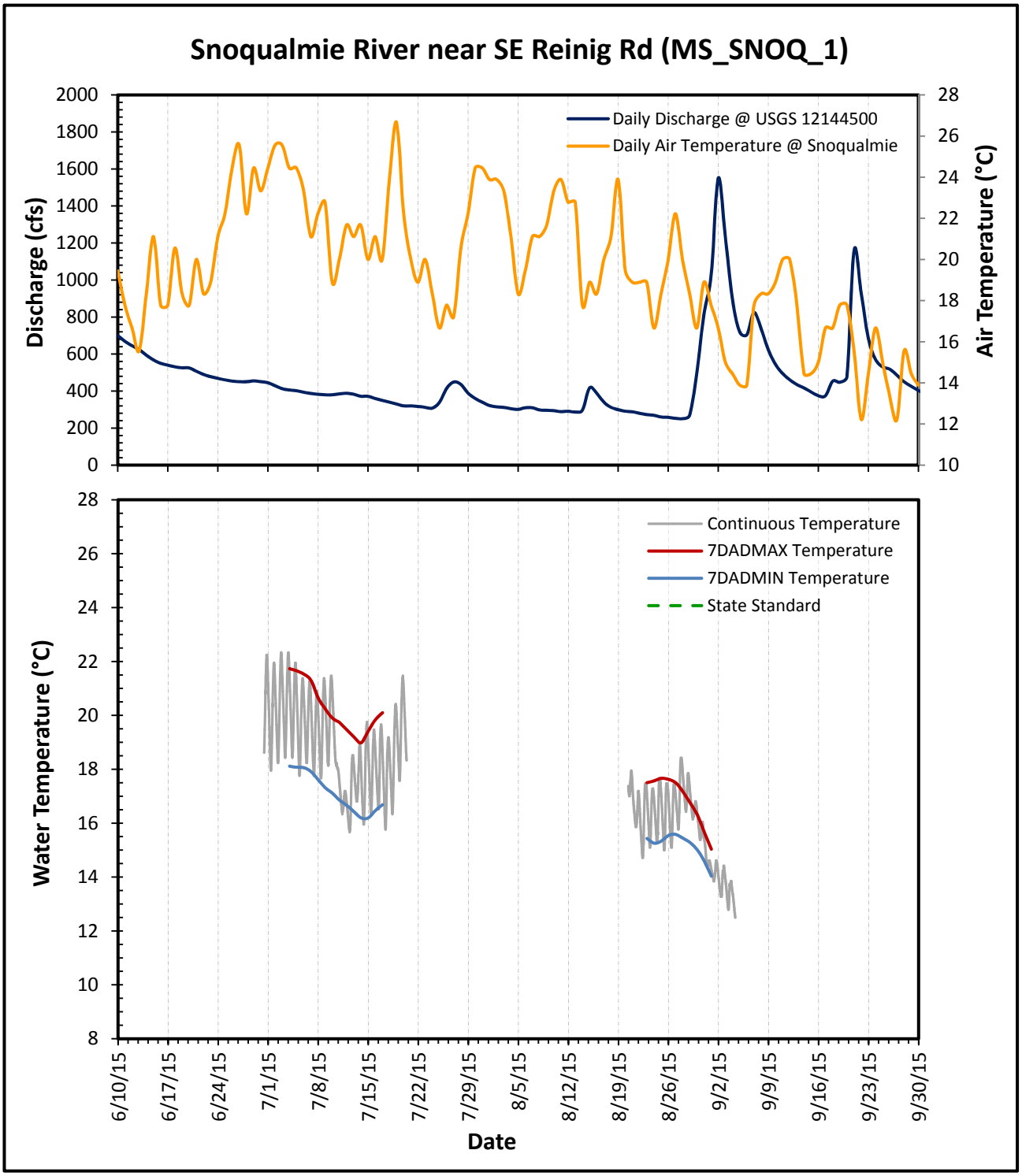
9/2/15
9/9/15
9/16/15
9/23/15
9/30/15
Date


Snoqualmie River near SE Reinig Rd (MS_SNOQ_1)
Daily Discharge @ USGS 12144500
Daily Air Temperature @ Snoqualmie
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
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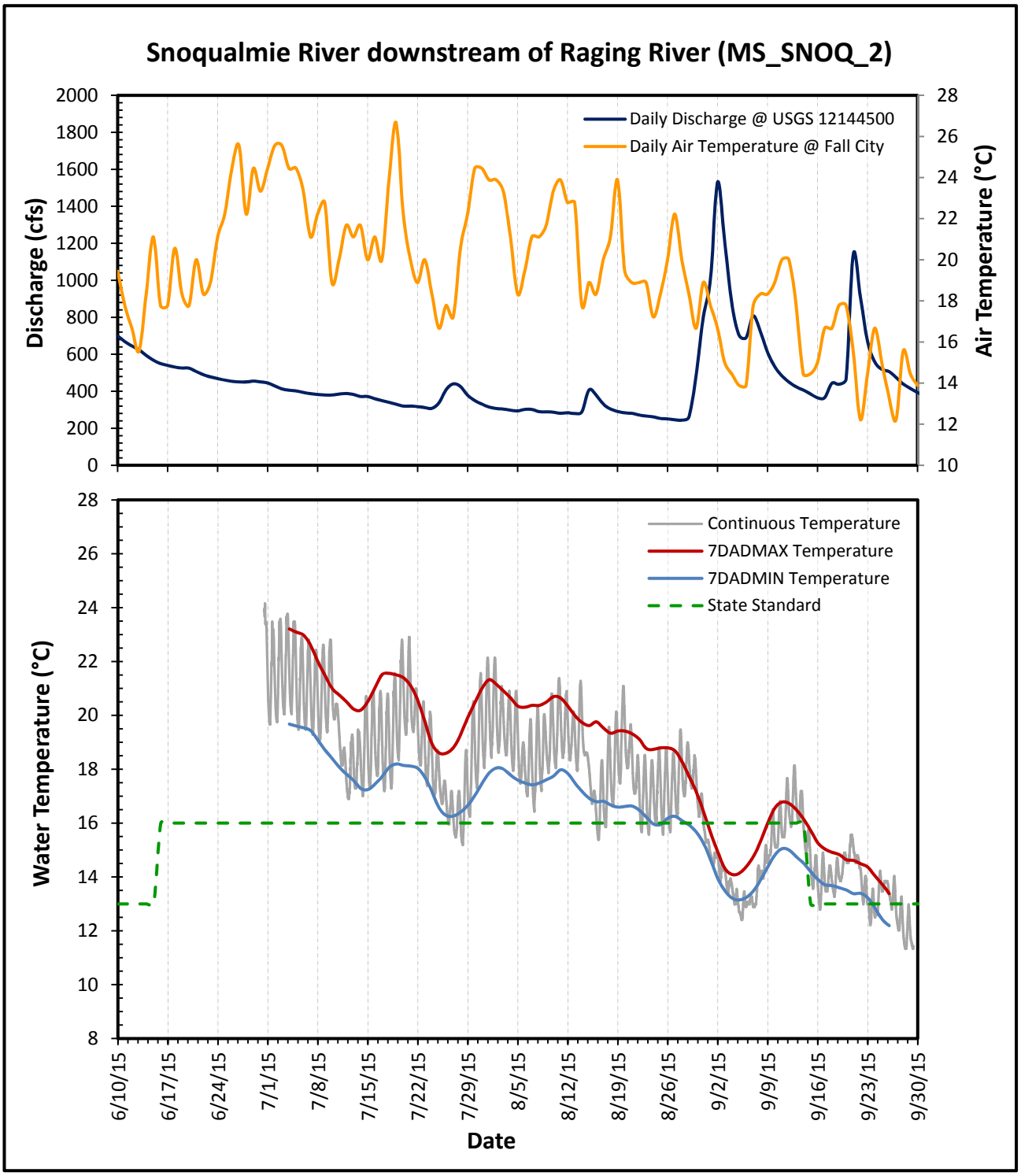
9/23/15
9/30/15


Snoqualmie River downstream of Raging River (MS_SNOQ_2)
Discharge (cfs)
Air Temperature (°C)
Daily Discharge @ USGS 12144500
Daily Air Temperature @ Fall City
Water Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
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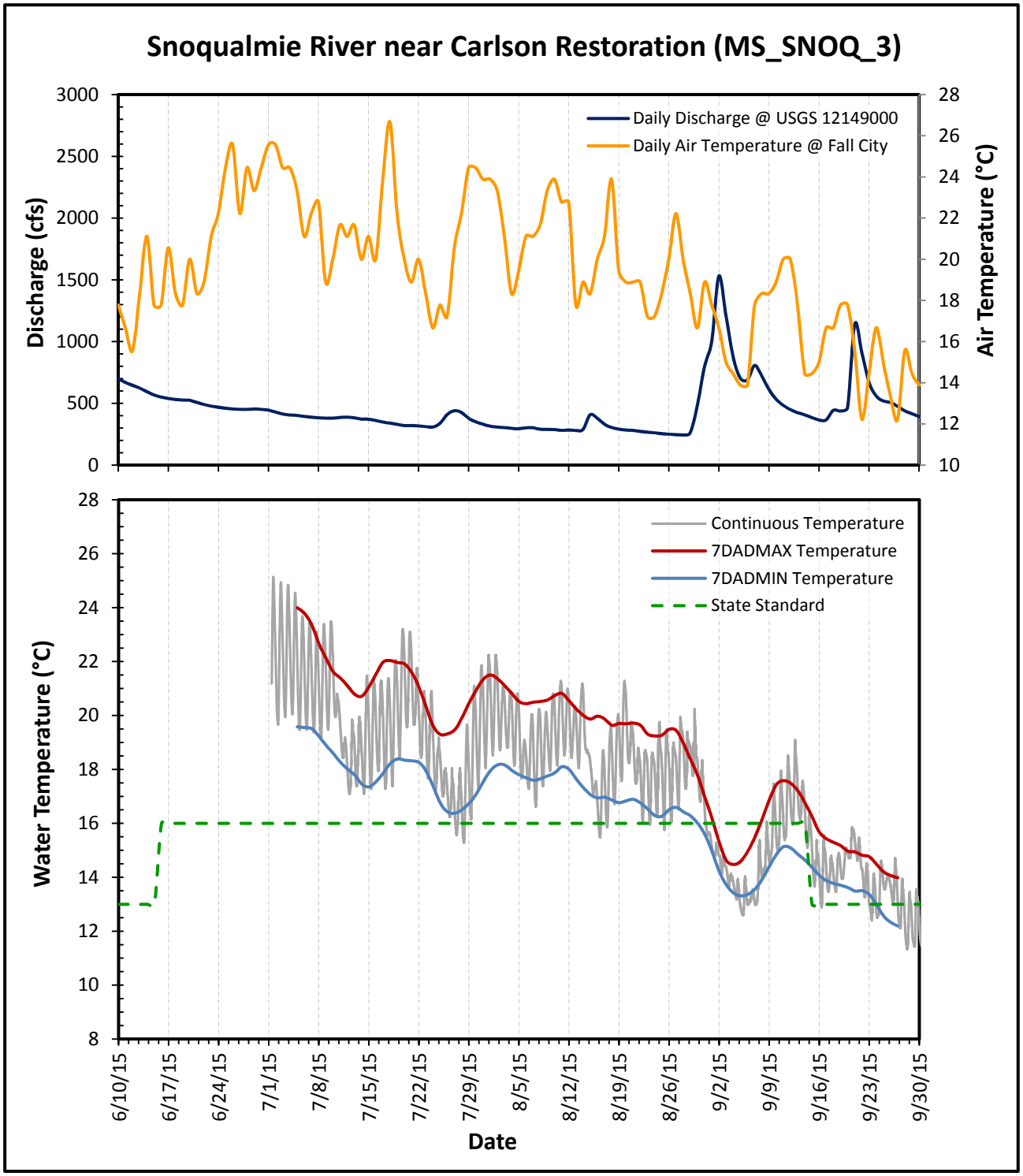
9/23/15
9/30/15


Snoqualmie River near Carlson Restoration (MS_SNOQ_3)
Discharge (cfs)
Air Temperature (°C)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Fall City
Water Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
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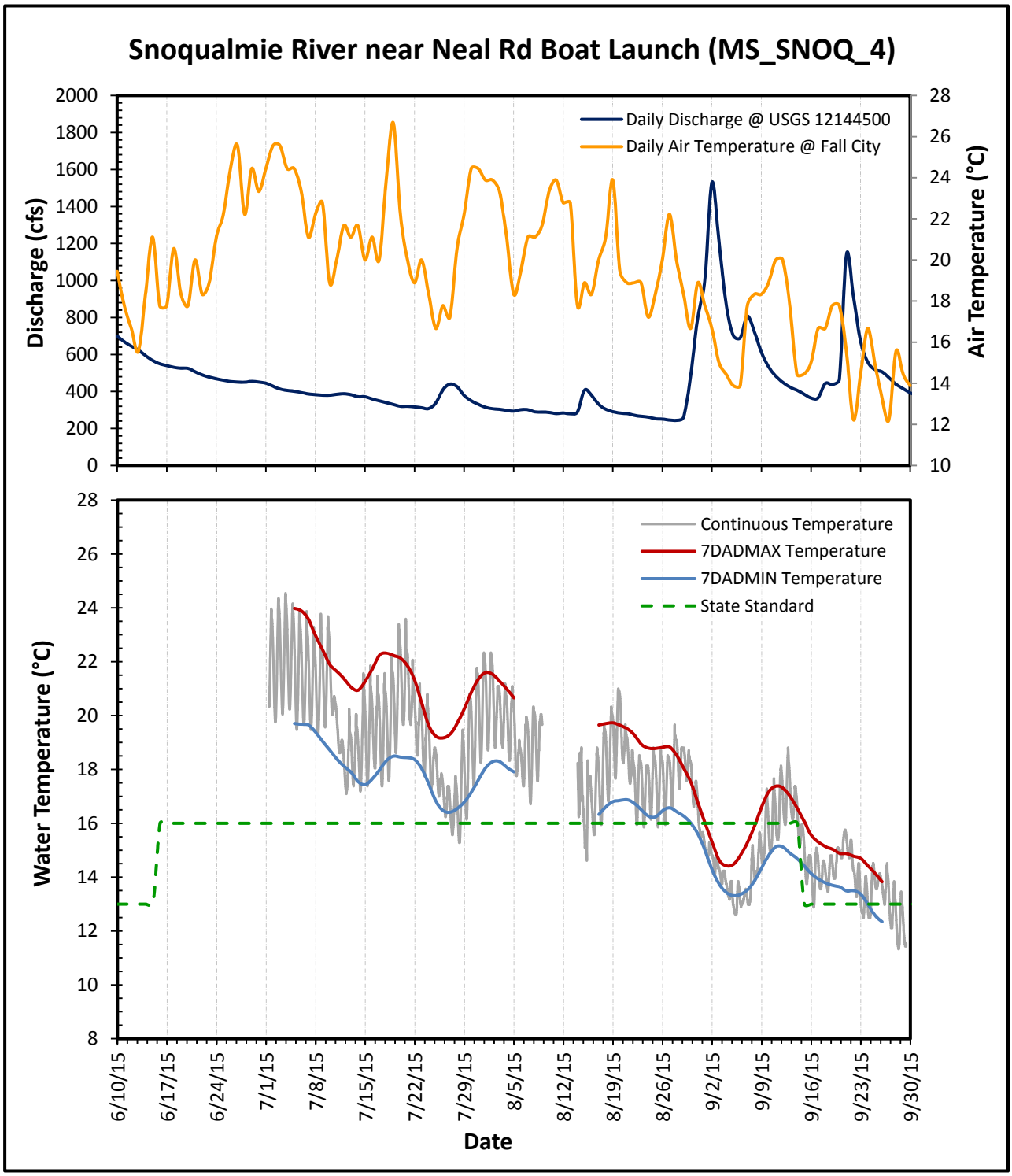
9/23/15
9/30/15


Snoqualmie River near Neal Rd Boat Launch (MS_SNOQ_4)
Daily Discharge @ USGS 12144500
Daily Air Temperature @ Fall City
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
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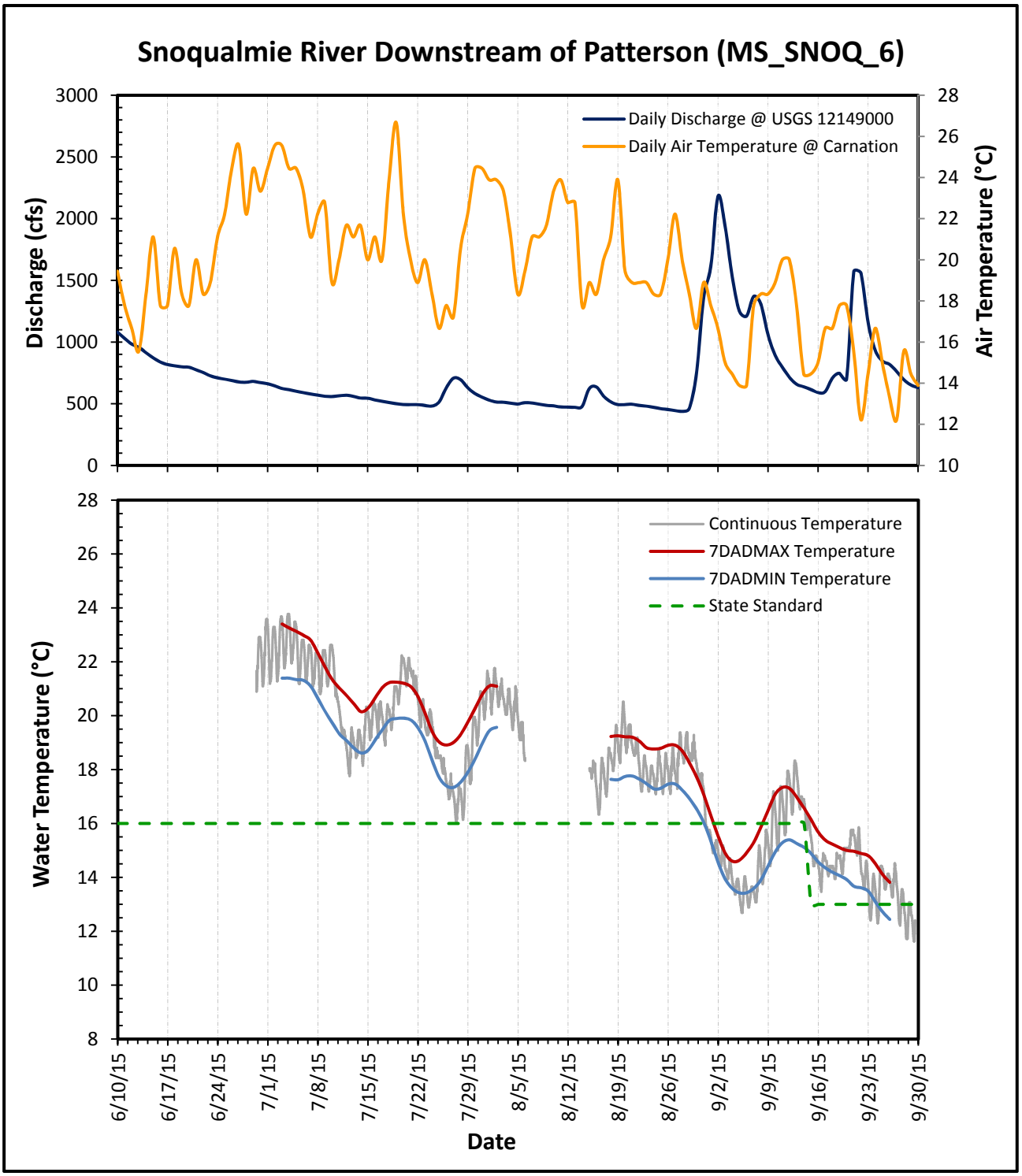
Snoqualmie River Downstream of Patterson (MS_SNOQ_6)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Carnation
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
Date
6/10/15
6/17/15
6/24/15
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7/22/15
7/29/15
8/5/15
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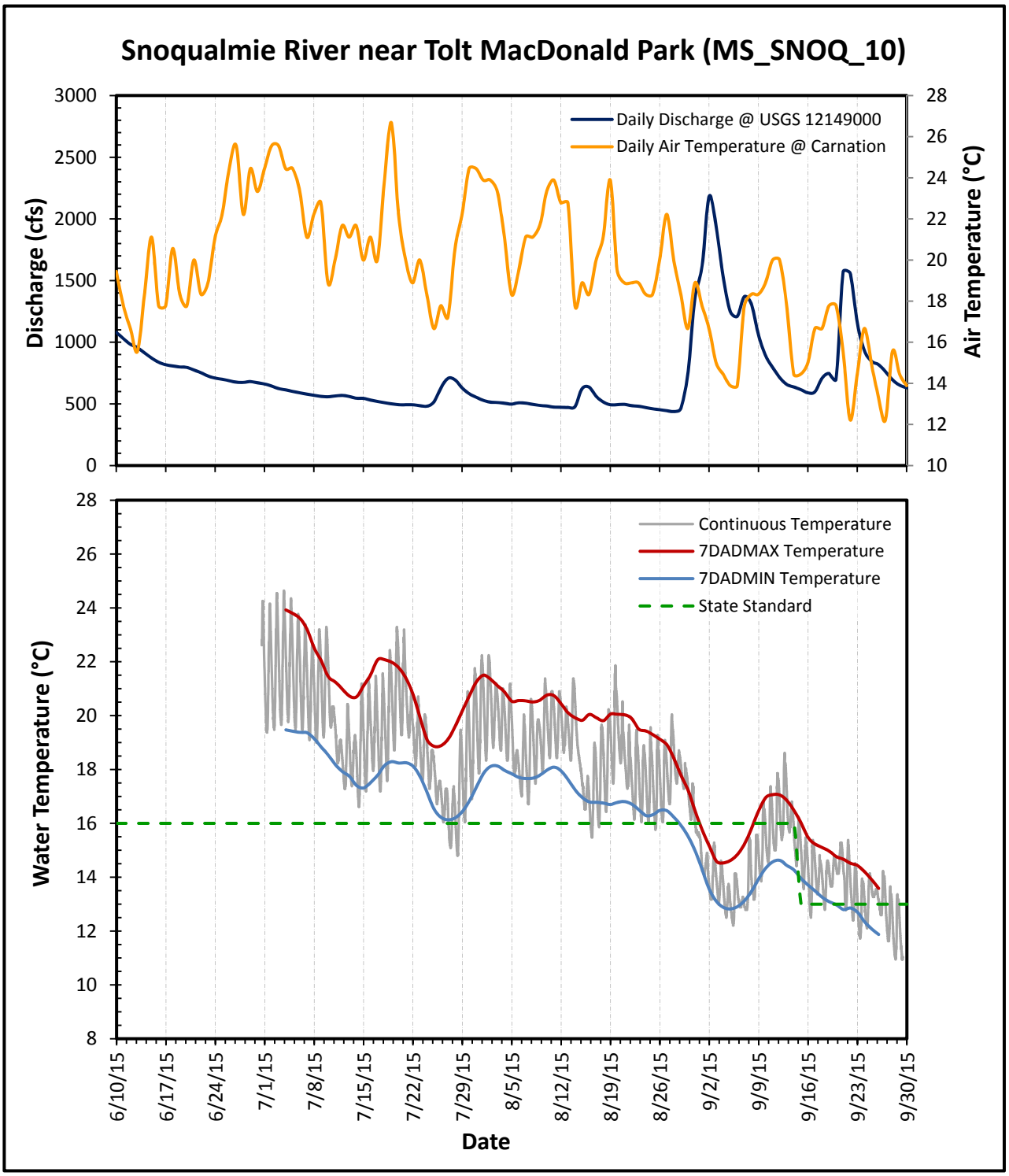
9/30/15


