Green/Duwamish Watershed Natural-Origin Chinook Salmon Annotated Conceptual Model Developed for the Water Quality Benefits Evaluation

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King County

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EXECUTIVE SUMMARY

As part of the Water Quality Benefits Evaluation (WQBE), we developed an annotated conceptual model with subject matter experts for natural-origin[1] Chinook salmon in the Green/Duwamish watershed. This model captures the existing science and understanding of factors affecting those subpopulations.

The key factors limiting natural-origin Chinook recovery in the Green/Duwamish are:

- **limited accessible rearing habitat in the Upper, Middle, and Lower Green River**
    - Limited habitat in the Green River forces juveniles downstream to the **Duwamish Estuary**, which has poor habitat and elevated toxicant exposure potential. Habitat limitations amplify the potential for toxicant impacts because there is less food for juveniles and juveniles remain smaller.
- **low survival during marine maturation**

Further detail on these factors and an overall summary graphic are provided below.

The purpose of this annotated conceptual model is to communicate key influential factors for natural-origin Chinook salmon population growth and recovery in the Green/Duwamish Watershed. With a particular focus on an audience of wastewater and stormwater utility managers, we want readers to understand the general outcomes they may reasonably expect from water quality management actions.

Water quality, however, is only one piece of the overall picture of salmon recovery in this watershed. While the WQBE project is intended to aid water quality management decision-making, actions taken to improve water quality for the overall benefit of Chinook population growth and recovery will be more effective if made in partnership with the Green/Duwamish and Central Puget Sound Watershed (a.k.a. Water Resource Inventory Area [WRIA] 9) Salmon Recovery Council. This council has funded prior research and prioritization efforts and oversees habitat restoration that is crucial for rebounding salmon populations.

We worked with a team of subject matter experts from municipal, state, and tribal organizations to develop the annotated conceptual model, looking at each life stage of salmon that live in King County waters. This report stands as documentation of the experts' understanding of the system and the limiting factors therein. We want to acknowledge that there are limitations to expert knowledge and all individuals are subject to biases. Our elicitation strategy sought to minimize these biases and identify the underlying assumptions and understanding that constitute the experts' knowledge through individual interviews and group discussion. We explicitly acknowledge where experts disagreed or stated a lack of confidence. We also reviewed literature to examine marine survival and toxicant impacts.

[1] Natural-origin Chinook are defined as Chinook that arise from spawning grounds rather than a hatchery.

Limited Rearing Habitat

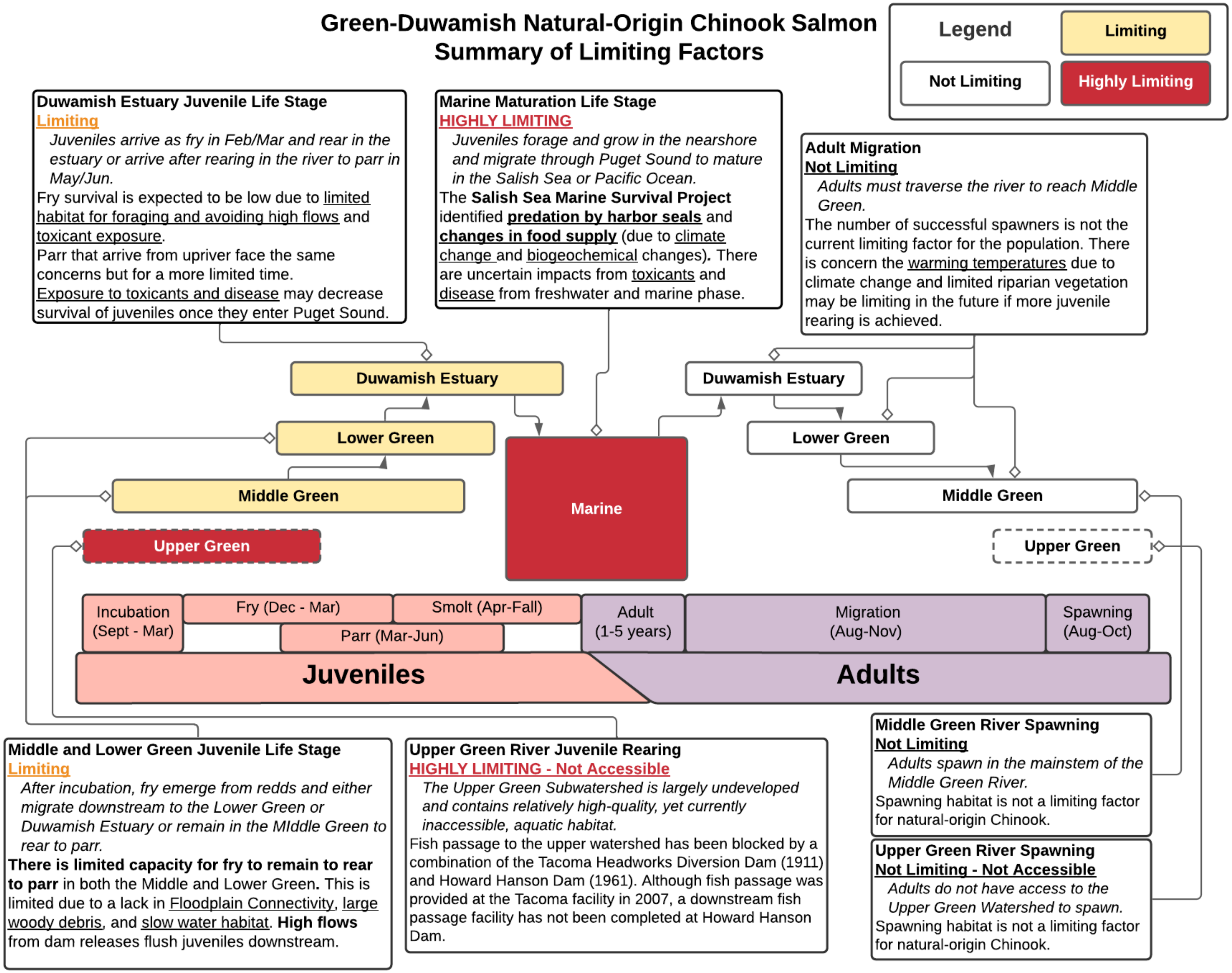
There is **limited capacity for fry to remain in the Middle and Lower Green River to rear to parr**. Due to the Howard Hanson Dam, the Upper Green River, which boasts high quality habitat, is not accessible. Habitat improvements in the Middle and Lower Green River that provide foraging habitat and high flow refugia during rearing would increase the capacity for parr. An increased number of parr outmigrants would increase the overall survival rate of juvenile outmigrants. The WRIA 9 Salmon Habitat Plan states that **"long-term recovery of Chinook salmon depends on providing fish passage to the Upper Watershed."**

Poor Conditions in the Duwamish

Because there is inadequate habitat for fry to rear to parr in the Green River, most juveniles leave the river or are pushed down by high flows and enter the Duwamish Estuary during the fry life stage. The Duwamish Estuary, due to a history of industrial development, **lacks suitable shallow-water rearing habitat for juveniles to forage and avoid high flows**. Furthermore, **contamination in the estuary may decrease growth rates, increase disease susceptibility, and increase the risk of mortality**, either in the estuary, or following outmigration. These impacts can lead to increased predation and decreased survivorship after entering Puget Sound.

Marine Survival

The **Salish Sea Marine Survival Project** identified the key factors limiting survival during the marine life stage in the Salish Sea/Puget Sound as **predation by harbor seals** and **changes in food supply**. Experts believe that changes in food supply are due to large-scale shifts in circulation, temperature, and river flows that impact the timing and availability of light, nutrients, and other factors necessary for the base of the food web. These shifts are likely linked to climate change, although we lack the long-term datasets needed to define causal linkages with much certainty. Toxicants and disease may be an additional stressor layered on predation pressure and inadequate food supply.


Green-Duwamish Natural-Origin Chinook Salmon
Summary of Limiting Factors
Legend
Limiting
Not Limiting
Highly Limiting
Duwamish Estuary Juvenile Life Stage
Limiting
Juveniles arrive as fry in Feb/Mar and rear in the estuary or arrive after rearing in the river to parr in May/Jun.
Fry survival is expected to be low due to limited habitat for foraging and avoiding high flows and toxicant exposure.
Parr that arrive from upriver face the same concerns but for a more limited time.
Exposure to toxicants and disease may decrease survival of juveniles once they enter Puget Sound.
Marine Maturation Life Stage
HIGHLY LIMITING
Juveniles forage and grow in the nearshore and migrate through Puget Sound to mature in the Salish Sea or Pacific Ocean.
The Salish Sea Marine Survival Project identified predation by harbor seals and changes in food supply (due to climate change and biogeochemical changes). There are uncertain impacts from toxicants and disease from freshwater and marine phase.
Adult Migration
Not Limiting
Adults must traverse the river to reach Middle Green.
The number of successful spawners is not the current limiting factor for the population. There is concern the warming temperatures due to climate change and limited riparian vegetation may be limiting in the future if more juvenile rearing is achieved.
Duwamish Estuary
Lower Green
Middle Green
Upper Green
Marine
Duwamish Estuary
Lower Green
Middle Green
Upper Green
Incubation (Sept - Mar)
Fry (Dec - Mar)
Smolt (Apr-Fall)
Parr (Mar-Jun)
Adult (1-5 years)
Migration (Aug-Nov)
Spawning (Aug-Oct)
Juveniles
Adults
Middle and Lower Green Juvenile Life Stage
Limiting
After incubation, fry emerge from redds and either migrate downstream to the Lower Green or Duwamish Estuary or remain in the MIddle Green to rear to parr.
There is limited capacity for fry to remain to rear to parr in both the Middle and Lower Green. This is limited due to a lack in Floodplain Connectivity, large woody debris, and slow water habitat. High flows from dam releases flush juveniles downstream.
Upper Green River Juvenile Rearing
HIGHLY LIMITING - Not Accessible
The Upper Green Subwatershed is largely undeveloped and contains relatively high-quality, yet currently inaccessible, aquatic habitat.
Fish passage to the upper watershed has been blocked by a combination of the Tacoma Headworks Diversion Dam (1911) and Howard Hanson Dam (1961). Although fish passage was provided at the Tacoma facility in 2007, a downstream fish passage facility has not been completed at Howard Hanson Dam.
Middle Green River Spawning
Not Limiting
Adults spawn in the mainstem of the Middle Green River.
Spawning habitat is not a limiting factor for natural-origin Chinook.
Upper Green River Spawning
Not Limiting - Not Accessible
Adults do not have access to the Upper Green Watershed to spawn.
Spawning habitat is not a limiting factor for natural-origin Chinook.

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1.0 INTRODUCTION

1.1 Water Quality Benefits Evaluation (WQBE)

The Water Quality Benefits Evaluation (WQBE) Toolkit provides consistent, science-based methods for assessing how water quality management actions improve environmental outcomes. The holistic evaluation of environmental outcomes from these models provides better information for decision-makers to consider alongside other factors, such as reversing environmental inequities, costs to ratepayers, and other community priorities. The Toolkit is an adaptable framework containing a watershed pollutant loading model, a pollutant-reduction and cost optimization model, and causal models representing systems surrounding specified environmental outcomes (endpoints). We developed causal models for seven endpoints:

- Algal toxins at King County lakes
- Fecal contamination at swimming beaches
- Fecal contamination at shellfish beds
- Southern resident killer whale (orca) population health
- Toxics in edible fish
- Chinook salmon population growth and recovery in the Cedar/Sammamish/Lake Washington watershed
- Chinook salmon population growth and recovery in the Green/Duwamish watershed

The causal models include Bayesian networks, narrative conceptual models, and fish bioaccumulation models. They account for the location, timing, and magnitude of pollutant reductions, as well as other factors that are influential for each endpoint. The models provide a technical foundation for understanding the actions that might be necessary to improve outcomes for each endpoint.

1.2 Model Purpose and Scope

The purpose of this annotated conceptual model is to communicate key factors for natural-origin Chinook recovery in the Green/Duwamish watershed. The audience for this report is primarily wastewater and stormwater utility managers. We want readers to understand the outcomes they may reasonably expect from water-quality management actions. All references to salmon in this report are intended to describe natural-origin Chinook from the specified subpopulations unless otherwise explicitly stated.

Water quality, however, is only one piece of the overall picture of salmon recovery in this watershed. While the WQBE project is intended to address water quality issues and aid water quality management decision-making, actions taken to improve water quality for the overall benefit of Chinook population growth and recovery will be more effective if made in partnership with the Green/Duwamish and Central Puget Sound Watershed (a.k.a. Water

Resource Inventory Area [WRIA] 9) Salmon Recovery Council. This council has funded prior research and prioritization efforts and oversees habitat restoration and recovery that is crucial for rebounding salmon populations (e.g., WRIA 9, 2021).

In Chapters 2 through 6 of this report, our conceptual model describes each of the Chinook salmon life stages using a simple framework which corresponds to specified life history needs of Chinook within geographic areas. The life stages and geographic areas in this conceptual model are:

- Middle Green River Juveniles (Chapter 2)
- Lower Green River Juveniles (Chapter 3)
- Duwamish Estuary Juveniles (Chapter 4)
- Marine Survival (Chapter 5)
- Freshwater Spawner Success (Chapter 6)

The overall conceptual model consists of submodels to describe conditions in each of these life stages and geographic areas. Each submodel describes the specific habitat and water quality conditions potentially affecting the success of the Chinook salmon life stage within the subject area. Each discrete factor is a "node" within the submodel, with each node designated as one of the following:

- Water quality, such as water temperature or toxics
- Physical environment, such as flows, lighting, access to the floodplain
- Habitat capacity, availability, and quality
- Juvenile salmon activity, primarily migration
- Predators and predation

We did not develop a submodel for the Upper Green River, upstream of Howard Hanson Dam. The Upper Green contains high-quality salmon habitat but is not accessible due to the Tacoma Headworks Diversion Dam and Howard Hanson Dam. According to the WRIA 9 Salmon Habitat Plan, long-term recovery of Chinook salmon depends on providing fish passage to the Upper Green. The Upper Green's primary land use is commercial forestry and serves as the primary drinking water source for the City of Tacoma.

Each submodel is described by a figure, and the specific details of each node are detailed in tables of annotations. The tables provide greater detail on the definitions, uncertainties, and relationships between factors. We acknowledge other important factors that were ultimately excluded from the final model due to relatively minor influence or an expectation that those factors will not change based on potential water quality investments; those factors should still be considered to fully understand the issues faced by Chinook salmon in the watershed.

The resulting conceptual model serves the objectives of WQBE by providing a detailed framework within which to evaluate and prioritize potential water quality investments or

habitat improvements based on their potential benefit to the Green/Duwamish Chinook salmon subpopulation. The model also identifies important data gaps and uncertainties that can inhibit effective decision-making.

Within each chapter, we first provide the key takeaways of the subject matter experts' understanding of the system, followed by a narrative describing the annotated conceptual model submodel. The submodel contains the factors driving salmon success and survival for that geographic area or topic. Each node in the model has a shorthand for ease of reference to a table of annotations. For example, "(MG_17)" refers to the Middle Green juvenile submodel factor 17, "Fry Emergence."

Toxicants and their potential impacts are summarized in Chapter 7 to address natural resource managers and WQBE's particular interest in the water quality, with a detailed discussion in a companion report (King County, 2022).

This qualitative model seeks to represent the existing knowledge and uncertainty in the system. Some of the key overall knowledge gaps identified over the course of the development of the model are summarized in Chapter 8. The annotated conceptual model could be developed into a computational model, such as a Bayesian network, in the future. Model development followed the initial four steps outlined in King County (2020) for constructing a Bayesian network, which includes defining meaningful, mutually exclusive states for each model node. These states are presented in Appendix A along with model node definitions. The remaining steps in that technical memorandum could be followed to complete the Bayesian network, beginning with eliciting estimates of conditional probabilities from subject matter experts.

1.3 How Was this Model Developed?

As part of an earlier WQBE stage, we developed a detailed and comprehensive conceptual model of factors that influence Chinook salmon in this watershed (King County, 2021). This original conceptual model included four sub-models for different life stages and geographic areas of the Chinook life cycle, each made up of dozens of factors and sometimes over a hundred relationships between factors. Using the original conceptual model as a starting place, we continued to sharpen our focus on the most critical limiting factors for Chinook population growth and recovery in the Green/Duwamish watershed. The result of that process is the model presented in this report.

As with the original conceptual model, we followed a structured process using best practices in expert elicitation to minimize bias and uncover assumptions. This was a modified version of the IDEA protocol described by Hemming et al. (2018), which consists of four steps: investigate, discuss, estimate, and aggregate. Each expert gives their initial input privately, individuals' input is shared anonymously with the group followed by a live discussion, the individuals are provided an opportunity to revise their input, and then the final output is an aggregate of individual responses. We worked with a team of subject matter experts from municipal, state, and tribal organizations in an elicitation process that included the following steps:

1. We divided the full group of experts into subgroups for each of the identified critical geographic areas (Middle Green River, Lower Green River, and Duwamish Estuary) (see Table 1). (Pearsall et al. 2021) For Middle Green, Lower Green, and Estuary expert groups, we individually interviewed each of the experts to identify what factors most limit Chinook salmon recovery within the given geographic area. We asked them to discuss the mechanisms behind each causal relationship between factors to uncover their assumptions. We used the original conceptual model to initiate this discussion. For the marine life stage, we relied on the expertise provided in the Synthesis of findings of the Salish Sea Marine Survival Project (Pearsall et al. 2021).
2. We then presented anonymized summaries of those individual interviews to the subgroup of experts for each geographic area to examine their understanding of the system and its limiting factors. During and following a live discussion, experts were able to change their original input if desired.
3. We built draft refined conceptual models representing the factors and relationships from the original conceptual models considered to be most influential by the expert group. Annotations define each modeled factor based on the preceding discussion, highlighting uncertainties and data gaps. We worked with the experts within the subgroup for each geographic area to review and update these conceptual models. Although we did not require a consensus, each group arrived at a model they were satisfied with.
4. We presented the draft annotated conceptual model to the WRIA 9 Technical Committee for feedback (several of our experts were also members of this committee). We updated and finalized the conceptual model based on feedback from the committee.

During discussions, experts acknowledged a lack of knowledge around toxicant impacts and a discomfort in providing input on that component of the model. In response to this, parallel to the expert elicitation, an ecotoxicologist on the WQBE team reviewed available literature to evaluate toxicant impacts on Chinook salmon while in King County waters. Regional experts, Julann Spromberg (National Oceanic and Atmospheric Administration), Jenee Colton (King County), and Sandra O'Neill (WA Department of Fish and Wildlife), assisted in scoping that review. That companion report is published alongside this (King County, 2022).

In the interest of providing context for factors limiting Chinook salmon recovery, we also reviewed available summaries of factors impacting the marine survival of Chinook salmon from the Salish Sea Marine Survival Project (Pearsall et al. 2021).

Table 1. Subject matter expert team. Model subset(s) indicate which geographic area they were originally interviewed.

