JOHNSON CREEK SALMONID POTENTIAL WITH FUTURE URBAN DEVELOPMENT, CLIMATE CHANGE AND RESTORATION: 2009 TO THE 2040S

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March 2011

ENVIRONMENTAL SERVICES
CITY OF PORTLAND
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Acknowledgments

Many people contributed time, expertise, and information to the process of creating this report. Kaitlin Lovell, Chris Prescott, and Cindy Studebaker, from (or formerly from) the City of Portland's Bureau of Environmental Services (BES), played leading roles in initiating and carrying out the project. Also from BES, Jennifer Antak, Chad Smith, and Ali Young provided information on the Johnson Creek watershed and the restoration projects in particular. The analysis and composition of the report were led by Dr. Willis McConnaha, John Runyon and Dr. Josh Caplan, from ICF International. Many other individuals from ICF assisted in technical aspects of the analysis, including Greg Blair, Bruce Watson, Rick Paquette, Dr. Lars Mobrand, and Dr. Jesse Schwartz. Ted Gresh of ICF helped manage the project while Deborah Bartley and Kristen Lundstrom provided editorial assistance, and Alice McKee and Tammy Stout assisted with data collection. Todd Alsbury, from the Oregon Department of Fish and Wildlife; Noah Jenkins, from the Johnson Creek Watershed Council; and Drs. Alan Yeakley and Heejun Chang, from Portland State University; also provided valuable expertise.

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Acronyms and Abbreviations

BES	Bureau of Environmental Services
BMPs	best management practices
cfs	cubic feet per second
City	City of Portland
DDT	dichlorodiphenyltrichloroethane
DPS	Distinct Population Segment
EDT	Ecosystem Diagnosis and Treatment
ESA	Endangered Species Act
ESEE	economic, social, environmental, and energy
ESU	Evolutionarily Significant Unit
NCPRD	North Clackamas Parks and Recreation District
ODEQ	Oregon Department of Environmental Quality
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
SAR	smolt-to-adult return
UGB	urban growth boundary
WPA	Works Progress Administration

Project Context

The City of Portland (City) has made significant investments in restoring floodplain, stream and riparian habitat to improve watershed conditions in the Johnson Creek watershed. The City made these investments to improve ecosystem services such as flood mitigation and water quality, contribute to recovery of salmonid populations listed under the federal Endangered Species Act (ESA) and to enhance the quality of life for Portland residents (City of Portland 2005).

The City's restoration efforts have been guided and tracked by application of a salmonid-habitat model based on the concept of Ecosystem Diagnosis & Treatment (Mobrand et al. 1997, EDT). The Johnson Creek-EDT model has been used to prioritize areas for restoration, to identify limiting factors and to track progress toward increasing salmonid habitat potential in Johnson Creek. A previous report (ICF International 2010, Appendix A) analyzed the impact of restoration projects in Johnson Creek between 2000 and 2009. During this period the City undertook several major stream and floodplain restoration actions in Johnson Creek to reduce flood damage and contribute to stream and riparian habitat improvements. The analysis assessed the biological benefits of these projects and quantified the contribution of the City's efforts to enhance key ESA-listed salmonid populations in the lower Willamette River: coho salmon, winter steelhead, and fall Chinook salmon. The previous analysis showed that the restoration projects undertaken by the City have substantially increased the potential of Johnson Creek to support ESA-listed salmonid species. The analysis also indicated the value of a strategic approach to restoration based on varying species perceptions of habitat quality and synergisms that exist between projects.

The latest phase of the analysis continues the City's analysis of status and trends in salmonid habitat potential in Johnson Creek. The analysis evaluates a new set of planned restoration projects in the context of a plausible future scenario for the Johnson Creek watershed under increased urbanization and climate change. Future urbanization can affect water quality, change the timing or magnitude of stream flows and have direct impacts on stream and riparian habitat. There is a growing consensus that climate change, with associated impacts related to increasing air temperatures and altered rainfall patterns, could significantly affect native fish populations (Independent Scientific Advisory Board 2007).

This report provides the results of the analysis of future actions and incorporates the results of the 2000-2009 analysis (Appendix A). The analysis evaluates the extent to which future urban development and climate change can be expected to influence the benefits of habitat restoration efforts on coho, winter steelhead, and fall Chinook salmon populations in Johnson Creek. The analysis focuses on multiple restoration actions planned for implementation in the near future for Johnson Creek, and a key tributary system, Crystal Springs Creek. Understanding the complex interactions between future urban development, a changing climate and habitat restoration activities is essential to predicting future watershed health and associated fish population responses. Information on the appropriate location and sequencing of multiple restoration actions, and the degree to which these actions will help counteract urban development and climate change, aids in the development of management strategies designed to improve the Johnson Creek watershed in the face of a changing environment.

Scope of Analysis

The effect of planned restoration projects, increased urban development and climate change in the Johnson Creek watershed is analyzed by evaluating the anticipated change in one or more attributes of the stream system's environment (e.g., channel condition, sediment, temperature) relative to the current condition. These environmental changes and the effectiveness of restoration actions are analyzed relative to the needs of three native salmonid fish populations: coho salmon (*Onchorhynchus kisutch*), fall Chinook salmon (*O. tshawytscha*) and winter steelhead (*O. mykiss*). The Johnson Creek EDT model is used to translate these environmental changes into the expected change in potential of Johnson Creek to support these fish populations. For this analysis, the current condition is assumed to be 2009, which is based on a previous analysis of the status and trend of salmonid populations in Johnson Creek between 2000 and 2009 (ICF International 2010, Appendix A). In all these analyses, habitat is analyzed with respect to the needs of native salmonid fishes because of the social and legal importance. However, the potential of habitat to support these fish species is also taken as a surrogate for the potential of the environment to support a normative biological community of fish, wildlife and invertebrates.

In the context of current conditions, and future scenarios of increased urbanization and climate change, the benefits of major restoration projects on the potential of the Johnson Creek watershed to maintain salmonid populations are evaluated. The investigation covered a suite of seven restoration actions planned for implementation in the near future within the watershed: Three projects are on Johnson Creek (Figure 1) and four projects are on Crystal Springs Creek (Figure 2), a small spring-fed tributary entering Johnson Creek approximately 1 mile upstream of the confluence with the Willamette River. The restoration projects are as follows:

- Johnson Creek—Confluence Habitat Restoration
- Johnson Creek—Luther Road Habitat Restoration
- Johnson Creek—East Lents Floodplain Restoration
- Crystal Springs—Multiple Fish Passage Improvements
- Crystal Springs—Umatilla to Tenino Fish Passage
- Crystal Springs—Westmoreland Pond Habitat Restoration
- Crystal Springs—SE 28th Avenue Habitat Restoration

In the case of fish passage improvements on Crystal Springs Creek, what is cited as a single fish passage project is, in reality, a suite of multiple actions (e.g., multiple stream crossings with fish passage improvements) that are grouped together for the analysis.

For the purpose of this analysis, the 2040s were assumed as the period for the predicted future urbanization and climate change conditions. Johnson Creek's environmental attributes were adjusted to reflect presumed changes in the watershed resulting from the planned actions under future conditions as predicted from evaluation of development patterns in the watershed and recent climate change modeling and analysis for western Oregon rain-dominated systems.

