Chapter 5: Strategic Assessment Update - New Science on Priority Pressures

The 2005 Strategic Assessment provided the scientific foundation for the Salmon Habitat Plan. Although the majority of science remains relevant today, new research findings have refined our understanding of priority pressures and limiting factors related to Viable Salmon Population (VSP) criteria. The 2005 Strategic Assessment evaluated functional linkages between priority pressures; habitat conditions; and Chinook abundance, diversity, productivity and spatial structure. The functional linkages were used to create a series of conservation hypotheses that outlined how improvements in habitat conditions and natural processes will drive changes in VSP parameters.

From 2017-2018, WRIA 9 produced a series of white papers as addendums to summarize new research and address priority data gaps in the original 2005 Strategic Assessment. White papers included *Fish Habitat Use & Productivity* (Higgins 2017)*; Water Temperature* (Kubo 2017)*; Contamination* (Colton 2018)*; and Climate Change* (Engel, Higgins and Ostergaard 2017). This chapter provides a summary of the highlights of those papers as they relate to priority pressures impacting Chinook salmon in the Green/Duwamish Watershed. These refinements in our understanding of priority pressures informed both the recovery strategies presented in Chapter 6 and the prioritization of capital projects in Chapter 7.

Priority Pressures (Basin of Focus)

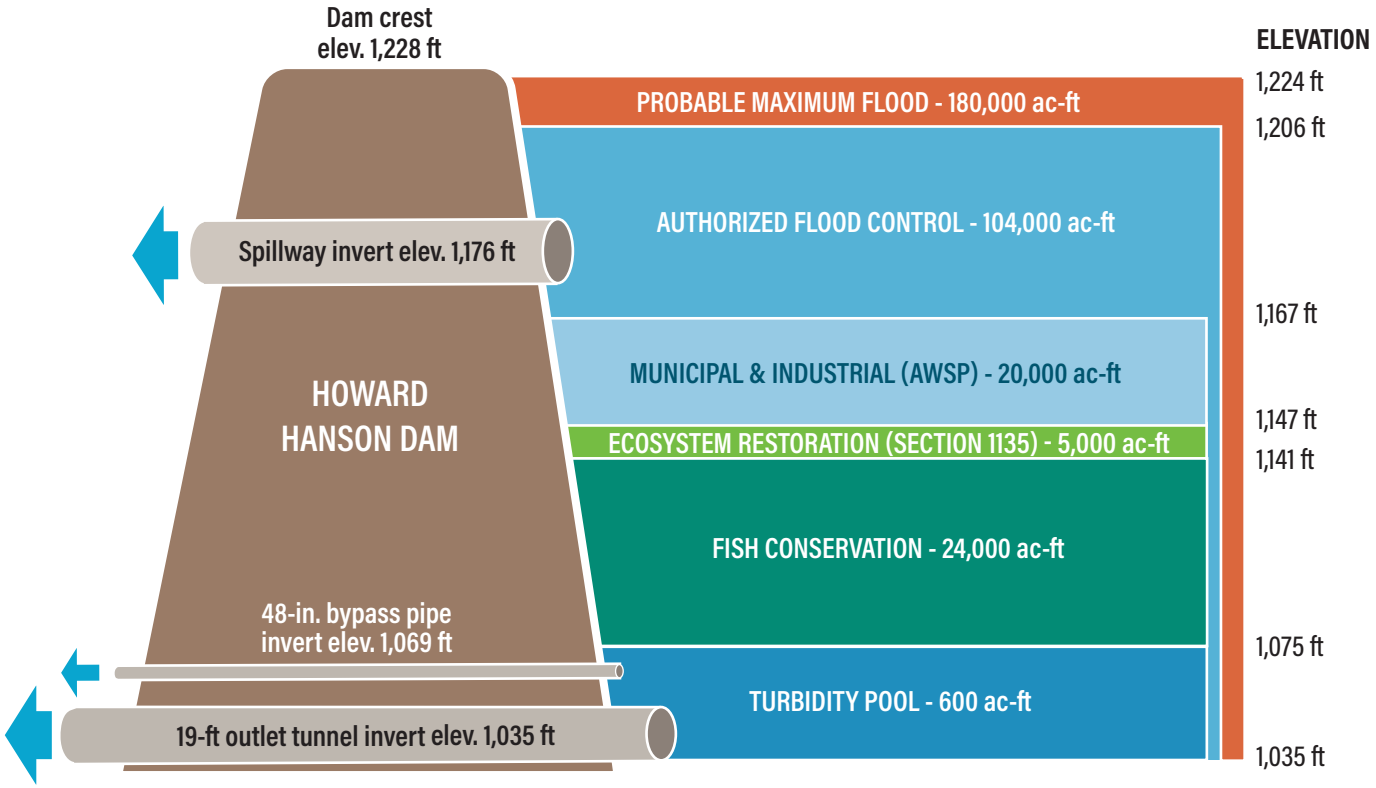
Addressing priority habitat stressors is critical to restoring a viable salmon population in the Green/Duwamish and Central Puget Sound Watershed. The following stressors have clear functional linkages to one or more VSP parameters (abundance, productivity, diversity, and spatial structure). Applicable research and monitoring information is highlighted to reflect new research and best available science since the 2005 Plan.

Altered Instream Flows (Middle Green, Lower Green)

Watershed Status

Operations at Howard Hanson Dam (HHD) and the Tacoma Headworks diversion dam regulate instream flows within the mainstem Green River below river mile 64.5. Water storage, diversion, and release are jointly managed by the U.S. Army Corps and Tacoma Water utility. Although flood risk reduction is the primary mission of HHD, water storage also supports Tacoma municipal and industrial uses, and fish conservation uses. In 2007, Tacoma Water's Additional Water Storage Project provided capacity to store an addition 20,000 acre-feet (ac-ft) for municipal use.

Figure 7. *Howard Hanson Dam spring water storage and allocation.*



Source: United States Army Corps of Engineers, Seattle District.

Water capture and storage generally occur between late February and June 1. Figure 7 depicts how a spring water storage target of 49,000 ac-ft is legally allocated between municipal and fish conservation uses. Phase 2 of the Additional Water Storage Project (to be completed at a later date following downstream fish passage) would raise the conservation pool to 1,177 feet and store an additional 12,000 ac-ft of water. The U.S. Army Corps convenes a bi-weekly Green River Flows Management Coordination Committee to inform water capture and a subsequent flow augmentation period that extends from July 15 to November depending on fall rainfall. Augmentation of flows is intended to support Chinook salmon migration and spawning, maximize summer rearing habitat, and minimize dewatering of steelhead redds. Limited Fish Conservation and Ecosystem Restoration allotments frequently require tradeoffs among these ecological benefits – especially in dry and/or warm years with low snowpack. The Tacoma Water Habitat Conservation Plan establishes a minimum stream flow of 225 cubic feet per second (cfs) at the Auburn gauge. During the summer of 2015, the minimum flow at the Auburn gauge reached 226 cfs.

