LOWER GREEN RIVER CORRIDOR FLOOD HAZARD MANAGEMENT PLAN

Draft Programmatic Environmental Impact Statement

Volume II

Appendix B: Natural Environment

KING COUNTY
FLOOD CONTROL
DISTRICT

March 2023

KING COUNTY
FLOOD CONTROL
DISTRICT

Appendix B

Natural Environment

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ACRONYMS AND ABBREVIATIONS

1D	one-dimensional
2D	two-dimensional
AEP	annual exceedance probability
AR	at-risk
B-IBI	Benthic Index of Biotic Integrity
BMPs	best management practices
Board	King County Flood Control District Board of Supervisors
BOD	Biological oxygen demand
CESCL	Certified Erosion and Sediment Control Lead
cfs	cubic feet per second
CIP	capital improvement plan
CIRC	Climate Impacts Research Consortium
CL	confidence limit
CO_2	carbon dioxide
Corps of Engineers	U.S. Army Corps of Engineers
CSWPPP	Construction Stormwater Pollution Prevention Plan
dB	decibel
District	King County Flood Control District
DO	dissolved oxygen
Ecology	Washington State Department of Ecology
EPA	Environmental Protection Agency
ESA	Endangered Species Act
FCD Motion	Flood Control District Motion
FEMA	Federal Emergency Management Agency
FIBI	Fish Index of Biotic Integrity
GCM	Global Climate Models
GIS	geographic information system
HEC-RAS 1D/2D	combined HEC-RAS 1D and 2D model
HEC-RAS	Corps Hydrologic Engineering Center’s River Analysis System
HHD	Howard Hanson Dam
LWD	large woody debris
NFC	necessary future condition

NHC	Northwest Hydraulic Consultants
NOAA	National Oceanic and Atmospheric Administration
NPF	not properly functioning
NR	not reported
NW CASC	Northwest Climate Adaptation Science Center
OHWM	ordinary high water mark
PBFs	physical and biological features
PEIS	programmatic environmental impact statement
PF	properly functioning
PL	Public Law
Plan	Lower Green River Corridor Flood Hazard Management Plan
RCPs	Representative Concentration Pathways
RCW	Revised Code of Washington
RM	river mile
RMS	root mean square
SAR	Strategic Assessment Report
SEPA	State Environmental Policy Act
SM	shoreline mile
SPCCP	Spill Prevention, Control, and Countermeasure Plan
SPL	sound pressure level
SWIF	System-Wide Improvement Framework
TMDL	total maximum daily load
TSS	total suspended solids
USC	United States Code
USGS	U.S. Geological Survey
UW CIG	University of Washington Climate Impacts Group
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation
WSEs	water surface elevations

1. INTRODUCTION

The King County Flood Control District (District) is proposing a Lower Green River Corridor Flood Hazard Management Plan (Plan) for a reach of the Lower Green River and its associated floodplains that occur in portions of the cities of Auburn, Kent, Renton, SeaTac, and Tukwila, as well as unincorporated King County (**Error! Reference source not found.**). The Lower Green River Corridor (corridor) covers approximately 21 river miles (RMs), the equivalent to 42 shoreline miles (SMs), from RM 11 to RM 32. The District is preparing a draft programmatic environmental impact statement (PEIS) that analyzes three alternative approaches to flood risk management in the corridor. The District is a county-wide special purpose district created to provide funding and policy oversight for flood risk reduction capital projects and programs in King County. The goal of the Plan is to provide a long-term approach to reduce flood risks, to address Tribal interests, and to improve fish habitat, while supporting the economic prosperity of the region. In 2014, the District Board of Supervisors (Board) set a provisional level of flood protection for the Lower Green River: a median flow of 18,800 cubic feet per second (cfs), plus 3 feet of freeboard, as measured at the Auburn gage, as the desired level of protection to meet this goal (King County Flood Control District Motion (FCD) 14-09).

The Green River is within the Washington State Department of Ecology's (Ecology's) Water Resource Inventory Area (WRIA) 9. It is 65 miles long between its mouth and the Howard Hanson Dam (HHD) near Palmer in unincorporated King County. As shown in Figure 1-2, it originates from headwaters in the Cascade Mountains in southeastern King County (Upper Green River Subwatershed), flows westward through the Green River Gorge State Park to an alluvial valley in mid-basin (Middle Green River Subwatershed), then turns north near Auburn through a lowland valley (Lower Green River Subwatershed) to the mouth of the Duwamish (Duwamish Estuary Subwatershed). At its confluence with the Black River, the Green River becomes the Duwamish River and continues northward, emptying into Puget Sound's Elliott Bay.

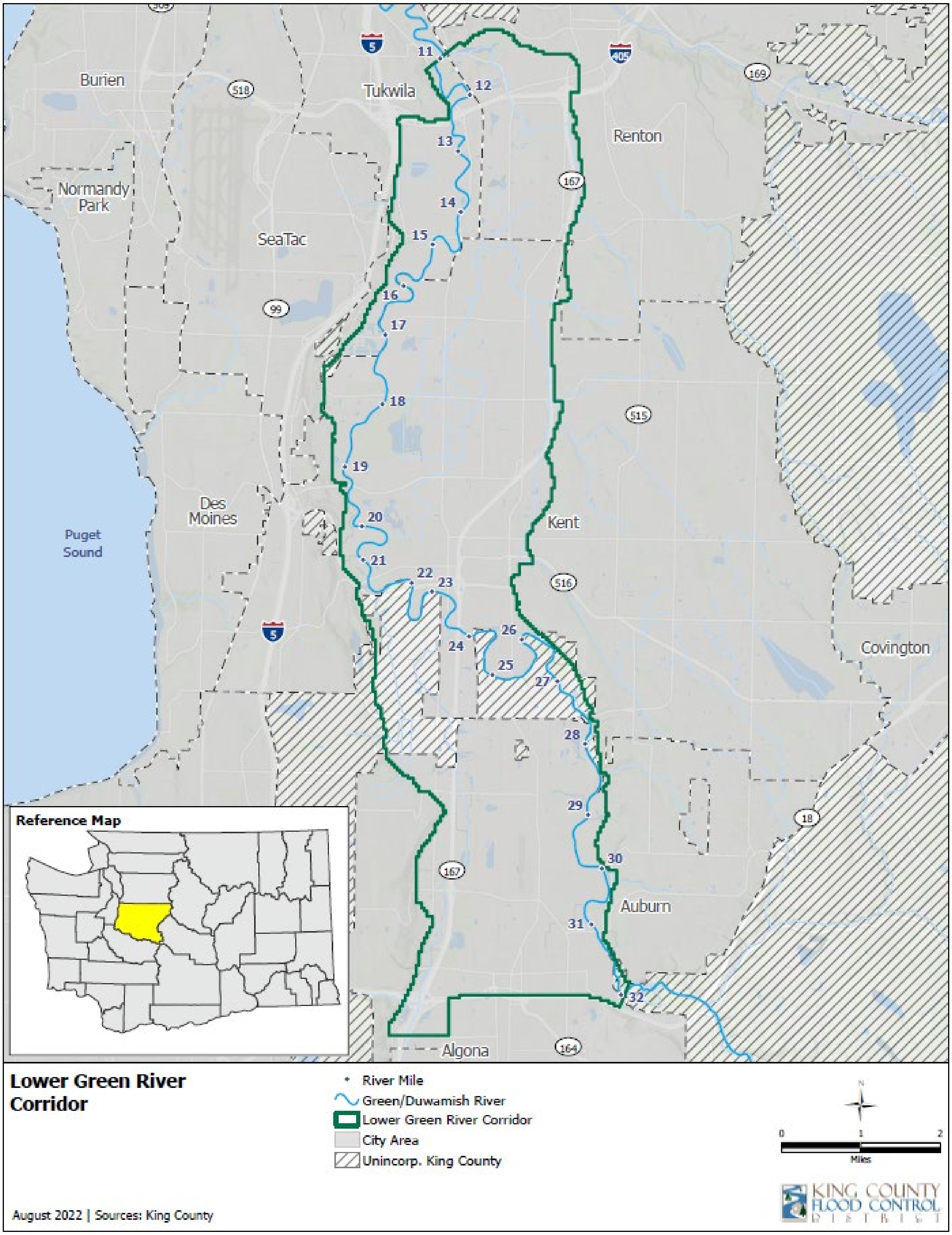


Figure 1-1. Lower Green River Corridor

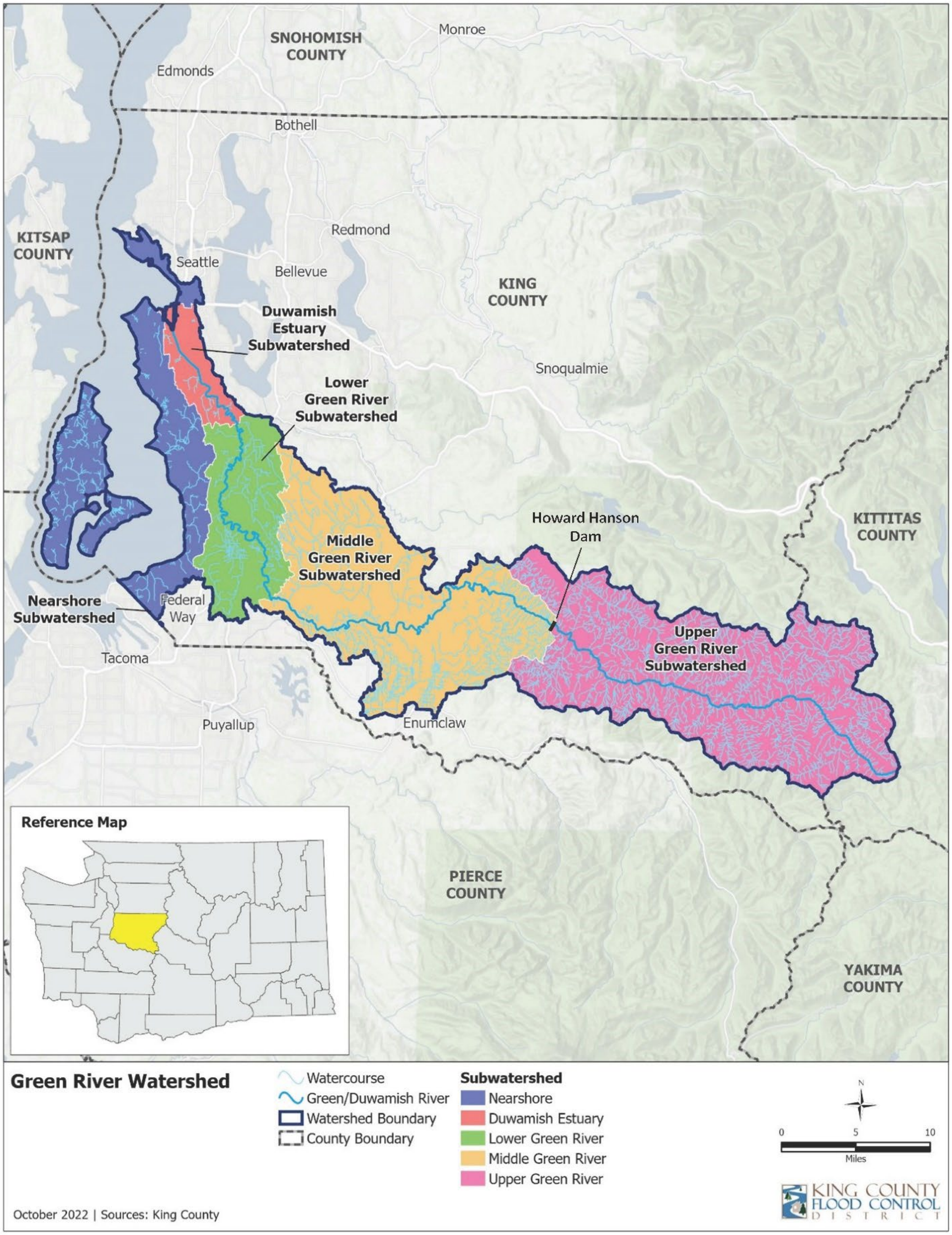


Figure 1-2. Green River Watershed

The information and analysis in the PEIS is based on the following technical appendices:

Appendix A: Alternatives Development describes the main policies and regulations that relate to flood hazard management on the Lower Green River. The appendix briefly explains the need for additional flood hazard management, the proposed alternatives, and how the alternatives were developed. The appendix describes structural and flood proofing approaches to flood management and includes preliminary, planning-level cost estimates.

Appendix B: Natural Environment describes the affected environment, methodologies, potential impacts, and mitigation for elements of the natural environment.

Appendix C: Built Environment describes the methodologies, affected environment, potential impacts, and mitigation for elements of the built environment.

Appendix D: Equity and Social Justice is based on information in appendices B and C and describes disadvantaged populations who experience inequities and how they could be impacted by flooding and flood hazard management.

Appendix E: Tribal Matters describes Tribal treaty rights and interests on the Lower Green River Corridor. The appendix is based on information in appendices B, C, D, and F and describes how Tribal treaty rights and interests intersect with existing conditions on the Green River and the potential impacts of flood hazard management.

Appendix F: Cumulative Impacts describes reasonably foreseeable and potential changes to the environment relevant to the Lower Green River Corridor. These changes are combined with past changes and potential impacts described in appendices B and C to evaluate the potential combined impacts over the 30- to 50-year planning horizon.

Appendix G: Outreach Summary contains outreach efforts during the scoping periods for the PEIS, as well as ongoing outreach and efforts to announce the availability of the draft PEIS.

PEIS Appendix A contains a description of the three alternative approaches to managing flood risk in the Lower Green River Corridor. They are summarized below for readers' convenience.

Alternative 1: Project-by-Project Multibenefit Implementation (No-Action Alternative)

This alternative illustrates how the District would provide flood hazard management on the Lower Green River following established policies and practices without the guidance of an area-specific Plan. Adoption of a Plan for the Lower Green River is the proposed action for the PEIS. This alternative is the benchmark for comparing alternatives.

The District adopted a multibenefit policy in 2020 (FCD Motion 20-07) that would be considered and incorporated to the extent feasible as individual projects were implemented. Flood hazard management projects would be implemented under successive capital improvement plans (CIPs) without guidance from an area-specific Plan for the Lower Green River. Alternative 1 incorporates the CIP approved in FCD Resolution 2021-16 (the 2022 6-year CIP list).

Alternative 2: Systematic Multibenefit Implementation

This alternative would systematically implement the multiple benefits described in FCD Motion 20-07. Implementation would include habitat conservation and fish restoration.

The District would develop an area-specific Plan for the Lower Green River Corridor in collaboration with Tribes, federal and state agencies, local jurisdictions, and stakeholders. The Plan would establish goals and indicators for managing flood hazards, would support a safe and healthy environment for communities along the river, and would conserve and, where possible, enhance aquatic and riparian habitats and conditions to support the recovery of threatened salmon and other species.

The Plan would describe actions the District would take under its authority and would highlight potential partnership opportunities with Tribes, federal and state agencies, local jurisdictions, and stakeholders. The multibenefits described in FCD Motion 20-07 would be systematically advanced in the Plan.

This alternative would introduce the potential use of flood proofing to reduce the effects of flooding, rather than to reduce the risk of flooding.

Alternative 3: Enhanced Systematic Multibenefit Implementation

This alternative would be a substantial shift from the District's current practices. Under this alternative, the District would continue to provide flood hazard reduction, but it would pursue habitat conservation and restoration to a notably greater extent than under either of the other alternatives, while achieving multiple benefits across the Lower Green River.

The District would develop an area-specific Plan for the Lower Green River in collaboration with Tribes, federal and state agencies, local jurisdictions, and stakeholders. This Plan would place a greater emphasis on conserving and restoring habitat for threatened salmon and other species. The Plan would establish goals and indicators for managing flood hazards in a manner that would protect, improve, and restore riparian and aquatic habitats, and it would establish conditions that would support the recovery of threatened salmon and other species. The Plan would describe the actions that the District would take under its authority, and it would highlight potential partnership opportunities with Tribes, federal and state agencies, local jurisdictions, and stakeholders. The multibenefits described in FCD Motion 20-07 would be systematically and rigorously advanced.

With this alternative, the District would maintain enrollment in the Public Law (PL) 84-99 facilities program, but it could, in conjunction with flood hazard management actions, pursue flood management improvements at a scale and design supporting progress towards achieving adopted salmon habitat goals. This alternative would include taking advantage of opportunities to restore habitat functions (e.g., increasing channel capacity to provide backwater or off-channel rearing habitat). With cooperation from local jurisdictions, some adjacent property owners could be provided with incentives to help accommodate these changes.

In addition to flood proofing, this alternative would introduce the potential acquisition of property that would meet certain criteria to preserve floodplain storage.

No Build Scenario

This scenario is included to illustrate the consequences of inaction. The description includes inundation maps and explanations of how the Lower Green River area would be affected by flooding. Because the core mission of the District is managing flood hazards, and this alternative does not provide flood hazard protection throughout the corridor, this scenario is not evaluated in detail as a potential alternative in the PEIS.

Under the No Build Scenario, the District would maintain existing facilities, including PL 84-99 facilities, to meet current requirements. Work would continue on facilities currently under construction. However, projects included in the CIP (2022 6-year CIP) that are not under construction would not proceed. Existing flood hazard management facilities would not be modified to provide the provisional 18,800 cfs level of protection, plus 3 feet of freeboard. No additional flood hazard management actions or related improvements on the Lower Green River would be undertaken.

This appendix evaluates these types of impacts:

- Direct:
    - Impacts that could primarily result from the District's actions to develop new, improved, or relocated flood hazard management facilities
    - Upstream or downstream increases in inundation, in depth, extent, or both, that could be caused by new, improved, or relocated flood hazard management facilities
- Indirect: Reasonably foreseeable impacts that could result from the District's flood hazard management actions, but that would be removed from the action in space and/or time
- Construction: Impacts that would be temporary in nature and that could primarily result from the development of new, improved, and relocated flood hazard management facilities
- Residual inundation: Flooding that could still occur at 18,800 cfs under the three alternatives, but that is not a result of the District's actions

2. CLIMATE CHANGE

Climate change is not listed as an element of the environment in the Washington State Environmental Policy Act (SEPA) rule WAC 197-11-444 but is an important factor in flood hazard management planning and in understanding potential long-term impacts. Earth's climate is now changing faster than at any point in the history of modern civilization, primarily as a result of human activities. The Fifth Assessment Report by the International Panel on Climate Change states the following:

> Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems. Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean have warmed, the amounts of snow and ice have diminished, and sea level has risen.

Climate change is a challenge to long-term planning, which assumes that if the planned activities perform well under historic climate conditions, they will perform sufficiently in the future. Planning methods often rely on historic, recorded data to represent the breadth of conditions a watershed will experience in the future if a region's climate conditions do not change over time. Climate change challenges this assumption and should be included in long-term planning.

The impacts of global climate change are already being felt in the United States, and they are projected to intensify in the future. The Fourth National Climate Assessment found that Americans increasingly recognize the risks that climate change poses to their everyday lives and livelihoods.

Climate change is already affecting the Pacific Northwest's watersheds, which support sustainable livelihoods for rural and Tribal communities. Climate change is expected to continue affecting watersheds; however, proactive management can increase the resilience of these watersheds.

The University of Washington Climate Impacts Group (UW CIG) has concluded that the Puget Sound region is experiencing long-term changes that are consistent with those observed globally as a result of human-caused climate change. These changes include a rise in air temperature, a rise in sea level, a reduced snowpack, and an increase in the intensity of heavy rainfall events.

Climate change will directly impact the Green River watershed. UW CIG and others predict that precipitation patterns will change, bringing warmer, wetter falls, winters, and springs. Floods will be more intense and more frequent. As winters become warmer and wetter, snow will melt from the mountains earlier and faster. The decrease in amount and earlier disappearance of the snowpack will exacerbate drought-like summer low flow conditions in currently snow- dominated areas of the watershed. Hotter air temperatures will increase water temperature in the river and tributaries.

2.1.1 Climate Modeling

Globally, greenhouse gas concentrations have risen substantially as a result of human activities, and they have been a primary driver of warming. To make projections of future climate, scientists use "what if" scenarios of plausible future greenhouse gas emissions to drive computer model simulations of the earth's climate. There are multiple greenhouse gas scenarios, numerous global climate models (each constructed slightly differently), and multiple techniques for "downscaling" coarse global model projections to local scales. The many possible combinations of scenarios, models, and downscaling techniques are used to estimate a range of possible future climates. The range reflects some of the important unknowns regarding future understanding of the climate system.

Projections of changes in the climate system are made using a hierarchy of climate models that range from simple models to models of intermediate complexity, to comprehensive climate models and earth system models. These models simulate changes based on a set of scenarios of anthropogenic (human-caused) forces on the climate.

Regional modeling is done by area-specific modeling centers. The Pacific Northwest Climate Impacts Research Consortium (CIRC) is funded nationally by the National Oceanic and Atmospheric Administration's (NOAA's) Regional Integrated Sciences and Assessments, and it is part of a national network of other climate research consortiums. The purpose of CIRC is to create the best available science and research to help the Pacific Northwest respond to climate change and climate variability. CIRC is hosted by Oregon State University, and it includes researchers from the University of Oregon, the University of Washington, and the University of Idaho.

Climate change impacts are often assessed by first downscaling coarse resolution global model projections to local scales. Global Climate Models (GCMs) simulate changes at coarse spatial scales (50 to 100 miles from one grid cell to the next). Therefore, they do not adequately represent local scale weather and climate patterns. Downscaled climate projections translate coarse resolution global model projections to a level of detail that is more relevant to management and decision-making. This increased resolution (usually about 5 to 10 miles from one grid cell to the next) often provides a better representation of local climate, but it also entails additional assumptions, which means that different approaches can give different results.

There are two different approaches to downscaling global climate projections to local climate projections.

1. "Statistical downscaling" uses observed relationships between weather observations and coarse-scale GCM weather patterns. An advantage of statistical downscaling is that it is inexpensive to implement. A disadvantage is that it does not capture the local-scale processes that can alter the response to warming at any given location.
2. "Dynamical downscaling" uses a physical model, such as a regional climate model, which is driven by coarse-resolution GCM weather patterns. An advantage of dynamical downscaling is that the model can capture important local-scale changes that cannot be represented with a statistical approach. A disadvantage is that it is expensive to implement, although regional climate model simulations are becoming increasingly feasible.

Studies used to evaluate the impact of climate change on the Lower Green River use both methods of downscaling. The scientific community has defined a set of four scenarios called Representative Concentration Pathways (RCPs). These scenarios, which are used in modeling global and regional climate impacts, represent differing concentrations of greenhouse gases in the atmosphere. The four scenarios are:

- Very low - RCP 2.6
- Low - RCP 4.5
- Moderate - RCP 6.0
- High - RCP 8.5

These descriptors are based on cumulative emissions by 2100 for each scenario in all RCPs, atmospheric carbon dioxide (CO_2) concentrations are higher in 2100 relative to the present day because of further increase in cumulative emissions of CO_2 to the atmosphere during the 21st century. Based on a range of outputs from climate models, different futures are projected, and they address the larger uncertainties in climate modeling.

For projecting future climate scenarios and the use of dynamic downscaling running multiple scenarios is costly and unnecessary. For studies that use dynamic downscaling a select number of scenarios are used based on trends in carbon emissions. The UW CIG is using only RCP 8.5 and RCP 4.5 for the heavy precipitation and river flow studies. When selecting the RCPs, mid-century differences in outcomes between the RCPs is often very small. The reason for this is that the climate system responds relatively slowly to changes in greenhouse gas concentration. So, the choice of RCP is not important until midcentury. For analyses after mid-century, it is important to distinguish between different RCPs. RCP 8.5 gives a much more rapid warming and more pronounced changes in important indicators such as river flow, water temperature and precipitation.

Because there are many variables involved in climate, it is not possible to predict exactly how climate change will play out into the future. As a result, modeling of future climate change must account for uncertainty. Sources of uncertainty in climate forecasting include the following:

1. Uncertainty in levels of anthropogenic forcing due to different emission paths (“scenario uncertainty”)
2. Uncertainty due to natural variability, encompassing internal chaotic climate variability and externally driven (e.g., solar, volcanic) natural climate change (“natural variability”)
3. Uncertainty in the climate system’s response to external forcing due to incomplete knowledge of feedback and timescales in the system (“response uncertainty”)

These different sources of uncertainty have different implications. This discussion explains each source of uncertainty listed above, both in the data presented and in the overall uncertainty in addressing climate change. Acknowledging uncertainty allows for a range of actions beyond the present or near-term future. Ultimately, uncertainties in climate projections are unknowable since they can only be verified in the future.

2.1.2 Effect of Climate Change on the Green River

2.1.2.1 Flooding

The UW CIG has conducted multiple studies for future projections of heavy precipitation. The District provided funding to UW CIG to determine the effect of climate change on flooding in the Snoqualmie River, South Fork Skykomish River, and Green River. For the Green River, the model for the HHD developed by the U.S. Army Corps of Engineers (Corps of Engineers) was used by UW CIG in their modeling of the Green River.

Based on the UW CIG study, uncertainty in the estimates of extreme flooding event statistics can be important. This is primarily a consequence of sample size, and it is a challenge for both observations and model results. For example, the results suggest that for 60 years of observations (about the length of time that weather observations have been made at Sea-Tac Airport), the uncertainty in the 100-year precipitation extreme is approximately ±10 percent. This means that changes in the 100-year storm that are lower than 10 percent could potentially be inaccurate due to data limitations. For the 30-year time periods used by the CIG to evaluate projected changes, the uncertainties are greater.

Changes in peak flows in the Green River are influenced both by declines in snowpack and by higher-intensity heavy rain events. As the temperature warms, snowpack decreases, and a greater percentage of winter precipitation falls as rain. This shift from snow to rain causes more direct runoff to the Green River and results in higher peak winter flows, instead of the historical spring runoff flows caused by the melting of the snowpack.

Although both changes act to increase the risk of flooding, the UW CIG study indicated that the decrease in snowpack and the resulting increase in flow during rain events have the greatest impact on peak flows in the first half (2050) of the twenty-first century. The UW CIG study projects by the 2080s the average streamflow during October through March will increase between 10 and 22 percent due to the runoff caused by more rain and less snow.

Later in the century, the increase in rain intensity is predicted to be the more important driver of changing peak flows in the Green River. As a result, the projections reflect the changes in precipitation intensity seen in the two regional climate model simulations. The high-end simulation (RCP 8.5), which projects a large increase in precipitation intensity, shows a correspondingly large increase in peak flows. For example, by the 2050s (relative to 1970 to 1999), the amount of flow associated with a 10-year peak flow is projected to increase by 14 percent for the Green River near Auburn.

UW CIG simulated reservoir operations at the HHD using reservoir simulation model (RiverWare) developed by the Corps of Engineers suggest that the largest floods in the future are still within the dam's capacity to manage flows downstream. However, a few of the statistically downscaled climate projections indicate the potential for large floods that would exceed the capacity of the reservoir to mitigate peak flows downstream. As suggested in the preceding discussion of uncertainty, it is not clear whether these potential flows represent an accurate projection of future peak flows or if they are a result of random variability.

2.1.2.2 Temperature

As described in Section 4, water temperature has been highlighted as a concern for cold-water fish in the Green River, and higher summer air temperatures contribute to higher water temperatures. The Northwest Climate Adaptation Science Center (NW CASC) used ten climate change models to predict the average rate of climatic warming in the Pacific Northwest. Forty-one global climate models were evaluated as part of the study and ten models best reflected historical trends. For the period from 2041 to 2070, relative to 1950 to 1999, annual average temperature is projected to rise 4.3 to 7.1 degrees F for the high greenhouse gas scenario (RCP 8.5). During the same time period summer temperatures are projected to rise 4.8 to 9.7 degrees F and winter temperatures are projected to rise 3.2 to 6.5 degrees F. There is a high level of confidence that both air and water temperatures will increase significantly across the Puget Sound region because of global climate change later in this century. Stream temperatures are projected to increase by 2.7 to 5.8 degrees F by the 2050s relative to the period from 1970 to 1999.

2.1.2.3 Sea-level Rise

The Puget Sound region is projected to experience continued sea level rise throughout the 21st century, increasing the potential for more frequent coastal flooding and increased erosion. Sea level rise will permanently inundate some low-lying areas and will increase the frequency, depth, and duration of coastal flood events by expanding the reach of storm surge and making it harder for flood waters in rivers and streams to drain into Puget Sound. At the Seattle tide gauge, one of the longest-running gauges in Puget Sound, sea level rose by 8.6 inches from 1900 to 2008 (increasing 0.8 inch per decade). However, because flows in the Green River and downstream in the Duwamish River are controlled by the HHD, sea level rise is not expected to impact the severity of flooding past the Turning Basin at river mile (RM) 5.3. Continued navigational dredging would protect the upper Duwamish and Lower Green River from tidal inundation.

3. HYDRAULICS AND HYDROLOGY

If an 18,800-cubic feet per second (cfs) flooding event occurred in 2022, most of the Lower Green River Corridor would experience inundation. All three PEIS alternatives include actions and policies to manage flood risk, and all could substantially reduce the amount of land area that is at risk of inundation during a flood event compared to today's conditions. However, there are some minor differences in the land areas that could experience flooding. This chapter of Appendix B – Natural Environment Report describes the hydraulic modeling of the alternatives and compares and contrasts the patterns of potential flooding among the three alternatives.

3.1 Methodology

3.1.1 Study Area

The study area (Lower Green River Corridor) is generally described in Section 1. As it pertains to hydraulic model it should also be noted that the Lower Green River has a relatively low gradient, and the surrounding areas are more developed than the areas around the Middle Green River. This section of the river is heavily diked and leveed, with little riparian vegetation capable of producing shade (King County 2017a). Land uses that affect the overall basin's water resources are logging and manufacturing, as well as commercial, agricultural, and residential activities (Ecology 1980).

3.1.2 Hydrologic Conditions

The most recent analysis of Green River hydrology, incorporating HHD operations and local inflows, was published by the Seattle District of the Corps of Engineers in 2012. Flood hydrographs for inflow to the HHD reservoir and local inflow between the dam and the Auburn gauge were developed for the 50, 10, 4, 2, 1, 0.5 and 0.2 percent annual exceedance probability (AEP) floods (commonly known by recurrence intervals as the 2-, 10-, 25-, 50-, 100-, 200-, and 500-year floods). For each flood event, uncertainty was captured by developing the high (5 percent) and low (95 percent) confidence limit (CL) hydrographs in addition to the median event, resulting in 21 hydrographs. The CL expresses the probability that a given flow will be exceeded for a particular flood event; for instance, the low CL flow means there is a 95 percent likelihood that the true flow will exceed this value. The median is the 50 percent CL hydrograph, or the flow most likely to occur for a given flood probability. The 50 percent CL is implied when no CL is stated, for instance a "1 percent annual chance flood" (Northwest Hydraulic Consultants [NHC] 2021).

Table 3-1 lists the flow conditions selected for environmental evaluation, ranging from low flows that are of ecological concern to major floods that would cause extensive damage under current conditions. Of these, six flow conditions representing peak discharges of 9,900 cfs), 11,900 cfs, 12,600 cfs, 15,100 cfs, 18,800 cfs, and 26,800 cfs were hydraulically modeled (NHC 2023), and two low steady-state flows of 300 cfs and 2,030 cfs were simulated. By determining the different surface elevations of the Lower Green River at low flows and at various times of year, the effects of different alternatives could be compared.

Table 3-1. Selected Flows for Environmental Evaluation

Flow (cfs)[1]	Exceedance Probability	Recurrence Frequency (years)	Description
~ 300		Mean August Low Flow	This represents commonly expected dry season flows. This is the period when water temperatures in the Green River main channel are highest. Low flows combined with high water temperatures may be especially stressful to fish. This is similar to the estimated September median flow, which is meaningful for water quality analysis.
2,030		Mean Winter Flow	This represents commonly expected wet season flows (November to February). Mean daily flows from January to May are also in this range, at 1,920 cfs (1962 to 2016). Mean daily flows during juvenile Chinook outmigration are 1,770 cfs from January to June (1962 to 2016).
9,900	4.0%	25	This is the high confidence limit (5%) of the 2-year flood.
11,900			This is the low confidence limit (95%) of the 10-year flood. This is the low volume flood event in the range of 12,000 cfs (similar to current 100-year flood).
12,600	0.5%	200	This is the median estimate of the 200-year flood. The high-volume flood event is in the range of 12,000 cfs. The 1996 flood was 12,400 cfs (the highest since HHD was constructed in 1961).
15,100	0.29%	350	This is the high confidence limit (5%) of the 100-year flood (thought to be equivalent to approximately the median estimate of a 350-year flood).
18,800	0.2%	500	This is the median estimate of the 500-year flood as determined by the Corps of Engineers (Corps of Engineers 2012); it is the level of protection adopted by the District. This is the event for which some jurisdictions are now regulating in preparation for climate change.
26,800	0.2%	500	This is the high confidence estimate of future 500-year floods, and it is used to evaluate potential conditions under climate change.

[1] All flows are based on the U.S. Geological Survey (USGS) Green River gauge in Auburn, with a typical data period of 1962 to 2019.

3.1.3 Hydraulic Model Description

The PEIS Appendix A, describes the three alternative approaches to managing flood risk in the Lower Green River Corridor to meet the provisional level of protection of 18,800 cfs (the median 500-year flow). Applying the three approaches could result in adverse impacts, environmental benefits, or both. Section 1, Introduction, summarizes these alternative approaches and describes the types of impacts, including direct, indirect, construction, and cumulative impacts.

To facilitate hydraulic modeling and the evaluation of potential impacts, the potential locations of future flood hazard management facilities were estimated based on the policy-level approaches and guidelines for each alternative. These estimates include improvements to facilities in their current location, relocation of existing facilities further from the river, and development of new facilities. The resulting renderings are intended to facilitate development of model geometry for each alternative and a comparison of flooding patterns among the alternatives. No specific flood management projects have yet been identified. Please refer to Appendix A, Attachment 1 for the spatial renderings.

For this PEIS, a modern and robust hydraulic model called the Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) was used. HEC-RAS is the most widely used hydraulic modeling software in the world, and it has been used for many riverine applications such as flood insurance studies, levee setback projects, flood reduction studies, river restoration studies, sediment transport, water quality, and flood forecasting and warning. HEC-RAS introduced two-dimensional (2D) modeling capabilities in 2016 (in version 5). The approach used by HEC-RAS allows topographic features of the floodplain to be represented in each model cell. It can, therefore, model flow routing in the drainage ditches, depression areas, culverts, and small streams that are common in the Lower Green River floodplain.

The PEIS consultants adopted a current HEC-RAS model developed by the Corps' Seattle District for a Corps of Engineers water management system study of the entire Green River. The Green River HEC-RAS model uses one-dimensional (1D) cross sections in the main channels and 2D cells in the overbank areas, so it is a combined 1D and 2D model, hereafter referred to as HEC-RAS 1D/2D. The existing HEC-RAS 1D/2D model was refined by the PEIS consultants to add major culverts, among other modifications (NHC 2021).

The HEC-RAS 1D/2D model is an unsteady flow model, meaning that it simulates the rising and falling of water surface elevations during a flood event. The 1D portion of the model assumes that flood water moves in only one direction along main channels. Water surface elevations at a given cross section that is perpendicular to the flow do not vary across the channels. The physical laws that govern the flow of water in a channel are (1) the principle of conservation of mass (continuity) and (2) the principle of conservation of momentum. The continuity and momentum equations are discretized spatially at 1D cross sections and temporally at different times. They are solved numerically for water surface elevations and flow velocities at the cross sections.

The 2D portion of the model assumes that flood water moves in two directions over the floodplain, both laterally and longitudinally. The physical laws that govern the flow of water in a channel are (1) the principle of conservation of mass (continuity) and (2) the principle of conservation of momentum along the longitudinal and lateral directions. The continuity and momentum equations are discretized spatially at 2D cells and temporally at different times They are solved numerically for water surface elevations and flow velocities in the two directions at each cell.

The basic data required to compute water surface elevations at a 1D cross section or a 2D cell include geometric data and unsteady flow data. The basic geometric data consist of defining the connectivity of a river system, cross section data, reach lengths, and a 2D grid and 2D grid terrain surface. Data on hydraulic structures such as bridges, culverts, levees, or pumps are also considered geometric data. The typical source of the cross-section data is channel survey. LiDAR (light detection and ranging) data provide fine-resolution terrain surfaces in 2D areas. The unsteady flow data at the upstream end of the model domain create a flow hydrograph that defines the rising and falling phases of a flood event.

3.2 No Build Scenario and PEIS Alternatives

After model refinement, the HEC-RAS 1D/2D model was run for four scenarios: a No Build Scenario and the three alternatives. The alternatives are described in detail in Appendix A, and they are summarized in the introduction to this appendix for readers' convenience. For each alternative, the model geometry was revised according to the spatial rendering developed for each alternative. Graphics were developed to depict the flood characteristics and patterns of each alternative for the six hydrographs (Table 3-1). The graphics show the flooding sequence, paths, and contributions of flows from different areas for different magnitude events, depths, and water surface elevations for select discharges. The hydraulic performance of Alternatives 2 and 3 was typically compared to that of Alternative 1 to assess changes in inundation depths and the geographic extent of flooding. Spreadsheets, graphics, and narratives were developed to compare and contrast the alternatives. Output types included depths, water surface elevations, current speeds, shear stress, and inundation extents. In addition, the team compared the results between alternatives. The modeled scenarios are introduced in the sections below.

It is important to note that while the modeling of the No Build Scenario factored in the operation of two pump stations in the Lower Green River Corridor (the Black River and P17 pumps), those pump stations were not included in the modeling of the three alternatives (NHC 2023). A subsequent test, after the initial model run, found that this exclusion of the pumps did not significantly change the model results. Therefore, the existing simulations are compared to draw conclusions between the No Build Scenario and Alternatives 1, 2, and 3. The three alternatives and the No Build Scenario are described in detail in Appendix A. A summary is provided in Section 1.

3.3 Affected Environment

3.3.1 Pre Euro-American settlement Conditions

Before Euro-American settlers arrived in the 1850s, the White River ran westward along the southern border of what is now King County before turning north (Stein 2001). It was joined by the Green River near what would become Auburn. During this period, Lake Washington drained southward as the Black River, which was joined by the Cedar River before flowing into the White (Green) River in what is now Renton. Together, the Cedar River and the White (Green) River flowed towards Elliott Bay as the Duwamish River.

3.3.2 Major Modifications

As Euro-American settlements grew, farmers modified the White River channel, and a major flood in 1906 caused the White River to flow to Commencement Bay, where it still flows today (Stein 2001). The Green River then flowed to Elliott Bay in the former White River channel. After the Lake Washington Ship Canal was completed in 1916, and Lake Washington was lowered by nearly 9 feet (eliminating the Black River outflow), the city of Renton built a diversion channel that allowed the Cedar River to flow into the south end of Lake Washington. In major floods in the Cedar River, overflows can still reach the Lower Green River through the historic Black River channel.

In the 1950s, many of the existing Lower Green River levees and revetments were constructed to protect agricultural land from flooding. Since then, much of the land around the Lower Green River has been converted to other regional economic purposes, such as infrastructure, businesses, and housing (King County 2019).

In 1962, the HHD was completed to reduce flooding in the Lower Green River. The HHD is managed to control the 1 percent AEP (100-year) flood to about 12,000 cfs at Auburn. In fact, the Corps of Engineers' analysis found that the regulation of HHD could maintain 12,000 cfs at Auburn up to about the 140-year flood. For less-frequent floods, HHD could achieve only partial regulation and peak releases would be expected to exceed 12,000 cfs at Auburn.

3.3.3 Inundation for the No Build Scenario

Evaluating inundation results for the No Build Scenario serves several purposes. First, and as previously described, they illustrate the consequences of not providing additional flood hazard management on the Lower Green River for an 18,800 cfs flow (the median 500-year flow and the provisional level of protection adopted by the District for the Lower Green River). As shown in Figure 3-1, substantial overbank flooding would be expected during this event, with inundation throughout much of the Lower Green River Corridor.

Another purpose for evaluating inundation under the No Build Scenario is to identify surface water levels during the median 100-year flow, which is the flood event that is planned for under applicable floodplain policies and regulations. The PEIS analysis modeled a peak flow of 11,900 cfs. This flow would approximate the 100-year flood level of 12,000 cfs at Auburn, which would trigger the HHD release under current guidance. Figure 3-2 shows the maximum inundation extents for the No Build Scenario with a peak flow of 11,900 cfs.

An additional purpose of analyzing inundation under No Build Scenario is the ability to compare potential future inundation extents between different flood events. The difference in the extent of flooding between Figure 3-1 and Figure 3-2 illustrates the areas where additional measures could be needed to meet the 18,800 cfs level of protection and the extent to which existing levees might have to be raised to provide future freeboard of 3 feet. The main purpose of Alternatives 1, 2, and 3 would be to reduce overbank flooding of flood hazard management facilities between RM 11 and RM 32 during the 18,800 cfs event.

Modeling for Figure 3-1 and Figure 3-2 does not include breaches. Model simulations that included scenarios in which levees were breached were developed only for the No Build conditions, assuming that improved levees in the three plan alternatives would not fail. The results show that very extensive flooding would be possible if existing levees were to fail.