Expert	Title	Organization	Model subset(s)
George Blomberg	Senior Environmental Program Manager	Port of Seattle	Duwamish Estuary

Expert	Title	Organization	Model subset(s)
Chris Gregersen	Salmon Ecologist	King County Water and Land Resources Division	Middle Green, Lower Green
Kollin Higgins	Salmon Ecologist	King County Water and Land Resources Division	Middle Green, Lower Green, Duwamish Estuary
Matt Goehring	WRIA 9 Technical Coordinator	King County Water and Land Resources Division	Middle Green, Lower Green
Jillian Howard, Ph.D.	Quantitative Fisheries Scientist	Muckleshoot Indian Tribe	Duwamish Estuary
Kathleen Hurley	Senior Environmental Program Manager	Port of Seattle	Duwamish Estuary
Tom Nelson	Fisheries Biologist	Retired (King County Water and Land Resources Division)	Duwamish Estuary
Nik Novotny	Watershed Fisheries Biologist	Tacoma Water	Middle Green, Lower Green
Jason Schaffler	Senior Quantitative Scientist	Muckleshoot Indian Tribe	Duwamish Estuary

Additionally, Brian Footen (WA Department of Fish and Wildlife) provided input on the definitions of many of the nodes in the Middle and Lower Green submodels.

1.4 Green/Duwamish Chinook Salmon Life History

The foundation of the conceptual model is the life history cycle of the natural-origin Green/Duwamish Chinook population. This section briefly describes Chinook life histories used to structure the conceptual model. A map of the watershed is provided in Figure 1.

Adult Chinook salmon primarily spawn in the mainstem of the Middle and Lower Green River, and in lower Newaukum Creek. Additional spawning occurs in Soos Creek and other streams. The majority of spawning occurs in the Middle Green mainstem and is the primary focus for this model. Salmon place thousands of fertilized eggs in depressions called redds between September and November. The eggs incubate and hatched alevin remain in the redds until January through March of the following year. Juvenile salmon emerge as fry from the redds, where they begin one of the life history types described in Table 2. In this effort to model the prime limiting factors for this population, we focused primarily on the Middle and Lower Green River-rearing and Duwamish Estuary-rearing life histories.

Table 2. Green/Duwamish Chinook salmon life histories.

Life History Type	Description	Location	Typical Time Period	Proportion of Juveniles[1]	Proportion of Returning Adults[2]
Marine Direct Fry Migrants	Fry leave the Middle Green shortly after hatching and move quickly from the estuary into Puget Sound	Middle Green + Lower Green + Duwamish Estuary	Jan to Apr – Briefly	Rare	Rare (<1%)

Life History Type	Description	Location	Typical Time Period	Proportion of Juveniles[1]	Proportion of Returning Adults[2]
Estuary-rearing Fry	Fry leave the Middle Green shortly after hatching and move quickly to the Duwamish Estuary	Middle Green + Lower Green	Jan to Apr – Briefly	Most abundant (~50 to 90%)	Rare (<1%)
		Duwamish Estuary	Jan to June		
Lower Green River-rearing Fry	Fry leave the Middle Green shortly after hatching and rear in the Lower Green.	Middle Green	Jan to Apr - Briefly	Unknown[3]	Unknown
		Lower Green	Jan to June		
		Duwamish Estuary	Apr to June - Briefly		
Middle Green River-rearing Fry	Fry rear in the Middle Green until leaving the Green River and moving quickly through the Estuary into Puget Sound	Middle Green	Jan to June	Second-most Abundant	Nearly all
		Lower Green + Duwamish Estuary	Apr to June - Briefly		
Yearling	Juveniles spend an entire year in freshwater before leaving the Green River. It is not clear where in the broader Green River they overwinter	Green River	Whole-year	Rare	Rare

1. Based on fish trap monitoring by WDFW on the Green River (Topping and Anderson, 2021).
2. Based on otolith monitoring presented by Campbell and Claiborne (2017)
3. The proportion of juveniles in this life history type may be larger than previously thought. Forthcoming data from a King County available in late 2022 will suggest more detailed numbers for outmigrants rearing in the Lower Green (Chris Gregersen, personal communication).

Most juveniles will outmigrate into Puget Sound from April to July, primarily in June and July. Some juveniles enter Puget Sound shortly after hatching (Marine Direct Fry). During outmigration, juveniles undergo physiological changes to adapt to living in marine waters, becoming smolts. Upon entering Puget Sound, smolts forage in the nearshore environment through fall. The duration of Puget Sound residence is highly variable; smolts generally transition from nearshore to offshore rearing/foraging within the first few weeks/months of Puget Sound residence and some proportion overwinter in Puget Sound (termed blackmouth).

Salmon will mature in Puget Sound and the Pacific Ocean for 1 to 5 years before returning to freshwater to spawn. Most Green/Duwamish salmon return at age 3 or 4. Adults migrate back through the Duwamish Estuary and Lower Green to the Middle Green from August through November.

1.5 Model Overview

Table 3 describes each of the submodels (including their endpoints) that comprise the overall model. In some cases, the same factors are used in more than one submodel. For example, both the Middle and Lower Green submodel have model nodes for the hours of high flow measured in the Green River. No submodel was developed for Freshwater Spawner Success (see Chapter 6).

Table 3. Summary of the submodels in the Green/Duwamish natural-origin Chinook salmon annotated conceptual model.

Submodel	Endpoint(s)	Description
Middle Green River Juveniles	Middle Green Parr Outmigrants	This submodel evaluates the capacity of the Middle Green River to rear juveniles.
Lower Green River Juveniles	Lower Green Parr Outmigrants (relative to Middle Green)	This submodel evaluates the capacity of the Lower Green River to rear juveniles that arrived in the Lower Green as fry. This is defined relative to the capacity of the Middle Green.
Duwamish Estuary Juveniles	Duwamish Estuary Fry-to-Parr Rearing Capacity Duwamish Estuary Parr Outmigrant Capacity	This submodel evaluates (1) the capacity of the Duwamish Estuary to rear juveniles that arrived in the estuary as fry and (2) the capacity of the Duwamish Estuary to support juveniles arriving from the Middle and Lower Green River as parr.
Marine Survival	Green Duwamish Adult Returners	This submodel evaluates how juvenile, subadult, and adult salmon survive in the Salish Sea and Pacific Ocean.

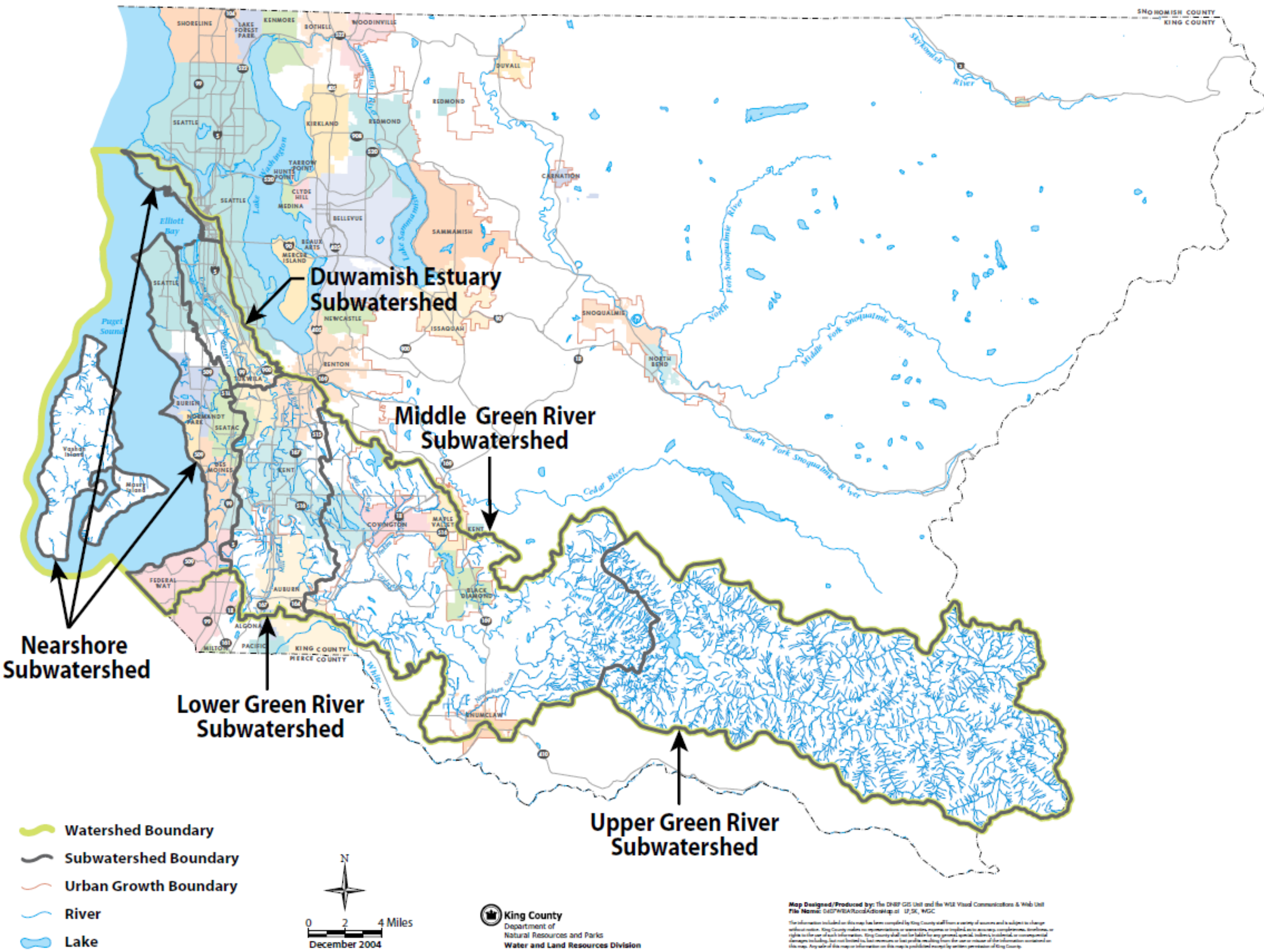

Figure 1. Map of the Green/Duwamish watershed and its subwatersheds.

2.0 MIDDLE GREEN RIVER JUVENILES

This chapter covers the juvenile life stages of Chinook salmon in the Middle Green River after they emerge as fry until they migrate downstream to the Lower Green River and eventually the Duwamish Estuary. The boundary separating the Middle and Lower Green River is defined as the Fenster Levee in Auburn, RM 32, just downstream of where Soos Creek enters.

Below are the key takeaways followed by a narrative that summarizes the conceptual submodel (Figure 2) and its annotations (Table 4).

Key Takeaways

- **The Middle Green River is the best available, accessible, rearing habitat** for juvenile Chinook salmon within the Green/Duwamish Watershed. Experts believe that increasing the amount of rearing habitat in the Middle Green would most benefit the population.
- Experts believe that **increasing the number of parr outmigrants from the Middle Green would increase overall return rates**. Increasing the number off parr outmigrants represents an important opportunity to benefit overall Chinook population growth and recovery in the watershed.
    - This is because of the poor rearing conditions in the Lower Green and Duwamish Estuary (see chapters 3 and 4).
- The **rearing capacity in the Middle Green is limited** by (1) **high flows** that displace juveniles coupled with **inadequate high flow refugia**, and (2) **insufficient foraging habitat**.
    - High flows displace juveniles that are not able to find lower-velocity areas, forcing them downstream to the Lower Green and the Duwamish Estuary.
        - Howard Hanson Dam is managed to decrease the frequency and magnitude of high flows through the river. Although high flows happen less frequently than historic flow conditions, when they do happen, they have a large impact.
        - Connected floodplains and tributaries and large woody debris provide high flow refugia for juveniles. Removal of fish passage barriers and shoreline armoring increases floodplain connectivity.
        - However, high flows can also be habitat-forming. High flows are essential to create new channel and floodplain habitats in the Green River. The net impact of these positive and negative influences on salmon are somewhat uncertain.
    - Limited foraging habitat in the Middle Green results in more fry migrating downstream to search for foraging habitat.

- Large woody debris and channel complexity are important factors for foraging habitat. Channel complexity includes off-channel habitat, braiding, and gradually sloping river banks. Experts suggested using confined bankfull width to estimate channel complexity, as the absence of bank confinement is a corollary for complexity.

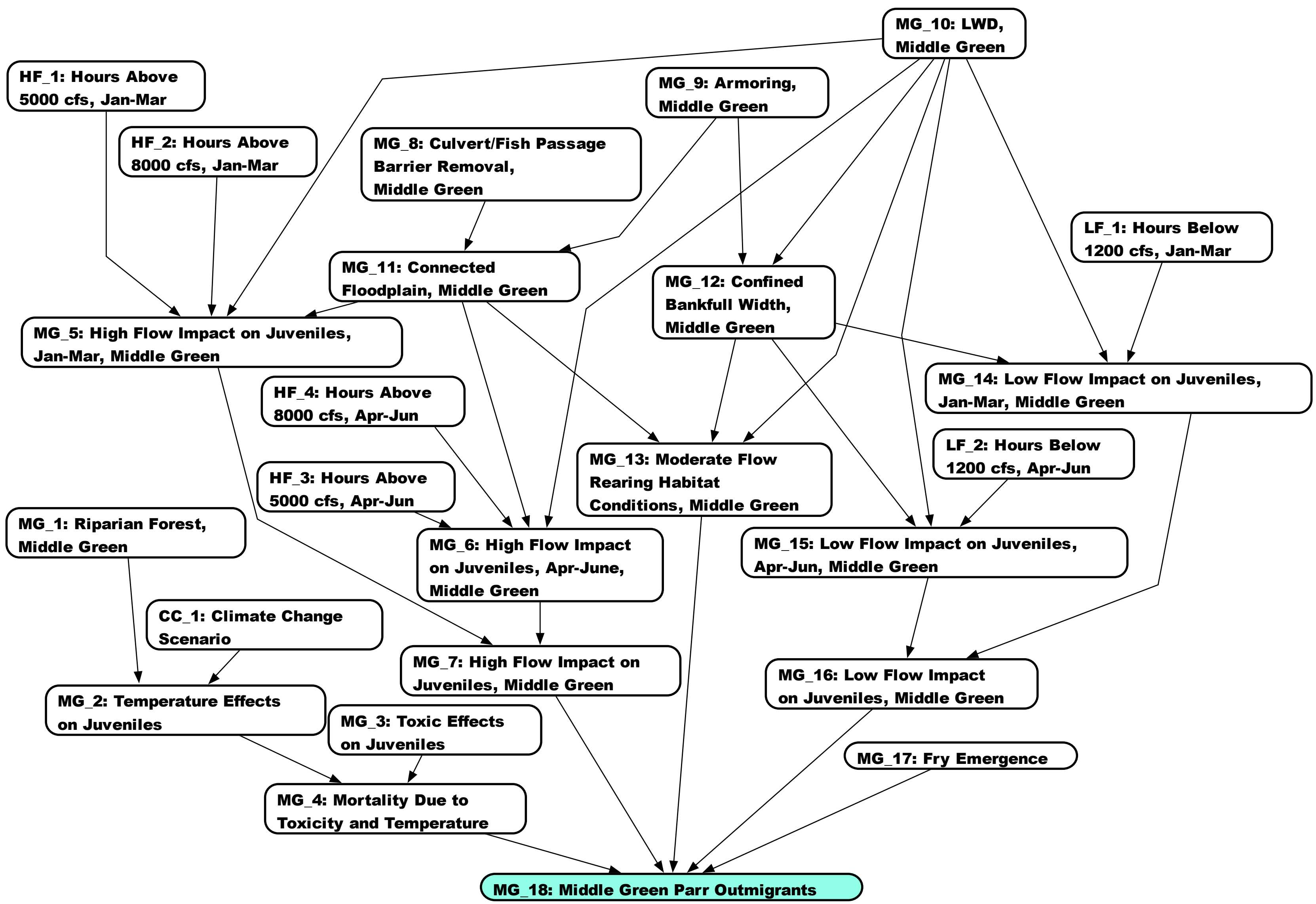

Figure 2. Middle Green River juvenile outmigration conceptual model. Refer to 4 for factor definitions and descriptions of the interrelationships between factors and key uncertaities.

Narrative

This section describes the above model structure. Detail on how the individual factors interact is provided in the following table (Table 4).

The number of parr outmigrants that can rear in the Middle Green River (MG_18) is influenced primarily by the combined impacts of rearing habitat and the frequency and magnitude of high- and low-flow events. Fry emergence (MG_17) sets the stage for the initial juvenile population influenced by the other factors in the submodel. Experts were not sure whether there is direct or indirect mortality resulting from temperature or toxics impact in the Middle Green (due to increased disease or predation susceptibility), and we elected to retain those factors in the model.

Several physical habitat features impact juvenile Chinook's ability to find forage in order to grow and develop, and also to find refuge during high flow events in order to avoid being pushed downstream. Culvert/Fish Passage Barrier Removal (MG_8), Armoring (MG_9), and Confined Bankfull Width (MG_12) estimate limitations to habitat formation and juvenile Chinook's access to off-channel habitat. Large Woody Debris (MG_10) and Connected Floodplain (MG_11) provide forage opportunities and high flow refugia during high flow events. We summarize the quality and relative amount of suitable habitat for juveniles under normal conditions in a single factor, Moderate Flow Rearing Habitat Conditions (MG_13). This overall habitat capacity of the Middle Green is considered the most influential factor on the number of parr outmigrants, which is a measure of the populations' most likely returners.

High flows can displace juveniles downstream to the Lower Green and Duwamish Estuary. The model captures this by considering both the frequency and magnitude of high flows and the availability of suitable habitat that provides high flow refugia. High flows can also create habitat by increasing access to off-channel areas of the floodplain and by scouring channels, especially with the aid of large woody debris. We describe the net outcome of these combined factors as High Flow Impact on Juveniles (MG_5, MG_6, and MG_7). We consider flows during both January the March (during the fry life stage) (HF_1, HF_2) and April through June (during the parr life stage) (HF_3, HF_4). Although these life stage changes occur on a continuum through the season, we model them in these two time periods, which we believe represent a rough breakdown for most juveniles. Due to flow management and the larger size of parr, experts believe that the April to June high flow impacts are less influential.

Low flows are also divided into a January through March (LF_1) and April through June (LF_2) time period. The net Low Flow Impact on Juveniles (MG_14 and MG_15) is an interaction between the measured low flows and physical habitat features Large Woody Debris (MG_10) and Confined Bankfull Width (MG_12). The two time periods are summarized as Low Flow Impact on Juveniles (MG_16) throughout the season.

Riparian Forest (MG_1), which provides shade over the river, interacts with the Climate Change Scenario (CC_1) to produce Temperature Effects on Juveniles (MG_2). Temperature

Effects and Toxic Effects on Juveniles (MG_3) combine to form a summary factor, Mortality Due to Toxicity and Temperature (MG_4). Experts consider this to be of relatively low influence on the number of parr outmigrants leaving the Middle Green; however, it represents a data gap and therefore an area of uncertainty.

Further details on the links and influences within the Middle Green River submodel are provided in the table below.

Table 4. Middle Green River juvenile outmigration conceptual model annotations.