Although flows are not regulated in tributaries, in-streams flows are impacted by stream withdrawals and groundwater wells used to support residential and agricultural uses. In 2018, the Washington Legislature passed the Streamflow Restoration Law to offset the impacts of future permit exempt domestic groundwater withdrawals and help restore instream flows. The law was in response to a 2017 Washington State Supreme Court decision (Hirst Decision) that restricted building permits for new residential homes that would be reliant on permit-exempt wells. The legislature appropriated $300 million over 15 years to support implementation of projects to improve stream flows across the state. The Washington State Department of Ecology is developing a Watershed Restoration and Enhancement Plan to identify and prioritize water offset projects in WRIA 9.

Research/Monitoring

Flow management at HHD dictates instream habitat conditions within the mainstem Green River. As a result, water storage and subsequent release timing not only impacts natural hydraulic processes, but also influences available salmon habitat and productivity. Maintaining minimum instream flows of 250 cfs during dry summer months provides important benefits to available fish habitat. However, associated water capture and storage has reduced the frequency and magnitude of high – habitat forming – flows while prolonging the duration of moderate flows (Higgins 2017). Moderate flows between 5000-8000 cfs are not sufficient to drive process-based habitat formation, but do have the potential to scour redds (R2 Resource Consultants 2014).

Flows above 8,800 cfs are needed to initiate lateral channel migration and support creation of off-channel habitats that are critical for juvenile Chinook rearing (Konrad et al. 2011).

Long-term juvenile Chinook outmigration data collected by WDFW highlights the function relationship between instream flows and Chinook productivity (Anderson and Topping 2018). High flows (between ~8,000–10,000 cfs) from November through mid-January appear to scour eggs, sharply reducing the overall productivity of the number of juveniles per spawner. High flows (~6,000-8,000 cfs) during the typical fry outmigration period (mid-January through the end of March) reduce the number of parr produced in the Middle Green, likely because fish are flushed into habitats downstream of the trap. The frequency of spring flows (April through June) above 1,200 cfs appears to increase the number of parr produced. This is likely due to increased connectivity to off-channel habitats, like side-channels. A separate study (R2 Resource Consultants 2013) showed that, at flows below 1,200 cfs, side channel habitats become less connected to the mainstem and overall habitat complexity decreases.

Climate Change (Watershed-wide)

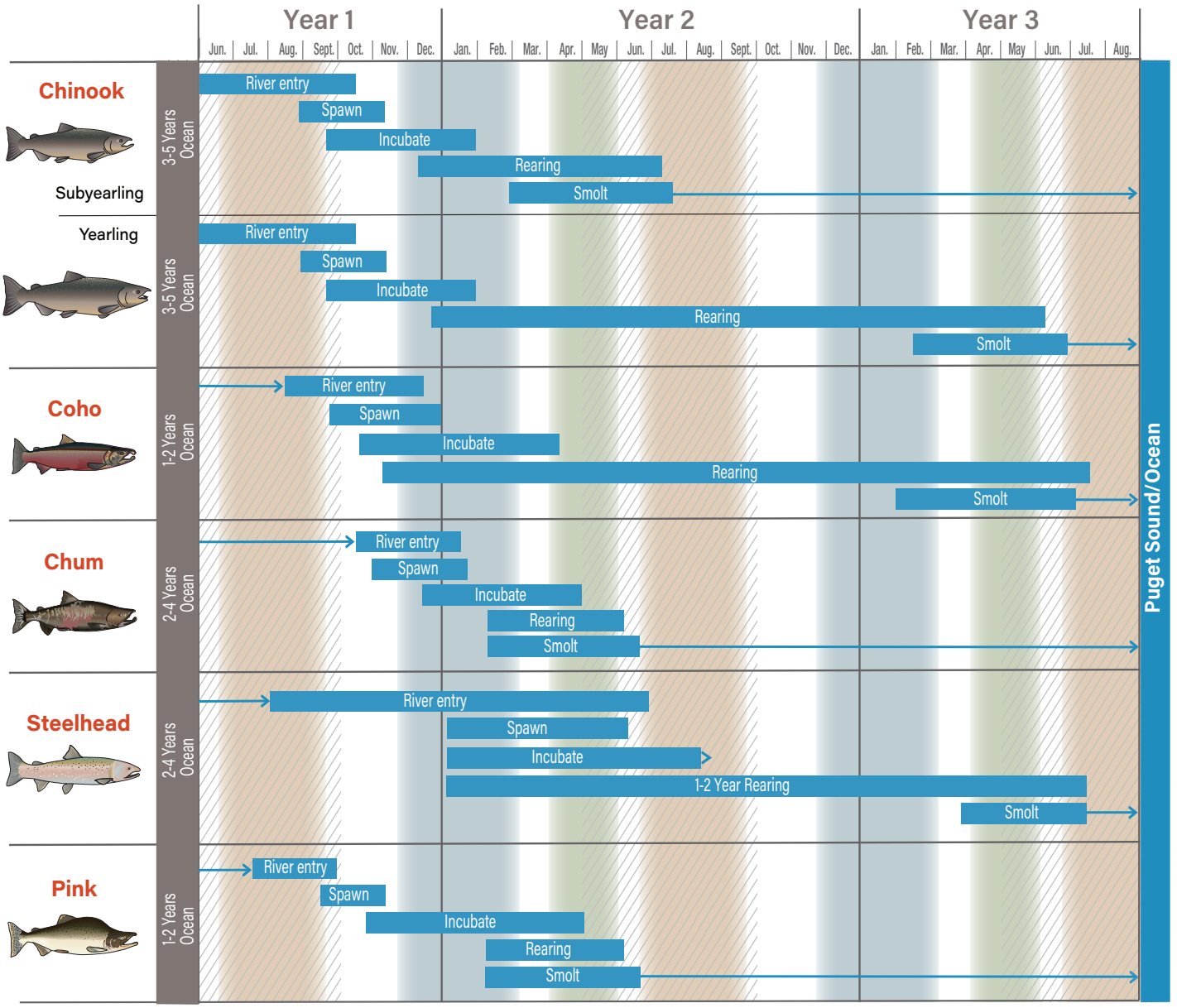
Watershed Status

Climate change science was not incorporated into the 2005 Plan because future climate scenarios were unclear. However, climate change has been the focus of intense research, both global and regional, over the last decades. This research highlights the need to prepare for the current and future impacts of climate change and incorporate what we know about climate change into salmon recovery actions.

Climate change will directly impact salmon recovery work in the Green/Duwamish and Central Puget Sound watershed. The UW Climate Impacts Group (Mauger et al. 2015) and others predict that Pacific Northwest precipitation patterns will change, bringing warmer, wetter falls, winters, and springs. Floods will be more intense and more frequent, with peak flows expected to increase by 28-34 percent by 2080. As winters become warmer and wetter, the watershed is projected to shift from mixed rain and snow to a rain-dominated basin with less mountain snow melting earlier in the spring. The decrease in amount and earlier disappearance of the snow pack will exacerbate drought-like summer low flow conditions in currently snow-dominated areas of the watershed. Summertime rain is expected to decrease by ~22% by 2050. A projected 4-5°F increase in air temperatures will increase water temperature in both rivers and the ocean. Nearshore and estuary areas will be impacted by sea level rise, food web alteration and ocean acidification. A changing climate will exacerbate typical climate variability, causing environmental conditions that will negatively impact our salmonids and their habitat. The potential impacts to various life histories of salmonids, including Chinook salmon, as a result of climate change are summarized in Figure 8.