Figure 1. The Johnson Creek Watershed with Johnson Creek Stream Reaches and Projects Considered in this Analysis

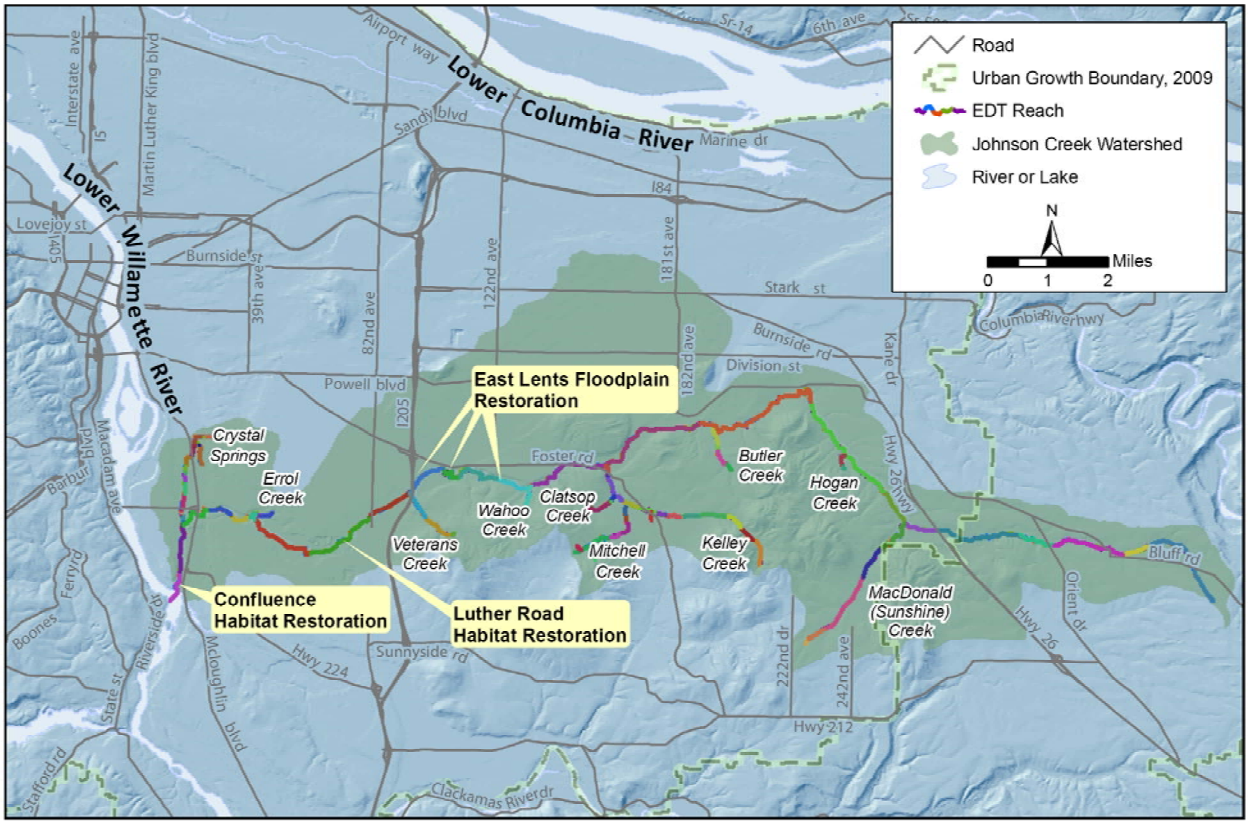
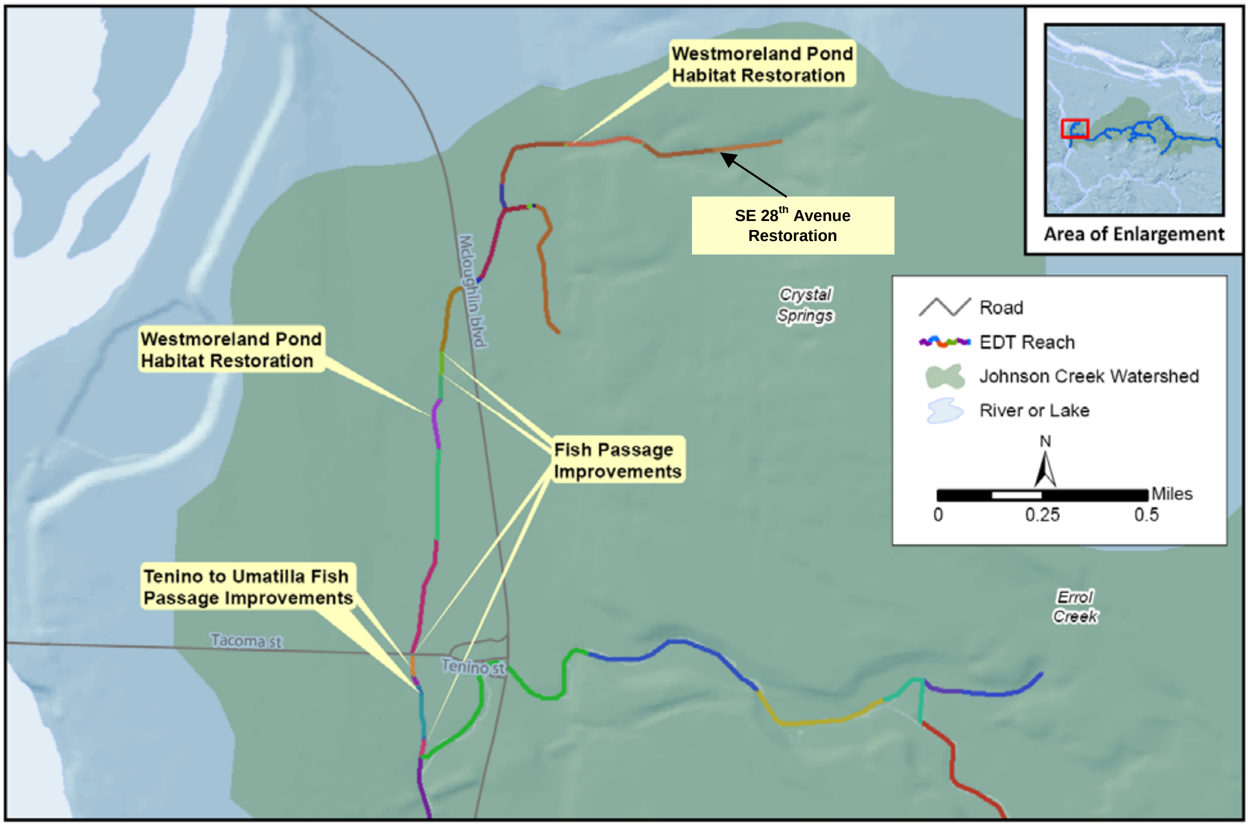


Figure 2. A portion of the Johnson Creek Watershed with Crystal Springs Creek Stream Reaches and Projects Considered in this Analysis



Watershed Description

The following description is based on the draft watershed characterization by the Bureau of Environmental Services (Portland BES 2005). The Johnson Creek watershed (54 square miles) is within the Willamette River basin in western Oregon. The mouth of the creek is approximately 18 miles from the confluence of the Willamette River with the Columbia River. Headwaters of the Johnson Creek watershed are largely within unincorporated Clackamas and Multnomah counties and in the cities of Gresham and Damascus, while the lower watershed is primarily within the cities of Portland (38% of the watershed) and Milwaukie. Land use is highly variable, with predominantly agricultural and forested land outside the regional urban growth boundary (UGB) and mixed urban uses (i.e., residential, industrial, commercial, and open space) within the UGB.

The strong contrast of winter versus summer precipitation in the Pacific Northwest gives Johnson Creek a strong seasonal hydrograph. For example, in mid-lower Johnson Creek (at the Sycamore U.S. Geologic Survey gauge), flow during winter storms is often between 100 and 300 cubic feet per second (cfs), while summer baseflow is typically less than 10 cfs (Lee and Snyder 2009b; Lee and Snyder 2009a). The dimensions of the watershed (i.e., long with relatively short tributaries) and impervious surfaces in urbanized portions of the watershed cause rapid fluctuations in flow during storms (Clark 1999). Several tributaries in the watershed are spring-fed (e.g., Crystal Springs and Errol Creek), and therefore, have less variable flow throughout the year.