Node ID	Node Name	Node Parents	Definition/Description
MG_1	**Riparian Forest, Middle Green**	*None*	Riparian forest cover, as measured within the channel migration zone, may lower instream temperatures through shade and evapotranspiration. Riparian forest cover also contributes large woody debris and may serve has habitat for terrestrial prey for salmon.
CC_1	**Climate Change Scenario**	*None*	This node defines specific climate change scenarios. *Factors not included* Although we expect climate change to impact several factors in this model (including high and low flows), those linkages are not shown between nodes because climate change can be incorporated into starting conditions for those boundary nodes under modeling scenarios. Because climate change and the condition of riparian forests work together to influence water temperature and its effects on juveniles, we have included climate change explicitly as a parent to Temperature Effects on Juveniles (MG_2).
MG_2	**Temperature Effects on Juveniles, Middle Green**	MG_1. Riparian Forest, Middle Green CC_1. Climate Change Scenario	This node denotes the temperature stress experienced by juveniles, coming into play primarily during the April through June timeframe. This includes heightened metabolism and physiological stress. Experts do not expect this to be a strong influence on direct mortality. *Relation to parent factors* **Riparian Forests** provides shading over the river, lowering temperatures. The **Climate Change Scenario** used in a model run may include overall annual warming as well as increases in extreme temperatures and rainfall patterns. We can expect climate change to result in warmer summer water temperatures due to warmer air temperatures, less summer rainfall, and lower summer river flows in the Pacific Northwest. Warmer summer temperatures would impact the later juvenile outmigrants.
MG_3	**Toxic Effects on Juveniles, Middle Green**	*None*	This node denotes the toxic stress experienced by juveniles. It includes increased predation and disease caused by sublethal effects of toxicant exposure. *Key uncertainties* This is an area of uncertainty due to lack of data. Presently, experts do not consider toxic effects on juveniles to be highly influential on the number of parr outmigrants in comparison to habitat limitations. Juveniles sampled from the Green River have low levels of contaminants like PCBs in their tissue.

Node ID	Node Name	Node Parents	Definition/Description
MG_4	**Mortality Due to Toxicity and Temperature, Middle Green**	MG_2. Temperature Effects on Juveniles MG_3. Toxic Effects on Juveniles	This node captures the severity and risk of mortality caused by elevated temperatures and concentrations of toxics. This includes exacerbation of predation and disease due to sublethal effects. Experts do not expect a strong influence of temperature and toxicity on direct mortality based on current understanding.
			Relation to parent factors This is a summary factor combining **Temperature** and **Toxic Effects on Juveniles.**
HF_1	**Hours above 5000 cfs, Jan-March**	*None*	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.
			Factors not included Climate change is not explicitly modeled because changes in flows due to climate change may be developed in future versions of the hydrologic model developed for WQBE and therefore represented in estimates of this factor.
HF_2	**Hours above 8000 cfs, Jan-Mar**	*None*	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 8,000 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE's hydrologic model (see HF_1).

Node ID	Node Name	Node Parents	Definition/Description
MG_5	**High Flow Impact on Juveniles, Jan-Mar, Middle Green**	HF_1. Hours above 5000 cfs, Jan-Mar HF_2. Hours above 8000 cfs, Jan-Mar MG_10. Large Woody Debris, Middle Green MG_11. Connected Floodplain, Middle Green	The impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from January through March (independent of other population factors such as emergence). Compared with historic flow regimes, high flows are rare due to dam management, but when they do happen, they have a large impact on juveniles.
			Relation to parent factors Volume and duration of high flows result in juveniles getting flushed downstream. Experts identified **Hours Above 5000 cfs** during this time period as a threshold for high flows we expect to impact juvenile salmon and cause channel scour, and **Hours Above 8000 cfs** as a threshold for higher flows we expect to have an even greater impact. **Large Woody Debris** present in the channel and access to **Connected Floodplain** both can offer refuge to juveniles from the negative impacts of high flows, allowing them to stay further upstream for a longer portion of their growth.
			Key uncertainties In addition to flushing juveniles downstream, high flows can also cause channel scouring and create access to off-channel habitat (“habitat-forming flow”). Experts expressed some uncertainty about the net impact of these benefits and costs.
HF_3	**Hours above 5000 cfs, Apr-Jun**	*None*	The number of hours from April through June where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE’s hydrologic model (see HF_1).
HF_4	**Hours above 8000 cfs, Apr-June**	*None*	The number of hours from April through June where maximum discharge measured at USGS gauge site 12113000 exceeded 8,000 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE’s hydrologic model (see HF_1).

Node ID	Node Name	Node Parents	Definition/Description
MG_6	**High Flow Impact on Juveniles, Apr-Jun, Middle Green**	HF_3. Hours above 5000 cfs, Apr-Jun HF_4. Hours above 8000 cfs, Apr-Jun MG_10. Large Woody Debris, Middle Green MG_11. Connected Floodplain, Middle Green	The impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from April through June. Compared with historic flow regimes, high flows are rare due to dam management, especially during this time period, but when they do happen, they have an impact on juveniles. Due to lower and less frequent high flows during this period, and the larger size of the older juveniles, the impact of high flows on juveniles from April through June is lower than during the January through March period.
			Relation to parent factors Volume and duration of high flows result in juveniles getting flushed downstream. Experts identified **Hours Above 5000 cfs** during this time period as a threshold for high flows we expect to impact juvenile salmon and cause channel scour, and **Hours Above 8000 cfs** as a threshold for higher flows we expect to have an even greater impact. **Large Woody Debris** present in the channel and access to **Connected Floodplain** both can offer refuge to juveniles from the negative impacts of high flows, allowing them to stay further upstream for a longer portion of their growth.
			Key uncertainties In addition to flushing juveniles downstream, high flows can also cause channel scouring and create access to off-channel habitat (“habitat-forming flow”). Experts expressed some uncertainty about the net impact of these benefits and costs.
MG_7	**High Flow Impact on Juveniles, Middle Green**	MG_5. High Flow Impact, Jan-Mar, Middle Green MG_6. High Flow Impact, Apr-Jun, Middle Green	The total impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from January through June.
			Relation to parent factors This is a summary factor combining the cumulative effects of **High Flow Impact on Juveniles from January through March** and **April through June.**

Node ID	Node Name	Node Parents	Definition/Description
MG_8	**Culvert/Fish Passage Barrier Removal, Middle Green**	*None*	Culverts and other fish passage barriers removed from the Middle Green River. This does not include fish barriers in tributaries, except in the cases that the mouth of the tributary into the Middle Green is a culvert/fish passage barrier. Opening up passage barriers adds length and area of habitat to the sub-basin.
			Suggested metrics Area of newly accessible floodplain following barrier removal.
MG_9	**Armoring, Middle Green**	*None*	Armoring is defined as levees, riprap, bulkheads, revetments, or other hardscape meant to prevent erosion and allow flood protection. Armoring impedes floodplain function and reduces habitat complexity. It disconnects large portions of the historical floodplain, off-channel habitat, and tributaries, which provide juvenile salmon with forage and refuge from extreme flows.
MG_10	**Large Woody Debris, Middle Green**	*None*	Estimated average number of log jams per river mile. A log jam is defined as a minimum of 10 pieces of wood that are at least 12 feet long and ≥4" in diameter. Above this minimum, log jam size varies. R2 (2017) defines small jams as 10 to 50 pieces, medium jams as 51 to 100 pieces, and large as greater than 101 pieces. Jam size is not considered in the Salmon Habitat Plan goals.
			Factors not included Although **Riparian Forests** contribute large woody debris (LWD) to the river system, LWD in this model is intended to be directly measured as a model input, not modeled based off of its causal factors. Therefore, the two nodes are not linked.
MG_11	**Connected Floodplain, Middle Green**	MG_8. Culvert/Fish Passage Barrier Removal MG_9. Armoring, Middle Green	Area of floodplain accessible to juveniles within the Middle Green River subbasin, as defined by the WRIA 9 Technical Committee.
			Relation to parent factors **Culvert/Fish Passage Barrier Removal** creates access to floodplain area for juvenile salmon to use. **Armoring** impedes floodplain function and prevents juveniles from accessing floodplain where it exists.
			Suggested metrics Area of floodplain habitat subject to lateral channel migration. Number of accessible tributaries within the connected floodplain.

Node ID	Node Name	Node Parents	Definition/Description
MG_12	**Confined Bankfull Width, Middle Green**	MG_9. Armoring, Middle Green MG_10. LWD, Middle Green	Percent of the Middle Green, by length, with confined bankfull width. This can be anthropogenic (e.g., levees, roadways) or natural (e.g., canyons). Currently, approximately 75% of the Middle Green is confined. Restoring lateral channel migration is dependent on removal of armoring and the addition of large woody debris to create slow water habitat. Confined bankfull width is a surrogate (measured via its inverse) for slow water habitat complexity and lateral channel migration.
			Relation to parent factors **Large woody debris** impacts confined bankfull width by accelerating channel migration and habitat formation. Removal of **Armoring** alone will not result in loss of confinement.
			Suggested metrics Confined bankfull width is defined as a river segment that is of relatively uniform and below average width.
MG_13	**Moderate Flow Rearing Habitat Conditions, Middle Green**	MG_10. Large Woody Debris, Middle Green MG_11. Connected Floodplain, Middle Green MG_12. Confined Bankfull Width, Middle Green	This factor measures the benefits to juveniles of suitable habitat accessible outside of low flow or high flow events (between 1200 and 5000 cfs). Rearing habitat provides juveniles with the ability to forage for prey and grow larger. Those juveniles that are able to stay in the Middle Green river longer will have access to this habitat and its benefits over a longer time period. Juveniles that move downstream in search of suitable rearing habitat, including those that are crowded out by other juveniles, will be forced to rear in lower stretches of the river, which are generally of poorer habitat quality.
			Relation to parent factors Rearing habitat is a cumulative qualitative measurement of juveniles' access to **Connected Floodplain** (including off-channel habitat and tributaries) and in-channel slow water habitat provided by **Large Woody Debris** and channel complexity. Both provide juvenile salmon with forage and refuge. **Confined Bankfull Width** is a proxy for (lack of) channel complexity.
			Key uncertainties Experts generally consider physical habitat to be a proxy for forage opportunities for juvenile Chinook, however, some changes, including adding riparian vegetation, could add prey habitat and therefore forage capacity without adding physical space to the habitat.

Node ID	Node Name	Node Parents	Definition/Description
LF_1	**Hours Below 1200 cfs, Jan-Mar**	*None*	The number of hours from January through March where minimum discharge measured at USGS gauge site 12113000 was less than 1200 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE's hydrologic model (see HF_1).
MG_14	**Low Flow Impact on Juveniles, Jan-Mar, Middle Green**	LF_1. Hours Below 1200 cfs, Jan-Mar MG_10. Large Woody Debris, Middle Green MG_12. Confined Bankfull Width, Middle Green	The impact of the duration and volume of low flows on juvenile salmon from January to March in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.
			Relation to parent factors Experts identified **Hours Below 1200 cfs** during this time period as a threshold for low flows we expect to impact juvenile salmon. Volume and duration of low flows can result in juveniles getting forced downstream due to habitat restrictions or experiencing mortality due to heightened predation, starvation, stranding, or other causes during this time period. **Large Woody Debris** present in the channel and access to off-channel habitat blocked by **Confined Bankfull Width** can offer refuge to juveniles from increased predation and competition experienced during low flows.
LF_2	**Hours Below 1200 cfs, Apr-Jun**	*None*	The number of hours from April through June where minimum discharge measured at USGS gauge site 12113000 was less than 1200 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE's hydrologic model (see HF_1).

Node ID	Node Name	Node Parents	Definition/Description
MG_15	**Low Flow Impact on Juveniles, Apr-Jun, Middle Green**	LF_2. Hours Below 1200 cfs, Apr-Jun MG_10. Large Woody Debris, Middle Green MG_12. Confined Bankfull Width, Middle Green	The impact of the duration of low flows on juvenile salmon in April through June in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes. Due to increased frequency of low flows and dam management, the impact of low flows on juvenile Chinook is more pronounced during this period. *Relation to parent factors* Volume and duration of low flows result in juveniles getting forced downstream due to habitat restrictions or experiencing mortality due to heightened predation, starvation, stranding, or other causes during this time period. Experts identified **Hours Below 1200 cfs** during this time period as a threshold for low flows we expect to impact juvenile salmon. Low flows are more common during this time period than earlier. **Large Woody Debris** present in the channel and access to off-channel habitat blocked by **Confined Bankfull Width** can offer refuge to juveniles from increased predation and competition experienced during low flows.
MG_16	**Low Flow Impact on Juveniles, Middle Green**	MG_14. Low Flow Impact on Juveniles, Jan-Mar, Middle Green MG_15. Low Flow Impact on Juveniles, Apr-Jun, Middle Green	The impact of the duration of low flows on juvenile salmon in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes. *Relation to parent factors* This is a summary factor combining the cumulative effects of **Low Flow Impact on Juveniles from January through March** and **April through June.**
MG_17	**Fry Emergence**	*None*	The total number of fry in the Middle Green that have survived from egg to fry. Their survival is greatly impacted by scouring flows in fall and winter.

Node ID	Node Name	Node Parents	Definition/Description
MG_18	**Middle Green Parr Outmigrants**	MG_4. Mortality Due to Toxicity and Temperature MG_7. High Flow Impact on Juveniles, Middle Green MG_13. Moderate Flow Rearing Habitat Conditions, Middle Green MG_16. Low Flow Impact on Juveniles, Middle Green MG_17. Fry Emergence	The number of juvenile Chinook that rear to the parr stage in the Middle Green before outmigration to lower stretches of the river. The initial number of fry to emerge (MG_17) is reduced by the amount of accessible, quality habitat and mortality due temperature and toxics.
			Relation to parent factors The number of juveniles able to successfully rear to the parr stage in the Middle Green and outmigrate to the lower river is a function of initial **Fry Emergence**, decreased by **Mortality Due to Toxicity and Temperature** and by the number of juveniles forced downstream as fry to rear in lower stretches of the river. These fry outmigrants from the Middle Green are flushed downstream by **High Flows** or move downstream in search of suitable rearing conditions due to limitations in **Moderate Flow Rearing Habitat Conditions** and by **Low Flow Impact** decreasing access to available off-channel habitat. Experts considered the physical habitat features described by **Moderate Flow Rearing Habitat Conditions** to be the most influential on the number of parr outmigrants, with High Flows also important. Mortality due to temperature and toxic effects is believed to be of minor influence to the outmigrant endpoint, based on conversations with the SMEs.

3.0 LOWER GREEN RIVER JUVENILES

This chapter covers the juvenile life stages of Chinook salmon in the Lower Green River after they migrate downstream from the Middle Green River and before they enter the Duwamish Estuary. The boundary separating the Lower Green River and the Duwamish is located at RM 11 (where the Black River enters near Fort Dent).

Below are the key takeaways followed by a narrative that summarizes the conceptual model (3) and its annotations (5).

Key Takeaways

- Experts believe **increasing the habitat capacity in the Lower Green River could increase return rates**, although they also believe that opportunities to do this are few.
- Experts considered the **lack of off-channel and floodplain habitat to be the most influential factor on juvenile Chinook's ability to remain in the Lower Green** and continue to rear.
    - Rearing capacity in the Lower Green is limited by (1) high flows that displace juveniles coupled with inadequate high flow refugia and (2) insufficient foraging habitat.
        - High flows displace juveniles that are not able to find lower-velocity areas, forcing them downstream towards the Duwamish Estuary and its poor rearing conditions (see Chapter 4).
    - Limitations to rearing capacity are more amplified than what is experienced in the Middle Green. There is less off-channel and floodplain habitat in the Lower Green.
    - Limited foraging habitat in the Lower Green results in more fry migrating downstream to search for foraging habitat.
        - Large woody debris and the channel complexity are important factors for foraging habitat. Channel complexity includes off-channel habitat, braiding, and gradually sloping river banks. Experts suggested using confined bankfull width to estimate channel complexity, as the absence of bank confinement is a corollary for complexity.
- Low flows can create shallow, low-velocity habitat within the main channel, banks, and sandbars. Because of the extreme lack of off-channel habitat, this is some of the only such habitat available to Chinook in the Lower Green. **Low flows are therefore a positive influence on juvenile Chinook under current conditions**.

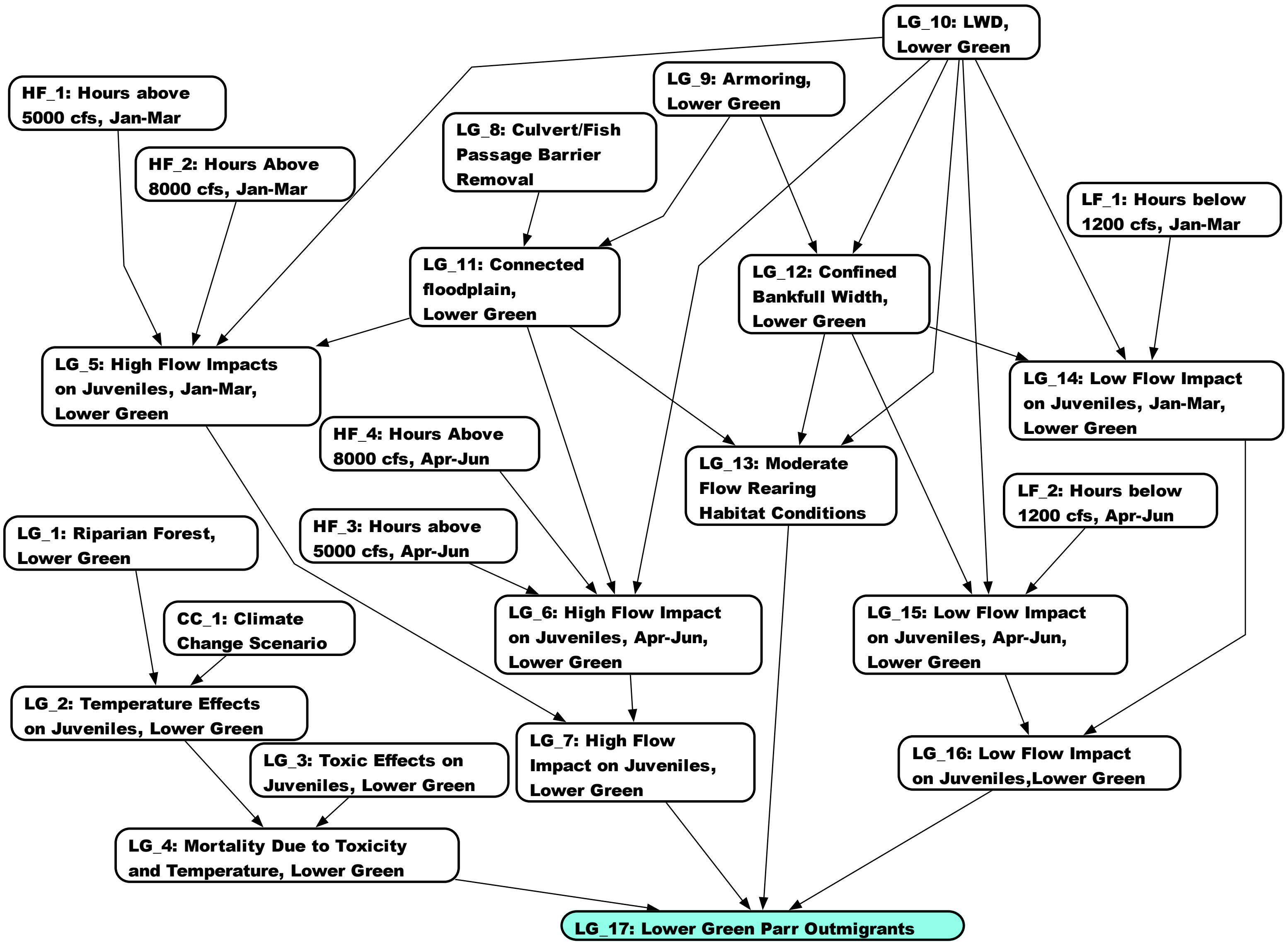

Figure 3. **Lower Green River juvenile outmigration conceptual model. Refer to Table 5 for factor definitions and descriptions of the interrelationships between factors and key uncertaities.**

Narrative

This section describes the above model structure. Detail on how the individual factors interact is provided in the following table (Table 5).