Climate Change Impacts on WRIA 9 Salmonids

Adapted from Beechie et al. (2012). Fish timing represents typical fish behavior.



Increased summer temperature may decrease growth or kill juvenile salmon where temperatures are already high and block/delay migration. May also decrease spawning fecundity (e.g. Chinook).

Increased winter floods may increase scour of eggs, or increase mortality of rearing juveniles where flood refugia are not available, displace juveniles to less desira ble habitats.

Decreased summer low flow may contribute to increased temperature, decrease rearing habitat capacity for juvenile salmonids, and decrease access to or availability of spawning areas.

Loss of spring snowmelt may decrease or eliminate spawning opportunities for steelhead, may alter survival of eggs or emergent fry for other salmonid species, cause early dewatering of off-channel and side channel habitats, and reduce connectivity to the floodplain.

Figure 8. *Projected impacts to Green/Duwamish and Central Puget Sound salmon as a result of climate change.*

Research/Monitoring

A changing climate will exacerbate typical climate variability causing environmental conditions that will negatively impact our salmonids and their habitat. The summer of 2015 likely provided a glimpse of the future ecological conditions in the Green/Duwamish watershed. A warm, wet winter with extreme low snowpack levels, coupled with a dry, hot summer, created dire conditions for salmon. (DeGasperi 2017) The Muckleshoot Indian Tribe reported adult Chinook salmon dying in the stream just below the Soos Creek hatchery (H. Coccoli, pers. comm.), and Washington Department of Fish and Wildlife (WDFW) data indicated higher than typical numbers of female Chinook mortality with high egg retention (pre-spawn mortality) (Unpublished WDFW data). Other sublethal impacts associated with temperatures in excess of 17°C can include developmental abnormalities, altered growth rates, and non-fertilization of eggs; altered migration timing; altered predator/prey relationship; and reduced disease resistance.

Sea level in Puget Sound rose 20 centimeters from 1900-2008 and scientists project sea level will rise an additional 0.6 meters by 2100. A 1-foot increase in water surface elevation means an order of magnitude increase in high water events—so a 100-year event turns into a two year event (Mauger et al. 2015). Sea level rise will have myriad effects on the marine nearshore habitats, including increased bank/bluff erosion, landslides, and lost nearshore habitats (e.g., eelgrass, forage fish spawning habitat, estuary mudflats, etc.) due to the "coastal squeeze" adjacent to armored shorelines. In addition, increased risk of erosion could contribute to a growing demand for additional shoreline armoring.

Water temperatures as measured on July 4, 2015, exceeded the potential lethally threshold (22°C) for salmonids downstream of the Green River Gorge (DeGasperi 2017).

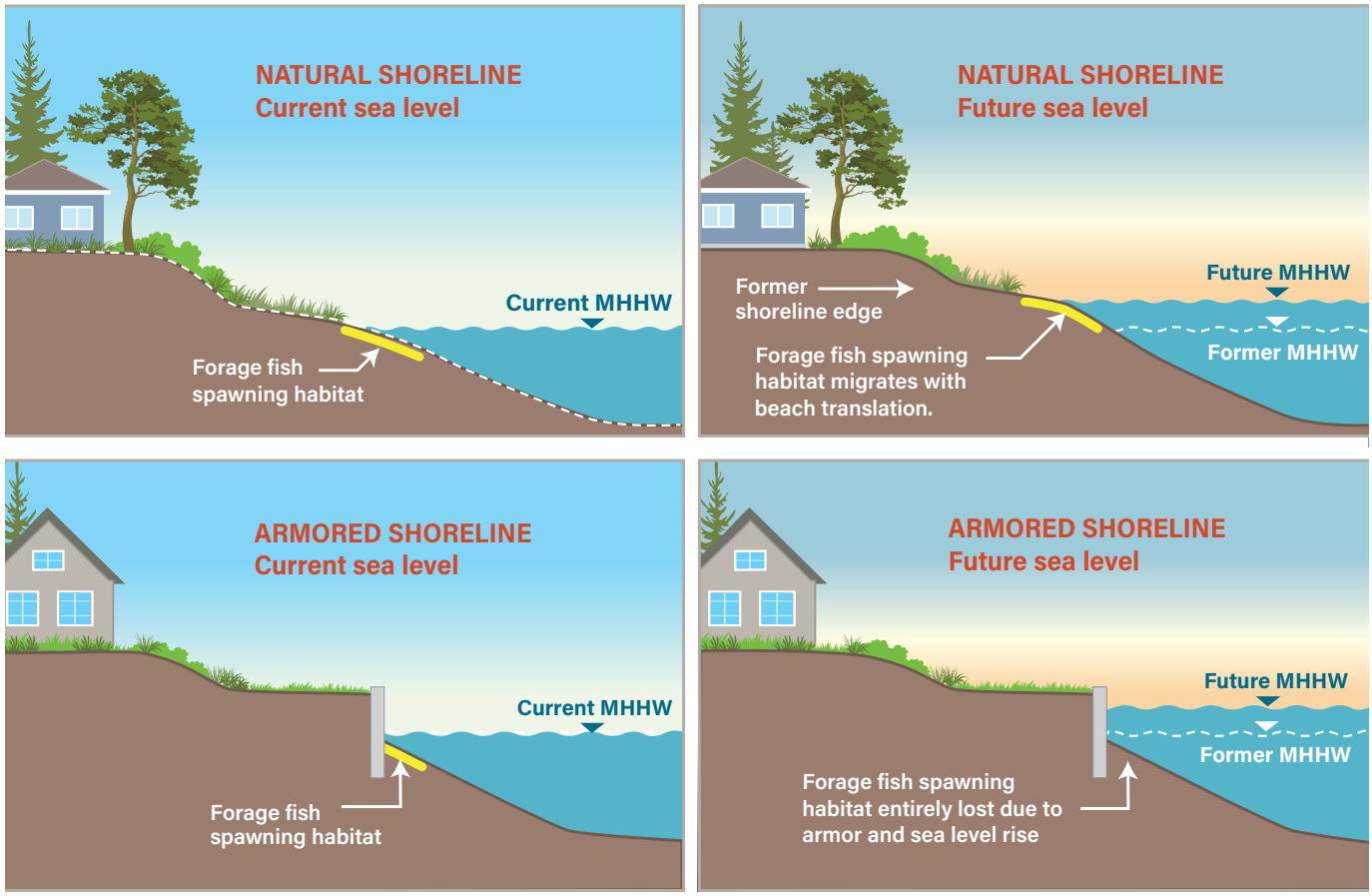


***Figure 9**. Coastal squeeze in nearshore graphic along the Puget Sound Nearshore refers to the shallow areas where forage fish spawn and are being squeezed out of existence by shoreline armoring and sea level rise (Coastal Geologic Services).*

A growing body of research is focusing on the potential impacts of ocean acidification on the Puget Sound ecosystem. Ocean acidification is driven by the absorption of carbon dioxide and is expected to impact survival, growth and behavior of marine organisms. In addition to observed impacts to calcifying organisms (e.g., oysters and crab) there is more recent evidence that ocean acidification may impair sense of smell in salmon, impede growth in herring and other species, and alter plankton populations – which may have a cascading impact on marine food webs. Experiments have shown that coho salmon's ability to avoid predators declines and risk of being eaten increases in low pH waters (Dunagan 2019). Although considerable uncertainty surrounds the potential impacts of ocean acidification on salmon, there is potential for it to exacerbate the issue of marine survival.