Snoqualmie River near Tolt MacDonald Park (MS_SNOQ_10)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Carnation
Discharge (cfs)
Air Temperature (°C)
3000
2500
2000
1500
1000
500
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28
26
24
22
20
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16
14
12
10
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
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26
24
22
20
18
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8
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
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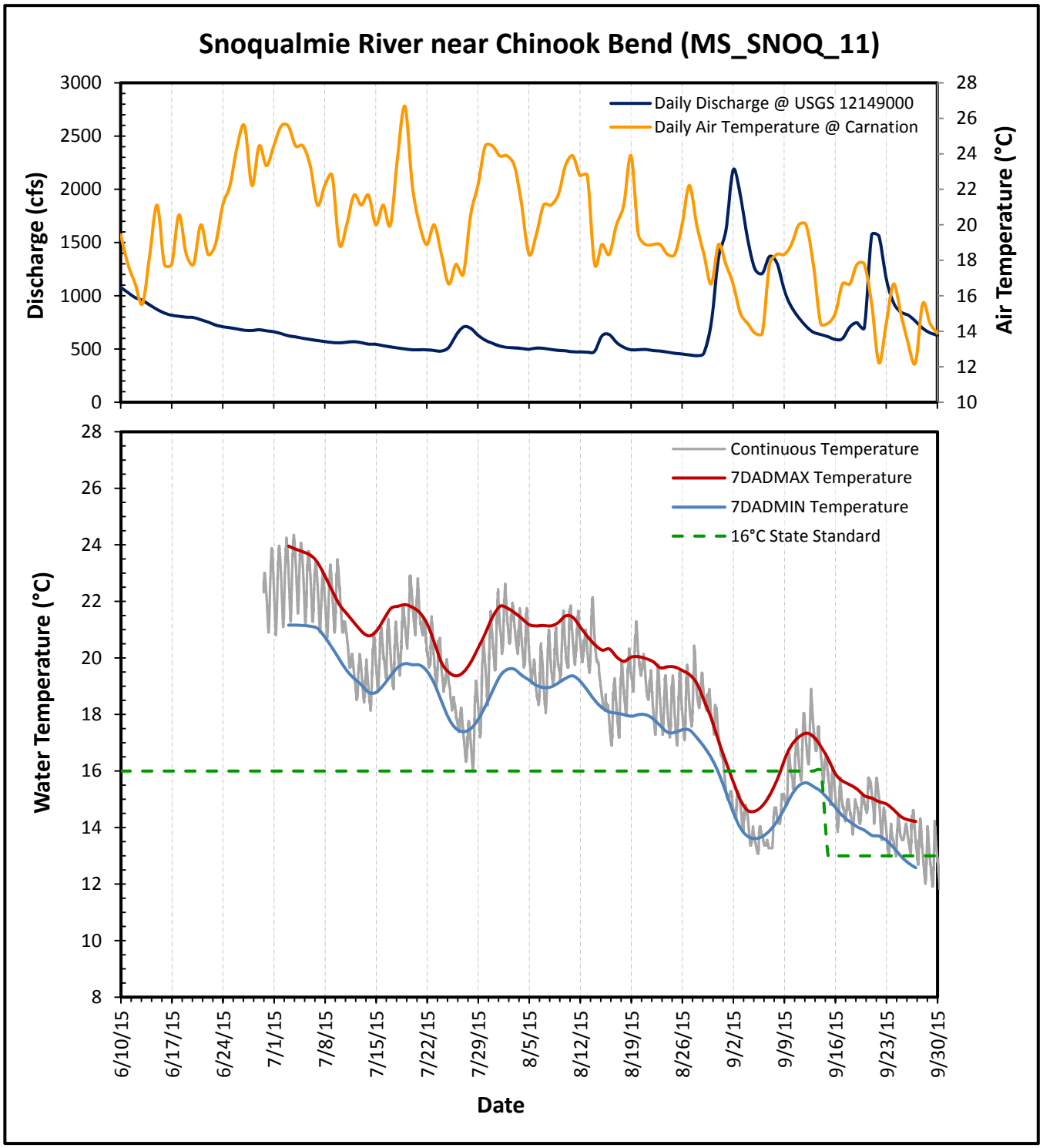
9/30/15
Date


Snoqualmie River near Chinook Bend (MS_SNOQ_11)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Carnation
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
16°C State Standard
Water Temperature (°C)
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
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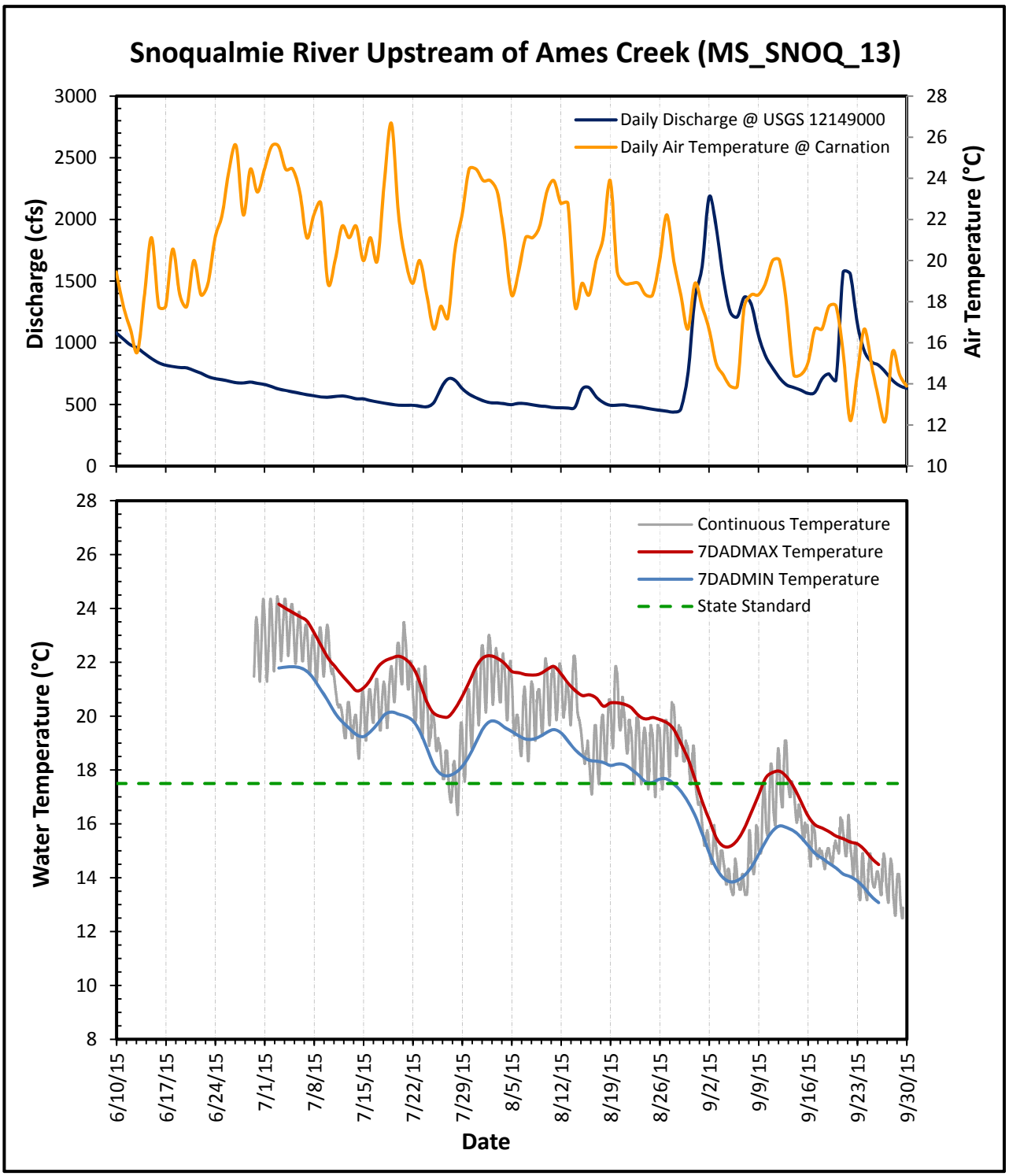
9/30/15


Snoqualmie River Upstream of Ames Creek (MS_SNOQ_13)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Carnation
Discharge (cfs)
Air Temperature (°C)
3000
2500
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1000
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Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
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6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
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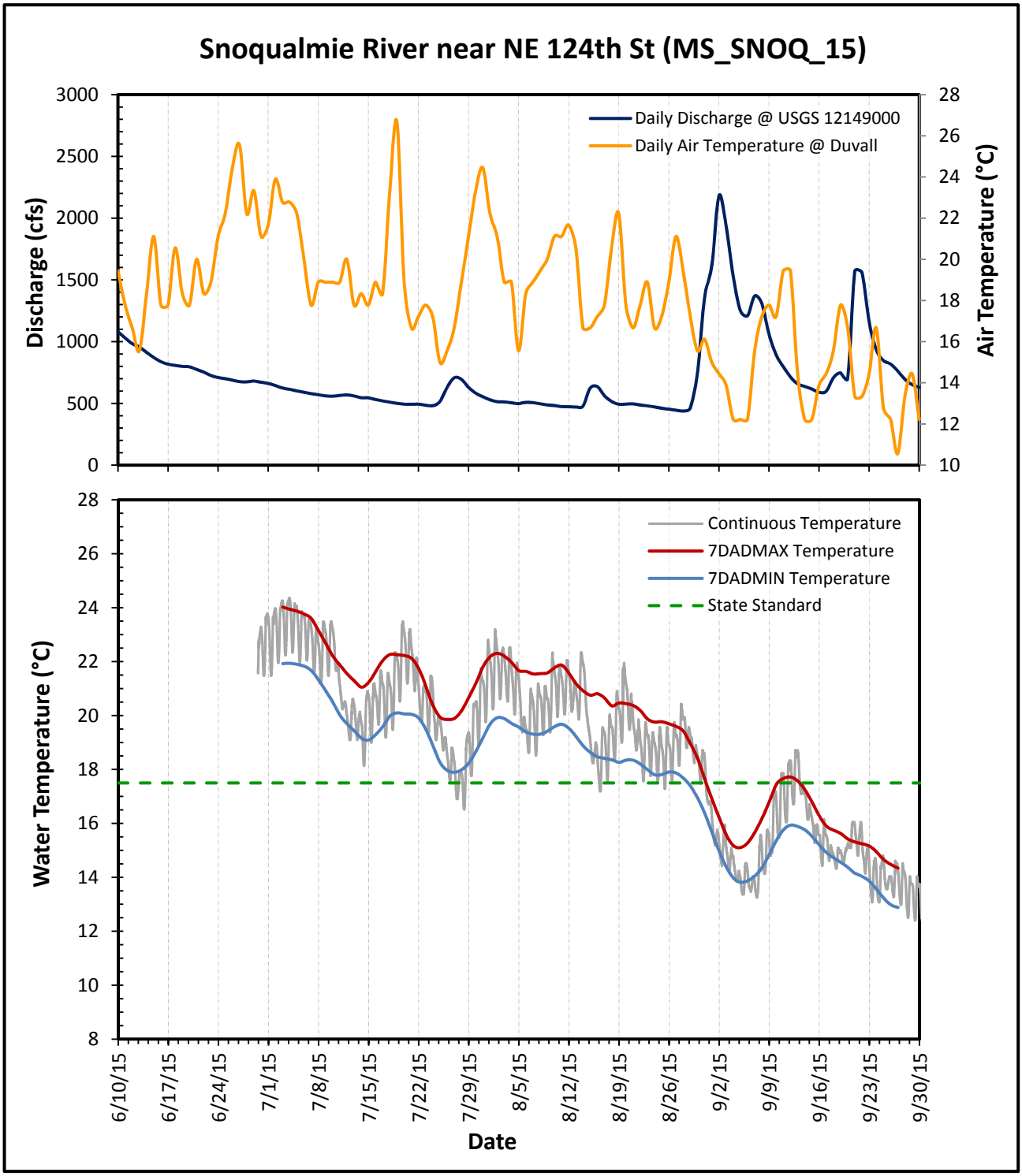
9/30/15
Date


Snoqualmie River near NE 124th St (MS_SNOQ_15)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Duvall
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
Date
6/10/15
6/17/15
6/24/15
7/1/15
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7/29/15
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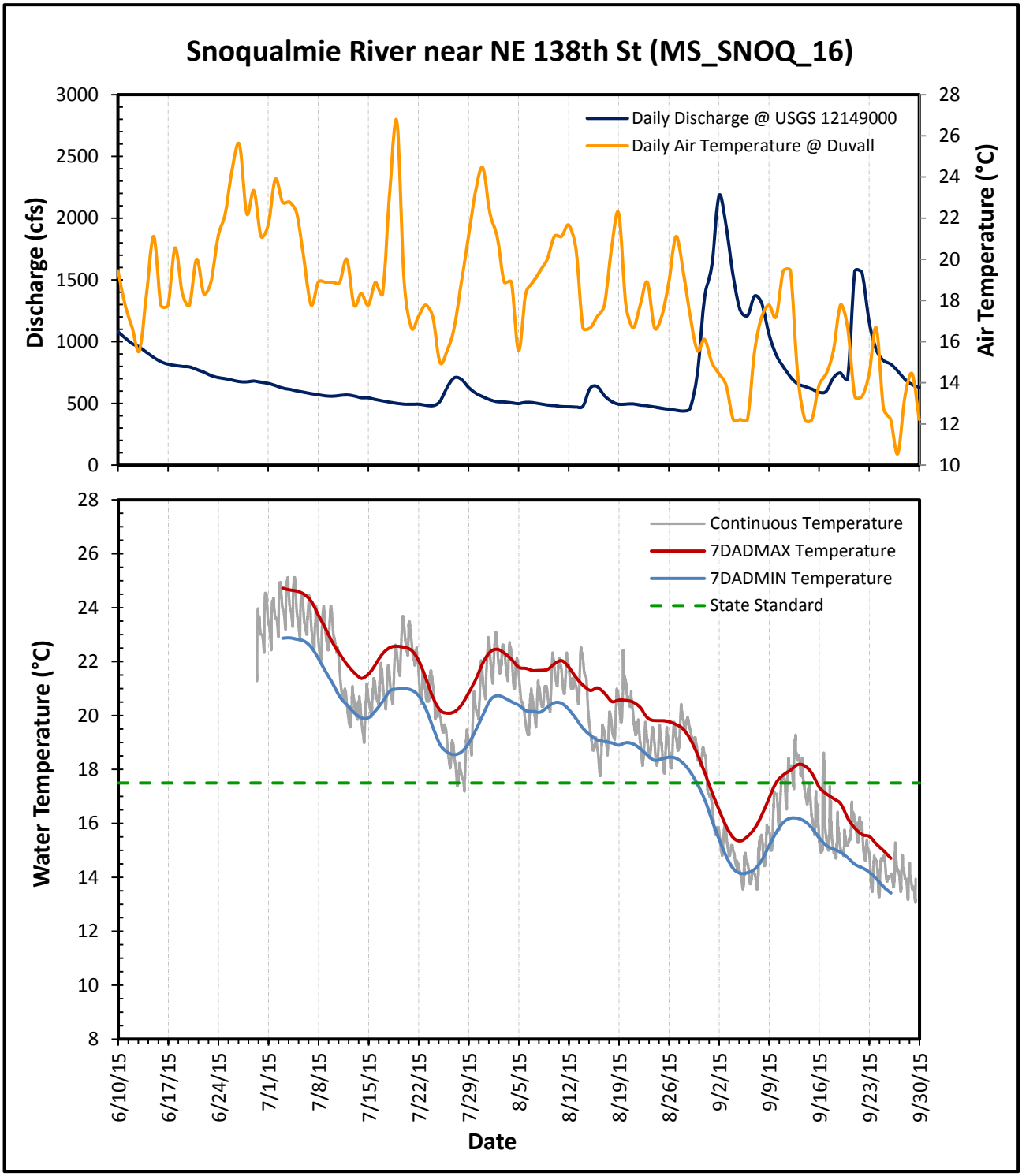
Snoqualmie River near NE 138th St (MS_SNOQ_16)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Duvall
Discharge (cfs)
Air Temperature (°C)
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20
18
16
14
12
10
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
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24
22
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18
16
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8
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
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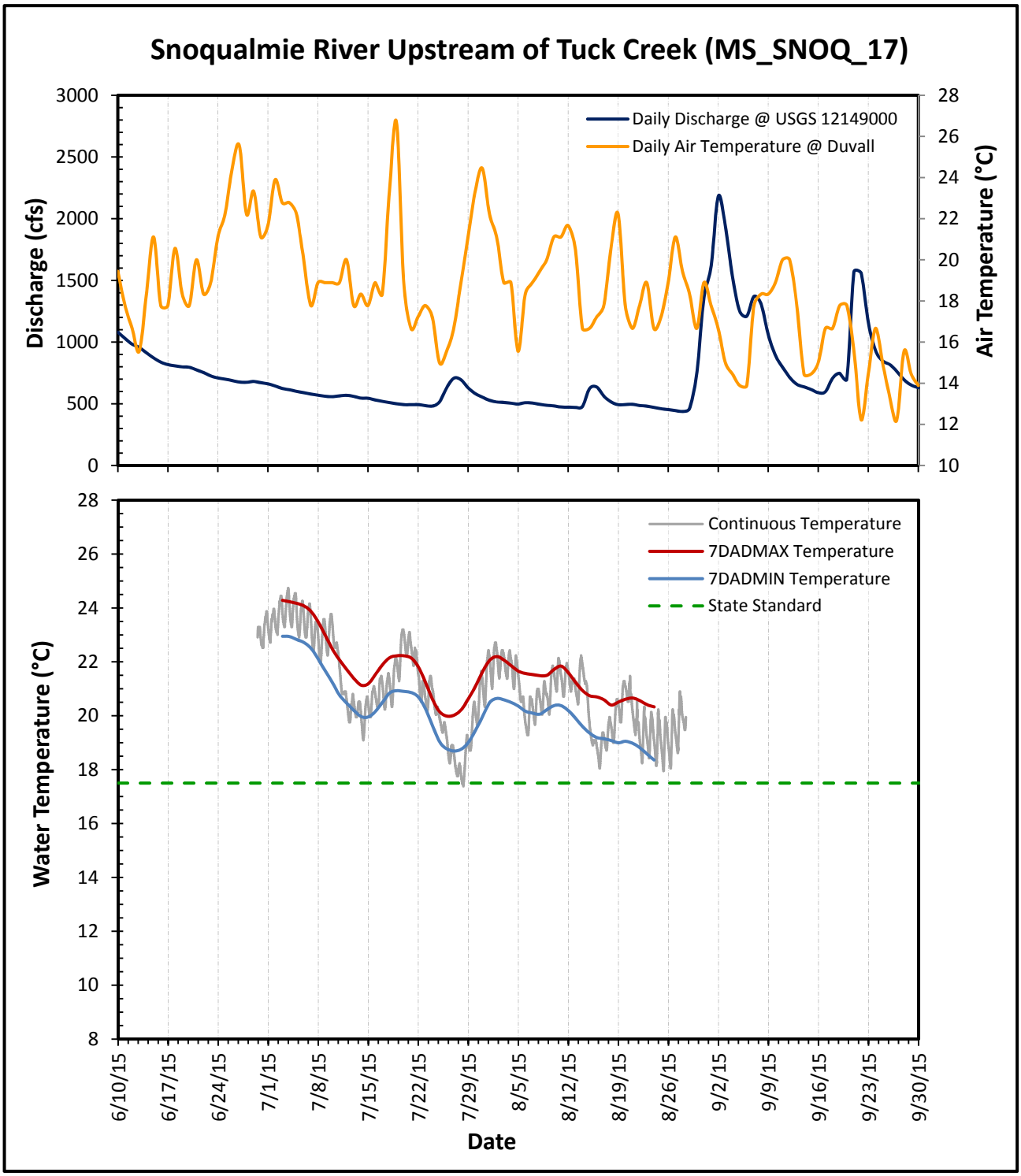
9/30/15
Date


