Green River Temperature and Salmon

Technical Briefing for the Implementation Technical Committee

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WRIA 9 Technical Briefing Rationale

- Warm water temperatures influence salmonid survival in WRIA 9
- Three areas in the Green River watershed have temperature TMDLs (completed or are still in process of completion): Middle and Lower Green River, Soos Creek, and Newaukum Creek
- The WRIA 9 Forum recently adopted a new conservation hypothesis (All-7) that focuses on improving water temperature and reducing chemical contamination. This briefing documents the scientific basis for that decision, discusses known human impacts to water temperature, and discusses key actions that can improve water temperature.

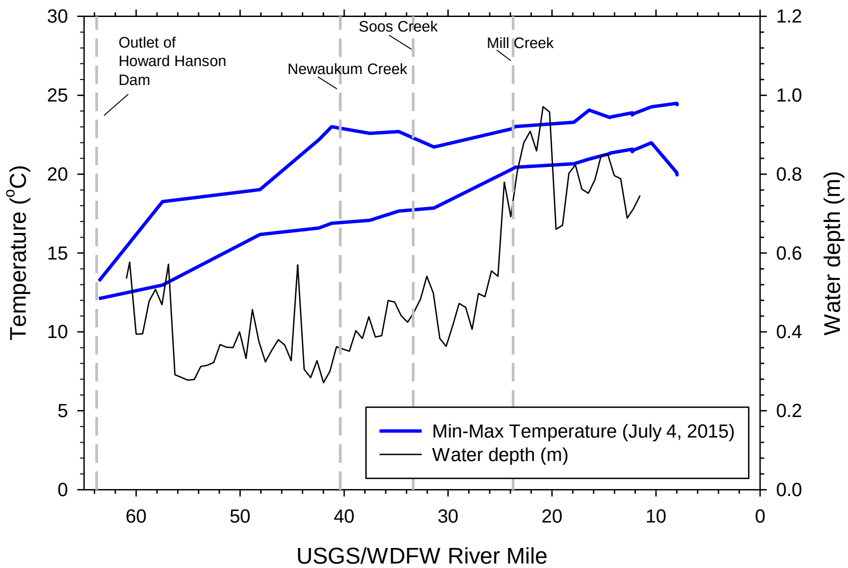
Water Temperature Drivers and Cold Water Refugia

Factors influencing Stream Temperature [2, 5, 8, 10, 12, 16, 21, 35, 37, 42, 71, 75, 89, 94, 99]

- Climatic drivers (e.g., solar radiation, air temperature, precipitation, and windspeed)
    - Heat gains and losses from short-wave solar radiation (sun), long-wave atmospheric radiation (air temperature), and precipitation
    - Air temperature is the dominant factor explaining long-term stream temperature trends and inter-annual variability, except during the summer when discharge accounts for approximately half of the inter-annual variation in stream temperatures (e.g., during a dry year with exceptionally low flow, water is warmer)
    - *Green River example*:
        - Analyses indicate that air temperature appears to be the primary driver of water temperature in the Green River [20,44]
- Stream morphology (e.g., dimension, pattern, profile, and bed materials) and topographic characteristics (e.g., aspect and confinement)
    - Friction created by water flowing over the bed increases water temperature and direct conduction from the stream bed can heat but usually cools water
    - *Green River examples*:

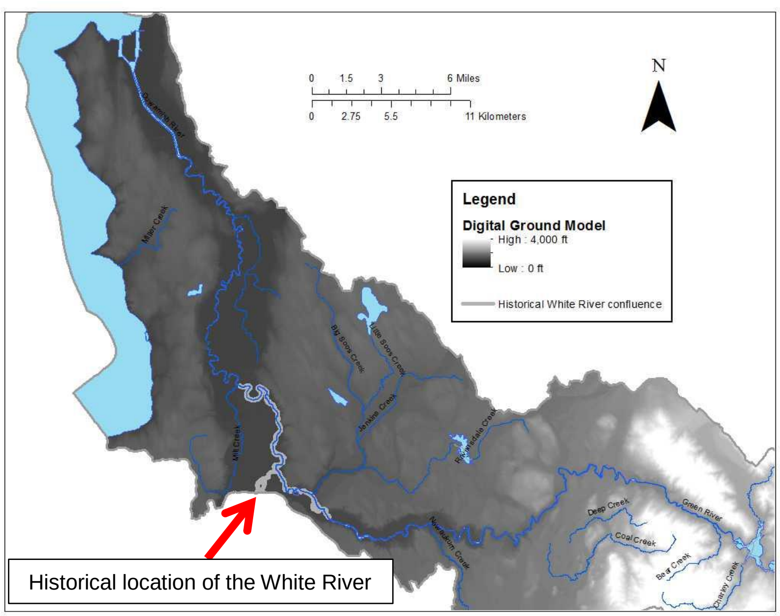
- Increase in daily temperature ranges (fluctuations between min and max) from Flaming Geyser State Park (RM 43.1) to just above Soos Creek (RM 33.4) is likely due to the relatively shallow water depth throughout this reach (**Figure 1**) [44]