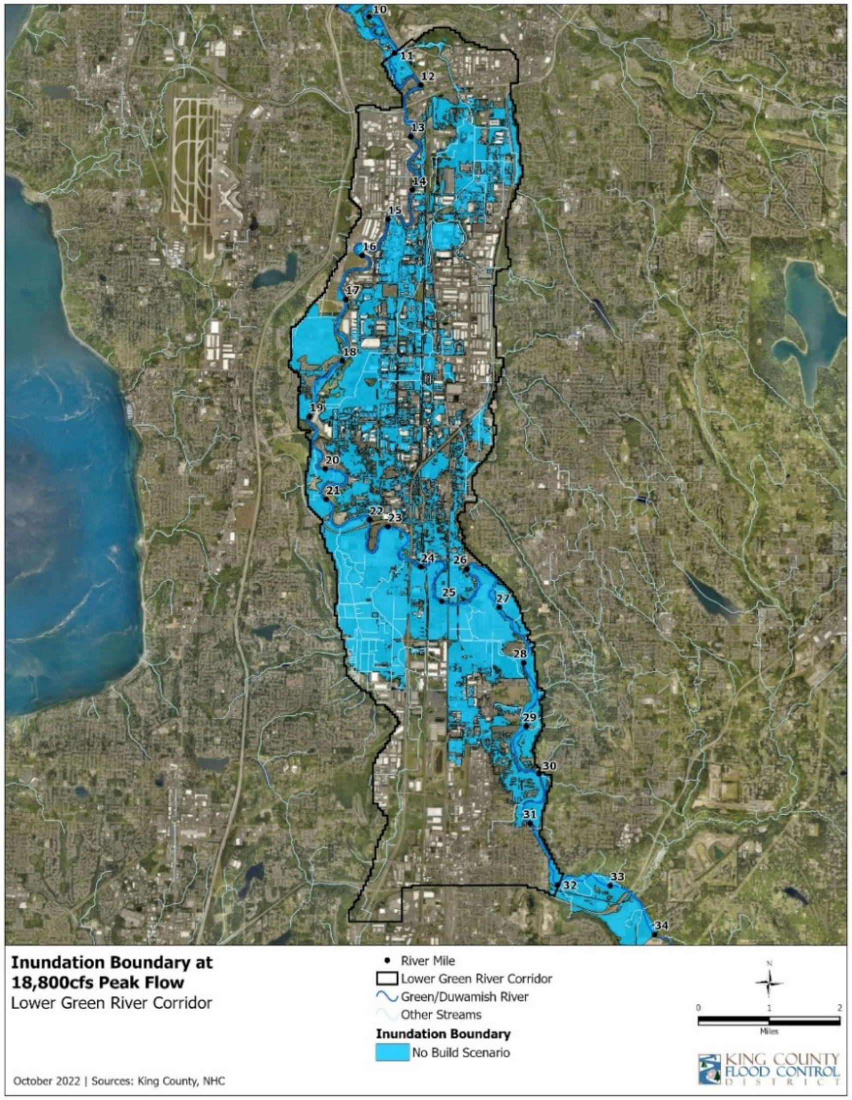


Figure 3-1. Maximum Inundation Extents for No Build Scenario at 18,800 cfs

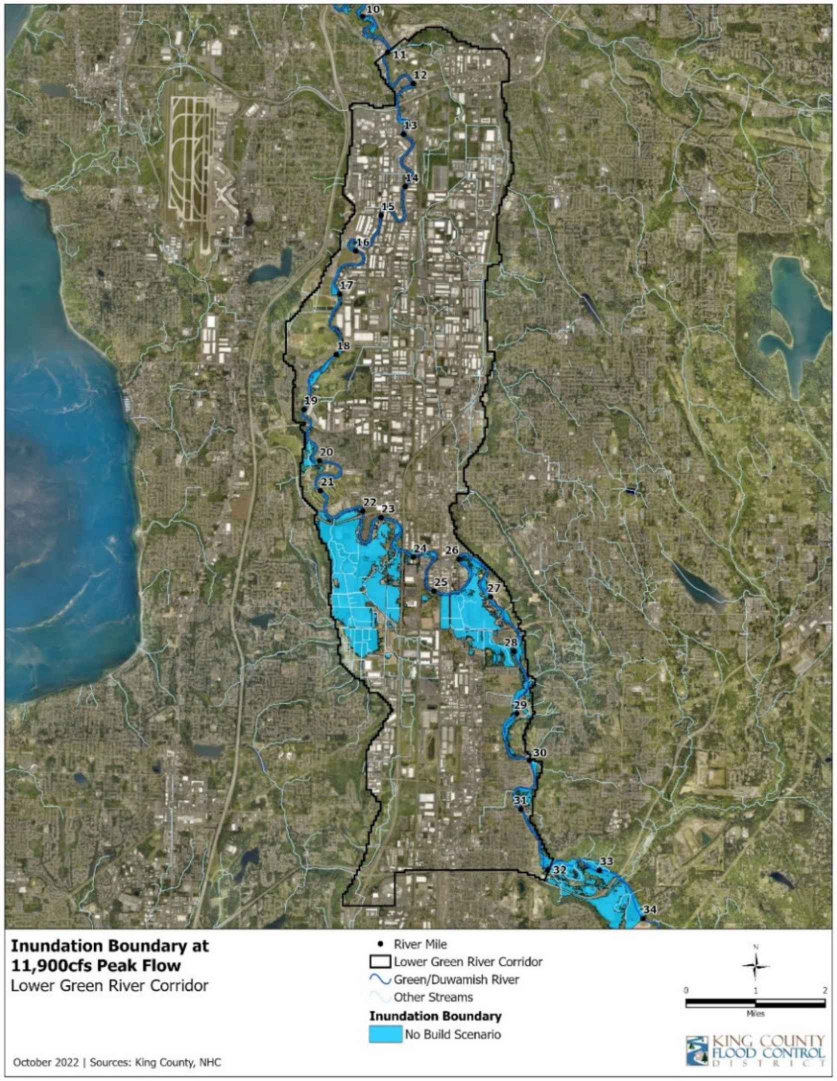


Figure 3-2. Maximum Inundation Extents for No Build Scenario at 11,900 cfs

3.4 Potential Impacts

Modeling results showing inundation patterns in the Lower Green River Corridor are presented in the sections below, first for the 18,800 cfs flood event and then for the 11,900 cfs flood event. These results are followed by discussions regarding potential localized changes in flooding within and downstream of the Lower Green River Corridor. For a discussion of changes in flood patterns on agricultural lands, please refer to Appendix C, Built Environment, Sections 4.1.6 and 4.2.6.

3.4.1 Inundation for Alternatives 1, 2, and 3 for the 18,800 cfs Event

Future levee construction and other flood reduction measures would be designed to manage a flow of 18,800 cfs (the median 500-year flood event) with 3 feet of freeboard. This is the provisional level of protection designated by the District for the Lower Green River Corridor. For purpose of accounting for future flood hazard management facilities, the model was used to simulate water surface elevations (WSEs) along the Lower Green River for this event, and then 3 feet was added to achieve the design top-of-levee. Alternatives developed to raise levees to this standard should not result in overflows to overbank areas along the leveed reaches. Therefore, this analysis focuses on evaluating the response in the Lower Green River during the 18,800 cfs event.

Figure 3-3, Figure 3-4, and Figure 3-5 show the maximum extents of flooding for Alternatives 1, 2 and 3, respectively, that could occur at 18,800 cfs. At an overview level, all the alternatives would considerably reduce flooding between RM 11 and RM 26 compared the No Build Scenario conditions (see Figure 3-2), as well as reducing some flooding between RM 26 and RM 32. Looking at the entire study reach (RM 11 to RM 32), there would be little difference in the area flooded among the three alternatives.

In all alternatives, flooding along the left bank in the vicinity of RM 17 to RM 18 could be over 10 feet deep and could provide meaningful flood storage. Frager Road could be overtopped and could back up through the low-lying area between RM 17.8 and 18.5 (NHC 2023). Alternative 3 flooding would be less than for Alternatives 1 and 2, but substantial areas could be inundated.

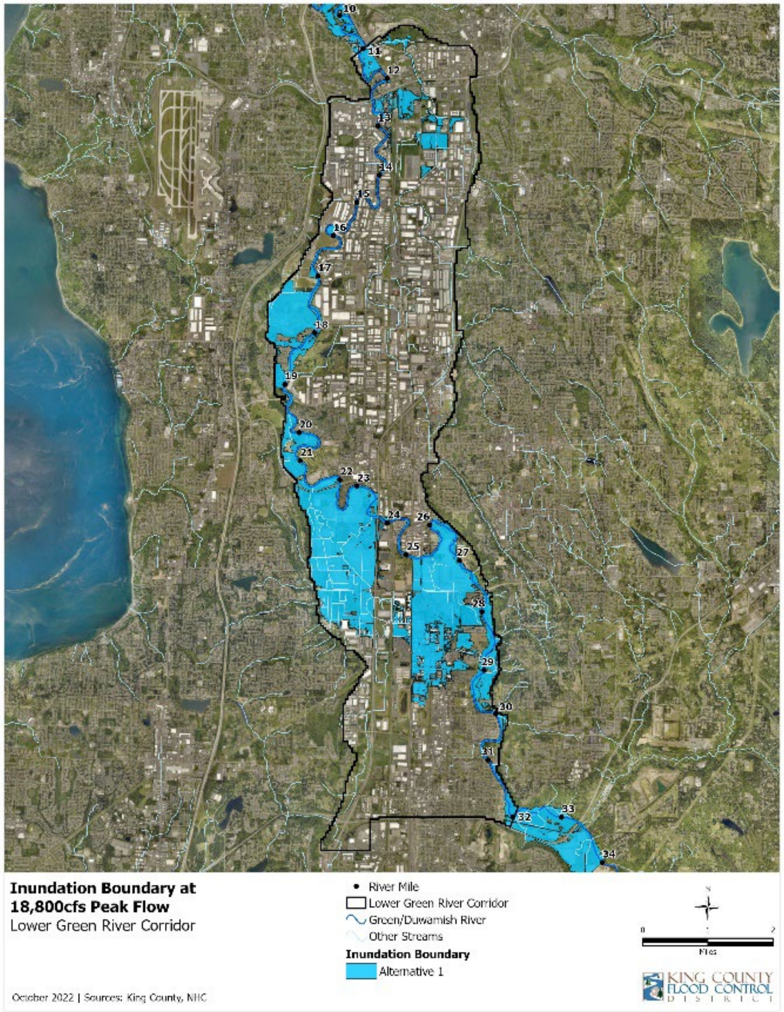


Figure 3-3. Maximum Inundation Extents for Alternative 1 at 18,800 cfs

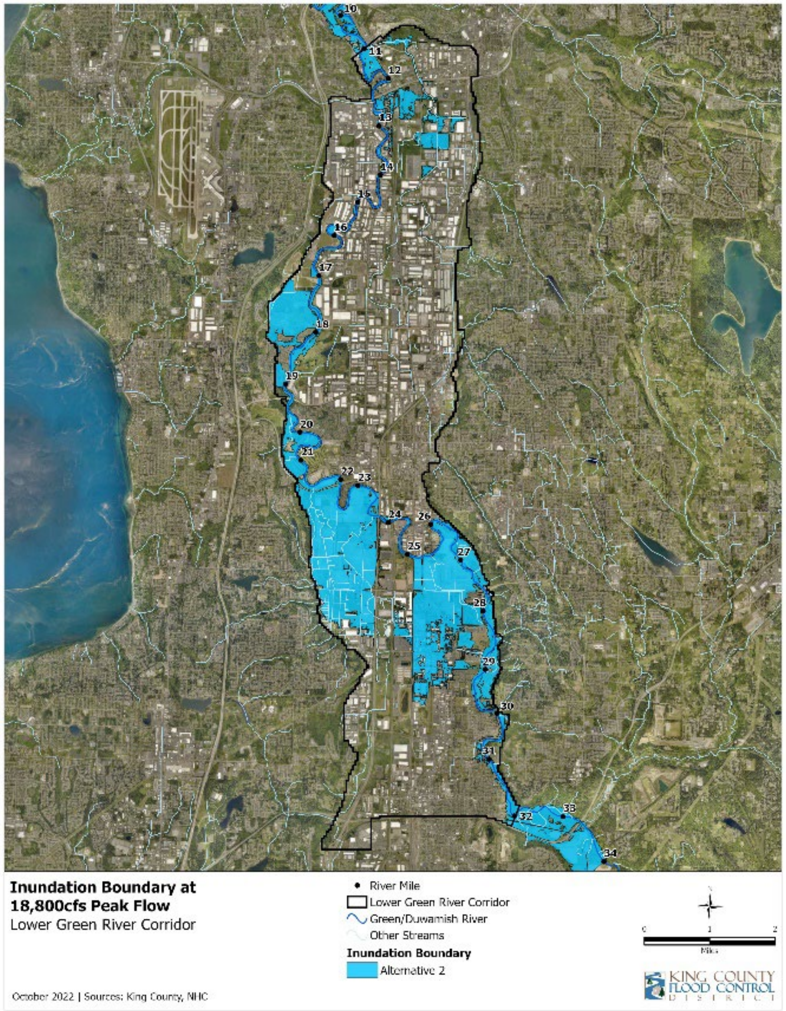


Figure 3-4. Maximum Inundation Extents for Alternative 2 at 18,800 cfs

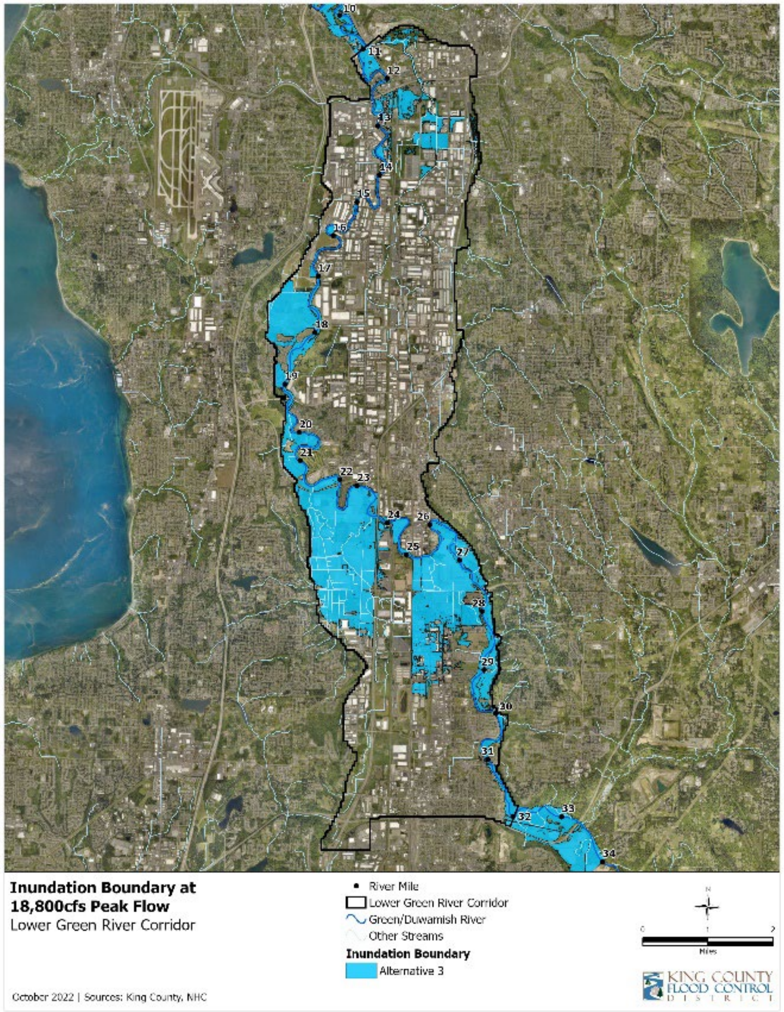


Figure 3-5. Maximum Inundation Extents for Alternative 3 at 18,800 cfs

Figure 3-6 compares maximum WSEs along the Lower Green River for the three alternatives during the 18,800 cfs flood event. The figure also shows the thalweg, or invert elevation, of the Lower Green River main channel. At this scale, the differences in WSEs between alternatives are difficult to clearly identify over the 34-mile study reach, but they would generally be less than 0.5 feet. Figure 3-7, Figure 3-8, and Figure 3-9 show details for several sub-reaches.

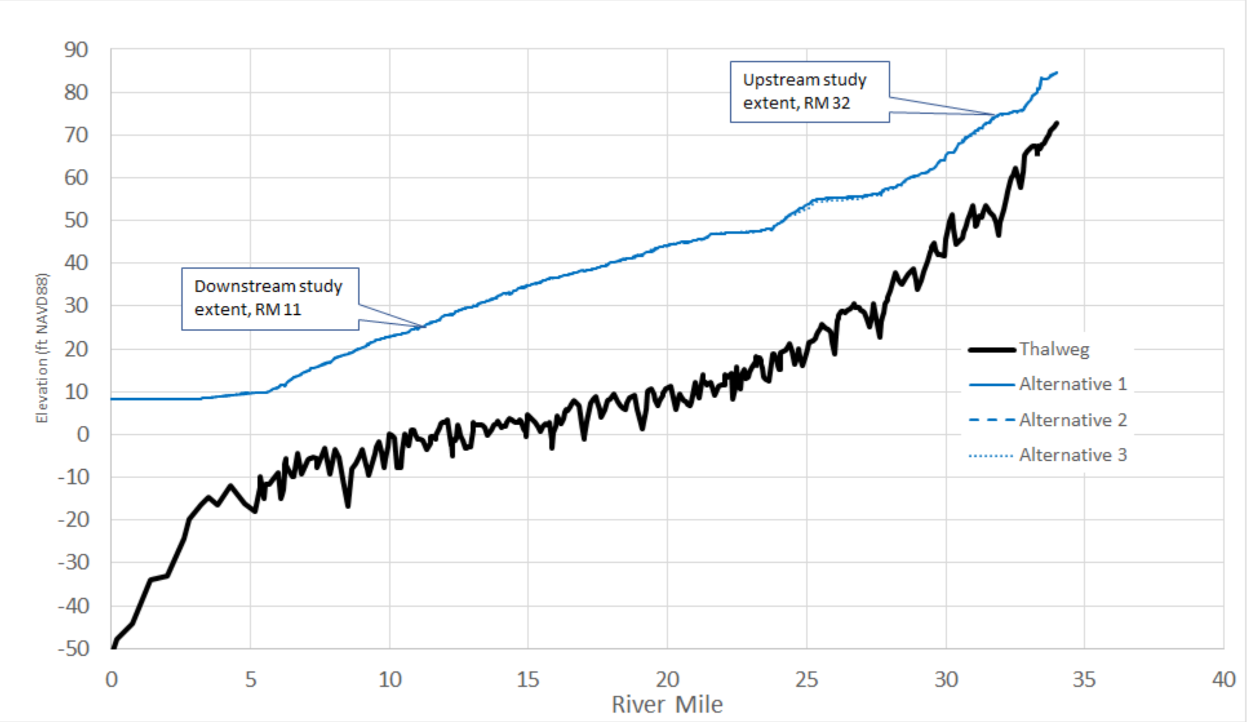


Figure 3-6. Water Surface Elevations along the Lower Green River for Alternatives 1, 2, and 3

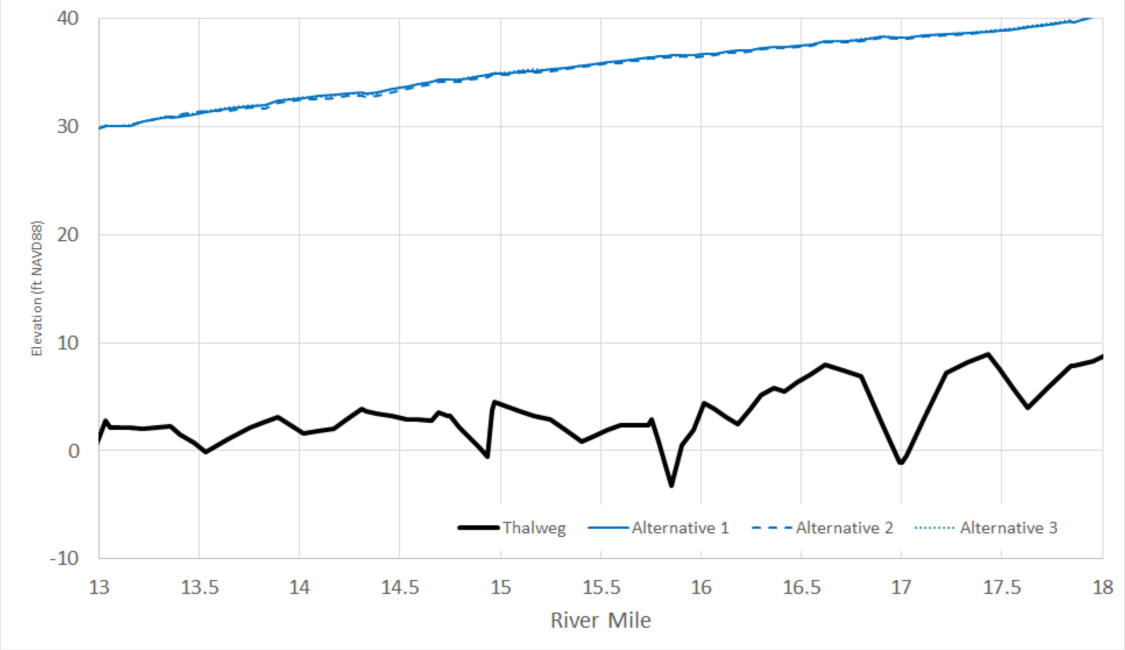


Figure 3-7. Details of Water Surface Elevations for RM 13 to RM 18

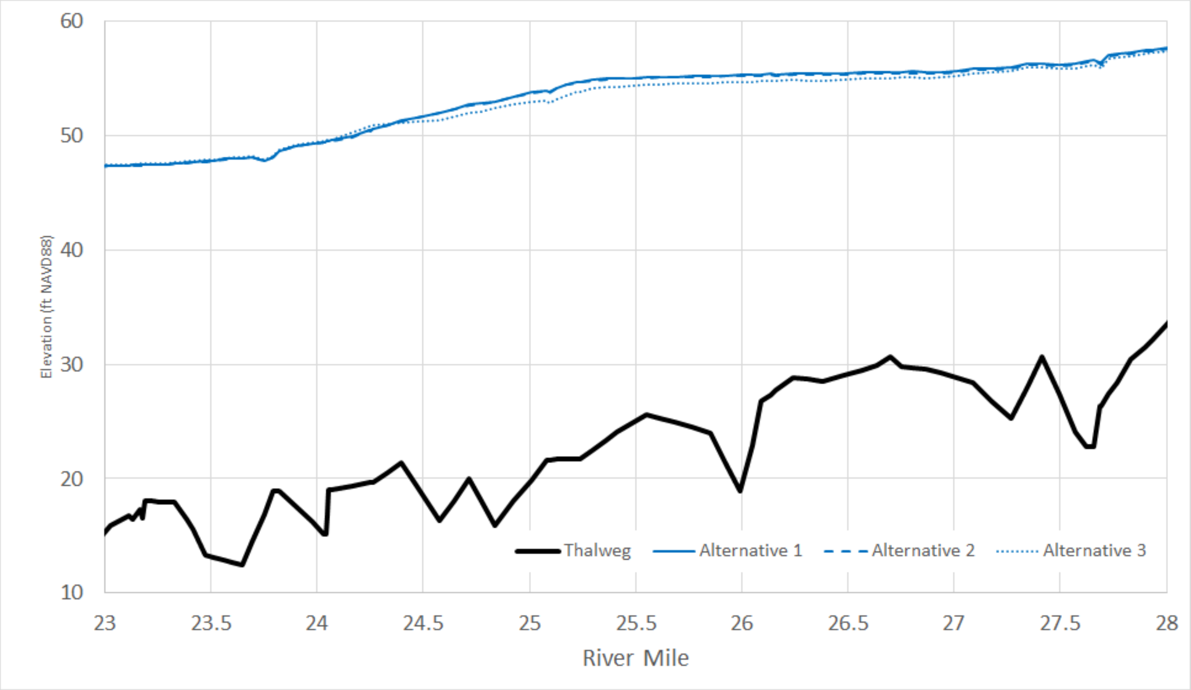


Figure 3-8. Details of Water Surface Elevations for RM 23 to RM 28

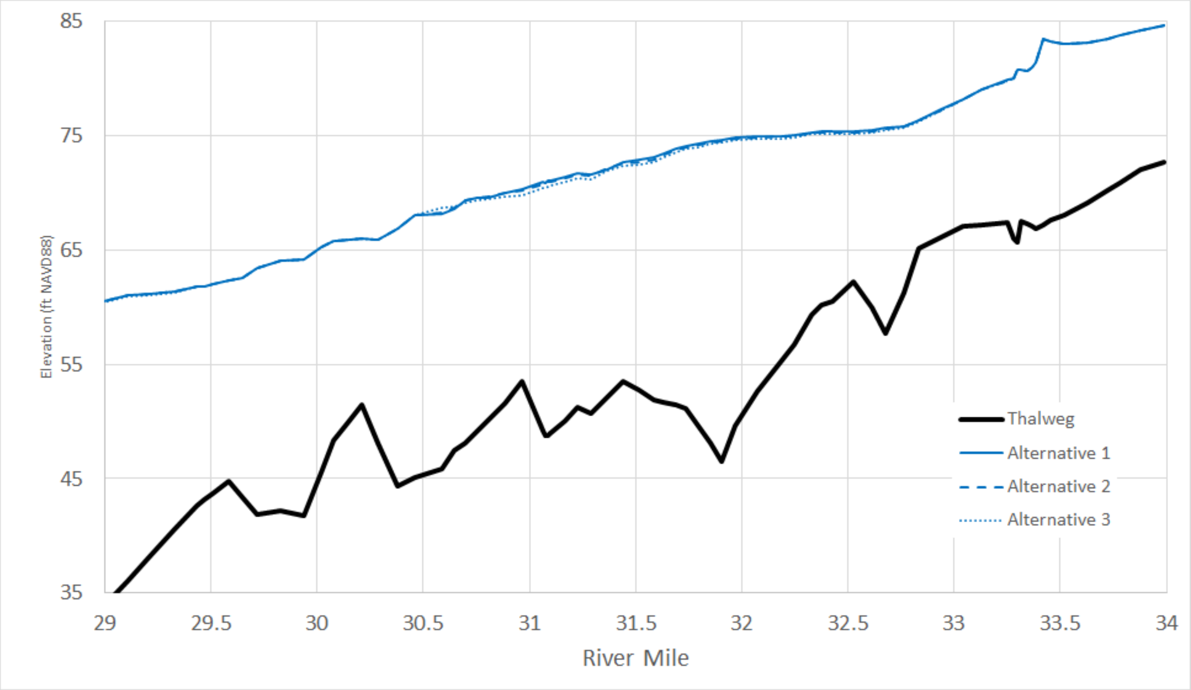


Figure 3-9. Details of Water Surface Elevations for RM 29 to RM 34

Figure 3-10 shows the differences in WSE among the alternatives, as well as the maximum difference from Alternative 1. The greatest difference in WSE, about 1 foot, would occur near RM 25. The figure shows three distinct regions:

- Downstream of RM 11, Alternatives 2 and 3 show small WSE increases (on the order of 0.1 foot) compared to Alternative 1. This is because Alternatives 2 and 3 include additional levees, which could increase downstream peak flows and, therefore, peak downstream WSEs. The WSEs for

Alternative 3 would be slightly lower than those for Alternative 2 because Alternative 3 would provide some additional overbank storage upstream.

- Between RM 11 and RM 24, Alternative 2 shows small decreases in WSEs (up to 0.2 foot), but Alternative 3 shows small increases (up to 0.1 foot) compared to Alternative 1.
- Upstream of RM 24, Alternatives 2 and 3 generally show lower WSEs compared to Alternative 1.

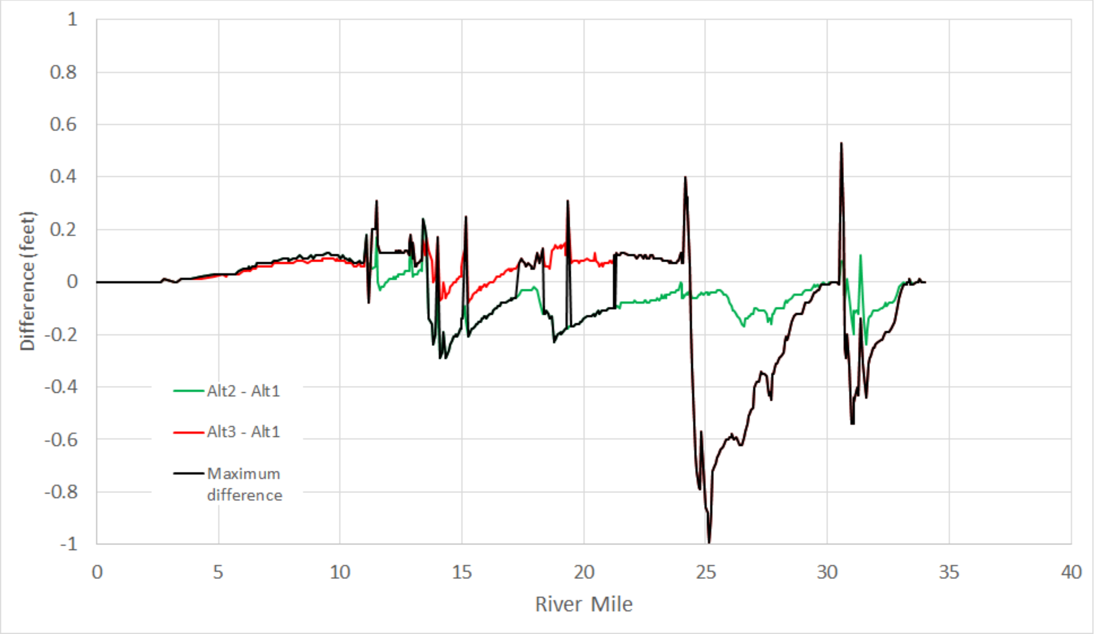


Figure 3-10. Differences in Water Surface Elevations Among Alternatives at 18,800 cfs

3.4.2 Inundation for Alternatives 1, 2, and 3 for the 100-Year Flow

The effective median 100-year flow in the Lower Green River is 12,000 cfs. Of the six flood flows modeled for the PEIS analysis (see Table 3-1), a flow of 11,900 cfs is the closest to this level. Although Alternatives 1, 2, and 3 were developed for a provisional design flow of 18,800 cfs, plus 3 feet of freeboard, it is useful to examine how the alternatives would perform under the effect of the 100-year flow (evaluated here at 11,900 cfs) because that is the flood event described in local, state, and federal regulations.

Figure 3-11, Figure 3-12, and Figure 3-13 show the maximum extents of flooding modeled for Alternatives 1, 2, and 3. At an overview level, all the alternatives, as well as the No Build Scenario (Figure 3-1), show similar flooding in the agricultural areas and toward the upstream extent of the corridor. This is expected, because the existing levee system was designed to contain the 100-year flood event as controlled by HHD. Levee breaching was not considered in this analysis.

The improvements in Alternative 3 would provide some protection in the Horseshoe Bend left bank area (RM 25.2-27.5, King County) compared to Alternatives 1 and 2. However, at a flow of 12,600 cfs, the differences would be smaller (NHC 2023). In all scenarios, the western portion of the agricultural area near the intersection of S 77th St and 83rd Ave S would be inundated under all alternatives.

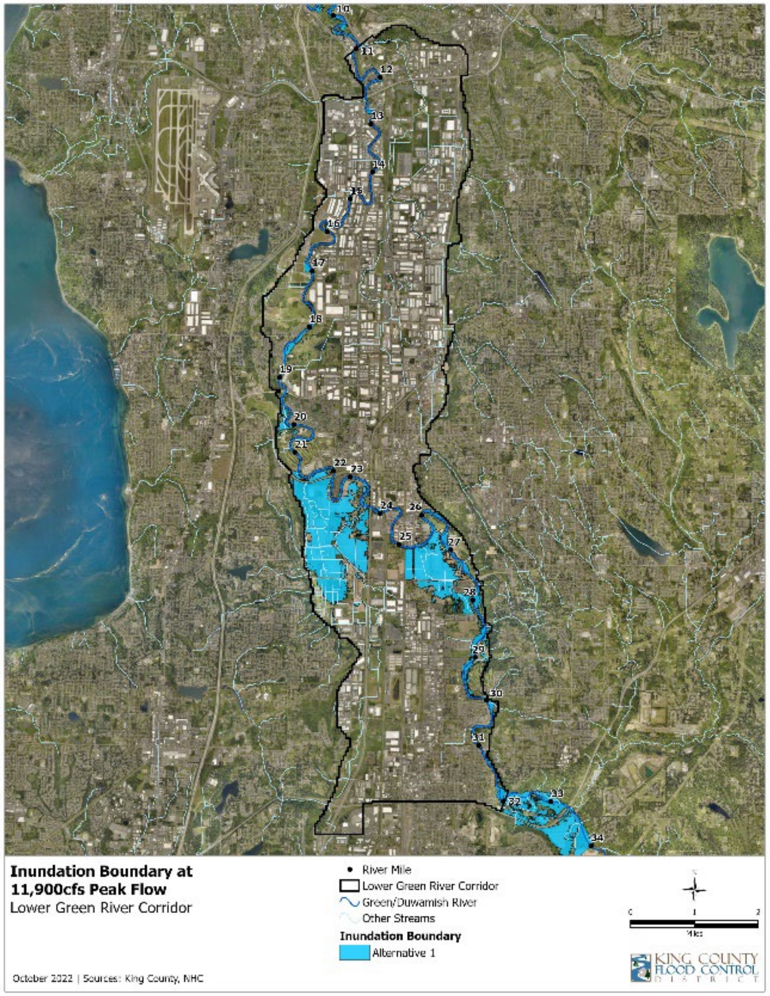


Figure 3-11. Maximum Inundation Extents for Alternative 1 at 11,900 cfs

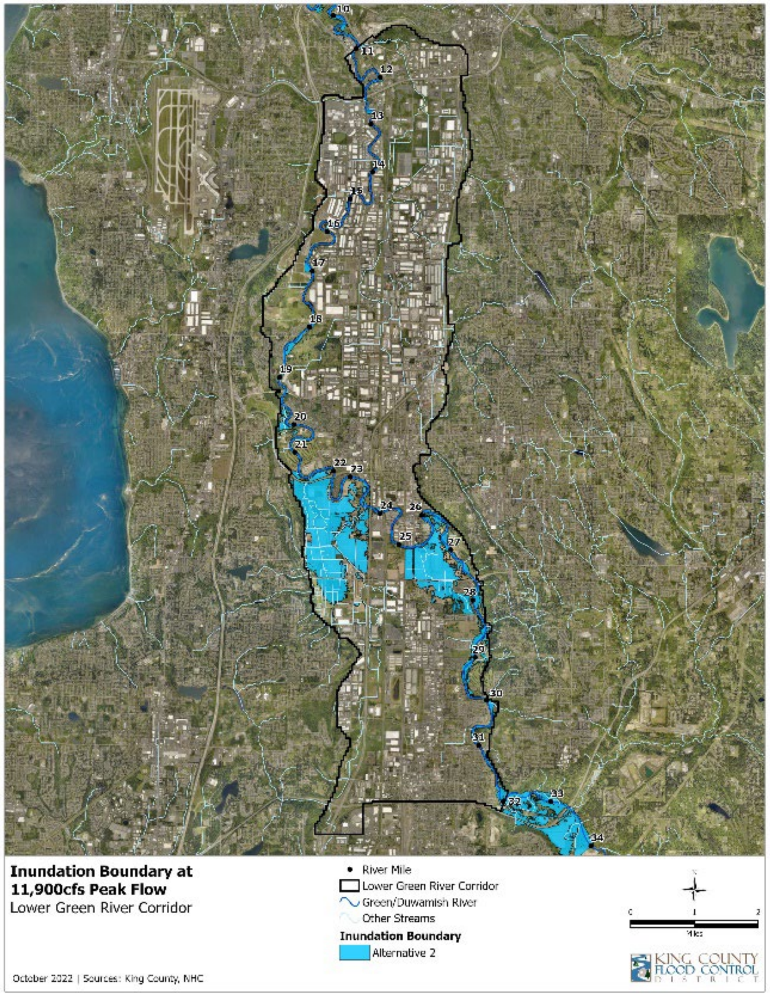
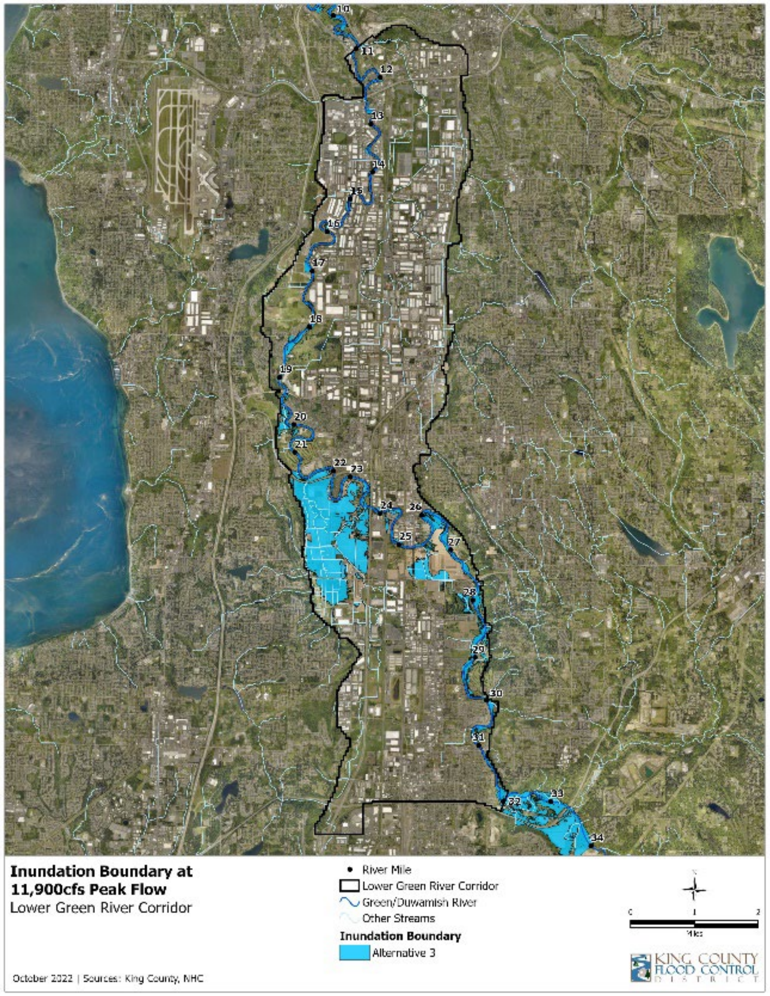


Figure 3-12. Maximum Inundation Extents for Alternative 2 at 11,900 cfs



October 2022 | Sources: King County, NHC

Figure 3-13. Maximum Inundation Extents for Alternative 3 at 11,900 cfs

3.4.3 Localized Changes in Flooding

3.4.3.1 Changes in Upstream Flooding South of S. 277th Street

Relatively well-developed portions of Auburn south of S. 277th Street could potentially be affected by flood waters from the north between RM 25 and RM 27, an area in which the left bank has no existing flood hazard management facilities. For all three alternatives, the approach the District would take to managing flood risk in this area would be focused on implications to the agricultural lands immediately adjacent to the river. Under Alternatives 1 and 2, no new flood hazard management facilities would be considered. Under Alternative 2, drainage improvements and non-structural measures would be considered. Under Alternative 3, an intermittent levee providing flood protection to 11,900 cfs would be provided.

Consideration of new and improved flood hazard management facilities upstream and downstream of this area could also potentially change the extents and WSEs of flood waters moving south. For example, under Alternative 1, a new levee would be considered, as shown by the yellow arrow in Figure 3-14. This levee could protect the overbank area to the east. This levee would not be included in Alternatives 2 and 3. Based on the comprehensive application of policy-level approaches in the alternatives, Alternative 2 could potentially reduce the WSEs in this area by 0.01 to -0.15 foot compared to Alternative 1 (Figure 3-7). However, Figure 3-14 and Figure 3-15 show there would be very little change in the extent of flooding to the south of S. 277th Street.

Alternative 3 would include more setback flood hazard management facilities, which would provide additional flood storage compared to Alternatives 1 and 2. As a result, Alternative 3 could potentially reduce WSEs in this area by up to 1 foot (Figure 3-10). Alternative 3 could also reduce the flood extents to the south of S. 277th Street as shown in Figure 3-16 (red arrows), and Figure 3-17.