Water quality in Johnson Creek varies with land use and underlying geology (Sonoda et al. 2001) but does not meet Oregon Department of Environmental Quality (ODEQ) water quality standards for bacteria, summer temperature, or compounds including dichlorodiphenyltrichloroethane (DDT), polychlorinated biphenyls (PCBs), and polycyclic aromatic hydrocarbons (PAHs)(ODEQ 2000). Given that the Damascus area is expected to experience a ten-fold increase in population from 1994 to 2020 (Metro 2004), urbanization will be an increasingly important driver for water quality in Johnson Creek in the foreseeable future.

Information on pre-European development conditions in Johnson Creek is sparse; however, the stream is part of a stream-riverine wetlands complex that characterized the predevelopment condition of the lower Willamette River (Davis 1994). Prior to about 1900, the watershed was largely forested, including extensive forested wetlands, especially in very low-gradient areas such as the Lents Neighborhood (Johnson Creek Watershed Council 2003). Johnson Creek was a low-gradient stream with a complex channel and high levels of structure provided by large amounts of downed trees and wood (McConnaha 2003)

The entire Johnson Creek watershed has been dramatically altered over the years as a result of urbanization and agriculture. The upper watershed now has predominantly agricultural land uses, consisting of small farms and nursery operations. Proceeding toward the mouth, the watershed is increasingly urbanized. The most pervasive modification of the stream itself occurred in the 1930s when the Works Progress Administration (WPA) undertook a major re-engineering of the stream in an effort to control persistent flooding. Extensive sections of the stream were diverted into an artificial channel constructed with basalt armoring on the bank and large cobble on the channel floor (Photo 1). The stream was straightened and diverted from its original floodplain. Although the

WPA work was not effective in controlling flooding of the stream, it did radically alter the character of the stream (McConnaha 2003) Salmon were reported in some abundance in the stream up through the mid-twentieth century despite degradation of water quality, riparian condition and other factors. During the latter part of the century and following the WPA modifications, salmon abundance declined to the present condition resulting in the ESA listing of most anadromous salmonids in Johnson Creek.

Photo 1. Example of WPA Modification of Johnson Creek Stream Channel (Reach 13 off Foster Road)

Indicator Species

This analysis examines the effectiveness of habitat restoration projects in Johnson Creek from the perspective of three co-occurring native fish species. The analysis looks at the species "through the eyes" (Lichatowich et al. 1995) of coho salmon fall Chinook salmon and winter steelhead that were historically present in Johnson Creek (Folger 1998). Each species views the effects of habitat degradation and restoration differently based on their unique habitat and life history needs. Viewing the projects from three independent biological perspectives provides a community and ecosystem view of habitat limitations and restoration benefits in Johnson Creek.

The three focal species are used as indicators of diverse conditions in the stream relative to its normative condition (or intrinsic potential). In this light, our analysis is relevant not only to the focal fish species but also to the co-evolved biological community typical of tributary streams within the lower Columbia River area. The analysis addresses conditions for the focal fish populations directly and provides insights into how well the Johnson Creek ecosystem sustains a healthy watershed.

Coho, Chinook, and steelhead were historically abundant in the lower Willamette River, but have experienced significant declines including dramatically reduced populations in many urban streams, including Johnson Creek (Meross 2000; Myers et al. 2006) Populations of the three indicator species do exist in the nearby Clackamas River. While all three species are still present in Johnson Creek (Tinus et al. 2003; Van Dyke and Storch 2009) they are not considered to be self-sustaining and are probably supported to a large degree by the more productive populations in the Clackamas River. All three fish species are listed under ESA (NMFS 2011). Coho in Johnson Creek are part of the lower Columbia River coho Evolutionarily Significant Unit (ESU), which is listed as threatened. Fall Chinook in the lower Willamette River are part of the lower Columbia River Chinook ESU, which is listed as threatened. Winter steelhead populations are part of the lower Columbia River steelhead Distinct Population Segment (DPS), which is also listed as threatened. Critical habitat for steelhead includes the entirety of Johnson Creek, whereas critical habitat for Chinook includes lower Johnson Creek, up to and including Crystal Springs. Critical habitat for coho has not yet been designated.

While this analysis focuses on the Johnson Creek watershed, conditions in the lower Willamette and Columbia rivers strongly influence the performance of the focal fish populations in Johnson Creek. For instance, habitat in the Willamette River provides rearing and migration habitat (Friesen 2005) that is critical for the Johnson Creek salmon and steelhead populations to complete their life cycle (McConnaha 2003) Juvenile salmonids, especially coho, also make use of the Columbia River estuary for additional growth that likely increases marine survival (smolt-to-adult return [SAR]) rates (Bottom et al. 2005) Thus, it is most accurate to consider Johnson Creek as part of a continuum of freshwater habitats that extend from the headwaters, through the lower Willamette River, and into the Columbia River estuary.

Coho Salmon

Coho generally spawn in small, lower-gradient stream reaches and side channels during mid-autumn or early winter (Brown and Hartman 1988). In Johnson Creek, coho likely spawn from mid-October through the end of January (Todd Alsbury, ODFW pers. comm.). Based on habitat preferences, the analysis presumed that all reaches of Johnson Creek below barriers[1] were potentially available to coho salmon. A small portion of male coho return to freshwater in their first ocean year (as jacks), but most coho return after 2 years in the ocean. Adults proceed upstream to spawning grounds at approximately 3 years of age and die after spawning.

Juvenile coho favor relatively slow-moving water such as pools downstream of riffles. Juvenile coho have been observed in lower mainstem reaches of Johnson Creek and in lower reaches of Crystal Springs (Tinus et al. 2003). Coho usually spend 1 year in freshwater and emigrate in the spring of their second year. In Johnson Creek and nearby streams, smolts move into the Willamette River and then into the Columbia River estuary where they may feed and rear for periods of a few days to months prior to entering the ocean (Bottom et al. 2005). Freisen et al (2005) reported extensive use of the lower Willamette River by juvenile coho, although they moved through the area in 1 to 2 weeks. Juvenile coho were abundant in shallow-water areas where feeding and growth occur. Once in the ocean, coho remain over the continental shelf, and are, therefore, a target of commercial and sport troll fisheries. Coho have been extensively exploited by commercial and sport fisheries with harvest rates exceeding 80% in the mid-1980s (PFMC 2001). Recent harvest rates have been considerably reduced, but significant harvest continues on lower Columbia River coho, including coho originating from Johnson Creek.

[1] Examples of barriers in the upper watershed include a dam at Norander Farms on Kelley Creek, dams on reservoirs on Butler and Hogan Creeks, and a bio-swale on Veteran's Creek.

Winter Steelhead

Native steelhead in the Willamette River are classified as winter-run (Busby et al. 1996). Summer-run steelhead may occur as well, but these are the result of hatchery releases in the Clackamas River and elsewhere in the Willamette system. Steelhead are renowned for their ability to ascend into the upper areas of streams and often spawn in higher-gradient reaches of streams (Busby et al. 1996). In the Clackamas River, winter steelhead usually spawn from January through April. However, in Johnson Creek, the spawning period would likely end earlier as a result of the warm temperatures in Johnson Creek late spring (Todd Alsbury, ODFW pers. comm.). Based on habitat preferences, the analysis presumed that all of Johnson Creek was potentially usable by steelhead.

Juvenile steelhead emerge from the gravel in spring. As juveniles, winter steelhead use the shallower, faster-moving water more than coho or Chinook. Juvenile steelhead have been observed as far in the system as the City of Portland boundaries in Johnson Creek (Reach 16) (Van Dyke and Storch 2009). In spring, usually 1 to 3 years after hatching, steelhead juveniles emigrate from Johnson Creek. Friesen et al. (2005) reported that steelhead move rapidly through the lower Willamette and were usually found in deep-water areas. Steelhead continue to move rapidly downstream toward the ocean and spend little time in the Columbia River estuary (Bottom et al. 2005).