Figure 1: Plot of 7-DMax and 7-DMin water temperature on July 4, 2015 for the Green River mainstem compared to the water depths estimated as part of the Green River Temperature TMDL [20, 44]



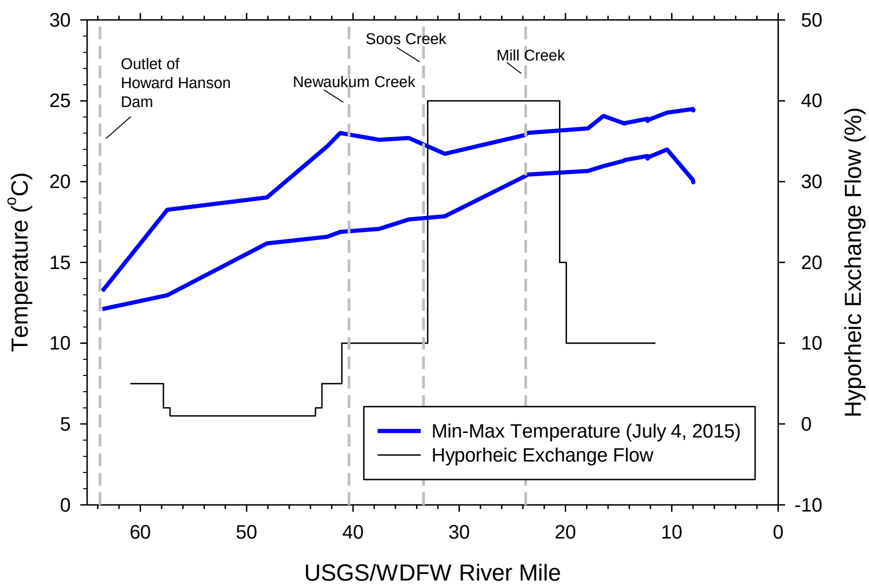
- Smaller than typical increases in maximum temperatures in the Green River gorge (~RM 48-58) are likely due to topographic shading [44]
- Narrowing of the daily temperature range and minimal increase in maximum temperatures from Soos Creek (RM 33.4) to Mill Creek (RM 23.8) are likely associated with alluvial deposits from historical connection to the White River (**Figure 2**) [44]

Figure 2: Map showing the location of the historical confluence of the White River with the Green River [44]



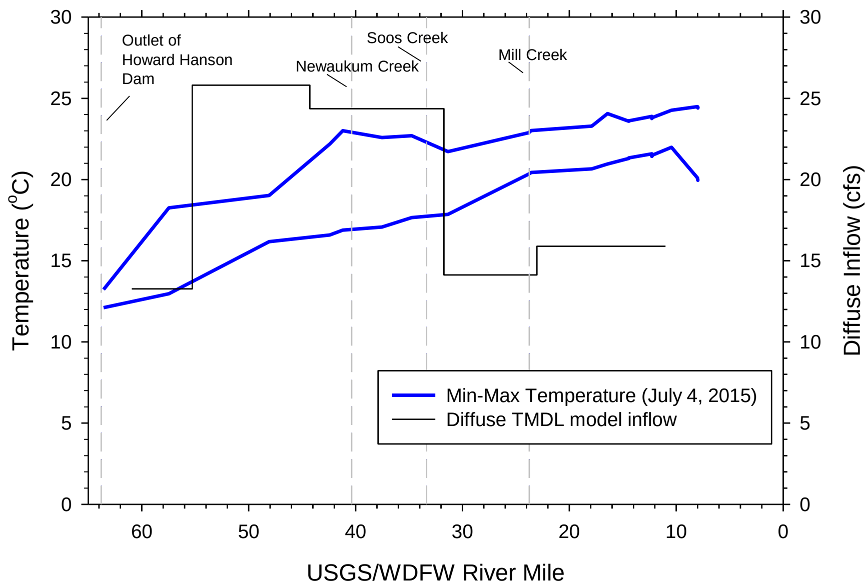
- Groundwater, hyporheic, tributaries, and tides
  - Infiltration and recharge throughout the watershed contribute to groundwater
  - Heat gains and losses from groundwater and tributary inputs can influence minimum and maximum temperature as well as buffer temperature fluctuations
  - Hyporheic exchange affects the minimum and maximum temperature, but has little effect on the daily average water temperature; hyporheic exchange doesn't lower the average temp, however, it can lower the 7-DMax as well as the range in daily temperatures
  - Tidal exchange can push colder estuarine salt-water up into lower portions of rivers
  - *Green River examples*:
    - Narrower temperature ranges around the Green River Gorge (~RM 48-58) are likely due to inputs of cold water via tributaries and springs (e.g., Palmer Springs, Icy Creek) and groundwater [20,44]
    - Narrow temperature ranges and minimal increases in maximum temperatures below Soos Creek (RM 33.4) to Mill Creek (RM 23.8) are likely due to increased hyporheic exchange along this portion of the river (**Figure 3**) [20,44]