Snoqualmie River Upstream of Tuck Creek (MS_SNOQ_17)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Duvall
Discharge (cfs)
Air Temperature (°C)
3000
2500
2000
1500
1000
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26
24
22
20
18
16
14
12
10
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
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26
24
22
20
18
16
14
12
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8
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
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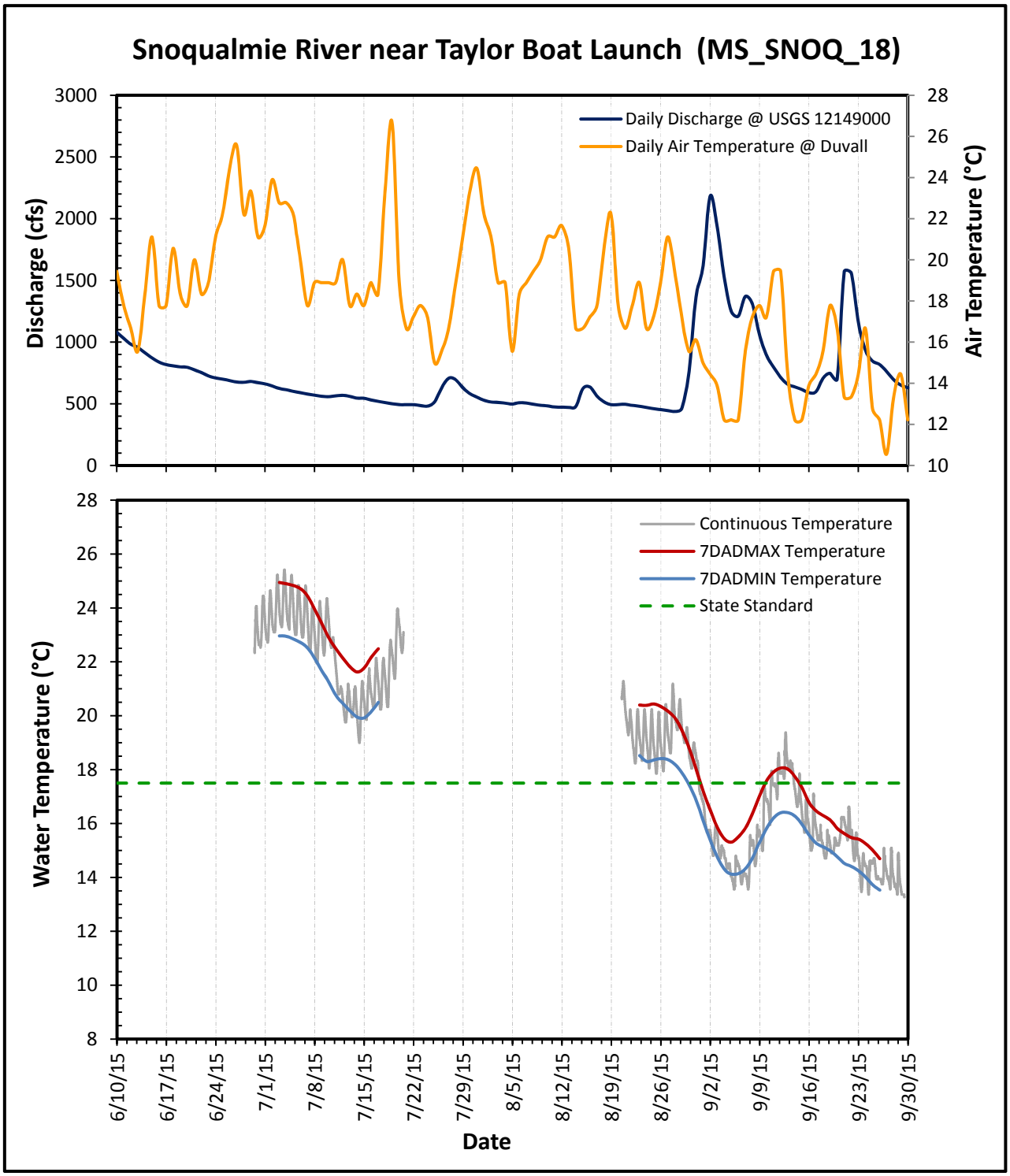
Date


Snoqualmie River near Taylor Boat Launch (MS_SNOQ_18)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Duvall
Discharge (cfs)
Air Temperature (°C)
3000
2500
2000
1500
1000
500
0
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26
24
22
20
18
16
14
12
10
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
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26
24
22
20
18
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6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
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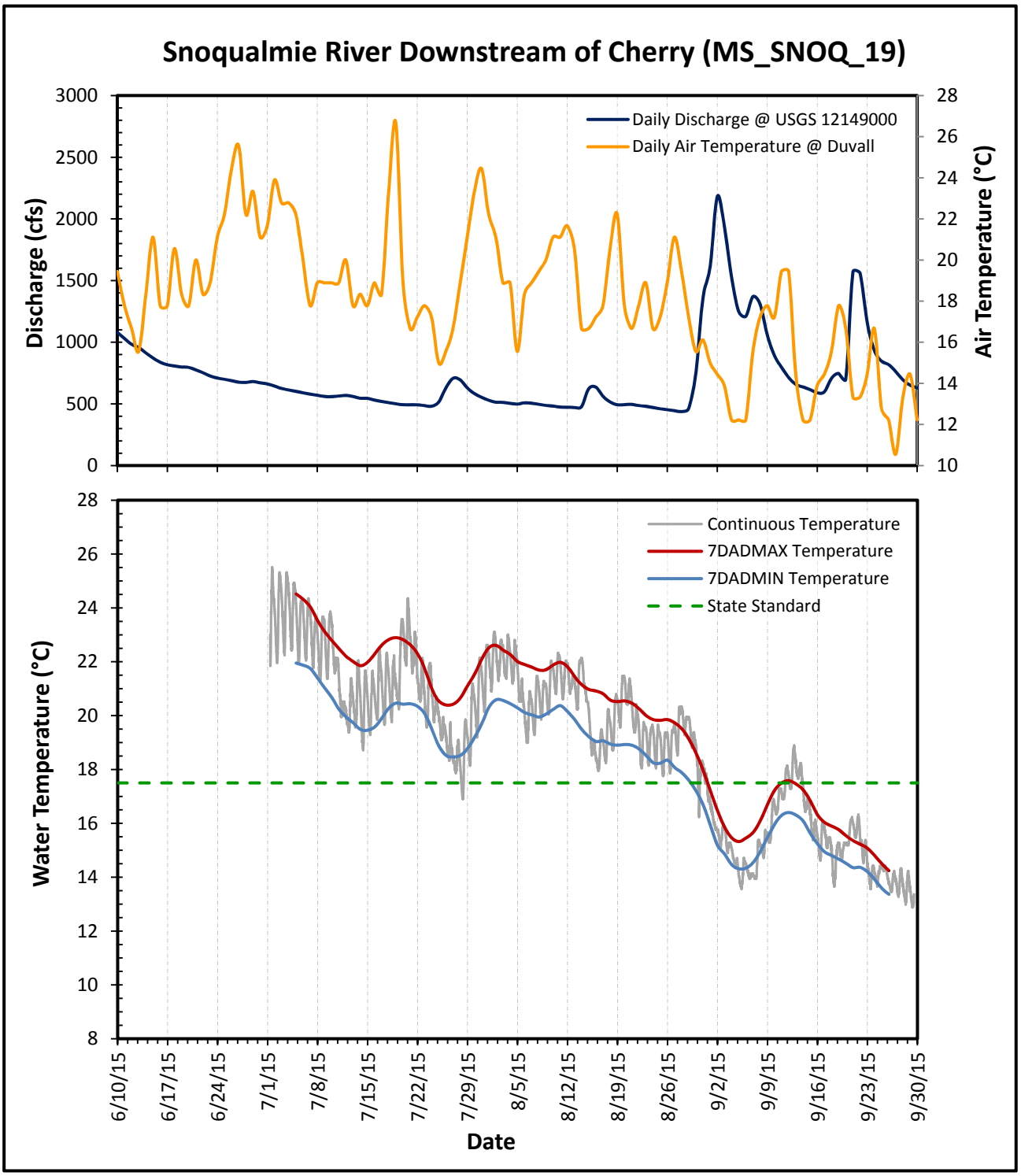
9/30/15
Date


Snoqualmie River Downstream of Cherry (MS_SNOQ_19)
Daily Discharge @ USGS 12149000
Daily Air Temperature @ Duvall
Discharge (cfs)
Air Temperature (°C)
3000
2500
2000
1500
1000
500
0
28
26
24
22
20
18
16
14
12
10
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
28
26
24
22
20
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16
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6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
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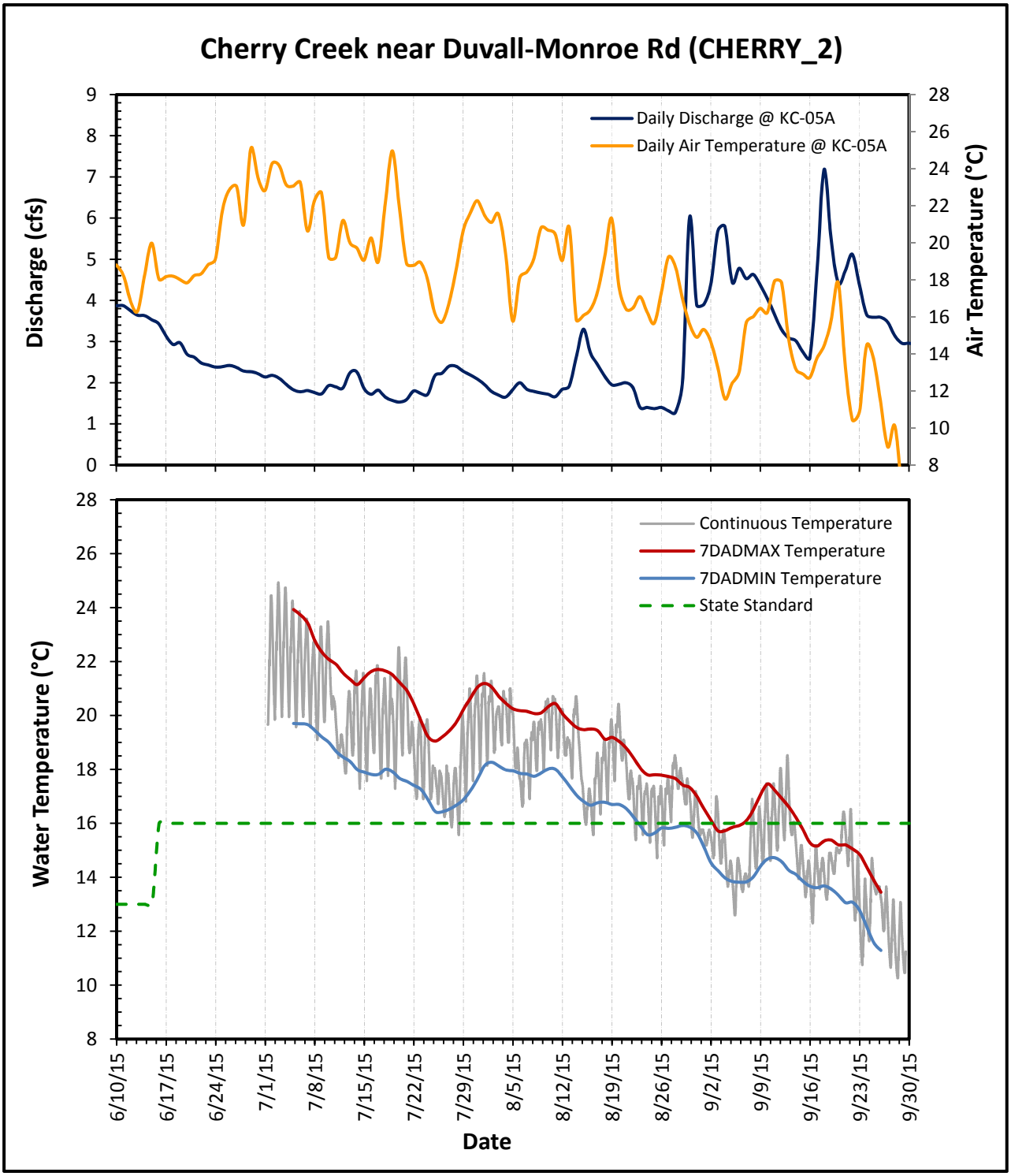
9/30/15
Date


Cherry Creek near Duvall-Monroe Rd (CHERRY_2)
Daily Discharge @ KC-05A
Daily Air Temperature @ KC-05A
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
8/12/15
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9/9/15
9/16/15
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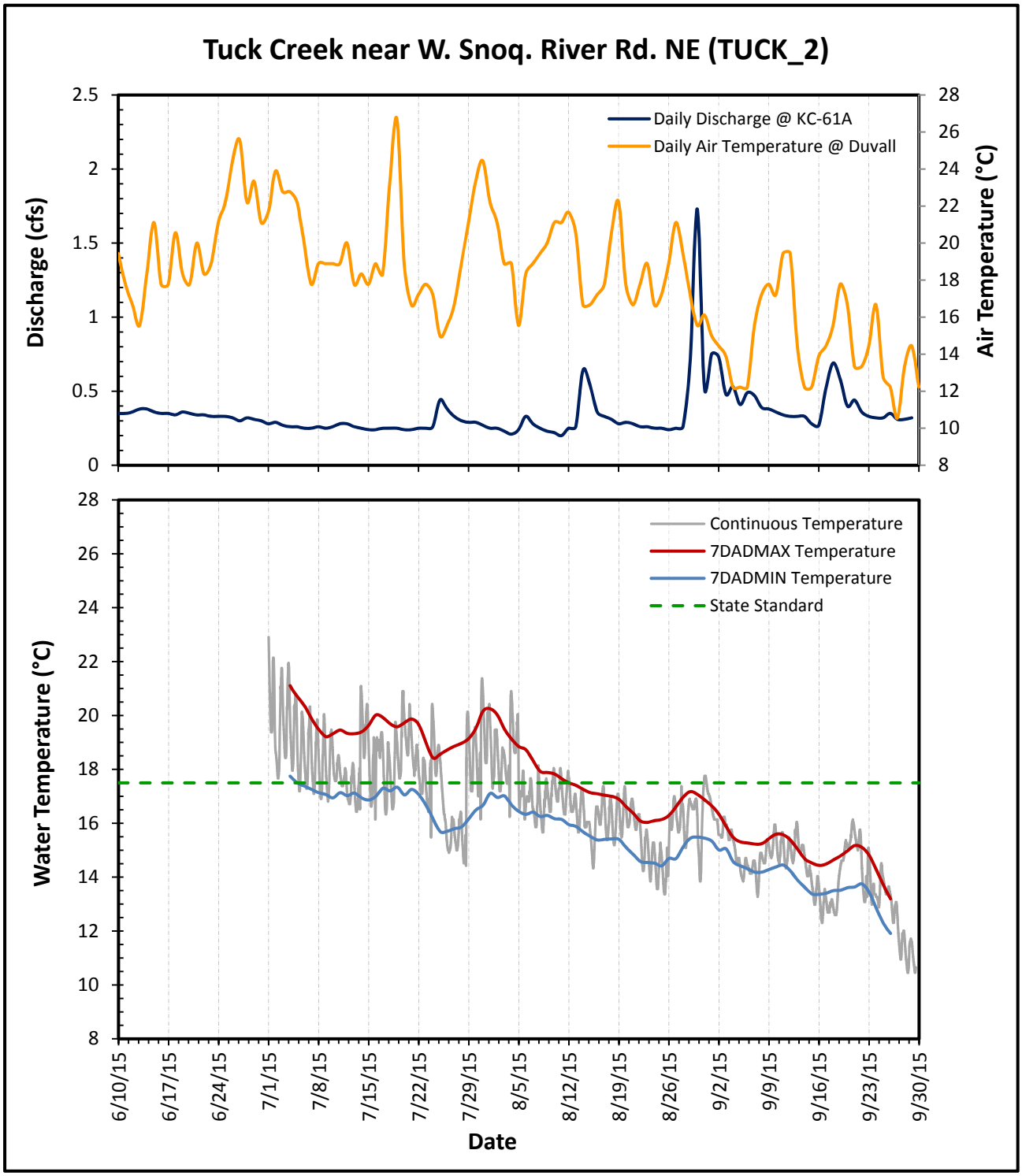
9/30/15
Date


Tuck Creek near W. Snoq. River Rd. NE (TUCK_2)
Daily Discharge @ KC-61A
Daily Air Temperature @ Duvall
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
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7/22/15
7/29/15
8/5/15
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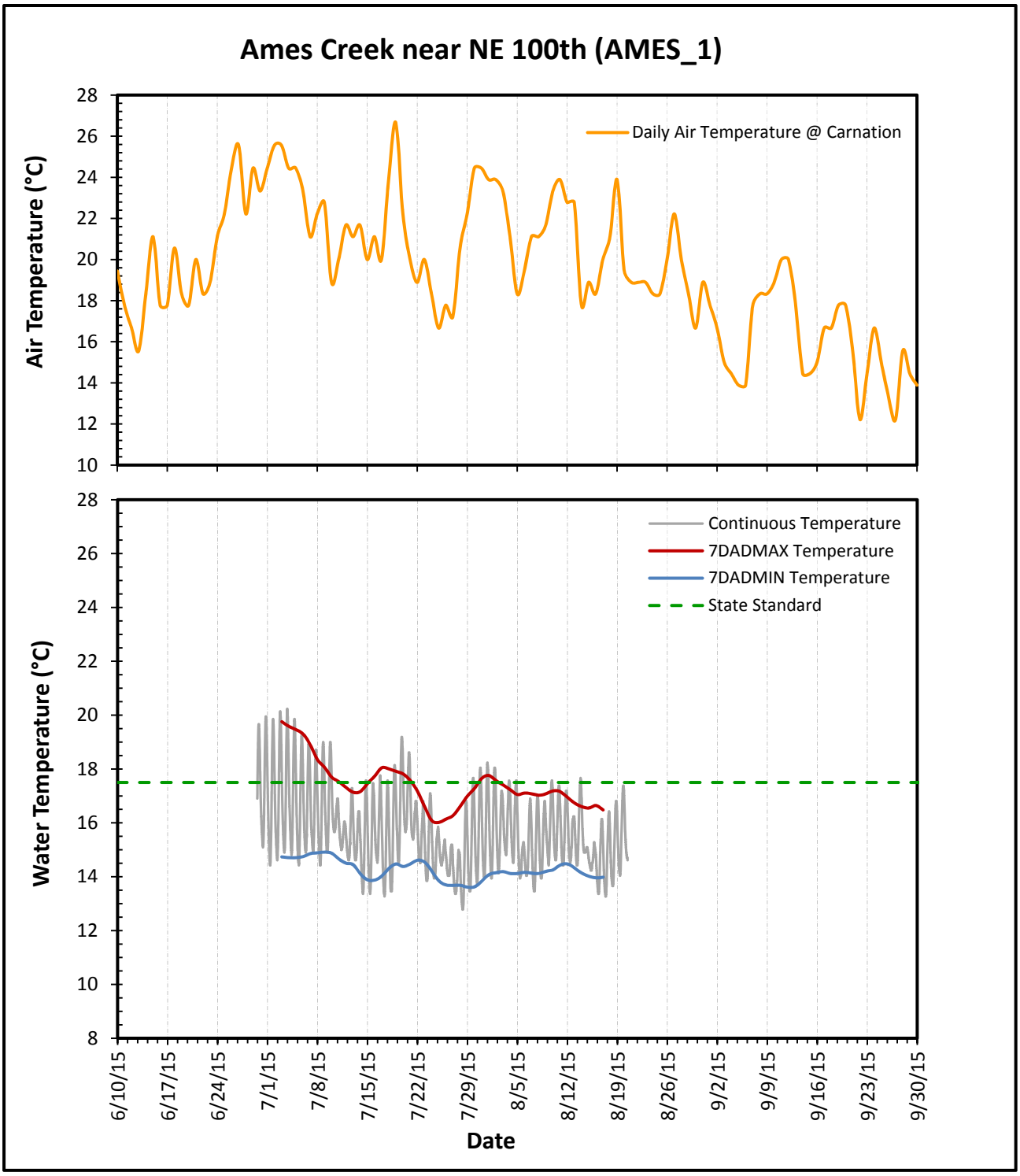
Date