The age structure of a viable steelhead population in Johnson Creek is not known. The analysis hypothesized that adverse habitat conditions in Johnson Creek would favor a population in which most steelhead smolt after 1 or 2 years, giving the population a younger age distribution than in the Clackamas (Todd Alsbury, ODFW pers. comm.). Steelhead usually spend 1 to 3 years in the ocean and return to freshwater to spawn; winter steelhead enter the watershed during late fall. Although most adults die after spawning, some fraction undergo multiple cycles of migration and spawning.

Fall Chinook

Fall Chinook spawn in mainstem reaches and generally favor larger river areas compared to coho and steelhead. Their natural distribution in Johnson Creek is unknown; however, it is likely that fall Chinook would favor the lower portions of the stream, especially the mainstem of Johnson Creek. This analysis assumed that fall Chinook were limited to the lower stream reaches below Interstate 205 (near the confluence of Veterans Creek) including the Crystal Springs tributary.

In the lower Columbia River, fall Chinook spawn from mid-October through the end of November. Fall Chinook in the Columbia Basin are predominantly ocean-type, meaning they spend a relatively short time in their natal areas and begin moving toward the estuary during their first summer (sub-yearlings). Juvenile Chinook have been observed in lower Johnson Creek, especially the Crystal Spring tributary (Tinus et al. 2003). Friesen et al. (2005) reported large numbers of sub-yearling fall Chinook in the lower Willamette River, where they favored shallow-water areas, likely indicating feeding and rearing. Fall Chinook remain in coastal waters for 2 to 4 years, where they are heavily impacted by commercial and sport fisheries. A portion of males return to freshwater as jacks in their first year. Pre-spawning adults enter the Columbia River in August and September and move rapidly to mainstem and tributary spawning areas.

The analysis assumed that all Chinook were fall run exhibiting an ocean-type life history. Juveniles were modeled to leave the system in their first spring and not be present in Johnson Creek in the summer. Because fall-run Chinook do not generally penetrate far into small streams like Johnson Creek, it was also assumed that spawning was limited to areas below the Interstate 205 Bridge. Thus restoration of habitat above that point was not experienced by fall Chinook in this analysis.

Future Status of Johnson Creek Salmonid Populations under Planned Restoration Projects, Development and Climate Change Scenario

Analytical Approach

This analysis compared the habitat potential of Johnson Creek in 2009 and under future development and climate change scenarios for coho salmon, fall Chinook salmon, and winter steelhead. Conditions in 2009 were taken as the baseline condition based on a previous analysis (ICF International 2010, Appendix A). "Habitat potential" refers to the capability of the environment, in a given condition, to support a species of interest. It is based on both the genetically determined habitat needs and preferences of the species, as well as the quantity and quality of habitat available to the species in a particular environment over the course of its life history. Because each of the indicator species has its own habitat requirements and preferences, each views the Johnson Creek environment in a slightly different way (Mobrand et al. 1997), requiring species-specific assessments of the stream and of the restoration projects. The multispecies approach used in this analysis provides a broader, community based assessment of the stream and the restoration projects.

The Johnson Creek salmonid habitat model is based on the EDT concept described by Lichatowich et al. (1995) and Mobrand et al. (1997). The mathematical underpinnings of EDT and algorithms in the model are described by Blair et al. (2009). Habitat potential is measured by the expected species performance under the environmental condition. An example performance measure is the theoretical adult abundance in the watershed when the population is in equilibrium with the environment. Actual abundance of fish observed in any year may differ considerably from the modeled habitat potential, because actual returns reflect natural environmental variation and the effect of non-habitat factors (e.g., harvest and ocean survival conditions, incomplete colonization of newly available habitat). Several metrics of habitat potential, in addition to abundance, are available from this analysis, including biological capacity, productivity, and life history diversity. These metrics are consistent with measures of a "viable salmon population" used to assess salmonid populations under the ESA (McElhany et al. 2000).

For the purpose of this analysis it was assumed the 2040s were the period for the predicted future urban development and climate change conditions. Johnson Creek's environmental attributes were modified in the EDT model to reflect changes in the watershed habitat values and process under anticipated future conditions. The following sections describe the analytical approach for determining future conditions in the Johnson Creek watershed with planned restoration projects, increasing urban development, and climate change.

Planned Restoration Projects

Seven of the planned projects in the Johnson Creek watershed were evaluated in this study (Table 1). Some of these projects have not yet been implemented. All of the projects are intended to improve the watershed's natural infrastructure, such as flood attenuation, water quality and stream and riparian conditions for fish and wildlife. The fish habitat characteristics of the projects were summarized from engineering designs or descriptions provided by city staff. While one project, Crystal Springs Culvert and Stream Enhancement at SE 28th Street (at Reed College), was completed in the fall of 2009 the methods for summarizing the conditions are consistent for all of the projects—the summary of habitat conditions for this project was based on the engineering design and not a field inventory of conditions after construction.

Each project results in significant changes to the conditions in the stream that affect fish populations. The habitat characteristics of the projects (e.g., large wood, fish passage) were summarized into EDT attributes to gauge the likely biological response to these changes and to compare and assess the contribution of the projects to restoring native salmonids and their ecosystems.

Table 1. Restoration Projects in Johnson Creek Considered in this Analysis

Restoration Projects	Primary Reach(s) or Locations
Johnson Creek—Confluence Habitat Restoration	Johnson 1
Johnson Creek—Luther Road Habitat Restoration	Johnson 7
Johnson Creek—East Lents Floodplain Restoration	Johnson 9, Johnson 10, Johnson 11
Crystal Springs—Fish Passage Improvements	SE Tacoma St., Glenwood Blvd., and Bybee Blvd.,
Crystal Springs—Fish Passage Improvements	Crystal 1B, Crystal Umatilla Obst., Crystal 1C, Crystal 1D, Crystal Tenino Obst., Crystal 1E
Crystal Springs—Westmoreland Pond Habitat Restoration	Crystal 2A Pond
Crystal Springs—SE 28th Ave Habitat Restoration	Crystal 4C

Johnson Creek—Confluence Habitat Restoration

The Confluence project is a partnership between the Johnson Creek Watershed Council and the Oregon Watershed Enhancement Board in cooperation with the City. The intent of the project is to improve in-stream habitat complexity, create backwater pools to provide high-flow refugia for juvenile salmon and steelhead, and enhance the riparian corridor. The project is located immediately upstream of the mouth of Johnson Creek and extends upstream approximately 1,200 feet to 17th Avenue.

The project has the following design features relevant to this assessment:

- Reshape the streambed and bank to improve in-stream habitat complexity, including the construction of several backwater pools (alcoves) to provide high flow refugia.
- Install engineered log jams at key locations to improve in-stream habitat complexity.

An important caveat is that this analysis only looks at the benefits of projects to fish originating from Johnson Creek. It is likely that a major benefit of the confluence project is that it would expand off-channel habitat in the lower Willamette River and provide benefits to fish from throughout the Willamette Basin. These impacts on non-Johnson Creek fish have not been considered in the present analysis.

Johnson Creek—Luther Road Habitat Restoration

The Luther Road project was identified as a priority because of untreated storm water outfalls, the exposed Lents Interceptor Sewer, and the benefits of habitat improvements to fish, birds, and wildlife. The project will protect public health, restore a portion of Johnson Creek and its floodplain, and improve water quality.

The project is a partnership between the City Bureau of Environmental Services (BES), Metro and the North Clackamas Parks and Recreation District (NCPRD). The project site comprises 10 acres of open space that the three agencies purchased in 2009. The site is adjacent to the Springwater Corridor Trail and Johnson Creek near SE 72nd Avenue and Luther Road in Clackamas County.

The 76-inch-diameter Lents Interceptor Sewer crosses Johnson Creek at the project site. Erosion in the creekbed and banks has exposed a portion of the sewer pipe and a nearby manhole, increasing the possibility of damage to the pipe and creating a fish passage barrier. A break in the pipe would release a significant amount of sewage and storm water and threaten public health and wildlife, including sensitive, threatened and endangered species.