Figure 3: Plot of 7-DMax and 7-DMin water temperature on July 4, 2015 for the Green River mainstem compared to the hyporheic exchange flow estimated as part of the Green River Temperature TMDL [20, 44]



- In the Middle Green, primary diffuse flow (flows from ungauged tributaries and groundwater) occurs from RM 55 to RM 32 (**Figure 4**) [20,44]

Figure 4: Plot of 7-DMax and 7-DMin water temperature on July 4, 2015 for the Green River mainstem compared to the estimated diffuse water inputs (ungauged tributaries and groundwater) estimated as part of the Green River Temperature TMDL [20, 44]

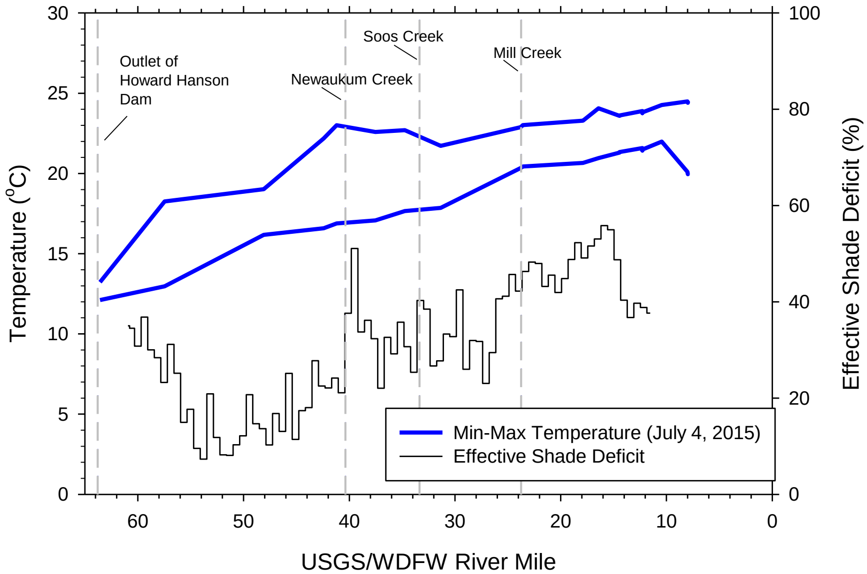


- Large temperature ranges at downstream locations in the Duwamish River are likely due to fluctuations from warmer upstream water temperatures and cooler estuarine water[44]

- Riparian corridor conditions
  - Riparian tree canopy buffers heat exchange between the river and solar-atmospheric radiation (heating caused by sun and warm air)
    - The effectiveness of shade provided by trees increases with the height of the trees, the width of riparian corridor, and the density of the planted riparian areas
    - Contiguous shade from wide riparian corridors (as compared to segmented or narrow corridors) is most effective at keeping water from warming from solar radiation
  - Wide riparian corridors support microclimate conditions that insulate stream temperatures from atmospheric radiation
    - Microclimate conditions from wide riparian corridors are most effective at insulating water from warmer air temperatures
    - A continuous buffer of at least 150 feet wide with trees ~104 feet tall and 90 percent canopy density is necessary to prevent temperature increases
  - The absence of insulating and buffering influences will cause streams to rapidly trend away from groundwater temperature and toward atmospheric temperatures; where insulating and buffering influences are strong, downstream temperature trends are reduced or eliminated
  - *Green River examples*:
    - Downstream increase in maximum water temperatures below Howard Hanson Dam is primarily due to the lack of riparian shade [44]

- Shade deficit (difference between mature riparian shade and current conditions) exists throughout the Middle and Lower Green River riparian corridor, below Howard Hanson dam to the Green River George, and from below the gorge around Flaming Geyser State Park to Tukwila (**Figure 5**) (20,44)

Figure 5: Plot of 7-DMax and 7-DMin water temperature on July 4, 2015 for the Green River mainstem compared to the estimated Effective Shade deficit determined as part of the Green River Temperature TMDL (20, 44)



- Priority areas for riparian plantings along the banks of the Green River, based on steep increases in maximum temperatures, include reaches downstream of Howard Hansen to ~RM 58 and from ~RM 48 to Newaukum Creek.
- Geographic priorities for revegetation, in order of the most to least important, are: the mainstem Middle Green River and Lower Green River; Soos and Newaukum Creeks and their tributaries; the Duwamish River; tributaries to the Middle Green River, Lower Green River and the Duwamish; the Upper Green River; and finally, the marine nearshore, and nearshore drainages (98)