Elevated Water Temperatures (Watershed-wide)

Watershed Status

Water temperature is a key determinant of the biological integrity of a river – especially as it relates to cold-water dependent salmonids. High water temperatures can act as a limiting factor for the distribution, migration, health and performance of salmon. Washington State's water quality standards are protective of viable salmonid habitat in the Green River by assigning a numeric criterion of 16°C, above which the water body is considered impaired (WAC 173-201A-602). A supplemental criterion of 13°C, in effect between September 15 and July 1 further protects salmonid habitat. The widespread removal of tall, native trees along the riparian corridor – especially in the middle and lower Green River – allows solar-atmospheric radiation to rapidly warm water as it moves downstream below HHD. As a result, large stretches of the Green River, Soos Creek and Newaukum Creek regularly exceed established water quality standards for temperature. In 2011, the Washington State Department of Ecology developed total maximum daily loads (TMDLs) for the Green River and Newaukum Creek that outlined an implementation plan for improving temperatures. Another TMDL for Soos Creek is under development.

The Green/Duwamish experienced widespread potentially lethal water temperatures in 2015 (DeGasperi 2017). In response, WRIA 9 led the development of the *Re-Green the Green: Riparian Revegetation Strategy* (2016) to emphasize the critical need for increasing riparian canopy and to prioritize revegetation efforts within the watershed. The strategy was adopted as an addendum to the 2005 Salmon Habitat Plan. It incorporated solar aspect shade maps published in 2014 by the Muckleshoot Indian Tribe to prioritize areas where increased tree canopy – and thus shade – could provide the largest benefit to preventing elevated water temperatures. It also established revegetation goals that were directly incorporated into this Plan Update. WRIA 9 developed a Re-green the Green grant program using Cooperative Watershed Management funds from the Flood Control District to accelerate revegetation efforts across the watershed.

Research/Monitoring

In addition to periodic exceedances of potential lethal water temperatures, a review of 7-DMax water temperatures at Whitney Bridge (RM 41.5) shows that instream temperatures regularly exceed established thresholds for sublethal impacts to salmon. Figure 10 shows 7-DMax temperatures from 2001-2016 in relation to key Chinook salmon life history stages. These data suggest migration, early spawning, egg incubation, yearling and parr rearing all potentially subject to sublethal impacts associated with elevated water temperatures.

A literature review completed for WRIA 9 (Kubo 2017) provides a summary of potential temperature-related impacts to Chinook salmon. Adult fish migrating upstream may be subject to increased metabolic demand, delayed migration, increased disease exposure, decreased disease resistance, and even direct mortality. Spawning fish may experience reduced gamete quality and quantity and reduced fertilization success. Chinook eggs may be subject to reduced embryo survival, decreased hatching-emergence condition, increased abnormalities, and altered metabolic rates. Juveniles and outmigrants may be subject to reduced feeding and growth rates, increased disease susceptibility, and accelerated onset of smoltification and desmoltification. Although many impacts may be sublethal, they can contribute to an increase in delayed mortality.

Protecting and restoring mature riparian tree canopy, protecting cold water sources, and promoting hyporheic exchange between the river/floodplain and the alluvial aquifer are essential to build ecological

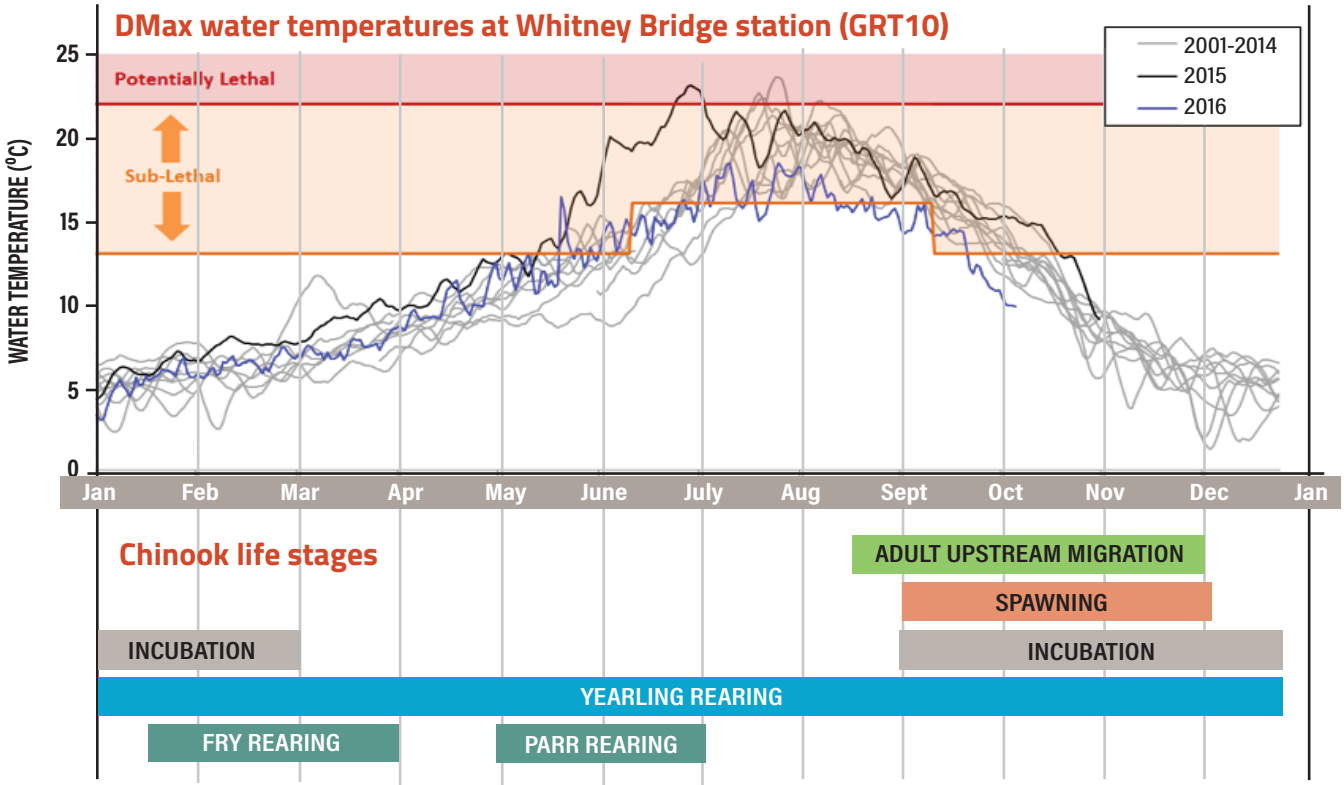


Figure 10. Plot of 7-DMax water temperatures for the 2015 and 2016 calendar years measured by King County at the Whitney Bridge station (GRT10) compared to 7-DMax temperatures measured from 2001-2014. State standards for designated uses are noted by the orange line and potentially lethal impacts are 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 lifestages included below.