This project will bury the sewer pipe crossing in Johnson Creek to stabilize it, establish a new stable stream crossing, and move the creek and its floodplain away from adjacent private property.

According to preliminary design drawings the project has the following design features relevant to this assessment:

- Relocate and restore approximately 2,400 feet of creek channel and floodplain.
- Bury the Lents Interceptor Sewer crossing and manhole.
- Collect and treat storm water runoff from a nearby industrial area to improve water quality.
- Establish open space for habitat and recreation purposes.
- Reshape the streambed and bank to improve connectivity to the floodplain and to improve in-stream habitat complexity.
- Regrade floodplain areas to increase flood storage and provide off-channel habitat during flood events.
- Install engineered log jams at key locations to prevent erosion and improve in-stream habitat complexity.

Johnson Creek—East Lents Floodplain Restoration

The City of Portland is planning a significant floodplain restoration project along Johnson Creek south of SE Foster Road from about SE 106th Avenue to SW 110th Drive. The project is part of the *Johnson Creek Restoration Plan* (Johnson Creek Watershed Council 2003), which calls for improving creek conditions for fish, birds and wildlife, and preventing damage from nuisance floods that occur about every 10 years.

Johnson Creek flows through the site, most of which is within the 100-year floodplain. The project is intended to provide flood storage and conveyance and will reduce the frequency of flooding on Foster Road and area homes and business. Total stream length of the project area is approximately 5,600 feet.

According to preliminary design drawings the project has the following design features relevant to this assessment:

- Remove concrete rubble and bank hardening material at multiple locations to improve riparian functions.
- Reshape the streambed and bank to improve connectivity to the floodplain and to improve in-stream habitat complexity.
- Regrade floodplain areas to increase flood storage and provide off-channel habitat during flood events.
- Install engineered log jams at key locations to prevent erosion and improve in-stream habitat complexity.
- Increase tree canopy and terrestrial vegetation by planting x# native trees and shrubs on about 60 acres

Crystal Springs—Fish Passage Improvements (Tacoma, Glenwood, and Bybee)

The project involves retrofitting multiple fish passage barriers located in the middle portions of Crystal Springs Creek at SE Tacoma Street, and SE Bybee Boulevard and Glenwood Boulevard. The combined project will replace three culverts that currently are undersized and create velocity barriers that prevent upstream passage of juvenile salmon and are partial barriers to upstream migrating adult salmon and steelhead. The culverts will be replaced by either bridges or open-bottomed arched culverts that provide more natural streambed and allow improved adult and juvenile fish passage for a range of stream flows.

Crystal Springs—Fish Passage Improvements (Umatilla to Tenino)

The project is located in the lower portion of Crystal Springs in southeast Portland between SE Tenino Street and SE Umatilla Street at SE 21st Avenue. The project will replace two culverts that are currently undersized and create velocity barriers that prevent upstream passage of juvenile salmon and are partial barriers to upstream migrating adult salmon and steelhead. In addition to replacing the culverts the project also includes removing an existing private building, carport, and driveway that was purchased by the City.

The project has the following design features relevant to this assessment:

- Replace existing culvert beneath the intersection of SE Tenino Street and SE 21st Avenue with a bridge and a natural streambed.
- Replace existing culvert at SE Umatilla Street with an open-bottomed arch culvert. The streambed will include gravel substrate with larger rocks to provide a more natural streambed.
- Remove a building, driveway, and carport covering Crystal Springs at 8220 SE 21st Avenue.
- Reshape the streambed and bank at 8220 SE 21st Avenue and install individual pieces of wood throughout to improve in-stream habitat complexity and to prevent bank erosion.
- Increase riparian vegetation and tree canopy.

- Provide storm water management at 5 facilities along SE Tenino, SE 21st and SE Umatilla Streets..

Crystal Springs—Westmoreland Pond Restoration

This habitat restoration project, in the middle portion of Crystal Springs Creek, was identified as a priority because untreated Westmoreland Pond is a heat sink, creating higher water temperatures and has other water quality issues associated with bacterial contamination from waterfowl. The project implements Portland Park's Westmoreland Park Master Plan and will protect public health, restore a portion of Crystal Springs Creek and its floodplain, and improve water quality.

The project, a partnership between BES, Portland Parks, Metro, and TriMet, will replace the 2-acre instream pond with a meandering stream channel. The project will include wetland and floodplain restoration and riparian planting. Over 2,000 linear feet of concrete that now line the stream channel will be removed and replaced with natural substrate.

Crystal Springs—SE 28th Ave Habitat Restoration

The Crystal Springs SE 28th Street project was a collaboration between Reed College, BES, Metro and OWEB. The project re-meandered Crystal Springs where it was previously straightened. The project is located on Crystal Springs immediately upstream of SE 28th Avenue on the Reed College campus.

The project constructed a bioswale and sidewalk along the frontage of the restoration site. The project replaced a 2-foot-diameter culvert under SE 28th Avenue with a 12 foot culvert with a natural stream bottom that improves fish passage.

According to design drawings, the project had the following design features relevant to this assessment:

- Relocate and restore approximately 390 feet of creek channel.
- Reshape the streambed and bank to improve in-stream habitat complexity.
- Excavate three spring-fed off-channel alcoves.
- Although not explicitly identified in the drawings, project photos taken in late August 2010 show multiple individual pieces of wood throughout to improve in-stream habitat complexity and prevent bank erosion.
- Improve fish passage by replacing culvert beneath SE 28th Avenue with a box culvert with a natural stream bottom .
- Plant native trees and shrubs

Future Urban Development and the Johnson Creek Watershed

The analysis of future effects of urbanization focuses on the extent to which planned development in the Johnson Creek watershed might impact stream habitat features such as modified water quality, changes in the timing or magnitude of stream flows. Because very few areas within the basin are undisturbed by land use practices, this evaluation assumes that any future urban development (housing, new roads, industrial areas, etc.) within the Johnson Creek watershed would be characterized as a land use change or redevelopment of undeveloped areas.

Undeveloped areas within the Johnson Creek watershed are generally in agricultural or rural residential land use as well as parks and open spaces. Agricultural and rural residential land uses modify watershed processes and habitat and can affect Johnson Creek through several primary pathways. First, vegetated riparian corridors are narrowed or there is change in the composition of the vegetation (i.e., from trees to weedy species), which limits stream shading and large wood, insect drop, and other organic inputs, affecting both water temperatures, energy flow, and channel habitat structure (Hachmoller et al. 1991). Second, the network of roads, ditches, and farm fields impairs water infiltration into the subsurface and limits groundwater recharge. These changes in infiltration result in rapid runoff of water into stream channels and increases the magnitude and frequency of flood flows (Konrad 2000). Changes in groundwater flows from reduced infiltration can also decrease summer base flows which can contribute to increased stream temperatures and reduced habitat areas (Konrad 2000). In addition, impervious surfaces generally increase pollutant loadings into creeks (Booth et al. 2001).

The Johnson Creek watershed encompasses six local jurisdictions that regulate land use practices (Table 2). The combined areas of Portland, unincorporated Clackamas County (outside of Milwaukie and Happy Valley), unincorporated Multnomah County and Gresham cover the greatest portion of the Johnson Creek system, totaling 96% of the watershed's area. The Milwaukie and Happy Valley UGBs encompass a little over 4% of the watershed.

Table 2. The Percent of the Johnson Creek Watershed Covered by the Major Jurisdictions with Control over Land Use Practices

Jurisdiction	Percent (%) of Johnson Creek Watershed
Portland	38
Unincorporated Clackamas County	24
Gresham	23
Unincorporated Multnomah County	11
Milwaukie	4
Happy Valley	0.1

Source: Johnson Creek Watershed Council 2001.