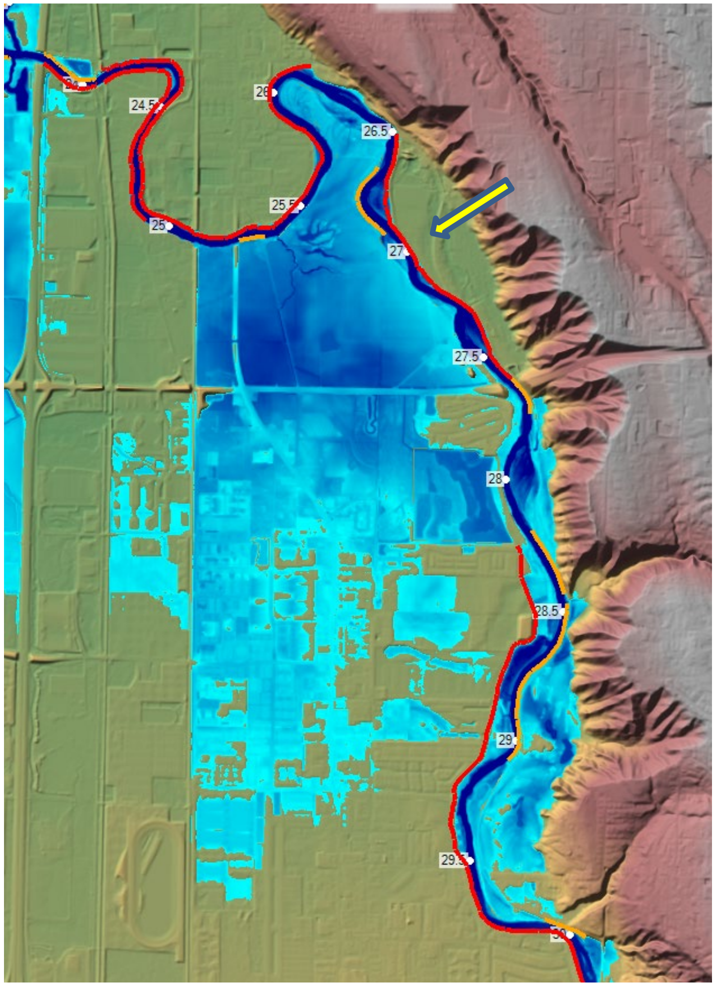


Figure 3-14. Alternative 1 Flooding Near S. 277th Street

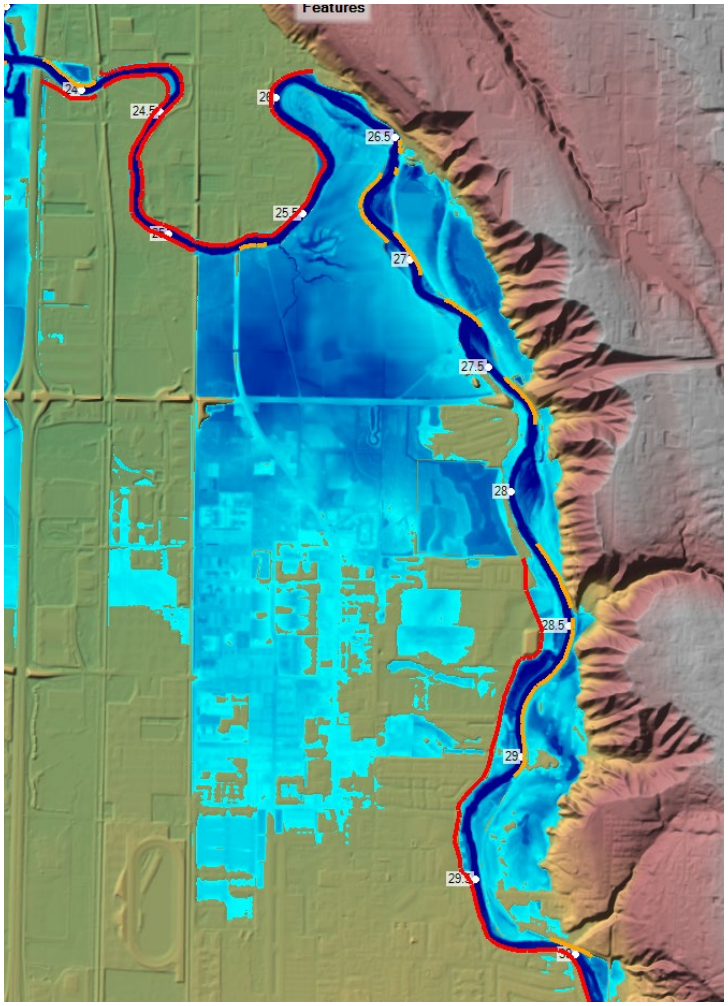


Figure 3-15. Alternative 2 Flooding Near S. 277th Street

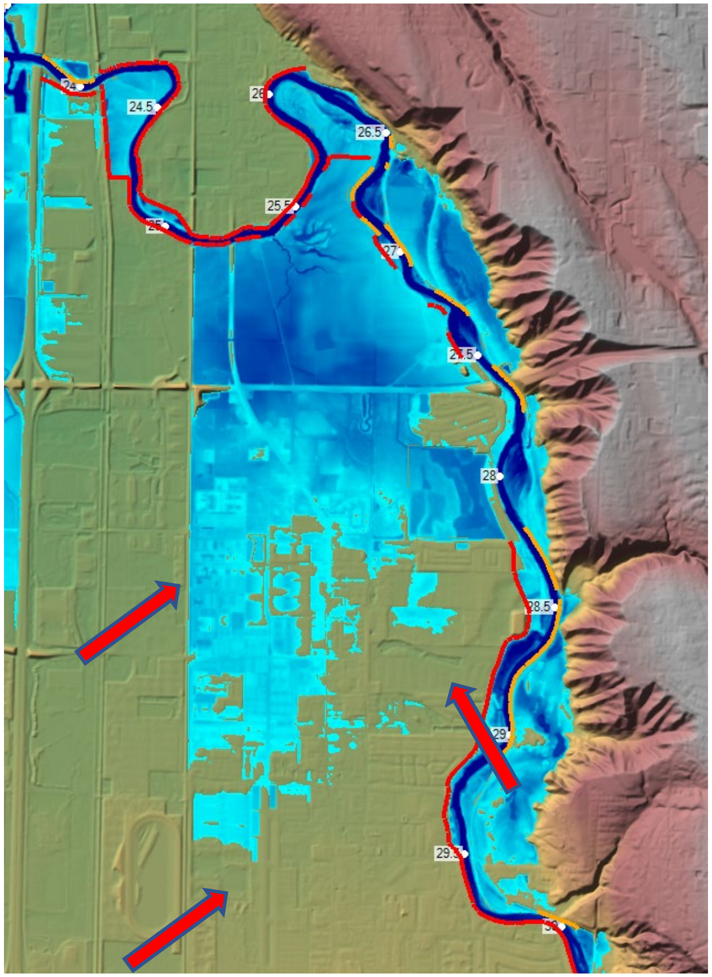


Figure 3-16. Alternative 3 Flooding Near S. 277th Street

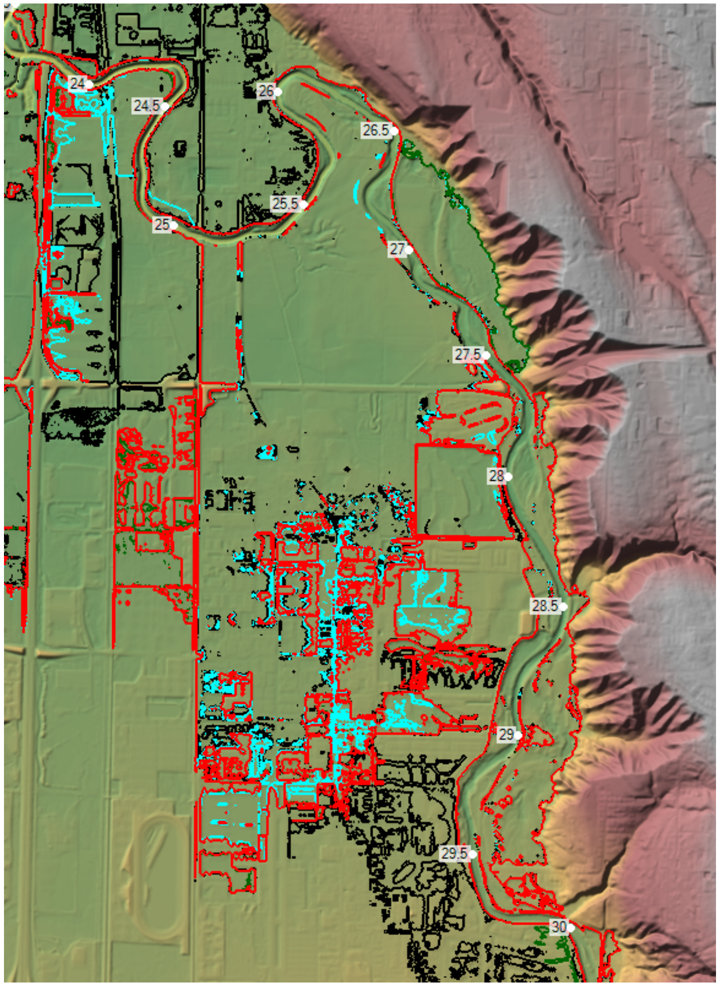


Figure 3-17. Maximum Flood Extents Near S 277th Street

3.4.3.2 Other Differences Between Alternative 1 and Alternative 2

There would be relatively few differences between the flooding extents in Alternative 1 and Alternative 2. The main differences are that Alternative 2 could result in a small increase in the right overbank areas near RM 13.6 (due to an overflow triggered near RM 12.5) and inundation of the right overbank near RM 26 (because the levee that protects this area in Alternative 1 would not be included in Alternative 2).

3.4.3.3 Other Differences Between Alternative 1 and Alternative 3

Figure 3-18 and Figure 3-19 compare the changes that would occur in flood extents from Alternative 1 to Alternative 3. In Figure 3-19, the areas in blue are increases in flood extent. The right overbank near RM 27 is designed to be flooded in Alternative 3, as there would be a revetment and not a levee (as in Alternative 1) in this reach. In Figure 3-18, the flood extent decreases are shown in red. Overall, the additional flood storage provided in Alternative 3 could offset some of the increased flooding south of S. 277th Street that could result from construction of Alternative 1 (compared to the No Build Scenario condition).

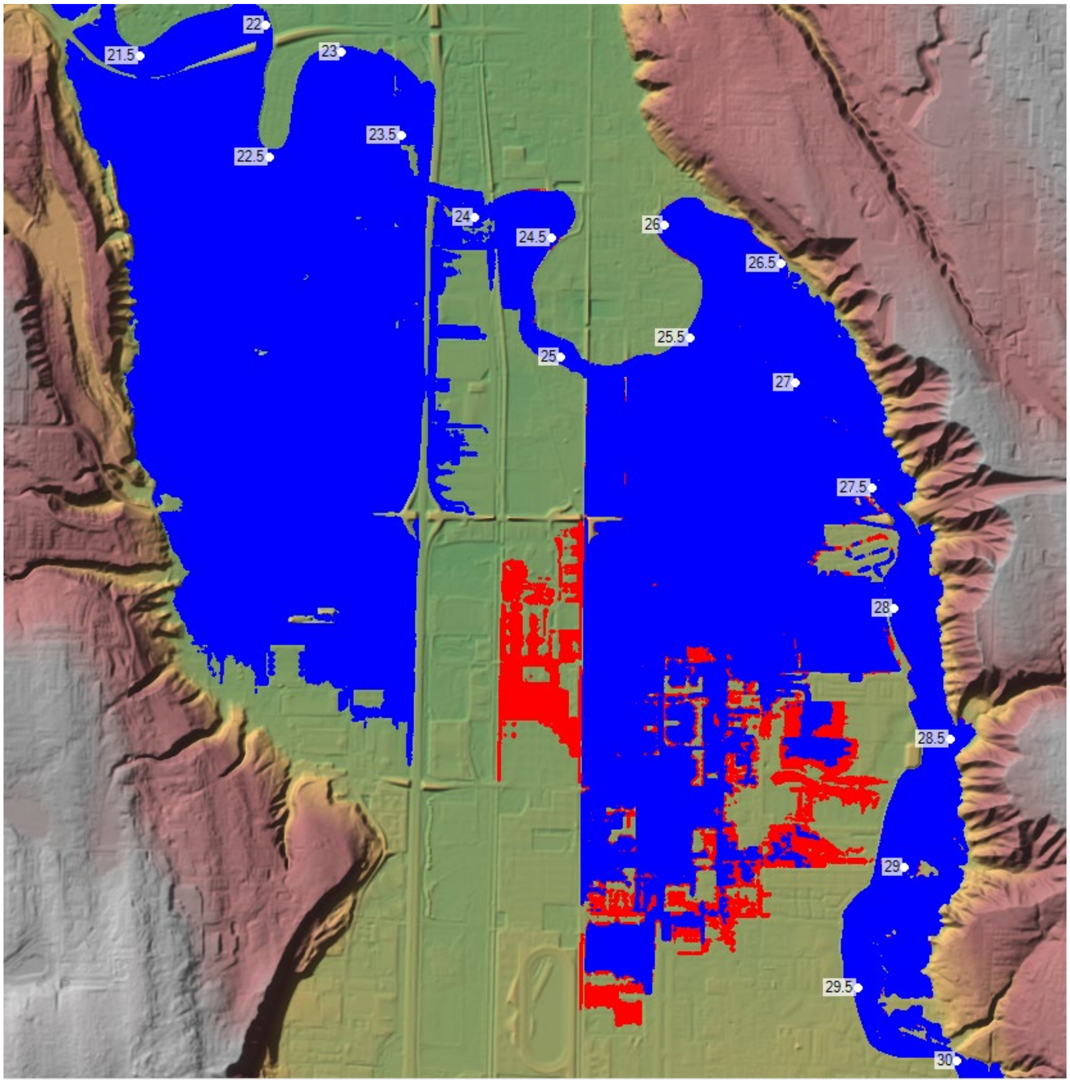


Figure 3-18. Decreases in Flood Extents (areas in red) from Alternative 1 to Alternative 3

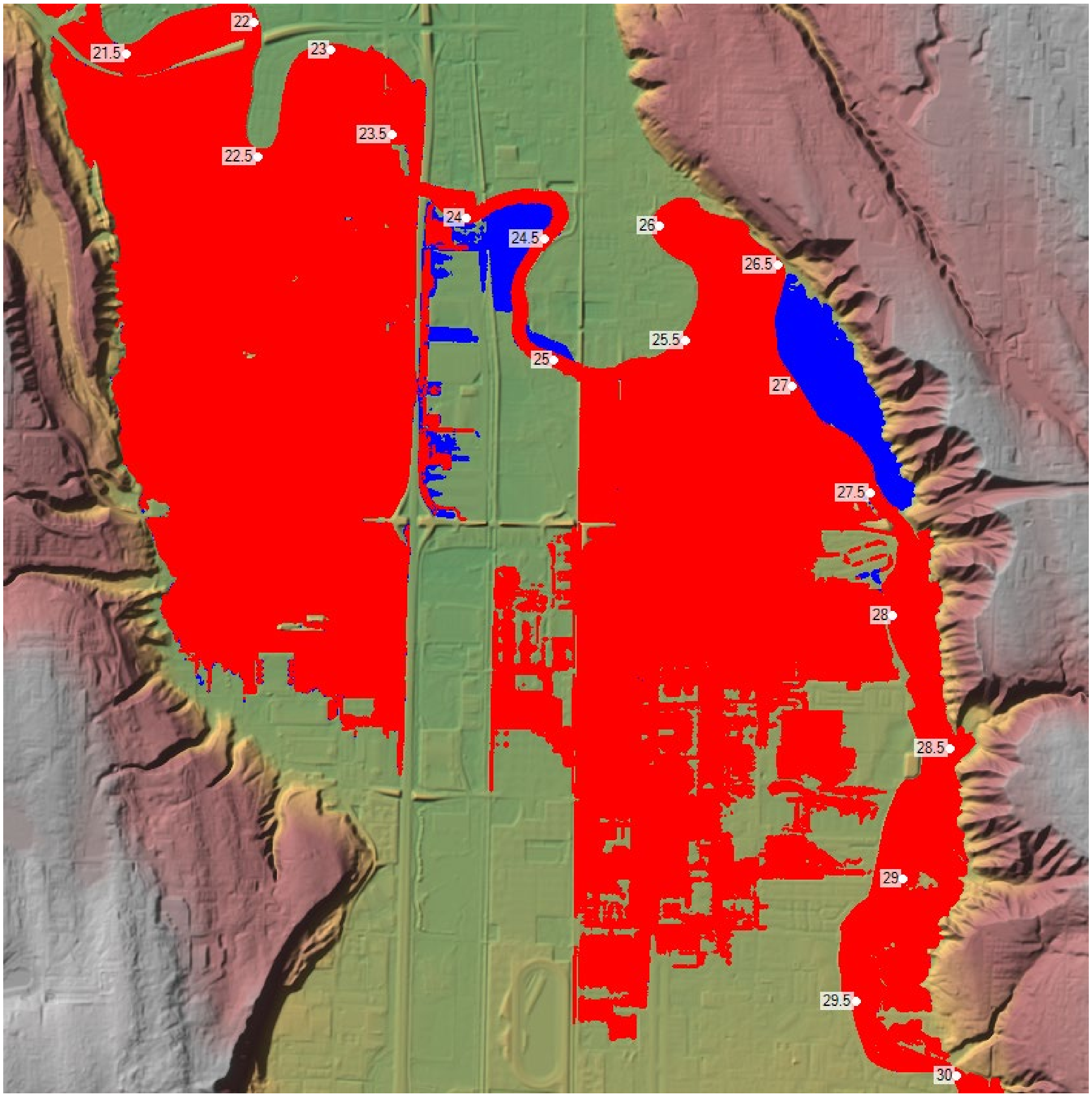


Figure 3-19. Increases in Flood Extents (areas in blue) from Alternative 1 to Alternative 3

3.4.4 Changes in Flooding Downstream of the Lower Green River Corridor

If levees were constructed or raised, then WSEs along the Lower Green River downstream of RM 11 could change due to overbank flows in some upstream reaches being constrained to remain within the main, leveed channel. Such constraints could increase the downstream peak flows and could increase downstream overbank flooding. Figure 3-10 shows a small (approximately 0.1 foot) increase in WSEs just downstream of the project reach compared to Alternative 1. However, as shown in Figure 3-20, Figure 3-21, and Figure 3-22, the maximum depths for the three alternatives show very little difference in the extents of overbank flooding. This is confirmed in Figure 3-23, which shows the modeled maximum flood extents. The small increase in downstream WSEs would not substantially affect flood extents.

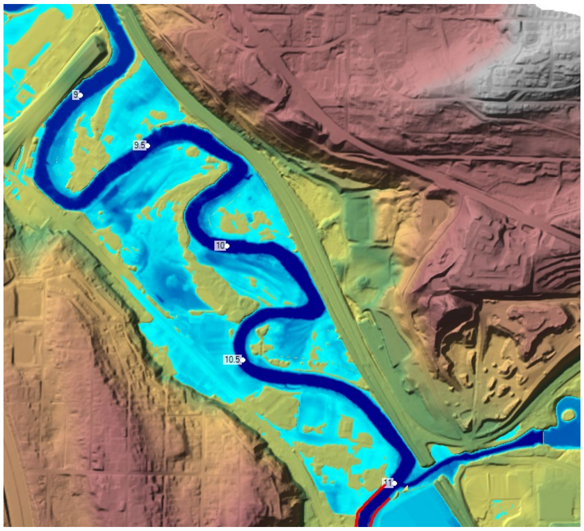


Figure 3-20. Downstream Flooding for Alternative 1 Between RM 9 and RM 11

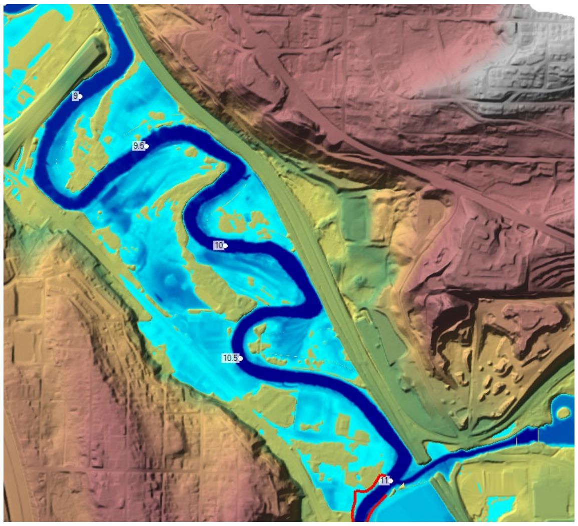


Figure 3-21. Downstream Flooding for Alternative 2 Between RM 9 and RM 11

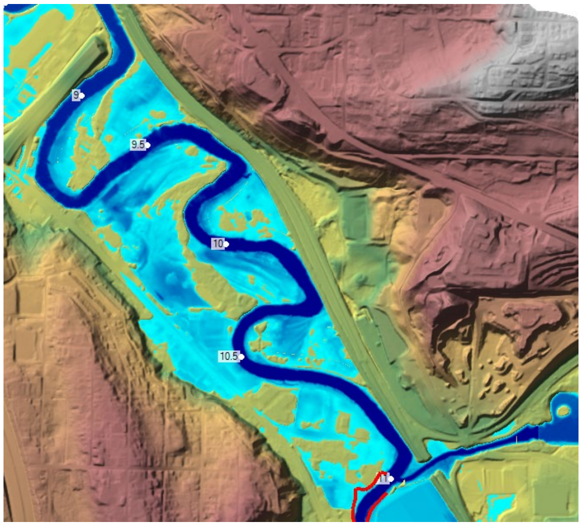


Figure 3-22. Downstream Flooding for Alternative 3 Between RM 9 and RM 11

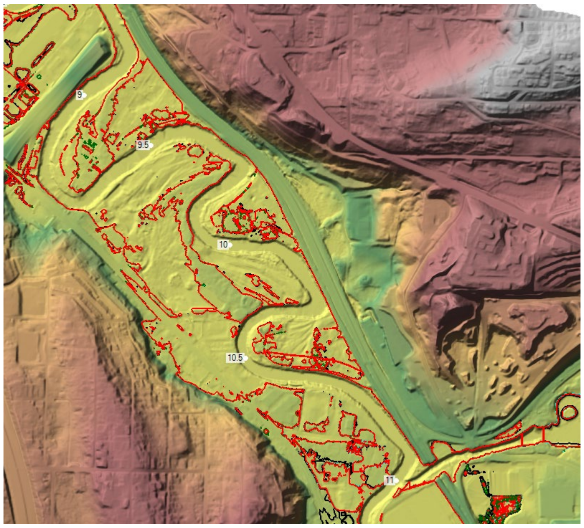


Figure 3-23. Maximum Flood Extents Between RM 9 and RM 11

3.5 Mitigation

As described in PEIS Appendix C: Built Environment, Section 3.1.2, a variety of federal, state, and local regulations apply to development within the floodplain of the Lower Green River Corridor. The definition of development includes new, improved, and relocated flood hazard management facilities. Although the details vary between agencies, these regulations generally prohibit or limit development that would result in changes to the base (i.e., 100-year) flood elevation or reduce available flood storage compared to existing conditions. Based on the modeling results, at 12,600 cfs, the WSEs of the three alternatives would generally be within 0.5 foot of one another, and within 0.5 foot of the No Build Scenario (NHC 2023). At the median 100-year flood event, differences in WSE should be similar. However, during project-specific implementation, potential increases in base WSE as a result of the District’s actions would require detailed hydraulic study, potential adjustments in project features, and mitigation.

4. WATER QUALITY

This section discusses the water quality analysis of the Plan alternatives, which consist of flood risk reduction measures located in the Lower Green River Subwatershed. Potential impacts and benefits to water quality are discussed in comparison to baseline conditions and each other. However, it is important to note that the overall effect on water quality that could be generated from flood risk reduction actions is limited in the larger context of any watershed. In other words, the magnitude of effects on water quality from the flood risk reduction measures outlined in each Plan alternative would be small in comparison to the effects from ongoing trends of population Increase, land development, and climate change in the Green River Watershed; as well as efforts within the watershed that are directly focused on water quality such as salmon protection campaigns, water quality improvement plans, and shade improvement plans. Therefore, the discussions of impacts and recommended mitigation in this section should be considered in the context of all factors that affect water quality within the Lower Green River Watershed.

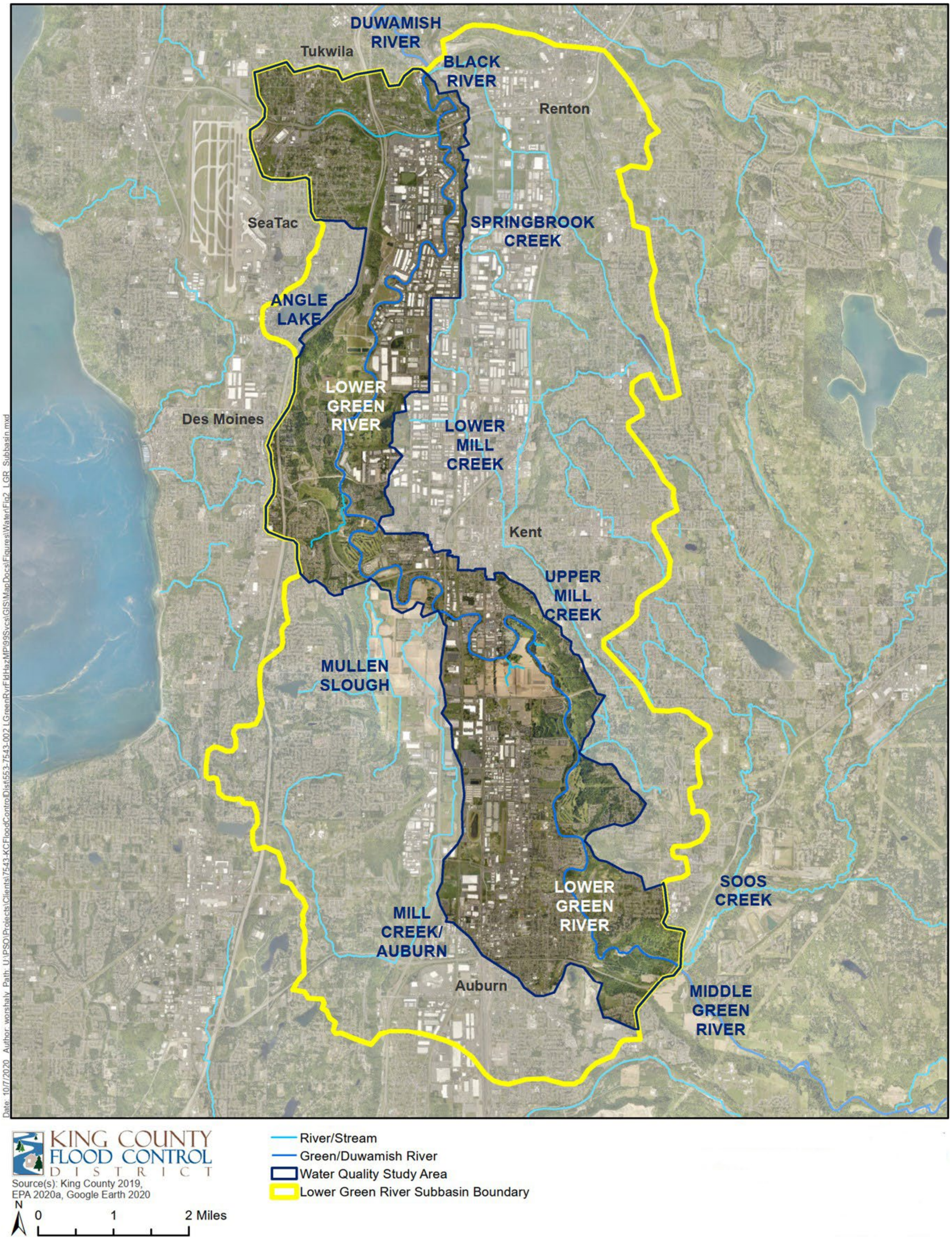
4.1 Methodology

The water quality analysis of the alternatives consisted of the following steps:

- Define the study area with respect to the relevant boundaries of potential impacts related to water quality resources.
- Characterize existing conditions within the study area.
- Identify potential water quality impacts and benefits associated with each of the Plan alternatives.
- Introduce applicable mitigation measures that could be implemented to avoid and minimize potential adverse impacts or to compensate for unavoidable impacts.
- Identify any potential opportunities to enhance water quality within the study area by incorporating the opportunities into the project flood risk reduction measures.

4.1.1 Study Area

The Lower Green River Corridor is generally described in Section 1. The water quality study area (Figure 4-1) is the river reach within the Lower Green River Subwatershed and catchments that drain directly to the Lower Green River channel. Potential water quality impacts from the Plan alternatives are evaluated based on project changes within this study area as they might impact water quality in the river channel and not in tributaries.



Source(s): King County 2019, EPA 2020a, Google Earth 2020

Date: 10/7/2020 Author: worshaly Path: U:\PSO\Projects\Clients\7543-KCFloodControlDist\553-7543-002 LGreenRvrFldHazMP\99Svcs\GIS\MapDocs\Figures\Water\Fig2_LGR_Subbasin.mxd

Figure 4-1. Lower Green River Subbasin and Water Quality Study Area

4.1.2 Affected Environment

The description of existing conditions of water resources in the study area is based on available water quality data, reviews of scholarly literature, and reviews of aerial imagery such as geographic information systems (GIS). Water quality data include stream gauge readings for temperature, flows, and sediment, as well as the Environmental Protection Agency (EPA) 303(d) list of impaired and threatened waters for temperature, instream flows, or the presence of regulated contaminants. No site visits, field surveys, water quality sampling, or modeling efforts were used in evaluating the alternatives. Topics such as water quality, potential scour changes, and potential changes (if any) to riverbed substrate characteristics are described both quantitatively and qualitatively and used in a comparative analysis.

The water quality data attributes analyzed as indicators for the impact analysis include the following:

- Temperature
- Turbidity
- Nutrient load, dissolved oxygen (DO), and biological oxygen demand (BOD)
- Depth or velocity of flows
- EPA 303(d) list of impaired waters
- Riverbed substrate characteristics

4.1.3 Data Collection

The water quality impact analysis included review of relevant studies and other information pertaining to the study area. For context and background purposes, those data sources are listed below. Where information was taken from any of the data sources, direct citations are included later in the water quality impact analysis discussion.

- EPA’s Water Quality Data Portal (https://www.epa.gov/waterdata/water-quality-data)
- EPA’s Watershed Report website (https://watersgeo.epa.gov/watershedreport/)
- USGS National Water Information System (https://www.usgs.gov/tools/national-water-information-system-nwis-mapper-0)
- Federal Emergency Management Act (FEMA) Flood Maps and Flood Insurance Studies (https://msc.fema.gov/portal/home)
- Ecology water quality assessment 303(d) and 305(b) lists (https://ecology.wa.gov/Water-Shorelines/Water-quality/Water-improvement/Assessment-of-state-waters-303d)
- Ecology WRIA data for WRIA 9 – Duwamish-Green (https://ecology.wa.gov/Water-Shorelines/Water-supply/Water-availability/Watershed-look-up)
- King County Hydrologic Information Center website (https://green2.kingcounty.gov/hydrology/GaugeMap.aspx)
- King County iMap (https://kingcounty.gov/services/gis/Maps/imap.aspx)

- King County B-IBI stream database (https://benthos.kingcounty.gov/Biotic-Integrity-Map.aspx)
- King County Green-Duwamish River Watershed Quality Assessment (https://kingcounty.gov/services/environment/watersheds/green-river/watershed-quality-assessment.aspx)
- King County *Assessment of Current Water Quantity Conditions in the Green River Basin* (King County 2005)
- King County tax assessor GIS water resources data
- Stream inventories and water quality reports from local jurisdictions
- Publicly available GIS aerial mapping
- Critical areas GIS data available from local jurisdictions
- Flood mapping from local jurisdictions that supplement effective FEMA maps
- Flood district conceptual design information

4.1.4 Policies, Regulations, and Standards

Federal, state, and local laws, regulations, and permits related to water quality have been summarized below. Relevant design guidance documents are also listed. The area-specific Plan for the Lower Green River Corridor would not be subject to all the listed regulations, but the regulations provide the framework for development and implementation of water-quality-related project aspects, and they influence required mitigation.

4.1.4.1 Federal Policies, Regulations, and Standards

- Clean Water Act, 33 United States Code (USC) 1251 et seq., including the following sections:
    - 401 – Water Quality Certification
    - 402 – National Pollutant Discharge Elimination System
    - 404 – Permits for Dredge or Fill (also Section 10 of the Rivers and Harbors Act)
    - 408 – Alteration of an existing Civil Works project (from Section 14 of the Rivers and Harbors Act)
- Coastal Zone Management Act, 16 USC 1451 et seq.
- National Flood Insurance Act of 1968 and Flood Disaster Protection Act of 1973, 42 USC 4001 et seq.
- Floodplain Management Presidential Executive Order 11988
- Safe Drinking Water Act, 42 USC 300 et seq., Chapter 6A

4.1.4.2 State Policies, Regulations, and Standards

- Aquatic Use Authorization: Aquatic Lease – Washington State Department of Natural Resources
- Hydraulic Project Approval (HPA) – Washington Department of Fish and Wildlife (WDFW) (Revised Code of Washington [RCW] 77.55)
- Flood Control Management Act, 86 RCW
- Growth Management Act, 36.70a RCW
- Shoreline Management Act, 90.57 RCW, WAC 173-26
- SEPA, 43.21C RCW, WAC 197-11, and WAC 468-12
- Stormwater Management Manual for Western Washington (Ecology Manual) (Ecology 2019)
- Washington State Department of Transportation (WSDOT) Highway Runoff Manual (WSDOT 2019a)
- WSDOT Hydraulics Manual (WSDOT 2019b)
- Washington State Hydraulic Code Rules, WAC 220-660
- Water Quality Standards for Surface Waters, WAC 173-201A
- Water Quality Standards for Groundwater, WAC 173-200
- Water Pollution Control Act, 90.48 RCW

4.1.4.3 Local Policies, Regulations, and Standards

- Applicable titles of King County Code, Auburn Municipal Code, Kent Municipal Code, Renton Municipal Code, and Tukwila Municipal Code:
  - Critical Areas – Regulations regarding activities within and adjacent to critical areas, including fish and wildlife habitat conservation areas
  - Shoreline Management Program – Regulations regarding development in the shoreline environments, including the Lower Green River and associated shorelands
  - SEPA—Applies as implemented by local jurisdictions
  - Water Quality—Regulations regarding water quality standards for surface and groundwaters to protect existing and future beneficial uses
  - Flood Hazard Areas —Regulations requiring maintaining flood storage and conveyance capacity in flood zones, restriction of certain types of construction and activities in flood zones, preservation of wetlands or other natural flood storage features, and requirements for construction flood proofing
- Construction/Development Permits—King County; cities of Auburn, Kent, Renton, SeaTac, and Tukwila

4.1.4.4 Tribal Treaty Rights

The corridor lies within lands and waters once occupied by Lakes Duwamish Indians, whose descendants are enrolled into several federally recognized Indian Tribes. These include the Muckleshoot Indian Tribe, the Suquamish Tribe, the Snoqualmie Tribe, the Tulalip Tribes, and the Yakama Nation, as well as the non-federally recognized Duwamish Tribe.

Federal agencies are bound by their trust responsibilities, and they require that projects address impacts on Tribal treaty rights before issuing permits. Federal regulations with a nexus to treaty rights include, among others, the Endangered Species Act (ESA) and the Clean Water Act. ESA requires evaluation of the potential impacts of federal actions (including permit issuance) on threatened and endangered species and their habitats. For aquatic species such as salmon, which Tribes are guaranteed by treaty the right to harvest, water quality is a critical component of habitat. Several sections of the Clean Water Act also protect various aspects of water quality.

4.1.5 Impact Analysis

Direct impacts to water quality from the Plan alternatives are assessed in terms of operational (long-term) and construction-related (short-term) impacts. Indirect impacts are also evaluated. Direct impacts occur at the same time and location as the proposed action. Indirect impacts are caused by the proposed action, but they are separated from direct impacts by time or distance.

4.1.5.1 Operational Impacts

Potential impacts on and enhancements to water quality are evaluated within the Lower Green River Corridor. Elements associated with the proposed alternatives, including long-term maintenance, are compared qualitatively to Alternative 1, and they are ranked in terms of highest to lowest expected impact on water quality. The alternatives are evaluated in consideration of the following components, which are the direct features of potential Lower Green River flood hazard management facilities that could have the most impact on water quality in the channel. The components are presented below:

- Vegetation that may contribute to pollutant filtering or uptake
- Vegetation that may contribute to shading
- Overall biologic input, notably addition of organic materials that add organic carbon, which reduces bioavailability of metals
- Bank and bed material that may contribute to pollutant filtering or uptake (e.g., native or natural soils compared to riprap)
- Bank and bed material that may contribute to cooling through groundwater recharge or expression (e.g., subsurface materials designed to support hyporheic zone exchange)
- Potential changes in duration or extent of inundation of low flows such as the summer mean low flow or other representation of commonly expected dry season flows, which represent periods when water temperatures in the Lower Green River main channel are typically the highest and pollutant mixing can have the greatest impacts on water quality

The water quality analysis was coordinated with other disciplines (land use, aquatic resources, and stormwater utilities) to evaluate components of those disciplines that impact water quality, such as the following:

- Channel habitat diversity within the project area as it affects temperature and turbidity
- Stormwater infrastructure, notably stormwater systems that go through levees and roads, as well as maintenance related to levees

- Land-use changes resulting from the Plan that could impact runoff from pollution-generating surfaces in the study area
- Land-use changes resulting from the proposed action that could impact groundwater recharge or flow patterns in the study area

4.1.5.2 Construction Impacts

As individual projects under the Plan are developed, BMPs likely will be required by federal, state, and local regulations to ensure that construction activities occur at times or in a manner that will reduce and/or avoid substantial impacts on water quality. The qualitative assessment of temporary construction impacts relative to each facility type incorporates the extent of in-water work, the severity of disturbance to riverbed or riverbank substrate, and the likelihood of dewatering or flow diversion activities. Assessment of temporary construction impacts also incorporates impacts related to erosion and sediment control during construction and transport of materials, concrete work and paving, storm drainage utility work, and potential equipment leaks or spills. The assessment outlines the appropriate permitting and approval processes to avoid and minimize these impacts by using BMPs. All BMPs would be based on the design of specific projects, and those BMPs identified in this PEIS may change.

4.1.6 Indirect Impacts

Indirect impacts are reasonably foreseeable impacts that could result from the District's flood hazard management actions, but that would be removed from the action in space and/or time, In the case of water quality, indirect impacts may occur as the result of interactive effects of the Plan alternatives with other non-Plan events or conditions in the area, especially those that might change pollutant sources. For example, if a Plan alternative is expected to protect lands from flooding that might otherwise be unattractive for development or redevelopment, then a resulting indirect water quality effect could include impacts on water temperature through removal of vegetative cover, creation of new pollution-generating surfaces, or retrofits of old impervious surfaces with improved water quality management facilities.

4.1.7 Mitigation Measures

As previously discussed, the magnitude of effects on water quality from the flood risk reduction measures outlined in each Plan alternative would be small in comparison to the effects from ongoing trends of population increase, land development, and climate change in the Green River Watershed; as well as efforts within the watershed that are directly focused on water quality such as salmon protection campaigns, water quality improvement plans, and shade improvement plans. Therefore, potential mitigation measures are identified based on the potential water quality impacts from the Plan alternatives; but these measures cannot and should not be intended to address greater, non-Plan factors that impact water quality within the Lower Green River Watershed.

4.2 Affected Environment

This section discusses existing water quality within the study area that could be affected by the potential improvements identified in the Plan alternatives. The identification of the affected environment for water quality is focused on conditions relevant to the Plan, while still being broad enough to include the range of water quality characteristics that could be impacted. The existing condition provides a baseline for comparison of the potential water quality impacts and benefits associated with each of the alternatives.

4.2.1 Current Water Quality Conditions

4.2.1.1 Known Water Quality Impairments

Known impairments to water quality are catalogued in Washington State's Water Quality Assessment, which is required under the Clean Water Act and is managed by Ecology. The assessment contains what is known as the Section 303(d) list (Ecology 2016), which designates waters that have beneficial uses—such as drinking water, recreation, aquatic habitat, and industrial uses—but that are impaired by pollution. Pollutant limits called total maximum daily loads (TMDLs) are established for impaired waters. A TMDL study identifies impairments in a watershed, then develops a plan that details actions to control the impairments and to monitor the effectiveness of the actions designed to achieve clean water and meet water quality standards. Impaired waters are those designated as Category 5 (TMDL needed), Category 4A (TMDL approved), Category 4B (TMDL-equivalent plan in place) and Category 4C (cannot be addressed through a TMDL). Within the study area, portions of the Lower Green River are listed for a Category 5 impairment of DO, a Category 4A impairment for temperature, or both (Figure 4-2).

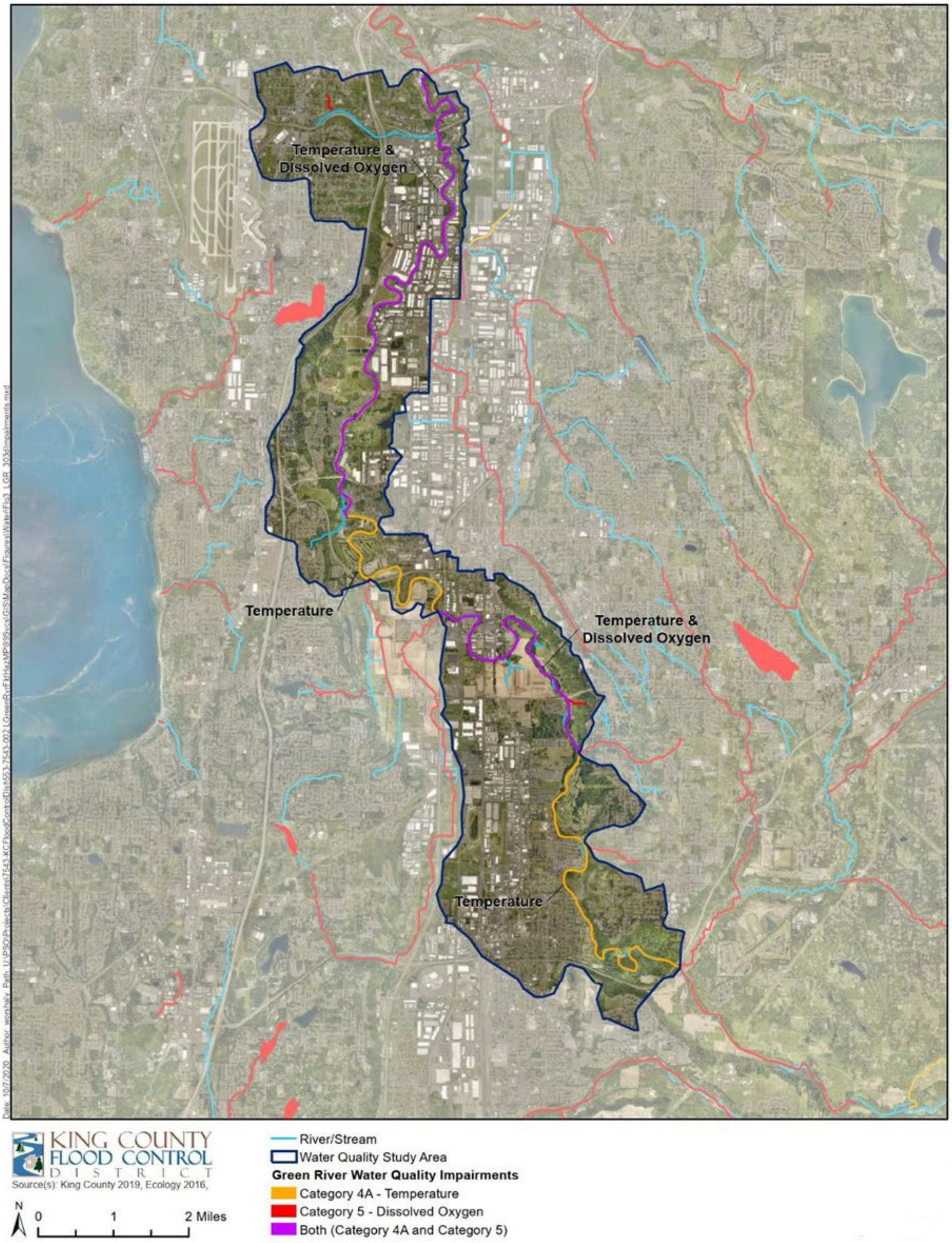
4.2.1.2 Relevant Water Quality Standards

While the study area for water quality impacts is located within the Lower Green River Subwatershed, the regulatory protections and the baseline quality of the water coming into the study area from upstream reaches of the river is important for the context of the impacts analysis. Beginning at the study area and moving upstream, Table 4-1 identifies aquatic life uses designated in the state Surface Water Quality Standards, WAC 173-201A-080, for various reaches of the Lower Green River and the associated criteria for DO and maximum allowable temperature (as a 7-day average of daily maximum temperatures).