Source: Adapted from King County 2016.

resilience to rising temperatures and moderate the impacts associated with climate change. By 2080, it is expected that the number of river miles exceeding salmonid thermal tolerances (>18°C) will increase by 70 miles in the Green/Duwamish watershed (G. Mauger 2016). One study suggests that warming of 2-5.5°C could result in the loss of 5-22 percent of salmon habitat by 2090 (O'Neal 2002).

Predicted temperature increases, lower summer flows and altered precipitation patterns are likely to exacerbate temperature-related stress for Chinook salmon.

Fish Passage Barriers (Watershed-wide)

Watershed Status:

Fish passage barriers are a critical obstacle to Chinook salmon recovery in the watershed. The presence of Howard Hanson Dam and the Tacoma Headworks Diversion facility block access to approximately 40 percent of the historical Chinook salmon spawning and rearing habitat (NOAA 2019). This barrier alone blocks access to somewhere between 78-165 miles of suitable fish habitat. The 2005 Plan assumed fish passage would be provided by 2015. Tacoma completed an upstream trap and haul facility at the headworks facility in 2007; however, downstream fish passage at Howard Hanson Dam has not been completed.

In 2019, the NOAA Fisheries released a biological opinion (BiOp) that concluded U.S. Army Corps operations at Howard Hanson Dam would "jeopardize the continued existence of ESA-listed Puget Sound (PS) Chinook salmon, PS steelhead, and Southern Resident killer whales (SRKW), and that the proposed action is likely to result in the adverse modification of these three species' critical habitat designated under the ESA." In issuing the jeopardy opinion, NOAA stated that without fish passage the population's abundance, productivity, and spatial diversity could not achieve established viability criteria, thus increasing the risk of extirpating the population.

In order to avoid jeopardizing ESA-listed Chinook, the BiOp concluded that the U.S. Army Corps must provide operational downstream fish passage no later than February 2031. The resulting facility would be required to satisfy established performance criteria, including achieving 98 percent survival of all fish passing through the facility. The BiOp states that if established performance standards are satisfied, the Upper Green watershed could support self-sustaining populations of Chinook salmon and steelhead, "dramatically improving the likelihood that the Chinook salmon population would achieve a highly viable status."

In addition to HHD, an unknown number of smaller fish passage barriers impact Chinook salmon movements within the watershed. There is a growing recognition that a number of barriers associated with smaller tributaries adjacent to roads, revetments and flood control structures block juvenile access to critical rearing habitats. One of the larger existing barriers is the Black River Pump Station. The pump station is a flood control facility built in 1970, located near the mouth of the Black River. While the facility was originally constructed with both upstream and downstream fish passage facilities, they are outdated and currently do not meet federal fish passage criteria (Jacobs 2020). In its current state, the facility limits both upstream and downstream fish passage and restricts access to over 50 miles of stream, including Springbrook Creek, Panther Lake Creek, Garrison Creek, and Mill Creek. Although the majority of stream habitat is primarily suitable for coho and steelhead, Chinook salmon have been found in the system, and the area immediately upstream of the facility could provide important rearing and refuge habitat for juvenile Chinook.

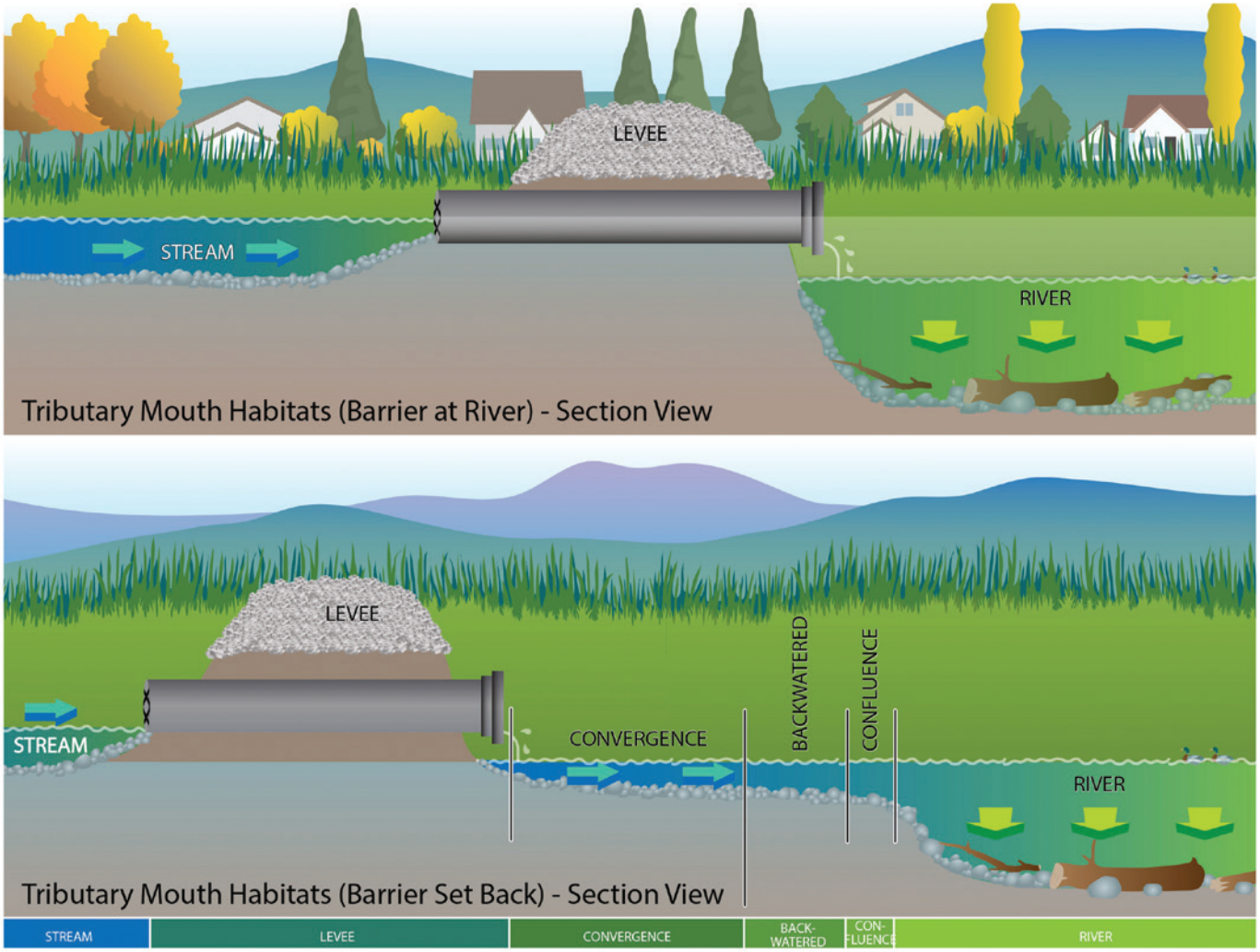
Research/Monitoring

A 2019 study evaluating the use of small non-natal tributaries (streams that do not support Chinook spawning) by juvenile Chinook highlighted the importance of these habitats for both juvenile rearing and flood refuge. Juvenile Chinook were identified in eight of the nine tributaries sampled in the Lower Green River basin and were found up to 480 meters above the confluence with the Green River. The results demonstrated (1) widespread use of non-natal tributaries for extended lengths of time; (2) heavily urbanized streams with a large amount of impervious surfaces appear capable of supporting non-natal juvenile rearing; (3) juvenile upstream passage is an important consideration for fish barriers; and (4) variability in flapgate performance for juvenile fish passage (King County 2019). A follow-up study was funded by WRIA 9 in 2019 to assess flapgate performance and identify potential retrofit and replacement options to improve juvenile passability.