Ames Creek near NE 100th (AMES_1)
Air Temperature (°C)
Daily Air Temperature @ Carnation
Water Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
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7/29/15
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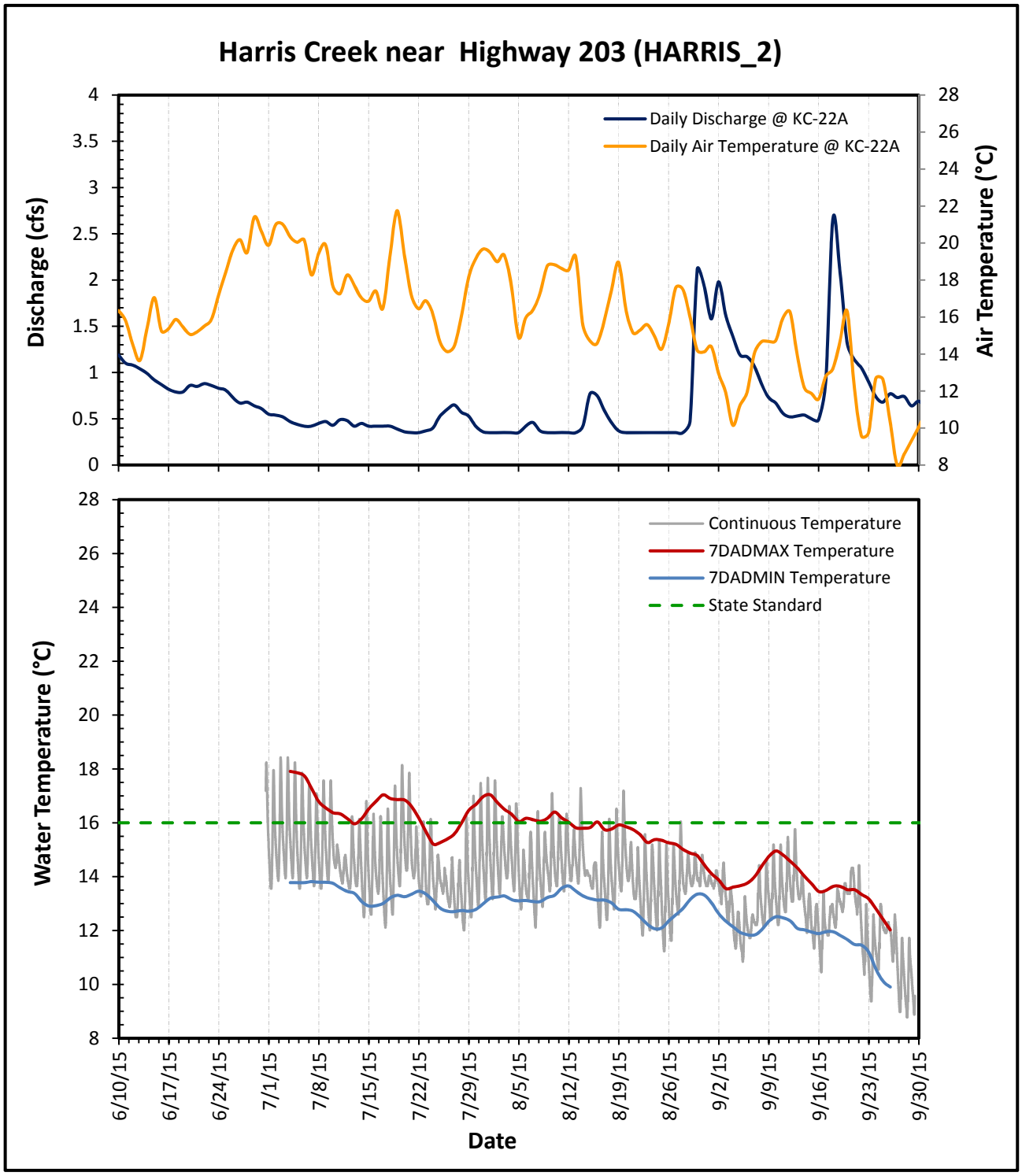
Harris Creek near Highway 203 (HARRIS_2)
Daily Discharge @ KC-22A
Daily Air Temperature @ KC-22A
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
6/10/15
6/17/15
6/24/15
7/1/15
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7/29/15
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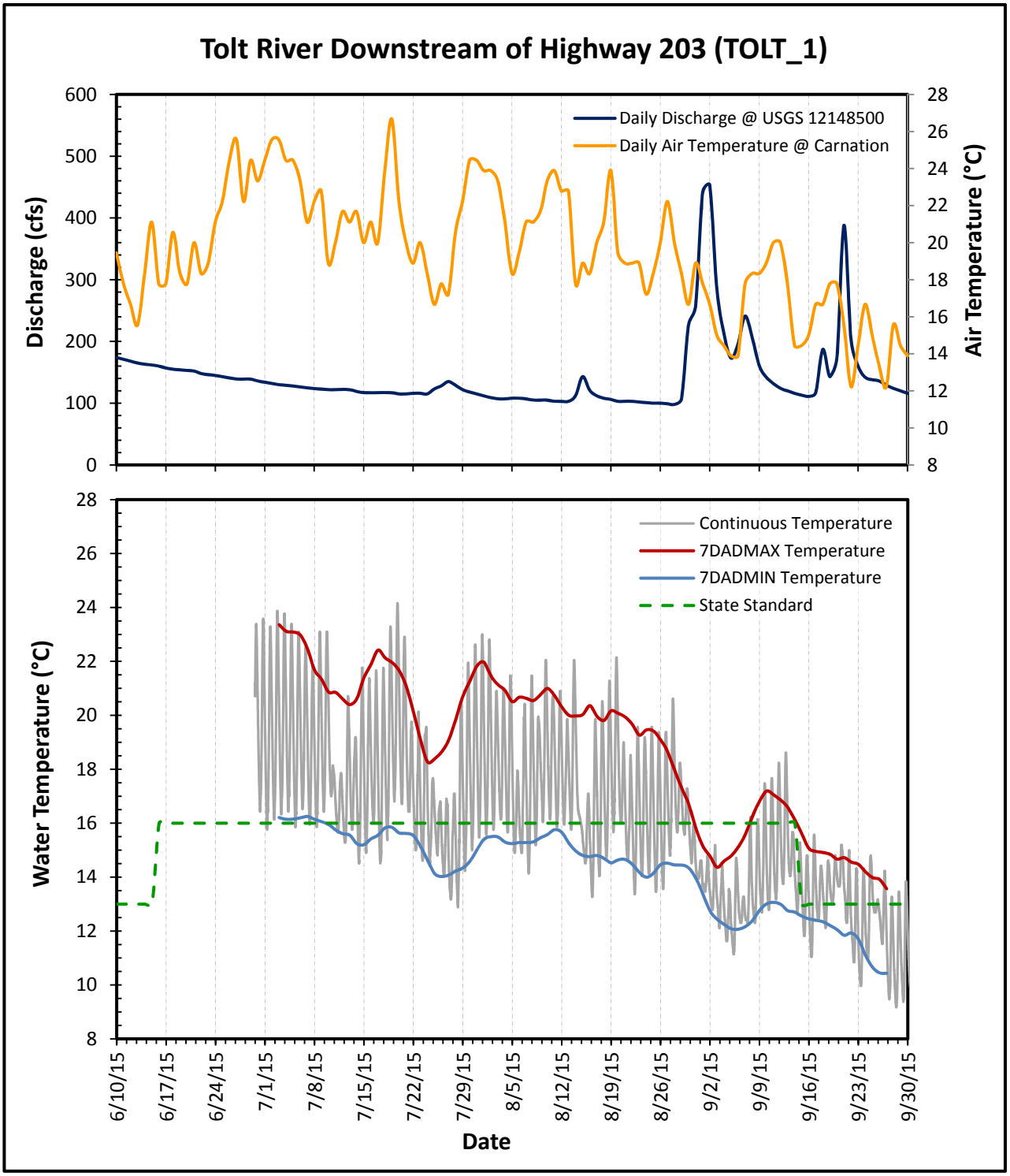
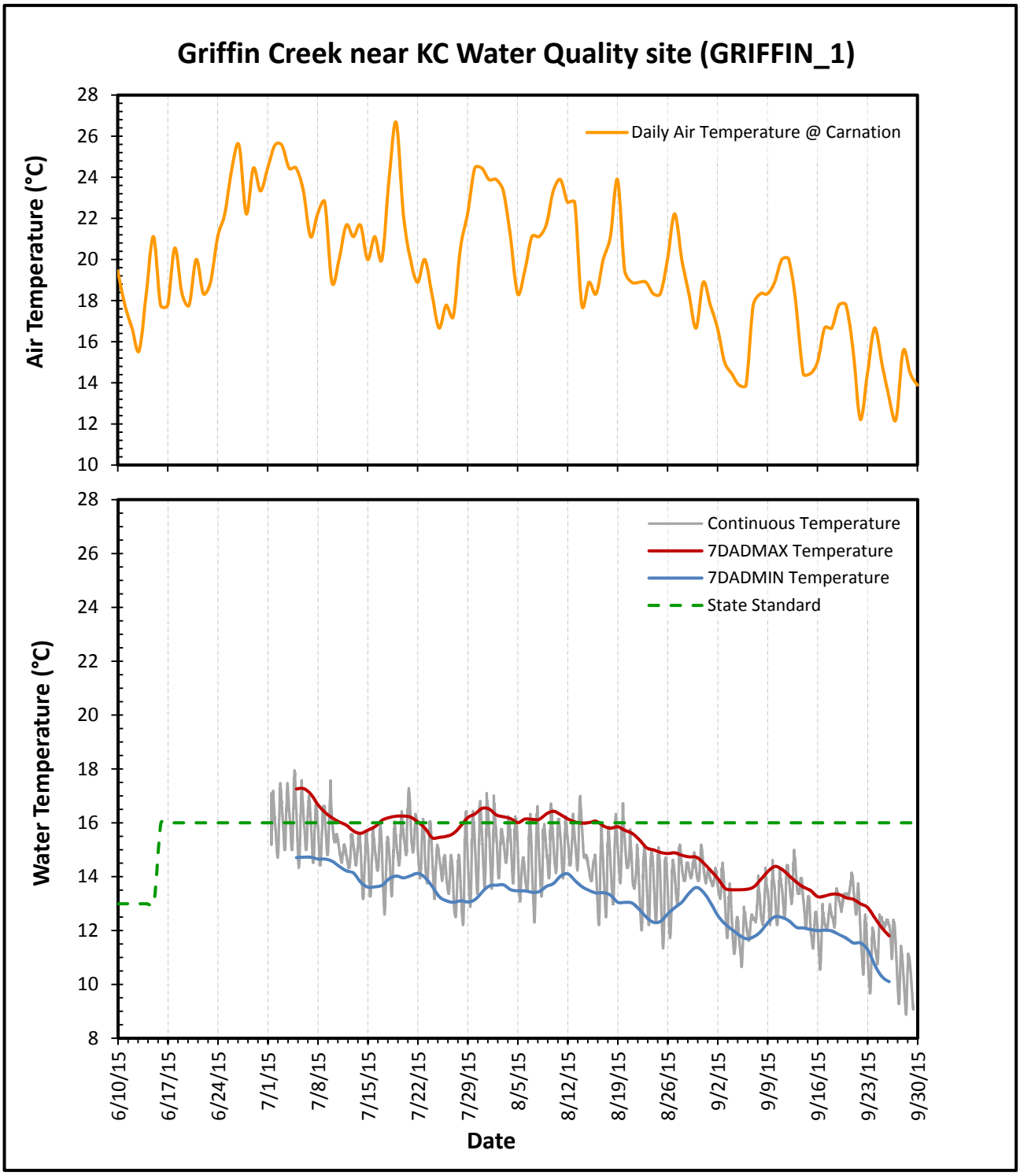
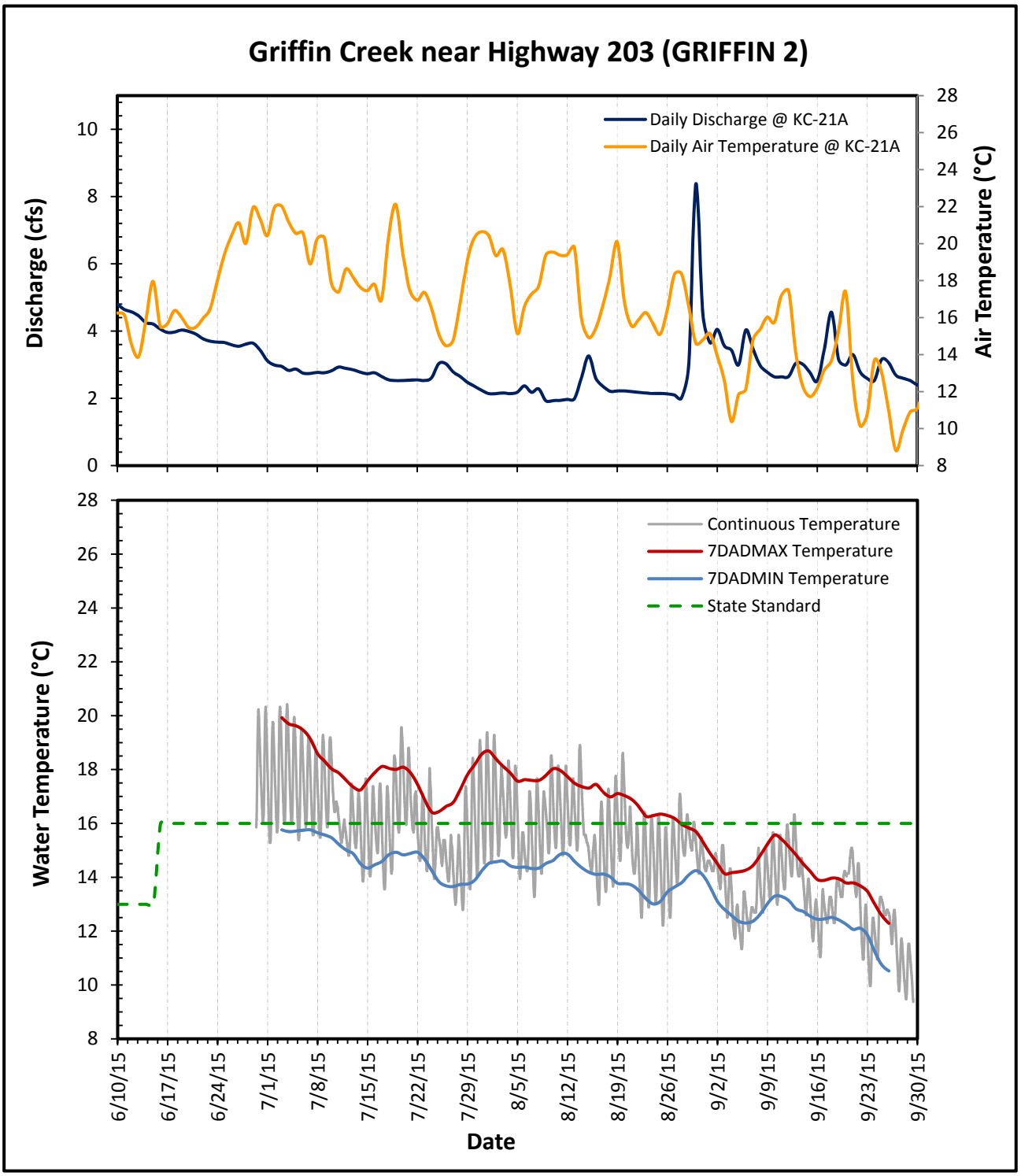
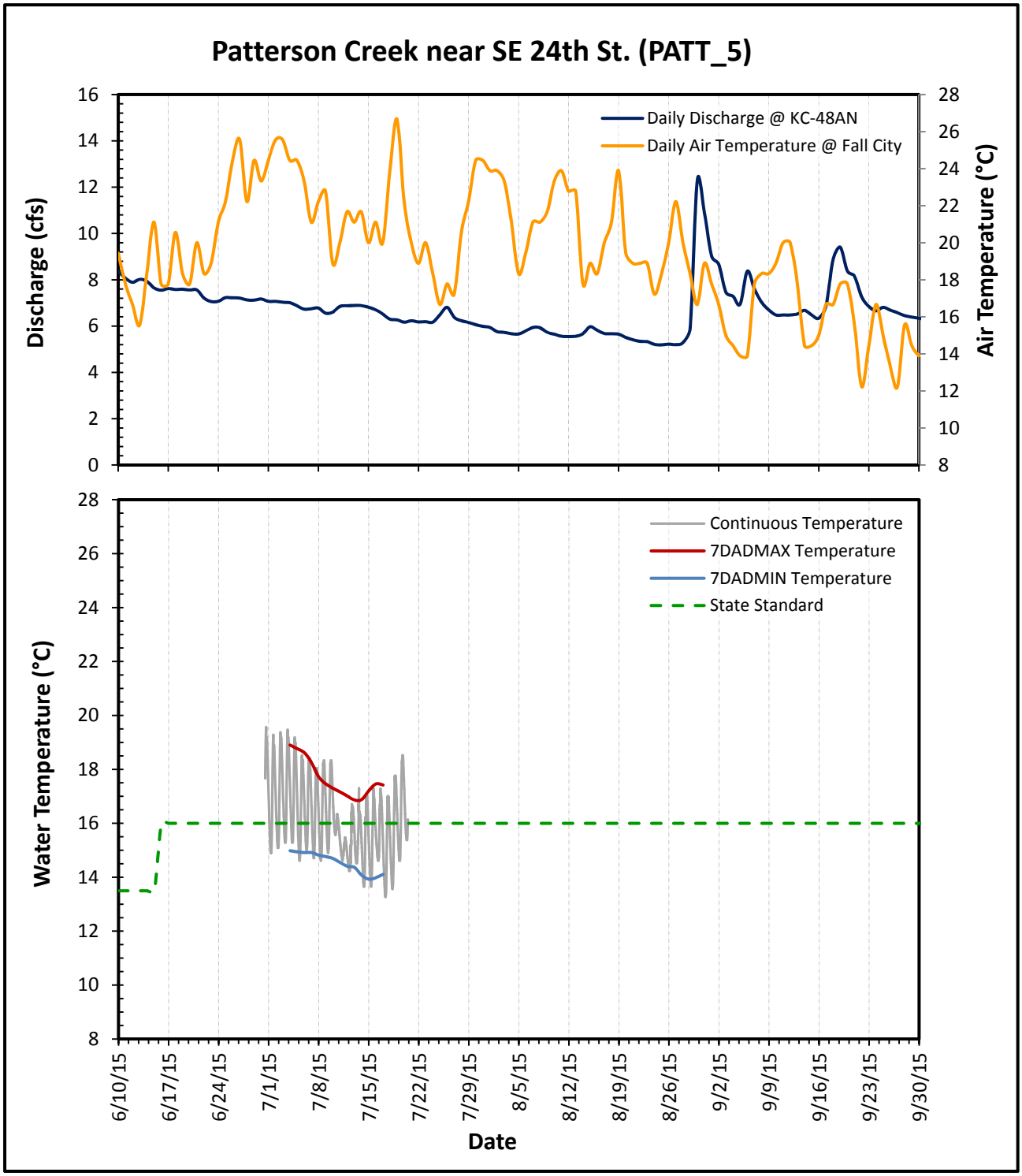
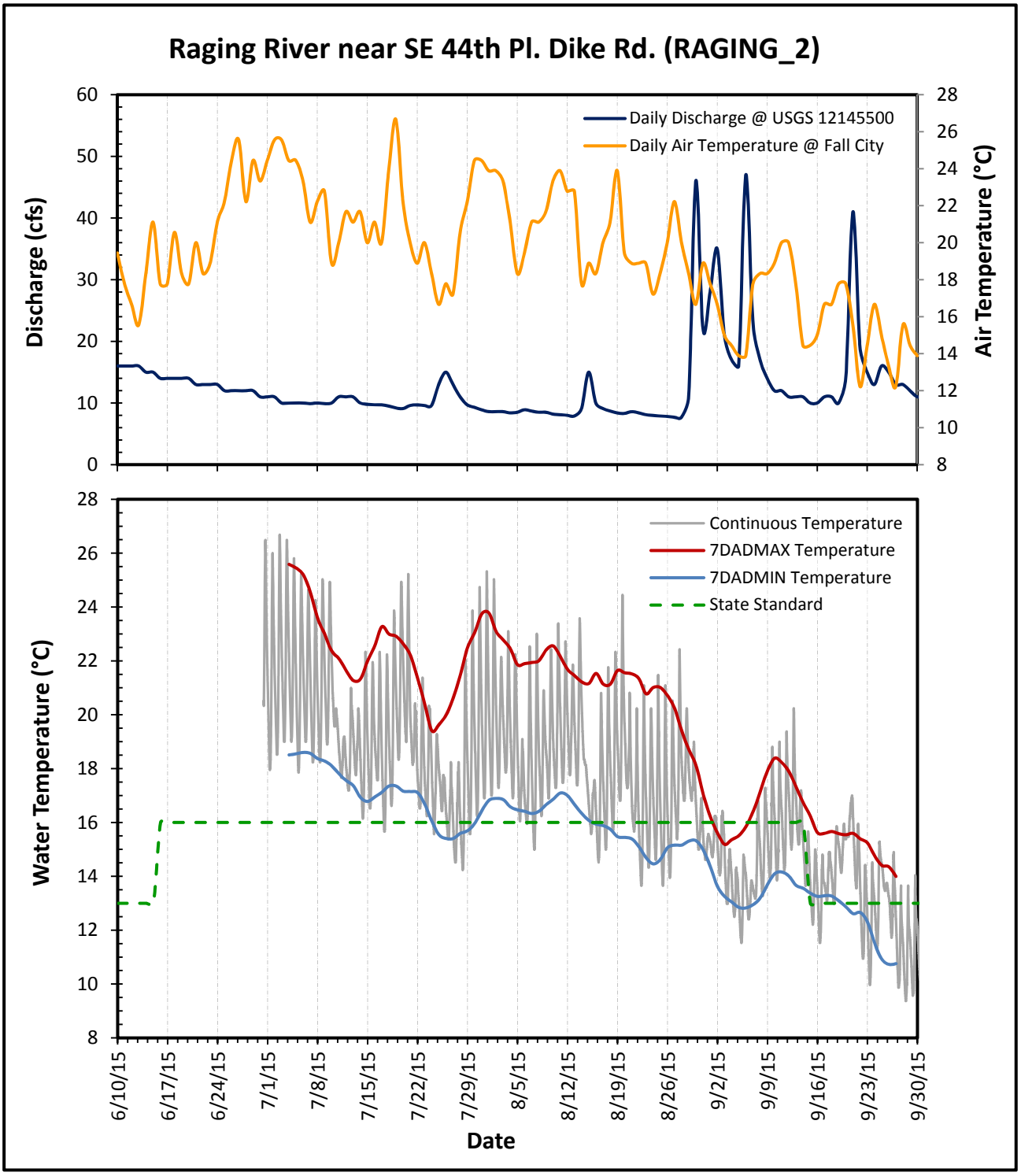
8/19/15
8/26/15
9/2/15
9/9/15
9/16/15
9/23/15
9/30/15
Date

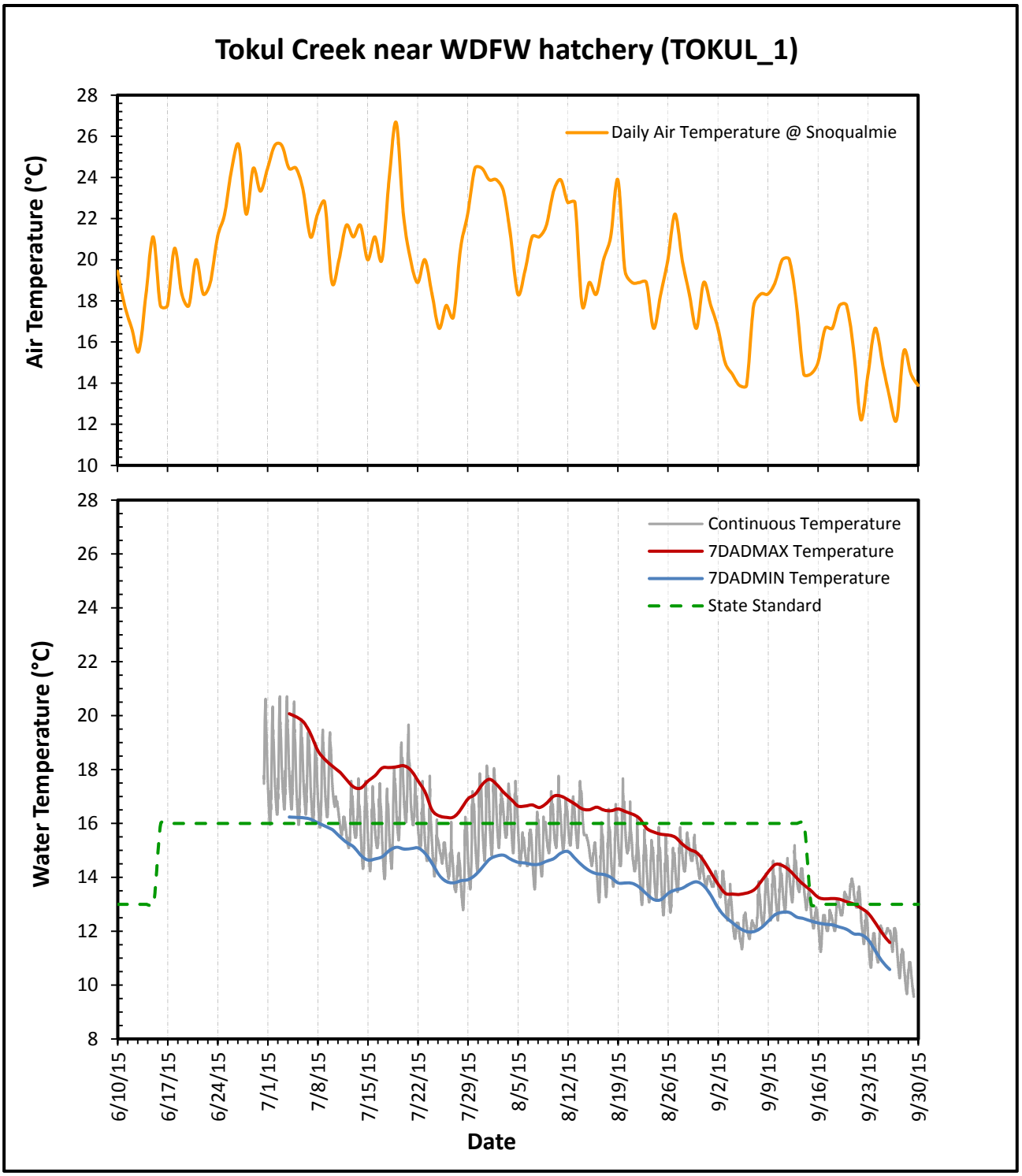

Tolt River Downstream of Highway 203 (TOLT_1)
Daily Discharge @ USGS 12148500
Daily Air Temperature @ Carnation
Discharge (cfs)
Air Temperature (°C)
600
500
400
300
200
100
0
28
26
24
22
20
18
16
14
12
10
8
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
8/12/15
8/19/15
8/26/15
9/2/15
9/9/15
9/16/15
9/23/15
9/30/15
Date