Three areas were identified in the Johnson Creek watershed as having the greatest potential to affect the system through a transition from forest, agricultural or rural residential lands to more urbanized land uses:

- The Pleasant Valley area which was recently brought into the regional UGB and will transition to urbanized areas (Alison Young, BES, pers. comm.).
- The Springwater area which also was recently brought into the UGB (Alison Young, BES, pers. comm.).
- Headwater tributary areas outside the UGB within the Johnson Creek watershed that are relatively undeveloped, largely in forest cover, and provide ecological functions for the watershed, but are unprotected and therefore vulnerable to development (Jennifer Antak, BES, pers. comm.).

Pleasant Valley Area

The Pleasant Valley area, added to the UGB in March 1998, is located southwest of Gresham in the Kelley Creek subbasin of the Johnson Creek Watershed. The area is 2.4 square miles, covers 48% of the Kelley Creek subbasin, and includes a small area along Johnson Creek. Existing land cover includes forest, agricultural lands, and rural residential. The area is defined by a series of volcanic buttes that are typically forested and steep and divided by perennial and seasonal streams. The buttes are surrounded by valleys. The buttes forests were cleared in the early 1900s and are now covered mostly by mid-successional 60–100 year old forest. The lowland valleys were forested, but cleared in the late 1800s and early 1900s for farming and timber uses. The majority of the lowland is now in agricultural and residential land use. Public water, wastewater, and storm water systems are not currently in place. Water drainage in most of the agricultural areas has been modified through the extensive placement of drain tiles and ditches.

The *Pleasant Valley Concept and Implementation Plans* (City of Gresham and City of Portland 2004) address the 1,532-acre study area with the overall goal of "creating a complete community". The area has been brought into Portland and Gresham's urban services boundary Portland and Gresham have agreed to adopt similar policies and development codes to achieve the goals of the concept plan by creating the Pleasant Valley Plan District.

Housing in the Plan District will be organized in eight neighborhoods including low-, medium-, and high-density housing with an overall density of 10 dwelling units per net residential acre (City of Gresham 2005a). The estimated housing capacity is approximately 5,000 dwellings. There will also be two 5-acre mixed-use neighborhood centers. The Pleasant Valley Plan District also provides a framework for protection, restoration, and enhancement of the area's streams, flood plains, wetlands, riparian areas, and major tree groves through the designation of "environmentally sensitive/restoration areas (ESRAs)" (City of Gresham 2005a).

Springwater Area

The Springwater area, added to the UGB in March 2002, is located south of Gresham, adjacent to the southeastern neighborhoods of the existing city. The 1,272-acre area is primarily rural residential with pockets of commercial and recreational land uses (City of Gresham 2005b). A golf course (Persimmon) occupies a large area on the west side of Hogan Road. The existing transportation system was designed primarily to serve rural residential uses and a farm to market route for past agricultural uses. There are no public water, wastewater, or storm water systems; water is currently accessed via underground wells and wastewater is primarily treated in private subsurface disposal systems. Storm water runoff is conveyed to natural channels or to drainage ditches adjacent to local roads that drain directly into Johnson Creek and its tributaries.

Gresham's *Springwater Community Plan* (City of Gresham 2005b), complies with local and state requirements for land use planning. The *Springwater Community Plan* provides for industrial, office, village, attached housing, and detached housing land uses. Major elements of the Springwater Plan include employment areas such as industrial sites, small commercial areas, a Village Center area, and a variety of housing types including a mixed-use and small and large-lot single-family housing. In addition, the Springwater area will include new transportation infrastructure and parks and open spaces. The Springwater Plan identifies over one third of the land as environmentally sensitive, including the critical habitats located along Johnson Creek and its tributaries. These are areas that are anticipated to have a range of protection, from lightly limited development to City purchase for protection and enhancement.

Future Watershed Health with Development of the Pleasant Valley and Springwater Areas

For both the Pleasant Valley and Springwater, Green Development Practices are required to manage all storm water runoff from private property, prior to discharge to public infrastructure. Green Development Practices reduce the volume of storm water flowing off-site by retaining it near the source. Onsite storm water management devices include rain gardens , swales, storm water planters, porous pavement, and tree planting. New streets will incorporate green elements to manage storm water such as shallow, heavily planted storm water planters that convey, treat, and infiltrate storm water to mimic natural runoff .

Other natural resources, including riparian areas and wetlands, will be protected through the ESRA overlay. An economic, social, environmental, and energy (ESEE) analysis was conducted by the cities of Gresham and Portland as part of the *Pleasant Valley Natural Resources Protection Plan* (City of Gresham and City of Portland 2004) The ESEE analysis included an assessment of the potential environmental effects of the Pleasant Valley Development Plan. The ESEE analysis concluded that the *Pleasant Valley Concept and Implementation Plans* conserve most of the environmental resources and functional values identified in the natural resource inventory. According to the plan development impacts are limited to areas generally outside the ESRA and development impacts will be mitigated through Green Development Practices and restoration (City of Gresham and City of Portland 2004).

Headwater Tributary Areas

City of Portland staff identified two unincorporated tributary areas within the Johnson Creek watershed as areas of primary concern: 1) 250-acres in the headwaters of Mitchell Creek (tributary to Kelley Creek), and 2) Kelly Creek, Hogan Creek, and Sunshine Creek headwaters (800 acres). The headwaters of Mitchell Creek are within the jurisdiction of Happy Valley. The Kelley Creek, Hogan Creek, and Sunshine Creek headwaters found in the East Buttes area are within the City of Damascus.

Current information on development patterns and natural resource protection for these areas is not available. More analysis is required to determine how the jurisdictions of Happy Valley and Damascus will apply environmental best management practices (BMPs) and development codes that protect watershed habitat and mitigate storm water impacts. If future development in these areas is similar to the Springwater and Pleasant Valley, with protections for riparian and wetland areas and practices that will retain storm water on site, then negative impacts from future development, though difficult to quantify, would be minimized. However, much of the future development areas are rural residential or forested and development of these habitats, particularly forested areas, can have dramatically negative impacts on the watershed. Forested areas offer high quality ecological functions that are increasingly rare in the Johnson Creek watershed. Forested and undeveloped areas provide shade that cool small streams. Natural vegetation allows groundwater infiltration and recharge, releasing flows slowly back into streams, cooling summer water temperatures and mitigating high flows during winter storms (Leavitt 1998).

Analysis of Future Urbanization Patterns on Watershed Health

A recent study of the hydrology of the Johnson Creek Watershed concluded that trends in flow typically associated with urban development were absent in Johnson Creek (Lee and Snyder 2009b). No changes in annual, low and high flows were observed over the period of analysis from 1941 to 2006. The study concluded that the absence of stream flow changes during this period is attributed to the fact that infrastructure and other watershed modifications (e.g., roads and ditches) that may affect runoff from agricultural, residential, and urban development were in place prior to the collection of hydrologic data. The dense network of roads, ditches, and farm fields that minimize infiltration and direct runoff away from the land surface and into Johnson Creek and its tributaries were in place by 1941 (Lee and Snyder 2009b). Given that little change occurred in the hydrologic baseline for the Johnson Creek system, the authors state that current land use BMPs could actually improve flow regime and water temperature patterns: “Land-use decisions that foster increased infiltration (and subsequent groundwater discharge), limit instream withdrawals, and increase nearstream shading may improve the summer temperature regime in Johnson Creek” (Lee and Snyder 2009b).

Assuming future development of the watershed within the Pleasant Valley, Springwater area, and headwater tributaries is done consistent with current plan designations, development will still affect the health of Johnson Creek. However, consistent application of good management practices could minimize the impacts. The application of appropriate BMPs (e.g., on-site storm water management), targeting development away from sensitive areas, protection of key habitats (particularly forested habitats, riparian areas and wetlands), and continued aquatic and riparian habitat restoration should help minimize the impacts on watershed processes and habitat. Trends in improved habitat conditions through restoration and improved practices could help counteract negative effects of future development, particularly if actions are taken to protect existing high quality areas. It is assumed that improved groundwater infiltration, enhanced stream shading, and floodplain restoration actions will reduce development impacts on the low- and high-flow regimes and water temperatures. The application of the appropriate aquatic and riparian habitat restoration strategies within these areas could improve watershed conditions, but this outcome is uncertain and depends on how the jurisdictions implement restoration actions.