Non-natal tributaries provide important rearing and refuge habitat in the Lower Green subwatershed.

Long-term fish-in fish-out monitoring by WDFW indicates that Chinook salmon population productivity is limited by available rearing habitat and that parr outmigrants disproportionately contribute to the abundance of returning adults (Anderson and Topping 2018). Restoration of non-natal tributaries has the potential to complement ongoing restoration efforts in the Lower Green River mainstem to provide additional capacity to support fry growth into parr prior to outmigration to the Duwamish estuary. Larger (basins >100 acres), low-gradient (<2%) tributaries likely provide a large amount of rearing habitat and support higher densities of juvenile Chinook (King County 2019; Tabor et al. 2011; Tabor and Moore 2018; Tabor, Murray and Rosenau 1989; Scrivener et al. 1994; Bradford et al. 2001).

Figure 11. *Representative tributary mouth habitats associated with flapgate flood control structures.*



Source: King County, 2019: Juvenile Chinook Use of Non-natal Tributaries in the Lower Green River

Land Conversion (Watershed-wide)

Watershed Status

Located within the greater Seattle metropolitan area, population growth and economic development have significantly modified the watershed, its underlying hydrology, and the salmon habitat within it. In addition to legacy impacts (Chapter 3 of 2005 Plan), the watershed experienced tremendous population growth and development in the 15 years since the 2005 Salmon Plan. The population of King County population swelled approximately 25 percent, adding an additional 444,000 residents (U.S. Census Bureau 2019; King County 2006). During the same timeframe, 46,000 new housing units were constructed in the watershed (WA Dept. of Commerce 2017).

The extensive development pressures within the watershed – especially in the Nearshore, Duwamish and Lower Green watershed – have degraded large portions of the watershed from natural conditions. In addition to direct habitat loss, land conversion contributes to increased impervious coverage and stormwater runoff. Refer to the Stormwater section in this chapter for additional information on stormwater impacts on salmon. Approximately 32 percent of the watershed is located within established urban growth areas (UGAs). Competition for scarce available land contributes to high restoration/acquisition costs and the loss of restoration priorities to redevelopment pressures.

Research/Monitoring

Despite the tremendous growth and development pressure, growth management efforts have concentrated new housing construction within urban growth areas. Only about 3 percent of housing units constructed in the watershed since the 2005 Plan have occurred outside of UGAs (WA Dept. of Commerce 2017). While this is a positive outcome, a compree hensive assessment of changes in forest cover and impervious surfaces has not been completed since 2006. In addition, the basin-wide effectiveness of critical area and shoreline protections has not been assessed. A WRIA 9-funded study of marine shoreline development from 2016-2018 observed a net increase in shoreline armoring and permit compliance rates below 50 percent (King County 2019). Additional information about the status of marine shorelines is presented in the Shoreline Armoring section.

Levees and Revetments (Middle and Lower Green)

Watershed Status

An extensive network of flood containment and training levees and revetments protect economic development and agricultural land in the Lower and Middle Green River valleys. In total. there are approximately 36 miles of levees and revetments in the watershed. Over 27 miles of facilities provide flood protection for the Lower Green River valley – the second largest warehouse and distribution center on the west coast. The valley contains $7.3 billion of structures and associated content, supports over 100,000 jobs, and generates an annual taxable revenue of $8 billion (Reinelt 2014).

Flood control facilities degrade floodplain function and reduce habitat complexity. They disconnect large portions of the historical floodplain, off-channel habitats, and tributaries – all important juvenile salmon rearing and refuge habitats. Associated vegetation maintenance standards limit riparian revegetation and contribute to elevated instream temperatures. Facilities also disrupt sediment delivery and filtration, water storage and recharge, and large wood input to the river channel. In addition to the direct impacts of the facilities, they also support land use development on historic floodplains habitats.

Due to the diversion of the White and Black rivers, much of the "connected" floodplain is perched above the river channel and only connected during very high flows. Current flows with a 100-year flood event equate to an historic two-year event (King County 2010). At these flows, only 18 percent (3,518 of 19,642 acres) of the historic Lower Green River floodplain is connected (Higgins 2017). The loss of juvenile Chinook salmon-rearing habitat reduces juvenile survival and overall population productivity. Restoration of floodplain habitat in the Lower Green River valley not only requires levee setbacks, but also requires extensive fill removal to reconnect perched floodplains across a larger range of flows.

Research/Monitoring

Since the 2005 Plan, studies have shown higher growth rates for Chinook salmon accessing floodplains when compared to fish rearing exclusively in the mainstem. Increased growth likely results from increased food availability and foraging efficiency in floodplain habitats (Henning 2004; Sommer et al. 2001; Jeffres, Opperman and Moyle 2008; and Lestelle et al. 2005). This research also suggests that any increased risk of stranding during retreating flows is offset by the potential for increased growth rates. These studies emphasize how important floodplain habitats are to juvenile Chinook growth and provide an important context for understanding how the magnitude of habitat loss in the Lower Green and to a lesser extent in the Middle Green have impacted juvenile Chinook production locally.

Analysis of juvenile life history success in adult Green River Chinook salmon (2015-2017) found parr outmigrants disproportionately contribute to adult returns relative to their abundance. Although parr comprised 3-56 percent of the out-migrating juveniles, more than 97 percent of returning adults were found to have exhibited the parr life history. In comparison, the parr life history is reflected in 64 and 76 percent, respectively, of the adult returns in the Skagit and Nooksack watershed (Campbell and Claiborne 2017; Campbell et al. 2019). These data indicate that Chinook salmon life history success varies between watersheds and that productivity (adult spawner abundance) in the Green is currently driven by parr production, as juveniles exhibiting the fry life history rarely survive to adulthood.

An analysis of long-term juvenile outmigration data collected by WDFW identified a density-dependent relationship between adult spawner abundance and relative parr abundance (Anderson and Topping 2018). Figure 6 shows that adult escapements in excess of 3,000 fish did not generally result in increased parr production. In contrast, fry production was observed to be density independent. Juvenile Chinook require rearing and refuge habitats (e.g., off-channel habitats, side-channels, etc.) to grow into parr prior to outmigration. When considered in concert with the Campbell and Claiborne studies, these results highlight the importance of reconnecting floodplains and restoring rearing habitat to increasing Chinook returns.