The number of Lower Green River Parr Outmigrants (LG_17) is influenced primarily by the combined effects of rearing habitat and the frequency and magnitude of high- and low-flow events. Experts were not sure whether there is direct or indirect mortality resulting from temperature or toxics impact in the Lower Green (due to increased disease or predation susceptibility), and we elected to retain those factors in the model.

Several physical habitat features impact juvenile Chinook's ability to forage in order to grow and develop, and also to find refuge during high flow events in order to avoid being pushed downstream. Culvert/Fish Passage Barrier Removal (LG_8), Armoring (LG_9), and Confined Bankfull Width (LG_12) estimate limitations to habitat formation and juvenile Chinook's access to off-channel habitat. Large Woody Debris (LG_10) and Connected Floodplain (LG_11) provide forage opportunities and high flow refugia during high flow events. We summarize the quality and relative amount of suitable habitat for juveniles under normal conditions in a single factor, Moderate Flow Rearing Habitat Conditions (LG_13). Rearing habitat in the Lower Green, especially off-channel habitat, is severely limited. This overall habitat condition and its interaction with flow is considered the most influential factor on the number of juveniles able to stay in the Lower Green.

High flows can displace juveniles further downstream into the Duwamish Estuary. The model captures this by considering both the frequency and magnitude of high flows and the availability of suitable habitat that provides high flow refugia. We describe the net outcome as High Flow Impact on Juveniles (LG_5, LG_6, and LG_7). Because of the severely limited amount of high flow refugia in the Lower Green, the impact of high flows is more pronounced than in the Middle Green. We consider flows during both January through March (during the fry life stage) (HF_1, HF_2) and April through June (during the parr life stage) (HF_3, HF_4). Although these life stage changes occur on a continuum through the season, we model them in these two time periods, which we believe represent a rough breakdown for most juveniles. Due to flow management and the larger size of parr, experts believe that the April to June high flow impacts are less influential than those in the earlier time period.

Low flows are also divided into a January through March (LF_1) and April through June (LF_2) time period. The net Low Flow Impact on Juveniles (LG_14 and LG_15) is an interaction between the measured low flows and physical habitat features Large Woody Debris (LG_10) and Confined Bankfull Width (LG_12). The two time periods are summarized as Low Flow Impact on Juveniles (LG_16) throughout the season. In contrast to the Middle Green, low flows in the Lower Green River create the only shallow and low velocity habitat available to juvenile Chinook under current conditions, since off-channel habitat is not available, making the impact of low flows a net positive. If habitat conditions change in the future, we expect both the magnitude and direction of the relationship to change.

Riparian Forest (MG_1), which provides shade over the river, interacts with the Climate Change Scenario (CC_1) to produce Temperature Effects on Juveniles (MG_2), which are more influential in the Lower Green than in the Middle Green. Temperature Effects and Toxic Effects on Juveniles (MG_3) combine to form a summary factor, Mortality Due to Toxicity and Temperature (MG_4). Experts consider toxicity to be of relatively low influence on juveniles in the Lower Green, but it also represents a data gap and therefore an area of uncertainty.

Further details on the links and influences within the Lower Green River model are provided in the table below.

Table 5. Lower Green River juvenile outmigration conceptual model annotations.

Node ID	Node Name	Node Parents	Definition/Description
LG_1	**Riparian Forest, Lower Green**	*None*	Riparian forest cover, as measured within the channel migration zone, may lower instream temperatures through shade and evapotranspiration. Riparian forest cover also contributes large woody debris and may serve as habitat for terrestrial prey for salmon.
CC_1	**Climate Change Scenario**	*None*	This node defines specific climate change scenarios.
			Factors not included Although we expect climate change to impact several factors in this model (including high and low flows), those linkages are not shown between nodes because climate change can be incorporated into starting conditions for those boundary nodes under modeling scenarios. Because climate change and the condition of riparian forests work together to influence water temperature and its effects on juveniles, we have included climate change explicitly as a parent to Temperature Effects on Juveniles (LG_2).
LG_2	**Temperature Effects on Juveniles, Lower Green**	LG_1. Riparian Forest, Lower Green CC_1. Climate Change Scenario	This node denotes the temperature stress experienced by juveniles, coming into play primarily during the April through June timeframe. This includes heightened metabolism and physiological stress. Experts do not expect this to be a strong influence on direct mortality, however temperature effects are more pronounced in the Lower Green than the Middle Green and will likely be exacerbated by climate change.
			Relation to parent factors **Riparian Forests** provides shading over the river, lowering temperatures. The **Climate Change Scenario** used in a model run may include overall annual warming as well as increases in extreme temperatures and rainfall patterns. We can expect climate change to result in warmer summer water temperatures due to warmer air temperatures, less summer rainfall, and lower summer river flows in the Pacific Northwest. Warmer summer temperatures would impact the later juvenile outmigrants.

Node ID	Node Name	Node Parents	Definition/Description
LG_3	**Toxic Effects on Juveniles, Lower Green**	*None*	This node denotes the toxic stress experienced by juveniles. It includes increased predation and disease caused by sublethal effects of toxicant exposure.
			Key uncertainties This is an area of uncertainty due to lack of data. Presently, experts do not consider toxic effects on juveniles to be highly influential on the number of parr outmigrants in comparison to habitat limitations. Juveniles sampled from the Green River have low levels of contaminants like PCBs in their tissue.
LG_4	**Mortality Due to Toxicity and Temperature, Lower Green**	LG_2. Temperature Effects on Juveniles LG_3. Toxic Effects on Juveniles	This node captures the severity and risk of mortality caused by elevated temperatures and concentrations of toxics. This includes exacerbation of predation and disease due to sublethal effects. Experts do not expect a strong influence of temperature and toxicity on direct mortality based on current understanding.
			Relation to parent factors This is a summary factor combining **Temperature** and **Toxic Effects on Juveniles.**
HF_1	**Hours above 5000 cfs, Jan-Mar**	*None*	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.
			Factors not included Climate change is not explicitly modeled because changes in flows due to climate change may be developed in future versions of the hydrologic model developed for WQBE and therefore represented in estimates of this factor.
HF_2	**Hours above 8000 cfs, Jan-Mar**	*None*	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 8,000 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE’s hydrologic model (see HF_1).

Node ID	Node Name	Node Parents	Definition/Description
LG_5	**High Flow Impact on Juveniles, Jan-Mar, Lower Green**	HF_1. Hours above 5000 cfs, Jan-Mar HF_2. Hours above 8000 cfs, Jan-Mar LG_10. Large Woody Debris, Lower Green LG_11. Connected Floodplain, Lower Green	The impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from January through March (independent of other population factors such as emergence). Compared with historic flow regimes, high flows are rare due to dam management, but when they do happen they have a large impact on juveniles. This impact is exacerbated by the highly confined channel of the Lower Green.
			Relation to parent factors Volume and duration of high flows result in juveniles getting flushed downstream. Experts identified **Hours Above 5000 cfs** during this time period as a threshold for high flows we expect to impact juvenile salmon and cause channel scour, and **Hours Above 8000 cfs** as a threshold for higher flows we expect to have an even greater impact. **Large Woody Debris** present in the channel and access to **Connected Floodplain** both can offer refuge to juveniles from the negative impacts of high flows, allowing them to stay further upstream for a longer portion of their growth. Because of the lack of both of these and access to off-channel habitat generally, high flow impacts in the Lower Green are more pronounced than in the Middle Green.
			Key uncertainties In addition to flushing juveniles downstream, high flows can also cause channel scouring and create access to off-channel habitat (“habitat-forming flow”). Experts expressed some uncertainty about the net impact of these benefits and costs.
HF_3	**Hours above 5000 cfs, Apr-Jun**	*None*	The number of hours from April through June where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE’s hydrologic model (see HF_1).
HF_4	**Hours above 8000 cfs, Apr-June**	*None*	The number of hours from April through June where maximum discharge measured at USGS gauge site 12113000 exceeded 8,000 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE’s hydrologic model (see HF_1).

Node ID	Node Name	Node Parents	Definition/Description
LG_6	**High Flow Impact on Juveniles, Apr-Jun, Lower Green**	HF_3. Hours above 5000 cfs, Apr-Jun HF_4. Hours above 8000 cfs, Apr-Jun LG_10. Large Woody Debris, Lower Green LG_11. Connected Floodplain, Lower Green	The impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from April through June. Compared with historic flow regimes, high flows are rare due to dam management, especially during this time period, but when they do happen, they have an impact on juveniles. This impact is exacerbated by the highly confined channel of the Lower Green. Due to lower and less frequent high flows during this period, and the larger size of the older juveniles, the impact of high flows on juveniles from April through June is lower than during the January through March period.
			Relation to parent factors Volume and duration of high flows result in juveniles getting flushed downstream. Experts identified **Hours Above 5000 cfs** during this time period as a threshold for high flows we expect to impact juvenile salmon and cause channel scour, and **Hours Above 8000 cfs** as a threshold for higher flows we expect to have an even greater impact. **Large Woody Debris** present in the channel and access to **Connected Floodplain** both can offer refuge to juveniles from the negative impacts of high flows, allowing them to stay further upstream for a longer portion of their growth. Because of the lack of both of these and access to off-channel habitat generally, high flow impacts in the Lower Green are more pronounced than in the Middle Green.
			Key uncertainties In addition to flushing juveniles downstream, high flows can also cause channel scouring and create access to off-channel habitat (“habitat-forming flow”). Experts expressed some uncertainty about the net impact of these benefits and costs.

Node ID	Node Name	Node Parents	Definition/Description
LG_7	**High Flow Impact on Juveniles, Lower Green**	LG_5. High Flow Impact, Jan-Mar, Lower Green LG_6. High Flow Impact, Apr-Jun, Lower Green	The total impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from January through June. Due to highly constrained channel conditions and lack of high flow refugia, High Flow impacts are even more influential in the Lower Green than in the Middle Green.
			Relation to parent factors This is a summary factor combining the cumulative effects of **High Flow Impact on Juveniles from January through March** and **April through June.**
LG_8	**Culvert/Fish Passage Barrier Removal, Lower Green**	*None*	Culverts and other fish passage barriers removed from the Lower Green River. This does not include fish barriers in tributaries, except in the cases that the mouth of the tributary into the Lower Green is a culvert/fish passage barrier. Opening up passage barriers adds length and area of habitat to the sub-basin.
			Suggested metrics Area of newly accessible floodplain following barrier removal.
LG_9	**Armoring, Lower Green**	*None*	Armoring is defined as levees, riprap, bulkheads, revetments, or other hardscape meant to prevent erosion and allow flood protection. Armoring impedes floodplain function and reduces habitat complexity. It disconnects large portions of the historical floodplain, off-channel habitat, and tributaries, which provide juvenile salmon with forage and refuge from extreme flows. Armoring is widespread in the Lower Green.

Node ID	Node Name	Node Parents	Definition/Description
LG_10	**Large Woody Debris, Lower Green**	*None*	Estimated average number of log jams per river mile. A log jam is defined as a minimum of 10 pieces of wood that are at least 12 feet long and ≥4" in diameter. Above this minimum, log jam size varies. R2 (2017) defines small jams as 10 to 50 pieces, medium jams as 51 to 100 pieces, and large as greater than 101 pieces. Jam size is not considered in the Salmon Habitat Plan goals. Large woody debris is relatively scarce in the Lower Green.
			Factors not included Although **Riparian Forests** contribute large woody debris (LWD) to the river system, LWD in this model is intended to be directly measured as a model input, not modeled based off of its causal factors. Therefore, the two nodes are not linked.
LG_11	**Connected Floodplain, Lower Green**	LG_8. Culvert/Fish Passage Barrier Removal LG_9. Armoring, Lower Green	Area of floodplain accessible to juveniles within the Lower Green River subbasin. This can also be influenced by lowering the floodplain shelf and select culvert removal.
			Relation to parent factors **Culvert/Fish Passage Barrier Removal** creates access to floodplain area for juvenile salmon to use. **Armoring** impedes floodplain function and prevents juveniles from accessing floodplain where it exists.
			Suggested metrics Area of floodplain habitat subject to lateral channel migration. Number of accessible tributaries within the connected floodplain.
LG_12	**Confined Bankfull Width, Lower Green**	LG_9. Armoring, Lower Green LG_10. LWD, Lower Green	Percent of the Lower Green, by length, with confined bankfull width. This can be anthropogenic (e.g., levees, roadways) or natural (e.g., canyons). Currently, approximately 90% of the Lower Green is confined. Restoring lateral channel migration is dependent on removal of armoring and the addition of large woody debris to create slow water habitat. Confined bankfull width is a surrogate (measured via its inverse) for slow water habitat complexity and lateral channel migration.
			Relationship to parent factors: **Large woody debris** impacts confined bankfull width by accelerating channel migration and habitat formation. Removal of **Armoring** alone will not result in loss of confinement.
			Suggested metrics Confined bankfull width is defined as a river segment that is of relatively uniform and below average width.

Node ID	Node Name	Node Parents	Definition/Description
LG_13	**Moderate Flow Rearing Habitat Conditions, Lower Green**	LG_10. Large Woody Debris, Lower Green LG_11. Connected Floodplain, Lower Green LG_12. Confined Bankfull Width, Lower Green	This factor measures the benefits to juveniles of suitable habitat accessible outside of low flow or high flow events (between 1200 and 5000 cfs). Rearing habitat provides juveniles with the ability to forage for prey and grow larger; this is severely limited in the Lower Green. Those juveniles that are able to stay in the Lower Green river longer will have access to this habitat and its benefits over a longer time period. Juveniles that move downstream in search of suitable rearing habitat, including those that are crowded out by other juveniles, will be forced to rear in the Duwamish Estuary, which is generally of poorer habitat quality.
			Relation to parent factors Rearing habitat is a cumulative qualitative measurement of juveniles' access to **Connected Floodplain** (including off-channel habitat and tributaries) and in-channel slow water habitat provided by **Large Woody Debris** and channel complexity. Both provide juvenile salmon with forage and refuge. **Confined Bankfull Width** is a proxy for (lack of) channel complexity.
			Key uncertainties Experts generally consider physical habitat to be a proxy for forage opportunities for juvenile Chinook, however, some changes, including adding riparian vegetation, could add prey habitat and therefore forage capacity without adding physical space to the habitat.
LF_1	**Hours Below 1200 cfs, Jan-Mar**	*None*	The number of hours from January through March where minimum discharge measured at USGS gauge site 12113000 was less than 1200 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE's hydrologic model (see HF_1).

Node ID	Node Name	Node Parents	Definition/Description
LG_14	**Low Flow Impact on Juveniles, Jan-Mar, Lower Green**	LF_1. Hours Below 1200 cfs, Jan-Mar LG_10. Large Woody Debris, Lower Green LG_12. Confined Bankfull Width, Lower Green	The impact of the duration and volume of low flows on juvenile salmon from January to March in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.
			Relation to parent factors Experts identified **Hours Below 1200 cfs** during this time period as a threshold for low flows we expect to impact juvenile salmon. Volume and duration of low flows can result in juveniles getting forced downstream due to habitat restrictions or experiencing mortality due to heightened predation, starvation, stranding, or other causes during this time period. However, experts considered the net impact of low flows under current conditions to be a positive one for juvenile Chinook. Because of the lack of accessible tributaries within the floodplain, restricting juveniles to the main channel, low flows can create shallow/low velocity habitat from sand bars and bottom channel areas that otherwise wouldn't be there during high or moderate flows. If access to off-channel habitat were to change under future scenarios, this relationship could also change. **Large Woody Debris** present in the channel and access to off-channel habitat blocked by **Confined Bankfull Width** can offer refuge to juveniles from increased predation and competition experienced during low flows.
			Key uncertainties Nature, magnitude, and direction of influence of low flows on juveniles could change under future scenarios where more off-channel habitat was available.
LF_2	**Hours Below 1200 cfs, Apr-Jun**	*None*	The number of hours from April through June where minimum discharge measured at USGS gauge site 12113000 was less than 1200 cfs.
			Factors not included Climate change-induced changes in flows may be captured in future versions of WQBE's hydrologic model (see HF_1).

Node ID	Node Name	Node Parents	Definition/Description
LG_15	**Low Flow Impact on Juveniles, Apr-Jun, Lower Green**	LF_2. Hours Below 1200 cfs, Apr-Jun LG_10. Large Woody Debris, Lower Green LG_12. Confined Bankfull Width, Lower Green	The impact of the duration of low flows on juvenile salmon in April through June in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.
			Relation to parent factors Experts identified **Hours Below 1200 cfs** during this time period as a threshold for low flows we expect to impact juvenile salmon. Volume and duration of low flows can result in juveniles getting forced downstream due to habitat restrictions or experiencing mortality due to heightened predation, starvation, stranding, or other causes during this time period. However, experts considered the net impact of low flows under current conditions to be a positive one for juvenile Chinook. Because of the lack of accessible tributaries within the floodplain, restricting juveniles to the main channel, low flows can create shallow/low velocity habitat from sand bars and bottom channel areas that otherwise wouldn't be there during high or moderate flows. If access to off-channel habitat were to change under future scenarios, this relationship could also change. **Large Woody Debris** present in the channel and access to off-channel habitat blocked by **Confined Bankfull Width** can offer refuge to juveniles from increased predation and competition experienced during low flows.
LG_16	**Low Flow Impact on Juveniles, Lower Green**	LG_14. Low Flow Impact on Juveniles, Jan-Mar, Lower Green LG_15. Low Flow Impact on Juveniles, Apr-Jun, Lower Green	The impact of the duration of low flows on juvenile salmon in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.
			Relation to parent factors This is a summary factor combining the cumulative effects of **Low Flow Impact on Juveniles from January through March** and **April through June.**

Node ID	Node Name	Node Parents	Definition/Description
LG_17	**Lower Green Parr Outmigrants**	LG_4. Mortality Due to Toxicity and Temperature LG_7. High Flow Impact on Juveniles, Lower Green LG_13. Moderate Flow Rearing Habitat Conditions, Lower Green LG_16. Low Flow Impact on Juveniles, Lower Green	The number of juvenile Chinook that rear to the parr stage in the Lower Green before outmigration to the estuary. This number is expressed as proportion of the current rearing capacity in the Middle Green (circa 2020).
			Relation to parent factors The habitat capacity of the Lower Green is a function of **Moderate Flow Rearing Habitat Conditions** and their interaction with **extreme (high and low) flows** and reduced by **Mortality Due to Toxicity and Temperature**. Mortality due to temperature and toxic effects is believed to be of minor influence to the outmigrant endpoint, based on conversations with the SMEs. High flows are relatively rare due to dam management but have a large (negative) influence on habitat capacity. The severe limitations on rearing habitat conditions in the lower river, especially lack of high flow refugia, make high flows very influential on flushing juveniles downstream. Low Flows can create the only opportunity for low-velocity habitat in channel bottoms and banks due to the high amount of armoring and lack of off-channel habitat during moderate and high flows, meaning that low flows can positively influence habitat capacity.