Griffin Creek near KC Water Quality site (GRIFFIN_1)
Air Temperature (°C)
Daily Air Temperature @ Carnation
Water Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
8/12/15
8/19/15
8/26/15
9/2/15
9/9/15
9/16/15
9/23/15
9/30/15

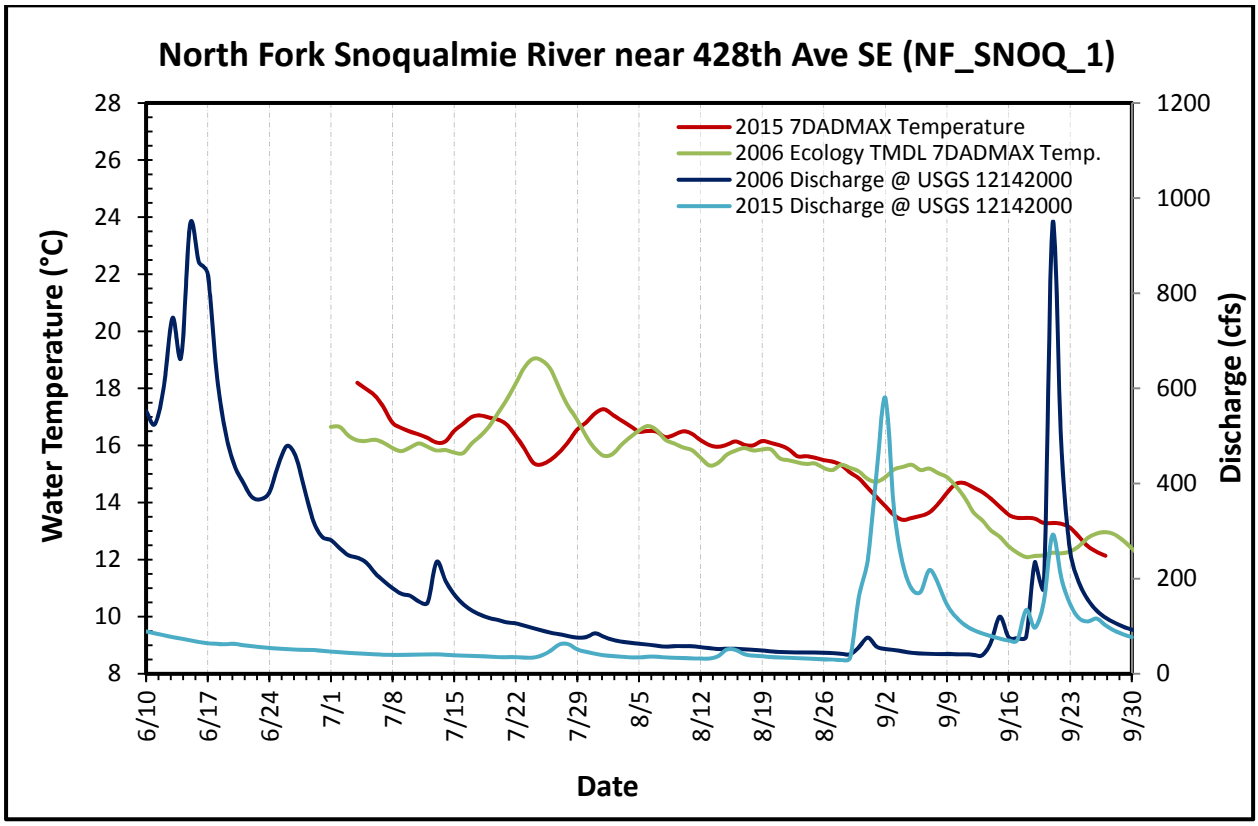

Griffin Creek near Highway 203 (GRIFFIN 2)
Daily Discharge @ KC-21A
Daily Air Temperature @ KC-21A
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
8/12/15
8/19/15
8/26/15
9/2/15
9/9/15
9/16/15
9/23/15
9/30/15
Date

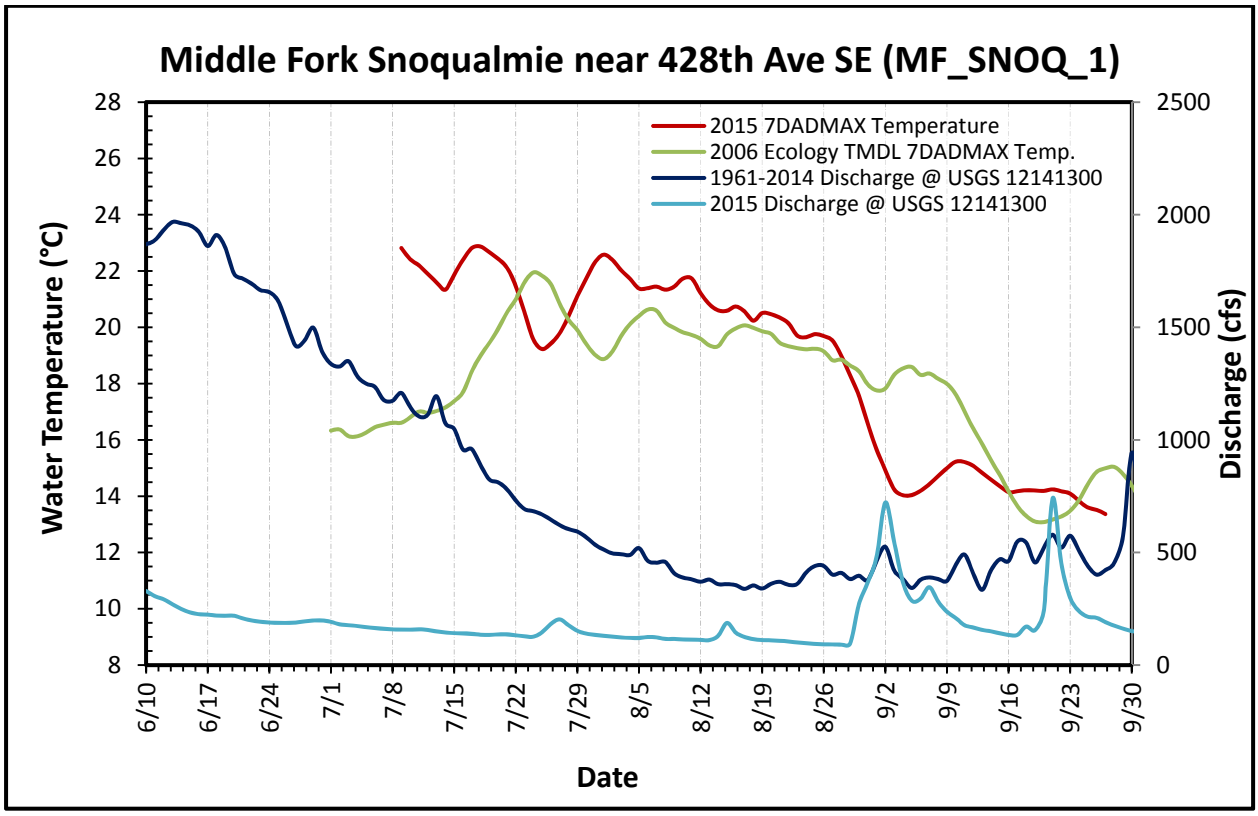

Patterson Creek near SE 24th St. (PATT_5)
Daily Discharge @ KC-48AN
Daily Air Temperature @ Fall City
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
8/12/15
8/19/15
8/26/15
9/2/15
9/9/15
9/16/15
9/23/15
9/30/15
Date

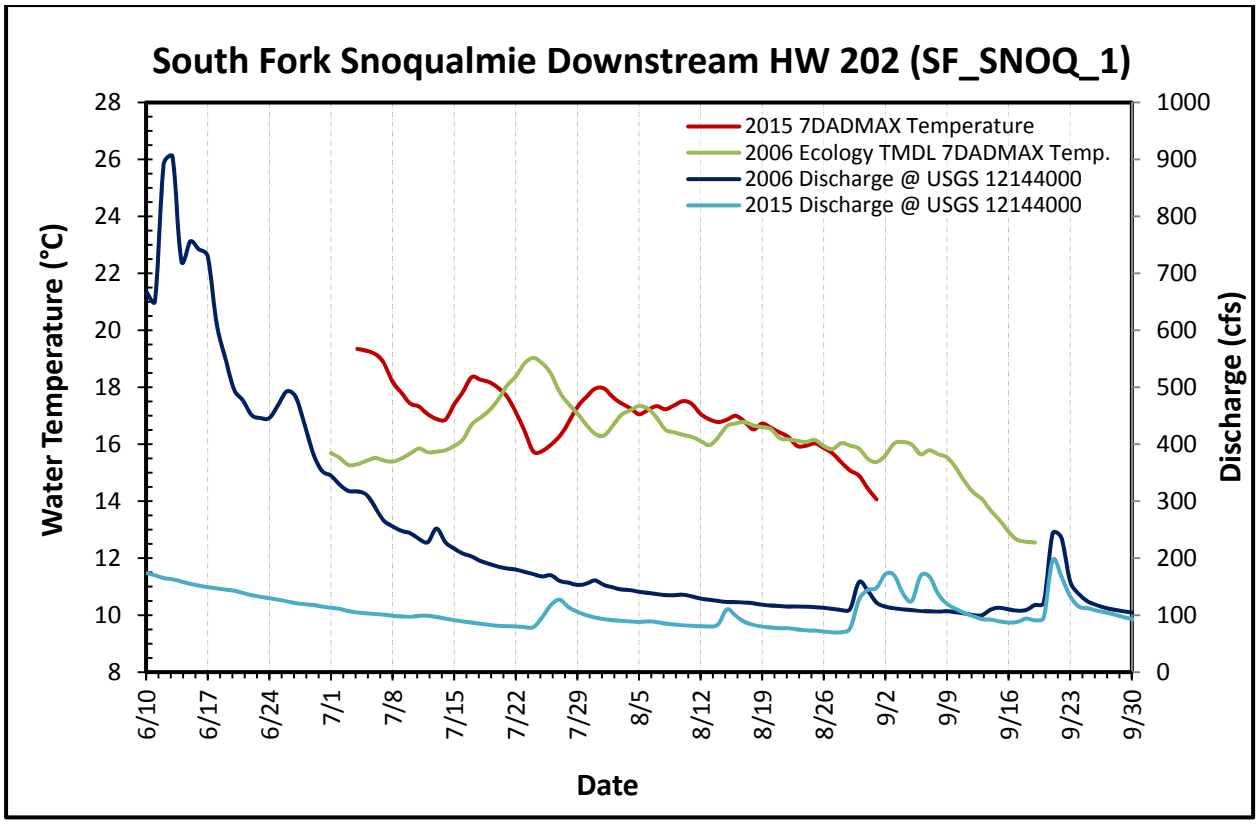

Raging River near SE 44th Pl. Dike Rd. (RAGING_2)
Daily Discharge @ USGS 12145500
Daily Air Temperature @ Fall City
Discharge (cfs)
Air Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Water Temperature (°C)
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
8/12/15
8/19/15
8/26/15
9/2/15
9/9/15
9/16/15
9/23/15
9/30/15
Date

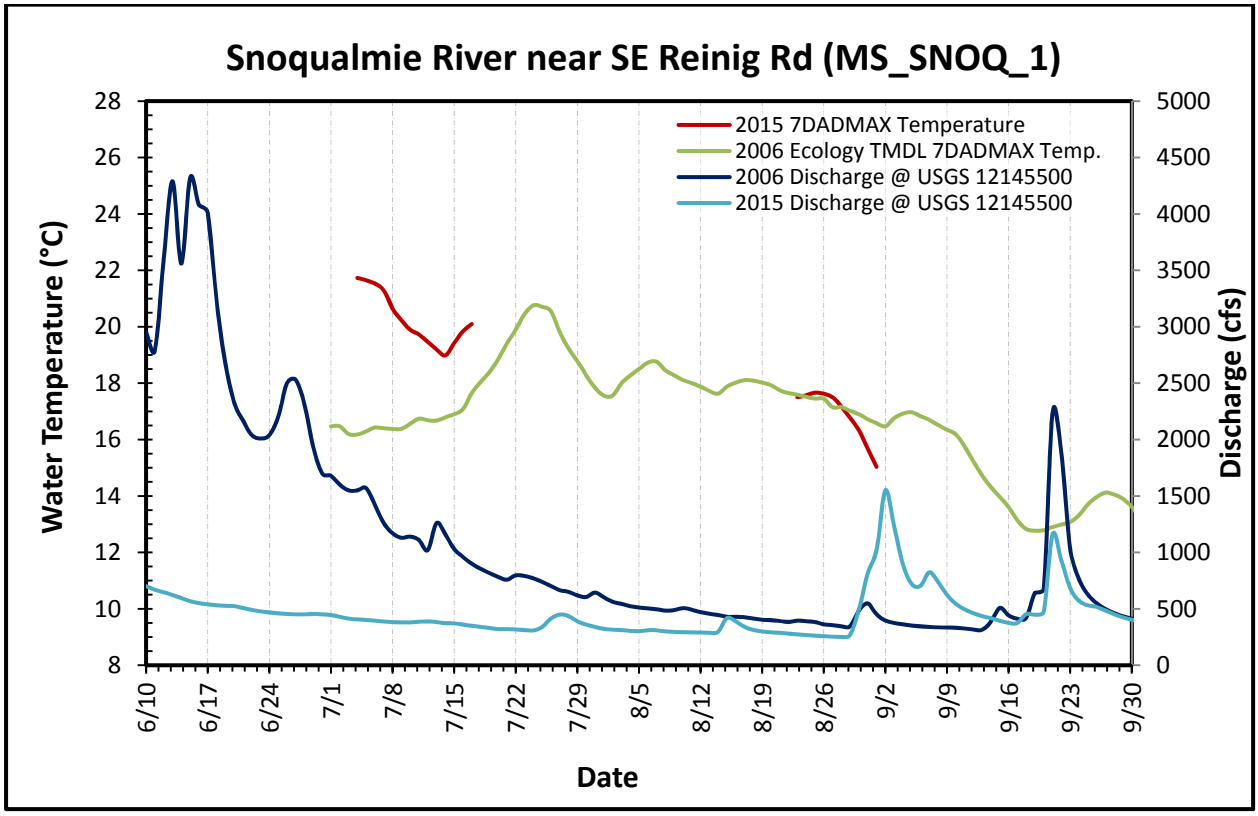

Tokul Creek near WDFW hatchery (TOKUL_1)
Air Temperature (°C)
Daily Air Temperature @ Snoqualmie
Water Temperature (°C)
Continuous Temperature
7DADMAX Temperature
7DADMIN Temperature
State Standard
Date
6/10/15
6/17/15
6/24/15
7/1/15
7/8/15
7/15/15
7/22/15
7/29/15
8/5/15
8/12/15
8/19/15
8/26/15
9/2/15
9/9/15
9/16/15
9/23/15
9/30/15

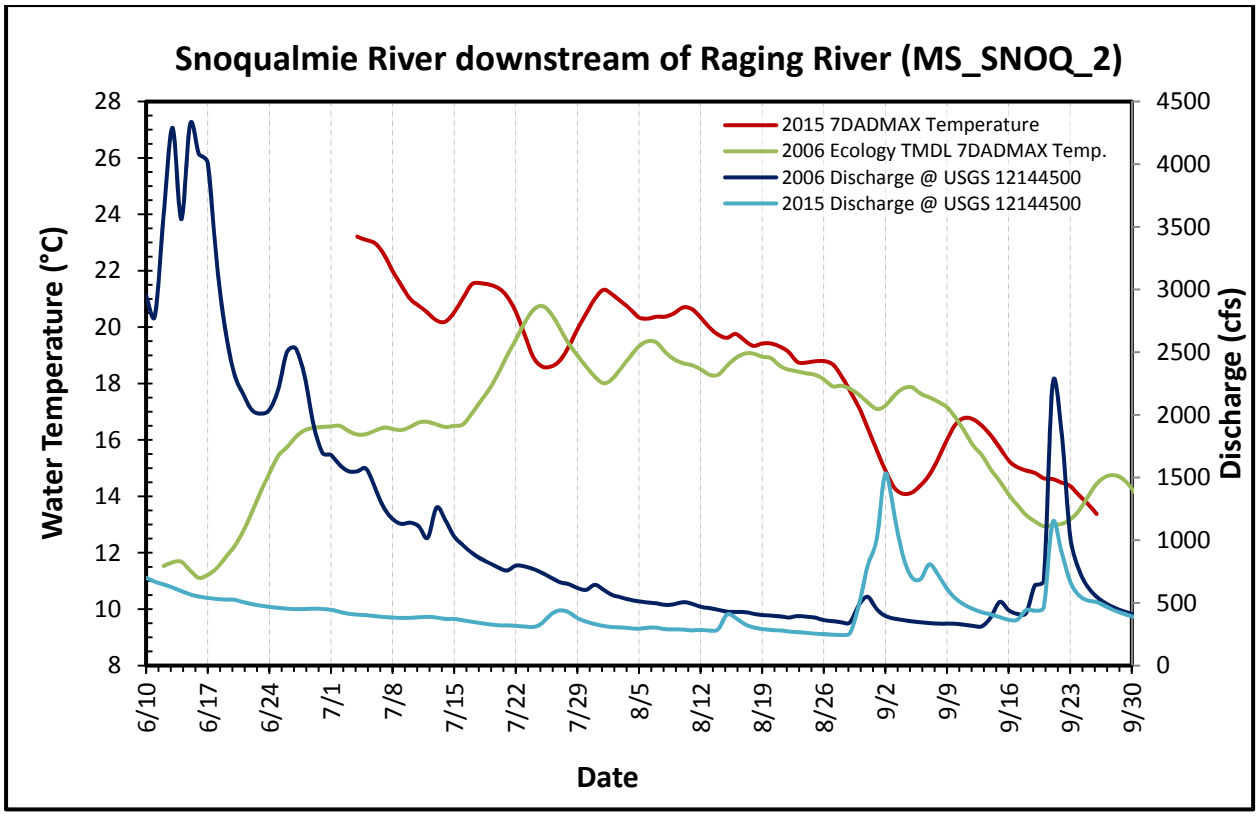
Appendix B. Temperature and flow comparisons across sample sites.