Table 4-1. State Water Quality Standards for Temperature and DO

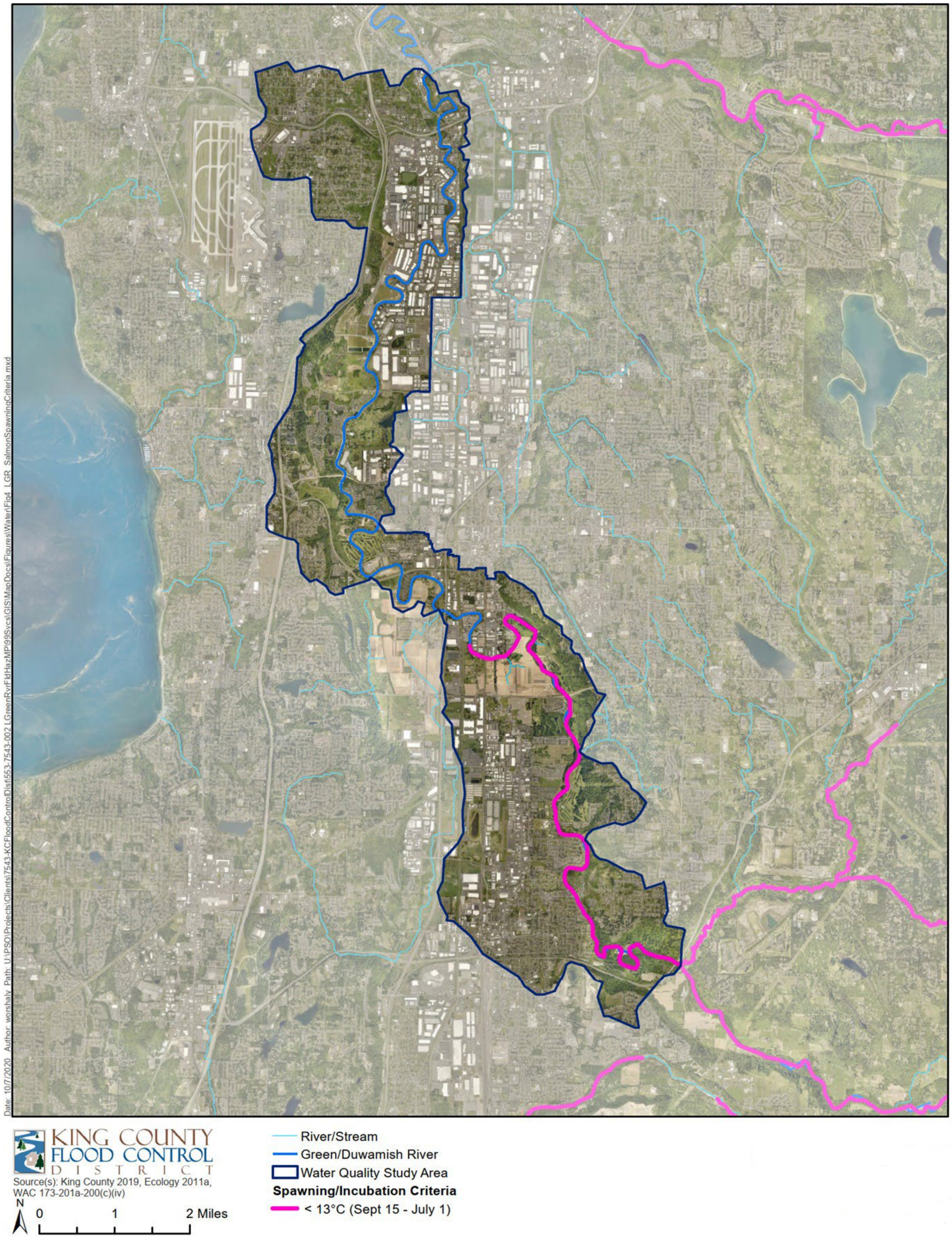
River Reach	Aquatic Life Use	Maximum Temperature	Minimum DO
Upstream from the Black River to just above the confluence with Mill Creek	Spawning/rearing	17.5°C (63.5°F)	8.0 mg/L
Upstream from above the confluence with Mill Creek to the west boundary of Flaming Geyser State Park	Core summer habitat	16°C (60.8°F)	9.5 mg/L
Special temperature protection area designated by Ecology (Figure 4-3).	Salmon and trout spawning and incubation	13°C (55.4°F)	As designated in rows above

Surface water quality standards for the protection of different aquatic uses include a broad range of parameters, such as temperature and DO, that are intended to protect fish populations during various aquatic life cycles throughout the year. As shown in Figure 4-3, a portion of the Lower Green River has been designated as a special temperature protection area to help support spawning and incubation for salmon and trout.



Source(s): King County 2019, Ecology 2016,

Figure 4-2. 303(d) Listed Water Quality Impairments in the Study Area



Source(s): King County 2019, Ecology 2011a, WAC 173-201a-200(c)(iv)

Figure 4-3. Green River Spawning and Incubation Protection Area

The Water Quality Standards assume that the criteria are protective, as long as human actions do not significantly disrupt the normal patterns of fall cooling and spring warming that provide significantly colder temperatures over most of the protected salmonid incubation period (WAC 173-201A-200; WAC 173-201A-602).

4.2.1.3 Temperature

Historical Background

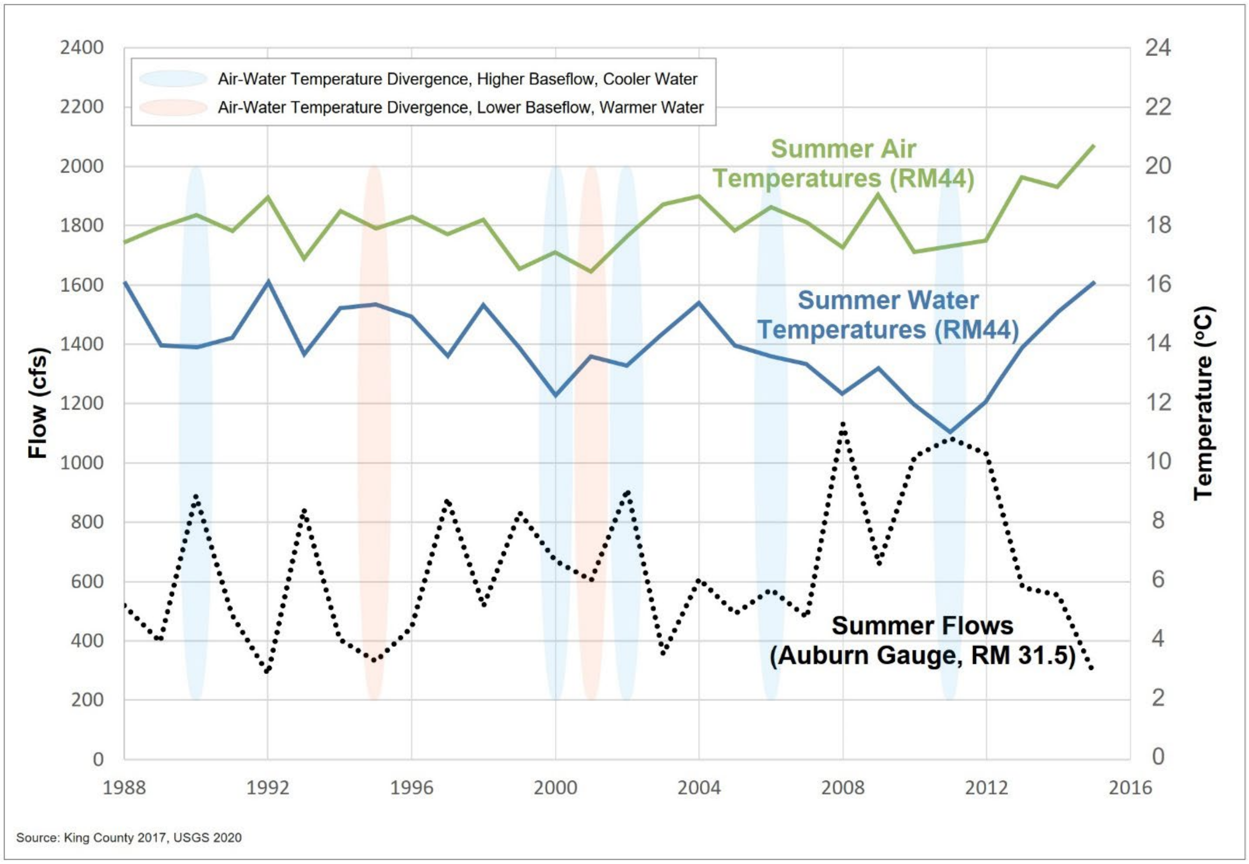
The Green River watershed and its riparian vegetation have undergone extensive alterations over the past 150 years, and cool water inputs from groundwater and small tributary streams have been altered and disrupted. Studies have shown that cool water temperatures that meet regulatory standards are key elements for the health and survival of native fish and aquatic communities. Water temperatures affect embryonic development, juvenile growth, adult migration, competition with non-native species, and risk and severity factors related to disease. As early as 1978, water temperature has presented a concern for cold-water fish in the Green River (Ecology 1980).

In 2005, the WRIA 9 Salmon Habitat Plan was developed to guide the protection and restoration of the Green-Duwamish and Central Puget Sound watershed ecosystem for both people and fish. The Salmon Habitat Plan identified elevated summer river and stream temperatures due to the loss of groundwater baseflow and riparian vegetation (as well as other issues) as limiting factors for salmon recovery in the Green-Duwamish River (King County 2017a).

Watershed Baseflow and Shade

The supply of baseflows (which are typically the coolest flows) is a key element that directly affects channel temperatures in the Lower Green River and indirectly affects how much influence the surrounding air temperature has on channel temperatures. In the summer, baseflows come from rain stored in the watershed’s soil (e.g., rain stored in aquifers, shallow soil, and hyporheic zones) that is kept cool in the ground. A stronger antecedent rain season can result in a larger supply of cool baseflow throughout the summer, either through higher flow rates or through longer baseflow duration compared to the annual summer low flow. Also, additional precipitation during the spring or summer can increase or extend baseflow amounts. Riparian vegetation plays a valuable role in buffering the heating effects of the sun and ambient air temperatures in small streams. In turn, inputs to the Green River from well-shaded tributary streams are part of the river’s cool baseflow supply.

At the same time that cool water is delivered to the Lower Green River from tributary streams, groundwater, and other baseflows, the surrounding air temperature raises or lowers water temperature. However, the magnitude of water temperature change from air temperature is generally the same, regardless of the amount of water in the channel. In part, this is based on the way air-to-water contact surface areas change with the amount of water. However, if the river water starts at a lower temperature due to a larger and continuing baseflow supply, then the air temperature heating effect is lessened, compared to a channel that lacks cool baseflow input. This relationship is illustrated for the Green River in Figure 4-4, which shows historical summer channel temperatures and ambient air temperatures compared to summer stream flow data. While the data was collected from different locations on the river (temperatures are from a gauge just upstream of the confluence with Newaukum Creek near RM 44 in the Middle Green River Subwatershed and flow data comes from the USGS stream gauge in Auburn near RM 31.5), the overall relationship trend shows that when there is a difference between the ambient air temperature and river water temperature, it can be attributed to whether there are higher base flows (cooler water) or lower base flows (warmer water) in the channel.



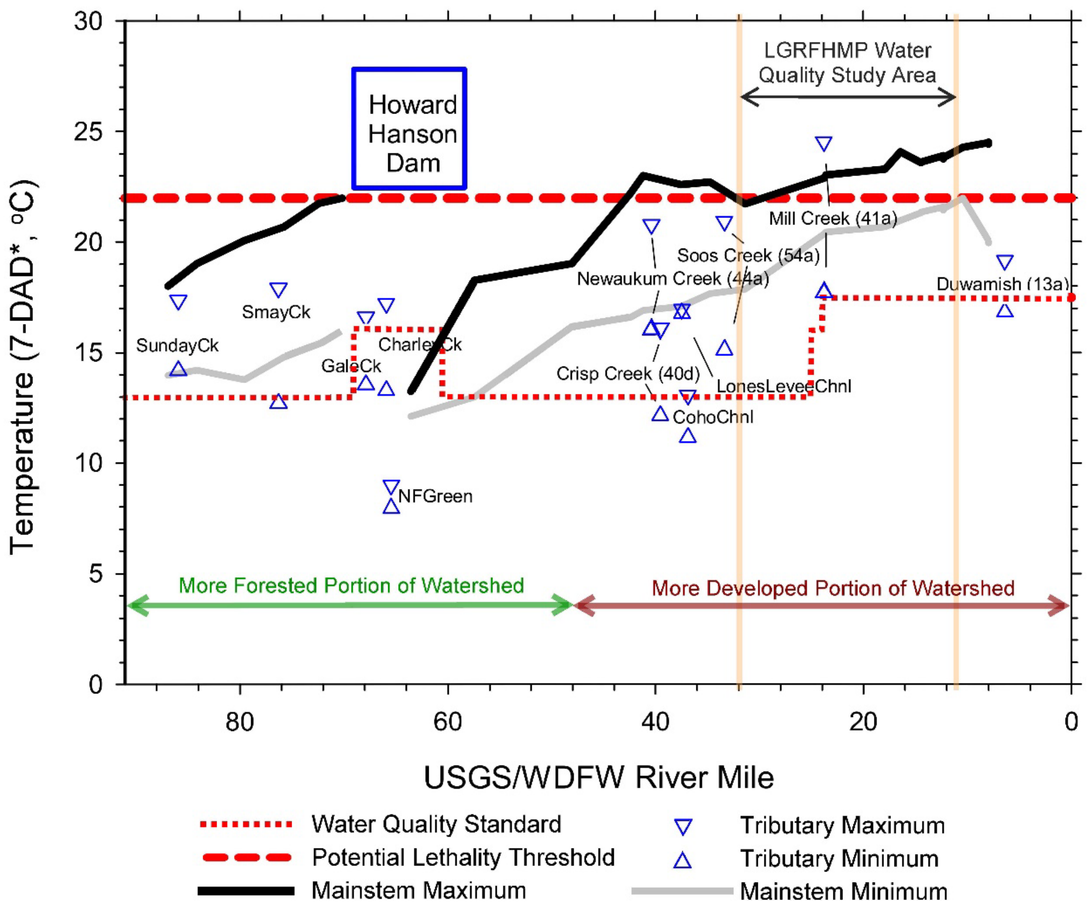
Source: King County 2017, USGS 2020

Figure 4-4. Water Temperature Influences from Air Temperature and Baseflow (Summer Averages)

Key Factors Along the River Profile

In addition to the role of riparian vegetation and shade throughout the watershed, several factors along the river profile have major influences on Lower Green River temperatures. Some of these factors raise temperatures, while others lower it. The factors include the HHD water storage and outlet temperature, relatively large inputs from cold springs and groundwater around the Green River Gorge State Park, hyporheic exchanges between the Lower Green River and Soos Creek and Mill Creek, and the tidal backwater effects in the river below Mill Creek to Tukwila. Figure 4-5 illustrates the temperature differences at several landmarks in the Green River channel in 2015.

Of the factors discussed above, one that may appear counter-intuitive is the temperature effects from the reservoir behind the HHD. Typically, large, ponded reservoirs allow water to be heated and contribute to higher temperatures at their discharge. The HHD reservoir does become thermally stratified during the summer, with warm water on the surface; however, it has much colder water at its depth. Because the main outlet used during summer months for the release of water downstream is near the bottom of the reservoir, relatively cold water with substantially less diurnal variability is released downstream during the summer. Nevertheless, despite this introduction of colder water from the HHD reservoir, high temperatures have been historically observed through Auburn and Tukwila during the summer months, which is suspected to be the result of low streamflows combined with lack of shade (Ecology 1980).



** The arithmetic average of seven consecutive measures of daily maximum (or minimum) temperatures. The 7-DADMax (or 7-DADmin) for any individual day is calculated by averaging that day's daily maximum (or minimum) temperature with the daily maximum (or minimum) temperatures of the three days prior and the three days after that date.*

Source: King County 2017

Figure 4-5. July 4, 2015, Temperatures in the Green River

Temperatures TMDL Water Quality Improvement Plan

In 2011, Ecology conducted a TMDL study and proposed an implementation strategy for improving temperature in the Middle and Lower Green River Subwatersheds (Ecology 2011). Monitoring and modeling conducted for the study showed that a shade deficit exists throughout the Middle and Lower Green River riparian corridors (except for the reach through the Green River Gorge State Park). The most prevalent area of effective shade deficit was documented within the study area, just downstream of the city of Auburn. In the study area, the Lower Green River was documented as being channelized by a series of revetments, levees, and steep banks, and it was generally found to be devoid of trees and any significant riparian cover.

Ecology modeled existing and forecasted temperatures for the Lower Green River by comparing a temperature scenario with existing tree cover in the riparian corridor against a future scenario (the future scenario projected changes in shade, but did not include climate change forecasts). In the future scenario, the riparian corridor would be replanted so that every location either had a minimum tree height of 104 feet or the height of the existing trees in the corridor, whichever was taller. A sensitivity analysis showed that when an additional 33 feet of tree height were added to model a minimum 138 feet of tree height, an additional 7 percent of effective shade could be achieved on average with the taller trees. A shade sensitivity analysis was also conducted for narrowing the riparian buffer width once a large buffer (48 feet) was established. The analysis examined the difference between a 148-foot and 82-foot riparian buffer width, but found that the change in buffer width made less than a 2 percent difference in system potential effective shade.

The model results of Ecology's TMDL analysis showed that temperatures exceeding the safe criterion for salmon (16°C) can be expected in the Lower Green River during current high summer air temperatures and low flow conditions. Under these conditions, modeled temperatures exceed the 16°C criterion by approximately 5.5 degrees. Future scenarios showed that the water temperature may exceed the 16°C criterion by 2 to 3°C, even with increased shade from the future tree planting scenario described above. However, the model showed that the 17.5°C criterion that applies to the Lower Green River below the confluence with Mill Creek is nearly achievable when using the 104-foot tree potential shade scenario. The simulation in model showed that this criterion could be fully achievable when using a future scenario with minimum tree height of 138 feet. Ecology's model results showed that in order to achieve the temperature criterion for the Lower Green River, effective shade from mature riparian vegetation would have to be increased by 33 percent to 53 percent, depending on the area. However, it should be noted that the tree planting densities that were simulated adjacent to the river would likely not be achievable with flood hazard management facility types A and B.

Model simulations under scenarios where all riparian areas along the Lower Green River are vegetated with trees of the minimum height set for each scenario (104 feet or 138 feet) but banks along levee areas are left unplanted also demonstrated that lethal temperatures would still occur in the lower 6 miles (10 kilometers) of the Lower Green River. When levees are not planted, modeled temperatures were 1 to 4°C warmer than when planted.

Ecology presented a range of implementation strategies to improve temperature in the Middle and Lower Green River. Those most relevant to the Plan are shown in Table 4-2.

Table 4-2. Middle and Lower Green River Temperature TMDL Implementation Strategies

Provide more shade and improve riparian areas
Assess potential planting sites along the Middle and Lower Green River and along tributaries.
Encourage riparian planting projects.
Locate available funding for watershed restoration projects.
Complete the necessary negotiations with Corps of Engineers and other agencies and/or municipalities that own or control levees and the adjacent properties to allow an adequate riparian buffer to be developed along the length of the Lower Green River.
Incorporate TMDL actions into local land use and regulatory programs and policies.
Protect cool groundwater and enhance current summer baseflows
Consider TMDLs during SEPA and other land use planning reviews.
Restore and/or create beneficial wetlands.
Monitoring
Conduct in-stream water quality and flow monitoring.
Conduct effectiveness monitoring.

The proposed strategies in Table 4-2 that are relevant to the project have been considered in analyzing impacts from the Plan and identifying potential mitigation.

Future Projections

Because of weather conditions in Western Washington in 2015, including record low spring Cascade snowpack and warmer than normal winter, spring, and early summer air temperatures, unusually low flows in unregulated streams and rivers generally resulted in elevated water temperatures. After a statewide drought was declared early in 2015, some regional scientists suggested that the 2015 water year might potentially be a good proxy for future (mid-twenty-first century) conditions expected as the result of human-influenced climate change (King County 2017).

Future conditions expected as a result of several factors, including further tributary area land development and increased density of impervious surfaces, flood risk reduction and water storage, and human-influenced climate change, are anticipated to contribute to the future elevation of water temperatures. Stream temperatures in the Puget Sound area are projected to increase by 2.2 to 2.5°C (4.0 to 4.5 degrees F) by the period from 2070 to 2099, compared to the baseline period from 1970 to 1999 (King County 2017).

4.2.1.4 Dissolved Oxygen

Oxygen in its dissolved form is measured as DO. As previously stated, the Lower Green River has been identified as having an impairment of DO in the study area (Ecology 2016). The biological consumption of oxygen in a system is known as the BOD. BOD directly affects the amount of DO in rivers and streams. The greater the BOD, the more rapidly oxygen is depleted in the stream, and the less oxygen is available to higher forms of aquatic life. The consequences of high BOD are the same as those for low DO: aquatic organisms become stressed, suffocate, or die.

DO levels fluctuate seasonally and over the course of a day, varying with water temperature and altitude. Cold water holds more oxygen than warm water, and all water holds less oxygen at higher altitudes. Thermal discharges, such as water used to cool machinery in a manufacturing plant or a power plant, raise the temperature of water and lower its oxygen content. Aquatic animals are most vulnerable to lowered DO levels in the early morning on hot summer days when stream flows are low, water temperatures are high, and aquatic plants have not been producing oxygen since sunset.

Certain discharges contain organic materials that are decomposed by microorganisms, a process that uses oxygen. Sources of oxygen-consuming waste include discharges from food-processing plants, paper/pulp mills, sewage treatment plants, and failing septic systems, as well as stormwater runoff from farmland, urban streets, and feedlots. In addition, reduced supplies of water from filtered, cooled baseflows can result in poorer water quality, including lower concentrations of DO that may be harmful to fish and other aquatic life. Sources of BOD include decaying plants and animals (EPA 2012). Potential changes, if any, that may result from the Plan to the quantities or locations of the organic material in these types of discharges have been considered as part of the impact analysis.

4.2.1.5 Flow Supply

Reduced supplies of water from naturally filtered, cooled baseflows and reduction in existing flows because of diversions and water consumption can result in poorer water quality, including higher temperatures and lower concentrations of DO that may be harmful to fish and other aquatic life. Green River flows have been substantially altered by past and ongoing human activities, including groundwater supply interference, major surface water diversions, consumptive water withdrawals, and flood risk reduction activities (King County 2017).

4.2.1.6 Additional Water Quality Concerns

The Green River has been documented as having poor water quality since the early 1960s, though conditions improved in the 1980s after reductions in discharges from domestic and industrial sources. The Lower Green River within the study area has had historical 303(d) listings for chemical contaminants in sediments, DO, and fecal coliform. However, it has since been removed from 303(d) listing for all contaminants other than temperature and DO (King County 2005; Ecology 2016). In 2005, King County conducted a screening-level risk assessment of the Green River, which included evaluation of nitrogen compounds, metals, and total suspended solids (TSS). The overall conclusions of the risk-assessment showed that there is a potential water quality risk to aquatic life posed by TSS for the Lower Green River in the study area, though assessing the risks can be challenging since TSS is a natural and necessary component of an aquatic system. Ammonia, nitrite and nitrate, and metals in the study area were found to cause negligible risks to aquatic life. Risks from organic compounds and pesticides were found to be uncertain due to a lack of data (King County 2005).

4.3 Impacts

4.3.1 Long-Term Operational Impacts

4.3.1.1 Relevant Facility Features

This section documents the potential long-term, operational impacts to water quality from the Plan alternatives. As discussed in Section 4.1.4, these impacts are assessed based on the features of potential Lower Green River flood management facilities that could impact water quality in the channel, which are presented below:

- Vegetation that may contribute to pollutant filtering or uptake
- Vegetation that may contribute to shading
- Overall biologic input, especially adding organic materials that increase organic carbon, which reduces bioavailability of metals
- Bank and bed material of the type that may contribute to pollutant filtering or uptake (e.g., native or natural soils compared to riprap)
- Bank and bed material of the type that may contribute to cooling through groundwater recharge or expression (e.g., subsurface materials designed to support hyporheic zone exchange)
- Potential changes in duration or geographical inundations of low flows (such as the summer mean low flow or other commonly expected dry season flows), which represent periods when water temperatures in the Lower Green River main channel are typically the highest, and pollutant input can have the greatest relative potential effect on water quality

As discussed in Section 4.2, Affected Environment, the Lower Green River in the study area has been channelized by a series of revetments, levees, and steep banks, and is generally devoid of trees and significant riparian cover. This has resulted in a lack of shade protection and increased river temperatures in the study area. Therefore, an important element for comparing water quality under the alternatives is how much vegetation—especially trees—could be included with each facility type.

A Vegetation Plan was prepared for the PL 84-99 facility shoreline portions of the Lower Green River as part of the System-Wide Improvement Framework (SWIF) (King County 2019) to provide guidelines for maintenance, repairs and capital design, and long-term stewardship of shoreline vegetation near levees and floodwalls enrolled within the Corps of Engineers' PL 84-99 Levee Rehabilitation and Inspection Program (see PEIS Appendix A). The Vegetation Plan was intended to ensure that SWIF implementation would manage vegetation to support regional considerations for aquatic, floodplain, and riparian habitat under the Clean Water Act and ESA. For the purpose of evaluating the Plan alternatives, this Vegetation Plan was assumed to be implemented for all flood hazard management facilities under consideration.

Achieving enhanced vegetation near levees and floodwalls would require space between the flood facility and the river's edge to support large trees and other specified vegetation. An analysis of the amount of space available between the river's edge and the levee or floodwall was conducted to determine how much and what types of vegetation it would be possible to plant and sustain over time, as discussed in the sections below.

4.3.1.2 Summary of Impacts

The relevant features of each flood facility type and their expected effect on water quality are summarized in Table 4-3. An overview of the expected impacts to water quality from the proposed alternatives based on the expected share of each facility type is summarized in Table 4-4 and discussed in the sections that follow.

Table 4-3. Flood Facility Features—Potential Effects on Water Quality

		Vegetation			Bank and Bed Materials			
Type	**Features Relevant to Water Quality**	**Pollutant filtering or uptake**	**Shading**	**Organic materials**	**Pollutant filtering or uptake**	**Ground-water recharge**	**Improved low flows**	**Overall**
None	No flood facility project, bank remains in existing unarmored condition. Assumes no change from existing land cover, side channels, or ground density. May allow for increased erosion.	○ None	○ None	○ None	↓ Impact	○ None	○ None	↓ Less Impact
Revetment	Streambank hardened to reduce channel migration; no flood hazard management provided. Assumes removal of any existing vegetation and compaction of ground.	↓ Impact	↓ Impact	↓ Impact	↓ Impact	↓ Impact	↓ Impact	↓↓ **Most Impact**
Type A	Levees or floodwalls with steeper (2.5:1 or steeper) riverward side slopes with an approximate footprint of 100 feet or less from the OHWM to the landward side of the facility. Assumes minimum to no tree cover, including removal of existing tree cover.	○ None	↓ Impact	○ None	○ None	○ None	↓ Impact	↓ Medium Impact
Type B	Levees or floodwalls with flatter (2.5:1 or flatter) riverward side slopes that can be planted with vegetation and/or have a bench enhanced with LWD, scour protection, and native vegetation. Typical cross-sectional footprint would be approximately 100 to 150 feet from the OHWM to the landward side of the facility.	↑ Benefit	↑ Benefit	↑ Benefit	↑ Benefit	↑ Benefit	↑ Benefit	↑ Medium Benefit
Type C	Levee setbacks or floodwalls with benches, enhanced shade, and greater opportunity for riparian and aquatic enhancement. Typical riverward slopes 3:1, with a typical cross-sectional footprint of 150 feet or more from the OHWM to the landward side of the facility. Setback distances for some facilities may be considerably larger.	↑↑ Most Benefit	↑↑ Most Benefit	↑↑ Most Benefit	↑↑ Most Benefit	↑↑ Most Benefit	↑↑ Most Benefit	↑↑ **Most Benefit**
Type D	Flood proofing solutions, such as home elevation, basement removal with utility addition, berms, ring levees, farm pads, and/or drainage improvements.	○ None	○ None	○ None	○ None	↓ Impact	↓ Impact	↓ Medium Impact

Table 4-4. Bank Treatment and Facility Type by Alternative

	Facility Type (Potential Effect on Water Quality)							
Alternative	**Unarmored bank** (↓ Less Impact)	**Revetment** (↓↓ Most Impact**)**	**Type A** (↓ Less Impact)	↓ **Share of Impacting Facility Types**	**Type B** (↑ Medium Benefit)	**Type C** (↑↑ Most Benefit)	↑ **Share of Benefitting Facility Types**	**Total**
	Share of Alternative Footprint (Linear feet)							
1	27% (60,000)	14% (31,000)	35% (77,000)	**76%** (168,000)	12% (27,000)	12% (27,000)	**24%** (54,000)	100% (222,000)
2	29% (64,000)	15% (34,000)	29% (64,000)	**73%** (162,000)	13% (28,000)	14% (31,000)	**27%** (59,000)	100% (221,000)
3	28% (62,000)	15% (33,000)	26% (59,000)	**69%** (154,000)	12% (27,000)	19% (42,000)	**31%** (69,000)	100% (223,000)

Values represent the hypothetical share of the river bank that each type of facility would occupy under each alternative. For this analysis, influence from Type D flood proofing solutions are included with unarmored bank and revetment as it is assumed those areas are where Type D facility would most likely be implemented.

4.3.1.3 Alternative 1: Project-by-Project Multibenefit Implementation

Under Alternative 1, facilities would be built one at a time without coordination with other projects, goals, and sequencing, following established policies and practices without the guidance of an area-specific Flood Hazard Management Plan. As shown in Table 4-4, Alternative 1 would likely include the largest percentage of facility types that could adversely impact water quality. Because of this facility type combination, less space would typically be available to support vegetation and other outcomes with new, improved, and relocated levees or floodwalls that could more frequently be located within 100 feet of the river. Therefore, the greatest adverse impacts to water quality would be expected as a result of Alternative 1 compared to the other alternatives.

In Alternative 1, the District would consider the adopted multibenefit policy and incorporate its elements to the extent feasible as individual projects were implemented. It is expected that this approach could miss larger coordination opportunities to expand the types of vegetation plantings, improve the types of channel conditions, and increase base flows to an extent that could benefit water quality. Therefore, Alternative 1 would present the least opportunity to benefit water quality among the alternatives.

4.3.1.4 Alternative 2: Systematic Multibenefit Implementation

Flood hazard management facilities under Alternative 2 would be built systematically and in coordination with Tribes and applicable agencies to implement more of the multiple benefits described in FCD Motion 20-07, including habitat conservation and fish restoration. Corridor-wide coordination could take advantage of project sequencing and more shared benefits. Also, as shown in Table 4-4, Alternative 2 would fall between Alternative 1 and Alternative 3 in the percentage of facility types that could adversely and beneficially impact water quality. Some space could be available to support vegetation and other outcomes with new, improved, and relocated levees or floodwalls that would be located along the river. Therefore, a moderate benefit to water quality would be likely from Alternative 2 compared to Alternative 1.

Under Alternative 2, the District would develop an area-specific Plan for the Lower Green River Corridor that would seek partnership opportunities with Tribes, federal and state agencies, local jurisdictions, and stakeholders and would systematically advance the multibenefit policy. Alternative 2 would likely take advantage of more potential opportunities that could come from multi-agency coordination and project sequencing to expand the types of vegetation plantings, improve the types of channel conditions, and increase base flows to an extent that could benefit water quality. Alternative 2 would, therefore, present more opportunity to benefit water quality than Alternative 1.

4.3.1.5 Alternative 3: Enhanced Systematic Multibenefit Implementation

Under Alternative 3, flood hazard management facilities would be built systematically and in coordination with Tribes and applicable stakeholder agencies to pursue habitat conservation and restoration to a notably greater extent than with either of the other alternatives, while achieving multiple benefits across the Lower Green River. This corridor-wide coordination and habitat improvement focus would likely provide the greatest opportunities to improve water quality compared to the other alternatives. Also, as shown in Table 4-4, Alternative 3 would include the lowest percentage of facility types that would adversely impact water quality and the highest percentage of facilities that would benefit water quality. Alternative 3 would provide more space than the other alternatives to support vegetation and other outcomes with new, improved, and relocated levees or floodwalls. It would also include the potential acquisition of undeveloped floodplains for long-term flood storage, offering opportunities to better preserve beneficial vegetation along tributaries and in associated wetlands compared to other alternatives. Therefore, Alternative 3 would likely provide the most benefits to water quality compared to the other alternatives.

Under Alternative 3, the District would pursue habitat conservation and restoration to a notably greater extent than under either of the other alternatives, while advancing the multibenefit policy across the Lower Green River. The Plan would establish goals and indicators for managing flood risk in a manner that could protect, improve, and restore riparian and aquatic habitats and establish conditions that could support recovery of threatened salmon and other species. Alternative 3 would likely take advantage of the most opportunities that could arise from multi-agency coordination and project sequencing to expand the types of vegetation plantings, improve the types of channel conditions, and increase base flows to an extent that would benefit water quality. Alternative 3, therefore, would likely present the most opportunity to benefit water quality compared to the other alternatives.

4.3.1.6 No Build Scenario

The No Build Scenario would maintain existing flood management facilities and complete those under construction, but would not build any new facilities. As a result, more of the riverbank would remain in its existing unarmored or unimproved (previously impacted) condition. While this would not directly impact existing vegetation cover, it may allow for increased erosion. Overall, the No Build Scenario would provide no improvement to the current water quality degradation trend within the study area.

4.3.2 Temporary Construction Impacts

As discussed in Section 3.3.2 above, construction of flood hazard management facilities under Alternatives 1, 2, and 3 could have temporary effects on water quality, such as an increase in suspended sediments in the water column and the removal of riparian vegetation. Construction impacts are temporary in nature and could be controlled by complying with the NPDES Construction Stormwater General Permit process, the WDFW HPA process, the King County Stormwater Pollution Prevention Manual, and Ecology Manual standards and best management practices (BMPs), as appropriate. Through compliance with these requirements, an approved Construction Stormwater Pollution Prevention Plan (CSWPPP) would be developed and implemented for the proposed Project. The CSWPPP would serve as the overall construction stormwater mitigation plan by describing overall procedural and structural pollution-prevention and flow control BMPs, including location, size, maintenance requirements, and monitoring. An Ecology Certified Erosion and Sediment Control Lead (CESCL) would be employed to conduct the inspections, and deficiencies could be promptly corrected. In addition, the CSWPPP would include each of the following plans:

- Temporary Erosion and Sediment Control Plan – This plan would outline the design and construction specifications for BMPs to be used to identify, reduce, eliminate, or prevent sediment and erosion problems.
- Spill Prevention, Control, and Countermeasures Plan – This plan would outline requirements for and implementation of spill prevention, inspection protocols, equipment, material containment measures, and spill response procedures.
- Concrete Containment and Disposal Plan – This plan would outline the management, containment, and disposal of concrete debris, slurry, and dust and discuss BMPs that would be used to reduce high pH.
- Dewatering Plan – This plan would outline procedures for pumping groundwater away from the construction area, and storing (as necessary), testing, treating (as necessary), and discharging or disposing of the dewatering water.
- Fugitive Dust Plan – This plan would outline measures to prevent the generation of fugitive dust from exposed soil, construction traffic, and material stockpiles.

Specific BMPs would be designed based on the manuals previously mentioned. BMPs could potentially include the following:

- Working only during the approved in-water work windows, which are periods of the year identified by the timeframe when potential effects to fish are minimized
- Phasing the work to minimize the amount of disturbed area at any one time
- Developing construction plans for sensitive areas (such as stream crossings and river banks) that minimize the need for haul roads using fill material, such as building temporary bridges or platforms with small piles (i.e., pin piles)
- Marking/fencing of construction limits
- Minimizing the amount of cleared and cut areas at any one time to the extent feasible
- Stabilizing construction entrances and haul roads using quarry spalls (crushed basalt)
- Washing truck tires at construction entrances, as necessary
- Cleaning construction site track-out from public roads, as necessary
- Constructing silt fences downslope from exposed soil
- Using silt curtains in the river channel for work near or on the river bank
- Protecting catch basins from sediment
- Containing and controlling concrete and hazardous materials on site
- Installing temporary ditches or asphalt berms to route runoff around or through construction sites, with periodic check dams to slow and settle runoff
- Providing temporary plastic or mulch to cover soil stockpiles and exposed soil

- Using temporary erosion control blankets or mulch on exposed steep slopes to minimize erosion before vegetation is established
- Constructing temporary sedimentation ponds or cells to remove solids from concentrated runoff and dewatering before being discharged
- Conducting vehicle fueling and maintenance activities no closer than 100 feet from waters of the state
- Providing secondary containment for all potential sources of leaks and spills
- Implementing stream protection measures, as necessary, including diverting stream flow around the construction area

Many of the additional BMPs identified to minimize impacts to ecosystems in Section 3.4.1 could also help to minimize impacts to water quality during construction.

4.3.3 Indirect Impacts

Indirect impacts are reasonably foreseeable impacts that could result from the District's flood hazard management actions, but that would be removed from the action in space and/or time. Indirect impacts on water quality from flood hazard management improvements are possible if these improvements influence changes in factors such as land use patterns which in turn may affect the location or prevalence of pollutant sources.

Adverse indirect impacts could result if the proposed action were expected to protect lands from flooding that might otherwise be unattractive for development or redevelopment, especially land closest to the river and within the natural floodplain. Such development would be subject to land use regulation by the local jurisdiction but would have been made more attractive by flood hazard management. In this case, indirect water quality impacts could include increases in water temperature through removal of vegetative cover and increased pollutant load from creation of new pollution-generating surfaces.

In contrast, beneficial indirect effects could result if the District were to acquire already developed land and covert it to vegetated open space to be reserved for flood storage; again, this would be especially true for land closest to the river and within the natural floodplain. In this case, the indirect water quality benefits could include removal of impervious surfaces and pollution-generating surfaces. This scenario is more likely with Type B facilities and the most likely with Type C facilities, which provide some and the most potential areas for increased vegetation and improved bank materials, respectively (see Table 4-3). Therefore, more indirect benefits would be expected from Alternative 2, and the most indirect benefits would be expected from Alternative 3 because of their respective percentages of Type B and C facilities (see Table 4-4).

4.4 Mitigation

As previously discussed, the magnitude of effects on water quality from the flood risk reduction measures outlined in each Plan alternative would be small in comparison to the effects from ongoing trends of population increase, land development, and climate change in the Green River Watershed; as well as efforts within the watershed that are directly focused on water quality such as salmon protection campaigns, water quality improvement plans, and shade improvement plans. Mitigation measures considered based on the potential water quality impacts from the Plan alternatives cannot and should not be intended to address greater, non-Plan factors that impact water quality within the Lower Green River Watershed.

Based on the potential impacts to water quality that are specific to the Plan alternatives and discussed in Section 4.2, the Ecology temperature improvement strategy referenced in Section 4.1.2.3 has been found to provide the most relevant mitigation measures to avoid or minimize these impacts. Mitigation measures to be considered are as follows:

- Follow recommendations in the *Green River Temperature Total Maximum Daily Load Water Quality Improvement Report* (Ecology 2011) regarding maximizing the distance between levees and the OHWM of the riverbank and planting these areas with trees of specified minimum height and buffer width.
- Follow recommendations in the *Green River Temperature Total Maximum Daily Load Water Quality Improvement Report* (Ecology 2011) regarding maximizing planting of trees of specified minimum height and buffer width in all non-leveed riparian areas along the Lower Green River and tributary streams.
- Minimize the use of structural bank stabilization methods (e.g. revetments, groins, riprap, etc.).
- Restore and/or create wetland complexes to replace lost wetlands in conditions that would support wetland systems.
- Add or restore channel migration zone complexity (e.g. side channels, oxbows, etc.).
- Incorporate TMDL actions into projects.
- Conduct in-stream water quality and flow monitoring.

5. AQUATIC RESOURCES

5.1 Methodology

PEIS Appendix A describes the three alternative approaches to managing flood risk in the Lower Green River Corridor to meet the provisional level of protection of 18,800 cfs (the median 500-year flow). These are summarized in Section 1. Applying the three approaches could result in adverse impacts, enhancements, and benefits, or both. The types of potential impacts are described in Section 1 and include direct, indirect, construction, and cumulative impacts.

To facilitate the evaluation of potential impacts, the extent of streambank affected by flood hazard management facilities is estimated based on the policy-level approaches and guidelines for each alternative described in Appendix A, Section 3.2.2. These estimates include improvements to facilities in their current locations, relocation of existing facilities further from the river, and development of new facilities. These estimates are presented as ranges (+/- 20 percent) to reflect the programmatic level of analysis. The estimates are intended to facilitate a comparison of alternatives. No specific flood management projects have yet been identified.

The impacts of proposed PEIS alternatives are analyzed using a two-step process. Step 1 applies an ordinal ranking method that combines a qualitative assessment of resource impacts from the development of the four types of proposed flood facility projects (A, B, C, and D—described below) weighted by the length of streambank in each project type under each alternative. Step 2 evaluates the potential impacts of each alternative on specific ecological functions associated with riparian and floodplain habitats by estimating the acres of habitat potentially available for floodplain and riparian habitat restoration under each alternative. Steps 1 and 2 are described in the following sections.

While this analysis method includes quantitative elements, it should not be viewed as a quantitative assessment of impacts on ecosystem function. That level of analysis would require site-specific ecological conditions data and project-specific design information that are not currently available. However, the conceptual flood facility designs considered in this analysis could be used to assess the likelihood that a given facility type would improve or degrade the condition of a given ecological function when compared to its counterparts. This analysis assumes that each aquatic resource and its associated ecological functions would achieve equilibrium with the respective analysis scenario over a 30-year analysis period.

Table 5-1 presents the streambank condition and flood facility types considered in this analysis.

Each project type would likely have different effects on streambank and in-channel habitat conditions, as well as on the amount of riparian and floodplain habitat available for the restoration of associated ecological functions. For example, existing and planned Type C facilities would incorporate functional LWD, the expansion of pool and shallow-margin habitat, and the creation of inundated flood bench habitat as intentional design features that would not be provided by Type A counterparts. As such, replacement of existing legacy levees that are similar in configuration to Type A facilities with new Type C facilities would likely result in a beneficial effect on ecosystem functions supporting juvenile and adult salmonid habitat, commensurate with the linear and areal extent of this facility type. However, the actual extent and functional value of shallow-margin, riparian, pool, and flood-bench habitat provided by a given Type C facility would vary, depending on project-specific factors such as the levee setback distance and the presence of features like roadways and trails within the riparian zone riverward of the levee.

Table 5-1. Streambank Conditions by Flood Facility Types

None	No flood facility project would be proposed; bank would remain in unarmored condition.
Revetment	Streambank would be hardened to reduce channel migration; no flood facility would be provided.
Type A	Would include levees or floodwalls with riverward side slopes that would generally be less than 2.5 to 1, with an approximate footprint of 100 feet or less, measured from the ordinary high-water mark (OHWM) to the landward side of the facility.
Type B	Would include levees or floodwalls with riverward side slopes, typically 2.5 to 1 or greater, that could be planted with vegetation and/or would have a bench enhanced with large woody debris (LWD), scour protection, and native vegetation. Typical cross-sectional footprint would be approximately 100 to 150 feet from OHWM to the landward side of the facility.
Type C	Would include levee setbacks or floodwalls with benches, enhanced shade, and greater opportunity for riparian and aquatic enhancement. Would have typical riverward slopes 3 to 1, with a typical cross-sectional footprint of 150 feet or more from OHWM to the landward side of the facility. Setback distances for specific facilities might be considerably larger.
Type D	Would include flood proofing solutions, such as home elevation, basement removal with utility addition, berms, ring levees, farm pads, and/or drainage improvements.