4.0 DUWAMISH ESTUARY JUVENILES

This chapter covers the juvenile life stages of Chinook salmon in the Duwamish Estuary after they enter the estuary as fry or parr until they migrate to Elliott Bay. We are only considering the sub-yearling life histories.

Below are the key takeaways followed by a narrative that summarizes the conceptual model (Figure 4) and its annotations (Table 6).

Key Takeaways

- **The estuary-rearing fry life history makes up about half of juveniles, but only three percent of returning adults.** Experts believe poor return rates are due to poor rearing conditions in the Duwamish Estuary.
- **The Duwamish Estuary does <u>not</u> provide suitable rearing habitat for juvenile Chinook salmon**. Industrial development removed critical habitat and contaminated the waterbody. Both estuary-reared and river-reared juvenile success is limited by conditions in the Duwamish Estuary.
    - **Limited habitat decreases the availability of prey and increases exposure to predators.**
        - **Higher water temperatures** increase the metabolism of predators, causing them to eat more, and **artificial lighting** increases predator activity and may change juvenile behavior. **Overwater structures** provide ambush habitat for predators. All three factors make juvenile Chinook more susceptible to predation.
    - **Juveniles are exposed to toxics in the Duwamish Estuary from contaminated sediments and pollutant discharges.** Toxic impact is believed to be dependent on the life stage, duration, and magnitude of exposure.
        - Estuary-rearing fry reside in the estuary for longer than river-rearing fry (which pass through quickly) and thus the former are believed to suffer greater exposure to toxicants. However, existing fish tissue monitoring studies have not distinguished between the two life histories in their sampling plan or reporting.
        - Recent tissue samples of parr in the Duwamish Estuary measured concentrations of PCBs below observed effects levels for juvenile Chinook. However, these samples are more likely to represent river-rearing juveniles than estuary-rearing juveniles based on the timing of sample collection.

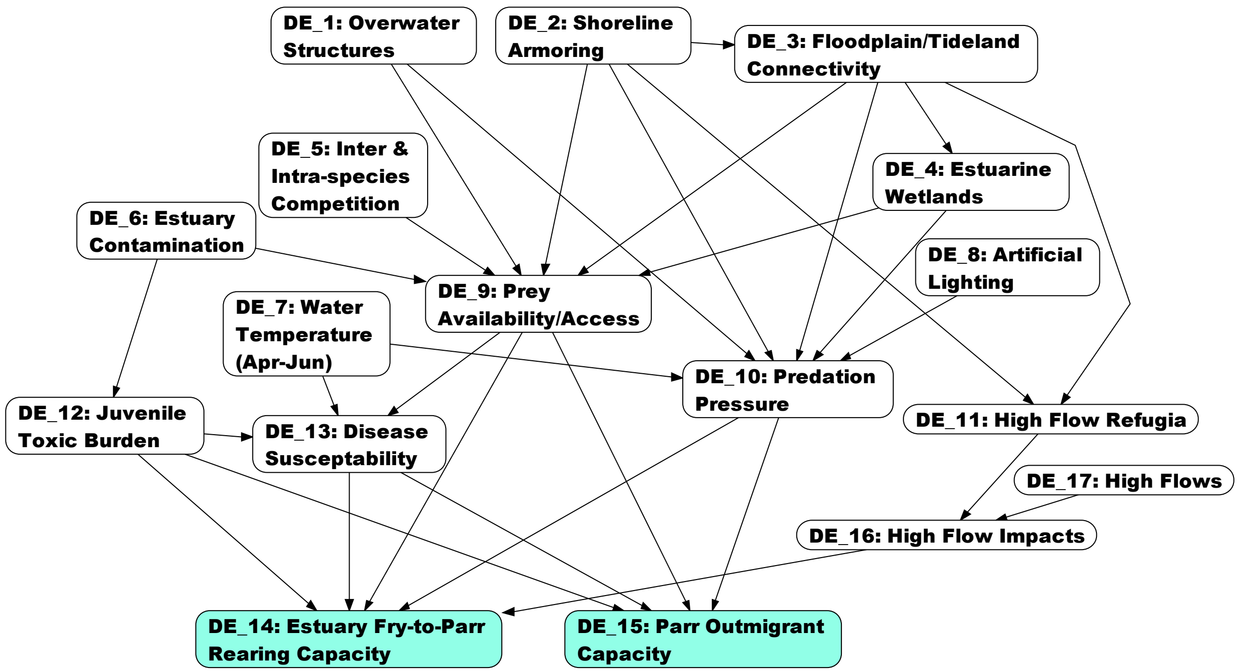

Figure 4. Habitat and contamination limit successful rearing and outmigration of juvenile Chinook salmon in the Duwamish Estuary. The conceptual model and annotations in Table 6 describe how conditions in Duwamish Estuary impact juvenile Chinook.

Estuary-rearing Fry

Fry predominately enter the Duwamish Estuary between February and March, where they rear for weeks to months after being forced downstream from the Green River by high flows or in search of forage habitat. Fry need shallow, low velocity habitat to forage. The Duwamish Estuary has very little such habitat. Therefore, estuary-rearing fry struggle to find areas to forage and grow.

The growth limitation is exacerbated by toxic impacts from ingesting contaminated prey and from toxicants in the water column and/or sediments (DE_12). These toxicants can retard growth and increase susceptibility to disease (DE_13). Impaired growth may increase the juveniles' susceptibility to predation. Toxic exposure during the critical growth period for juveniles in the estuary and after entering Puget Sound is a concern for long-term survivorship (Meador, 2014). Chapter 7 provides further depth on toxicant impacts on juveniles.

Critical habitat for juvenile salmon and their prey are wetlands (DE_4) and floodplains/tidelands (DE_3). Shoreline development and channelization removed those habitats. Shoreline armoring (DE_2) is not suitable foraging habitat for juveniles due to exposure to predators and poor prey abundance. Shoreline armoring also prevents access to estuarine wetlands and disconnects the estuary from floodplains/ tidelands.

The lack of habitat may also increase the threat of predation by fish, birds, and pinnipeds (DE_10). Within the Duwamish Estuary, piscine predators are a primary concern during the

fry life stage and avian and pinniped predators a concern when juveniles are larger during the parr life stage. Higher water temperatures (DE_7) increase the metabolism of predators, causing them to eat more juveniles, and artificial lighting (DE_8) increases predator activity and may change juvenile behavior, making them more susceptible to predation. Overwater structures (DE_1) also provide ambush habitat for predators. And because juveniles may avoid overwater structure due to predation risk, this limits their access to potential prey resources near the shoreline. Predation was generally not thought to be a limiting factor under current conditions, but experts expressed concern that predation could worsen with increased temperature.

An additional potential concern is fry flushing into saltwater Elliott Bay prematurely due to high flows (DE_17) in the Green River and a lack of high flow refugia in the Lower Green River (see Chapter 3) and in the Duwamish Estuary (DE_11). Prematurely entering Elliott Bay, prior to smoltification, can result in osmoregulatory stress and mortality. This has not been directly observed but was suggested as likely by a subject matter expert.

Parr Survival

Green River-reared parr predominately enter the Duwamish Estuary between May and June, where they rear for days to weeks, joining the surviving estuary-rearing fry (now in the parr stage). Parr face the same limited habitat and toxicant exposure in the Duwamish as fry, but for a shorter period and are better suited to handle it. Parr, due to their larger size and improved swim strength, are better able to forage pelagically on zooplankton and avoid piscine predation. Benthic macroinvertebrates still constitute an important prey resource, and ingestion of toxicants still occurs.

There is believed to be some level of competition for prey resources and habitat when hatchery smolt are released (DE_5), though some experts suggested that hatchery released juveniles move through the estuary quickly and would not have a substantial effect.

Table 6. Duwamish Estuary chinook juvenile limiting factor conceptual model annotations.

Node ID	Node Name	Node Parents	Definition/Description
DE_1	Overwater Structures	*None*	Docks, piers, pilings, and other overwater structures that make juveniles more susceptible to predation. Overwater structures can provide cover for predators, and/or juveniles will avoid these areas and move to deeper water where they are more susceptible to predators.
			Suggested metrics Percent of shoreline with overwater structures.
DE_2	Shoreline Armoring	*None*	Armoring is defined as levees, riprap, bulkheads, revetments, or other hardscape meant to prevent erosion and allow flood protection.
			Suggested metrics Percent of shoreline length with armoring.
DE_3	Floodplain/Tideland Connectivity	DE_2. Shoreline Armoring	This node represents the accessibility of floodplains and tidelands to juvenile salmon in the Duwamish Estuary. Juvenile salmon benefit from access to additional habitat areas during high flows and tides.
			Relation to parent factors **Shoreline Armoring** degrades floodplain function and reduces habitat complexity. It disconnects large portions of the historical floodplain, off-channel habitat, and tributaries.
			Suggested metrics Acreage of floodplains/tidelands.
DE_4	Estuarine Wetlands	*None*	Estuary wetlands include mud flats, emergent marshes, scrub-shrub tidal wetlands, and tidal freshwater swamps. Submerged plants, such as eelgrass, are also present. There is very little floodplain/tideland in the Estuary; it exists only at the mouth of Hamm Creek and Salmon Cove Park. This node is distinct from **Floodplain/Tideland Connectivity (DE_3)** because it considers the quality of areas (i.e., developed tidelands vs. wetlands).
			Suggested metrics Acres of estuarine wetlands.

Node ID	Node Name	Node Parents	Definition/Description
DE_5	Inter- and Intra-species Competition	*None*	Resident fish and hatchery-released fish compete with natural-origin chinook for foraging habitat and prey resources. The Soos Creek Hatchery releases around 3 million sub-yearling fall Chinook in late May/June. These fish typically travel through the Lower Green River at a time when smaller and much less abundant natural-origin parr are present, thus the more abundant and larger hatchery fish may prematurely force natural fish to the estuary. As a result of such interactions, hatchery fish likely have a competitive advantage (e.g., due to fat reserves) over their natural-origin juveniles if the food supply is limited. The subyearling fall Chinook compete with natural-origin parr for the same habitat and prey.
			Suggested metrics Number of hatchery-origin subyearling Chinook released during the parr life stage.
DE_6	Estuary Contamination	*None*	The level of contamination that juveniles are exposed to in the Duwamish Estuary. This is influenced by the cleanup status of the Lower Duwamish Waterway Superfund site, discharges from CSO and stormwater outfalls in the estuary, and contamination coming from upstream in the Green River.
DE_7	Water Temperature (April to June)	*None*	This node represents the general temperature regime of the Duwamish Estuary during the parr life stage (April through June).
			Suggested metrics Days where the 7-DADMax exceeds 14 degrees C for April to June.
			Key uncertainties Climate change is expected to cause increased water temperature. Several experts suggested that climate-change-induced warming could result in increased disease susceptibility, toxicity, and piscine predation rates, but were highly uncertain regarding the magnitude of those changes and the specific resulting impacts.
DE_8	Artificial Lighting	*None*	The level of lighting from docks, vessels, buildings, bridges, skyglow, and other light sources that illuminate the surface waters of Duwamish Estuary.

Node ID	Node Name	Node Parents	Definition/Description
DE_9	Prey Availability and Access	DE_1. Overwater Structures DE_2. Shoreline Armoring DE_3. Floodplain/ Tideland Connectivity DE_4. Estuarine Wetlands DE_5. Inter/Intra-Species Competition DE_6. Estuary Contamination	Juvenile foraging success relies both on the abundance of prey and the conditions at foraging locations. Cordell et al., (2001) concluded that juvenile Chinook are more opportunistic feeders in the Duwamish Estuary compared with other systems due to a lack of shoreline habitat. In the Duwamish Estuary, juveniles forage benthic, planktonic, and terrestrial macroinvertebrates.
			Relation to parent factors **Overwater Structures** inhibit juvenile foraging underneath. Juveniles avoid passing under overwater structures and thereby cannot access prey resources that may be present. **Shoreline Armoring** limits prey resources. It inhibits benthic macroinvertebrate productivity. It is also tied to decreased riparian vegetation that is suitable to provide terrestrial prey resources. Juveniles also tend to avoid areas of shoreline armoring because it makes them vulnerable to predators. **Floodplain/Tideland Connectivity** provides habitat for prey and juvenile foraging. **Estuarine Wetlands** provide important habitat for terrestrial and aquatic macroinvertebrate prey resources. Additionally, wetlands are preferred foraging habitat by juveniles because of refuge from predators. Under limited prey resources, juveniles face **Inter- and Intra-species competition** with other fish to meet their metabolic needs. During the parr life stage, natural-origin juveniles compete with hatchery-released salmon juveniles. The feeding rates of natural-origin juveniles in a past study dropped when hatchery juveniles entered the estuary (Nelson et al. 2004). **Estuary Contamination** in sediments and water can limit prey abundance and quality. High sediment contamination in some areas in the Duwamish Estuary show depressed macroinvertebrate communities.
			Suggested metrics Relative food supply for juveniles (e.g., Limited, Adequate, Abundant)

Node ID	Node Name	Node Parents	Definition/Description
DE_10	Predation Pressure	DE_1. Overwater Structures DE_2. Shoreline Armoring DE_3. Floodplain/ Tideland Connectivity DE_4. Estuarine Wetlands DE_7. Water Temperature (April-June) DE_8. Artificial Lighting	A measure of piscine, avian, and pinniped predation on juvenile Chinook. Some habitat features such as natural shoreline may allow Chinook to escape even if predators are present, while factors like artificial lighting may increase exposure to predation.
			Relation to parent factors **Estuarine Wetlands & Floodplain/Tideland Connectivity** provide juveniles foraging habitat that allow them to avoid predators. **Overwater Structures** provide ambush habitat for piscine predators. Increases in **Water Temperature** increase the metabolism of piscine predators, causing them to eat more juveniles Emerging research suggests that nighttime **Artificial Lighting** may alter juvenile fish behavior in a way that makes them more susceptible to predators, and that artificial light increases the length of time predators actively feed.
			Suggested metrics Number of juveniles lost to predation.
			Factors not included Experts discussed that predation pressure may be influenced by the presence of other fish, including hatchery-origin Chinook and coho. The addition of other fish may provide cover to juvenile natural-origin Chinook. The experts, however, felt that this factor was relatively minor compared to the impacts of habitat limitation and toxicant exposure and so it was not included in the model.
DE_11	High flow Refugia	DE_2. Shoreline Armoring DE_3. Floodplain/ Tideland Connectivity	The availability of habitat suitable for juveniles, specifically fry, avoid high velocity flows. High flows from the Green River may forcefully relocate juveniles into Elliott Bay.
			Relation to parent factors Juveniles avoid high velocity flows by entering off-channel habitats such as tributary mouths and other physically complex habitat. **Shoreline Armoring** restricts their access and **Floodplain/Tideland Connectivity** enables it.
			Suggested metrics Relative area of low-velocity waters during specific high flows.

Node ID	Node Name	Node Parents	Definition/Description
DE_12	Juvenile Toxic Burden	DE_6. Estuary Contamination	The level of toxicant exposure of juveniles. This includes PCBs, pesticides, metals, and other pollutants.
			Relation to parent factors Juvenile Chinook exposed directly to **Estuary Contamination** from water and sediments in the Duwamish can take up some of that contamination into their tissues.
			Key uncertainties See Chapter 7
			Suggested metrics Contaminant tissue concentrations in juveniles, e.g., PCBs.
DE_13	Disease Susceptibility	DE_7. Water Temperature (April-June) DE_9. Prey Availability/ Access DE_12. Juvenile Toxic Burden	Exposure and susceptibility of juveniles to disease during rearing and migration in the freshwater system. Myxozoan parasites are of particular concern as they may be impacting long-term survivorship through renal disease. Slow moving waters with stable substrate are prime habitat for obligate-host polychaetes
			Relation to parent factors Sublethal impacts of **Juvenile Toxic Burden** can compromise immune response. Present-day levels of toxicants indicate that juvenile immune systems are compromised. Disease susceptibility increases when juveniles are malnourished and struggle to forage. Limited foraging habitat and decreased **Prey Availability/Access** leads to higher densities of juveniles, which increases disease transfer. Increased **Water Temperature (April – June)** can increase the prevalence of disease and the susceptibility of juveniles to disease.

Node ID	Node Name	Node Parents	Definition/Description
DE_14	Estuary Fry-to-Parr Rearing Capacity	DE_9. Prey Availability/ Access DE_10. Predation Pressure DE_16. High Flow Impacts DE_12. Juvenile Toxic Burden DE_13. Disease Susceptibility	The capacity of the Duwamish Estuary to support natural-origin fry to successfully rear to become parr. *Relation to parent factors* Rearing fry need abundant **Prey Availability/Access** to grow. Smaller and malnourished fry are less able to withstand high flows, predators, disease, and toxics. ***Predation Pressure*** describes rearing fry being eaten and harassed by predators while in the Duwamish Estuary. Disease, toxic impacts, and limited prey resources may increase the susceptibility of juveniles to predation. High flows from the Green River and a lack of high flow refugia, summarized as ***High Flow Impacts***, may forcefully relocate juveniles into Elliott Bay. This is particular concern for fry while Green River flows are high in winter and early spring (January through April). High flow refugia includes side channels, floodplains/tidelands, and tributaries. If fry are pushed prematurely into Elliott Bay, they are not expected to survive due to the osmoregulatory shock and exposure to predators in open water. Rearing fry may have increased risk of mortality due to sublethal effects of the **Juvenile Toxic Burden** caused by exposure in the Duwamish. Rearing fry may die from disease before becoming parr, **Disease Susceptibility** may be exacerbated by toxic exposures, limited foraging habitat, and predator harassment. *Suggested metrics* Number of estuary-reared fry that remain in the Duwamish Estuary and survive to reach the parr life stage. *Key uncertainties* There is little data on the fate of juveniles that arrive in the Duwamish Estuary as fry, beyond that virtually none return as adults to spawn. We do not know how many juveniles arriving as fry are pushed out into Elliott Bay by high flows and limited habitat and suffer osmoregulatory stress, are eaten by predators, or die from disease or toxic exposure.

Node ID	Node Name	Node Parents	Definition/Description
DE_15	Parr Outmigrant Capacity	DE_9. Prey Availability/ Access DE_10. Predation Pressure DE_12. Juvenile Toxic Burden DE_13. Disease Susceptibility	The capacity of the Duwamish Estuary to support natural-origin parr to successfully outmigrate to Elliott Bay as smolt. This includes both parr that reared in the estuary as fry and those migrating down from the Lower and Middle Green River.
			Relation to parent factors Parr rely on **Prey Availability/Access** to grow. Smaller and malnourished parr are less able to withstand predators, disease, and toxics. **Predation Pressure** describes parr being eaten and harassed by predators while in the Duwamish Estuary. Disease, toxic impacts, and limited prey resources may increase the susceptibility of juveniles to predation. Parr may have an increased risk of mortality due to sublethal effects of the **Juvenile Toxic Burden** caused by exposure in the Duwamish. Tissue data from juveniles sampled from the Duwamish Estuary have detected levels of PCBs that exceed thresholds associated with increased mortality. **Disease Susceptibility**, which can cause parr to die before outmigration, may be exacerbated by toxic exposures, limited foraging habitat, and predator harassment
			Suggested metrics Number of juveniles that can outmigrate through the Duwamish Estuary that reared in the estuary or the Lower or Middle Green River.
			Key uncertainties There is little data on the numbers of juvenile Chinook outmigrating from the Duwamish Estuary into Elliott Bay. The WDFW-run screw trap only captures how many and when juveniles leave the Middle Green. This gap prevents empirical analysis of the survivorship of estuary-reared and river-reared juveniles within Duwamish Estuary. Annual Duwamish Estuary outmigrant data would allow assessment of climatic conditions, predator abundance and activity, habitat improvement and degradation, contamination cleanup, and other factors that could vary between broods.