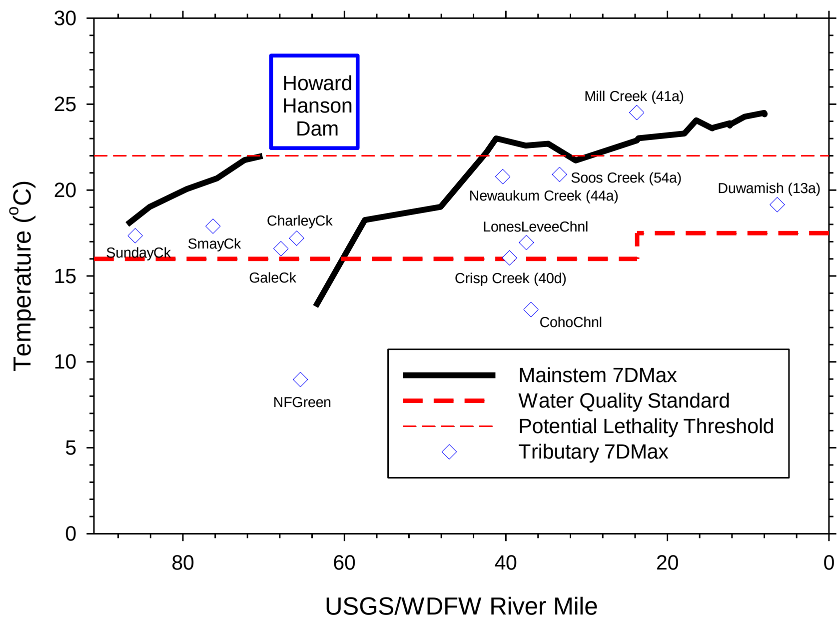
Cold-water refugia for salmonids (52, 72, 86, 91)

- Cold-water refugia are characterized as being at least 2°C colder than the daily maximum temperature of adjacent waters
- Cold-water refuges provide areas that maintain temperature conditions beneficial for cold-water species such as salmonids; these areas provide physiological and ecological benefits
- Permanent shifts in stream temperature regimes can render formerly suitable habitat unusable for native species
- Fish may use cold-water refuges at various temporal and spatial scales
    - Basin scale: cold water refugia driven by elevation, topography, geology, channel slope, and interactions with surface and subsurface hydrology
    - Segment and reach scale: cold water refugia driven by tributary confluences, bounded alluvial valley segments (vertical hyporheic exchange), relic floodplain channels (lateral hyporheic exchange)

- Channel habitat unit scale = cold water refugia driven by tributary confluences, side-channels, vertical and lateral hyporheic exchange, diel and temporal variation

- Cold water refugia can be eliminated by activities such as building levees and revetments along channels that block hyporheic exchange; urban development that prevents water infiltration, lowers groundwater tables, and removes trees
- *Potential cold water refugia in the Green River (below Howard Hansen Dam)*:
  - Green River gorge (~RM 48-58) (topographic shading and groundwater inputs)
  - Tributaries, confluences, and side-channels: Duwamish Tributary (RM 6.4), Palmer Springs (RM 56.3), Resort Springs (RM 51.3), Black Diamond Springs (RM 49.5), Icy Creek (RM 48.3), Crisp Creek (RM 39.6), Lones Levee Channel (RM 37.5), Coho Channel (RM 36.9) (**Figure 6**) [44]

Figure 6: Plot of 7-DMax water temperature on July 4, 2015 at Green River mainstem and selected tributary and side channel locations [20, 44]



  - Groundwater and hyporheic exchange zones: RM 55 - RM 32 in the Middle Green; areas around alluvial deposits between Soos Creek (RM 33.4) to Mill Creek (RM 23.8) (**Figure 3**) [44]
  - Reaches downstream of Howard Hansen where hypolimnetic withdrawals bring colder water into the mainstem Green River
- *Potential cold water refugia in the Green River (above Howard Hansen Dam)*:
  - North Fork Green (RM 65.5), Charley Creek (RM 65.9), Gale Creek (RM 67.9), Smay Creek (RM 76.3), and Sunday Creek (RM 85.9)

Table 1: Temperature Impacts on Chinook Life Stages

Life Stage	Impaired and Detrimental Temperature Range	Potential Temperature-related Impacts	Citations
Adult Upstream Migration	• Migration = average >15°C , maximums >18-20°C, 7-DMax >20°C • Complete blockage = 21-22°C • Disease susceptibility = average >17.5°C, 7-DMax > 15-19°C • Instant mortality = 32-33°C	• Increased metabolic demand • Delayed migration • Increased disease exposure • Direct lethality	1, 11, 15, 24, 25, 26, 29, 41, 51, 55, 56, 57, 58, 79, 78, 80, 84
Adult Pre-spawning	• Disease susceptibility = average >13-14°C, maximums >17-18°C • Gamete development = average >13-16°C	• Increased susceptibility to disease (e.g., *Ichthyophthirius multifillis*, *Ceratomyxa shasta*, columnaris disease) • Increased disease virulence • Decreased immune system condition • Reduced gamete quality and quantity	12, 14, 23, 24, 26, 55, 56, 57, 76, 78, 80
Adult Spawning	• Gamete viability = average >13-16°C • Spawning = average >12-13°C , 7-DMax > 12-14°C • Mortality = 7-DMax 21-25°C, maximum 24-25°C	• Reduced fertilization success • Reduced embryo survival to emergence	14, 22, 24, 56, 57, 75, 74
Egg	• Incubation = average >8-10°C, maximum >13-15°C	• Reduced embryo success, hatching-emergence, condition, and survival • Increased abnormalities and mortality • Altered metabolic rates, metabolic energy deficits	14, 23, 31, 32, 39, 56, 57, 65, 81, 95
Juvenile rearing and outmigration	• Growth = average >13-15°C, 7-DMax > 14-17°C, maximum > 17-19°C • Rearing = average >16°C, 7-DMax > 15-18°C • Disease susceptibility = average >14-17.5°C • Feeding = average >18-20°C • Smoltification = average >15.5°C, 7-DMax > 15-16°C • Migration = average >18-22°C • Mortality = average >23°C	• Reduced growth and feeding rates • Reduced competitive advantage with warm-water species • Reduced survival • Increased susceptibility to disease • Altered development and migration timing • Accelerated onset of smoltification and desmoltification	3, 7, 14, 23, 26, 46, 54, 55, 56, 57, 81, 87, 96, 99