While the alternatives provide an estimate of the number of projects and the overall extent of each flood facility type likely to be implemented under their respective policy approaches, project-specific designs have not been developed. Therefore a full quantitative analysis of alternative impacts is not possible. Instead, a categorical comparison of potential ecological impacts based on the linear extent of streambank and area of floodplain habitat available for restoration under each alternative is considered. These results can be used to evaluate relative progress towards ecological restoration objectives for the Lower Green River, such as those presented in the WRIA 9 Salmon Habitat Plan 2021 Update (WRIA 9 2021). These objectives are described in Section 5.6.1.5 below.

5.1.1 Studies and Information Sources

Studies and information sources used to evaluate the potential effects of the alternatives are summarized by resource and ecosystem function in Table A-1, Attachment 1. Reference citations are presented at the end of this report.

5.1.2 Ordinal Ranking of Impacts to Lower Green River Channel Margins

Step 1 of the effects analysis combines ecological impact rankings with the anticipated linear extent of Lower Green River streambank modified by each facility type under each alternative. The scheme assigns an ordinal ranking to each ecosystem function by facility type based on potential functional impact. The rankings range from 1 to 5 and are a qualitative representation of the anticipated impact on the metric used to measure each ecosystem function (e.g., number of LWD elements, pool area, and/or extent of floodplain habitat). The ranking for each function is weighted by the length of streambank that would remain in or would be converted to that facility type by alternative. For example, a Type A facility would have the lowest possible impact ranking for LWD, as this facility type typically would eliminate functional riparian vegetation and would not incorporate LWD into its design. In contrast, Type B and C facilities would maintain and restore riparian vegetation and would incorporate LWD and small woody debris pieces to emulate the functional benefits provided by natural woody debris jams. The ordinal LWD rankings for these facility types considers these functional benefits. The weighted LWD ranking for each alternative is calculated by multiplying the length of Lower Green River streambank in each facility type under each alternative by their respective woody debris rankings, divided by total streambank length. For example, the LWD weighted rank for facility type A under Alternative 1 would be calculated as follows:

$$LWD\ Weighted\ Rank\ = \frac{L_{A1} \times R_A}{L_T}$$

Where:

L_{A1} = Length of bank converted to facility type A under Alternative 1

R_A = The LWD effect rank for facility type A

L_T = The total length of streambank in the Lower Green River (approximately 220,000 feet)

Weighted LWD rankings are calculated for each facility type using the same formula, considering the estimated streambank length in each facility type. The facility type rankings are then summed to produce a combined LWD ranking for Alternative 1. The same method is used to calculate weighted LWD rankings for each Alternative. These rankings are then used to compare relative ecological effects across alternatives.

The ordinal ranking schema used to characterize the effects on juvenile salmonid rearing and adult migration are presented in Table 5-2. The ranking schema for ecosystem processes and other stream biota are presented in Table 5-3 and Table 5-4, respectively. The estimated linear extent of each type of flood facility under the current Lower Green River conditions and the PEIS alternatives is presented in Table 5-5. The supporting rationale for the ordinal ranking schema and the calculation of combined ranks by ecosystem function and resource are presented in Attachments 1 and 3, respectively. References and information sources used to support this analysis are cross-referenced by topic in Attachment 2.

Table 5-2. Ordinal Ranking Schema Used to Evaluate Alternative Impacts on Ecological Functions Affecting Juvenile Rearing and Adult Migration

Level of Effect Rating	Effect on Ecological Function Condition
1	Facility type would degrade ecological function to not properly functioning (NPF) condition. It would not contribute to necessary future condition (NFC).
2	Facility type would degrade ecological function; it would maintain limited habitat value.
3	Facility type would provide partially functional condition, approximating at risk (AR). It would contribute to NFC as defined by WRIA 9 (2021).
4	Facility type would provide partial functional condition between AR and properly functioning (PF) condition. It would contribute to NFC.
5	Facility type would maintain, enhance, or restore PF condition. It would contribute to NFC.

Table 5-3. Ordinal Ranking Schema Used to Evaluate Alternative Impacts on Ecological Functions Associated with Ecosystem Processes

Level of Effect Rating	Effect on Ecological Function Condition
1	Facility type would degrade ecological function to NPF condition or would deviate most from natural reference conditions. It would not contribute to NFC.
2	Facility type would degrade ecological function from natural reference conditions; it would maintain limited habitat value.
3	Facility type would provide partially functional condition, approximating AR. It would contribute to NFC.
4	Facility type would provide partial functional condition between AR and PF; it would trend some toward natural reference conditions. It would contribute to NFC.
5	Facility type would maintain, enhance, or restore PF condition; it would trend most toward natural reference conditions. It would contribute to NFC.

Table 5-4. Ordinal Ranking Schema Used to Evaluate Alternative Impacts on Other Stream Biota

Level of Effect Rating	Effect on Ecological Function Condition		
	Other Fishes	Macroinvertebrates	Aquatic Vegetation
1	Facility type contributes to severely degraded fish community composition, corresponding to Fish Index of Biotic Integrity (FIBI) rating of 'Very poor' (FIBI < 14.5). Species richness and ecological functional diversity severely degraded.	Facility type contributes to severely degraded macroinvertebrate community composition, corresponding to Benthic Index of Biotic Integrity (B-IBI) score of 'Very Poor' (0-20). Taxa diversity very low, Ephemeroptera, Plecoptera, Trichoptera (EPT) taxa largely absent	Facility type eliminates or maintains near-zero amount of shallow margin habitat suitable for aquatic vegetation.
2	Facility type contributes to degradation toward, or fails to improve existing, FIBI score of 'Poor' (14.6-21.5). Species richness and functional diversity degraded. Dominance by species tolerant of disturbance.	Facility type contributes to degradation toward, or fails to improve, 'Poor' B-IBI (20-40). Taxa diversity and proportion of predators depressed, and community dominated by a few abundant taxa.	Facility type eliminates large majority of shallow margin habitat. Suitable marginal habitat capable of supporting aquatic vegetation exists only in small areas.
3	Facility type contributes to moderate degradation relative to undisturbed historical condition. OR contributes to moderate improvement from baseline highly degraded condition of 'Poor' or 'Very poor' FIBI.	Facility type contributes to moderate degradation relative to undisturbed historical condition. OR contributes to moderate improvement from baseline highly degraded condition of 'Poor' or 'Very poor' B-IBI.	Facility type includes moderate area of shallow margin habitat with capable of supporting aquatic vegetation.
4	Facility type contributes to improvement to FIBI relative to current baseline condition. Moderately reduced species richness relative to undisturbed condition.	Facility type contributes to moderate improvement to B-IBI relative to current baseline condition. Moderately reduced species richness relative to undisturbed condition.	Majority of undisturbed level of shallow margin and aquatic vegetation is maintained or restored. Slight reduction from true undisturbed or fully restored condition.
5	Facility type contributes to substantial improvement of FIBI relative to baseline, to the extent possible within the widely degraded Green-Duwamish watershed. High taxonomic and functional diversity.	Facility type contributes to substantial improvement to B-IBI relative to degraded baseline, to the extent possible within the Green-Duwamish watershed. High taxonomic and functional diversity.	Comparable to undisturbed condition. Shallow margins with native aquatic vegetation present.

Table 5-5. Estimated Linear Extent of Planned Flood Facility Types by Alternative

	Approximate Facility Type Extent by Alternative (linear feet)		
Flood Facility Type	**Alternative 1**	**Alternative 2**	**Alternative 3**
Unarmored bank	60,000	64,000	62,000
Revetment	31,000	34,000	33,000
A	77,000	64,000	59,000
B	27,000	28,000	27,000
C	27,000	31,000	42,000

Values represent the hypothetical extent of Type A, B, and C facilities under each alternative. Type D flood proofing solutions may be implemented in areas where unmodified bank and revetments are present.

The values presented in Table 5-5 are the total estimated length of Lower Green River streambank that would remain in or would be converted to the identified facility type under each alternative. The extent of streambank left unarmored or as revetment is also included to account for the total linear distance if study area streambank. In other words, this would potentially be the condition of the streambank at the end of the 30- to 50-year planning period. These estimates are based on the policy-level direction and guidelines for each alternative described in Attachment 1, Section 3.2.2. The linear extents of facility types by alternative are presented as ranges in the PEIS, the high and low ends of which are plus or minus 20 percent of the estimated facility extent, respectively. Ranges are used in the PEIS to reflect the programmatic nature of the action. However, it was not practicable to use ranges for the ecological impacts analysis because the range of remaining unarmored bank and revetment under each alternative would be uncertain.

These values are planning-level estimates that enable the comparison of the alternatives. However, because no specific flood management projects are being proposed the streambank length by facility type estimates for each alternative are imprecise. As such, the weighted ranking formula may over or underestimate ecological effects in certain cases. While these limitations are acknowledged, the weighted ranking method is still useful for comparing alternatives. Each alternative is based on a hypothetical analysis scenario that considers a diverse range of actions with offsetting effects that will likely balance out across the entire Lower Green River.

5.1.3 Quantification of Floodplain and Riparian Impacts

Step 2 of the impact analysis considers the amount of habitat that each alternative would make available for potential floodplain and riparian habitat restoration. In addition to their streambank effects, each of the proposed facility types presents different levels of opportunity for restoration of ecological functions associated with riparian and floodplain habitats. These potential benefits can be expressed in terms of the areal extent of each facility type and the extent of habitat available for restoration that would be activated at ecological flows.

Ecological flows are defined as peak winter stream flows with a recurrence interval of 2 to 10 years, as described in Table 5-6. Flows of this frequency likely occur at least once during the life cycle of an individual salmonid, meaning that the habitats available at these flows strongly influence individual survival and fitness. In unmodified or less modified environments, ecological flows activate channel margin, riparian, and floodplain habitats that are used by juvenile salmonids. In the absence of these habitats, juvenile salmonids can be displaced by high stream flows and transported to areas that are unfavorable for survival. High flows at this frequency are also necessary to maintain the ecological processes that support functional floodplain wetland and riparian habitats. As such, the amount of riparian and floodplain habitat made available to inundation within this range of flows provides a basis for differentiating between alternatives in terms of their potential effects on juvenile and adult salmonids, other aquatic biota, and ecosystem processes.

Table 5-6. Lower Green River Flow Frequencies Used to Compare Alternatives

Flow (cfs)	Exceed. Prob.	Recurrence Frequency (years)	Ecological Flow	Description and Application
~ 300	n/a	Mean August Low Flow	No	This is a general representation of commonly expected dry season flows, similar to the September median. This is the period when water temperatures in the Green River main channel are highest. Low flows combined with high water temperatures may be especially stressful to fish. The Lower Green River has minimal connectivity to riparian and floodplain habitats during this flow period. However, functional riparian vegetation provides shade that maintains water temperature and terrestrial/riparian inputs that support juvenile salmonids and other aquatic resources.
2,030	n/a	Mean Winter Flow	No	This represents commonly expected November to February wet season flows and is also representative of the upper bound of typical flows from January to May (mean of 1,920 cfs from 1962 to 2016) and flows during juvenile Chinook outmigration from January to June (mean of 1,770 cfs from 1962 to 2016). It represents the lower bound of flows that activate edge habitats incorporated into Type B and Type C facilities.
9,900	50%	2	Yes	This is the high confidence limit (5 percent) of the 2-year flood and the minimum flow modeled to assess inundation under each alternative. A figure of 9,900 cfs is a useful representation of flows that inundate channel margins and activate flood bench and floodplain habitats. There is an approximately 50 percent probability of this flow occurring each year. Individual salmonids have a high likelihood of exposure to the 2-year flow at least once during their life cycle. This flow also supports floodplain activation. Regular inundation of floodplains and riparian zones is necessary to maintain their ecological function.
11,900	10%	10	Yes	This is the low confidence limit (95 percent) of the 10-year flood and a useful representation of the upper bound of ecological flows having approximately a 1 in 10 chance of occurring each year. While less frequent than the 2-year event, flows of this volume occur frequently enough to influence salmonid population dynamics. Periodic disturbance at this frequency is also an important component of floodplain habitat processes.
12,600	0.5%	200	No[†]	This is the median estimate of the 200-year flood. The high-volume flood event is in the range of 12,000 cfs. The 1996 flood was 12,400 cfs (the highest since the HHD was constructed in 1961).
15,100	0.29%	350	No[†]	This is the high confidence limit (5 percent) of the 100-year flood (thought to be equivalent to approximately the median estimate of a 350-year flood).
18,800	0.2%	500	No[†]	This is the median estimate of the 500-year flood as determined by the Corps of Engineers (Corps of Engineers 2012); it is the provisional level of protection adopted by the District. This is the event for which some jurisdictions are now regulating in preparation for climate change.

[†] Flood events that occur at this or higher frequency are less relevant to salmonid population productivity and the ecosystem processes that maintain floodplain wetland and riparian function in highly modified environments like the Lower Green River.

The potential areal footprint of new Type A, B, and C facilities has been estimated for each alternative analysis scenario. The total acreage for each facility type represents the area riverward of the hypothetical future levee crest. Consistent with the ranking methods described above, some proportion of the total footprint of each facility type could be available for future restoration of floodplain and/or riparian habitat function. The following guidelines were used to estimate the acres of habitat potentially available for restoration by facility type:

- Existing levees and floodwalls are improved in place – No additional habitat is available for restoration.
- New or improved Type A facilities – No additional habitat is available for restoration.
- New or improved Type B facilities – Assume that 50 percent of project footprint is available for riparian and channel margin restoration and enhancement. Remaining footprint is required for access roads or trails on levee crest.
- New or relocated Type C facilities – Area available for restoration would vary depending on the levee setback as follows:
    - Type C-1: Small setbacks that allow for creation of a narrow flood bench (20 to 30 feet wide). Assume 75 percent of project footprint is available for restoration of riparian and flood bench habitat.
    - Type C-2: Large setbacks that set the levee crest well away (more than 100 feet) from the Lower Green River, allowing for the creation of wide, vegetated flood benches with high flow channels. Assume 90 percent of project footprint is available for restoration.

In addition to the above, the District could acquire certain properties under Alternative 3 to preserve floodplain flood storage. These properties would have to provide flood storage capacity and meet other specific conditions to deliver ecological and other benefits. These properties might or might not be contiguous with the shoreline of the Green River, and they might or might not be activated at ecological flows. For this analysis, up to 90 percent of the total footprint of these facilities is assumed to be available for habitat restoration.

The hypothetical areal footprint for each project type and the proportion of that footprint available for floodplain and/or riparian restoration is summarized by alternative in Table 5-7. To provide an ecological benefit to the ecosystem functions considered, a facility type polygon must receive some level of inundation during ecological flows. NHC (NHC 2021) modeled the projected inundation at the stepwise flows above 9,900 cfs shown in Table 5-6 under each alternative. NHC (NHC 2023) inundation maps were used to identify the hypothetical flood facility project polygons receiving at least some level of inundation at ecological flows (i.e., at 9,900 cfs and/or 11,900 cfs) under each alternative. Facilities that are not inundated at ecological flows would not provide the level of hydraulic connectivity to the Lower Green River necessary to support ecological functions.

Table 5-7. Estimated Future Areal Extent of Potential Flood Facility Types by Alternative

Alternative	Facility Type	Facility Type Area (acres)†	Proportion of Area Available for Restoration¥
1 – Project by Project	Type A	85-125	0%
	Type B	30-50	50%
	Type C-1	20-30	75%
	Type C-2	60-90	90%
2 – Systematic	Type A	70-105	0%
	Type B	35-55	50%
	Type C-1	15-25	75%
	Type C-2	75-110	90%
3 – Enhanced Systematic	Type A	65-95	0%
	Type B	40-60	50%
	Type C-1	20-30	75%
	Type C-2	170-255	90%
	Flood storage‡	220-325	Varies

† The area riverward of the levee crest

¥ Available restoration area multipliers are only applied to flood facilities that are inundated at ecological flows determined by the hydraulic model range for the 2-year and 10-year flow events. It is assumed that project-specific design criteria will integrate habitat improvements at a range of normal flows typical during adult and juvenile migration periods (i.e., ~1,750 cfs, less than 2-year flow).

‡ Flood storage facilities are lands that could be acquired by the District to preserve flood storage and to provide ecological and other benefits. These areas may or may not be directly connected to the Lower Green River.

5.2 Historic Habitat Conditions

Prior to the twentieth century, the Green River met the White River near Auburn and then joined the Cedar River and the Black River to create the Duwamish River. However, permanent diversion of the White River to the Puyallup River the diversion of the Cedar River to flow into Lake Washington, and the creation of the Ship Canal to drain Lake Washington shifted the flow of water. Historically, the Green River watershed covered about 1,600 square miles and encompassed the Green River, White River, and Lake Washington. Today, the Green River watershed is just a third of that size (approximately 482 square miles) due to the redirection of the White River and outflows from Lake Washington. The diversion of the White River is estimated to have reduced the flows within the Lower Green River by approximately 50 percent (Kerwin and Nelson 2000).

Using maps and notes from the General Land Office, U.S. Geological Survey, and other sources, Collins and Sheikh reconstructed the historic aquatic habitats of the Lower Green River from approximately 1865 (Collins and Sheikh 2005). This stretch of the river included an extensive network of hydrologically connected wetlands and channels that meandered through the surrounding low gradient valley. The valley averages about 2.2 miles wide, with an average gradient of approximately 0.03 percent (about a tenth of the gradient of the Middle Green River valley) (Collins and Sheikh 2005). Of the 5,288 acres (8.26 square miles) analyzed by Collins and Sheikh, the river channel (including mainstem and tributaries) made up 1,025 acres (1.6 square miles), ponds made up 72 acres (0.1 square mile), and the rest (4,198 acres; 6.6 square miles) was wetlands (Collins and Sheikh 2005).

Common tree species documented along the active river channel and within the Lower Green River valley include red alder (*Alnus rubra*), willow (*Salix spp.*), black cottonwood (*Populus trichocarpa*), bigleaf maple (*Acer macrophyllum*), vine maple (*Acer circinatum*), and Oregon ash (*Fraxinus latifolia*) (Collins and Sheikh 2005). These trees likely provided LWD to the river channel. The most common streamside tree species was red alder. Approximately 75 percent of the floodplain was considered forested in 1865 (Collins and Sheikh 2005; King County Flood Control District 2016).

5.3 Current Habitat Conditions

The Lower Green River has been significantly altered due to human population growth, development in the surrounding area, and flood protection structures. Habitat conditions as they currently exist are described in the subsequent sections. The discussion below is divided into descriptions of 1) aquatic habitat, 2) riparian vegetation, and 3) wetlands.

5.3.1 Aquatic Habitat

The aquatic habitat within the Lower Green River is characterized largely by fast flows, steep banks, and uniform habitat types. The following sections provide further details on the habitat types and features present within the lower reaches of the Green River. Water quality in the Lower Green River is described in Section 4.

5.3.1.1 In-Stream Habitat

The complexity of in-stream habitat is often assessed by quantifying the proportion of glide, run, riffle, cascade, and pool habitats within a stretch of river. During the 2013 habitat assessment, R2 Resource Consultants classified fast water habitats as 1) riffles, if they were turbulent with a less than 4 percent grade, 2) cascades, if they were turbulent with a greater than 4 percent grade, 3) runs, if they were non-turbulent with a well-defined thalweg, or 4) glides, if they were non-turbulent without a well-defined thalweg (R2 Resource Consultants 2014a). Slow-water habitats were classified as either pools or backwaters, depending on their depth.

The Lower Green River was predominantly classified as glide habitat (76.2 percent), with occasional run (11.4 percent) and riffle (8.4 percent) habitats. No cascade habitat was identified. Fifteen pools were identified throughout the 21-mile stretch of river (R2 Resource Consultants 2014a). In general, the habitat complexity within the Lower Green River decreased moving downstream. Pools that are present were formed primarily where the river was going around a meander; a few pools were formed by LWD or other naturally occurring debris jams (R2 Resource Consultants 2014a).

5.3.1.2 Spawning and Incubation Habitat

Spawning and incubation habitat occur primarily in the Middle Green River, upstream of RM 32. However, Chinook salmon spawning has been documented downstream to RM 24.5 (Washington State Department of Fish and Wildlife [WDFW] 2020a). Fall chum salmon and steelhead spawning has also been documented in the upper reaches of the Lower Green River, above RM 27 (WDFW 2020a). Thus, assuming that certain habitat criteria are met, spawning could occur within the Lower Green River. Appropriate gravel substrates are typically found in riffle, run, or pool-tailout habitats. Based on R2 Resource Consultants' 2013 survey, there are approximately 22.2 acres of potentially suitable spawning habitat in the Lower Green River (R2 Resource Consultants 2014a). Additional criteria that would affect the suitability of spawning habitat in this area include gravel substrate size, habitat cover, water depth, and water flow. For Chinook salmon, suitable spawning substrate size ranges from 1.3 to 10.2 cm (Bell 1986). Pebble counts taken during the 2013 survey near the upstream edge of the Lower Green River resulted in D50[1] values of 1.1 inches (2.9 cm) and 0.9 inch (2.2 cm), suggesting that these habitats would be suitable for spawning (R2 Resource Consultants 2014a). Required depths and water velocities are species-dependent, but Chinook salmon require depths greater than or equal to 9 inches (24 cm) and velocities of 11 inches to 35 inches per second (30 to 91 cm per second) (Bjornn and Reiser 1991).

Overall, spawning habitat is limited within the Lower Green River. Alterations to the river upstream and within this section of the river have depleted supplies of suitable spawning gravels and have reduced the area of suitable spawning habitat.

5.3.1.3 Large Woody Debris

Large Woody Debris is an important part of functioning stream habitat. According to NMFS, properly functioning stream habitat west of the Cascades should have 80 pieces of large wood (defined as more than 24 inches in diameter and more than 50 feet in length) per mile (NOAA 1996). LWD in streams helps create habitat complexity (pools, cover/refugia), and it represents an important link between terrestrial and aquatic habitats (Bilby 1984; Lienkaemper and Swanson 1987; Bilby and Ward 1991). Trees within riparian buffers along streams and rivers provide a source of LWD. While residence times of key LWD pieces within rivers depend on species of trees and flow conditions, research in the Queets River, Washington, has shown an exponential decay in the depletion rate, with more than 80 percent of LWD less than 50 years old (Hyatt and Naiman 2001). This suggests that most of the LWD within a given stream system could disappear in approximately 50 years without a supply of new wood. Compared to conditions before Europeans settlement, the prevalence of LWD has decreased by one or two orders of magnitude in Puget lowland rivers (Collins et al. 2002). Thus, alterations to the riparian and stream conditions in that time have likely reduced the supply and residence of LWD within these systems.

LWD is largely lacking within the Lower Green River. According to a survey by R2 Resource Consultants (2014a), 531 pieces of LWD were counted from RM 32.1 downstream to RM 11 (the confluence with the Black River). This comes to an average of approximately 25 pieces of LWD per mile. Logs and woody debris counted as LWD in this survey if they measured at least 12 inches in diameter and more than 30 feet long. Between RM 26.5 and RM 32.1, most wood was of natural origin (69 of 120 total pieces). Rootwads were the most sighted type of woody debris in this stretch of the river (48 of 120 total pieces). Three natural jams were located around an island complex near RM 30.1, which represents one of the only stretches of complex habitat (braided channels, large and small woody debris, and cover) in the Lower Green River. Between RM 19.2 and RM 26.5, 232 individual pieces of LWD were enumerated. Ten engineered log jams (ELJs) were also installed in this reach. Ninety-seven pieces of LWD were counted between RM 15.5 and RM 19.2, most of which were natural in origin (70 pieces). Four ELJs created by placed logs were also counted. Finally, the stretch between RM 11 and RM 15.5 contained 82 pieces of LWD with three ELJs.

The low prevalence of LWD would be expected given the highly altered nature of the Lower Green River. Natural origin LWD is present, and the placement of ELJs throughout the Lower Green River helps add complex habitat and potential for recruitment of other woody debris. Nonetheless, consideration of LWD prevalence and its sources is important to ensure appropriate habitat and stream functioning into the future.

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[1] D50 equals the median grain size of the sample.

5.3.1.4 Off-channel Floodplain Habitat

In river systems, off-channel floodplain habitat provides additional area for water storage and refugia during high-flow periods, as well as slow, shallow-water habitats critical for juvenile rearing during low-flow periods. Levee development and other alterations within the Lower Green River floodplain have reduced the amount of available off-channel floodplain habitat between RM 11 and RM 32. Areas that historically served as floodplain habitat have since been developed. Forest now represents only about 8 percent of the floodplain, while 74 percent of the floodplain has been disconnected and developed (King County Flood Control District 2016). Further discussion of the current conditions of riparian and wetland habitats in the floodplain can be found in Sections 5.3.2 and 5.3.3 below.

Consistent with the reduced extent of off-channel floodplain habitat, side channel habitats are also rare in the Lower Green River. Two side channels were identified during the 2013 survey by R2 Resource Consultants (2014a). One side channel is a 630-foot channel associated with the Reddington revetment near RM 29. The other (700-feet) is at the Riverview Park complex near RM 23.5 (R2 Resource Consultants 2014a; King County Flood Control District 2016). Together, these side channels make up just 1 percent of the total length of the Lower Green River, demonstrating the limited off-channel habitat available.

5.3.2 Riparian Vegetation

Consistent with the highly developed condition of the Lower Green River, riparian vegetation is limited. The Lower Green River was identified as the highest priority for riparian revegetation efforts within WRIA 9 in 2016 (WRIA 9 Riparian Revegetation Work Group 2016). Analysis of 2009 and 2012 aerial orthoimages and 2013 LIDAR data indicated that the most common land cover class within the 200-foot riparian zone was impervious surface (27 percent) (King County Flood Control District 2016). Natural land cover types made up the next most abundant categories: trees (24 percent), shrubs (19 percent), and grass (19 percent). The remaining 11 percent is made up of other, less common land cover types (e.g., bare earth, ornamental vegetation, etc.). While this gives a broad sense of the land cover, there is a high degree of variation. Where there are levees or revetments along the river, there is a higher proportion of impervious surface and grass. A large proportion of trees within the riparian zone are found in reaches without levees or revetments (Figure 5-1).

Other factors that can help inform the value of riparian vegetation along the Lower Green River include tree or vegetation height and the proportion of native versus non-native species. Along leveed reaches of the river, non-native blackberry and reed canary grass are common. Native vegetation has been largely displaced, and non-native species do not necessarily provide the shade or habitat complexity provided by native species. Using aerial imagery, the amount of sun exposure and available shade have been assessed along the Lower Green River (King County 2005a, Fox 2013; King County Flood Control District 2016). Each study indicates an overall lack of available shade provided by riparian vegetation. Locations of the highest priority include those facing south, due to increased sun exposure, and those with few trees or vegetation (Fox 2013; King County Flood Control District 2016). Even a single row of trees was shown to provide significant shade to the river. Trees within the riparian corridor are typically 50 to 100 feet high. Patches of trees are rare; trees usually occur as individuals or in a single row. Within the lower section of the reach (RM 11 to RM 26), the largest patch of trees extends for approximately 3,500 feet on the left bank near RM 20. Between RM 26 and RM 32, patches of trees are more extensive, but there are gaps of 1,000 feet or more between patches (King County Flood Control District 2016). Trees make up 41 percent of the riparian zone for this section of the river, compared to 18 percent for the section downstream.

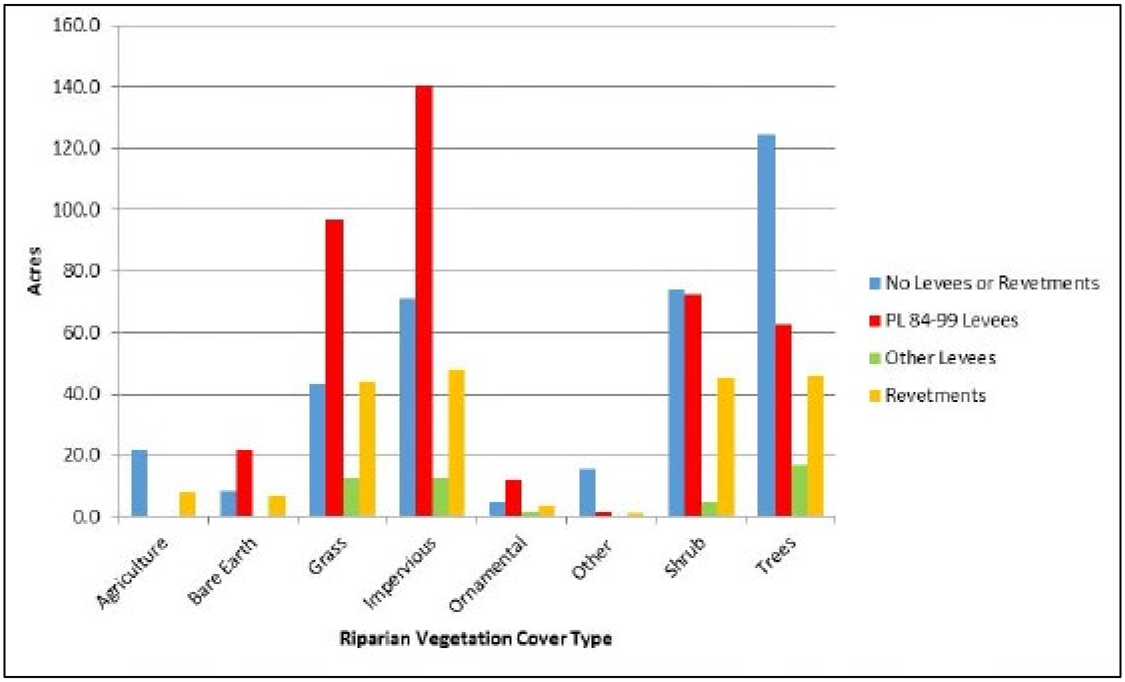

Figure 5-1. Comparison of Riparian Vegetation Cover between Levee Systems and Non-levee system Reaches for RM 11 to 32
Source: King County Flood Control District 2016.

5.3.3 Wetlands

As noted above, the Lower Green River floodplain has largely been developed, limiting the area available for wetland habitat. The National Wetland Inventory currently includes 7,920 acres of freshwater emergent or freshwater forested/shrub wetlands within WRIA 9, the area encompassing the Green-Duwamish watershed (U.S. Fish and Wildlife Service [USFWS] 2020a). This is approximately 2 percent of the total area of the watershed. However, much of this information was inferred from aerial imagery collected in 1980 and 1981. Aerial imagery analysis of the Lower Green River floodplain in 2011 showed that wetlands made up 13 percent (2,579 acres) of the floodplain (King County Flood Control District 2016). While these datasets represent different analysis areas, they both indicate the relatively small portion of area surrounding the Lower Green River that is currently wetland habitat.

5.4 Biological Resources

This section details the biological resources that use the aquatic habitat described in the previous section. The Lower Green River supports several salmonid species, along with other fish, aquatic species, birds, and mammals. The current status and the habitat requirements of species in each group are discussed below.

5.4.1 Salmon Populations in the Green River Basin

The Green River Basin is known to be used by a variety of salmonid species at different points in their life cycles. The following sections describe the timing, abundance, distribution, and habitat needs of each species documented within the Lower Green River. Use of habitats within other reaches of the Green River are mentioned, but they are not discussed in detail.

5.4.1.1 Chinook Salmon

Chinook salmon (*Oncorhynchus tshawytscha*) have an historic and current presence within the Lower Green River. Historically, the Green River supported a spring run of Chinook salmon, but this run is now considered extinct within the basin (Kerwin and Nelson 2000; Ruggerone and Weitkamp 2004). The current population of Chinook salmon returns in the summer and fall, entering the Duwamish River between mid-June and November (Ruggerone and Weitkamp 2004). Spawning typically follows in September through November, with peak spawning in October. The population within the Lower Green River includes both natural-origin and hatchery-origin fish. WDFW operates the Soos Creek Hatchery, which releases fall Chinook salmon, coho salmon, and summer and winter steelhead. The breakdown between natural-origin and hatchery-origin escapement within the Green River between 2003 and 2019 is shown in Figure 5-2. Historic run sizes documented over the period of 1968-1996 averages about 5,700 natural-origin spawners and 24,000 hatchery origin spawners (Kerwin and Nelson 2000). In 2018, it was estimated that 23,910 juvenile Chinook salmon of hatchery-origin migrated through the Lower Green River between January and June (Topping and Anderson 2020). This hatchery-origin population is meant to integrate with the natural population and is primarily designated for harvest. The following sections provide further details on habitat use by Chinook salmon within the Lower Green River, as well as general habitat requirements of the species at different life stages.

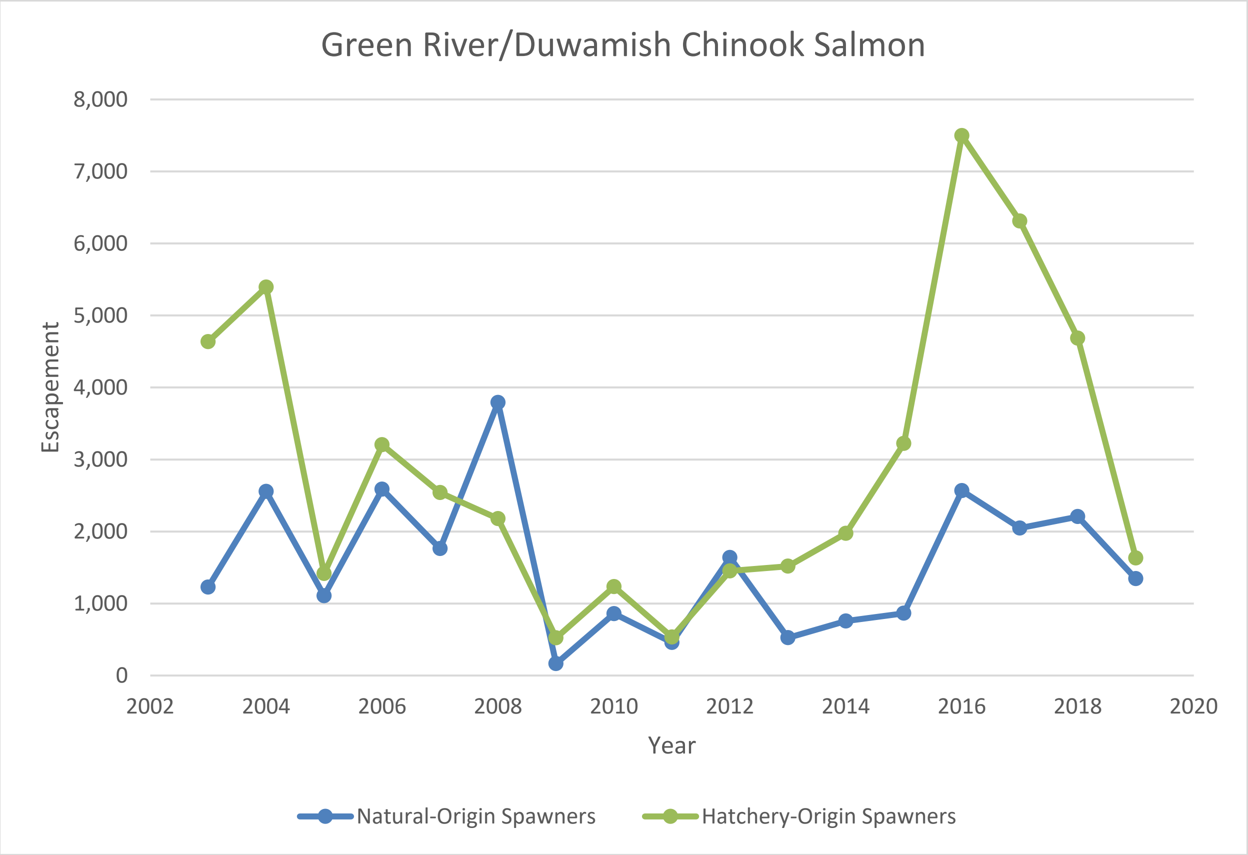

Figure 5-2. Natural-origin and Hatchery-origin Escapement of Chinook Salmon within the Green River/Duwamish River between 2003 and 2019

Source: WDFW 2020b.

Both adult and juvenile Chinook salmon migrate through the Lower Green River. Chinook salmon spawning has been observed downstream as far as RM 24, but most spawning occurs within the Middle Green River, especially since the construction of the Tacoma Headworks Dam, which blocked upstream fish passage (King County Flood Control District 2016). In 2018, 320 Chinook salmon redds were counted downstream of RM 34.5, compared to 3,023 upstream of RM 34.5 (Topping and Anderson 2020).

Following incubation, juvenile Chinook salmon begin to out-migrate in low numbers in January (Topping and Anderson 2020). The out-migration of juvenile Chinook salmon in the Lower Green River is bimodal, peaking once in February/March and again in May/June. These two peaks represent two different life history trajectories: fingerlings and fry. Based on recent data from the WDFW screw trap at RM 34.5, most juvenile Chinook salmon out-migrate as fry (87 percent of juvenile Chinook salmon; 274,337 in 2018) compared to fingerlings (13 percent of juvenile Chinook salmon; 41,549 in 2018). In this dataset, individuals are classified as fry if they are less than 1.8 inches (45 mm) long. This breakdown of fry to fingerling migrants has varied over nearly 20 years of sampling at the screw trap, suggesting that there may be environmental fluctuations that contribute to the size of juveniles and timing of out-migration. Nonetheless, these two categories of Chinook salmon juveniles represent two of five possible life history trajectories within the Green River described by Ruggerone and colleagues (Ruggerone and Weitkamp 2004):

- Yearling migrants
- Marine-direct fingerlings
- Lower Green River-reared fry
- Estuarine-reared fry
- Marine-direct fry

The yearling migrant life history trajectory is no longer represented in Green River(Ruggerone and Weitkamp 2004). The other four trajectories are sub-yearling migrants that have different residence times at their incubation location, within the Lower Green River, and in the Duwamish River estuary. The two categories of juveniles observed at the WDFW screw trap are likely the marine-direct fingerlings and marine-direct fry. Due to the high degree of modification within the Lower Green River and the Duwamish River estuary, the residence time of Chinook salmon fry is expected to be on the order of days, limiting the rearing time in these habitats (R2 Resource Consultants 2014b; Topping and Anderson 2020). Thus, there are likely few Lower Green River-reared or estuarine-reared fry, but the breakdown of these different possible life history trajectories is unknown. Further sampling within the Lower Green River tracking individual fish would be required to achieve a full understanding of the residence time of juvenile Chinook salmon within this reach of the river.

Puget Sound Chinook salmon were listed as threatened under the ESA on March 24, 1999 (64 FR 14308), and critical habitat was designated on September 2, 2005 (70 FR 52629). With the designation of critical habitat for Puget Sound Chinook salmon (70 FR 52630), specific physical and biological features[2] (PBFs) were designated as essential for conservation of the species and each distinct population segment (DPS). Consideration of these features gives context for the type and

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[2] Listed as Primary Constituent Elements in final rules for Chinook salmon critical habitat (70 FR 52630).

quality of habitat available within the Lower Green River. For freshwater rearing sites, PBFs that have been identified include the following:

- Sufficient water flow and connectivity with the surrounding floodplain to support juvenile growth and mobility
- Water quality and prey resources to support juvenile development
- Habitat structure that creates natural cover and shade (e.g., large wood, aquatic vegetation, side channels, and undercut banks)

Freshwater migration corridors require similar features, along with routes that are free of barriers and areas with high levels of predation. Chinook salmon that are passing through the Lower Green River (either as juveniles moving downstream or adults moving upstream), rely on these features to achieve successful out-migration to the Puget Sound or upstream to spawning grounds. Section 5.3, above, contains details about the current prevalence of these habitat requirements within the Lower Green River.

5.4.1.2 Coho Salmon

The current population of coho salmon (*O. kisutch*) within the Lower Green River is made up of two stocks: (1) Green/Duwamish and (2) Newaukum Creek (Kerwin and Nelson 2000). Adults return to the Green River between August and December, with spawning occurring between September and January and peaking in November (Jeanes and Hilgert 2001; Nelson et al. 2004). This time range captures both the Green/Duwamish and Newaukum Creek stocks; the Newaukum Creek stock typically spawns later than the Green/Duwamish stock (King County Flood Control District 2016). Spawning within the mainstem river primarily occurs upstream of the Lower Green River between RM 34 and RM 61. The spawning population of coho salmon in the Green River consists of both natural-origin and hatchery-origin fish. Hatchery-origin fish are released from the WDFW Soos Creek Hatchery, which has released hatchery-reared coho salmon since the early 1900s. Figure 5-3 shows the total natural escapement (i.e., returning spawners) of coho salmon in the Green River/Duwamish from 1999 to 2019. While these data are not broken down by origin, production data from the Soos Creek Hatchery estimate that 45,070 hatchery adults were produced from 2007 to 2009, averaging to approximately 15,000 adults per year (WDFW 2020b).

Coho salmon use of the habitats available within the Lower Green River is limited. Coho salmon typically rear in freshwater habitats for one year prior to outmigrating as smolts. Fewer numbers of juvenile coho salmon out-migrate as sub-yearling fry (King County Flood Control District 2016). In 2018, 1,271 smolts and 161 fry were captured at the WDFW screw trap (Topping and Anderson 2020). Based on these values, the estimated abundance for natural-origin coho salmon smolts in 2018 was 58,011. Peak migration typically occurs in April, with most (more than 50 percent) juveniles outmigrating between March and May (Jeanes and Hilgert 2001; Nelson et al. 2004; King County Flood Control District 2016; Topping and Anderson 2020).

Habitat requirements for coho salmon are similar to those outlined for Chinook salmon in Section 5.4.1.1 above. Because they spend a year in freshwater habitats before outmigrating, coho salmon smolt rely heavily on woody debris and other instream cover in slow water habitats during rearing (King County Flood Control District 2016). Appropriate water quality and temperature are also necessary to ensure suitable habitat for coho salmon smolts. Due to the general lack of these characteristics within the Lower Green River, most of the juvenile coho salmon rearing likely occurs in the Middle Green River.