Node ID	Node Name	Node Parents	Definition/Description
DE_16	High Flow Impacts	DE_11. High flow Refugia DE_17. High Flows	The impact of the duration and volume of high flows on fry in the Duwamish Estuary from January through April. This represents both fry that are being flushed downstream from the Lower and Middle Green and fry that had previously arrived in the estuary due to high flows or their own volition.
			Relation to parent factors Volume and duration of high flows result in juveniles getting flushed downstream into Elliott Bay. **High flows** coupled with the availability of **high flow refugia** determine if and to what degree high flows push fry into Elliott Bay.
DE_17	High Flows	*None*	The frequency of high flows through the Duwamish Estuary from January through March. High flows are defined as over 8000 cfs measured at the Auburn gage.
			Suggested metrics The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.

5.0 MARINE SURVIVAL

This chapter covers the juvenile life stage of Chinook salmon in the Salish Sea and the Pacific Ocean from when they enter Elliott Bay as juveniles to the point where these fish are either captured as adults in fisheries or by natural predators or return to rivers to spawn.

Below are the key takeaways followed by a narrative that summarizes the conceptual model (Figure 5) and its annotations (Table 7).

Key Takeaways

- **Changes in Food Supply**
  - **Climate change** has likely driven changes in the base of the food web, phytoplankton and zooplankton. However, the complexity of the system and lack of long-term data preclude us from assigning causal relationships with confidence.
  - **Forage fish populations,** a food source for salmon, have declined.
  - **Degraded estuary and nearshore habitat** decrease forage habitat for both Chinook and their prey.
- **Predation by harbor seals** represents a major portion of juvenile salmon marine mortality – between 5 and 60 percent.
  - The **sheer abundance of harbor seals** is a major driver of this predation pressure.
  - **Decrease in forage fish populations** increases predators targeting Chinook.
- **Impacts of toxicants and disease** for Chinook in Puget Sound marine waters have not been systematically evaluated but are expected to influence population level performance.

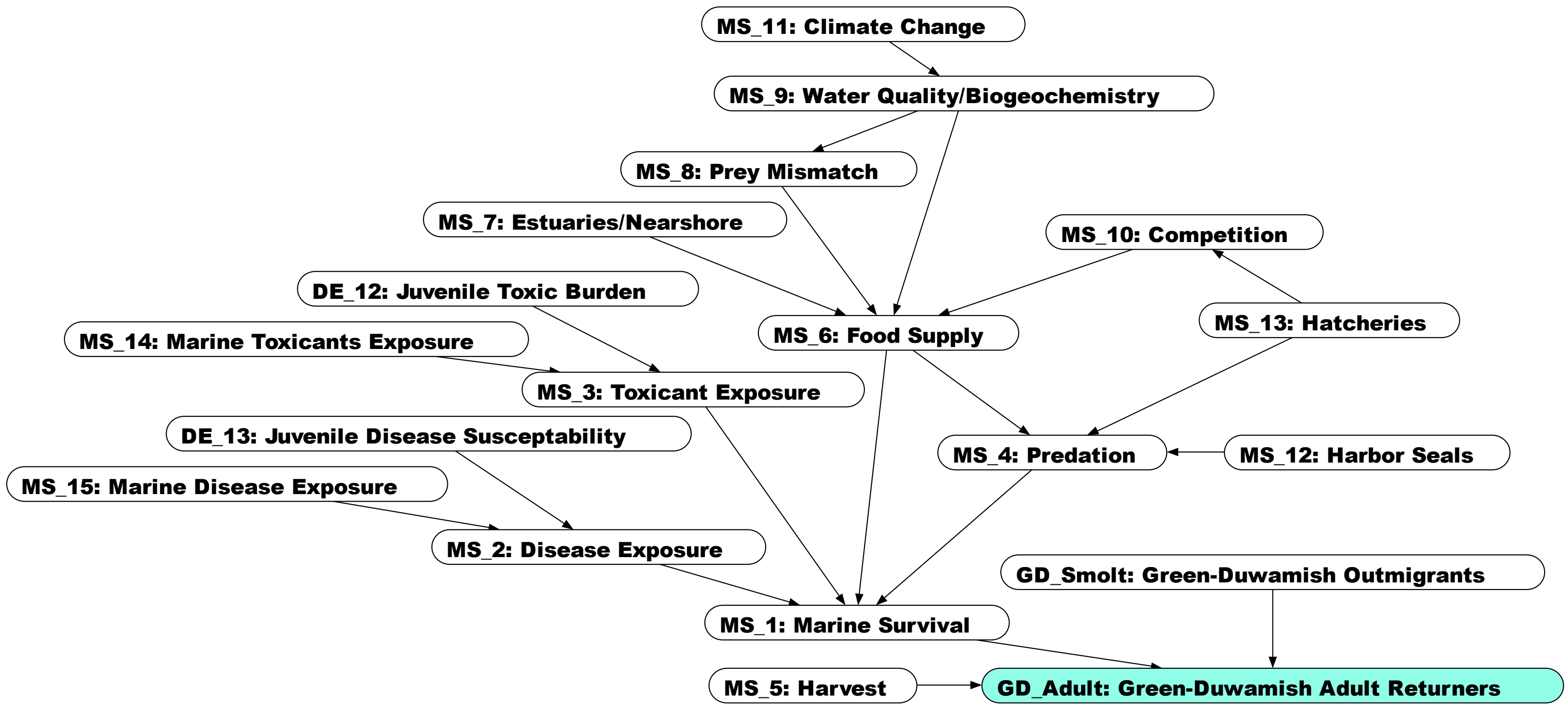

Figure 5. Marine survival conceptual model adapted from Table 3 in Pearsall et al. 2021 and infographic in Summary report of same document.

Salish Sea Marine Survival Project Summary

The Salish Sea Marine Survival Project[2] (SSMSP) is a multi-partner effort to examine the most likely factors influencing juvenile Chinook salmon, coho salmon, and steelhead survival in the Salish Sea. SSMSP was launched by the Pacific Salmon Foundation and Long Live the Kings in 2012, and is an international collaboration with over 60 federal, state, tribal, nonprofit, academic, and private entities. SSMSP published a synthesis report of the work to date in 2021 in collaboration with a Synthesis Committee made up of scientists from multiple disciplines. Work and further research are ongoing (Pearsall et al., 2021).

The conclusions of that synthesis are provided below verbatim:

The Synthesis Report identified two overarching phenomena behind declining Salish Sea marine survival:

1. ***Changes in food supply.*** *Young salmon, especially Chinook and* Coho, *need more and larger prey as they grow during their early marine period. Shifting environmental conditions, including weather, nutrients, and temperature, appear to be driving shifts in both phytoplankton and zooplankton at the base of the food web. Climate change is a likely underlying factor behind these changes, but the complexity of these dynamics is still not fully understood, and is a crucial area for further research. At the same time, populations of forage fish, including herring and eulachon, have also declined in many parts of the Salish Sea, limiting another important food source for salmon.*
2. ***Increase in predators.*** *Thanks to successful protections for marine mammals introduced on both sides of the border in the 1970s, harbor seal populations have exploded around the Salish Sea. While salmon and steelhead are a small component of the overall seal diet, the sheer number of seals means that even that small portion of their diet represents a major portion of juvenile salmon mortality – between 5 and 60 percent[3]. Human-made changes in the environment contribute to predation "hot spots," such as log booms or migration barriers like Puget Sound's Hood Canal Bridge, where seals have easy access to large numbers of fish. Reduced availability of forage fish, lack of complexity in nearshore habitats, and the consolidated timing of Chinook hatchery releases may also affect the number of salmon consumed by seals in a given year or location.*

Evidence also indicates that local factors contribute significantly to salmon health and survival in specific populations:

- *Habitat degradation, especially in crucial estuary and nearshore marine habitats for juvenile Chinook*
- *Toxic contaminants near urban areas and hotspots of infectious agents in the Strait of Georgia*
- *Differences in behavior and life histories within and among salmonid species interact with all the other factors above.*

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[2] http://marinesurvivalproject.com/

[3] A more recent modeling effort (Nelson et al., 2021) refined this estimate to consider seals' prey size selection based on observed seal diets. The resulting model estimated that harbor seal predation makes up 6 to 14% of Puget Sound Chinook mortality.

We adapted the infographic from the SSMSP's Summary report (page 6) and Table 3 from the Synthesis paper to focus specifically on Puget Sound Chinook salmon (Figure 5 above and Table 7 below).

Table 7. Marine survival conceptual model definitions and information for the conceptual model in Figure 5.

Node ID	Node Name	Node Parents	Definition/Description
MS_1	Marine Survival	MS_2. Disease Exposure MS_3. Toxicant Exposure MS_4. Predation MS_5. Food Supply	Marine survival considers Chinook salmon survival from their downriver migration as juveniles and through their ocean phase to the point where these fish are either captured as adults in fisheries or return to rivers to spawn. Overall marine survival rates are largely determined by a critical period immediately following entering marine waters and migrating through the Salish Sea.
			Relation to parent factors **Predation** is the primary cause of mortality of Chinook salmon. **Contaminants** and **disease** can affect fish growth and thereby predispose them to higher predation rates. **Food supply** in the Salish Sea, especially following juvenile outmigration, is crucial for growth and energy to avoid predators.
MS_2	Disease Exposure	MS_15. Marine Disease Exposure DE_13. Juvenile Disease Susceptibility	This factor is a combination of freshwater and marine exposures (**Marine Disease Exposure** and **Juvenile Freshwater Disease Exposure**). More infectious agents are found in young Chinook and Coho in the Strait of Georgia compared to the open coastline.
			Key uncertainties Infectious agents have not been well-studied in Puget Sound. Some disease may originate from King County waters.
MS_3	Toxicant Exposure	MS_14. Marine Toxicant Exposure DE_12. Juvenile Toxic Burden	This factor is a combination of freshwater and marine exposures (**Marine Toxicant Exposure** and **Juvenile Freshwater Toxicant Exposure**). Studies have found that juvenile Chinook are contaminated with PBDEs and PCBs in many urban watersheds. PCBs continue to accumulate in Chinook that stay in Puget Sound to adult age.
			Relation to parent factors **Marine Toxicant Exposure** represents most of a Chinook's exposure to toxicants. **Juvenile Toxicant Exposure** before entering marine waters, along with other stressors like smoltification, predator harassment, may have reduce growth during the critical growth phase upon entering marine waters, although most exposure occurs during the marine life stage.

Node ID	Node Name	Node Parents	Definition/Description
MS_4	Predation	MS_6. Food Supply MS_12. Harbor Seals MS_13. Hatcheries	Chinook salmon are eaten by a variety of predators as juveniles and adults while in the Salish Sea and Pacific Ocean. This factor captures the predation pressure on juvenile and adult Chinook while in the marine life stage.
			Relation to parent factors **Food Supply** changes may be due to fewer herring spawning areas throughout the Salish Sea, which could result in patchier distribution of forage fish, longer foraging times for salmon, and greater predation risk. Forage fish, like herring, make up a large portion of seal diets, so declines in the overall abundance of forage fish may indirectly contribute to a greater consumption of young salmon. The sheer abundance of **Harbor Seals** is a critical issue for Chinook populations, with a lot of seals each consuming a few juvenile salmon while foraging for other fish. The abundance of Chinook related to pulse releases from **Hatcheries** and the declines in other prey may result in disproportional predation on juvenile Chinook by seals and other predators. There is conflicting evidence as to whether releasing hatchery fish in pulses attracts predators. For example, pulse releases may also swamp predators and decrease morality for natural-origin fish. One SSMSP study found that seals respond to Coho entering the Strait of Georgia after release from a hatchery, but the same was not true for Chinook. This could be because Coho are larger than Chinook at the time of release, as newly released Coho are of suitable size for seals to eat.
			Also identified in the Marine Survival Project **Prey switching** occurs when predators have a strong preference for prey that are more common in the environment and a weak preference for prey that are rare, such that the predator switches its diet to prey that are most abundant and then feeds disproportionately on them. The Committee concluded that data were insufficient to state whether prey switching was occurring and affecting marine survival. **Predator specialization** describes the phenomenon of seals specializing in eating young salmon at fish migration barriers and other bottlenecks. This is captured in the Adult Spawner Success submodel.

Node ID	Node Name	Node Parents	Definition/Description
MS_5	Harvest	*none*	The rate of harvest of adult Chinook salmon by fisheries. The Pacific Fishery Management Council sets annual fisheries for Chinook, coho, and pink salmon in federal waters from three to 200 miles off the coasts of Washington, Oregon, and California. The Council manages these fisheries subject to the terms of the Magnuson-Stevens Fishery Conservation and Management Act.
MS_6	Food Supply	MS_7. Estuaries/ Nearshore MS_8. Prey Mismatch MS_9. Water Quality/ Biogeochemistry MS_10. Competition	This factor considers both the availability of forage fish and of zooplankton (primarily crab larvae and amphipods). These are the primary prey resources for juvenile and adult salmon. This factor also captures the availability of forage fish for salmon predators. Salmon eat forage fish once they are large enough. Forage fish include herring, anchovy, sandlance and eulachon.
			Relation to parent factors **Estuaries/Nearshore** areas provide habitat for juvenile salmon and forage fish. **Prey Mismatch** describes peak abundances of zooplankton sometimes preceding the arrival of outmigrating salmon. For example, experts found that if the start of the larval crab life cycle began as little as two weeks earlier, then the crabs could be too big for juveniles to eat. **Water Quality/Biogeochemistry** describes the abiotic factors that affect phytoplankton and thus zooplankton abundance. **Competition** is created as releases of hatchery Chinook have become more consolidated — with more fish released at the same time. This practice may exacerbate a misalignment between the time hatchery Chinook enter the Salish Sea and what food is available when they arrive.

Node ID	Node Name	Node Parents	Definition/Description
MS_7	Estuaries/ Nearshores	*none*	This factor represents the abundance of quality estuary and nearshore habitat for salmon outmigrating from King County rivers. Estuaries and the nearshore can be among the most productive marine habitats, providing food and shelter to young salmon as well as critical prey species, such as herring, sand lance, and crab. However, in many areas throughout the Salish Sea, estuary habitat has been replaced by urban development and farms. Throughout the nearshore regions, eelgrass has declined and eelgrass beds are more fragmented. The Synthesis Committee could not reach consensus regarding the role of physical or biogenic habitat in declines in marine survival. Degraded habitat is likely limiting the survival of some salmon populations, in particular the loss of estuary habitat for wild subyearling Chinook, such as those coming from the Cedar-Sammamish and Green/Duwamish watersheds. Much of the Puget Sound nearshore in King County is developed and does not offer habitat and refuge for Chinook and their prey.
MS_8	Prey Mismatch	MS_9. Water Quality/ Biogeochemistry	Prey Mismatch represents the availability of prey in consideration of the timing of prey abundance and the arrival of juvenile Chinook in the Salish Sea.
			Relation to parent factors **Water Quality/Biogeochemistry** changes can influence the timing of spring phytoplankton blooms, cascading through the food web so that zooplankton and herring are not available to young salmon in the size and quantities they need when they enter Salish Sea.

Node ID	Node Name	Node Parents	Definition/Description
MS_9	Water Quality/ Biogeochemistry (Abiotic Factors)	MS_11. Climate Change	Abiotic factors, especially sea surface temperatures, circulation, salinity, river flows, winds, and light/cloud cover. SSMSP hypothesize that the timing, duration, quantity, spatial extent, and/or composition/ quality of salmon preyis linked to these factors, which affect the conditions necessary for phytoplankton and zooplankton: nutrients (e.g., nitrogen, silica, phosphorus), light, water column stability, and sunlight. Currently, the evidence linking changes in biogeochemistry to salmon prey to salmon survival in the Salish Sea is predominantly correlational, with few to no understood mechanistic links. Limited amounts of long-term data are part of the problem (e.g., there are no adequate time series of zooplankton and limited time series of forage fish within the Strait of Georgia prior to the 1990s). With more recent data, Greene et al. (2020) found strong evidence for connections between temperature and salinity, primary and secondary production, and salmon growth, individual condition, and marine survival. However, due to the complex interrelationships between these factors and marine food supply, it is hard to assign causality with much certainty.
			Relation to parent factors **Climate Change** can shift the timing and availability of nutrients by altering larger biochemical processes like ocean circulation, days of sun, wind, spring river flows. Climate change can also affect localized seasonal temperature shifts.
MS_10	Competition	MS_13. Hatcheries	Competition for food between young salmon or between salmon and herring may occur when food supplies or habitat is limited. There is not strong evidence that competition is a primary cause for declines in Chinook marine survival independent of habitat limitations.
			Relation to parent factors **Hatcheries** releases can result in pulses of juvenile salmon arriving at a single time which compete with each other and wild salmon for prey resources.
MS_11	Climate Change	*none*	Climate change appears to be leading to more days of sun, less wind, earlier spring river flows, and increasing water temperatures, which can all affect, when, where, and how much food is available for young salmon.
MS_12	Harbor Seals	*none*	The factor represents the population of harbor seals in the Salish Sea.

Node ID	Node Name	Node Parents	Definition/Description
MS_13	Hatcheries	*none*	This factor represents the timing and abundance of hatchery releases of juvenile Chinook salmon.
MS_14	Marine Toxicants Exposure	*none*	This factor considers the exposure to toxicants following outmigration from freshwaters.
MS_15	Marine Disease Exposure	*none*	This factor considers the exposure to disease following out migration from freshwaters.
GD_Smolt	Green/Duwamish Outmigrants	*none*	The number of natural-origin juvenile smolts that originated from the Green/Duwamish that survive to reach Elliott Bay.
GD_Adult	Green/Duwamish Adult Returners	GD_Smolt. Green/Duwamish Outmigrants MS_1. Marine Survival MS_5. Survival	The number of natural-origin adults that originated from the Green/Duwamish that return to Elliott Bay without premature mortality or harvest. *Relation to parent factors:* The initial population of **Green/Duwamish-originating outmigrants leaving the Duwamish Estuary** is subject to **Marine Survival** and reductions due to **Harvest** before adult returners can make their way back to fresh water.

6.0 FRESHWATER SPAWNER SUCCESS

The subject matter experts did not identify freshwater spawner success as a primary limiting factor for the natural-origin Green/Duwamish Chinook population. They did express concern for en-route and pre-spawn mortality for adults once they return to the Duwamish Estuary due to high water temperature, and disease/toxicant impacts. They expressed further concern in how climate change will increase temperatures in the river.