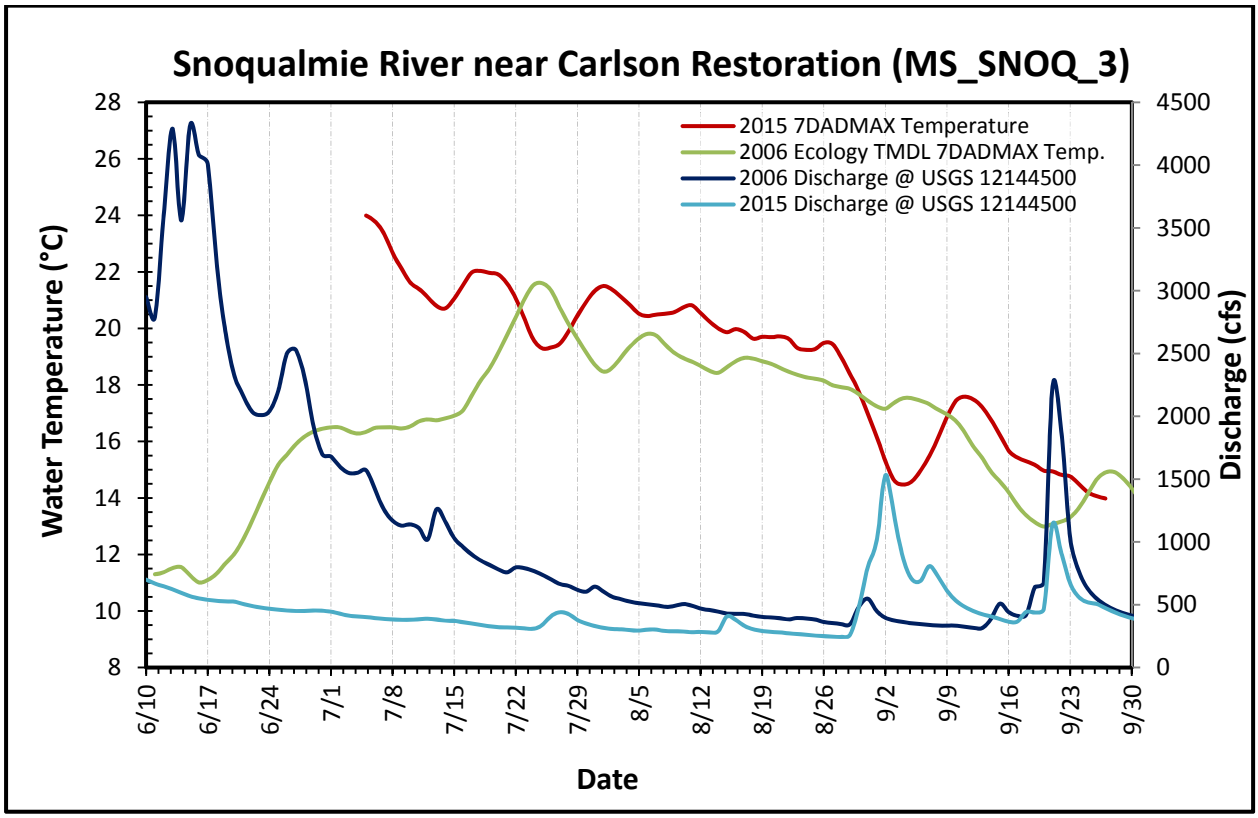


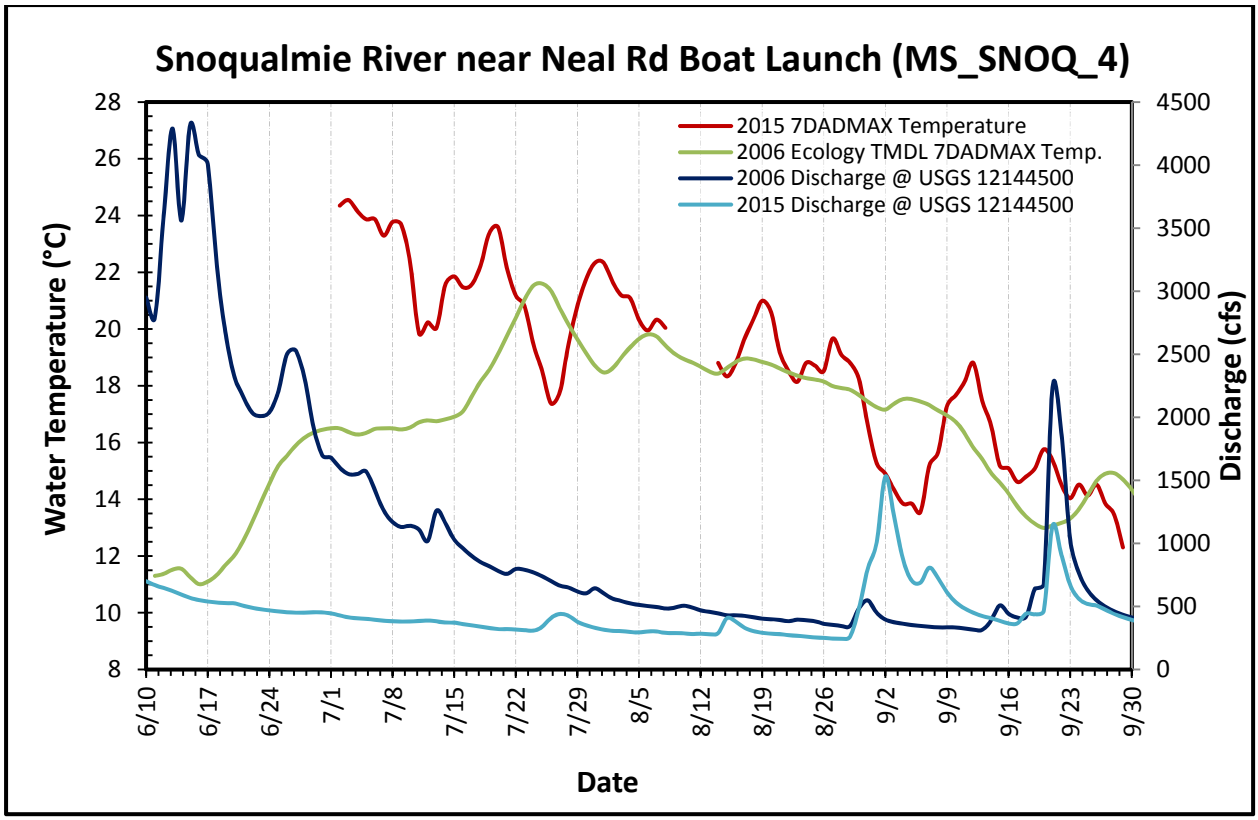


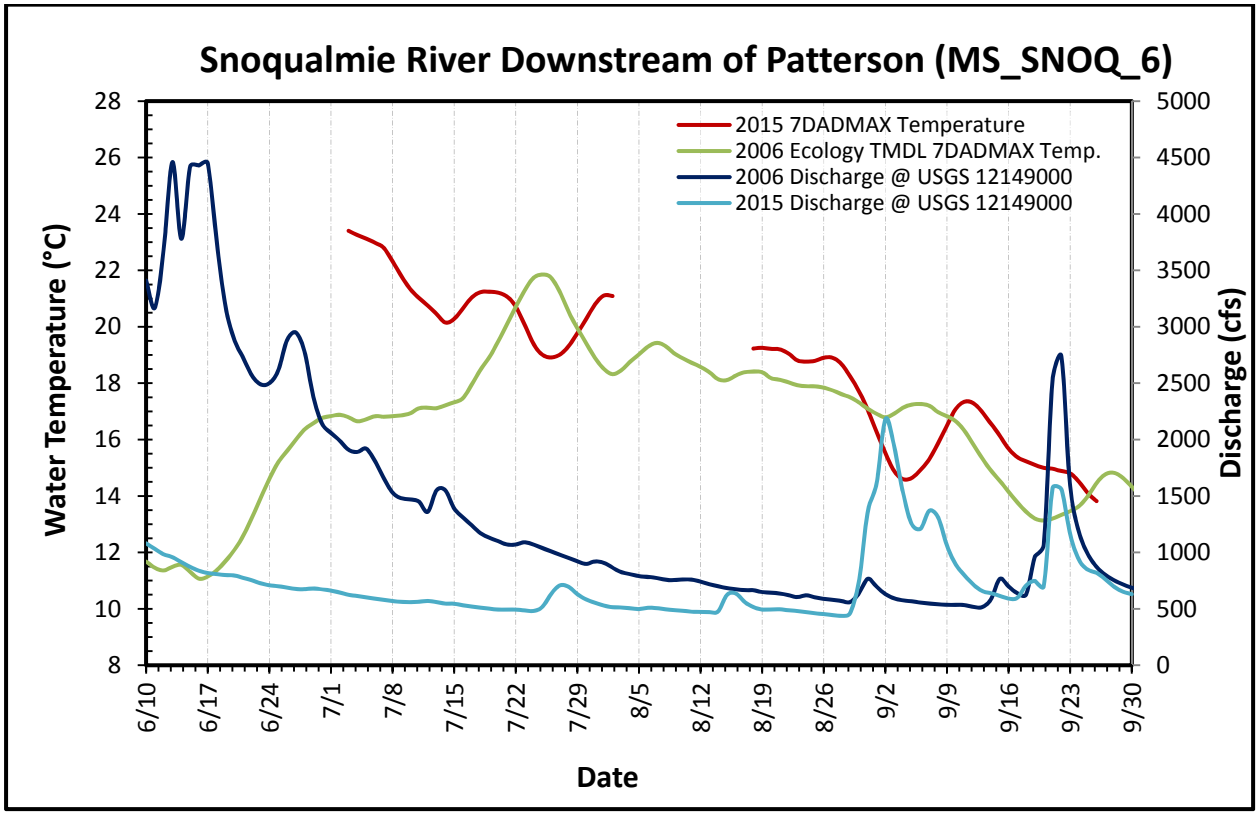

South Fork Snoqualmie Downstream HW 202 (SF_SNOQ_1)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12144000
2015 Discharge @ USGS 12144000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
1000
900
800
700
600
500
400
300
200
100
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

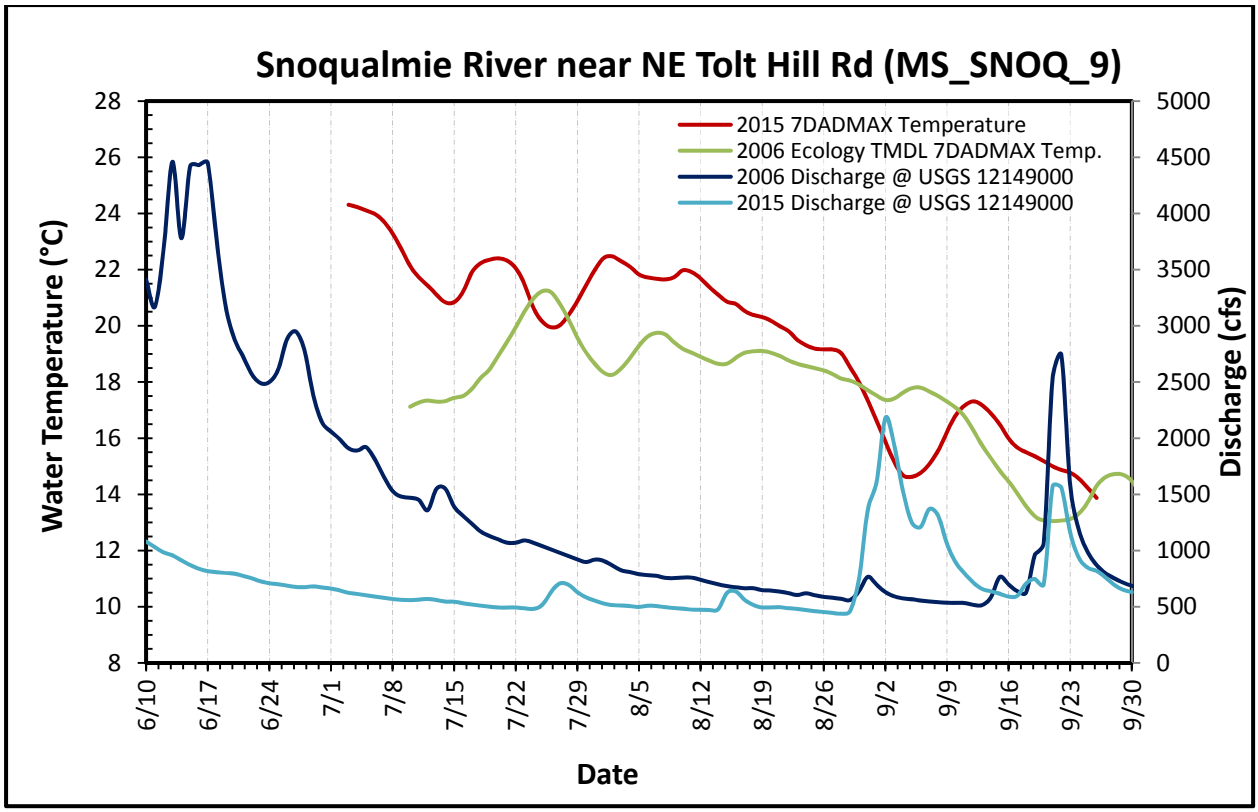

Snoqualmie River near SE Reinig Rd (MS_SNOQ_1)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12145500
2015 Discharge @ USGS 12145500
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

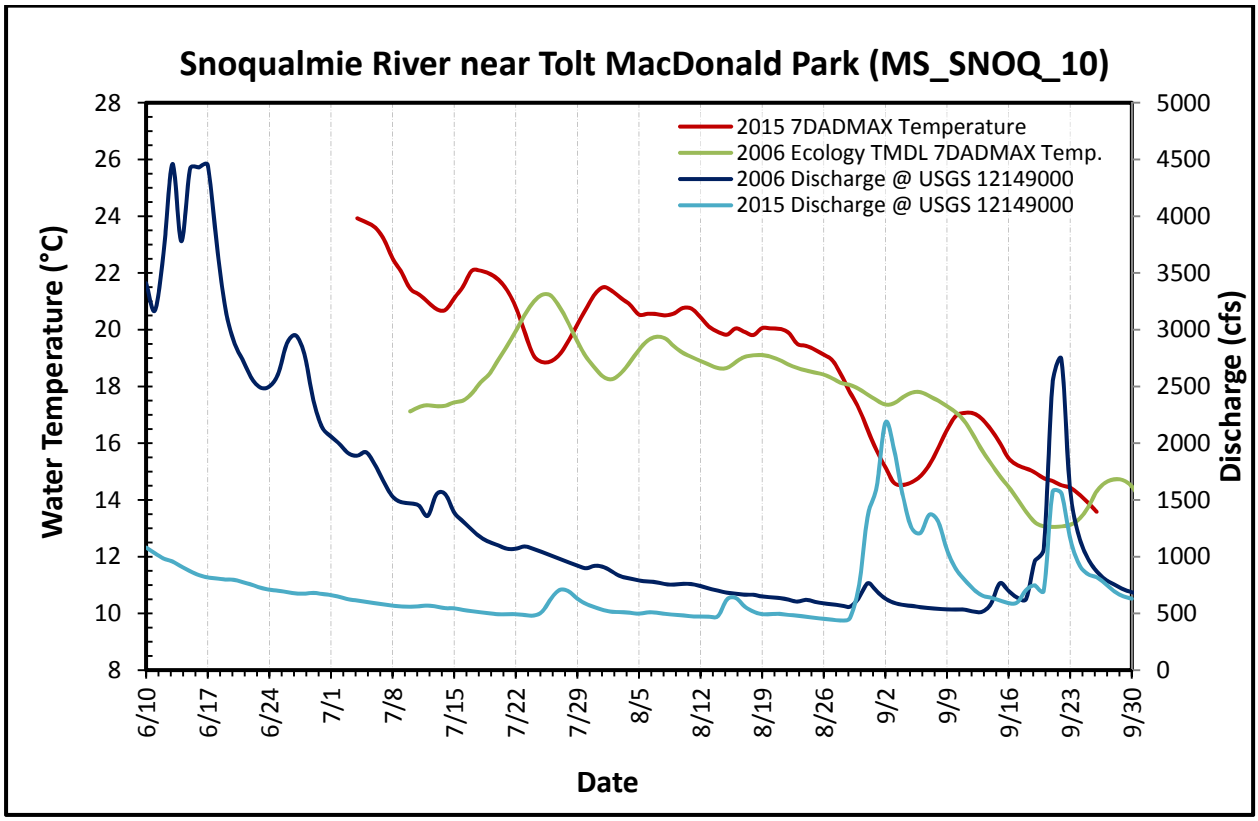

Snoqualmie River downstream of Raging River (MS_SNOQ_2)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12144500
2015 Discharge @ USGS 12144500
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

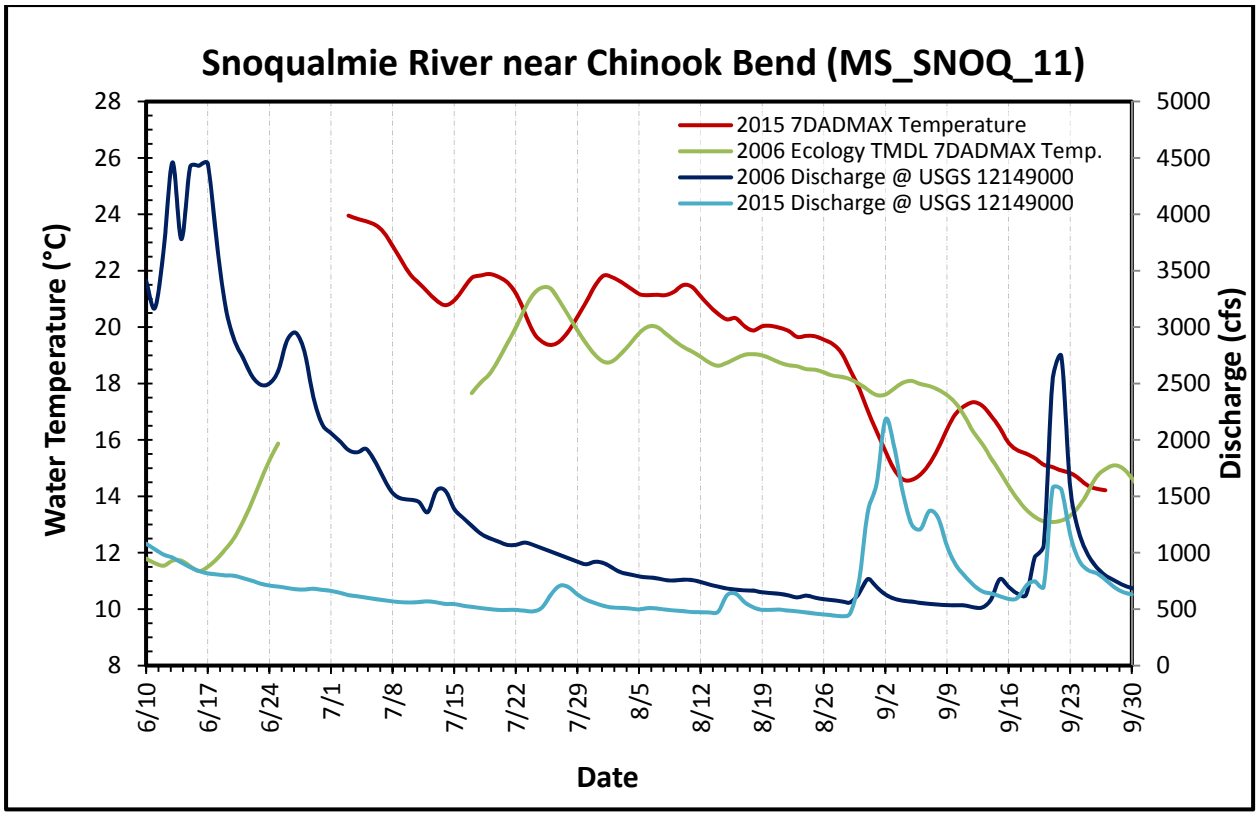

Snoqualmie River near Carlson Restoration (MS_SNOQ_3)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12144500
2015 Discharge @ USGS 12144500
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

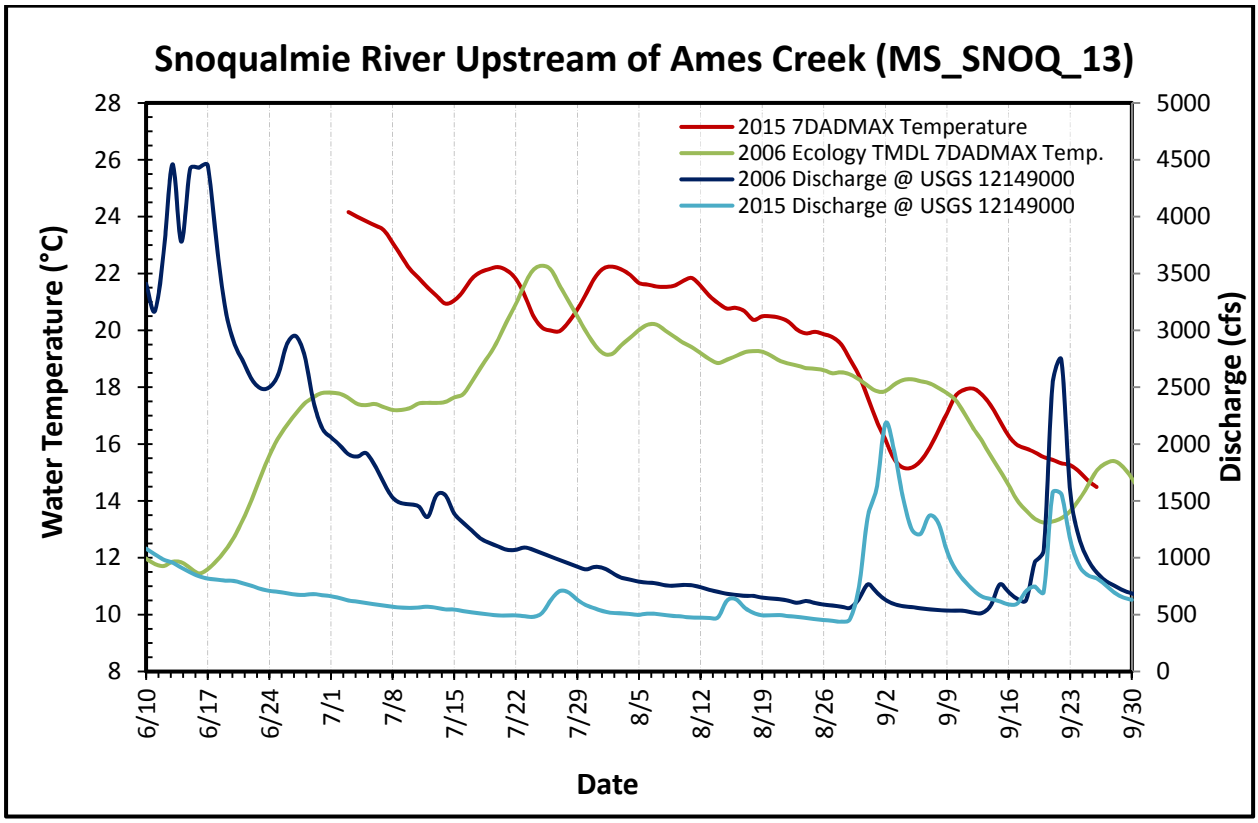

Snoqualmie River near Neal Rd Boat Launch (MS_SNOQ_4)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12144500
2015 Discharge @ USGS 12144500
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

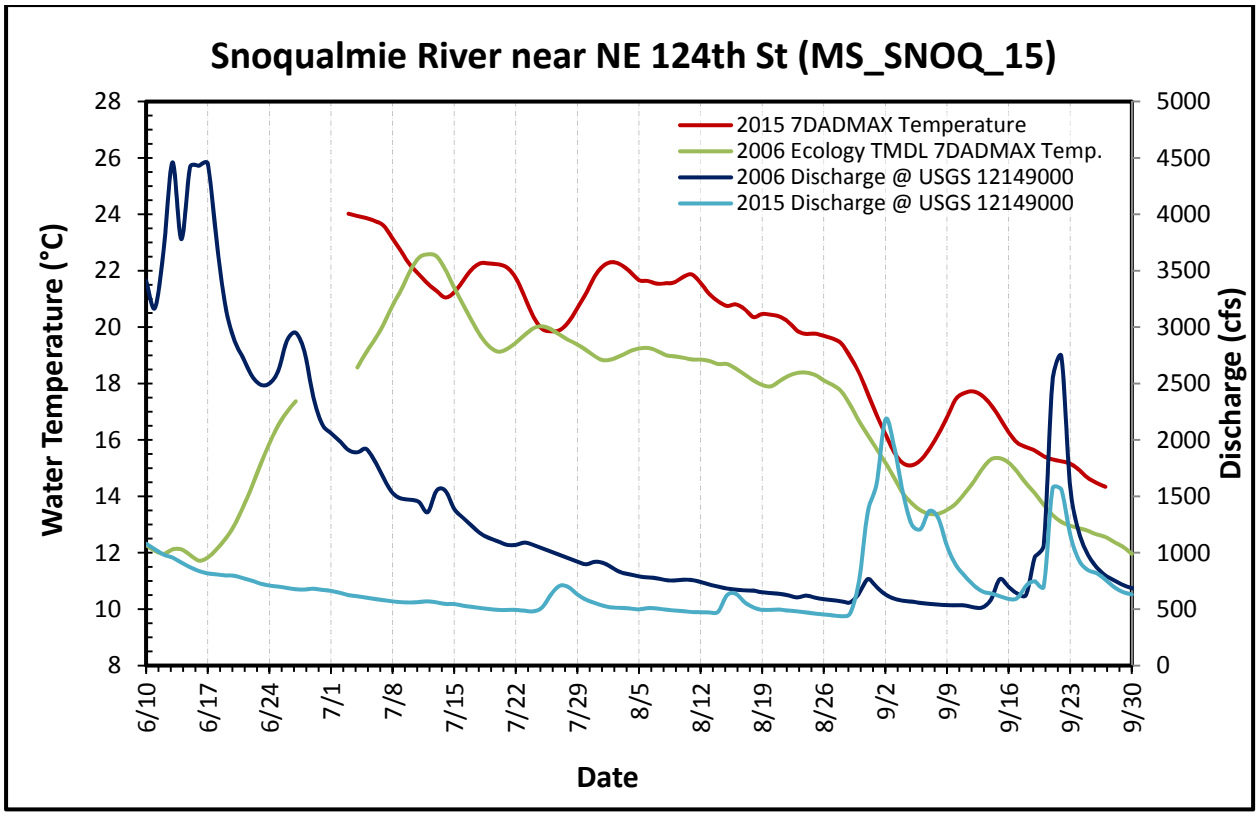

Snoqualmie River Downstream of Patterson (MS_SNOQ_6)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