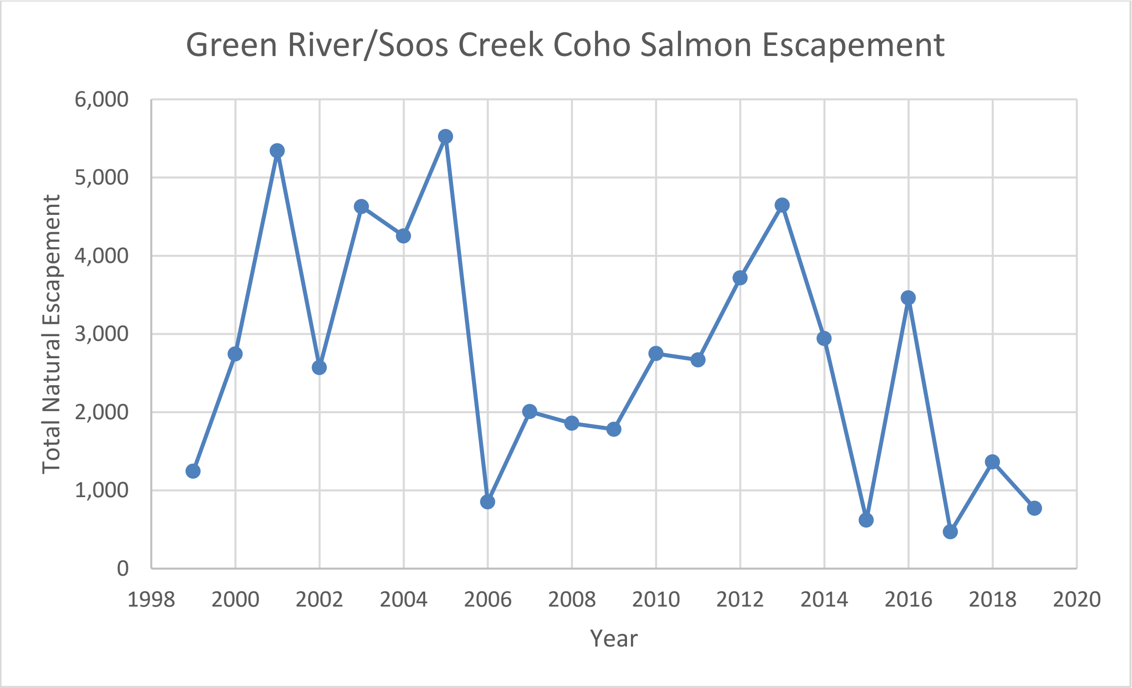

Figure 5-3. Total Natural Escapement of Green River/Soos Creek Coho Salmon from 1999 to 2019

Source: WDFW 2020b.

5.4.1.3 Chum Salmon

Chum salmon (*O. keta*) have an historic and current presence within the Green River, but their population numbers have not been well quantified over time. The chum salmon that occur within the Lower Green River are part of two separate stocks: (1) Green River fall-run and (2) Crisp Creek (or Keta Creek) fall-run (Kerwin and Nelson 2000). Adults of both stocks typically return between September and December, with spawning occurring from November through January (Jeanes and Hilgert 2001; Nelson et al. 2004).

Juvenile chum salmon out-migrate as fry between January and July, with numbers peaking in April (Jeanes and Hilgert 2001; Nelson et al. 2004; Topping and Anderson 2020). In 2018, the total catch of chum salmon fry at the WDFW screw trap was estimated to be 81,812, including estimated individuals missed during trap outages (Topping and Anderson 2020). A production estimate was not calculated for this population, and hatchery-origin fish could not be separated out because the Keta Creek Hatchery does not mark the chum salmon being released. However, the catch for 2018 was greater than the catches from 2011 and 2017 (25,796 and 49,515, respectively), suggesting a potential increase in the population size over time (Topping and Zimmerman 2012; Topping and Anderson 2018).

While the habitat requirements for chum salmon are largely the same as those described for other salmonids, juvenile chum salmon typically out-migrate shortly after emergence. This means that the rearing time for juvenile chum salmon in freshwater habitats is limited (King County Flood Control District 2016).

5.4.1.4 Pink Salmon

Historically, pink salmon (*O. gorbuscha*) were present in low numbers within the Lower Green River, with limited escapement data (Kerwin and Nelson 2000). However, more recent data suggest that the population of pink salmon in the Green River basin has expanded. WDFW forecast a run size of 141,130 individuals for the 2019 return year (WDFW 2019). As with the rest of the Puget Sound, the

Green River stock is believed to return only in odd numbered years (Kerwin and Nelson 2000). Consistent with this belief, catch at the WDFW screw trap in 2018 was estimated to be 143,640 pink salmon fry and zero in 2017 (Topping and Anderson 2018; 2020). Given the apparent historic scarcity of pink salmon within the Lower Green River, it is unknown whether the current stock consists of strays recolonizing the basin or a remnant population. Nonetheless, the presence of fry is an indication of reproductive success and potential for a self-sustaining population.

5.4.1.5 Steelhead

Steelhead (*O. mykiss*) within the Lower Green River consist of a summer and a winter run. The summer run is believed to be of hatchery-origin, deriving from the Skamania summer steelhead stock first introduced in 1965 (Kerwin and Nelson 2000). This run typically returns between April and October and spawns from January to March. Hatchery-origin fish within the Lower Green River are associated with the WDFW Soos Creek Hatchery. Between 2007 and 2009, it was estimated that the hatchery produced 613 summer steelhead adults and 510 winter steelhead adults (WDFW 2020b). The winter steelhead produced by the hatchery are part of a propagation program to mitigate for lost abundance associated with the installation of the HHD (NMFS 2017). The winter run is made up of natural-origin fish, along with some early spawning members of the hatchery stock (Kerwin and Nelson 2000). However, the hatchery-origin adults primarily return earlier than the natural-origin stock, so there is likely little genetic exchange between the stocks (WDFW 2020b). Winter steelhead return to the Green River between November and February and spawn from February to June. Spawning of winter steelhead within the Green River primarily occurs between RM 25 and RM 61 (WDFW 2020b). Escapement numbers from 1978 to 2019 for this natural stock in the Green River/Duwamish are shown in Figure 5-4.

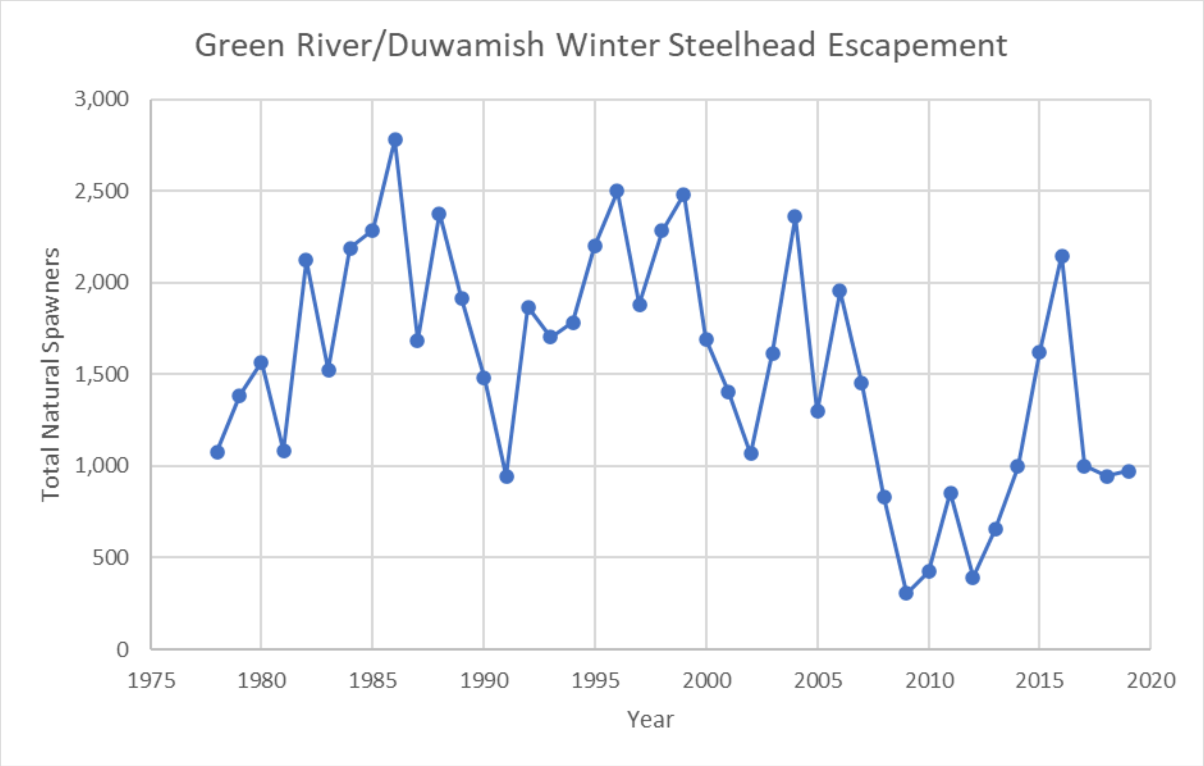

Figure 5-4. Total Natural Escapement of Green River/Duwamish Winter Steelhead from 1978 to 2019
Source: WDFW 2020b

Juvenile steelhead outmigrate primarily as smolt between January and July, with numbers peaking in May (Topping and Zimmerman 2012; Topping and Anderson 2018; 2020). In 2018, the total estimated catch of natural-origin steelhead smolts was 139 (Topping and Anderson 2020). An additional 165 hatchery-origin steelhead were captured. Catch numbers were not sufficient to estimate total production.

Puget Sound steelhead were listed as threatened under ESA on May 11, 2007 (72 FR 26722), and critical habitat was designated on February 24, 2016 (81 FR 9252). The characteristics important for critical habitat for steelhead are the same as those listed above for Chinook salmon (Section 5.4.1.1). Specific to the habitat within the Lower Green River, important characteristics include enough water quality and quantity for rearing and natural cover (i.e., large wood, side channels, and undercut banks).

5.4.1.6 Bull Trout

Bull trout were listed as threatened under ESA on November 1, 1999 (64 FR 58910), and critical habitat was designated on October 18, 2010 (75 FR 63898). While bull trout (*Salvelinus confluentus*) may occur within the Lower Green River, it is unlikely that there is a self-sustaining population (i.e., spawning does not occur within the river or its tributaries) (King County Department of Natural Resources 2000; Berge and Mavros 2001). However, the Lower Green River is included as foraging, migratory, and overwintering critical habitat for bull trout (USFWS 2010). This habitat is particularly important for bull trout of the amphidromous life history form that moves between salt and fresh water during its life cycle. Important characteristics of foraging, migratory, and overwintering habitat for bull trout include space for growth and normal behavior, food, cover or shelter, and habitats protected from disturbance (75 FR 63898). Thus, bull trout are rarely present within the Lower Green River as adults.

5.4.1.7 Coastal Cutthroat Trout

Coastal cutthroat trout (*O. clarki clarki*) are distributed from the Eel River in northern California to the Prince William Sound area in Alaska (Johnson et al. 1999). Compared to other salmonid species, the data available for coastal cutthroat trout historical and current populations are limited (Johnson et al. 1999; Kerwin and Nelson 2000). The USFWS has twice proposed a rule to list the southwestern Washington/lower Columbia River DPS of coastal cutthroat trout as threatened under ESA, but the ruling was subsequently withdrawn both times due to lack of evidence of marked declines (USFWS 2020b). The species is still listed as a federal species of concern.

Coastal cutthroat trout have been documented in the Lower Green River. In 2018, eight coastal cutthroat trout smolt and one adult were captured at the WDFW screw trap (Topping and Anderson 2020). In 2017, 54 coastal cutthroat smolt were captured (Topping and Anderson 2018). Upstream adult migration is believed to occur between July and January, with spawning occurring between February and May (Jeanes and Hilgert 2001; Nelson et al. 2004). Juvenile rearing occurs year-round, indicating that coastal cutthroat trout may be present within the Lower Green River throughout the year. Juvenile outmigration typically occurs between April and June (Jeanes and Hilgert 2001; Nelson et al. 2004).

Habitat requirements for coastal cutthroat trout are similar to those described above for the other salmonids. However, they typically rely more heavily on freshwater habitats. Particularly, coastal cutthroat trout prefer deeper pool habitats and natural cover (USFWS 2020b).

5.4.2 Other Fish

Other species of fish that occur within the Lower Green River include whitefish (*Coregonus clupeaformis*), largescale suckers (*Catostomus macrocheilus*), largemouth bass (*Micropterus spp.*), black crappie (*Pomoxis nigromaculatus*), white crappie (*Pomoxis annularis*), peamouth (*Mylocheilus caurinus*), and sculpins (*Cottoidea spp*.). Many of these species have been introduced to the Green River.

Warm water species (including bass and crappie species) likely use off-channel habitats outside of the main river flows. Cold water species like whitefish, largescale suckers, and sculpins are more likely to be found in the main channel, although suckers and sculpins may also use off-channel areas. The distinct temperature preferences of these species typically result in segregation by habitat within the river. Sampling of warm and cold water species in Lake Washington found that warm water gamefish made up most of the sample by number, but most of the biomass was made up of cold water species (Garrett et al. 2017). Given the proximity of the Green River to Lake Washington, other cold water and warm water species are likely present in the Lower Green River, as well.

5.4.3 Other Aquatic Biota

In addition to fish, other aquatic and aquatic-related biota that may occur within the Lower Green River or the adjacent habitat include macroinvertebrates, birds, and mammals. The following paragraphs describe common species within each group that are found within the Lower Green River, and the habitat features upon which they rely.

5.4.3.1 Benthic macroinvertebrates

Benthic macroinvertebrates are an important prey resource for fish in stream and river systems. Often considered the base of the food chain, the composition and abundance of benthic macroinvertebrate communities are good indications of the overall health of the system. King County has undertaken benthic macroinvertebrate sampling in many streams and rivers within the county to assess the condition of each system. Using King County's B-IBI score, various benthic macroinvertebrate community composition and abundance metrics are integrated to facilitate comparison over time and between sites (King County 2004, 2005b). The score ranges from 10 to 50, with values from 38 to 50 considered to be good or excellent and values lower than 26 to be poor or very poor. Benthic macroinvertebrate sampling from 2002 and 2003 highlighted the poor condition of the Lower Green River (King County 2004; 2005b). Mean B-IBI values for the lower Green River were 18.8 ± 9.5 and 23.6 ± 6.5 in 2002 and 2003, respectively. The B-IBI score relies heavily on the number of Ephemeroptera (mayfly), Plecoptera (stonefly), and Trichoptera (caddisfly) taxa. The relatively low B-IBI scores of the sites within the Lower Green River indicate a low abundance of these macroinvertebrates. A few common species collected at the Lower Green River sites in 2003 are *Narpus* spp., *Chironomidae* spp., and *Baetis tricaudatus* (King County 2005c). Although there are benthic macroinvertebrates present, the sampling results indicate an overall lack of diversity and functionality of the community within the Lower Green River.

5.4.3.2 Birds

A variety of resident and migrant bird species use the habitat in and around the Lower Green River. At the Green River Natural Resources Area (Kent, Washington), seasonal bird surveys have documented almost 200 species of birds using the aquatic and riparian habitat since the program began in 1999 (City of Kent 2020). Some common species sighted year-round include Canada geese (*Branta canadensis*), northern shovelers (*Anas clypeata*), gadwalls (*Mareca Strepera*), mallards (*A. platyrhynchos*), American coots (*Fulica americana*), great blue herons (*Ardea herodias*), and redtailed hawks (*Buteo jamaicensis*). Migratory species that are commonly sighted over the winter include buffleheads (*Bucephala albeola*), ring-necked ducks (*Aythya collaris*), lesser scaups (*Aythya affinis*), and double-crested cormorants (*Phalacrocorax auritus*).

In addition to these species of birds, bald eagles (*Haliaeetus leucocephalus*) have been documented along the Lower Green River. An active nest that usually produces two eaglets each year was recently monitored during a mitigation project at RM 20.3 (King County Department of Natural Resources and Parks 2017). The nest is in a cluster of three large cottonwood trees adjacent to the river. The proximity of this nest to the river is evidence that the aquatic and riparian habitat is suitable to support bald eagles.

5.4.3.3 Mammals

Mammals that may occur within the Lower Green River include muskrats (*Ondatra zibethicus*), North American beavers (*Castor canadensis*), and North American river otters (*Lontra canadensis*). These species are common within rivers and lakes throughout the Puget Sound lowlands. Additionally, harbor seals (*Phoca vitulina*) likely use the habitat within the Lower Green River. Seals often forage within the lower reaches of rivers, especially when adult salmon are returning.

5.5 Future Habitat Conditions

Future habitat conditions will depend largely on the magnitude of development and restoration priorities of resource managers within the Lower Green River Corridor, as well as future climate conditions. Trends in these elements are discussed below.

Development in the Lower Green River Corridor is expected to increase with population growth. The city of Auburn predicts an increase in population of over 12,500 people by 2040. Similarly, the city of Kent anticipates the additional of more than 17,000 households by 2040 (see Built Environment, Appendix C, Section 4.3.1). Growth in these cities and others along the Lower Green River is expected to put continued pressure on the river, its floodplain, and adjacent riparian and terrestrial habitats. However, given that much of the area is currently developed (Section 5.3.1.4), the relative increase in development is not expected to be significant. Compliance with existing regulations would avoid and minimize many of the potential environmental impacts.

Future climate change has the potential to alter the flow of rivers and streams throughout the Pacific Northwest. Warmer temperatures will result in a greater proportion of precipitation falling as rain instead of snow at higher elevations, leading to more immediate increases in flows, rather than the modulated and seasonal flows fed by melting snowpack. Models of climate change and flow in the Green River suggest that the watershed will be rain-dominant by the 2080s, leading to higher annual variability (Lee et al. 2018). Average streamflow between October and March in the Green River is predicted to increase by 10 to -22 percent near Auburn, relative to the 1970 to 1999 average. Additionally, the 10-year peak flow is projected to increase by 14 percent. However, while the flows are projected to increase, the model suggests that the HHD on the Green River has the reservoir capacity to manage flows downstream, even in the largest predicted floods (Lee et al. 2018). Thus, habitat within the Lower Green River is unlikely to be altered significantly by increased flows resulting from climate change.

The warmer air temperatures predicted with climate change are also likely to exacerbate the elevated water temperatures already seen within the Lower Green River. The lack of shade within the riparian zone means that many parts of the river receive significant direct sunlight. Temperatures above 22°C may be lethal to aquatic life, particularly salmonids, per state water quality standards (King County 2017a). Nonetheless, release of water from near the bottom of the

HHD reservoir during the summer means that relatively cold water is introduced downstream. This suggests, and temperature data collected on other regulated river systems support, that the release of water from the dam may help to modulate water temperature increases with climate change (King County 2017a).

Recent studies and reports have identified a number of strategies that could help to restore the aquatic habitat available in the Lower Green River, including riparian restoration (WRIA 9 Riparian Revegetation Work Group 2016, strategic shade improvements (Coffin et al. 2011; King County Flood Control District 2016), and rearing habitat enhancement (WRIA 9 2021). Prioritization of these efforts could alter the future aquatic habitat conditions of the Lower Green River. To fully understand aquatic habitat conditions in the future, these projects will have to be considered in concert.

5.6 Impacts

Permanent impacts from the presence and operation of the various flood management facility types, and the short-term impacts resulting from their construction are assessed here.

5.6.1 Permanent (Operational) Impacts

The projected linear feet of each flood facility type under each alternative are summarized in Table 5-5. The ecological effects of streambank modifications on each ecosystem function are ranked by alternative in Table 5-8. The estimated extents of channel margin and floodplain available for restoration of the floodplain and/or riparian habitat function are summarized by alternative and project type in Table 5-9.

Table 5-8. Summary of Anticipated Impacts on Environmental Resources and Associated Ecological Functions by Alternative

		Level of Effect on Ecological Function Rankings by Facility Type†						Weighted Level of Effect Rank by Alternative		
Resources/Issues	**Ecological Function**	**None**	**Revetment**	**Type A**	**Type B**	**Type C**	**Type D**	**Alt. 1**	**Alt. 2**	**Alt. 3**
Primary life stage – juvenile rearing	Off-channel habitat	5	3	1	1	2	4	2.5	2.6	2.6
	Tributary access	5	5	1	1	2	4	2.8	2.9	2.9
	Pool habitat	4	3	1	3	3	4	2.6	2.7	2.7
	Woody debris	5	3	1	3	4	4	3	3.1	3.2
	Shallow margins	5	2	1	3	4	4	2.8	3	3.1
	Riparian vegetation	5	3	1	2	3	4	2.7	2.9	2.9
	Substrate	4	3	2	2	3	4	2.8	2.9	2.9
Primary life stage – adult migration	Pool habitat	4	3	1	3	3	4	2.6	2.7	2.7
	Riparian vegetation/ shade	5	3	1	2	3	4	2.7	2.9	2.9
	Woody debris	5	3	1	3	4	4	3	3.1	3.2
	Fish passage improvements	5	4	1	1	2	5	2.8	2.9	2.9

Table 5-8. Summary of Anticipated Impacts on Environmental Resources and Associated Ecological Functions by Alternative (continued)

		Level of Effect on Ecological Function Rankings by Facility Type†						Weighted Level of Effect Rank by Alternative		
Resources/Issues	**Ecological Function**	**None**	**Revetment**	**Type A**	**Type B**	**Type C**	**Type D**	**Alt. 1**	**Alt. 2**	**Alt. 3**
Ecosystem processes	Floodplain interaction	5	3	1	1	2	4	2.5	2.6	2.6
	Habitat connectivity	5	2	1	1	2	4	2.3	2.5	2.4
	Hydrology/flow regime	4	3	1	2	3	4	2.5	2.6	2.6
	Sediment dynamics	5	3	1	2	3	4	2.7	2.9	2.9
	Wood load	5	2	1	2	3	4	2.6	2.7	2.8
	Trophic support	5	3	1	2	3	4	2.7	2.9	2.9
	Temperature	5	3	1	2	3	4	2.7	2.9	2.9
Other stream biota	Fish	4	3	1	2	3	4	2.3	2.4	2.5
	Macroinvertebrates	4	2	1	2	3	4	2.5	2.6	2.6
	Flora	5	3	1	2	3	5	2.7	2.9	2.9

† Rankings are a qualitative measure of effect on ecological function on a 1 to 5 scale, with a value of 1 indicating the highest level of degradation or loss, and a value of 5 indicating an increase in the highest level of functional gain. Rankings are intended as qualitative indicators, not as quantitative measures of functional gain.

Table 5-9. Estimated Facility Type Acres, Acres Available for Floodplain and/or Riparian Restoration, and Acres Supporting Inundation at Ecological Flows by Alternative

		Facility Type Area (acres)†		
Alternative	**Facility Type‡**	**Total Area**	**Available for Restoration**	**Percent of Total Area Receiving Some Inundation at Ecological Flows¥**
1 – Project by Project	Type A	85-125	0	100%
	Type B	30-50	15-25	100%
	Type C-1	20-30	15-20	93%
	Type C-2	60-90	55-80	100%
	Total	195-295	85-125	99%
2 – Systematic	Type A	70-105	0	100%
	Type B	35-55	20-30	100%
	Type C-1	15-25	15-20	92%
	Type C-2	75-110	65-100	100%
	Total	200-295	100-150	99%

Table 5-9. Estimated Facility Type Acres, Acres Available for Floodplain and/or Riparian Restoration, and Acres Supporting Inundation at Ecological Flows by Alternative (continued)

		Facility Type Area (acres)[†]		
Alternative	**Facility Type[‡]**	**Total Area**	**Available for Restoration**	**Percent of Total Area Receiving Some Inundation at Ecological Flows[¥]**
3 – Enhanced Systematic	Type A	65-95	0	100%
	Type B	40-60	20-30	100%
	Type C-1	20-30	15-25	93%
	Type C-2	170-255	150-230	100%
	Flood storage	220-325	195-295	41%
	Total	510-765	380-580	74%

[†] This is the area riverward of the levee crest.

[¥] Facility type acreage available for restoration that would experience some level of inundation at ecological flows, as determined by the hydraulic model range for the 2-year and 10-year flow events. This is not the inundated acreage total. It is assumed that project-specific design criteria would integrate habitat improvements at a range of normal flows typical during adult and juvenile migration periods (i.e., less than 2-year flow).

[‡] Subtype C-1 reflects the conceptual Type C facility with a habitat bench (typically 20-30 feet wide) just above the ordinary high-water line, and 3:1 riverward side slopes above the bench up to the levee crest. Subtype C-2 is where an alternative results in a levee setback well away from the river. Alternative 3 includes the proposed acquisition of 220 to 235 acres of floodplain habitat, approximately 90 percent of which could be restored to provide functional floodplain habitat. However, under the Alternative 3 analysis scenario, only 41 percent of the acquired parcel acreage would receive some level of inundation at ecological flows.

The anticipated permanent impacts of each alternative are analyzed and compared using ordinal ecosystem function condition rankings for each facility type, weighted by the projected linear feet of streambank in each facility type under each alternative. The ordinal ranking schema for each resource is defined in Section 2.1. The weighted ranking for each ecosystem function is calculated by multiplying the rank value for each facility type by the length of bank in that facility type (see Table 5-8). The rank values assigned to each facility type and the supporting rationales are described in Attachment 1, Table A-1. Weighted ordinal rankings by resource and ecosystem function are summarized for each PEIS alternative in Table 5-8. A ranking of 1 indicates the highest potential for resource degradation or loss, and a value of 5 indicates the highest level of potential functional gain for the resource.

Ecosystem function ranks are not intended to represent a quantitative score; they provide an index allowing for the comparison of alternatives against the qualitative ranking criteria described for each resource in Section 2.1. For example, consider two alternatives: one with an off-channel habitat rank of 4 for juvenile salmonid rearing, and the other with a rank of 2. The difference in rank would not indicate that the former alternative would provide twice as much off-channel habitat as the latter, or that it would have double the functional value for juvenile rearing. Rather, according to the ranking criteria in Table 5-2, the former alternative could provide qualitatively more off-channel habitat than the latter, and/or that habitat would likely have greater functional value. The former could contribute to NFC, whereas the latter would not.

As indicated in Section 2.2, the ecosystem function ranks are complemented by estimates of the amount of habitat that could be available for restoration of floodplain and/or riparian habitat function under each alternative. The facility type acreage available for restoration under each alternative was estimated using the methods described in Section 2.2 and is presented in Table 5-9. In combination, the qualitative ecosystem function rankings and the extent of habitat available for restoration of floodplain and riparian function provide a basis for evaluating and comparing how each alternative would likely affect the condition of its parent environmental resource. This comparison is provided by resource in the following sections.

When interpreting these results, it is important to recognize that, given the programmatic nature of the District's Plan, the size, location, and configuration of proposed facility types under each alternative have not been fully developed. This information would be developed in further planning and as each facility is designed. The ecosystem function rankings are based on the simplified conceptual design for each facility type relative to other facility types. The rankings for each facility type treat each flood management approach the same, regardless of differences in design that could have a substantial effect on ecosystem function. The ranking of facility types is also made irrespective of the existing condition of the adjacent floodplain. For example, a substantial proportion of the proposed facility types for each alternative could be associated with adjacent land uses that do not currently support important ecosystem functions (see Section 4.1.1 [Land Use], Appendix C). Much of the adjacent floodplain is occupied with commercial, industrial, residential, public facility, and right-of-way/utility land uses. A detailed assessment of a given facility type's effects on ecological functions would then have to occur on a site- and project-specific basis during the implementation of future projects.

The rankings, therefore, provide a basis for qualitative comparison of each alternative. They are not intended to evaluate the benefits provided by specific projects. In contrast, the quantification of habitat available for restoration considers both the type of project that could potentially be implemented and the extent to which that project would be inundated under ecological flows.

For example, the tributary access rank for each Type A and B facility would apply equally across all projects under a given alternative, regardless of whether these facility types could overlap a tributary confluence when that alternative would be fully implemented. Type C-1 levees are based on a conceptual design setback of 150 feet, slightly below the 165-foot minimum functional width target for riparian vegetation in the Lower Green River established by WRIA-9. Approximately 75 percent of the Type C-1 facility footprint could be available for floodplain and/or riparian restoration. In contrast, Type C-2 projects would have much wider setbacks that could allow for more extensive restoration covering up to 90 percent of the project footprint, including riparian enhancement and a portion available for inundation under ecological flows. This facility would likely provide a greater degree of riparian function, woody debris recruitment, and off-channel habitat potential than a C-1 facility.

The generalized results presented here do not capture the full range of site-specific conditions that could influence ecological function and restoration potential. For example, the existing Type C-2 Russell Road facility has large setbacks of several hundred feet integrated into a broader complex of floodplain and off-channel habitat restoration. However, the riparian zone is bisected by the roadway, which limits the functional riparian width to less than 70 feet over approximately 50 percent of the facility's 5,600 linear feet of bank length. In this case, the ecosystem function rankings and assumed restoration potential applied to Type C facilities may overestimate the amount of habitat available and the potential value of riparian enhancement. The impacts of each alternative on the environmental resources and associated ecological functions considered in this analysis are summarized in the following sections.

5.6.1.1 Juvenile Salmonid Rearing

The rankings for juvenile salmonid rearing were based on evaluation of seven ecological functions:

1. Access to off-channel habitat of sufficient quantity and quality for overwinter rearing
2. Access to tributary rearing habitats
3. Sufficient quantity and quality of pool habitat
4. Woody debris of sufficient size, density, and quantity to provide cover and refuge and create habitat complexity
5. Shallow margin habitat of sufficient quantity and quality to support fry colonization and early juvenile rearing
6. Riparian vegetation providing cover, shade, and allochthonous inputs
7. Low substrate embeddedness levels to maintain interstitial spaces that provide refuge from predation and high stream flows

The ranking criteria for juvenile salmonid rearing and adult spawning habitat (Table 5-2) are defined relative to the properly functional condition metrics described in the National Marine Fisheries Service (NMFS) (NMFS 1996) Matrix of Pathways and Indicators, as applied in the WRIA 9 (WRIA 9 and King County 2005; WRIA 9 2021) salmon habitat plans. The 2021 Salmon Habitat Plan defined a set of NFCs for selected environmental attributes that would contribute to salmonid habitat. The ranking criteria consider whether a facility type would contribute to, or degrade from, NFCs where objectives for that ecosystem function have been defined.

Alternative 1: Project by Project Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment 1, Table A-1, Alternative 1 could degrade the condition of six out of the seven ecosystem functions that support juvenile salmon rearing habitat based on streambank impacts. As shown in Table 5-8, this alternative could modestly reduce the quantity and quality of accessible off-channel, pool, and shallow margin habitat, could further limit tributary access, and would be unlikely to contribute to improved substrate conditions. The retention of existing and addition of new Type A and Type B facilities could contribute to further degradation of riparian conditions and could limit opportunities to restore riparian vegetation. Improvements to existing Type B and Type C facilities and the addition of new Type B and Type C facilities could contribute to increased woody debris density, but would not, in many cases, provide a reliable long-term source of woody debris recruitment.

While Alternative 1 could modestly degrade the condition of certain ecosystem functions that contribute to juvenile salmonid habitat based on streambank impacts, it could also make 85 to 125 additional acres of streambank available for floodplain and/or riparian habitat restoration. Nearly all of this area could be at least partially inundated under ecological flows and could contribute to juvenile salmonid rearing. Restoration of these habitats would likely achieve the WRIA 9 (2021) recommended 10-year targets for high flow channel and bank armor restoration, and it could contribute to the LWD restoration target.

Alternative 2: Systematic Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment 1, Table A-1, Alternative 2 could likely contribute to the degraded condition of five out of the seven ecosystem functions that support juvenile salmon rearing habitat based on streambank impacts. However, the extent and severity of these impacts could be reduced in comparison to Alternative 1. As shown in

Table 5-8, this alternative could likely reduce the quantity and quality of accessible pool habitat, could have the potential to limit tributary access, and would be unlikely to contribute to improved substrate conditions. The retention and/or improvement of approximately 14.5 miles of existing Type A facilities and the addition of 2.5 miles of new Type A facilities could exacerbate degraded riparian and streambank conditions. Those impacts could be partially offset by the replacement of existing levees with new Type B and C facilities, which would allow for riparian zone enhancement. Improvements to existing Type B and Type C facilities and the addition of new Type B and Type C facilities could contribute to increased availability of suitable shallow margin habitat and could increase woody debris density. In many cases, however, these improvements and additions would not provide a reliable long-term source of woody debris recruitment. The replacement of existing levees with new facilities that could provide opportunities for ecological enhancement could support the restoration of 100 to 150 acres of floodplain and/or riparian habitat.

The addition of new facilities and the improvement of existing levees under Alternative 2 could modestly degrade the condition of certain ecosystem functions that contribute to juvenile salmonid habitat. However, this alternative could also provide opportunities for riparian habitat restoration through the replacement of existing levees with Type C setback levees. Alternative 2 could increase the amount of partially inundated streambank area available for floodplain and/or riparian habitat restoration to 100 to 150 acres compared to the 85 to 125 acres available under Alternative 1. Restoration of these habitats could likely achieve the WRIA 9 (2021) recommended 10-year targets for high flow channel and bank armor restoration and could contribute to the LWD restoration target. Depending on design, the 65 to 100 acres of habitat available for restoration created by Type C-2 facilities could also contribute to the floodplain wetland restoration target.

Alternative 3: Enhanced Systematic Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment 1, Table A-1, Alternative 3 could likely contribute to the ongoing degraded condition of five out of the seven ecosystem functions that support juvenile salmon rearing habitat based on streambank impacts. However, the extent and severity of streambank impacts could be reduced relative to Alternative 1 and would be generally comparable to the impacts of Alternative 2. Moreover, Alternative 3 could substantially increase the amount of floodplain and riparian habitat available for restoration relative to Alternative 2. As such, this alternative would likely result in the highest level of achievable improvement and lowest level of degradation in the ecological functions that could support juvenile salmonid rearing.

As shown in Table 5-8, Alternative 3 could likely reduce the quantity and quality of accessible pool habitat, would further limit tributary access, and would be unlikely to contribute to improved substrate conditions based purely on streambank effects. The retention and/or improvement of approximately 9 miles of existing Type A facilities and the addition of approximately 4 miles of new Type A facilities could exacerbate degraded riparian and streambank conditions. However, those impacts could be partially offset by the replacement of existing levees with new Type B and Type C facilities, which could allow for riparian zone enhancement. Improvements to existing Type B and Type C facilities and the addition of new Type B and Type C facilities could contribute to increased availability of suitable shallow margin habitat and could increase woody debris density. In many cases, however, the improvements and additions would not provide a reliable long-term source of woody debris recruitment. The replacement of existing levees with new riparian buffers and the creation of new flood bench and high flow channels under this alternative could support the restoration of 185 to 285 acres of floodplain and/or riparian habitat. An additional 80 to 120 acres of habitat acquired for flood storage that could be at least partially inundated during ecological flows could be available for floodplain and riparian restoration.

While the new and improved Type A facilities created under Alternative 3 could modestly degrade the condition of certain ecosystem functions that contribute to juvenile salmonid habitat, this alternative could provide the greatest opportunity for restoration of habitats that could support juvenile salmonid rearing compared to the other alternatives. Alternative 3 could make 265 to 405 acres of streambank area available for floodplain and/or riparian habitat restoration (i.e., streambank area that is at least partially inundated under ecological flows), compared to 85 to 125 acres under Alternative 1 and 100 to 150 acres under Alternative 2. Restoration of these habitats could likely achieve the WRIA 9 (2021) recommended 10-year targets for high flow channel, low flow channel, and bank armor restoration and could contribute to the LWD restoration target recommended by WRIA 9 (WRIA 9 2021). The restoration of 66 acres of floodplain wetlands desired by WRIA 9 could also be achieved on the 150 to 230 acres of restorable habitat made available by new Type C-2 facilities and the 195 to 295 acres of habitat available for restoration on lands acquired for flood storage.

No Build Scenario

The No Build Scenario provides a useful basis for evaluating the projected change in the extent of flood facilities under each alternative and associated effects on juvenile salmonid rearing. This scenario assesses potential impacts to juvenile salmonid rearing that might occur if none of the Plan alternatives were constructed and if existing flood hazard reduction facilities were not maintained in the future. Under this scenario, the HHD would continue to manage flows to protect downstream communities from flooding damage. Existing flood facilities would remain in place without dedicated maintenance or improvements.

The existing streambanks in the Lower Green River consist of 13.1 miles of natural, unmodified bank, 19.6 miles of steep-banked PL 84-99 and similar flood facilities that result in simplified habitat, and 9.4 miles of hardened revetment intended to prevent channel migration. Little off-channel habitat is available to support juvenile salmonid rearing under existing conditions, and a substantial portion of the existing levee system is maintained to PL 84-99 facility standards requiring removal of large trees and brush. If the levees were no longer maintained under the No Build Scenario, trees could continue to grow and could eventually overhang the water. This could increase shading and shoreline complexity, which could benefit juvenile fish by providing cover from predators and, potentially, lower water temperatures due to reduced direct sunlight. While this evolution from existing conditions could result in some habitat improvement, it would not result in the same degree of habitat benefit provided by Alternatives 1, 2, and 3.

Comparison of Alternatives

Table 5-10 provides a comparison of the weighted level effect rankings by alternative on the ecosystem functions that support juvenile salmonid rearing. These rankings are a function of the qualitative rank representing the impact of each facility type on habitat quality, weighted by the linear feet of each facility type that could be implemented under each alternative. Table 5-10 provides a summary of the linear feet of unmodified bank, revetments, and levees by facility type, flood facility type acreage, acres available for riparian and floodplain habitat restoration, and percent of habitat exposed to partial inundation at ecological flows under each alternative.

Table 5-10. Comparison of Facility Type Linear Feet and Acreage by Alternative

		Alternative		
Facility Type	**Metric**	**1**	**2**	**3**
Unmodified Bank	Linear feet	60,000	64,000	62,000
Revetment	Linear feet	31,000	34,000	33,000
Type A Facilities	Linear feet	77,000	64,000	59,000
	Acres	85-125	70-105	65-95
	Acres available for restoration	0	0	0
	% of acres with exposure to inundation at ecological flows[¥]	100%	100%	100%
Type B Facilities	Linear feet	27,000	28,000	27,000
	Acres[†]	30-50	35-55	40-60
	Acres available for restoration	15-25	20-30	20-30
	% of acres with exposure to inundation at ecological flows[¥]	100%	100%	100%
Type C Facilities	Linear feet	27,000	31,000	42,000
	Acres[†]	80-110	90-135	190-285
	Acres available for restoration	70-100	80-120	165-255
	% of acres with exposure to inundation at ecological flows[¥]	98%	98%	99%
Floodplain acquisition	Acres[†]	0	0	220-325
	Acres available for restoration	--	--	195-295
	% of acres with exposure to inundation at ecological flows[¥]	--	--	41%

[†] This is the area riverward of the levee crest.

[¥] This is the facility type acreage available for restoration that could experience some level of inundation at ecological flows, as determined by the hydraulic model range for the 2-year and 10-year flow events. This is not the inundated acreage total. It is assumed that project-specific design criteria could integrate habitat improvements at a range of normal flows typical during adult and juvenile migration periods (i.e., ~1,750 cfs, less than 2-year flow).

As shown in Table 5-10, the proposed alternatives could result in varying levels of impact and could provide varying degrees of potential restoration benefit for the ecological functions that support juvenile salmonid rearing. Broadly speaking, each alternative could increase the extent of modified streambank and the overall extent of levees in the Lower Green River relative to existing conditions. However, each alternative could also remove some existing revetments and replace some existing levees with Type B or C facilities that could provide a higher degree of ecological function than the existing condition. The alternatives could differ in the extent of existing unmodified bank that could be replaced by levees, the amount of revetment that could be removed and replaced by other facility types, and the extent of existing levees that could be replaced. They also differ in the extent of floodplain and riparian habitat that could be made available for restoration of associated ecological functions.

Approximately 60,000, 64,000, and 62,000 linear feet (11.4, 12.1, and 11.7 miles) of unmodified bank could remain along the Lower Green River under Alternatives 1, 2, and 3, respectively. Approximately 18,000, 15,000, and 13,000 linear feet (3.4, 2.8, and 3.0 miles) of the existing 49,000 feet (9.4 miles) of revetments could be converted to levees under Alternatives 1, 2, and 3, respectively. Generally speaking, reducing the extent of unmodified streambank could have a detrimental effect on ecological functions that support juvenile salmonid rearing, with effects varying by alternative based on adjacent land uses, facility type extent, and levee design. In contrast, the proposed alternatives could beneficially improve juvenile salmonid rearing habitat in locations where levees could be replaced with more ecologically beneficial alternatives. No existing levees would be relocated under Alternative 1. In contrast, Alternatives 2 and 3 could convert approximately 1.3 and 2.9 miles of existing levees to Type B and C facilities, respectively. The affected new Type B and Type C facilities could be designed to improve streambank and riparian habitat conditions and, in the case of Type C facilities, could provide additional opportunity for floodplain and off-channel habitat enhancement.

The weighted impact rankings by alternative displayed in Table 5-10 reflect those effects. Conversion of unmodified streambanks and revetments to levees would likely result in negative impacts on potential off-channel habitat, tributary habitat access, riparian vegetation, and substrate conditions. Alternative 1 could have the largest negative impact on these ecosystem functions, while Alternatives 2 and 3 could have progressively smaller negative impacts by comparison. Each alternative could increase the amount of functional woody debris in the Lower Green River, with Alternatives 2 and 3 providing progressively greater net benefits compared to Alternative 1. Alternative 1 could negatively affect the extent of suitable shallow margin habitat available for juvenile rearing, while Alternatives 2 and 3 could marginally improve the condition of this ecosystem function across the Lower Green River. Alternative 3 could result in the greatest increase in shallow margin habitat.

As shown in Table 5-10, the total acreage of Lower Green River streambank- and floodplain-impacted Type A, Type B, and Type C facilities would vary by alternative. Type A facility area could be the most extensive under Alternative 1, with an estimated 85 to 125 acres of shoreline and riparian habitat impacted by this facility type. Type A facilities would provide little or no opportunity for restoration of floodplain and riparian ecosystem functions. Alternatives 2 and 3 could reduce the Type A facility extent to 70 to 105 and 65 to 95 acres, respectively. Alternative 1 could make approximately 85 to 125 acres of riparian and floodplain habitat available for restoration on 110 to 170 acres of Type B and Type C facilities, almost all of which would be connected to the stream channel at ecological flows. Alternative 2 could make approximately 100 to 150 acres of riparian and floodplain habitat available for restoration on 125 to 190 acres of Type B and Type C facilities, with almost all that habitat connected to the stream channel at ecological flows. Alternative 3 could provide the greatest opportunity for habitat restoration, making 185 to 285 acres, respectively, of habitat available for restoration on 230 to 345 acres of Type B and Type C facilities. Alternative 3 could provide additional opportunities for habitat restoration by acquiring 220 to 325 acres of floodplain property for flood storage and habitat restoration. Approximately 80 to 120 acres of the acquired habitat could have some connectivity to the stream channel at ecological flows.

In summary, while the three alternatives are broadly similar in terms of their effects on streambank conditions in the Lower Green River, they vary substantively in terms of the amount of habitat made available for restoration of floodplain and riparian habitat functions. Alternatives 2 and 3 could provide more opportunity to enhance and restore juvenile salmonid rearing habitat than Alternative 1, and Alternative 3 could make substantially more habitat available than Alternative 2. Alternative 3 could also provide for strategic coordination of property acquisitions, flood facility project design, and project siting to optimize habitat restoration opportunities. As such, Alternative 3 could likely result in the greatest benefits to juvenile salmonid rearing.