Department of Ecology Sub-lethal and Lethal Temperature Thresholds

- Water temperature is a key aspect of water quality for salmonids, and excessively high water temperature can act as a limiting factor for the distribution, migration, health and performance of salmonids [23, 24, 56, 57, 76]
- Washington Department of Ecology established water temperature standards for salmon habitat at various stages of their life history in Chapter 173-201A of the Washington Administrative Code (WAC)
- Thresholds for sub-lethal impacts: 7-DMax (7 day average of the daily maximum temperatures)
  - Salmon and Trout Spawning = 13°C 7-DMax (September 15th to July 1st)
  - Core Summer Salmonid Habitat = 16°C 7-DMax (June 15th to September 15th)
  - Salmonid Spawning, Rearing, Migration = 17.5°C 7-DMax (September 16th to June 14th)
- Thresholds for acute lethal impacts and barriers to migration: 7-DMax and 1-DMax (1 day average of the daily maximum temperatures)
  - Salmon acute lethality = 22°C 7-DMax and 23°C 1-DMax
  - Salmon barriers to migration = 22°C 1-DMax (3°C downstream differences)
- Exceedances above the aforementioned thresholds indicate likely sub-lethal and lethal impacts to salmonid
- If a water body is naturally warmer than or within 0.3°C of the standard/threshold for that water body, human caused increases (considered cumulatively) must not increase that temperature by more than 0.3°C

Temperature Conditions in the Green River in 2015

(Following section based on King County 2016)

The spring and summer of 2015 was abnormally warm and dry, with low snow pack due to a very warm winter. King County compiled water temperature data along the Green River from seven different entities in order to characterize water temperatures. According to climate change scenarios, we expect future years to look more like the spring and summer of 2015 than averages from the last 20 years.

- Precipitation and air temperature:
  - 2015 had average levels of fall and winter precipitation, but record warm temperatures led to winter rain rather than snow at higher elevations (snow drought)
  - 2015 air temperature frequently exceeded the 90th percentile (1949-2015) on several occasions from January through July 2015 by as much as 5 °C; most notable were substantial excursions above the 90th percentile in June and July
- Instream flow:
  - 2015 snowpack was low in the upper watershed; however, winter flows were not unusually low and summer flow targets set in the Tacoma Water Habitat Conservation Plan for extremely dry weather were met or exceeded
- Water temperature:
  - Water temperature in 2015 was similar to the 90th percentile (2001-2015) through late May; water temperatures were much higher than typical from late May through the beginning of July
  - 2015 peak daily maximum temperatures were observed in late June (compared to typical occurrence in July and August)
  - The relatively rapid rise in 7-DMax temperature between the outlet of Howard Hanson Dam and Kanaskat (approximately 6 miles downstream) was likely due to a lack of riparian cover
  - Relatively small increase in maximum temperature in the gorge is likely due to topographic shading and input of cold water via tributary springs

    - Increase in the diurnal range from Flaming Geyser State Park to Soos Creek is likely due to the relatively shallow water depth through this reach coupled with the lack of riparian shade
    - Narrowing of the temperature range below Soos Creek to Mill Creek is likely due to increased hyporheic exchange (potential for large alluvial deposits)

- 2015 Compared to 2006 and 2003
    - 2006 precipitation, snowpack, and air temperature were relatively typical of historic conditions; mainstem flows in 2006 were not unusually low
    - Water temperatures observed in 2006 were closer to 2001-2015 average conditions
    - The maximum 7-DMax temperatures observed downstream of the Green River gorge were consistently higher in 2015 compared to 2006 and 2003
    - System potential shade model predictions illustrate that even with extensive amounts of additional shade along the entire river, water temperatures would still likely exceed criteria under critical flow and weather conditions
        - 2015 stands out as having the highest 7-DMax temperatures below the gorge – higher even than the “worst case” existing condition shade model

Potential Temperature-related Impacts to Chinook in the Green

(Following section based on King County 2016)