Sediment Contamination (Duwamish)

Watershed Status

Industrial and commercial development in the Duwamish estuary not only led to dredge and fill of historical estuarine wetlands, but also left a legacy of persistent contaminants within the working waterfront. Two Superfund sites require additional clean-up in the Duwamish, the Lower Duwamish Waterway (LDW) and Harbor Island/East Waterway (EW). Both sites contain elevated levels of polychlorinated biphenyls (PCBs), arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), as well as dioxins and furans. The EPA's Record of Decision for the LDW (2014) outlines the cleanup plan for the 412 acre site, which includes 105 acres of dredging or partial dredging, 24 acres of capping, 48 acres of enhanced natural remediation and 235 acres of monitored natural attenuation. Although early action areas (Slip 4, Terminal 117, Boeing Plant 2/Jorgensen Forge, Diagonal Combined Sewer Overflow [CSO], and Norfork CSO) resulted in cleanup of approximately 50 percent of PCB contamination, cleanup will not be completed until after 2031. Cleanup options for the EW site are under development.

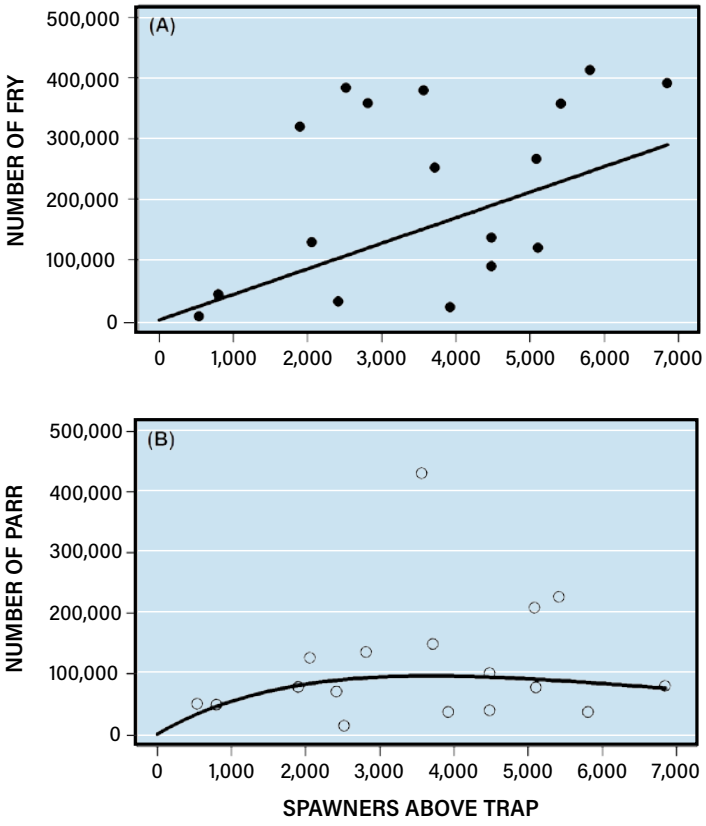


***Figure 12**. Spawners-recruit plots showing abundance of fry and parr produced based on estimated adult Chinook salmon escapement (Anderson and Topping 2017).*

Productivity in the Green/Duwamish is currently constrained by available rearing habitat in the Lower and Middle Green rivers.

Transport pathways carry contaminants from sources to surface waters, as well as within surface waters. Contaminants reach the Green/Duwamish receiving waters via point discharges (permitted industrial, stormwater and CSOs discharges), overland flow (stormwater runoff), groundwater, and direct atmospheric deposition, as well as by spills/leaks and bank erosion. Fish are exposed to chemicals through multiple routes including water passing through their gills and/or its ingestion, direct sediment contact and/or its ingestion, and/or through consumption of contaminated prey. Chinook experience greater chemical exposure during the juvenile phase than during the adult phase due to the comparatively different lengths of time they spend in the Duwamish during these life stages (Colton 2018).

Although the 2005 Salmon Plan hypothesized that sediment cleanup would benefit Chinook salmon, limited scientific data were available on the potential impacts of sediment contamination on productivity at the time.

Research/Monitoring

A growing body of research findings suggests that contaminant exposure for juvenile Chinook salmon in the Duwamish and Elliott Bay is affecting juvenile Chinook salmon growth, disease resistance, and immunosuppression, and ultimately marine survival. Juvenile Chinook salmon rearing in industrial estuary and nearshore habitats (e.g., Duwamish, Puyallup and Snohomish) contain elevated levels of organic contaminants as compared to those rearing in less developed watersheds (Skagit and Nisqually) (O'Neil et al. 2015; Varanasi et al. 1993). Juvenile Chinook salmon whole body PCB tissue concentrations from the Duwamish and associated nearshore areas have exceeded adverse impact thresholds (O'Neil et al. 2015; Johnson 2007). PCB levels in wild fingerlings have also been shown to have significantly higher PCB levels than their hatchery counterparts, suggesting that wild Chinook have a longer residence time within the Duwamish estuary (Nelson, et al. 2013).

An examination of 37 years of hatchery data from 20 hatcheries across 14 watersheds found 45 percent lower smolt-to-adult survival rates for hatchery Chinook that outmigrate through contaminated estuaries as compared to uncontaminated estuaries (Meador 2014). The study evaluated the findings against the total amount of estuary habitat, length of freshwater habitat between each hatchery and estuary, as well as growth rates and did not find these factors could explain observed variation in survival rates. Because wild Chinook – especially the fry outmigrant life history type – are more dependant on and have longer residence times in estuarine habitat, the observed decline in survial may be more pronounced in wild Chinook salmon.

A recent study by scientists at the NOAA Northwest Fisheries Science Center estimated the potential impact remediation of the Lower Willamette River Superfund site would have on Chinook salmon recovery (Lundin et al. 2019). The study used a combination of field and laboratory-collected exposure, growth, and disease resistance data to estimate acute and delayed mortality rates for juvenile Chinook. These estimates were then incorporated into a life cycle model that estimated sediment remediation could improve juvenile survival by 54 percent and increase population abundance by 20 percent. This study provides a population-scale assessment of the potential impacts of legacy pollutants on Chinook salmon and suggests that remediation in the Duwamish could be a significant driver for Chinook recovery.

Figure 13. *Chinook salmon that enter the estuarine waters as fry (< 60 mm) experience very low marine survival rates. In contrast to less developed watersheds, estuarine-reared fry in the Green/Duwamish are not contributing significantly to adult returns.*

The research on potential adverse impacts to juvenile Chinook as a result of contaminant exposure is consistent with a recent analysis of juvenile life histories expressed by adult Chinook salmon in the Green/Duwamish River. Analysis of otoliths from returning adult salmon allow resource managers to back-calculate size upon entry in marine waters, allowing differentiation between parr and fry migrants. Otolith collection from adult Chinook salmon (2015-2017) indicate that less than 3 percent of fish returning to the watershed entered marine waters as a fry migrant, despite representing between 44 and 97 of the total juvenile outmigrants (Campbell and Claiborne 2017; Campbell et al. 2019). Additional research is needed to assess the relative importance of contamination in relation to other stressors (i.e., existing estuarine habitat quality and capacity) in contributing to poor marine survival.

Research suggests that juvenile Chinook that enter the Duwamish as fry – as opposed to parr – experience very low survival and do not substantively contribute to population abundance as measured by adult escapement.