5.6.1.2 Adult Salmonid Migration

The rankings for adult salmonid migration are based on the evaluation of four ecological functions:

1. The availability of pool habitat of sufficient quality, frequency, and distribution to provide cover and thermal refuge for adult salmonids during migration
2. Functional riparian vegetation to provide cover and sufficient shade to moderate water temperatures during the adult migratory period
3. Woody debris of sufficient size, density, and quantity to provide cover and refuge and to create habitat complexity
4. Access to tributary habitats that can provide thermal refuge during migration and, where applicable, suitable spawning habitat

Alternative 1: Project by Project Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment 1, Table A-1, Alternative 1 could degrade the condition of three of the four ecosystem functions that support adult salmonid migration. As shown in Table 5-8, this alternative could modestly reduce the quantity and quality of pool habitat and access to tributaries. As with juvenile rearing habitat, Alternative 1 could degrade riparian conditions but could maintain and improve LWD density in the Lower Green River channel. As noted above, improvements to existing Type B and Type C facilities and the addition of new Type B and Type C facilities could contribute to increased woody debris density. In many cases, however, the improvements and additions would not provide a reliable long-term source of woody debris recruitment.

Approximately 85 to 125 acres of habitat could be made available for floodplain and/or riparian restoration under Alternative 1 (Table 5-9). This could contribute to, but would not achieve, the 10-year target of 250 acres and 8.5 linear miles of riparian restoration recommended by WRIA 9 (WRIA 9 2021). The amount of available pool habitat could decrease modestly. In contrast, Alternative 1 could at least maintain and could contribute to an increase in LWD density, depending on the amount of woody material incorporated into the design of future Type B and C facilities and woody debris recruitment sources provided by riparian restoration. As such, Alternative 1 could contribute to the target objective for LWD recommended by WRIA 9 (WRIA 9 2021).

Alternative 2: Systematic Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment A, Table A-1, Alternative 2 could likely degrade the condition of three of the four ecosystem functions that support adult salmonid migration, but to a lesser degree than Alternative 1. As shown in Table 5-8, this alternative could likely modestly reduce the quantity and quality of pool habitat and access to tributaries. The development of approximately 12 linear miles of updated and new Type B and Type C facilities could contribute to and could potentially achieve the 10-year target for LWD density, depending on the amount of woody material incorporated into the design of these facilities and their distribution over the Lower Green River. This could maintain and improve LWD density in the Lower Green River channel.

The 100 to 150 acres of habitat made available for floodplain and/or riparian restoration under Alternative 2 could contribute to, but would not achieve, the 10-year target of 250 acres and 8.5 linear miles of riparian restoration recommended by WRIA 9 (WRIA 9 2021). The minimum desired buffer widths of 165 feet could only be reliably achieved on the 83 acres of Type C-2 facilities proposed under Alternative 2. Buffer widths on Type B and C-1 facilities would typically be narrower. Riparian restoration on some Type C-1 and C-2 facilities could also provide a long-term source of woody debris recruitment, but that source would likely be insufficient to maintain desired wood densities in perpetuity.

Alternative 3: Enhanced Systematic Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment A, Table A-1, Alternative 3 could likely reduce the extent of degradation of ecosystem functions that support adult salmonid migration relative to Alternatives 1 and 2. As shown in Table 5-8, this alternative could result in a modest reduction in quantity and quality of pool habitat and access to tributaries. The development of approximately 13.7 linear miles of updated and new Type B and Type C facilities could contribute to, and could potentially achieve, the 10-year target for LWD density depending on the amount of woody material incorporated into the design of these facilities and their distribution over the Lower Green River. This could maintain and improve LWD density in the Lower Green River channel.

In addition, Alternative 3 could make approximately 165 to 255 acres of habitat available for riparian restoration over an estimated 1.9 and 6.4 linear miles of new Type C-1 and C-2 facilities, respectively, and could acquire 1.3 miles of streambank for flood storage and habitat restoration. Riparian restoration on the 7.7 miles of streambank associated with C-2 facilities and acquired streambank could contribute to the 10-year target of 250 acres and 8.5 linear miles of minimum 165-foot riparian buffer restoration recommended by WRIA 9 (WRIA 9 2021). Buffer widths on Type B and C-1 facilities would typically be narrower and would not contribute to this recommended target. Riparian restoration on Type C-1 and C-2 facilities and on acquired properties could also provide a reliable long-term source of woody debris recruitment.

No Build Scenario

Under the No Build Scenario, none of the policy alternatives considered in the PEIS would be implemented in the future, and existing levees and revetments would remain in place without dedicated maintenance or improvements. Flows from the HHD would continue to be managed to protect downstream communities from flooding damage. As noted in Section 3.3.1.1, if the 19.6 miles of existing PL 84-99 facilities were no longer maintained under the No Build Scenario, vegetation could continue to grow on these levees and could eventually overhang the water. This could increase shading, which could benefit migrating adult salmonids by reducing direct sunlight and lowering water temperatures. While this evolution from existing conditions could result in some habitat improvement, it would not result in the same degree of habitat benefit provided by Alternatives 1, 2, and 3.

Comparison of Alternatives

Table 5-8 provides a comparison of the weighted level effect rankings by alternative on the ecosystem functions that support adult salmonid migration. These rankings are a function of the qualitative rank representing the impact of each facility type on habitat quality, weighted by the linear feet of each facility type that could be implemented under each alternative. Table 5-10 provides a summary of the linear feet of unmodified bank, revetments, and levees by facility type, flood facility type acreage, acres available for riparian and floodplain habitat restoration, and percent of habitat exposed to partial inundation at ecological flows under each alternative.

As shown, all alternatives could result in varying levels of impact and would provide varying degrees of potential restoration benefit for the ecological functions that support adult salmonid migration. As stated in Section 3.7.1.1, each alternative could increase the extent of modified streambank and the overall extent of levees in the Lower Green River relative to existing conditions. However, each alternative could also remove some existing revetments and replace some existing levees with Type B or Type C facilities that could provide a higher degree of ecological function than the existing condition. The alternatives differ in the extent of existing unmodified bank that could be replaced by levees, the amount of revetment removed and replaced by other facility types, and the extent of existing facilities replaced. They also differ in the extent of floodplain and riparian habitat that could be made available for restoration of associated ecological functions.

Approximately 60,000, 64,000, and 62,000 linear feet (11.4, 12.1, and 11.7 miles) of unmodified bank could remain under Alternatives 1, 2, and 3, respectively. Approximately 18,000, 15,000, and 16,000 linear feet (3.4, 2.8, and 3.0 miles) of the existing 49,000 feet (9.4 miles) of revetments could be converted to levees under Alternatives 1, 2, and 3, respectively. Reducing the extent of unmodified streambank could have a detrimental effect on ecological functions that would support adult salmonid migration, with effects varying by alternative based on facility type extent and as a function of levee design. In contrast, the proposed alternatives could beneficially improve habitat conditions for adult salmonid migration in locations where existing levees could be replaced with ecologically beneficial alternatives. Alternatives 1, 2, and 3 could reduce existing levee extent by 20 miles to approximately 14.5, 12, and 11 miles, respectively. The affected levees could be replaced by a mixture of new Type B and Type C facilities specifically designed to improve streambank and riparian habitat conditions and, in the case of Type C facilities, provide additional opportunity for floodplain and off-channel habitat enhancement.

The weighted impact rankings by alternative displayed in Table 5-8 reflect those effects. Conversion unmodified streambank to levees would likely result in negative impacts on pool habitat, riparian vegetation and shade, and tributary habitat access. Alternative 1 would have the largest negative impact on these ecosystem functions, while Alternatives 2 and 3 would have smaller negative impacts by comparison. Each alternative could increase the amount of functional woody debris in the Lower Green River, with Alternatives 2 and 3 providing progressively greater net benefits compared to Alternative 1. When properly designed, incorporation of woody debris into levees could promote pool formation. This could, in turn, result in expansion of pool habitat at some locations in the Lower Green River where hydraulic and sediment transport conditions are favorable.

Riparian habitat restoration is a core objective of the WRIA 9 (WRIA 9 2021) watershed restoration plan. Restoration of riparian vegetation at targeted locations on the Lower Green River could provide a means to moderate water temperatures, thus improving water quality conditions for adult salmonid migration during peak summer months. As shown in Table 5-9, the extent of habitat made available for riparian vegetation varies by alternative. Alternative 1 could make approximately 85 to 125 acres available for riparian restoration on 110 to 170 acres of Type B and Type C facilities. Alternative 2 could make approximately 100 to 150 acres of habitat available for riparian restoration on 125 to 190 acres of Type B and Type C facilities. Alternative 3 could provide the greatest opportunity for riparian restoration. This alternative could make 185 to 285 acres of habitat available for restoration on 225 to 345 acres of Type B and Type C facilities. In addition, approximately 195 to 295 acres of floodplain property proposed for flood storage acquisition are also close to the stream channel and could provide opportunity for riparian restoration.

In summary, while the three alternatives are broadly similar in terms of their effects on streambank conditions in the Lower Green River, they vary substantively in terms of the extent of habitat made available for restoration of riparian habitat functions. Alternatives 2 and 3 could provide more opportunity to enhance and restore adult salmonid migration habitat than Alternative 1, and Alternative 3 could make substantially more habitat available than Alternative 2. Alternative 3 could also provide for strategic coordination of property acquisitions, flood facility project design, and project siting to optimize habitat restoration opportunities. As such, Alternative 3 could likely result in the greatest benefits to adult salmonid migration.

5.6.1.3 Ecosystem Processes

Flood facilities are well documented to substantially influence ecosystem processes through a variety of mechanisms (see Attachment B, Table B-1). The ecosystem processes considered in this analysis include floodplain interaction, habitat connectivity, hydrology/flow regime, sediment dynamics, wood load, trophic support, and temperature, and they are shown in Table 5-6.

Flood facilities reduce or eliminate hydraulic connectivity between river and floodplain habitats by design. In general, Type A facilities, which provide the highest degree of confinement of the fluvial system and the greatest disconnection from the riparian and floodplain habitats, degrade ecosystem processes the most, whereas Type B through Type D facilities provide an increasingly greater potential to provide or improve ecosystem processes, depending on the existing streambank and floodplain conditions. Unmodified streambanks, which are rare in the Lower Green River, retain the greatest potential for maintaining ecosystem processes. However, floodplain that is currently connected under ecological flows typically is located within agricultural lands, parks, and open spaces (e.g., golf courses), and residential land uses that frequently do not provide a full suite of ecosystem processes.

Greater constraints on the fluvial system contribute to less floodplain interaction, less connectivity or potential to form off-channel habitats, and higher velocity and more volatile peak flows. These factors, in turn, influence sediment dynamics and the potential to support intact riparian zones, which correlate highly with LWD elements, trophic support, and temperature processes. The basis of the following analysis draws heavily on the degree of overall floodplain confinement, while also considering the amount of potential habitat restoration that is associated with the relative amounts of proposed facility types by alternative (Table 5-9).

Alternative 1: Project by Project Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment A, Table A-1, Alternative 1 could result in an overall reduction of the potential for floodplain ecosystem processes in the Lower Green River due to a net increase in Type A, Type B, and Type C facilities and a net decrease in unmodified streambank. This alternative could maintain (or update to current standards) approximately 103,000 linear feet of Type A, Type B, and Type C facilities, and it could result in an increase of 28,000 linear feet of combined Type A, Type B, and Type C facilities. Alternative 1 could increase the degree of fluvial confinement of the Lower Green River by approximately 13 percent (Type A: 8 percent, Type B: 2 percent, Type C: 3 percent), thereby reducing the potential for all ecosystem processes, depending on the existing conditions at proposed new facility locations.

While Alternative 1 could modestly reduce ecosystem functions based on streambank impacts, it could also create approximately 85 to 125 acres of additional acres of streambank available for floodplain and/or riparian habitat restoration, almost all of which could be at least partially inundated under ecological flows and could contribute to improved ecosystem process conditions. Habitat improvements associated with Type B and Type C facilities could contribute modestly to the WRIA 9 (2021)) recommended 10-year targets for future habitat conditions.

Alternative 2: Systematic Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Appendix A, Table A-1, Alternative 2 could result in an overall reduction of the potential for floodplain ecosystem processes in the Lower Green River due to a net increase in Type A, Type B, and Type C facilities and a net decrease in unmodified streambank. However, the extent and severity of these impacts could be reduced compared to Alternative 1.

This alternative could maintain (or update to current standards) approximately 96,000 linear feet of Type A, Type B, and Type C facilities, and it could result in an increase of 27,000 linear feet of combined Type A, Type B, and Type C facilities. Alternative 2 could increase the degree of fluvial confinement of the Lower Green River by approximately 12 percent (Type A: 5 percent, Type B: 3 percent, Type C: 5 percent), thereby reducing the potential for all ecosystem processes depending on the existing conditions at proposed new facility locations.

While the new and improved Type A facilities created under Alternative 2 could modestly degrade the condition of certain ecosystem processes, this alternative could provide a greater opportunity for habitat restoration than Alternative 1. Alternative 2 could increase the amount of partially inundated streambank area available for floodplain and/or riparian habitat restoration to 100 to 150 acres compared to the 85 to 125 acres available under Alternative 1. Restoration of these habitats may support all analyzed ecosystem processes and could contribute to the WRIA 9 (2021) recommended 10-year targets for future habitat conditions to a greater degree than Alternative 1.

Alternative 3: Enhanced Systematic Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment 1, Table A-1, Alternative 3 could result in an overall reduction of the potential for floodplain ecosystem processes in the Lower Green River due to a net increase in Type A, Type B, and Type C facilities and a net decrease in unmodified streambank. However, the extent and severity of these impacts could be reduced compared to Alternatives 1 and 2.

This alternative could maintain (or update to current standards) approximately 86,000 linear feet of Type A, Type B, and Type C facilities, and it could result in an increase of 41,000 linear feet of combined Type A, Type B, and Type C facilities. Alternative 3 could increase the degree of fluvial confinement of the Lower Green River by approximately 18 percent (Type A: 4 percent, Type B: 5 percent, Type C: 10 percent), thereby reducing the potential for all ecosystem processes depending on the existing conditions at proposed new facility locations. Alternative 3 could include substantially more Type C facilities compared to Alternatives 1 and 2, thus increasing the potential for habitat enhancements within the associated setbacks.

While the new and improved Type A facilities created under Alternative 3 could modestly degrade the condition of certain ecosystem processes, this alternative could provide the greatest opportunity for restoration of floodplain ecosystem processes. Alternative 3 could make 265 to 405 acres streambank area available for floodplain and/or riparian habitat restoration (i.e., streambank area that is at least partially inundated under ecological flows—including areas on lands acquired by the District to preserve flood storage and to provide ecological and other benefits), compared to the 85 to 125 acres under Alternative 1 and 100 to 150 acres under Alternative 2. Restoration of these habitats would likely achieve the WRIA 9 (2021) recommended 10-year targets for high flow channel, low-flow channel, and bank armor restoration, and it could contribute to the LWD restoration target. The restoration of 66 acres of floodplain wetlands could also be achieved on the 150 to 230 acres of restorable habitat made available by new Type C-2 facilities and the 195 to 295 acres of habitat available for restoration on lands acquired for flood storage.

No Build Scenario

Under the No Build Scenario, none of the policy alternatives considered in the PEIS would be implemented in the future, and existing levees and revetments would remain in place without dedicated maintenance or improvements. Flows from the HHD would continue to be managed to protect downstream communities from flooding damage.

The existing streambanks in the Lower Green River consist of 13.1 miles of natural, unmodified streambank, 19.6 miles of steep-banked PL 84-99 and similar facilities intended to prevent flooding, and 9.4 miles of hardened revetment intended to prevent channel migration. Levees and revetments could continue to prevent channel migration, and levees could limit the extent of overbank flooding. Overbank flooding could still occur at locations without levees under typical high flow events below 18,800 cfs, the upper bound of existing levee capacity. Substantial flooding of the Lower Green River Corridor could occur at flows above this threshold. However, the ability of flooded areas to support ecosystem processes could depend on existing and future land uses in the affected areas. Flooded lands that are not currently in open space or agriculture could provide little to no beneficial ecological function to support ecosystem processes.

Comparison of Alternatives

Table 5-8 provides a comparison of the weighted rankings by alternative for the ecosystem functions that support ecosystem processes. These rankings are a function of the qualitative rank representing the impact of each facility type on habitat quality, weighted by the linear feet of each facility type that could be implemented under each alternative. Table 5-9 provides a summary of the acres of floodplain and riparian habitat potentially made available for restoration and enhancement of ecosystem processes. Table 5-10 provides a summary of the linear feet of unmodified bank, revetments, and levees by facility type, flood facility type, total acreage, acres available for riparian and floodplain habitat restoration, and percent of total acres exposed to partial inundation at ecological flows under each alternative.

All alternatives could increase the extent of fluvial confinement of the Lower Green River compared to existing conditions. However, each alternative could also make habitats that are currently modified by existing levees available for rehabilitation of degraded floodplain and riparian habitat functions. As shown in Table 5-9, development and improvement of Type B and Type C facilities would make an additional 85 to 125 and 100 to 150 acres available for restoration of riparian and floodplain bench habitat under Alternatives 1 and 2, respectively. Those habitats could be directly connected to the river channel. Certain floodplain parcels could remain connected to the channel under Alternatives 1 and 2, and they would continue to flood. The ability of those parcels to support ecosystem processes would, however, depend on associated land uses and related opportunities for habitat restoration.

Alternative 3 could increase the number and extent of Type B and Type C facilities, making 185 to 285 acres of habitat available for floodplain bench and riparian habitat restoration. In addition, Alternative 3 could include acquisition of selected floodplain properties for natural flood storage, of which 195 to 295 acres could potentially be available for restoration of floodplain wetlands and wetland buffers. The combined 380 to 580 acres of habitat available for floodplain and riparian restoration under Alternative 3 would be more than double the amount made available under Alternatives 1 and 2. Moreover, Alternative 3 could strategically coordinate the distribution of these restoration opportunities to optimize ecological benefits as part of periodic adaptive management reviews. On this basis, Alternative 3 could provide the greatest opportunity to maintain and enhance ecosystem processes on the Lower Green River.

5.6.1.4 Other Stream Biota

The rankings for other stream biota are based on the evaluation of three ecosystem functions:

1. Fish community diversity and abundance
2. Macroinvertebrate community composition
3. The condition of the native aquatic plant community

The ranking criteria for fish and macroinvertebrate community composition (Table 5-4) are based on the anticipated effect that each facility type would likely have on its respective IBI condition. Each ranking scheme considers the watershed conditions that contribute to degraded fish and macroinvertebrate community conditions in the Lower Green River and the extent to which flood facilities might improve or degrade each ecosystem function in this broader context. Aquatic vegetation function rankings are characterized based on the ability of each flood facility type to provide stable shallow margin habitat with suitable substrate to support native aquatic vegetation.

Alternative 1: Project by Project Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment 1, Table A-1, Alternative 1 could degrade the condition of all three ecosystem functions that comprise other stream biota. As shown in Table 5-8, this alternative could likely maintain existing degraded habitat conditions for the native fish and macroinvertebrate community. In effect, the changes in bank configuration proposed under this alternative could result in an overall reduction of the potential to support other biotic functions in the Lower Green River due to a net increase in Type A, Type B, and Type C facilities and a net decrease in unmodified streambank.

Alternative 2: Systematic Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment 1, Table A-1, Alternative 2 could degrade the condition of all three ecosystem functions that comprise other stream biota, but to a lesser degree than Alternative 1. As shown in Table 5-8, this alternative could likely maintain existing degraded habitat conditions for the native fish and macroinvertebrate community. In effect, the changes in streambank configuration proposed under this alternative could result in an overall reduction of the potential to support other biotic functions in the Lower Green River due to a net increase in Type A, Type B, and Type C facilities and a net decrease in unmodified streambank. However, the extent and severity of these impacts would be reduced compared to Alternative 1.

Alternative 3: Enhanced Systematic Multibenefit Implementation

Applying the ranking criteria in Table 5-2 and the rationale described in Attachment 1, Table A-1, Alternative 3 could result in the least amount of degradation of the ecosystem functions that comprise other stream biota compared to Alternatives 1 and 2. As shown in Table 5-8, Alternative 3 could likely maintain existing degraded habitat conditions for the native fish and macroinvertebrate community based on projected streambank impacts. However, this alternative could provide the greatest increase in the amount of floodplain and/or riparian habitat available for restoration. As described above in Section 5.1.1, Alternative 3 could result in the greatest improvement in potential off-channel, side channel, and associated riparian habitat, increasing the amount of complex and diverse habitats and organic litter inputs available to support the fish and aquatic macroinvertebrate communities of the Lower Green River, as well as the amount of suitable substrates available for aquatic plants. Moreover, a portion of the additional 195 to 295 acres of restorable floodplain lands acquired for flood storage presumably could be available for the enhancement and creation of permanently wetted habitats that could support fish, aquatic plants, and macroinvertebrates. Approximately 41 percent of this restored habitat could receive some level of inundation at ecological flows. Streambank and floodplain habitat under Alternative 3 could improve relative to the present condition and could provide more extensive benefits to other stream biota than Alternatives 1 and 2.

No Build Scenario

Under the No Build Scenario, none of the policy alternatives considered in the PEIS would be implemented in the future, and existing levees and revetments would remain in place without dedicated maintenance or improvements. Flows from HHD would continue to be managed to protect downstream communities from flooding damage. As described in previous sections, the existing streambanks in the Lower Green River consist of 13.1 miles of unmodified bank, 19.6 miles of steep-banked PL 84-99 and similar facilities intended to prevent flooding, and 9.4 miles of hardened revetment intended to prevent channel migration. Levees and revetments could continue to prevent channel migration under the No Build Scenario, and levees could limit the extent of overbank flooding. The ability of the Lower Green River to support other aquatic biota would likely remain degraded or would continue to degrade further under this scenario, combined with the cumulative impacts of climate change, land use, and other watershed-scale stressors.

Comparison of Alternatives

Table 5-8 compares the weighted rankings by alternative of the ecosystem functions that support other aquatic biota. These rankings are a function of qualitative rankings of the impact of each facility type on habitat quality, weighted by the linear feet of each facility type that could be implemented under each alternative. Table 5-10 provides a summary of the linear feet of unmodified bank, revetments, and levees by facility type, flood facility type acreage, acres available for riparian and floodplain habitat restoration, and percent of habitat exposed to partial inundation at ecological flows under each alternative.

The comparative effects of each alternative on other stream biota would generally be similar to those described above for juvenile salmonid rearing and ecosystem processes. All alternatives could reduce the extent of unmodified streambank and could increase fluvial confinement of the Lower Green River compared to existing conditions. This could contribute to degradation of ecological functions that comprise other stream biota. However, each alternative could also make habitats that are currently modified by existing levees available for rehabilitation of degraded floodplain and riparian habitat functions. This could improve conditions for other stream biota. For example, incorporation of LWD into Type B and Type C facilities could introduce organic substrates and promote pool formation and sediment sorting. The resulting increase in habitat diversity could support increased macroinvertebrate community diversity and could also provide prey and refuge habitat for non-salmonid fishes.

As shown in Table 5-9, development and improvement of Type B and Type C facilities could make an additional 85 to 125 and 100 to 150 acres available for restoration of riparian and floodplain bench habitat under Alternatives 1 and 2, respectively. The shallow margin and inundated habitats created by these facilities could, in turn, support native aquatic vegetation. Alternative 3 could increase the number and extent of Type B and Type C facilities, making 185 to 285 acres of habitat available for floodplain bench and riparian habitat restoration. In addition, Alternative 3 could include acquisition of selected floodplain properties for natural flood storage, of which 195 to 295 acres could potentially be available for restoration of floodplain wetlands and wetland buffers. The combined 380 to 580 acres of habitat available for floodplain and riparian restoration under Alternative 3 could more than double the amount made available under Alternatives 1 and 2. Moreover, Alternative 3 could strategically coordinate the distribution of these restoration opportunities to optimize ecological benefits. On this basis, Alternative 3 could provide the greatest opportunity to maintain and enhance ecosystem processes on the Lower Green River.

5.6.1.5 WRIA 9 Habitat Plan Targets

The WRIA 9 Strategic Assessment Report (SAR) – Scientific Foundation for Salmonid Habitat Conservation (WRIA 9 Steering Committee and King County 2005) 2021 Salmon Habitat Plan (WRIA 9 2021) describes what are considered necessary future habitat conditions to support a viable salmonid population[3]. Full implementation of the plan would restore approximately 45 percent of the historic, hydrologically connected floodplain and associated tributary/off-channel habitats in the Lower Green River. Table 5-11 summarizes the future habitat condition targets presented in the SAR and the 2021 Salmon Habitat Plan Update (WRIA 9 2021) that are applicable to actions that may fall

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[3] Displays population attributes necessary for long-term survival in the wild.

within the scope of a Flood Management Plan for the Lower Green River and subsequent design and implementation of flood management actions.

Table 5-11. WRIA 9 Proposed Targets for Future Habitat Conditions in the Lower Green Subwatershed

Future Habitat Conditions	Historic Condition	Current Condition	Necessary Future Condition [a]	Recommended 10-year Target (Increase) [b]
Floodplain Connectivity	19,595 ac	3,800 ac	8,839 ac [c]	240 ac [d]
Floodplain Wetlands	4,199 ac	1,440 ac	1,921 ac	66 ac
Backwater	NR	NR	NR	75 ac
Side Channels	4.0 mi	NR	4.0 mi	1.4 mi [e]
Large Woody Debris	1,705 total pieces/mi	~ 50	$\geq$31 *key pieces* [f] /mi	425 total pieces/mi
Riparian Zone	Throughout floodplain	222 ac/ 27% of shoreline with 165-ft buffer	Fully functioning [g]	250 ac/ ~30% of shoreline with 165-ft buffer
Bank Armor	N/A	42 mi	No new, decreasing amount	Setback 1 mi of levee

Notes: NR = not reported

[a] As defined in the 2005 SAR

[b] As defined by WRIA 9 (2021)

[c] Represents reconnection of floodplain habitat to support formation of below key, off-channel habitats. Value includes below (and other) key, off-channel habitat targets.

[d] Represents reconnection of floodplain habitat composed of below key, off-channel habitat targets in addition to 99 acres of other reconnected 100-year floodplain.

[e] Includes floodplain tributaries.

[f] Key pieces are of sufficient mass and persistence to allow habitat formation.

[g] Fully functioning riparian buffer is not defined, but it is assumed to include a forested riparian buffer along the ~75 percent of Green River shoreline.

This PEIS addresses a range of future actions that could be developed under the proposed alternatives, most of which have yet to be proposed and have not been fully designed. Therefore, it is not possible to fully determine the extent to which future projects would contribute to achievement of the recommended 10-year (2030) and longer-term habitat restoration targets in the WRIA 9 2021 Salmon Recovery Plan Update. However, some general conclusions can be drawn from the projected extent of Type A, B, C, and D flood facilities under each alternative, and the general conceptual design objectives of each facility type.

Alternative 1: Project by Project Multibenefit Implementation

By making additional habitat available at existing, improved, and new Type B, C-1, and C-2 facilities, Alternative 1 could support the restoration of approximately 85 to 125 acres of floodplain and/or riparian habitat that is at least partially inundated at ecological flows (Table 5-9). This could contribute to the recommended 10-year (2030) restoration targets for the Lower Green River (WRIA 9 2021) as follows:

- Off-channel habitat
    - Restore 550 feet of high-flow channels – likely achievable in 55 to 80 acres of restorable habitat created by new Type C-2 facilities that are inundated at ecological flows.
    - Restore 3,740 feet of low flow channels – likely not achievable.
    - Restore 75 acres of backwater habitats – unknown, dependent on specific facility design.
    - Restore 66 acres of floodplain wetland – likely not achievable.

- Riparian forest
  - Revegetate 250 acres (8.5 miles) of 165-foot-wide riparian buffer – not achievable in the estimated 15 to 20 and 55 to 80 acres of restorable habitat created by new Type C-1 and C-2 facilities, respectively (other facility types generally cannot achieve the 165-foot functional buffer width target).
- Large woody debris
  - Achieve 425 pieces/mile of functional woody debris – unknown, may be achievable dependent on the quantity of woody debris incorporated into 8 linear miles of updated and new Type B and C facilities and other theoretical actions.
- Bank armor
  - Set back 1 mile of levee – achievable based on proposed replacement of 4.1 miles (21,800 linear feet) of existing levees by Type C facilities under Alternative 1.

Alternative 2: Systematic Multibenefit Implementation

By making additional habitat available at existing, improved, and new Type B, C-1, and C-2 facilities, Alternative 2 could support the restoration of approximately 100 to 150 acres of floodplain and/or riparian habitat that is at least partially inundated at ecological flows. This could contribute to the recommended 10-year (2030) targets in the WRIA 9 (WRIA 9 2021) salmon recovery plan update as follows:

- Off-channel habitat
  - Restore 550 feet of high-flow channels – likely achievable in 65 to 100 acres of restorable habitat created by new Type C-2 facilities that are inundated at ecological flows.
  - Restore 3,740 feet of low flow channels – likely not achievable.
  - Restore 75 acres of backwater habitats – unknown, dependent on specific facility design.
  - Restore 66 acres of floodplain wetland – partially achievable on 80 to 120 acres of habitat available for restoration created by Type C-1 and C-2 facilities.
- Riparian forest
  - Revegetate 250 acres (8.5 miles) of 165-foot-wide riparian buffer – likely not achievable in the estimated 15 to 20 and 65 to 100 acres of restorable habitat created by new Type C-1 and C-2 facilities, respectively (other facility types generally cannot achieve 165-foot-wide functional buffers).
- Large woody debris
  - Achieve 425 pieces/mile of functional woody debris – unknown but potentially achievable depending on quantity of woody debris incorporated into 12 linear miles of improved and new Type B and C facilities and other theoretical actions.
- Bank armor
  - Set back 1 mile of levee – achievable based on proposed replacement of 5 miles (26,600 linear feet) of existing levees by Type C facilities under Alternative 2.

Alternative 3: Enhanced Systematic Multibenefit Implementation

Alternative 3 could support the restoration of approximately 265 to 405 acres of floodplain and/or riparian habitat that is at least partially inundated at ecological flows. This total could comprise 185 to 285 acres of at least partially inundated habitats made available by existing, improved, and new Type B, C-1, and C-2 facilities, plus 80 to 120 acres on properties acquired specifically for flood storage and habitat restoration. An additional 115 to 175 acres of property acquired for flood storage would not be inundated at ecological flows but could be available for floodplain wetland restoration. This could contribute to the recommended 10-year (2030) targets in the WRIA 9 (WRIA 9 2021) salmon recovery plan update as follows:

- Off-channel habitat
  - Restore 550 feet of high-flow channels – achievable in 150 to 230 acres of restorable habitat created by new Type C-2 facilities that are inundated at ecological flows.
  - Restore 3,740 feet of low flow channels – likely achievable on the 150 to 230 acres of restorable habitat created by new Type C-2 facilities.
  - Restore 75 acres of backwater habitats – potentially achievable on restorable habitats created by 150 to 230 acres of restorable habitat on Type C-2 facilities and 80 to 120 acres of periodically inundated habitat acquired for flood storage that is available for habitat restoration.
  - Restore 66 acres of floodplain wetland – achievable on 165 to 255 acres of habitat available for restoration created by Type C-1 and C-2 facilities and 195 to 295 acres available for restoration on floodplain properties acquired for flood storage.
- Riparian forest
  - Revegetate 250 acres (8.5 miles) of 165-foot-wide riparian buffer – partially achievable in the estimated 15 to 25 and 150 to 230 acres of restorable habitat created by new Type C-1 and C-2 facilities, respectively, and approximately 80 to 120 acres of property acquired for flood storage. In theory, these areas could restore a minimum 165-foot-wide buffer on up to 7.7 miles of streambank, but the actual extent of functional vegetation would depend on the presence of roads, trails or other encroaching features.
- Large woody debris
  - Achieve 425 pieces/mile of functional woody debris – unknown but potentially achievable depending on the quantity of woody debris incorporated into 12 linear miles of improved and new Type B and C facilities and other theoretical actions.
- Bank armor
  - Set back 1 mile of levee – achievable based on proposed replacement of 6.3 miles (33,100 linear feet) of existing levees replaced by Type C facilities under Alternative 3.

5.6.2 Indirect Impacts

Indirect impacts are those impacts that are likely to occur as a result of an action, but that occur at greater distance from and/or later in time than direct effects. In the case of aquatic resources, indirect effects may occur as the result of synergistic effects of the proposed alternatives on the aquatic environment. Potential indirect effects are described by resource below.

5.6.2.1 Juvenile Salmonid Rearing

The PEIS alternatives include several components with the potential to improve aquatic ecosystem function in ways that could benefit juvenile salmonid rearing. Several of these components could interact synergistically, such that the indirect effects of the alternatives could increase over time. For example, as described below in Section 5.1.2, riparian restoration and increased woody debris density could contribute to the expansion of thermal refugia in the Lower Green River over time. This could increase the value of pool habitats used by juvenile salmonids during the summer months. Riparian habitat restoration, increased floodplain habitat connectivity, and increased habitat complexity could, in turn, likely lead to an increase in biological productivity (see discussion under Adult Salmonid Migration below). These effects would likely evolve synergistically over the life of the Plan. This could, in turn, lead to improved habitat conditions for juvenile salmonid rearing.

Broadly speaking, these beneficial indirect effects could scale with the extent of floodplain and riparian habitat enhancements provided by each alternative, with Alternative 1 providing the least extensive indirect benefits. Alternative 2 could provide more opportunity for habitat and floodplain restoration, which could, in turn, translate to more extensive indirect habitat benefits for juvenile salmonid rearing. Alternative 3 could make the most habitat available for floodplain and riparian habitat restoration, likely leading to greater indirect benefits. Alternatives 2 and 3 could plan and implement flood management projects systematically to optimize flood risk reduction and habitat benefits, whereas Alternative 1 could not.

5.6.2.2 Adult Salmonid Migration

The PEIS alternatives include several components with the potential to improve aquatic ecosystem function in ways that could benefit adult salmonid migration. In theory, restoration of riparian vegetation could help ameliorate high water temperatures during the summer migration period and could offset some of the adverse effects of climate change on water quality. Incorporation of LWD into levee designs may, in some locations, cause geomorphic effects that could lead to an increase in the frequency and depth of pool habitat. These habitat changes could evolve over time as restored riparian vegetation matured and the channel responded to the presence of woody debris. Depending on how these effects were distributed, channel shading could combine synergistically with pool habitat to create thermal refugia, providing valuable habitat for adult and juvenile salmonids during the summer months.

The PEIS alternatives could all likely result in an increase in the extent of mature riparian vegetation and the amount of functional LWD in the Lower Green River over the next 30 years. Each alternative includes implementation of Type B and Type C flood facilities that could support restoration of riparian vegetation and could incorporate functional woody debris to varying degrees. This indicates that each alternative could likely lead to beneficial indirect effects on adult salmonid migration. However, these effects would likely vary considerably between alternatives.

Alternative 1 could result in the fewest linear feet of Type B and Type C facilities, and it could make the least amount of habitat available for riparian restoration. These facilities could also be developed on a project-by-project basis, meaning that projects would not be designed and sited to optimize the distribution of thermal refugia across the Lower Green River to provide the greatest habitat benefit. In contrast, Alternative 2 could increase the extent of Type B and Type C facilities and the acres of habitat available for functional riparian restoration, as well as planning and implementing these projects systematically to optimize flood risk reduction and habitat benefits. Alternative 3 could present the greatest opportunity for beneficial indirect effects on adult salmonid migration. This alternative could further increase the linear feet and acres of habitat available for riparian and woody debris restoration. Additional restoration could be conducted on properties acquired for flood storage, and flood risk reduction and habitat restoration projects could be designed and sited strategically to optimize habitat benefits throughout the entire system.

5.6.2.3 Ecosystem Processes

Ecosystem processes comprise a set of interdependent ecosystem functions. These functions represent the longitudinal distribution of habitats within the Lower Green River channel; the lateral connectivity of the Lower Green River to its riparian zone and floodplain; how water, woody debris, and sediment move through this system; and how these factors combine to influence biological productivity and water quality conditions relied upon by a variety of aquatic resources.

The historical modification of the Lower Green River channel and floodplain has substantially altered these ecosystem processes to the extent that this ecosystem is no longer properly functioning. The channelization of a substantial portion of the Lower Green River within Type A levees is a primary factor contributing to these existing conditions.

Each alternative could incorporate a combination of flood risk reduction projects designed to ameliorate some of these historical effects. Type B and Type C facilities are designed to rehabilitate lateral habitat connectivity, increase the longitudinal distribution of complex channel habitats, and increase woody debris recruitment potential. Wood loading, sediment dynamics, allochthonous inputs providing trophic support, and channel shading and thermal refugia could evolve in response to the maturation of restored riparian and floodplain habitats. Given the synergistic nature of these ecosystem functions, these beneficial indirect effects would likely vary depending on the extent and distribution of channel, floodplain, and riparian habitat restoration under each alternative.

Following this rationale, Alternative 1 could provide the least extensive indirect benefits to ecosystem processes. Alternative 2 could provide more opportunity for habitat and floodplain restoration, which could, in turn, translate to more extensive indirect habitat benefits for ecosystem processes. Alternative 3 could make the most habitat available for floodplain and riparian habitat restoration, likely leading to larger indirect benefits. Alternatives 2 and 3 could plan and implement flood management projects systematically to optimize flood risk reduction and habitat benefits, whereas Alternative 1 could not.

5.6.2.4 Other Stream Biota

The same indirect effects described above for juvenile and adult salmonids and ecosystem processes could likely apply to other stream biota. Non-salmonid fishes could realize the same indirect benefits as those described for juvenile salmonids. Beneficial indirect effects on ecosystem processes could lead to increased habitat availability for aquatic vegetation and an increase in the abundance and diversity of macroinvertebrates. These beneficial indirect effects would vary by alternative, based on the same rationales presented for ecosystem processes described above.

5.6.3 Short-Term Impacts – Construction

Construction of Types A, B, and C levee and floodwall capital projects would share similar means and methods, equipment, best management practices, and timing restrictions for in-water work. Flood facility construction is summarized in Appendix A, Section 3.5.5. The following summarizes impacts typical of levee construction on aquatic/riparian habitats and biota after implementation of avoidance and minimization measures (see Section 3.7) and based on the assumed activities and mechanisms of impact.

5.6.3.1 Work Zone Isolation and Fish Exclusion

Cofferdams would likely be used to isolate in-water work and contain any sediments disturbed by construction. Placement of a cofferdam may temporarily reduce available substrate and other suitable habitat, and construction activities may disturb and displace fish, causing them to move to other parts of the river. Dewatering of a cofferdam would have a lethal effect on any fish confined inside the cofferdam; therefore, any fish inside the cofferdam would be captured, handled, and relocated by a qualified biologist. Fish exclusion and handling may harm some juvenile salmonids, disrupt their normal behavior, and cause short-term stress and fatigue, with the potential for injury and mortality. Electrofishing for fish exclusion can result in fish mortality or injury, including spinal hemorrhages, internal hemorrhages, fractured vertebrae, spinal misalignment, and separated spinal columns.

Cofferdam installation, dewatering, and streambed excavation would result in removing and/or smothering some benthic invertebrates that provide food for salmonids. Effects to aquatic macroinvertebrates from smothering would be temporary, and the river would return to natural contours following construction completion. Macroinvertebrates are expected to rapidly recolonize disturbed areas (within approximately 2 weeks to 2 months).

5.6.3.2 Underwater Noise

Sheet pile coffer dam systems may require vibratory pile driving. Based on an assumed sound pressure level (SPL) of 165 dB RMS (measured at 10 meters from the source), propagation of underwater noise to the behavioral effect threshold of 150 dB RMS (Washington State Department of Transportation [WSDOT] 2022) could extend 328 feet upstream and downstream from the source or to the nearest land mass. Evidence is lacking as to whether increases in underwater noise from vibratory pile driving result in adverse behavioral shifts in adult fish. It is possible that juvenile salmonids or small fish exposed to elevated underwater noise levels could exhibit an avoidance response or temporary displacement from foraging activities, resulting in reduced foraging success or undue energy expenditure. These effects would be intermittent and short-term, occurring only during pile-driving activity.

5.6.3.3 Suspended Sediment

Project construction would disturb the channel bed and riparian zone and may release pulses of fine sediment into the water column, resulting in minor temporary increases in suspended sediment levels. Elevated suspended sediment levels would most likely occur during initial cofferdam placement and subsequent rewatering of the in-water work areas. Pulses of sediment may also occur during pumping of the work area.

5.6.3.4 Riparian Clearing

Levee construction would result in temporary clearing in the riparian zone to complete the site improvements. Indirect effects associated with removal of riparian vegetation could include increased water temperatures and decreased water quality, attributable to a loss of shade and cover adjacent to the active channel. Clearing could also reduce detrital input of insects and organic litter. The potential severity of these effects would depend on the existing vegetation community composition and density. Clearing of dense woody vegetation communities would have greater and longer-term effects than clearing herbaceous plant communities.

Maturation of proposed restoration plantings would likely return disturbed areas to function similar to, or improved over, the baseline within several growing seasons. The maturing riparian improvements would improve detrital prey and organic litter production over time.

5.6.4 Climate Change

Climate change is projected to substantially alter the hydrologic regime of the Green River over the next 30 years (Lee et al. 2018). Broadly speaking, the hydrologic regime of this watershed is anticipated to shift from mixed rain and snow to predominantly rain, with a decreasing proportion of mountain precipitation occurring in the form of snow (Lee et al. 2018). This will likely result in an increase in the frequency and magnitude of high flow events and a general decrease in average flows during the spring snowmelt and summer low flow period from April through September (Lee et al. 2018; Mauger et al. 2015, 2020).

The streamflow regulation provided by the HHD will allow for maintenance of minimum base flows within the system. However, average streamflows during the April to September period will likely decrease over the next 30 years, increasing the likelihood of minimum baseflow occurrence in any given year. Decreasing baseflows combined with increasing air temperatures are, in turn, likely to lead to increased summer water temperatures. This will contribute to degraded water quality conditions that are detrimental to juvenile salmonid rearing and adult salmonid migration. Changes in flood frequency, inundation rates, and water quality conditions are similarly likely to adversely affect ecosystem processes, salmonid habitat, and other aquatic biota.