- 7-DMax temperatures exceeded the relevant temperature standard throughout the mainstem – upstream and downstream of Howard Hanson Dam (exception being at the outlet of the dam up until late summer where discharge of cool hypolimnetic bottom waters from the pool behind Howard Hanson Dam cool mainstem temperatures)
- The 7-DMax observed in July 2015 exceeded the 22 °C potential lethal criterion at almost every mainstem location sampled from Flaming Geyser State Park below the Green River gorge to the most downstream station in the Duwamish River
- Green River Water Temperature Exceedances **(Table 2)**
    - Consistent exceedance of 7-DMax Salmon Core Summer Habitat criterion (mid-June to mid-September); 2015 had exceedance as early as late May
    - Consistent exceedance of 7-DMax Salmon Spawning Habitat criterion (mid-June to mid-September); 2015 had exceedance as early as late May
    - Occasional exceedance of 7-DMax Potentially Lethal criterion

Table 2: Department of Ecology salmon and trout designated aquatic use designation, respective 7-DMax temperature criteria, and 2015 temperature trends. Use designation and temperature criteria based on Table 200 and 602 of WAC 173-201A-602.

Location Along Green River	Use Designation	7-DMax (°C)	2015 Temperature Trends
Mouth to Black River (RM 0-11)	Salmon/trout migration and rearing • Migration • Rearing	 17.5 17.5	• 7-DMax temperatures consistently exceeded the salmon/trout rearing and migration criterion until about September 2, 2015 • 7-DMax temperatures consistently exceeded the salmon/trout 22°C lethal criterion for several days at the end of June and early July and the most downstream stations exceeded lethal criterion in July and again at the beginning of August
Black River to Mill Creek (RM 11-23.8)	Salmon/trout migration, spawning, and rearing • Migration • Rearing • Spawning • Incubation	 17.5 17.5 13 13	
Mill Creek to Flaming Geyser State Park (RM 23.8-42.3)	Salmon/trout core summer habitat • Migration • Rearing • Spawning • Incubation	 16 16 13 13	• 7-DMax temperatures consistently exceeded the salmon/trout core summer habitat criterion • 7-DMax temperatures exceeded the salmon/trout spawning and incubation criterion through July 1st and again at the end of the summer • 7-DMax temperatures from RM 34.8-41.2 (below gorge) exceeded the salmon/trout 22°C lethal criterion for several days at the end of June and beginning of July; no observed exceedances from RM 23.8-33.4
Flaming Geyser State Park to headwaters (RM 42.3-85.9)	Salmon/trout core summer habitat • Migration • Rearing • Spawning • Incubation	 16 16 13 13	• 7-DMax temperatures consistently exceeded the salmon/trout core summer habitat criterion • 7-DMax temperatures exceeded the salmon/trout spawning and incubation criterion at the beginning and end of the summer • 7-DMax temperatures exceed the salmon/trout 22°C lethal criterion for a few days at RM 70.2
Green River and Sunday Creek: all waters above confluence	Char • Rearing • Spawning • Incubation	 12 9 9	• 7-DMax temperatures consistently exceeded the char spawning and rearing habitat criterion
Smay Creek and West Fork Smay Creek: all waters			

- Green River Chinook life stages likely impacted by high water temperatures (**Figure 7 & Table 3**)
  - Parr rearing (core summer criterion)
  - Yearling rearing (core summer criterion)
  - Adult upstream migration (migration/spawning/incubation criterion)
  - Early spawning and incubation (spawning/incubation criterion)

Figure 7 (adapted from King County 2016): Plot of 7-DMax water temperatures for the 2015 and 2016 calendar years measured by King County at the Whitney Bridge station (GRT10) compared to 7-DMax temperatures measured from 2001-2014. State standards for designated uses are noted by the orange line and potentially lethal impacts are indicated by the red line. State standards for designated uses include core summer salmonid habitats (July 1 – September 15) as well as spawning and incubation periods (September 16 – July 1). Timing of specific Green River Fall Chinook life-stages included below.