Key Takeaways

- **Freshwater spawning success is currently <u>not a limiting factor</u> for the Green/Duwamish Chinook population.** Habitat limitations for rearing juveniles is the greater limiting factor.
- **Freshwater conditions may limit the spawning success of returning adults**.
- **High temperatures and other compounding factors (e.g., low oxygen, osmo-regulatory stress, stress from predator harassment, disease, etc.)** in **the Green River** can cause **mortality** before spawning and **decrease spawning success**.
    - Large stretches of the Green River, Soos Creek and Newaukum Creek regularly exceed established water quality standards for temperature (16 deg C).
    - While lethal temperatures are rare, sublethal effects that impede successful spawning are common in Lower and Middle Green.
    - River flow and temperature influence adults when they begin migrating upstream. High temperatures can delay upstream migration and increase exposure to pinniped predators in marine water.
    - 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.
    - This is expected to worsen with climate change.
- **Disease/Toxicants**
    - Exposure to disease as juveniles and as adults may also cause mortality and decreased spawning success.
        - There is a hypothesis that exposure to a particular parasite as juveniles in the Lower Green River may inhibit kidney function. Proper kidney function is necessary as salmon adjust from marine to fresh water.
    - The impacts of toxicants are unknown, but some of the toxicants Chinook are known to be exposed to cause increased susceptibility to disease and may worsen temperature impacts.

7.0 TOXICANTS

Chinook salmon are exposed to toxicants during each of their life stages. At sufficient exposure levels, adverse effects may occur, such as changes in endocrine system function, sensory inhibition, immune system impairment, growth reduction, impaired reproductive success, and mortality. The presence and magnitude of toxicant impacts on the Chinook populations may be evaluated through examining chemical exposures and comparison with effects thresholds found in published ecotoxicological studies. Such data should be considered in light of the physiological stresses of outmigration and transition to marine life.

WQBE staff performed a review of literature investigating the exposures and potential adverse impacts of chemicals on juvenile Chinook. For that compilation, only the life stages when juveniles were in King County waters were evaluated. Exposure data included both tissue and stomach content concentrations and, for zinc and copper, concentrations in ambient water. The review (King County, 2022) provides detail and nuance of the available toxicity thresholds and exposure data. The impacts of toxicants are presented in the context of other stressors like the physiological changes associated with migration from freshwater to marine water (i.e., smoltification), the potential presence of multiple chemicals that have not been monitored, and increasing water temperatures resulting from climate change. The review focused on direct impacts to Chinook and did not examine toxicant impacts on Chinook food sources. This chapter provides a high-level summary to provide context for other factors impacting Chinook salmon detailed in this report.

Key takeaways from the literature review:

- **Current toxicant exposure conditions for juvenile Chinook in both the Green River and Duwamish Estuary are not well described.** The most recent data on tissue contamination levels are over 5 years old. For PCBs, the most studied toxicant in juvenile Chinook, 77% of the data were collected prior to 2009. There are no data to definitively describe exposure in the most vulnerable type: estuarine-reared fry outmigrants with prolonged exposure to contaminants in the estuary.
- According to the most recent data collected in 2013 and 2016 (O'Neill et al., 2015; WDFW 2016, unpublished data), **juvenile Chinook contamination within estuaries appears to be lower and less variable than before the Lower Duwamish Waterway was listed as a Superfund site** in 2001. Prior to listing, juvenile Chinook salmon from the Duwamish Estuary (primarily Kellogg Island and Slip 4) were among the most highly exposed to PCBs, PAHs and pesticides among juvenile Chinook in Puget Sound rivers.
- **In the most recent sampling by WA Dept. of Fish and Wildlife (2016, unpublished data), PCB and PBDE concentrations in Chinook were below levels associated with adverse effects in the Green River and Duwamish Estuary**. PBDE exposures in the Duwamish Estuary were above levels associated with increased mortality due to depressed immunity in 2006 and 2013. Data from

the mid-2000s also indicate PCB levels above adverse effects thresholds for growth and survival.

  - **Toxic exposure of estuary-rearing juveniles is an important knowledge gap.**

- Exposures to PAHs in the Duwamish Estuary appear to have dropped substantially since the late 1990s and are currently below known adverse effects levels. However, recent data for PAHs exposures are limited.
- **DDT (and its metabolites) exposures in the Green River and Duwamish are low and are not expected to cause adverse effects.**
- **Copper and zinc exposures in the Green River and Duwamish Estuary do not appear high enough to cause severe impacts**, but there are uncertainties related to limited available data.
  - Additional data collection to better characterize dissolved and bioavailable copper could resolve some of this uncertainty and help focus future efforts to reduce potential for toxicant impacts.
  - Brief exposures to copper, even at levels below state water quality criteria, can have neurotoxic effects in juvenile salmon that lead to changes in behavior, including predator avoidance. Impairment of sensory function lasts for hours or days following exposure. King County's analysis does not address the potential for toxicity to sensory nerves that control salmonid behaviors.
- The impact of chlordanes and the multitude of chemicals of emerging concern - those chemicals not regularly monitored and not regulated - are uncertain.
- Because of the stress of smoltification which is governed by complex endocrine system processes and includes depletion of lipids, toxicant exposures occurring within freshwater and estuarine habitats may adversely affect juvenile Chinook following outmigration. This aspect of toxicant-related risk to juvenile Chinook has not been directly evaluated.
- Population modeling and studies of adult returns in Chinook from the Green Duwamish provide evidence that toxicant exposures in this system contribute to poor population performance.

The literature review sought to inform answers to the following questions:

- Are there toxicant exposures during a given life stage in the Green/Duwamish that could influence the survivorship of Chinook ***during*** that life stage and to what degree? For example, do fry exposed to PCBs in the Middle Green River experience direct or indirect mortality due to that exposure while in the Middle Green River?
- Are there toxicant exposures during any life stages occurring in the Green/Duwamish that influence the survivorship or behavior of Chinook ***after*** that life stage and to what degree? For example, do parr exposed to PCBs in the Duwamish Estuary experience effects that reduce survival in Puget Sound and the Pacific Ocean, thereby reducing numbers of adults returning to spawn?

- How do sublethal toxicant effects ***interact with or worsen*** the other factors in the model (e.g., predation or disease)?

Table 8 summarizes the available data and knowledge gaps.

To better answer the relevant questions about potential for toxicant effects in the watershed, we recommend collecting samples in a manner that differentiates specific Chinook life stages and life histories. This more refined sampling approach will improve understanding of whether and to what degree toxicity impacts juvenile success for specific life histories. Additional data collection is warranted and should include exposure assessment for juvenile Chinook in the Middle Green from both the fry and parr outmigrant runs; Lower Green and Duwamish Estuary sampling prior to the arrival of parr outmigrants; and nearshore Elliott Bay near the mouth of the Duwamish during the smolt outmigration. A study directed at the role of toxicants during the smoltification process, and the relative success of hatchery vs. natural-origin juveniles, would help to address uncertainties on the current degree of toxicant risk to vulnerable life stages. Once the specific contaminants of interest are defined, the target sample type (water, sediment, fish prey tissue, whole juvenile Chinook composites) and study designs can be determined. Chemicals of emerging concern such as per- and poly-fluoroalkyl substances (PFAS), which have been found in Lake Washington fish samples (Ecology 2017), and endocrine disrupting compounds should be considered for further study.

Specifically, near-term investigations are needed to address the following questions:

- Does toxicant exposure by estuary-rearing fry in the Duwamish result in increased susceptibility to growth inhibition or disease-related mortality? (fry sampling in the Duwamish Estuary from Jan to March)
- Does toxicant exposure throughout the watershed result in potential for sublethal effects that could decrease marine survival? (Duwamish Estuary/Elliott Bay sampling)
- What toxicant exposure occurs in the Middle Green? (fry and parr outmigrant sampling at fish traps)
- What toxicant exposure occurs in the Lower Green? (fry and parr outmigrant sampling in Lower Green)
- How do the different life history types experience the effects of toxicant exposures during and after outmigration?
- What are the primary sources of the risk-driving chemicals?

Toxicants are expected to worsen existing predation, habitat, disease, and temperature issues for Chinook salmon in the Green/Duwamish system and Puget Sound. Toxicant effects cannot be separated from these other stressors because some of them may amplify toxicant effects. Increasing water temperatures due to climate change and reduced habitat availability make juvenile Chinook more susceptible to negative impacts from toxicants.

Table 8. Chinook salmon toxicant exposure and impact summary for natural-origin Chinook in the Green/Duwamish (King County, 2022).

Life History	Life Stage	Location	Observed Exposure	Notes
Middle Green Rearing	Fry	Middle Green	Not sampled	
	Parr	Middle Green	Samples from June 2016 found PCB and PBDE concentrations below adverse effects levels. DDT breakdown products (DDx) levels in all samples collected in 2016 were well below effects threshold. Data for other contaminants are insufficient to evaluate potential for adverse impact. Chlordanes were detected in 2016 but no toxicity effects level was available. Ambient levels of copper and zinc were below state water quality criteria.	The June 2016 sample included 4 unmarked (likely natural-origin) Chinook composites and 1 marked (hatchery-origin) composite. Each composite was of 6 juveniles.
		Lower Green	Not sampled	
		Duwamish Estuary	PCB levels in 2013 and 2016 were below effects thresholds. Data for early-2000s showed about 10% of fish exceeded effects thresholds for PCBs. PBDE levels in some samples collected from 2006 to 2016 exceeded the threshold associated with immunotoxicity and increased mortality. PAH levels in stomach contents from 2003 to 2013 were below the lowest observed adverse effects level. DDT breakdown products (DDx) levels in all samples collected between 1989 and 2016 were well below effects threshold. Chlordanes were detected but no toxicity effects level was available. Ambient levels of copper and zinc were below state water quality criteria.	Sampling has not differentiated between life history types. Experts expect that the Middle Green parr outmigrants, which would have lower exposure and tissue concentrations, make up most of the samples.

Life History	Life Stage	Location	Observed Exposure	Notes
Lower Green Rearing	Fry	Middle Green	Not sampled	
		Lower Green	Not sampled	
	Parr	Lower Green	Not sampled	
		Duwamish Estuary	Same as Middle Green Rearing – Parr – Duwamish Estuary above.	Sampling has not differentiated between life history types. Experts expect that the Lower Green parr outmigrants are not well-represented in the sample. Those outmigrants may have greater exposure.
Estuary-rearing	Fry	Middle Green	Not sampled	
		Lower Green	Not sampled	
		Duwamish Estuary	Not sampled	
	Parr	Duwamish Estuary	Same as Middle Green Rearing – Parr – Duwamish Estuary above.	Sampling has not differentiated between life history types. Given the documented contamination in the estuary, it is expected that estuary-rearing juveniles are more greatly exposed to toxicants than other life histories.
All Life Histories	Smolt	Elliott Bay + Puget Sound Nearshore	Most recent samples for PCBs, PAH, and DDx (June 2013) were below effects levels. One of 10 PBDE samples from the same period exceeded the threshold associated with immunotoxicity and increased mortality	Juveniles may have ongoing adverse health outcomes from exposures in freshwater. Such effects may include decreased growth and survivorship.
	Adult	Salish Sea + Pacific Ocean	In resident (non-Oceanic) adult Chinook sampled in 2016 and 2017, PCB concentrations were high enough to potentially impair growth and reproduction in 15% of Chinook sampled and cause mortality in 1% of Chinook sampled. Concentrations were higher in populations residing in inner Puget Sound. PBDE levels were below the effects threshold (PSP, 2021).	Adult salmon acquire almost all their contaminants through bioaccumulation while in marine waters, where they typically acquire 99% of their final adult weight.
		Freshwater Spawning		Substantial toxicant exposure is not expected as adults return to freshwater to spawn.

8.0 SUMMARY OF KEY KNOWLEDGE GAPS

The following list summarizes the key knowledge gaps identified in the previous chapters. This is not an exhaustive list of all data gaps and uncertainties in the system. Additional information provided by future research in these areas would improve the model and our ability to estimate the impact of water quality and other projects on the Chinook population.

Overall

- What proportion of the total juvenile population is represented by the lower Green River-rearing fry life history type (juveniles that move quickly from the Middle to Lower Green as fry and spend the bulk of their rearing time in the Lower Green)? What are the return rates for this group, ie., what proportion of all juveniles in this life history type successfully return to spawn?
- What are the overall numbers of juveniles leaving the Duwamish Estuary and entering Elliott Bay? (Currently, the WDFW-run screw trap measures the number and timing of juveniles leaving the Middle Green River)

Juvenile High Flow Refugia

- How much high flow refugia currently exists in the Middle and Lower Green River?
- What is the net impact of high flows on juveniles? High flows can scour channels and flush juveniles downstream, but also open up access to off-channel habitat.

Juvenile Survival

- What is the overall impact of climate change-induced water temperature increases on disease susceptibility, toxicity, and piscine predation rates for juveniles?

Disease and Toxicants

- What are the sublethal effects of toxic exposures acquired at different life stages? The most useful data would differentiate between life stages and/or life history types (parsing samples by location, life stage, duration, or magnitude of exposure).
    - What is the effect of toxic exposure acquired by juveniles on growth and survival to outmigration? The most useful data would be contaminant tissue concentrations of estuary-reared fry.
    - What is the effect of toxic exposure acquired by juveniles on growth, adult survival, and return rates?
    - What is the effect of toxic exposure acquired by smolts and adults in the marine environment on their growth, survival, return rates, and successful spawning?
- What are the recent exposures and toxic impacts of copper and PAHs in the Duwamish Estuary?
- Which contaminants of emerging concern are of greatest importance to Chinook population performance in the Green/Duwamish watershed?

Marine Survival

- What are mechanisms for the altered food supply in the Salish Sea? How can they be altered to improve Chinook salmon survival? To what degree do activities and habitat in King County influence the food supply?
- What proportion of juvenile salmon mortality is attributed to harbor seals?

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Appendix A: Node Definitions and States

The teams of subject matter experts for the Middle and Lower Green River submodels drafted definitions for all nodes in the respective submodels, including proposed states. These states sought to represent realistic changes from current conditions and published management goals in the model's parameters or, for low and high flows, to capture the variability in conditions between years. Node states were defined such that they might be expected to produce meaningful changes in a child node. For example, the difference between 4 and 50 hours above 5000 cfs from January through March (HF_1) might make a difference in the high flow impact on juveniles (MG_5), but the difference between 4 and 5 hours above 5000 cfs during that period may not. We followed a modified version of the IDEA protocol for expert elicitation (Hemming et al. 2018) used in earlier stages of model development, as described in Section 1.3 of this report. Each expert provided their input on definitions of nodes and states individually, and anonymized input was shared with the expert group. The group then discussed differences in input and decided on an aggregated final version with facilitation by the King County model lead staff member. These definitions could be used in a potential future Bayesian network or similar model, by following the remaining steps outlined in King County (2020), beginning with eliciting estimates of conditional probabilities from subject matter experts. Some definitions may need further review and/or detail, depending on the type of model developed.

Table A-1. Node and state definitions for Middle Green River Juveniles submodel.

NodeID	Name	Definition	States	State Definitions	Source
MG_1	**Riparian Forest, Middle Green**	Riparian forest cover, as measured within the channel migration zone, may lower instream temperatures through shade and evapotranspiration. Riparian forest cover also contributes large woody debris and may serve has habitat for terrestrial prey for salmon.	2020 NFC	>65% of channel migration zone and up 165 ft wide where possible	2020 Salmon Habitat Plan Necessary Future Condition
			2020 10 Year Goal	58.5% of channel migration zone	2020 Salmon Habitat Plan 10 Year Target
			Current Condition	50.5% of channel migration zone forested	2020 Salmon Habitat Plan Current Condition (2009)
CC_1	**Climate Change Scenario**	This node defines specific climate change scenarios.	Not yet defined		
MG_2	**Temperature Effects to Juveniles, Middle Green**	This node denotes the temperature stress experienced by juveniles, coming into play primarily during the April through June timeframe. This includes heightened metabolism and physiological stress. Experts do not expect this to be a strong influence on direct mortality.	Same As Today	Temperature impacts are similar to today.	May be updated based on King County WQBE Team Literature Review
			Degraded	Temperature impacts have worsened meaningfully in an ecological context.	
MG_3	**Toxic Effects on Juveniles, Middle Green**	This node denotes the toxic stress experienced by juveniles. It includes increased predation and disease caused by sublethal effects of toxicant exposure.	Same As Today	Toxic impacts are similar to today.	May be updated based on King County WQBE Team Literature Review
			Degraded	Toxic impacts have worsened meaningfully in an ecological context.	
MG_4	**Mortality Due to Toxicity and Temperature, Middle Green**	This node captures the severity and risk of mortality caused by elevated temperatures and concentrations of toxics. This includes exacerbation of predation and disease due to sublethal effects. Experts do not expect a strong influence of temperature and toxicity on direct mortality based on current understanding.	Same As Today	Mortality due to toxicity and temperature impacts is similar to today	May be updated based on King County WQBE Team Literature Review
			Degraded	Mortality has increased meaningfully in an ecological context.	
HF_1	**Hours above 5000 cfs, Jan-Mar**	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.	0 to 5	hours	Approximate quartiles for Years 2000 to 2020
			5 to 100	hours	
			100 to 200	hours	
			200 to 450	hours	

NodeID	Name	Definition	States	State Definitions	Source
HF_2	**Hours above 8000 cfs, Jan-March**	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 8,000 cfs.	0	hours	Approximate quartiles for Years 2000 to 2020
			0 to 25	hours	
			25 to 50	hours	
			50 to 200	hours	
MG_5	**High Flow Impact on Juveniles, Jan-Mar, Middle Green**	The impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from January through March (independent of other population factors such as emergence). Compared with historic flow regimes, high flows are rare due to dam management, but when they do happen, they have a large impact on juveniles.	Minor	An ecologically insubstantial number and proportion of juveniles are flushed or killed by high flows (<20%).	An example year or years could be selected to represent this
			Moderate	A substantial number and proportion of juvenile salmon are flushed downstream or killed due to high flows (20 to 70%)	An example year or years could be selected to represent this
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are flushed downstream or killed due to high flows (>70%)	An example year or years could be selected to represent this
HF_3	**Hours above 5000 cfs, Apr-June**	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.	0	hours	Approximate quartiles for Years 2000 to 2020
			0 to 50	hours	
			50 to 100	hours	
			100 to 250	hours	
HF_4	**Hours above 8000 cfs, Apr-Jun**	The number of hours from April through June where maximum discharge measured at USGS gauge site 12113000 exceeded 8,000 cfs.	0	hours	Approximate quartiles for Years 2000 to 2020
			0 to 10	hours	
			10 to 25	hours	

NodeID	Name	Definition	States	State Definitions	Source
MG_6	**High Flow Impact on Juveniles, Apr-Jun, Middle Green**	The impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from April through June. Compared with historic flow regimes, high flows are rare due to dam management, especially during this time period, but when they do happen, they have an impact on juveniles. Due to lower and less frequent high flows during this period, and the larger size of the older juveniles, the impact of high flows on juveniles from April through June is lower than during the January through March period.	Minor	An ecologically insubstantial number and proportion of juveniles are flushed or killed by high flows (<20%).	An example year or years could be selected to represent this
			Moderate	A substantial number and proportion of juvenile salmon are flushed downstream or killed due to high flows (20 to 70%)	An example year or years could be selected to represent this
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are flushed downstream or killed due to high flows (>70%)	An example year or years could be selected to represent this
MG_7	**High Flow Impact on Juveniles, Middle Green**	The total impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from January through June.	Minor	An ecologically insubstantial number and proportion of juveniles are flushed or killed by high flows (<20%).	An example year or years could be selected to represent this
			Moderate	A substantial number and proportion of juvenile salmon are flushed downstream or killed due to high flows (20 to 70%)	An example year or years could be selected to represent this
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are flushed downstream or killed due to high flows (>70%)	An example year or years could be selected to represent this
MG_8	**Culvert/Fish Passage Barrier Removal, Middle Green**	Culverts and other fish passage barriers removed from the Middle Green River. This does not include fish barriers in tributaries, except in the cases that the mouth of the tributary into the Middle Green is a culvert/fish passage barrier. Opening up passage barriers adds length and area of habitat to the sub-basin.	All Prioritized Removed	All known barriers removed	WRIA 9 Technical Committee is generating a list for Lower green presently (possibly completed in the next 1 to 3 months)
			Top Priority Removed	Top 50% of priority barriers (as identified by WRIA 9 Technical Committee) are removed	
			Current Conditions	No Barrier Removal	