Chemicals of emerging concern (CECs) are another area of emerging research. The EPA defines CECs as "chemicals and other substances that have no regulatory standard, have been recently 'discovered' in natural streams (often because of improved analytical chemistry detection levels), and potentially cause deleterious effects in aquatic life (e.g., endocrine disrupters) at environmentally relevant concentrations" (EPA 2008). CECs include hormones, pharmaceuticals and personal care products (PPCPs), and industrial process chemicals. An analysis of juvenile Chinook whole body tissue in several Puget Sound estuaries detected 37 of 150 surveyed PPCPs (Meador et al. 2016). Metabolic disruption consistent with starvation was also observed in juvenile Chinook collected adjacent to waste water treatment plants in Sinclair Inlet and the Puyallup River (Meador 2018). The potential impacts to Chinook salmon growth, reproduction, and behavior are not well understood.

Stormwater (Nearshore, Duwamish, Lower and Middle Green)

Watershed Status

Stormwater runoff and associated hydrological modifications resulting from forest conversion and land use development within the Green/Duwamish watershed adversely impact water quality and salmon habitat. Approximately 59 and 24 percent, respectively, of the 165-foot riparian buffer in the Duwamish and Lower Green is characterized by impervious surfaces (King Co. unpublished data, 2013). Although watershed-wide data are not available, the impacts associated with the loss of forest cover and increase in impervious surfaces are not confined to riparian areas. At the basin-wide scale, these levels of impervious coverage can contribute to a two-three fold increase in stormwater runoff above natural conditions (Paul and Meyer 2001). Increased runoff contributes to rapid changes in flows, with larger peak flows and lower low flows; increased pollutant transport and degradation of water quality; shifts in benthic macroinvertebrates communities; elevated water temperatures; increased bank erosion and sediment transport capacity; and altered channel morphology and hydraulics.

The majority of the development within the watershed – and across Puget Sound – predates existing critical area ordinances and low-impact development standards designed to mitigate impacts to aquatic ecosystems. As a result, stormwater runoff is recognized within the region as one of the more significant challenges facing both salmon and Puget Sound recovery efforts.

Research/Monitoring

Since the 2005 Plan, a significant body of research has focused on stormwater toxicity impacts to salmon in urban creeks. Consistently high levels of mortality (up to 90 percent) in adult coho salmon have been observed in urban watersheds, with the extent of mortality rate related to an urbanization gradient and, more specifically, density of motor vehicle traffic (Scholz 2011; Feist 2017). More recent studies have connected observed mortality events to pollutants associated with highway runoff (Scholz 2016; Peter 2018).

Although Chinook salmon do not appear vulnerable to acute toxicity as a result of roadway runoff exposure (Scholz 2019), more research is needed to evaluate potential sublethal impacts.

Although studies have shown treatment of runoff can prevent acute toxicity, the large capital expenditures associated with stormwater retrofits have precluded widespread implementation. A comprehensive needs and cost assessment for stormwater retrofit within the Green/Duwamish and Central Puget Sound watershed was completed in 2014. The study evaluated 278 square miles of the watershed, excluding Seattle and areas upstream of Howard Hanson Dam. An estimated $210 million per year would need to be spend over the next 30 years to build necessary regional facilities, retrofit roads and highways, and retrofit non-forested lands not redeveloped within the next 30 years (King County 2014).

Shoreline Armoring (Nearshore)

Watershed Status

The Green/Duwamish and Central Puget Sound watershed encompasses 92 linear miles of marine shoreline. Associated nearshore habitats provide not only important rearing and migratory habitat for juvenile salmon, but also spawning habitat for forage fish (e.g., sand lance and surf smelt), which are important prey items for salmon, birds and marine mammals. Delivery of sediment and trees from natural bluffs helps sustain nearshore habitat complexity (beaches, spits, eelgrass beds, etc.) and shoreline resilience to coastal erosion and sea level rise.

The degradation of marine shorelines and associated ecological functions has implications not only for Chinook salmon recovery, but also for the ESA-listed southern resident orca population. Shoreline armor – especially along feeder bluffs – disrupts sediment supply and transport, altering nearshore habitat quantity and quality. Shoreline land use ranges from commercial and industrial waterfront in Elliott Bay, urban residential between Seattle and Federal Way, to rural residential and undeveloped shorelines along Vashon Island. Approximately 65 percent of the shoreline is currently armored and only 22 of 52 drift cells have greater than 50 percent of historical feeder bluffs intact (King County 2019; WRIA 9 2012).

Figure 14. *Shoreline modification identified during Marine Shoreline Monitoring and Compliance Project (Ecology).*

Research/Monitoring

Recent research reinforces assumptions in the 2005 Plan about the importance of nearshore habitats to salmon. The range of physical and biological impacts in response to shoreline armoring varies across spatial and temporal scales. Shoreline armoring impacts wrack and log accumulation, juvenile fish utilization, forage fish spawning, beach profiles, sediment grain size, and marine riparian vegetation. In particular, drift cells with a high proportion of armoring tend to be characterized by skinnier beaches, coarser sediments, fewer drift logs, fewer prey species (Dethier et al. 2016).

Natural shorelines convey important benefits to juvenile Chinook salmon. Small juvenile salmon preferentially use low-gradient, unarmored shorelines (Munsch, Cordell and Toft 2016). Riparian vegetation associated with unarmored beaches provide a source of terrestrial prey items for juvenile Chinook and benefit forage fish egg survival by moderating substrate temperatures and maintaining humidity (Rice 2006; Toft, Cordell et al. 2007). Even small-scale beach restoration projects (i.e., Olympic Sculpture Park) have resulted in measurable increases in larval fish abundance, juvenile salmon, and invertebrate diversity as compared to adjacent armored shorelines (Toft, Ogston et al. 2013).

The magnitude of unpermitted shoreline modifications threatens to negate investments in shoreline restoration and undermine the goal of "no net loss" established within the Shoreline Management Act. From 2013-2018, the watershed saw a net increase of 364 feet of shoreline armor despite armor removal and restoration of 382 feet shoreline during the same timeframe. Only 42 percent of observed shoreline modifications were permitted by local governments prior to construction (King County 2019).

Although juvenile Chinook from the Green/Duwamish River have been observed to use the marine shorelines throughout Central Puget Sound, considerable uncertainty surrounds the relative importance of non-natal coastal streams and pocket estuaries. A study in the Whidbey Basin found abundant use of non-natal coastal streams (32 of 63 streams) by juvenile Chinook. The presence of juvenile Chinook was influenced by (1) distance to nearest natal Chinook salmon river; (2) stream channel slope; (3) watershed area; and (4) presence and condition of a culvert at the mouth of a stream. The importance of non-natal coastal streams to juvenile Chinook salmon dropped significantly beyond 7 km from the mouth of a Chinook bearing river (Beamer, et al. 2013). Additional research is needed to prioritize non-natal coastal streams in WRIA 9 with respect to potential contribution towards Chinook salmon recovery.

Despite the recognized importance of natural shorelines and significant regional investment in armor removal, WRIA 9 continues to experience a net increase in shoreline armoring.