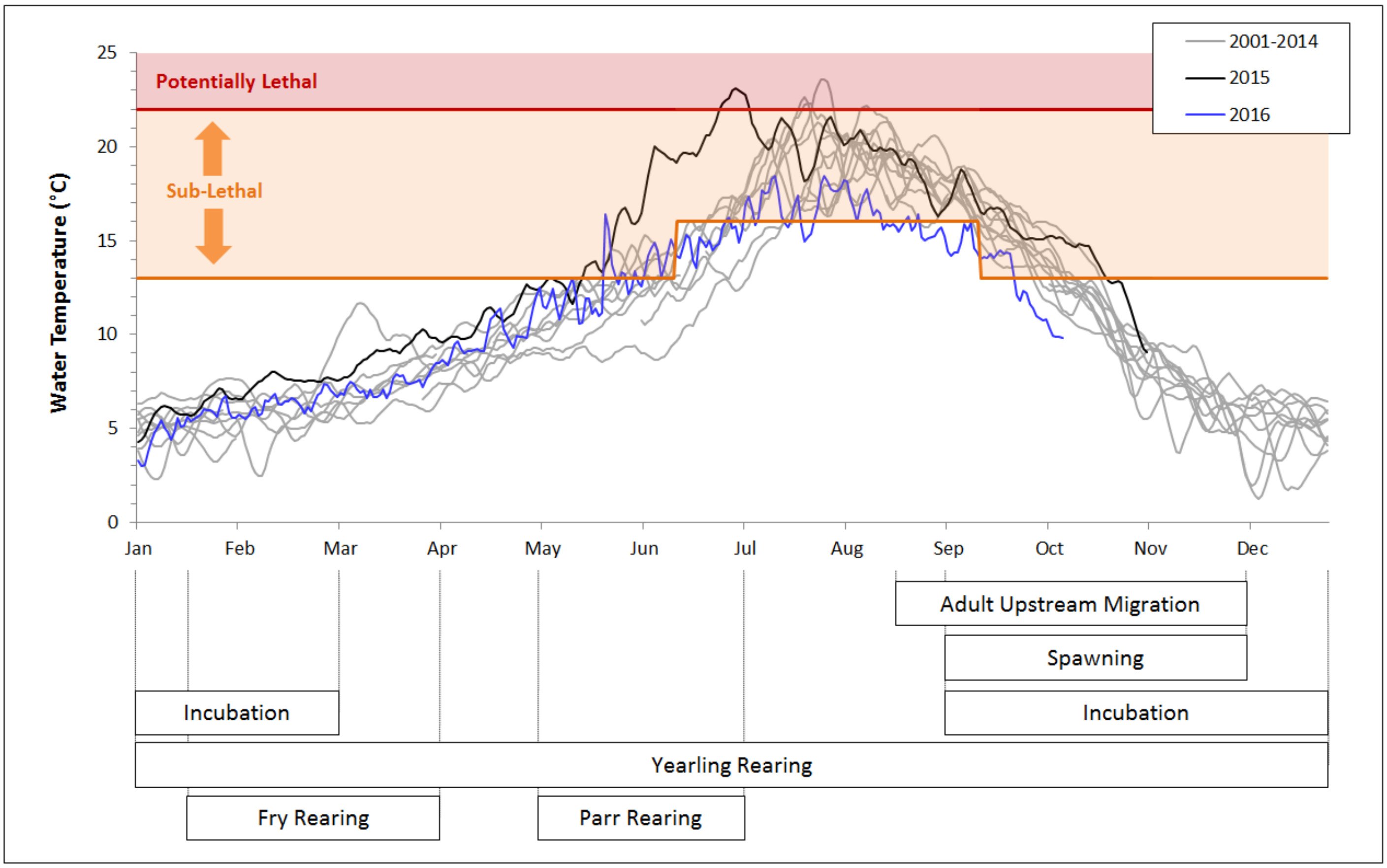


Table 3: Locations across the Green River of potential temperature-related impacts on Fall Chinook life stages.

Life Stage	Potential Temperature-related Impacts	Location in Green River
Adult Upstream Migration	• Increased metabolic demand • Delayed migration • Increased disease exposure • Direct lethality	• Migration Inhibited: RM 0 – RM 46 • Blockages: RM 0 – RM 44 • Disease: RM 0 – RM 48 • Lethality: RM 0 – 23.8, 34.8-41.2, 70.2
Adult Pre-spawning	• Increased susceptibility to disease (e.g., *Ichthyophthirius multifillis*, *Ceratomyxa shasta*, columnaris disease) • Increased disease virulence • Decreased immune system condition • Reduced gamete quality and quantity	• Migration Inhibited: RM 0 – RM 46 • Blockages: RM 0 – RM 44 • Disease: RM 0 – RM 48 • Lethality: RM 0 – 23.8, 34.8-41.2, 70.2
Adult Spawning	• Reduced fertilization success • Reduced embryo survival to emergence	• Mainstem spawning: Middle Green RM 25.4 – RM 60.8 • Tributaries: Soos Creek, Newaukum Creek
Egg	• Reduced embryo success, hatching-emergence, condition, and survival • Increased abnormalities and mortality • Altered metabolic rates, metabolic energy deficits	• Mainstem spawning: Middle Green RM 25.4 – RM 60.8 • Tributaries: Soos Creek, Newaukum Creek
Juvenile rearing and outmigration	• Reduced growth and feeding rates • Reduced competitive advantage with warm-water species • Reduced survival • Increased susceptibility to disease • Altered development and migration timing • Accelerated onset of smoltification and desmoltification	