Climate Change and the Johnson Creek Watershed

There is a growing consensus that climate change is occurring at global, national, regional and local scales (Karl et al. 2009). The impacts of projected climate change are expected to affect the abundance and persistence of many native fish, wildlife and plant species with significant impacts on native salmonids (Independent Scientific Advisory Board 2007). As a result, climate change can be expected to influence the benefits of habitat restoration efforts such as those analyzed in this report. For this reason, the restoration projects discussed above were examined in relation to two overall contexts. First, potential benefits of the projects individually and collectively were evaluated assuming that all conditions remain constant with the 2009 baseline except for conditions directly affected by the actions, i.e., without assuming any climate change impacts. Second, the collective impact of the actions was evaluated assuming a change in conditions in Johnson Creek as a result of climate change. **The analysis of climate change impacts on the restoration projects is intended to illustrate potential impacts and should not be interpreted as a projection of actual climate conditions in the future.** The projection of impacts of climate change, particularly at local scales can be highly complex and controversial. The kind of analysis that would be required to project actual conditions in Johnson Creek under climate change was not conducted for this study. Instead, a plausible climate change hypothesis was created based on existing projections for the purpose of demonstrating potential impacts and suggesting ways that the City might adapt to climate change regarding the restoration of Johnson Creek.

The Climate Impacts Group at the University of Washington has estimated that average annual air temperatures in western Oregon are projected to increase through the twenty-first century, resulting in warmer and drier summers (Climate Change Impacts Group 2011, Table 3). Based on their analysis of 20 climate model predictions, by the 2040s the annual mean temperature will increase by 3.2 degrees Fahrenheit (°F), and there will be a small increase in annual precipitation; air temperatures will continue to increase into the 2080s (Table 3).

Table 3. Average Changes in Pacific Northwest Climate from 20 Climate Models and Two Greenhouse Gas Emissions Scenarios for the 2020s, 2040s, and 2080s (Climate Change Impacts Group 2011)

Range	Average Annual Temperature	Precipitation
2020s		
Low	+ 1.1ºF (0.6ºC)	-9%
Average	+ 2.0ºF (1.1ºC)	+1.3%
High	+ 3.3ºF (1.8ºC)	+12%
2040s		
Low	+ 1.5ºF (0.8ºC)	-11%
Average	+ 3.2ºF (1.8ºC)	+2.3%
High	+ 5.2ºF (2.9ºC)	+12%
2080s		
Low	+ 2.8ºF (1.6ºC)	-10%
Average	+ 5.3ºF (3.0ºC)	+3.8%
High	+ 9.7ºF (5.4ºC)	+20%

Uncertainty is still high in projecting future changes in watershed runoff and air temperatures, with the major source of uncertainty resulting from the choice of global circulation models to predict climate patterns. As illustrated above, most of the models show an increase in air temperatures; there is, however, a much larger range of uncertainty associated with annual precipitation patterns (Climate Change Impacts Group 2011). Just over half (59%) of the models and scenarios analyzed show an increase in winter precipitation in the 2040s; more than 70% of models and scenarios analyzed agree that summer precipitation will decrease (Climate Change Impacts Group 2011). Changes in the intensity of precipitation are uncertain, although a preliminary analysis suggests that average monthly (November–March) winter precipitation could become more intense by the end of the twenty-first century. In warm rainfall-dominated areas, flood risk could significantly increase (Hamlet and Lettenmaier 2007). A case study of Portland shows that climate change will bring more frequent storm events with a return period of less than 25 years (Chang and Jones 2010).

Stream systems are sensitive to changes in precipitation patterns and air temperature, all of which will be modified under climate change scenarios. It is likely that these changes would be exacerbated in urban streams where natural systems for buffering the impacts of storms are often compromised. These include increased overland flow and reduced infiltration due to impervious surfaces and reduced watershed and riparian forests. Whether a stream system's hydrology is influenced by rain or a combination of rain and snowpack, is an important consideration when evaluating climate change scenarios. Johnson Creek is a rain-dominated system that does not depend on the accumulation of winter snowpack to sustain summer flows.

The following is a summary of how predicted climate change could affect rain-dominated watersheds in western Oregon (Chang and Jones 2010):

- More extreme hydrologic events such as floods and droughts to the region are likely.
- Higher summer air temperatures, accompanied by reduced precipitation, are projected to increase evapotranspiration from vegetation and decrease stream flow in the summer.

- Water temperature is projected to rise as air temperature increases in the twenty-first century, particularly in urban streams where natural riparian vegetation is typically lacking.
- The decline in stream flows will exacerbate water temperature increases because the lower volume of water will be heated up more quickly than during times with larger instream flows.
- Short-term droughts (3–6 months) are likely to increase in the Willamette Valley region. These droughts, combined with increased frequency of heat waves, could drive the increased frequency of sustained periods of high water temperatures and lower summer flows.
- Increased evapotranspiration due to warmer air temperatures may also result in reductions in total annual groundwater recharge, as less water will percolate below the rooting depth of plants.

The effects of climate change on salmon and steelhead populations and habitat are very similar to the effect of an urban landscape on aquatic habitat and watershed processes—an increase in water temperature, a decrease in summer low flow, and an increase in winter flows and flooding events. Thus, the effect of climate change may be amplified in Portland streams as a result of the effects of urbanization. For example, the increase in local storm frequency and intensity will be magnified by the amount of impervious surfaces in the Johnson Creek watershed (Chang and Jones 2010). Similarly, the lack of floodplain connections in Johnson Creek and the WPA channelization result in limited recharge of hyporheic system which can be expected to magnify the effect of a decrease in summer precipitation on summer base flows and channel width.

For the purpose of this analysis the period of evaluation was assumed to be the 2040s. Attributes were adjusted to reflect changes in the watershed under future climate conditions consistent with results from recent climate change modeling that are relevant to western Oregon rain-dominated systems. Three recent Pacific Northwest studies influenced our selection of the EDT parameters likely to be affected by climate change: A study of the impacts of climate variability on water temperature and flows in the nearby Tualatin Basin, Oregon (Chang and Lawler 2010); an evaluation of flood risks associated with climate change in the Portland area (Chang et al. 2010); and an examination of the effects of climate change on salmon and steelhead production in the Snohomish River, Washington and the degree to which existing habitat protection and restoration measures might mitigate these impacts (Battin et al. 2007).

High summer and early fall water temperatures will likely affect juveniles and migrating and spawning adult salmon and steelhead (Battin et al. 2007). Increased summer water temperatures affect fish indirectly as well as directly, through bioenergetic interactions with competitors, increased feeding rates of predators, and increased severity of low dissolved oxygen. Summer low flows will affect the quality of habitat available for adult migration and spawning, and juvenile residence (Battin et al. 2007). Based on these studies, EDT environmental attributes were identified that are likely to be affected by climate change specific to Johnson Creek by the 2040s. Climate change will have the greatest effect on selected EDT attributes (Table 4).