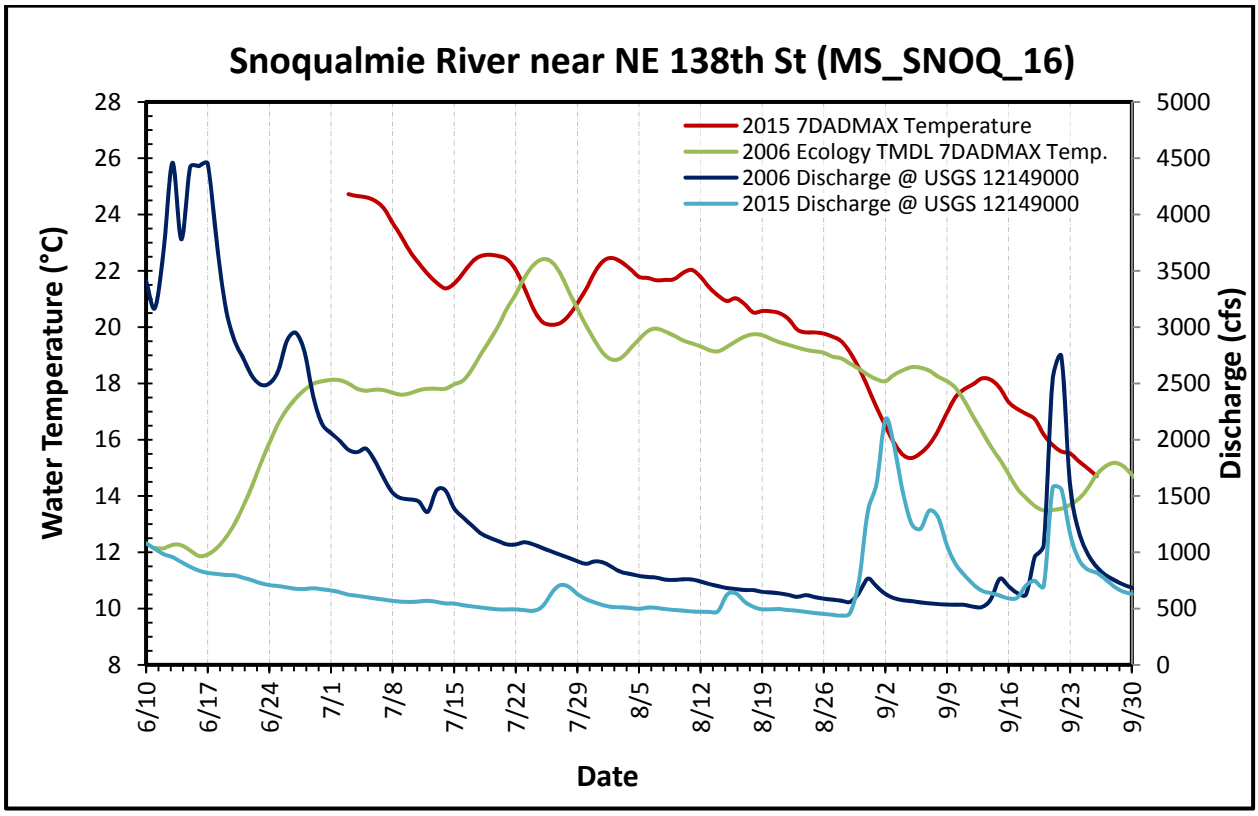

Snoqualmie River near NE Tolt Hill Rd (MS_SNOQ_9)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

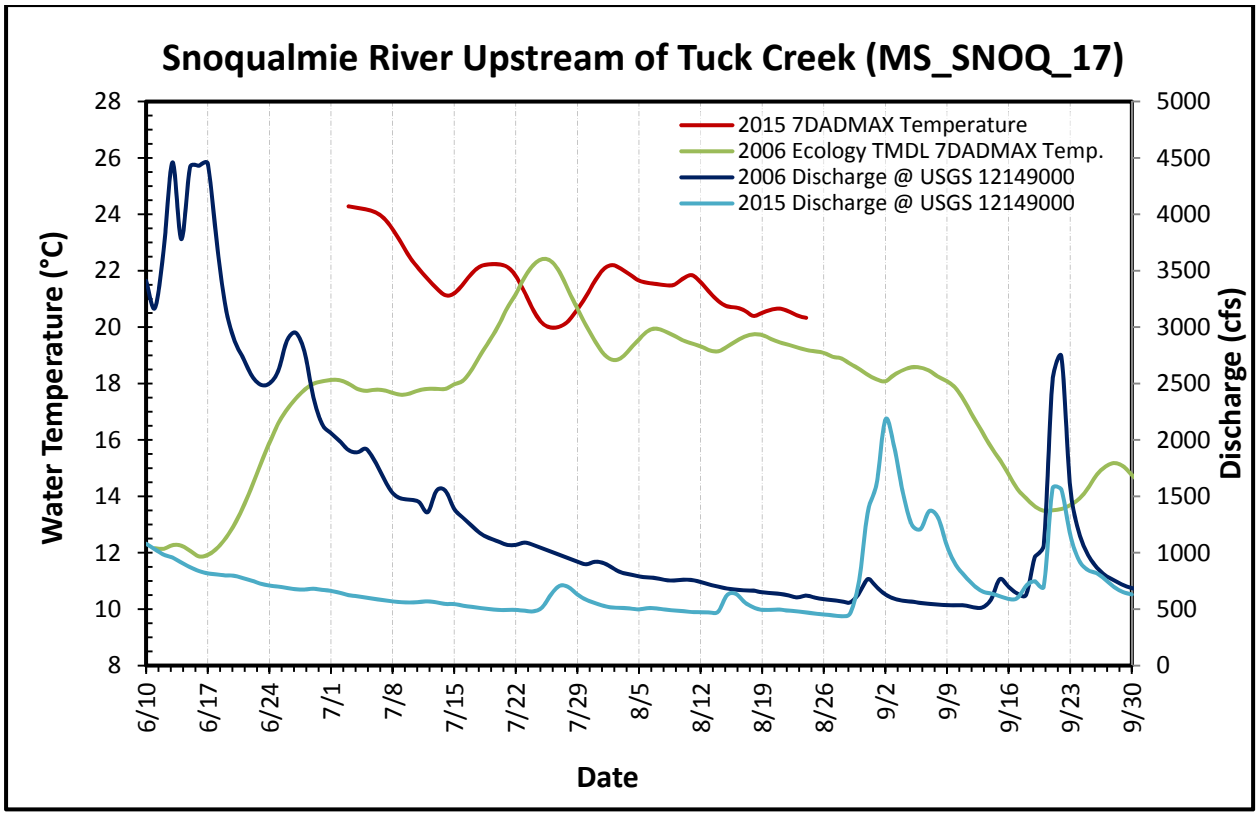

Snoqualmie River near Tolt MacDonald Park (MS_SNOQ_10)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

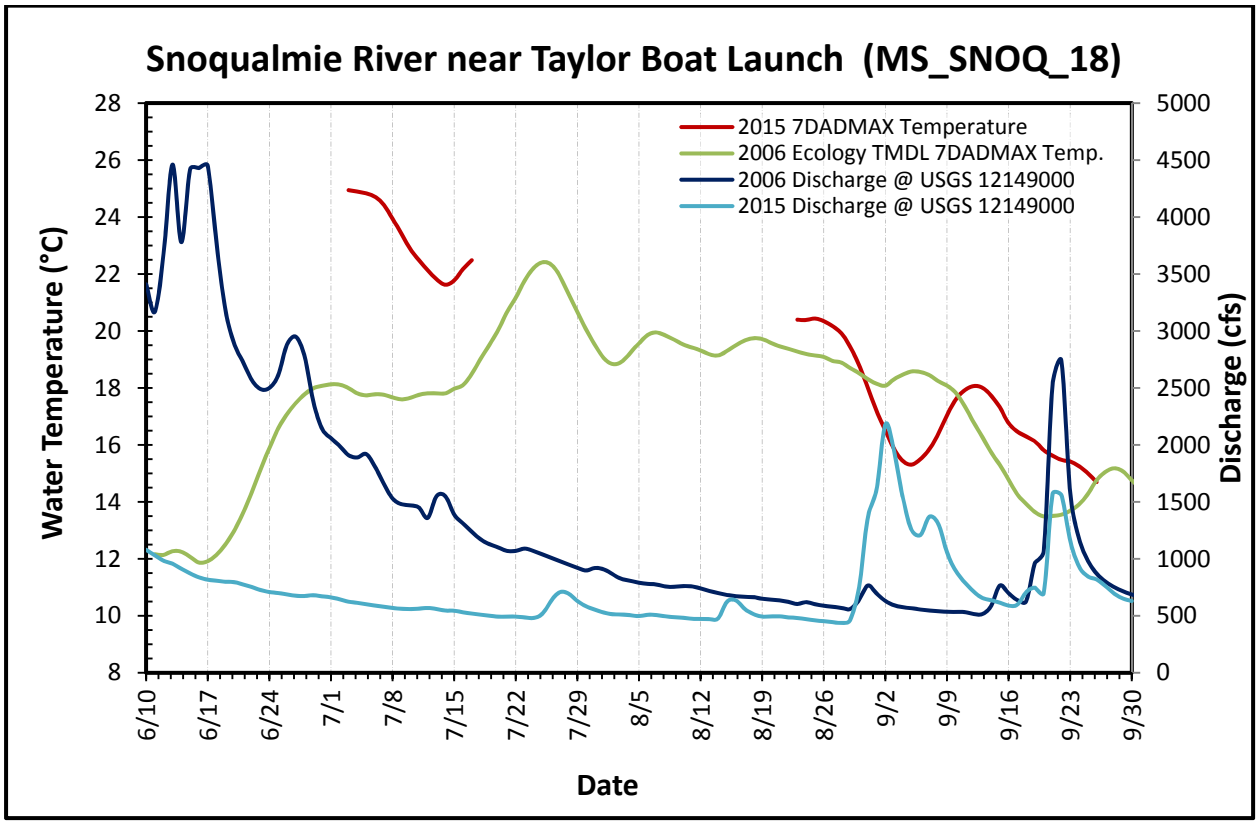

Snoqualmie River near Chinook Bend (MS_SNOQ_11)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

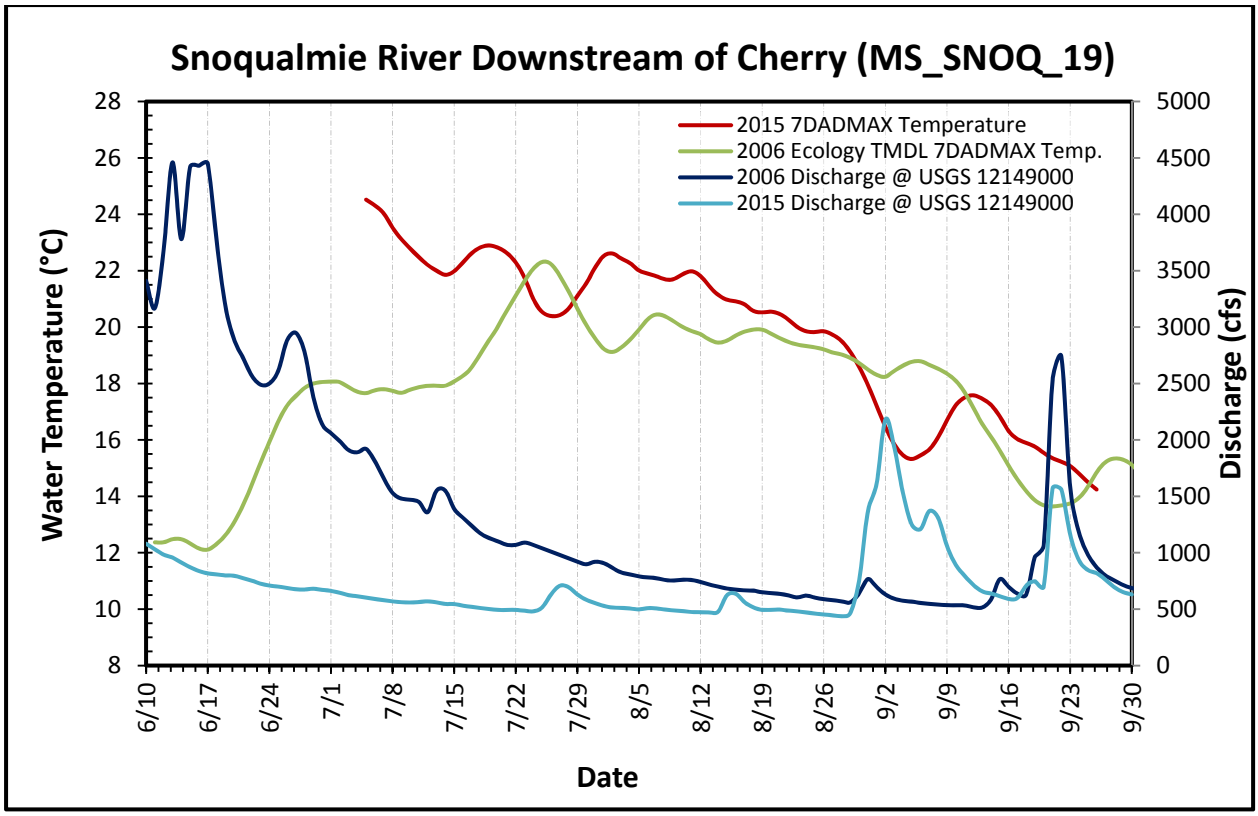

Snoqualmie River Upstream of Ames Creek (MS_SNOQ_13)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

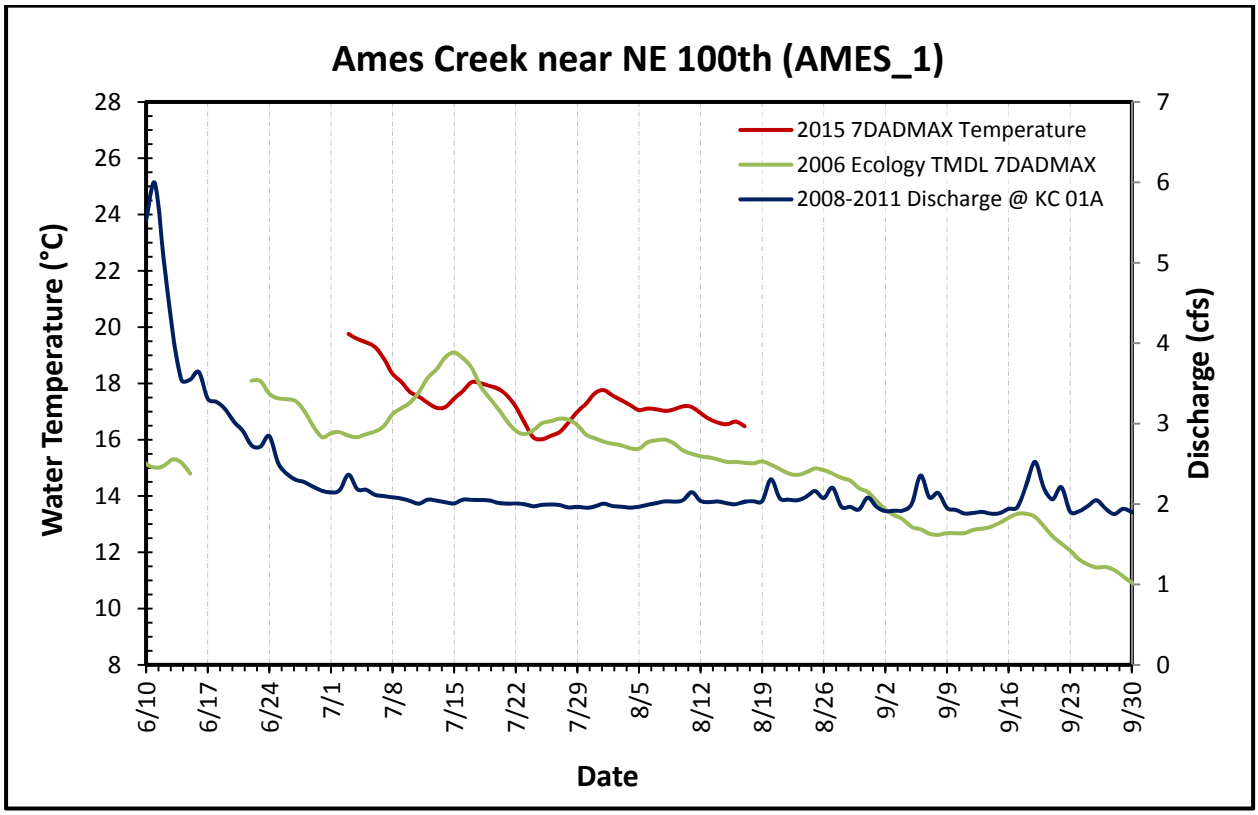

Snoqualmie River near NE 124th St (MS_SNOQ_15)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

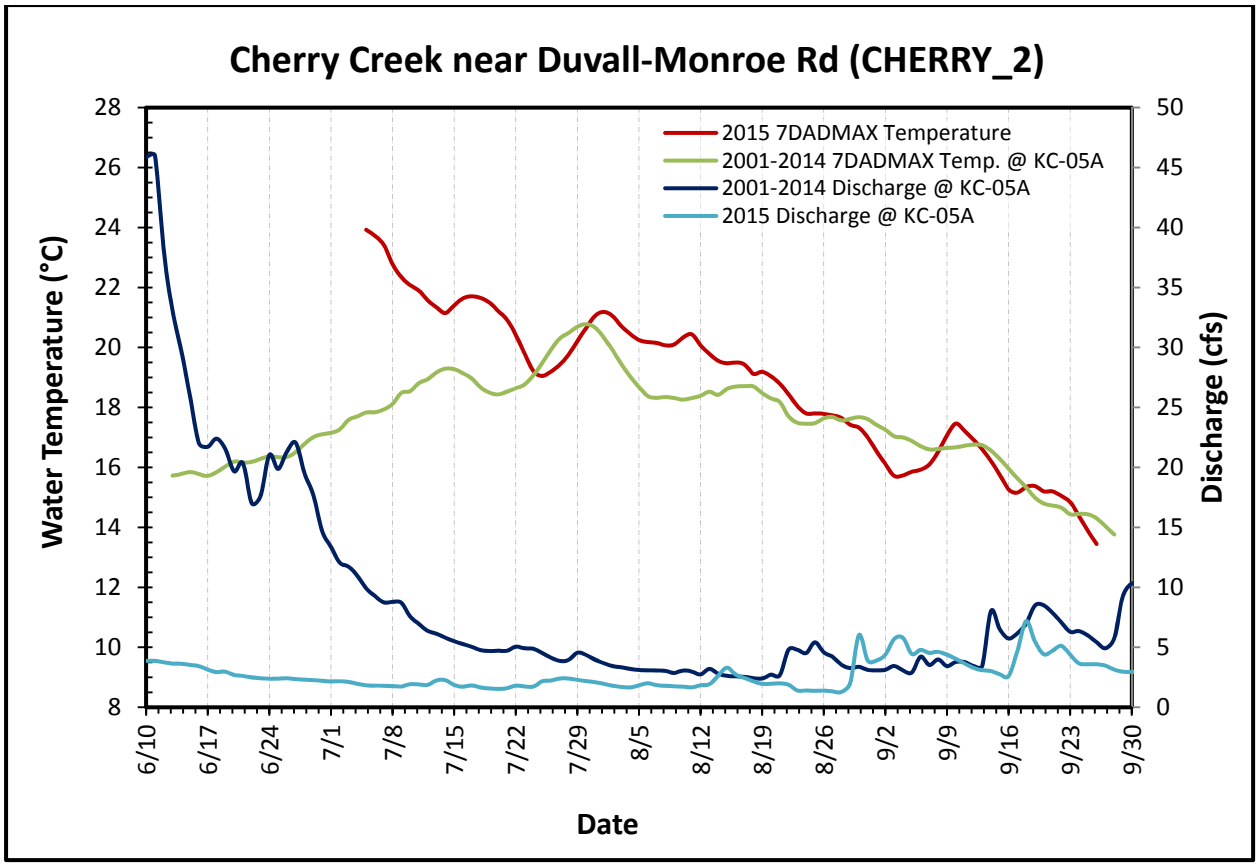

Snoqualmie River near NE 138th St (MS_SNOQ_16)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

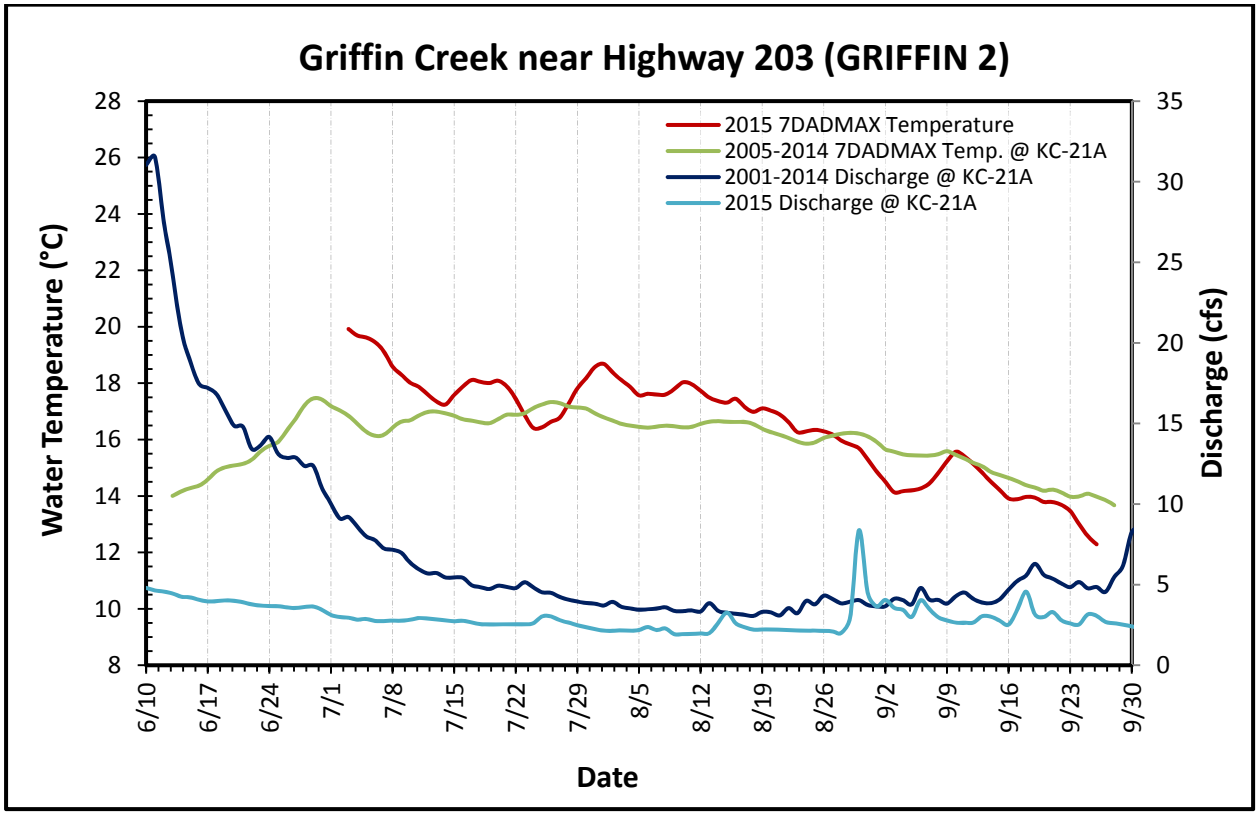

Snoqualmie River Upstream of Tuck Creek (MS_SNOQ_17)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