Potential Climate Change Impacts and Trends to Water Temperature Conditions

- Climate Change impacts: higher air and water temperatures, lower summer flows, altered precipitation and hydrologic regimes, and increased magnitude/frequency of winter peak flows [4, 22, 37, 52, 53]
- Summer periods of high temperatures and low flows
  - Summer flows have been trending lower for many decades resulting in decreased available habitats [48, 50, 77, 88]
  - Most models predict summer warming will exceed warming in other seasons [52, 53, 64]
  - At a summertime warming range of 2-5.5°C, there is potential for loss of 5 to 22% of salmon habitat by 2090 [69]
  - Significant increases in water temperatures and thermal stress for salmon statewide will occur with climate warming [52, 53]
  - Nearly 40-50% reduction in salmon cold-water habitat could occur with climate warming [19]; Disrupting migration as fish hold in cold-water refuges [27, 41, 90]
  - Competitive interactions will be increasingly skewed towards species with warmer temperature tolerances [17,59]
  - Yearling likely sensitive due to increased exposure to the highest water temperature conditions in summer [4]
- Changes in precipitation and hydrologic regimes
  - Changes in precipitation and temperature associated with regional warming in the PNW will alter snowpack and hydrologic regimes [22, 30, 49, 82]
  - *Green River Watershed*: significant reduction in snow water equivalence predicted to start in the 2020's; increased winter precipitation and decreased summer precipitation; higher runoff in cool season and lower runoff in warm season; altered timing of flows [22]
  - Shifting of watershed hydrographs from transient rain-snow and snow-dominant to rain-dominant [22]
  - Increased flood magnitude and frequency during incubation can decrease survival rates by scouring redds, crushing eggs, mobilizing gravels, and depositing fine sediments on redds [18, 7, 36, 61, 79]
  - Warmer cold season temperatures and warmer annual minima may shift biological processes (e.g. altered growth rates and food availability) ; warming trends will reduce the time between spawning and juvenile hatching [37]; snowmelt driven freshets have advanced 2-3 weeks in last 50 years [73, 88]
  - Possible desynchronization of juvenile hatching and emergence from optimal periods for flows and food availability [6]
  - Reduced availability of slow-water habitats, which can flush rearing juveniles downstream from preferred habitats and decrease freshwater survival rates [47]
  - Accelerated temperature regime during springtime can result in either earlier emigration (caused by more rapid development to the smolt stage) or less success in smoltification (caused by high temperature, desmoltification, or inhibitory effects) [56]

Human alteration to river thermal regimes:

  - Dams: reduced thermal and flow variability, potential for hyporheic exchange to act as a temperature buffer is reduced by flow regulation, altered sediment dynamics, alter thermal dynamics from storage reservoirs [68, 70, 72, 93]
    - Howard Hanson Dam has a large, deep reservoir with hypolimnetic withdrawals releasing colder water during the summer and warmer water during late summer, fall, and winter

- Water withdrawals: reduced in-stream flows result in reduced assimilative capacity of streams, draw hyporheic water away from the stream [33, 60, 66, 72]
- Channel engineering and connectivity (e.g., straightening, bank hardening, diking, and disconnection of surface-groundwater, side-channel, and floodplain exchange): decreases the interaction of stream channels with floodplain and alluvial aquifer, hyporheic areas, and reduces habitat variability (drive streambed hyporheic flow) [40, 72, 97]
    - Primarily Lower Green (King County maintains over 30 miles of levees and revetments on the Green/Duwamish); lower sections of the Middle Green.
- Removal of vegetation (upland or riparian): reduced insulating properties (reduces convective heat exchange), limited blocking of solar radiation and trapping of cool air temperature, altered infiltration and hydrologic dynamics [35, 56, 6, 98]
    - High priority areas with degraded riparian conditions include the Middle Green (RM 32 – 64), Lower Green (RM 11 – 32), Soos and Newaukum, Duwamish River (RM 0 – 11), small tributaries to Middle and Lower Green (e.g., Burns, Crisp, Mill, Mullen, Springbrook, Brooks creeks), etc.
- Land use (e.g., impervious related development): altered hydrologic regime, decreased infiltration and recharge, altered exchange between reach and alluvial aquifer, reduced storage/higher winter flows and reduced summer recharge [10, 12, 67, 83]
- Climate Change: increased air and water temperature, reduced snow storage (influencing summer low flows), altered precipitation and flow regime (frequency and timing of events), reduced rearing and suitable habitats availability, altered temperature-specific ecological timing across salmon life stages [4, 19, 22, 37, 48, 52, 53, 63]

Strategies for Cooler Water Temperatures

- Protect riparian forested areas as buffers to air and solar radiation warming water.
- Plant wide, contiguous riparian buffers of tall trees where possible. Priority areas include the six miles immediately downstream of Howard Hanson Dam, etc. (from above), and priorities listed in the WRIA 9 Riparian Revegetation Strategy.
- Purchase conservation easements or fee simple acquisition of riparian areas in order to protect and maintain native trees along channels.
- Protect existing cold water refugia from urban development, tree removal, and bank armoring.
- Protect and restore areas known to contribute to groundwater recharge.
- Restore areas of hyporheic exchange to cool water by setting back levees and taking other actions to reconnect channels to the historic floodplain.
- Work with the ACOE to consider options for pulling cooler water from the reservoir behind Howard Hanson Dam, especially in late summer.
- Reduce water withdrawals from the watershed, and encourage use of reclaimed water instead.
- Encourage low impact development practices that reduce impervious surfaces, and lot sizes, maintain forested areas and wildlife corridors, and promote stormwater infiltration and treatment.
- Retrofit developed areas to infiltrate and treat stormwater and plant trees to promote groundwater recharge, bolster summer stream flows, and cool stormwater runoff.

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