5.7 Mitigation

As described above, the implementation of Alternatives 1, 2, and 3 could have varying degrees of adverse impact on Lower Green River ecosystems by increasing the extent of streambank modification compared to existing conditions. This impact could be offset to some degree by opportunities to create or restore floodplain and riparian habitat. However, compensatory mitigation may be required by permitting agencies for impacts to regulated resources resulting from building new flood hazard management structures or improving existing structures. Mitigation requirements for ecosystem impacts typically are based on the following hierarchy:

1. Avoidance - Adverse impacts to regulated ecological resources are to be avoided, and no project will be permitted if there is a practicable alternative with less adverse impact.
2. Minimization - If impacts cannot be avoided, appropriate and practicable steps to minimize adverse impacts must be taken.
3. Compensation - Appropriate and practicable compensatory mitigation is required for unavoidable adverse impacts that remain after avoidance and minimization. The amount and quality of compensatory mitigation may not substitute for avoiding and minimizing impacts. Compensatory mitigation typically must result in no net loss of ecological functions.

This section describes potential avoidance, minimization, and compensatory measures that could apply to all Plan alternatives. These include measures applicable to project construction. This section also describes additional ecosystem enhancement measures applicable to operational impacts and that could provide offsetting benefits to help address the increase in streambank modification under the Plan alternatives.

5.7.1 Mitigation for Permanent Impacts

Compensatory mitigation for unavoidable, permanent, adverse impacts to regulated natural resources and their buffers that remain after avoidance and minimization measures have been employed is required under federal regulations (Code of Federal Regulations Title 33 Parts 325 and 332), state regulations (77.55.100 RCW, 90.48 RCW, and 90.74 RCW), and the local municipal codes (Critical Areas Regulations [WAC 365-196-832], and the Shoreline Management Act [Chapter 173-27 WAC]). Such mitigation is generally implemented through conditions on permits issued by regulatory agencies, such as Section 401 and 404 permits under the Clean Water Act, Hydraulic Project Approval permits under the Washington Hydraulic Code, and shoreline and critical areas permits issued by local jurisdictions.

As described previously, flood hazard management facilities associated with Alternatives 1, 2, and 3 have not been designed; therefore, it is not possible to anticipate the level of permanent impact that could be associated with these facilities. The District is committed to avoiding and minimizing these impacts to the greatest extent practicable during the design of individual facilities. However, given the fact that most of these facilities would be located in sensitive and highly regulated shoreline and aquatic environments, some degree of compensatory mitigation is likely to be needed. Compensatory mitigation may be implemented through several mechanisms:

- Mitigation banks, which are sites where resources (e.g., wetlands, streams, riparian areas) are restored, established, enhanced, and/or preserved for the purpose of providing compensatory mitigation for impacts authorized by permit. In general, a mitigation bank sells compensatory mitigation credits to permittees whose obligation to provide compensatory mitigation is then transferred to the mitigation bank sponsor.
- In-lieu fee mitigation credit programs, which involve the restoration, establishment, enhancement, and/or preservation of resources through funds paid to a governmental or non-profit natural resources management entity to satisfy compensatory mitigation requirements. Similar to a mitigation bank, an in-lieu fee program sells compensatory mitigation credits to permittees whose obligation to provide compensatory mitigation is then transferred to the in-lieu program sponsor. However, the rules governing the operation and use of in-lieu fee programs are somewhat different from the rules governing operation and use of mitigation banks.
- Permittee-responsible sites, which involve restoration, establishment, enhancement, and/or preservation activity undertaken by the permittee (in this case, the District) to provide compensatory mitigation for which the permittee retains full responsibility. Permittee-responsible site mitigation generally follows a hierarchy of preference for on-site/in-kind mitigation, on-site/out-of-kind mitigation, off-site/in-kind mitigation, and off-site/out-of-kind mitigation.

After implementation of avoidance and minimization measures, compensatory mitigation must ensure that the project would result in no net loss of ecological functions and would consider direct effects, indirect effects, and temporal loss of functions relative to the timing for implementation of the mitigation. Compensatory mitigation measures must meet short-term (5 to 10 years) performance standards, must adhere to a long-term management plan, and must be protected by a legal property instrument (e.g., conservation easement, deed restriction) in perpetuity.

Under Alternative 1, mitigation could occur on a project by project basis and have limited coordination across projects or throughout the Lower Green River Corridor. Each project could determine required mitigation during the regulatory review and permitting process, which could be implemented in sequence with project construction timelines. Alternatives 2 and 3 could also define mitigation on a project by project basis; however, this could also include coordination between project mitigation needs or identify mitigation actions applicable to multiple projects. This might include larger scale actions or actions in areas of high ecological value that address the mitigation needs of several projects. Additionally, mitigation elements may be implemented or constructed on different (e.g., earlier) timelines than project construction; they may therefore, provide benefits in advance of impacts.

5.7.2 Mitigation for Construction Impacts

Section 3.3.2 describes impacts associated with construction of the types of flood hazard management facilities included under Alternatives 1, 2, and 3. Construction impacts are temporary in nature, and they are often addressed through the use of construction best management practices (BMPs). Specific BMPs are often required as conditions of environmental permits and enforced through construction specifications provided to contractors. Examples of BMPs that could be used for various types of construction activities that would occur under all the alternatives are listed below.

BMPs for general impact avoidance and minimization include the following:

- Construction impacts would be confined to the minimum area necessary to complete the project.
- Boundaries of clearing limits would be clearly flagged to prevent disturbance outside of the limits.
- Removal of riparian vegetation would be minimized, and riparian vegetation would be replanted where possible.
- Vegetation would be grubbed only from areas undergoing permanent alteration. No grubbing would occur in areas slated for temporary impacts.
- All construction activities would comply with water quality standards set forth in the State of Washington Surface Water Quality Standards (WAC 173-201A).
- All construction activities would comply with conditions of applicable Corps of Engineers permit, Ecology Water Quality Certification, and WDFW Hydraulic Project Approval.

BMPs to reduce the risk of sediment entering waterbodies include the following:

- A temporary erosion and sedimentation control plan would be developed and implemented for all project elements that entail clearing, vegetation removal, grading, ditching, filling, embankment compaction, or excavation. The BMPs in the plan would be used to control sediment from all vegetation removal and ground-disturbing activities. Examples of applicable BMPs include silt fences, wattle, compost socks, ditch check dams, seeding and mulching, stabilized construction entrances, and street cleaning.
- The contractor would designate at least one employee as the erosion and spill control lead. This person would be responsible for installing and monitoring erosion control measures and maintaining spill containment and control equipment. The erosion and spill control lead would also be responsible for ensuring compliance with all local, state, and federal erosion and sediment control requirements, including discharge monitoring reporting for Ecology.
- Erosion and sedimentation control devices would be installed, as needed, to protect surface waters and other sensitive areas. Actual locations would be specified in the field, based upon site conditions.

- Project staging and material storage areas would be located a minimum of 150 feet from surface waters or in currently developed areas such as parking lots or previously developed sites.
- Erodible material that may be temporarily stored for use in project activities would be covered with plastic or other impervious material during rain events to prevent sediments from being washed from the storage area to surface waters.
- Erosion and sedimentation control BMPs would be inspected after each rainfall and at least daily during prolonged rainfall. Sediment would be removed as it is collected behind sedimentation control BMPs and prior to their final removal.
- All exposed soils would be stabilized during the first available opportunity, and no soils would remain exposed for more than 7 days from May 1 to September 30.
- All silt fencing and staking would be removed upon soil surface stabilization and project completion.
- Exposed soils would be seeded and covered with straw mulch or an equally effective BMP after construction was complete.
- The project would remove any temporary fills and till-compacted soils and would restore woody and herbaceous vegetation according to an engineer-approved restoration or planting plan.
- A minimum 1-year plant establishment plan would be implemented to ensure survival, or replacement, of vegetation by stem count at the end of 1 year.

BMPs to reduce the risk of introducing pollutants to waterbodies include the following:

- The contractor would prepare a Spill Prevention, Control, and Countermeasure (SPCC) plan prior to beginning any construction activities. The SPCC plan would identify appropriate spill containment materials (which would be available at the project site at all times), as well as specify what to do and whom to contact when spills occur. The plan would provide site- and project-specific details identifying potential sources of pollutants, exposure pathways, spill response protocols, protocols for routine inspection fueling and maintenance of equipment, preventative and protective equipment and materials, reporting protocols, and other information according to contract specifications.
- All equipment to be used for construction activities would be cleaned and inspected prior to arriving at the project site to ensure that no potentially hazardous materials would be exposed, no leaks would be present, and the equipment would be functioning properly. Should a leak be detected on heavy equipment used for the project, the equipment would immediately be removed from areas within or immediately adjacent to the OHWM of waterbodies.
- For construction access, a stabilized construction entrance, temporary access roads pads, and street cleaning would be provided.
- Absorbent materials would be placed under all vehicles and equipment on construction access or demolition laydown pads or other over-water structures. Absorbent materials would be applied immediately on small spills, promptly removed, and disposed of properly. An adequate supply of spill cleanup materials, such as absorbent materials, would be maintained and available on-site.

- Excavated material would be removed to a location that would prevent its reentry into waters of the state.
- As practicable, the contractor would fuel and maintain all equipment more than 200 feet from the nearest wetland, drainage ditch, or surface waterbody, or in currently developed areas such as parking lots or managed areas. Commercial facilities that provide such services, for example gas stations, would be excluded.
- Materials disposal would occur at contractor-provided disposal sites and in accordance with federal, state, and local laws and ordinances. Additionally, the contract may contain special conditions and requirements that pertain to the demolition and disposal of specific structures or to working in specific areas.

BMPs for in-channel construction include the following:

- All work below the OHWM would be completed during the approved in-water work window and would fully comply with all environmental permits and other authorizations.
- The work would follow WDFW's Level 1 Decontamination Protocols for invasive species management (WDFW 2022).
- To minimize fish handling, fish would be herded out of and excluded from re-entering the cofferdam area before the cofferdam is closed and dewatered.
- Before, during, and immediately after isolation and dewatering of the in-water work area, fish from the isolated area would be captured and released using methods that would minimize the risk of fish injury, in accordance with WSDOT protocols for such activities (WSDOT 2021).
- Lower Green River flows would be monitored throughout construction using an applicable stream gage near the project site. During flow events approaching a defined risk for discharge, equipment and materials would be moved out of potential flows until waters would subside.

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Attachment A: Rationale Supporting Facility Type Level of Effect Rankings for Ecological Functions Supporting Juvenile Salmonid Rearing and Adult Salmonid Migration

Table A-1. Rationale Supporting Facility Type Level of Effect Rankings for Ecological Functions Supporting Juvenile Salmonid Rearing and Adult Salmonid Migration

Resources/Issues	Ecological Function	Metric(s)	Rationale Supporting Facility Type Ranking
Primary life stage – juvenile rearing	Off-channel habitat	Area	Flood control facilities reduce or eliminate hydraulic connectivity between river and floodplain habitats by design. The extent of this effect varies by facility Type. In general, unmodified banks retain the greatest degree of floodplain connectivity and potential for off-channel habitat restoration (rank 5). Type D facilities would provide the highest level of connectivity of all flood control facility Types (rank 4), with Type C facilities providing less off-channel habitat function (rank 2). Setback levees can also substantially increase floodplain connectivity, but the degree of this effect would vary depending on distance from the channel (rank 3). Type A and B facilities would eliminate floodplain connectivity and off-channel habitat function (rank 1). Availability of off-channel habitat during ecological flows (i.e., flows between the 2-year and 10-year recurrence intervals, inclusive) is a core component of habitat function for juvenile rearing. Differences in the estimated quantity of off-channel habitat available under ecological flows is used to differentiate between alternatives.
	Tributary access	Habitat access	Gregersen (2019) defines 4 tributary habitat Types that provide varying degrees of habitat function for juvenile salmonids: stream, convergence, backwatered, and confluence. Effects on tributary access are ranked based on how each facility Type impacts the availability of and access to these four habitat Types. Unmodified streambanks and revetments maintain each habitat Type and do not restrict access (rank 5). Type D facilities would maintain all four habitat Types but may require culverts or other features that affect habitat access (rank 4). Type C facilities would likely retain convergence, backwatered, and confluence habitat Types, but would restrict access to stream habitat (rank 2). Depending on the setback distance, setback facilities would likely support and provide access to all four habitat Types but would not allow full access to available stream habitat (rank 3). Type A and B facilities would restrict access to stream habitat and would effectively eliminate the remaining tributary habitat Types (rank 1).
	Pool habitat	Area, #/distance	Channel modification by flood control facilities can alter hydraulic and sediment transport processes that contribute to pool formation and maintenance. Natural banks, setback levees and Type D facilities have greater potential to contribute to pool formation and maintenance of pool habitats over time than other Types of bank modification. While beneficial, these facility Types are unlikely to fully restore this ecosystem function due to the broader influence of watershed-level conditions on watershed processes in the Lower Green River (rank 4). Type B and C facilities that integrate woody debris can beneficially contribute to pool formation but also affect the capacity of the channel to manage pool-filling sediments by limiting overbank flooding (rank 3). Type A facilities have similar effects on sediment transport but are less likely to beneficially contribute to pool formation (rank 1).

Table A-1. Rationale Supporting Facility Type Level of Effect Rankings for Ecological Functions Supporting Juvenile Salmonid Rearing and Adult Salmonid Migration (continued)

Resources/Issues	Ecological Function	Metric(s)	Rationale Supporting Facility Type Ranking
Primary life stage – juvenile rearing (cont.)	Woody debris	#/distance	Unmodified streambanks, levee setbacks and facilities that promote the restoration of functional riparian vegetation are likely to establish and maintain future sources of woody debris recruitment. Depending on the setback distance, the areas riverward of setback levees can approach and potentially exceed the recruitment potential of unmodified banks depending on adjacent land uses. In this context, unmodified banks and setbacks are most likely to benefit woody debris density and recruitment potential over the long term (rank 5). Type C and D facilities incorporate large wood as design features and can beneficially increase the quantity of habitat-forming woody debris in the active stream channel and can provide a limited degree of woody debris recruitment (rank 4). Type B facilities similarly incorporate woody debris as a design feature but provide for little or no future woody debris recruitment (rank 3). Type A facilities do not incorporate woody debris in their designs and, like Type B facilities, would effectively prevent future woody debris recruitment under most circumstances (rank 1).
	Shallow margins	Area	Unmodified banks are most likely to maintain suitable shallow margin habitat for juvenile salmonids across a range of flow conditions (rank 5). Depending on configuration, Type C and D facilities can effectively maintain shallow margin habitat, but over a narrow range of relatively high flows (rank 4). Type B facilities that integrate woody debris and vegetation can provide a degree of shallow margin habitat at lower function than Type C and D facilities (rank 3). Revetments and Type A facilities provide the least shallow margin habitat (rank 2 and 1, respectively).
	Riparian vegetation	Length & Width	Unmodified streambanks have the greatest potential to provide functional riparian vegetation, contingent on surrounding land uses and effective habitat protection (rank 5). Type A facilities offer little to no functional riparian vegetation and degrade riparian habitat function (rank 1). Type B facilities can support wider riparian buffers and marginally improve riparian function, but typical vegetation widths are less than 100 feet and provide limited benefit (rank 2). Type C facilities and revetments allow for wider riparian buffers and greater channel connectivity to riparian vegetation at ecological flows (rank 3). Depending on affected land uses and associated habitat restoration, Type D facilities can provide a comparable level of riparian function to unmodified banks (rank 4 to 5). Channel connectivity to riparian vegetation and complex channel margins during ecological flows (i.e., flows between the 2-year and 10-year recurrence intervals, inclusive) is a core component of habitat function for juvenile rearing. Differences in the estimated quantity of habitat available for riparian restoration that is activated at ecological flows is used to differentiate between alternatives.
	Substrate	% Embeddedness	Flood control facilities alter sediment transport dynamics. In environments like the Lower Green River, this effect is most prominently expressed through the reduction or elimination of overbank flooding that allows for dispersal and storage of fine sediment on the floodplain. In constrained channels, fine sediments settle into the substrate on the descending limb of the hydrograph, contributing to sediment embeddedness. This reduces the amount of interstitial habitat available to juvenile salmonids for cover from predation and refuge from high flows. The sediment dynamics of the LRG have been modified by basin-level factors such that even full restoration of the Lower Green River would be unlikely to fully restore the natural sediment transport regime (rank 5). However, unarmored banks and Type 4 facilities would allow for overbank flooding and deposition of fine sediments on the floodplain (rank 4). Revetments and Type C facilities would also support overbank flooding, but to a lesser degree (rank 3). Type A and B facilities effectively eliminate overbank flooding and would effectively maintain the degraded embeddedness conditions that persist throughout the Lower Green River (rank 2).

Table A-1. Rationale Supporting Facility Type Level of Effect Rankings for Ecological Functions Supporting Juvenile Salmonid Rearing and Adult Salmonid Migration (continued)

Resources/Issues	Ecological Function	Metric(s)	Rationale Supporting Facility Type Ranking
Primary life stage – adult migration	Pool habitat	Area, #/distance	See above.
	Riparian vegetation/shade	Length & Width	See above
	Woody debris	#/distance	See above.
	Fish passage improvements	Habitat access	Unarmored banks and Type D facilities would eliminate most barriers to adult fish passage into Lower Green River tributaries, where tributary confluences are present in association with these facility Types (rank 5). Revetments would likewise pose minimal barriers to passage at confluences but may be associated with upstream flood or gradient control structures that could impede fish passage under certain conditions (rank 4). Type C facilities would require floodgates, creating barriers to fish passage. However, the floodgates would be located further upstream from the confluence, allowing at least some adult salmonid access to the lower reaches of tributary streams (rank 2). Type A and B facilities would impose barriers in the form of floodgates at or near confluences, effectively eliminating adult fish access to tributary stream habitat (rank 1).
	Floodplain Interaction		Flood control facilities reduce or eliminate hydraulic connectivity between river and floodplain habitats by design. The extent of this effect varies by facility Type. In general, unmodified banks retain the greatest degree of floodplain connectivity and potential for off-channel habitat restoration (rank 5). Type D facilities would provide the highest level of connectivity of all flood control facility Types (rank 4), with Type C facilities providing less floodplain interaction than Type D but increase floodplain connectivity relative to Type and B facilities (rank 2-3). Type A and B facilities preclude floodplain connectivity and off-channel habitat function (rank 1).
	Habitat Connectivity		Connectivity to off-channel habitat or channel margin habitat also varies by facility Type. In general, unmodified banks retain the greatest degree of floodplain connectivity and potential for off-channel habitat restoration (rank 5). Type D facilities would typically provide the highest level or potential of connectivity of all flood control facility Types (rank 4), with Type C facilities providing less off-channel habitat connectivity (rank 2-4). Type B facilities may provide greater shallow margin habitat, but generally preclude off-channel habitat function (rank 2-3). Type A facilities precludes off-channel habitat function (rank 1).
	Hydrology/Flow Regime		Greater constraints on the river hydrology through confinement of flow within levee systems can contribute to higher velocity and flashier flows. Generally, unconfined fluvial systems provide a more stable hydrograph and the greatest hydrologic moderation through floodplain engagement and high-friction complex habitats (rank 5). Type D facilities would provide the least confinement of flows of all flood control facility Types (rank 4), with Type C facilities providing less confinement (rank 2-3). Type A and B facilities effectively confine flows to a relatively greater extent and reduce hydrologic moderation (rank 1-2).
	Sediment Dynamics		Sediment dynamics are highly correlated with hydrology and the confinement of the fluvial system. A confined system can lead to aggradation or degradation of the channel bed that is out of equilibrium. An unconfined system will generally transport and distribute sediments in manner that supports more complex habitat formation (rank 5). Type D facilities would provide the least confinement of flows and sediment transport of all flood control facility Types (rank 4), with Type C facilities providing less confinement (rank 2-3). Type A and B facilities effectively confine flows to a relatively greater extent and can result in channel incision (rank 1-2).

Table A-1. Rationale Supporting Facility Type Level of Effect Rankings for Ecological Functions Supporting Juvenile Salmonid Rearing and Adult Salmonid Migration (continued)

Resources/Issues	Ecological Function	Metric(s)	Rationale Supporting Facility Type Ranking
Primary life stage – adult migration (cont.)	Wood load		Wood loading relative to flood reduction strategies are largely a function of the opportunity to support an intact forested riparian community or provide off-channel or channel margin habitat that can entrain transported wood. Confined systems limit this opportunity, whereas unconfined systems provide the greatest potential to support riparian areas and wood entrainment (rank 5). Type D facilities would provide the least confinement and greatest potential for riparian forest development all flood control facility Types (rank 4), with Type C facilities providing less confinement and greater potential for riparian zones than Type A and B facilities (rank 2-4). Type B facilities may provide some opportunity for tree growth and wood entrainment (rank 2-3). Type A facilities provide little opportunity for riparian forest or wood entrainment (rank 1).
	Trophic support		Trophic support is also largely a function of the potential to support a riparian community and floodplain engagement. Riparian vegetation provides habitat for terrestrial animals (primarily insects) and organic material (allochthonous inputs) and hydraulic engagement with the riparian zone and floodplain provides transport of the organic matter and other nutrients that supports primary productivity into the aquatic system (rank 5). Type D facilities would provide the least confinement and greatest potential for riparian forest development all flood control facility Types (rank 4), with Type C facilities providing less confinement and greater potential for riparian zones than Type A and B facilities (rank 2-4). Type B facilities may provide some opportunity for riparian zone development (rank 2-3). Type A facilities provide little opportunity for riparian development (rank 1).
	Temperature		Temperature effects related to flood reduction strategies are highly correlated to riparian vegetation potential. Confined systems with little opportunity to support forested riparian areas do not beneficially support temperature functions. Larger forested riparian areas with mature trees contribute to river shading and a cool microclimate (rank 5). Type D facilities would provide the least confinement and greatest potential for riparian forest development all flood control facility Types (rank 4), with Type C facilities providing less confinement and greater potential for riparian zones than Type A and B facilities (rank 2-4). Type B facilities may provide some opportunity for riparian zone development (rank 2-3). Type A facilities provide little opportunity for riparian development (rank 1).
Other biota	Macroinvertebrates	B-IBI	Aquatic macroinvertebrate communities are affected by a wide range of factors on scales beyond flood control levee construction. Urbanization of the Green-Duwamish watershed has resulted in widespread impacts on macroinvertebrate community composition (King County 2004a, 2005). The B-IBI is sensitive to disturbances to macroinvertebrate community structure but lacks the analytical ability to identify among various causes of disturbance. While a link can be inferred between changes in channel configuration associated with flood control infrastructure and shifts macroinvertebrate community composition, it is difficult to distinguish these effects from those caused by other watershed-level factors, such as changes in hydrology, sediment, and pollutant loading. As such, inferring the effect of flood control facilities on the macroinvertebrates must therefore rely on consideration of other ecosystem functions, including floodplain connectivity, side channel habitat, sediment impoundment and transport, and water quality. Using our best professional judgement, we have presented predictions for the effects of flood control facilities on the macroinvertebrate community structure, within the broader context of a widely degraded and urbanized watershed.

Table A-1. Rationale Supporting Facility Type Level of Effect Rankings for Ecological Functions Supporting Juvenile Salmonid Rearing and Adult Salmonid Migration (continued)

Resources/Issues	Ecological Function	Metric(s)	Rationale Supporting Facility Type Ranking
Other biota (cont.)	Fish		As is the case with invertebrates, aquatic fish communities in the Green-Duwamish watershed are affected broadly by anthropogenic effects. The Fish Index of Biotic Integrity is a useful measure of fish community structure but does not explicitly identify causes of detrimental or beneficial effects to the overall fish community. As with macroinvertebrates above, analysis of other ecological functions informs our predictions of flood control facilities' effects on riverine fish community structure.
	Aquatic vegetation	Off-channel habitat area, Shallow margin area	Submerged aquatic vegetation (SAV) relies on slow-moving, shallow water found at margins of streams and in backwater side channel habitat. While not all surface area meeting these conditions is suitable for or occupied by SAV, it is a useful metric for assessing the total area available for restoration and recovery of aquatic vegetation.

Attachment B: Information Sources Used in Analysis

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
Bisson et al. 1988			X																				Juvenile habitat preferences of coho, steelhead, and cutthroat trout differed in utilization of habitat Types.
Booth et al. 2014														X									Influence of urbanization on stream temperature confounded by watershed-scale factors, including underlying geology (influencing groundwater exchange), watershed area, upstream lakes, and riparian shading.
Coffin et al. 2011														X									Green River exhibits unhealthy and sometimes lethal temperatures for salmonids and fails to meet state water quality standards.
Collins et al. 2002				X						X		X											Lower Green River woody debris density is 1-2 orders of magnitude lower than historical levels, due to lack of key pieces and reduced recruitment rate. Loss of LWD has altered morphology, dynamics, and habitat of rivers, overall reducing suitable salmonid habitat.

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
Dauwalter et al. 2018				X		X																	Excluding grazers from riparian areas increased woody vegetation and resulted in less-altered streambanks. Sub-yearling salmonid densities increased with grazing exclusion. Instream habitat and macroinvertebrates were not affected, indicating that watershed-scale factors are responsible for biotic conditions.
Davies-Colley et al. 2009				X		X			X	X				X									Modeling showed greatest long-term benefit from mixed native riparian plantings. Initial planting of pine plantation resulted in earlier shade benefit, especially in narrow modeled streams more susceptible to solar heating. Recovery of LWD is expected to take decades to centuries.

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
Gregersen 2017	X		X																	X			Juvenile Chinook most abundant in Lower Green River side channel habitats. Abundance lowest in riprap armored reaches. Larger juvenile migrants have higher survival rates, indicating importance of quality rearing habitat. Differences in capture efficiency between habitat Types may confound results.
														X									Low flow conditions and hot summer led to unusually high river temperatures in 2015, a concern for cold-water fish including salmonids. Temperatures exceeded Ecology Category 5 criteria consistent with listing as impaired by temperature. 2015 is predicted to be typical of conditions expected later this century as a result of climate change. Adaptive management is recommended, as is development of models with changing climate conditions.

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
Gregersen et al. 2019		X																					Juvenile Lower Green River Chinook display differing habitat affinity for four Types of tributary habitat: stream, convergence, backwater, and confluence. Flood facility Type affects the extent of and ability to access these habitats.
Hall et al. 2018	X																						Chinook abundance positively correlated with river channel habitat complexity (i.e., braid and side channel density, LWD jam area, and side channel length).
Hyatt and Naiman 2001				X						X													LWD residence time in the Queets River was <50 yr for 80 percent of pieces. The halinear feet-life for LWD was approximately 20 years. LWD depletion is likely within a few decades of decreased recruitment, with associated loss of habitat function.
Jeanes and Hilgert 2001	X																						Complex accumulations of LWD were important for overyearling (coho and cutthroat) in side channels, but LWD is lower than other Pacific Northwest streams. Report contains details of abundance and timing of species occurrence.

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
Johnson 2004														X									Experimental shading in OR Cascades reduced max temperature, but not mean or minimum. Substrate was an important factor (bedrock vs. alluvium) in stream temperature dynamics.
King County 2004																		X			X		Benthic index of biotic integrity (B-IBI) was "fair" to "very poor" in the 20 subbasins studied in 2002. Duwamish and Black River subbasins heavily impacted by human development. B-IBI score was negatively correlated with degree of development and percent effective impervious area (%EIA).
King County 2005a														X									Study seeks to refine the Green River water quality model by integrating hi-res LIDAR data of riparian shade. Model prediction of shade conditions based on LIDAR tree heights correlated well with observed shade acquired by hemispherical photography.
King County 2005b																		X			X		Overall B-IBI were similar to 2002 observations. Green-Duwamish basin is heavily impacted by urbanization. Reduction in invertebrate biodiversity was correlated with increased area of development and percent effective impervious area (% PEIA).

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
King County 2014												X					X						Sampling of 58 sites in Duwamish basin to identify potential sources of contaminants in the LDW Superfund sites. More urbanized sites generally had higher concentrations of organic and metallic pollutants. All metals analyzed were present in all samples; not true of organic pollutants. All contaminants were below WA State Sediment Management Standards levels expected to cause minor adverse effects on benthic organisms.
King County 2017b	X																						Juvenile Chinook readily use off-channel habitat. Larger migrants survive at higher rates than small (early) migrants. Comparative value of different habitat Types compounded by small sample size and questions about capture efficiency in different environment Types.
Lee et al. 2011														X									Portions of Newaukum Creek do not meet State standards for temperature and oxygen concentration. Modeling shows that increases of riparian shade between 11 and 64 percent could meet the 16°C temperature standard for most of the stream length. Combined effects of restored baseflows, added riparian shade from mature trees, and improved riparian

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	Off-channel habitat	Tributary habitat access	Pool habitat	Woody debris	Shallow margins	Riparian vegetation	Substrate	Pool habitat	Riparian vegetation/shade	Woody debris	Fish passage improvements	Sediment Dynamics	Hydrology/Flow Regime	Temperature	Nutrient Supply	Floodplain Interaction	Organic matter	Trophic support	Habitat Connectivity	Fish	Macroinvertebrates	Flora	
																							microclimate from vegetation restoration. Target temperature should be achieved by 2040.
May and Lee 2004			X				X					X											Sediment Type and proximity to bedrock influenced pool distribution during summer drought in OR Coast Range streams. Juvenile salmonid mortality was higher in gravel streams than in bedrock due to loss of pool habitat.
Moore et al. 2005						X			X					X									Meta-analysis shows inconclusive impacts of riparian logging on stream temperature. Direct solar heating is an important factor, but some uncertainties remain regarding nearby clearing, air temperature, humidity, and soil temperature.
Morley et al. 2005	X																						Total densities of salmonids did not differ between natural and constructed side channels in the Skagit, Hoh, and Quillayute basins. Coho densities were higher in constructed channels while trout densities were higher in natural channels. Relative to

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	Off-channel habitat	Tributary habitat access	Pool habitat	Woody debris	Shallow margins	Riparian vegetation	Substrate	Pool habitat	Riparian vegetation/shade	Woody debris	Fish passage improvements	Sediment Dynamics	Hydrology/Flow Regime	Temperature	Nutrient Supply	Floodplain Interaction	Organic matter	Trophic support	Habitat Connectivity	Fish	Macroinvertebrates	Flora	
																							mainstem river habitat, side channels of both Types supported higher densities of juvenile salmonids.
Naiman et al. 2002															X								Broad overview of export of marine-derived nutrients into freshwater habitats by salmon migration. Includes discussion of salmon management, nutrient dynamics of lakes and streams, stable isotope analysis, nutrient uptake by terrestrial plants, large-scale processes, and climate variation.
Pess et al. 2012				X						X													Juvenile Chinook, coho, and trout tended to be more abundant in reaches with engineered log jams in the Elwha. Results suggest that placement of ELJs in river restoration can provide habitat complexity for juvenile salmonids.

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
Suttle et al. 2004							X					X											Experimental increase of fine sediment in N. CA river decreased growth and survival of juvenile steelhead. Declines associated with an invertebrate community shift to burrowing taxa unavailable as prey for salmonids. Linearity of relationship between fine sediment and salmonid growth inhibition suggests that no threshold exists below which added sediment is harmless, but also that any reduction in fine sediment loading can benefit salmonid growth and survival.
Swales and Levings 1989	X		X																				Off-channel ponds were important habitat for juvenile coho rearing. Coho were more abundant in ponds than in main channel. Chinook, steelhead, and Dolly Varden were abundant in the main river and scarce in off-channel ponds. Coho growth in ponds was higher than in main channel.

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							**Primary life stage - Adult migration**				**Ecosystem Processes**								**Other Stream Biota**			**Summary**
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
Sweeney and Newbold 2014						X												X		X	X	X	Literature review of riparian forest buffer effects on 8 parameters. 1) *subsurface NO2 removal*: varied inversely w/ subsurface water flux; efficiency 55 percent for buffers <40m and 89 percent for buffers >40m. 2) *sediment trapping*: 65 percent for 10m and 85 percent for 30m buffers. 3) *stream channel width:* significantly wider with 25m buffer (than w/ no buffer) but no increase past 25m. 4) *channel meandering and bank erosion*: less in forest banks, but more studies needed. 5) *temperature*: <2°C variation between fully forested and 20m buffer, but full protection requires 30m buffer. 6) *LWD*: buffer equal to height of mature streamside trees (~30m) can likely provide natural input levels. 7/8) *macroinvert and fish communities*: remain near natural levels with ≥30m buffer.
Topping and Anderson 2020																				X			Estimated approximately 350,000 natural origin juvenile Chinook for Green River basin for 2017. Fry (<45mm fork length) were 87 percent of sub-yearling migrants, while parr (>45mm) were 13%.

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
Wondzell et al. 2007						X			X					X									Early reporting of development of models to simulate effects of human disturbance on tributaries of Grande Ronde River in NE Oregon. Simulated 50 years of historical (pre-European-settlement) disturbance regime to model passive recovery. European settlement and disturbance regime associated with significant impairments to habitat quality.
Mellina and Hinch 2009				X		X			X	X													Meta-analysis: most studies showed negative response of LWD and pool habitat to logging but positive responses of salmonid density and biomass. Juveniles (1+ yr) more likely to be negatively impacted than fry (age 0). Within limited time frames, streams with logged banks may be able to sustain salmonid populations at pre-logging levels if LWD is not removed.
Rentz et al. 2020	X		X	X		X		X	X	X						X	X		X	X	X	X	WDFW recommendations for monitoring, adaptive management, and science-based practices.

Table B-1. Annotated Summary of Supporting References and Relevant Ecosystem Functions (continued)

	Primary life stage - Juvenile rearing							Primary life stage - Adult migration				Ecosystem Processes								Other Stream Biota			Summary
Source	**Off-channel habitat**	**Tributary habitat access**	**Pool habitat**	**Woody debris**	**Shallow margins**	**Riparian vegetation**	**Substrate**	**Pool habitat**	**Riparian vegetation/shade**	**Woody debris**	**Fish passage improvements**	**Sediment Dynamics**	**Hydrology/Flow Regime**	**Temperature**	**Nutrient Supply**	**Floodplain Interaction**	**Organic matter**	**Trophic support**	**Habitat Connectivity**	**Fish**	**Macroinvertebrates**	**Flora**	
WRIA 9 2021	X		X	X	X	X	X	X	X	X	X	X		X	X	X			X				Update to 2005 WRIA 9 Salmon Habitat Plan. Updated with NOAA criteria for Chinook population. Strategic Assessment Update w/ new research findings relating stressors, habitat conditions, and salmon parameters. Monitoring and Adaptive Management Plan outlines monitoring priorities and effectiveness measures.

Attachment C: Ordinal Ranking Analysis Tables

Table C-1. Weighted Level of Effect Ranking for Juvenile Salmonid Rearing by Alternative

			Alternative 1		Alternative 2		Alternative 3	
Ecological Function	**Flood Facility Type**	**Level of Effect Rank**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**
Off-channel habitat	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	1	27,000	0.12	28,000	0.13	27,000	0.12
	C	2	27,000	0.24	31,000	0.28	42,000	0.38
	D	4	0	0.00	0	0.00	0	0.00
			Off-channel habitat rank	***2.5***		***2.6***		***2.6***
Tributary access	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	5	31,000	0.70	34,000	0.77	33,000	0.74
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	1	27,000	0.12	28,000	0.13	27,000	0.12
	C	2	27,000	0.24	31,000	0.28	42,000	0.38
	D	4	0	0.00	0	0.00	0	0.00
			Tributary access rank	***2.8***		***2.9***		***2.9***
Pool habitat	None	4	60,000	1.08	64,000	1.16	62,000	1.11
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	3	27,000	0.36	28,000	0.38	27,000	0.36
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
			Pool habitat rank	***2.6***		***2.7***		***2.7***
Woody debris	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	3	27,000	0.36	28,000	0.38	27,000	0.36
	C	4	27,000	0.49	31,000	0.56	42,000	0.75
	D	4	0	0.00	0	0.00	0	0.00
			Woody debris rank	***3.0***		***3.1***		***3.2***

Table C-1. Weighted Level of Effect Ranking for Juvenile Salmonid Rearing by Alternative (continued)

Ecological Function	Flood Facility Type	Level of Effect Rank	Alternative 1 Length of Bank by Facility Type (linear feet)	Alternative 1 Weighted Effect Rank by Facility Type	Alternative 2 Length of Bank by Facility Type (linear feet)	Alternative 2 Weighted Effect Rank by Facility Type	Alternative 3 Length of Bank by Facility Type (linear feet)	Alternative 3 Weighted Effect Rank by Facility Type
Shallow margins	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	2	31,000	0.28	34,000	0.31	33,000	0.30
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	3	27,000	0.36	28,000	0.38	27,000	0.36
	C	4	27,000	0.49	31,000	0.56	42,000	0.75
	D	4	0	0.00	0	0.00	0	0.00
			Shallow margins rank	***2.8***		***3.0***		***3.1***
Riparian vegetation	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	2	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	3	27,000	0.24	28,000	0.25	27,000	0.24
	C	4	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
			Riparian vegetation rank	***2.7***		***2.9***		***2.9***
Substrate	None	4	60,000	1.08	64,000	1.16	62,000	1.11
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	2	77,000	0.69	64,000	0.58	59,000	0.53
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
			Substrate rank	***2.8***		***2.9***		***2.9***

Table C-2. Weighted Level of Effect Ranking for Adult Salmonid Migration by Alternative

			Alternative 1		Alternative 2		Alternative 3	
Ecological Function	**Flood Facility Type**	**Level of Effect Rank**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**
Pool habitat	None	4	60,000	1.1	64,000	1.2	62,000	1.1
	Revetment	3	31,000	0.4	34,000	0.5	33,000	0.4
	A	1	77,000	0.3	64,000	0.3	59,000	0.3
	B	3	27,000	0.4	28,000	0.4	27,000	0.4
	C	3	27,000	0.4	31,000	0.4	42,000	0.6
	D	4	0	0.0	0	0	0	0.0
			Pool habitat rank	***2.6***		***2.7***		***2.7***
Riparian vegetation/ shade	None	5	60,000	1.4	64,000	1.4	62,000	1.4
	Revetment	3	31,000	0.4	34,000	0.5	33,000	0.4
	A	1	77,000	0.3	64,000	0.3	59,000	0.3
	B	2	27,000	0.2	28,000	0.3	27,000	0.2
	C	3	27,000	0.4	31,000	0.4	42,000	0.6
	D	4	0	0	0	0.0	0	0.0
			Riparian vegetation/ shade rank	***3.2***		***3.3***		***3.3***
Woody debris	None	5	60,000	1.4	64,000	1.4	62,000	1.4
	Revetment	3	31,000	0.4	34,000	0.5	33,000	0.4
	A	1	77,000	0.3	64,000	0.3	59,000	0.3
	B	3	27,000	0.4	28,000	0.4	27,000	0.4
	C	4	27,000	0.5	31,000	0.6	42,000	0.8
	D	4	0	0.0	0	0.0	0	0.0
			Woody debris rank	***3.4***		***3.5***		***3.6***
Fish passage improvements	None	5	60,000	1.4	64,000	1.4	62,000	1.4
	Revetment	4	31,000	0.7	34,000	0.8	33,000	0.7
	A	1	77,000	0.3	64,000	0.3	59,000	0.3
	B	1	27,000	0.1	28,000	0.1	27,000	0.1
	C	2	27,000	0.2	31,000	0.3	42,000	0.4
	D	5	0	0.0	0	0.0	0	0.0
			Fish passage improvements rank	***3.1***		***3.2***		***3.2***

Table C-3. Weighted Level of Effect Ranking for Ecosystem Processes by Alternative

Ecological Function	Flood Facility Type	Level of Effect Ranking	Alternative 1		Alternative 2		Alternative 3	
			Length of Bank by Facility Type (linear feet)	**Weighted Effect Rank by Facility Type**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**
Floodplain Interaction	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	1	27,000	0.12	28,000	0.13	27,000	0.12
	C	2	27,000	0.24	31,000	0.28	42,000	0.38
	D	4	0	0.00	0	0.00	0	0.00
Floodplain Interaction rank				***2.5***		***2.6***		***2.6***
Habitat Connectivity	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	2	31,000	0.28	34,000	0.31	33,000	0.30
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	1	27,000	0.12	28,000	0.13	27,000	0.12
	C	2	27,000	0.24	31,000	0.28	42,000	0.38
	D	4	0	0.00	0	0.00	0	0.00
Habitat Connectivity rank				***2.3***		***2.5***		***2.4***
Hydrology / Flow Regime	None	4	60,000	1.08	64,000	1.16	62,000	1.11
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
Hydrology / Flow Regime rank				***2.5***		***2.6***		***2.6***
Sediment Dynamics	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
Sediment Dynamics rank				***2.7***		***2.9***		***2.9***

Table C-3. Weighted Level of Effect Ranking for Ecosystem Processes by Alternative (continued)

Ecological Function	Flood Facility Type	Level of Effect Ranking	Alternative 1 Length of Bank by Facility Type (linear feet)	Alternative 1 Weighted Effect Rank by Facility Type	Alternative 2 Length of Bank by Facility Type (linear feet)	Alternative 2 Weighted Effect Rank by Facility Type	Alternative 3 Length of Bank by Facility Type (linear feet)	Alternative 3 Weighted Effect Rank by Facility Type
Wood Load	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	2	31,000	0.28	34,000	0.31	33,000	0.30
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
			Wood Load rank	***2.6***		***2.7***		***2.8***
Trophic Support	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
			Trophic Support rank	***2.7***		***2.9***		***2.9***
Temperature	None	5	60,000	1.35	64,000	1.45	62,000	1.39
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.44
	A	1	77,000	0.35	64,000	0.29	59,000	0.26
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
			Temperature rank	***2.7***		***2.9***		***2.9***

Table C-4. Weighted Level of Effect Ranking for Other Stream Biota by Alternative

			Alternative 1		Alternative 2		Alternative 3	
Ecological Function	**Flood Facility Type**	**Level of Effect Ranking**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**	**Length of Bank by Facility Type (linear feet)**	**Weighted Effect Rank by Facility Type**
Macro-invertebrates	None	4	60,000	1.08	64,000	1.15	62,000	1.12
	Revetment	2	31,000	0.28	34,000	0.31	33,000	0.30
	A	1	77,000	0.35	64,000	0.29	59,000	0.27
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
			Macroinvertebrates Rank	***2.3***		***2.4***		***2.5***
Fishes	None	4	60,000	1.08	64,000	1.15	62,000	1.12
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.45
	A	1	77,000	0.35	64,000	0.29	59,000	0.27
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	4	0	0.00	0	0.00	0	0.00
			Fishes Rank	***2.5***		***2.6***		***2.6***
Aquatic flora	None	5	60,000	1.35	64,000	1.44	62,000	1.40
	Revetment	3	31,000	0.42	34,000	0.46	33,000	0.45
	A	1	77,000	0.35	64,000	0.29	59,000	0.27
	B	2	27,000	0.24	28,000	0.25	27,000	0.24
	C	3	27,000	0.36	31,000	0.42	42,000	0.57
	D	5	0	0.00	0	0.00	0	0.00
			Aquatic Flora Rank	***2.7***		***2.9***		***2.9***