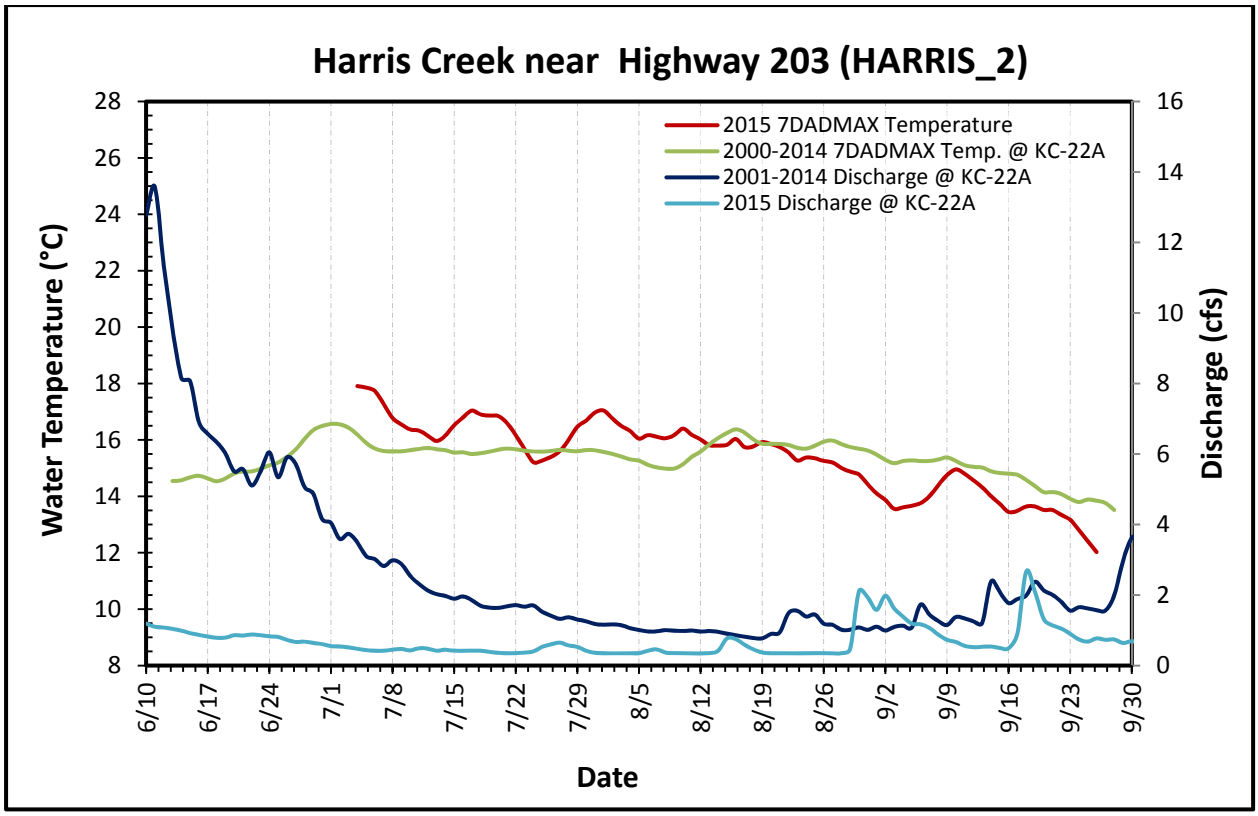

Snoqualmie River near Taylor Boat Launch (MS_SNOQ_18)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

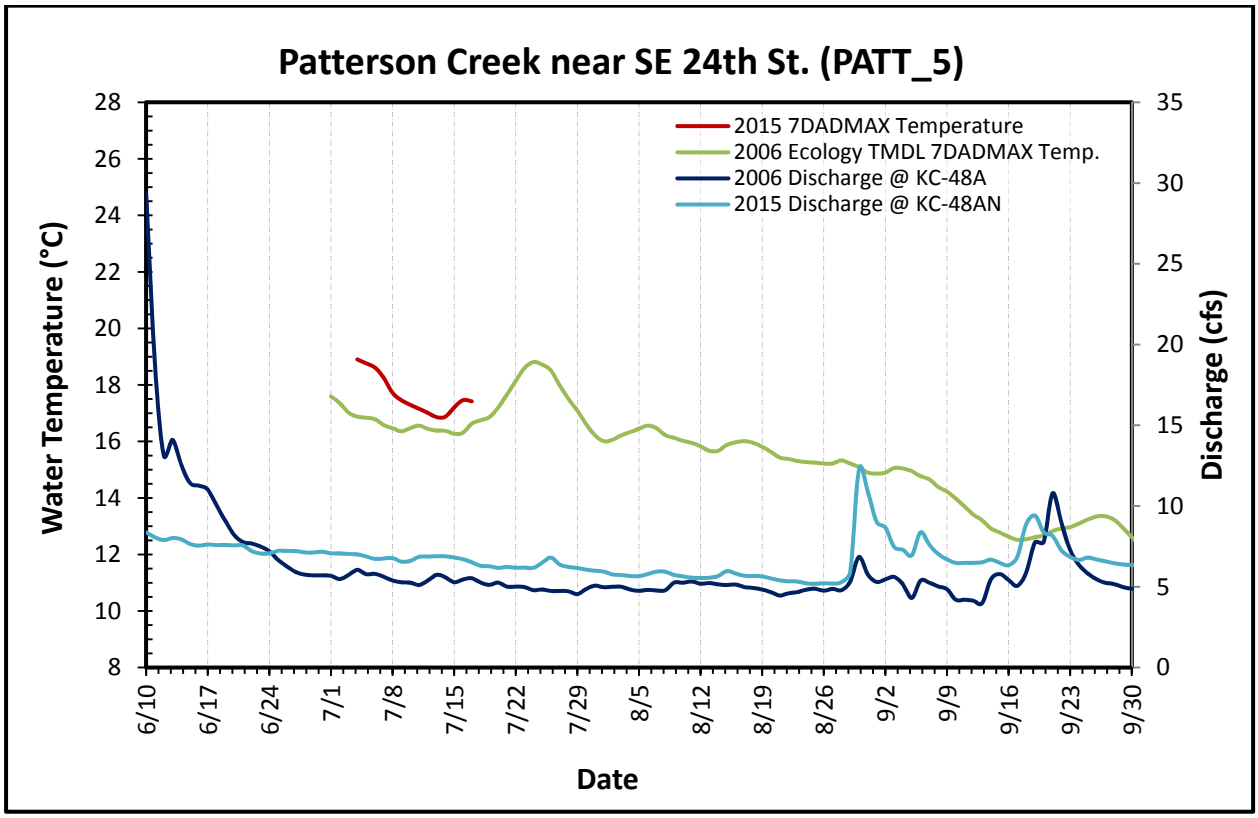

Snoqualmie River Downstream of Cherry (MS_SNOQ_19)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12149000
2015 Discharge @ USGS 12149000
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

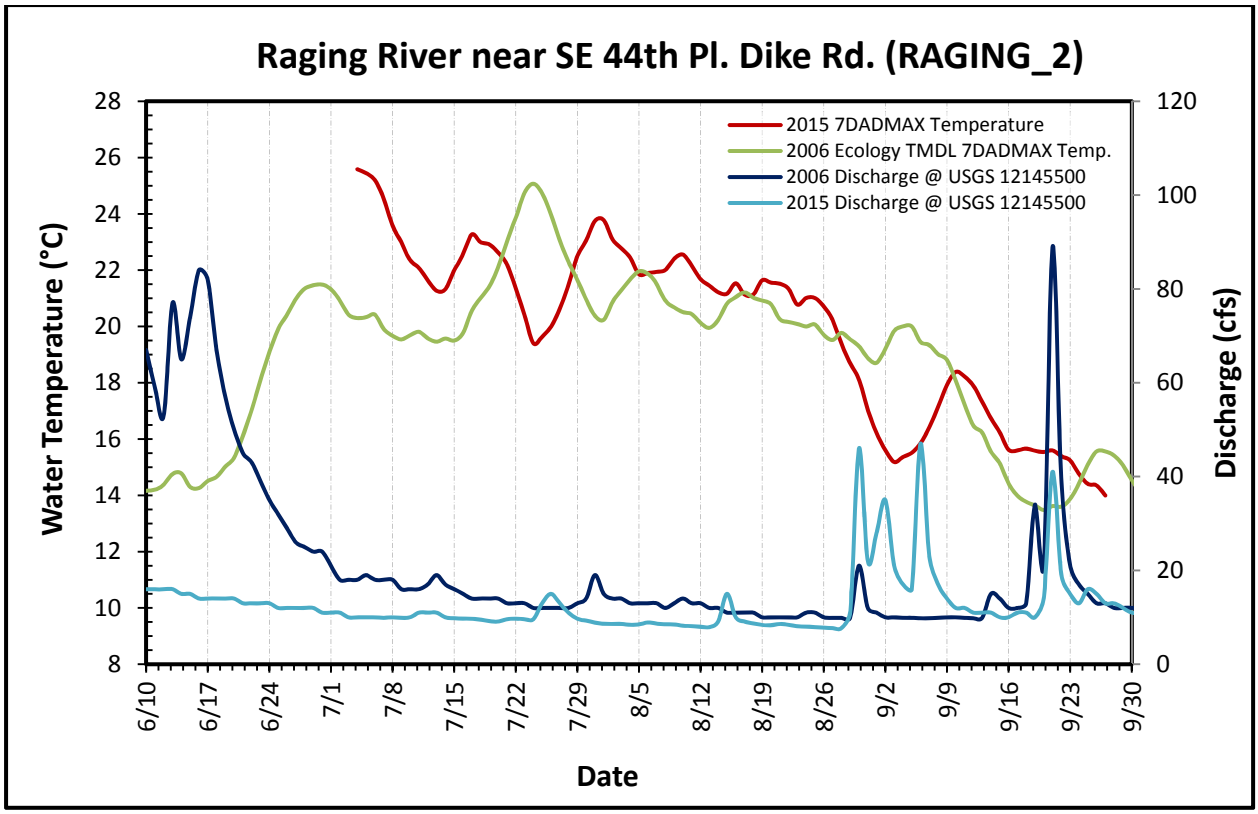

Ames Creek near NE 100th (AMES_1)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX
2008-2011 Discharge @ KC 01A
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
7
6
5
4
3
2
1
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

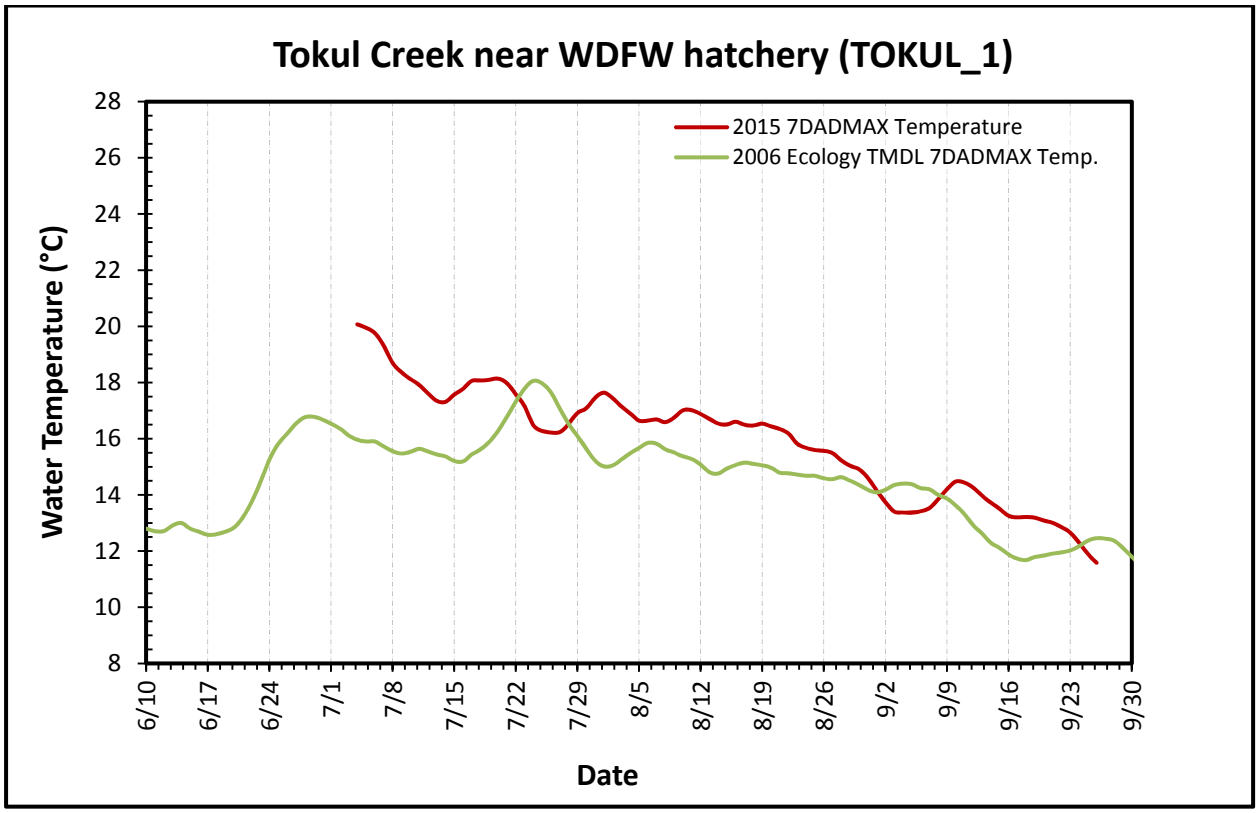

Cherry Creek near Duvall-Monroe Rd (CHERRY_2)
2015 7DADMAX Temperature
2001-2014 7DADMAX Temp. @ KC-05A
2001-2014 Discharge @ KC-05A
2015 Discharge @ KC-05A
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
50
45
40
35
30
25
20
15
10
5
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

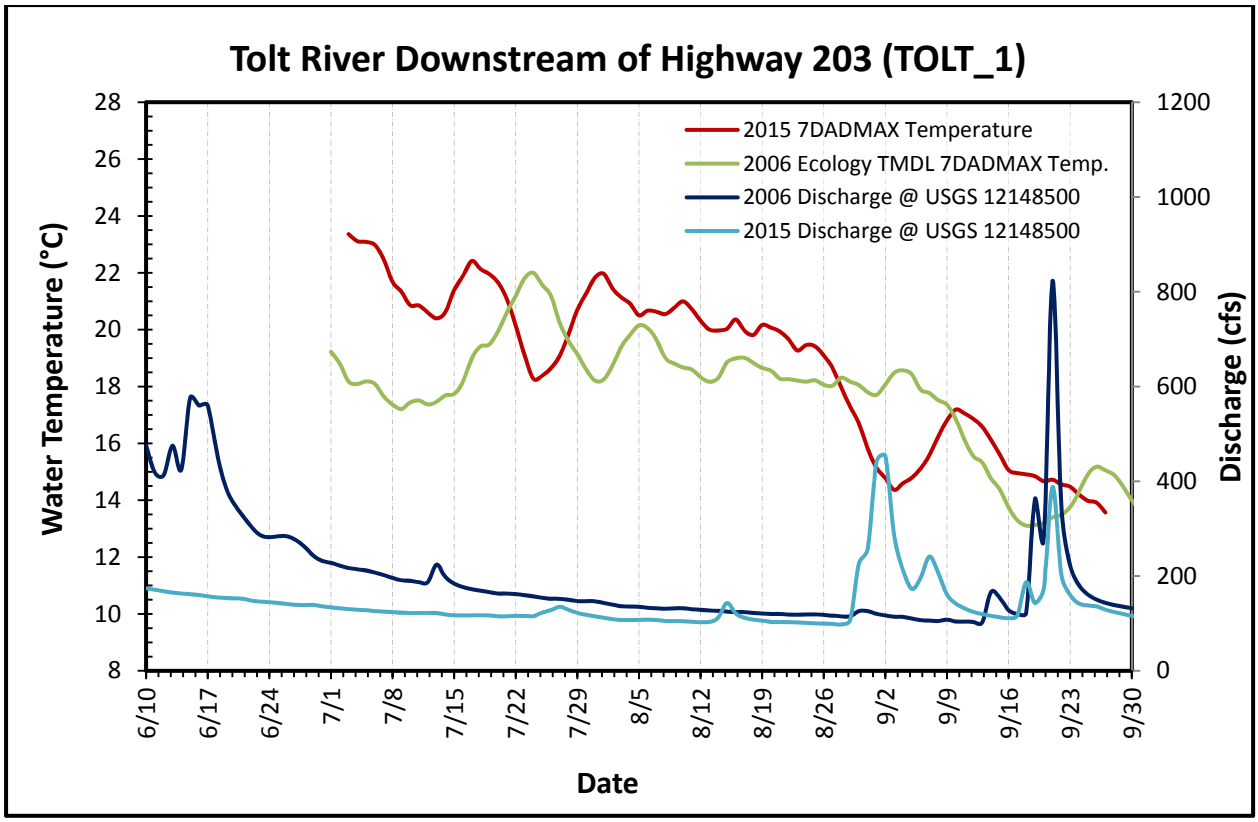

Griffin Creek near Highway 203 (GRIFFIN 2)
2015 7DADMAX Temperature
2005-2014 7DADMAX Temp. @ KC-21A
2001-2014 Discharge @ KC-21A
2015 Discharge @ KC-21A
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
35
30
25
20
15
10
5
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30

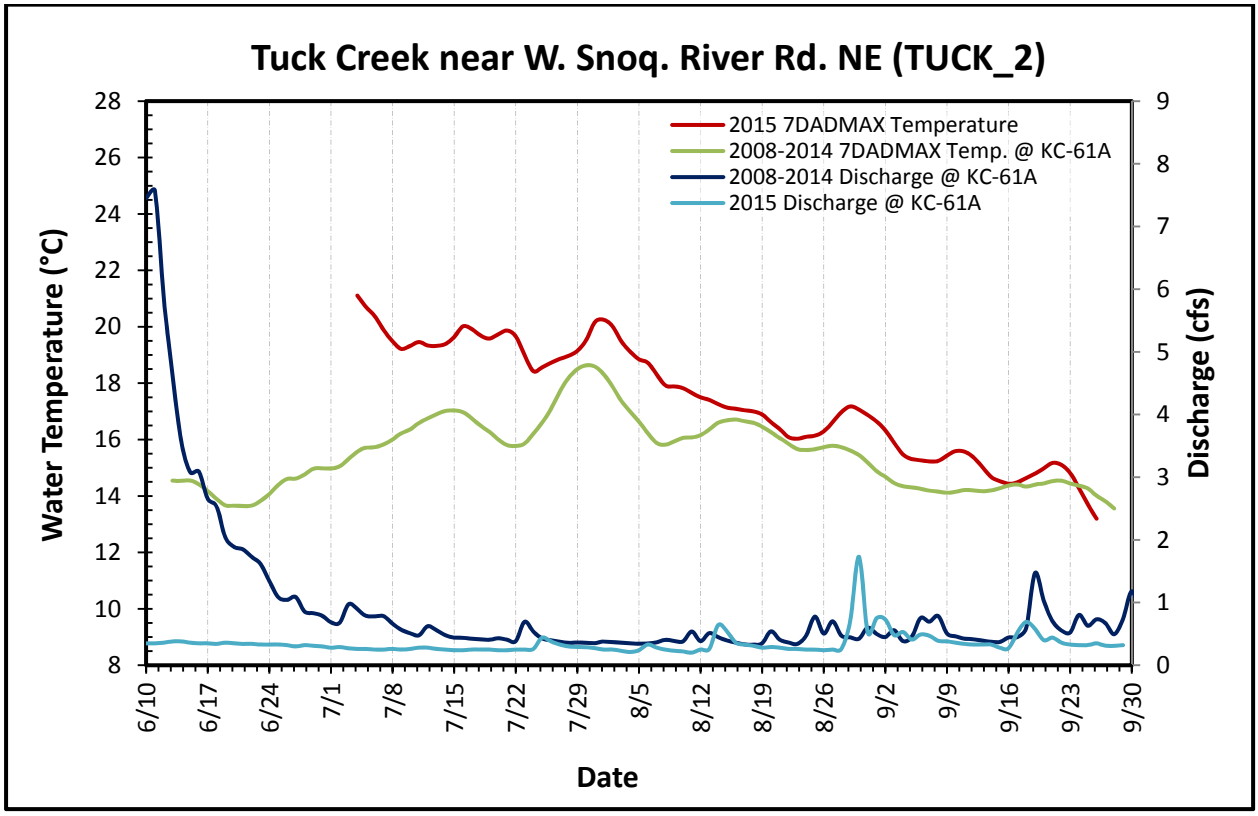

Harris Creek near Highway 203 (HARRIS_2)
2015 7DADMAX Temperature
2000-2014 7DADMAX Temp. @ KC-22A
2001-2014 Discharge @ KC-22A
2015 Discharge @ KC-22A
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
16
14
12
10
8
6
4
2
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30


Patterson Creek near SE 24th St. (PATT_5)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ KC-48A
2015 Discharge @ KC-48AN
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
35
30
25
20
15
10
5
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30


Raging River near SE 44th Pl. Dike Rd. (RAGING_2)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12145500
2015 Discharge @ USGS 12145500
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
120
100
80
60
40
20
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30


Tokul Creek near WDFW hatchery (TOKUL_1)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
Water Temperature (°C)
Date
28
26
24
22
20
18
16
14
12
10
8
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30


Tolt River Downstream of Highway 203 (TOLT_1)
2015 7DADMAX Temperature
2006 Ecology TMDL 7DADMAX Temp.
2006 Discharge @ USGS 12148500
2015 Discharge @ USGS 12148500
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
1200
1000
800
600
400
200
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30


Tuck Creek near W. Snoq. River Rd. NE (TUCK_2)
2015 7DADMAX Temperature
2008-2014 7DADMAX Temp. @ KC-61A
2008-2014 Discharge @ KC-61A
2015 Discharge @ KC-61A
Water Temperature (°C)
Discharge (cfs)
Date
28
26
24
22
20
18
16
14
12
10
8
9
8
7
6
5
4
3
2
1
0
6/10
6/17
6/24
7/1
7/8
7/15
7/22
7/29
8/5
8/12
8/19
8/26
9/2
9/9
9/16
9/23
9/30