NodeID	Name	Definition	States	State Definitions	Source
MG_9	**Armoring, Middle Green**	Armoring is defined as levees, riprap, bulkheads, revetments, or other hardscape meant to prevent erosion and allow flood protection. Armoring impedes floodplain function and reduces habitat complexity. It disconnects large portions of the historical floodplain, off-channel habitat, and tributaries, which provide juvenile salmon with forage and refuge from extreme flows.	Greatly Improved	25% decrease in armoring	Higgins suggestion
			Improved	Set back one mile of revetment	2020 Salmon Habitat Plan 10 Year Target
			Current Condition	24% armored	2020 Salmon Habitat Plan Current Condition (2009)
MG_10	**Large Woody Debris, Middle Green**	Estimated average number of log jams per river mile. A log jam is defined as a minimum of 10 pieces of wood that are at least 12 feet long and ≥4" in diameter. Above this minimum, log jam size varies. R2 (2017) defines small jams as 10 to 50 pieces, medium jams as 51 to 100 pieces, and large as greater than 101 pieces. Jam size is not considered in the Salmon Habitat Plan goals.	2020 NFC	10 jams per mile	2020 Salmon Habitat Plan Necessary Future Condition
			2020 10 Year Goal	5 jams per mile	2020 Salmon Habitat Plan 10 Year Target
			Current Condition	3.8 jams per mile	2020 Salmon Habitat Plan Current Condition (2015)
MG_11	**Connected Floodplain, Middle Green**	Area of floodplain accessible to juveniles within the Middle Green River subbasin, as defined by the WRIA 9 Technical Committee.	2020 NFC	65% of Historic (2029 acres)	2020 Salmon Habitat Plan Necessary Future Condition
			2020 10 Year Goal	200 acres reconnected (1951 acres - 61%)	2020 Salmon Habitat Plan 10 Year Target
			Current Condition	55% of Historic	2020 Salmon Habitat Plan Current Condition (2017)

NodeID	Name	Definition	States	State Definitions	Source
MG_12	**Confined Bankfull Width, Middle Green**	Percent of the Middle Green, by length, with confined bankfull width. This can be anthropogenic (e.g., levees, roadways) or natural (e.g., canyons). Currently, approximately 75% of the Middle Green is confined. Restoring lateral channel migration is dependent on removal of armoring and the addition of large woody debris to create slow water habitat. Confined bankfull width is a surrogate (measured via its inverse) for slow water habitat complexity and lateral channel migration.	Greatly Improved	25% improvement - 6.2 additional miles unconfined	
			Improved	10% improvement, 2.5 additional miles unconfined	
			Current Condition	75% of river confined.	Derived from GIS data and aerial imagery assessment
MG_13	**Moderate Flow Rearing Habitat Conditions, Middle Green**	This factor measures the benefits to juveniles of suitable habitat accessible outside of low flow or high flow events (between 1200 and 5000 cfs). Rearing habitat provides juveniles with the ability to forage for prey and grow larger. Those juveniles that are able to stay in the Middle Green River longer will have access to this habitat and its benefits over a longer time period. Juveniles that move downstream in search of suitable rearing habitat, including those that are crowded out by other juveniles, will be forced to rear in lower stretches of the river, which are generally of poorer habitat quality.	Greatly Improved	Area of <u>quality</u> Moderate Flow Rearing Habitat increased by 25 to 50%	
			Improved	Area of <u>quality</u> Moderate Flow Rearing Habitat increased by 10 to 25%	
			Current	Present-day area of quality Moderate Flow Rearing Habitat (this may not be known, but is our reference point)	
LF_1	**Hours below 1200 cfs, Jan-Mar**	The number of hours from January through March where minimum discharge measured at USGS gauge site 12113000 was less than 1,200 cfs.	0 to 400	hours	Approximate quartiles for Years 2000 to 2020
			400 to 900	hours	
			900 to 1400	hours	
			1400 to 2200	hours	

NodeID	Name	Definition	States	State Definitions	Source
MG_14	**Low Flow Impact on Juveniles, Jan-Mar, Middle Green**	The impact of the duration and volume of low flows on juvenile salmon from January to March in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.	Minor	An ecologically insubstantial number and proportion of juveniles are forced downstream due to habitat restriction or mortality (<20%).	An example year or years could be selected to represent this
			Moderate	A substantial number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (20 to 70%)	An example year or years could be selected to represent this
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (>70%)	An example year or years could be selected to represent this
LF_2	**Hours below 1200 cfs, April-Jun**	The number of hours from April through June where minimum discharge measured at USGS gauge site 12113000 was less than 1,200 cfs.	0 to 400	hours	Approximate quartiles for Years 2000 to 2020
			400 to 900	hours	
			900 to 1400	hours	
			1400 to 2200	hours	
MG_15	**Low Flow Impact on Juveniles, Apr-Jun, Middle Green**	The impact of the duration of low flows on juvenile salmon in April through June in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes. Due to increased frequency of low flows and dam management, the impact of low flows on juvenile Chinook is more pronounced during this period.	Minor	An ecologically insubstantial number and proportion of juveniles are forced downstream due to habitat restriction or mortality (<20%).	
			Moderate	A substantial number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (20 to 70%)	
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (>70%)	

NodeID	Name	Definition	States	State Definitions	Source
MG_16	**Low Flow Impact on Juveniles, Middle Green**	The impact of the duration of low flows on juvenile salmon in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.	Minor	An ecologically insubstantial number and proportion of juveniles are forced downstream due to habitat restriction or mortality (<20%).	
			Moderate	A substantial number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (20 to 70%)	
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (>70%)	
MG_17	**Fry Emergence**	The total number of fry in the Middle Green that have survived from egg to fry. Their survival is greatly impacted by scouring flows in fall and winter.	Normal Range	No severe event occurs.	
			Severe Event	A severe event occurs that greatly impacts of fry that survive to emergence, such as a high flow scouring event or low flow desiccation.	
MG_18	**Middle Green Parr Outmigrants**	The number of juvenile Chinook that rear to the parr stage in the Middle Green before outmigration to lower stretches of the river. This number, as a proportion of juveniles when compared with the initial number of fry to emerge (MG_17), is due to reduced by the amount of accessible, quality habitat and mortality due temperature and toxics.	Best Estimate from Experts	Experts will estimate the best guess, their lowest plausible number, highest, and level of confidence that its between.	

Table A-2. Node and state definitions for Lower Green River Juveniles submodel.

NodeID	Name	Defintion	States	State Definitions	Source
LG_1	**Riparian Forest, Lower Green**	Riparian forest cover, as measured within the channel migration zone, may lower instream temperatures through shade and evapotranspiration. Riparian forest cover also contributes large woody debris and may serve as habitat for terrestrial prey for salmon.	2020 NFC	75% of channel migration zone and up 165 ft wide where possible	2020 Salmon Habitat Plan Necessary Future Condition
			2020 10 Year Goal	57% of channel migration zone	2020 Salmon Habitat Plan 10 Year Target
			Current Condition	27% of channel migration zone forested	2020 Salmon Habitat Plan Current Condition (no date)
CC_1	**Climate Change Scenario**	This node defines specific climate change scenarios.	Not yet defined		
LG_2	**Temperature Effects to Juveniles, Lower Green**	This node denotes the temperature stress experienced by juveniles, coming into play primarily during the April through June timeframe. This includes heightened metabolism and physiological stress. Experts do not expect this to be a strong influence on direct mortality, however temperature effects are more pronounced in the Lower Green than the Middle Green and will likely be exacerbated by climate change.	Same As Today	Temperature impacts are similar to today.	May be updated based on King County WQBE Team Literature Review
			Degraded	Temperature impacts have worsened meaningfully in an ecological context.	
LG_3	**Toxic Effects to Juveniles, Lower Green**	This node denotes the toxic stress experienced by juveniles. It includes increased predation and disease caused by sublethal effects of toxicant exposure.	Same As Today	Toxic impacts are similar to today.	May be updated based on King County WQBE Team Literature Review
			Degraded	Toxic impacts have worsened meaningfully in an ecological context.	
LG_4	**Mortality Due to Toxicity and Temperature, Lower Green**	This node captures the severity and risk of mortality caused by elevated temperatures and concentrations of toxics. This includes exacerbation of predation and disease due to sublethal effects. Experts do not expect a strong influence of temperature and toxicity on direct mortality based on current understanding.	Same As Today	Mortality due to toxicity and temperature impacts is similar to today	May be updated based on King County WQBE Team Literature Review
			Degraded	Mortality has increased meaningfully in an ecological context.	
HF_1	**Hours above 5000 cfs, Jan-Mar**	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.	0 to 5	hours	Approximate quartiles for Years 2000 to 2020
			5 to 100	hours	
			100 to 200	hours	
			200 to 450	hours	

NodeID	Name	Defintion	States	State Definitions	Source
HF_2	**Hours above 8000 cfs, Jan-March**	The number of hours from January through March where maximum discharge measured at USGS gauge site 12113000 exceeded 8,000 cfs.	0	hours	Approximate quartiles for Years 2000 to 2020
			0 to 25	hours	
			25 to 50	hours	
			50 to 200	hours	
LG_5	**High Flow Impact on Juveniles, Jan-Mar, Lower Green**	The impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from January through March (independent of other population factors such as emergence). Compared with historic flow regimes, high flows are rare due to dam management, but when they do happen they have a large impact on juveniles. This impact is exacerbated by the highly confined channel of the Lower Green.	Minor	An ecologically insubstantial number and proportion of juveniles are flushed or killed by high flows (<20%).	An example year or years could be selected to represent this
			Moderate	A substantial number and proportion of juvenile salmon are flushed downstream or killed due to high flows (20 to 70%)	An example year or years could be selected to represent this
			Severe	A substantial and ecologically devasating number and proportion of juvenile salmon are flushed downstream or killed due to high flows (>70%)	An example year or years could be selected to represent this
HF_3	**Hours above 5000 cfs, Apr-June**	The number of hours from April through June where maximum discharge measured at USGS gauge site 12113000 exceeded 5,000 cfs.	0	hours	Approximate quartiles for years 2000 to 2020
			0 to 50	hours	
			50 to 100	hours	
			100 to 250	hours	
HF_4	**Hours above 8000 cfs, Apr-Jun**	The number of hours in April through June where maximum discharge measured at USGS gauge site 12113000 exceeded 8,000 cfs.	0	hours	Approximate quartiles for years 2000 to 2020
			0 to 10	hours	
			10 to 25	hours	

NodeID	Name	Defintion	States	State Definitions	Source
LG_6	**High Flow Impact on Juveniles, Apr-Jun, Lower Green**	The impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from April through June. Compared with historic flow regimes, high flows are rare due to dam management, especially during this time period, but when they do happen, they have an impact on juveniles. This impact is exacerbated by the highly confined channel of the Lower Green. Due to lower and less frequent high flows during this period, and the larger size of the older juveniles, the impact of high flows on juveniles from April through June is lower than during the January through March period.	Minor	An ecologically insubstantial number and proportion of juveniles are flushed or killed by high flows (<20%).	An example year or years could be selected to represent this
			Moderate	A substantial number and proportion of juvenile salmon are flushed downstream or killed due to high flows (20 to 70%)	An example year or years could be selected to represent this
			Severe	A substantial and ecologically devasating number and proportion of juvenile salmon are flushed downstream or killed due to high flows (>70%)	An example year or years could be selected to represent this
LG_7	**High Flow Impact on Juveniles, Lower Green**	The total impact of the duration and volume of high flows on juvenile salmon in terms of the proportion of juveniles that are flushed downstream or killed from January through June. Due to highly constrained channel conditions and lack of high flow refugia, High Flow Impacts are even more influential in the Lower Green than in the Middle Green.	Minor	An ecologically insubstantial number and proportion of juveniles are flushed or killed by high flows (<20%).	An example year or years could be selected to represent this
			Moderate	A substantial number and proportion of juvenile salmon are flushed downstream or killed due to high flows (20 to 70%)	An example year or years could be selected to represent this
			Severe	A substantial and ecologically devasating number and proportion of juvenile salmon are flushed downstream or killed due to high flows (>70%)	An example year or years could be selected to represent this
LG_8	**Culvert/Fish Passage Barrier Removal, Lower Green**	Culverts and other fish passage barriers removed from the Lower Green River. This does not include fish barriers in tributaries, except in the cases that the mouth of the tributary into the Lower Green is a culvert/fish passage barrier. Opening up passage barriers adds length and area of habitat to the sub-basin.	All Prioritized Removed	All known barriers	WRIA 9 Technical Committee is generating a list for Lower green presently (possibly completed in the next 1 to 3 months)
			Top Priority Removed	Top 50% of priority barriers (as identified by WRIA Technical Committee are removed)	
			Current Conditions	No Barrier Removal	

NodeID	Name	Defintion	States	State Definitions	Source
LG_9	**Armoring, Lower Green**	Armoring is defined as levees, riprap, bulkheads, revetments, or other hardscape meant to prevent erosion and allow flood protection. Armoring impedes floodplain function and reduces habitat complexity. It disconnects large portions of the historical floodplain, off-channel habitat, and tributaries, which provide juvenile salmon with forage and refuge from extreme flows. Armoring is widespread in the Lower Green.	Greatly Improved	25% decrease in armoring	Higgins suggestion
			Improved	Set back 1 mile of levee	2020 Salmon Habitat Plan 10 Year Target
			Current Condition	42 miles of river bank armored	2020 Salmon Habitat Plan Current Condition (2009)
LG_10	**Large Woody Debris, Lower Green**	Estimated average number of log jams per river mile. A log jam is defined as a minimum of 10 pieces of wood that are at least 12 feet long and ≥4" in diameter. Above this minimum, log jam size varies. R2 (2017) defines small jams as 10 to 50 pieces, medium jams as 51 to 100 pieces, and large as greater than 101 pieces. Jam size is not considered in the Salmon Habitat Plan goals. Large woody debris is relatively scarce in the Lower Green.	2020 NFC	1705 pieces per mile	2020 Salmon Habitat Plan Necessary Future Condition
			2020 10 Year Goal	425 pieces per mile	2020 Salmon Habitat Plan 10 Year Target
			Current Condition	48.5 pieces per mile	2020 Salmon Habitat Plan Current Condition (2014)
LG_11	**Connected Floodplain, Lower Green**	Area of floodplain accessible to juveniles within the Lower Green River subbasin. This can also be influenced by lowering the floodplain shelf and select culvert removal.	2020 NFC	5039 acres connected (45% historic)	2020 Salmon Habitat Plan Necessary Future Condition
			2020 10 Year Goal	240 acres restored	2020 Salmon Habitat Plan 10 Year Target
			Current Condition	Unknown	2020 Salmon Habitat Plan Current Condition

NodeID	Name	Defintion	States	State Definitions	Source
LG_12	**Confined Bankfull Width, Lower Green**	Percent of the Lower Green, by length, with confined bankfull width. This can be anthropogenic (e.g., levees, roadways) or natural (e.g., canyons). Currently, approximately 90% of the Lower Green is confined. Restoring lateral channel migration is dependent on removal of armoring and the addition of large woody debris to create slow water habitat. Confined bankfull width is a surrogate (measured via its inverse) for slow water habitat complexity and lateral channel migration.	Greatly Improved	25% improvement - 4.9 additional miles unconfined	
			Improved	10% improvement, 2 additional miles unconfined	
			Current Condition	90% of river confined	Derived from GIS data and aerial imagery assessment
LG_13	**Moderate Flow Rearing Habitat Conditions, Lower Green**	This factor measures the benefits to juveniles of suitable habitat accessible outside of low flow or high flow events (between 1200 and 5000 cfs). Rearing habitat provides juveniles with the ability to forage for prey and grow larger; this is severely limited in the Lower Green. Those juveniles that are able to stay in the Lower Green River longer will have access to this habitat and its benefits over a longer time period. Juveniles that move downstream in search of suitable rearing habitat, including those that are crowded out by other juveniles, will be forced to rear in the Duwamish Estuary, which is generally of poorer habitat quality.	Greatly Improved	Area of quality Moderate Flow Rearing Habitat increased by 25 to 50%	
			Improved	Area of quality Moderate Flow Rearing Habitat increased by 10 to 25%	
			Current	Present-day area of quality Moderate Flow Rearing Habitat (this may not be known, but is our reference point)	
LF_1	**Hours below 1200 cfs, Jan-Mar**	The number of hours from January through March where minimum discharge measured at USGS gauge site 12113000 was less than 1200 cfs.	0 to 400	hours	Approximate quartiles for Years 2000 to 2020
			400 to 900	hours	
			900 to 1400	hours	
			1400 to 2200	hours	

NodeID	Name	Defintion	States	State Definitions	Source
LG_14	**Low Flow Impact on Juveniles, Jan-Mar, Lower Green**	The impact of the duration and volume of low flows on juvenile salmon from January to March in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.	Minor	An ecologically insubstantial number and proportion of juveniles are forced downstream due to habitat restriction or mortality (<20%).	An example year or years could be selected to represent this
			Moderate	A substantial number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (20 to 70%)	An example year or years could be selected to represent this
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (>70%)	An example year or years could be selected to represent this
LF_2	**Hours below 1200 cfs, Apr-June**	The number of hours from April through June where minimum discharge measured at USGS gauge site 12113000 was less than 1200 cfs.	0 to 400	hours	Approximate quartiles for Years 2000 to 2020
			400 to 900	hours	
			900 to 1400	hours	
			1400 to 2200	hours	
LG_15	**Low Flow Impact on Juveniles, Apr-Jun, Lower Green**	The impact of the duration of low flows on juvenile salmon in April through June in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.	Minor	An ecologically insubstantial number and proportion of juveniles are forced downstream due to habitat restriction or mortality (<20%).	
			Moderate	A substantial number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (20 to 70%)	
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (>70%)	

NodeID	Name	Defintion	States	State Definitions	Source
LG_16	**Low Flow Impact on Juveniles, Lower Green**	The impact of the duration of low flows on juvenile salmon in terms of the proportion of juveniles that are forced downstream due to habitat restrictions or experience mortality due to heightened predation, starvation, stranding, or other causes.	Minor	An ecologically insubstantial number and proportion of juveniles are forced downstream due to habitat restriction or mortality (<20%).	
			Moderate	A substantial number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (20 to 70%)	
			Severe	A substantial and ecologically devastating number and proportion of juvenile salmon are forced downstream due to habitat restriction or mortality (>70%)	
LG_17	**Lower Green Parr Outmigrants**	The number of juvenile Chinook that rear to the parr stage in the Lower Green before outmigration to the estuary. This number is expressed as proportion of the current rearing capacity in the Middle Green.	1 to 5%		
			5 to 10%		
			10 to 15%		
			15 to 25%		