Table 4. EDT Environmental Attributes Assumed to be affected by Climate Change Specific to Johnson Creek

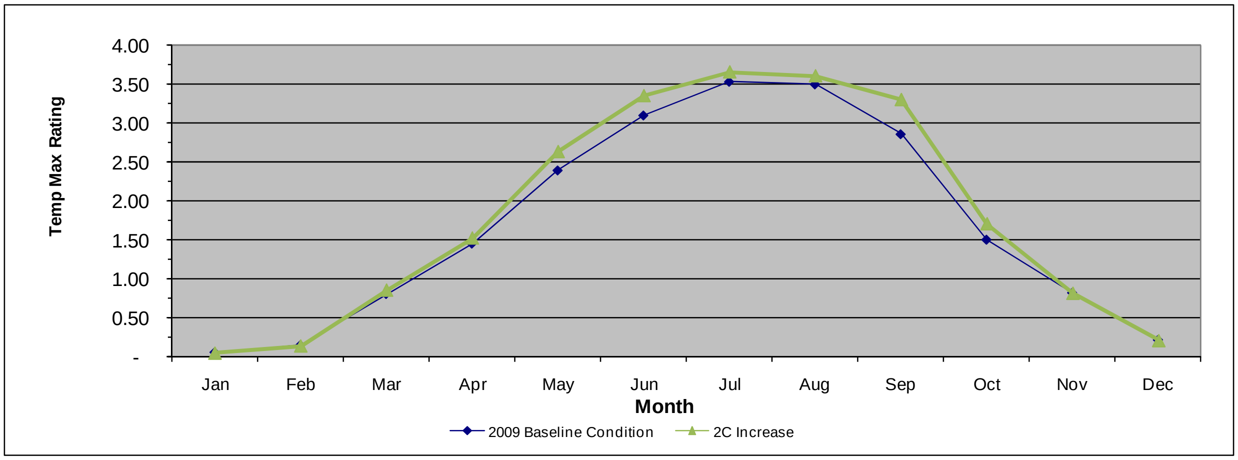
EDT Attribute	Description	Climate Change Consideration
Temp Maximum	Maximum daily water temperatures within the stream reach during a month.	Significant increase in summer water temperature likely in Johnson Creek due to projected increase in summer air temperatures and somewhat lower flows. Assume annual air temperatures to increase to 2.0 degrees Celsius (°C) in the 2040s (Climate Change Impacts Group 2011) The frequency and magnitude of summer and early fall heat waves is also projected to increase which will further elevate water temperatures during the warmest periods of the year.
Flow Low	The extent of relative change in average daily flow during the normal low flow period.	Summer flows will decrease due to drier summers and increased evapotranspiration. Assume a 5% decline in summer and early fall low flows (Chang and Lawler 2010).
Channel Wetted Width	Average width of the wetted channel.	Channel wetted widths will be somewhat narrower due to decreased summer flows (Battin et al. 2007; Chang and Lawler 2010).
Flow High	The extent of relative change in average peak annual discharge.	There will be a slight increase in winter precipitation and high flows, but most of this will come as increased frequency of high-intensity events(Chang and Jones 2010; Climate Change Impacts Group 2011). This increased stream “flashiness” would affect the flow intra-annual attribute.
Flow Intra-Annual	The extent of intra-annual flow variation during the wet season—a measure of a stream's "flashiness" during storm runoff.	Flood events, particularly 25-year events will increase in frequency (Chang et al. 2010).
Bed Scour	Average depth of bed scour in spawning areas (i.e., in pool-tailouts and small cobble-gravel riffles) during the annual peak flow event over approximately a 10-year period.	The effect of more intense fall and winter storm events on flow (Chang and Lawler 2010) will somewhat exacerbate bed scour in Johnson Creek due to shallow substrate depth over WPA channel armoring.

Table 5 outlines how the EDT attributes are modified to account for changes in the stream environment due to climate change. The analysis assumed that there would be differential effects in Johnson Creek and Crystal Springs Creek. The fllow regime in Crystal Springs Creek is dominated by consistent groundwater discharge, while Johnson Creek’s flow is more variable through the seasons. Groundwater discharge into Crystal Springs Creek provides relatively consistent flows through the year, including the summer months, and overall cooling of the stream in the summer and moderation in the magnitude diurnal fluctuation in temperature (Lee and Snyder 2009b). The dominance of groundwater in Crystal Springs Creek will moderate the effect of climate change on flow and water temperatures. In both systems, water temperatures naturally increase in a downstream direction due to wider stream channels, which results in increased thermal loads from reduced canopy shading over the channel.

Table 5. Modifications in the EDT Attributes to Reflect the Environmental Impacts of Climate Change

EDT Attribute	Climate Change Modification in Attribute
Temp Maximum	An analysis over a 10-year record (1998–2010) of temperature data from the Johnson Creek at Sycamore gage was used to develop the "2009" water temperature baseline over the time series. Increased water temperatures, driven by elevated summer temperatures and more frequent heat waves, are exacerbated by decreased low flows. The analysis assumes a 2 °C increase in water temperatures over the time series during the late spring through fall months. The elevated water temperatures will increase the water temperature impacts (as reflected in the EDT attribute rating) across the summer months, with larger relative impacts extending into September (Figure 3). As with the 2009 baseline, water temperatures will continue to increase in a downstream direction under climate change, but the temperatures will be further elevated.
Flow Low	Summer and early fall low flows will decrease. The analysis assumes an increased impact (as reflected in the EDT attribute ratings) of 5% in Johnson Creek and 2.5% in Crystal Springs due to decreased low flows.
Channel Wetted Width	Wetted widths will decrease. The analysis assumes an increased impact (as reflected in the EDT attribute ratings) of 5% in Johnson Creek and 2.5% in Crystal Springs due to decreased wetted. Spring-fed systems, which rely on groundwater to sustain summer flows, will be somewhat buffered from the modified summer precipitation patterns resulting from climate change.
Flow Intra-annual	Increased frequency of high flow events (25-year or greater events). The analysis assumes an increased impact (as reflected in the EDT attribute ratings) of 10% in Johnson Creek and 5% in Crystal Springs due to increased peak flood event and flashiness.
Bed Scour	The bed sour impacts are correlated with increased stream channel gradient: In streams with gradients less than 5%, the analysis assumes (as reflected in the EDT attribute ratings) an increased impact of 2.5% from bed scour; in streams with gradients from 0.5% to 2%, the analysis assumes the impact from bed scour increases from 2.5% to 15% in a linear progression across the range of gradients.

Figure 3. Impact of a 2 °C Increase in Water Temperatures from Climate Change on the EDT Maximum Temperature Rating



Applying Future Restoration Projects, Urban Development and Climate Change in the Portland EDT Model

The outputs from the Johnson Creek EDT model provide a comparison of the biological performance of the indicator species under four conditions:

- The template or reference condition;
- Conditions in 2009 representing the current environmental condition with restoration projects implemented since 1999 (ICF International 2010, Appendix A);
- Conditions with planned restoration projects; and
- Projected Conditions in the 2040s with future urban development and climate change.

An EDT model consists of two major components: The first component is the environmental description. For the Johnson Creek EDT model this is a reach-level depiction of conditions based on the empirical ODFW surveys and additional published information. The second component of an EDT model describes the biology of the indicator species. This includes life history information (e.g., time spent in Johnson Creek, maturation schedules, and fecundity) and the definitions of fish populations (e.g., spawning periods and spawning reaches). Population structure and assumptions in the Johnson Creek EDT model have been described by (Schwartz and Caplan 2009). The biological depiction of the indicator species also includes a library of species-habitat relationships, or the relationship between survival and capacity for life stages of each species (e.g., eggs, fry, smolts, and adults) and environmental conditions (e.g., temperature, sediment, structure, and flow). The combination of the environmental description and the biological information makes possible an evaluation of the environmental condition "through the eyes of salmon"(Mobrand et al. 1997)

Johnson Creek in 2009 with Implemented Restoration Projects

Previous analysis (ICF International 2010) indicated that the restoration projects undertaken by the City have substantially increased the potential of Johnson Creek to support coho, fall Chinook, and winter steelhead relative to the initial habitat conditions assessment in 2000. The projects implemented between 1999 and 2009 are clearly moving the stream in a trajectory toward the City's goal of establishing self-sustaining runs of salmon within Johnson Creek. The five projects implemented during this period enhanced conditions most dramatically for coho salmon, although conditions are improved to a lesser degree for the two other indicator species, fall Chinook and winter steelhead (Table 6). Habitat potential for coho increased by 30%, winter steelhead increased 43%, and fall Chinook increased 9%. The projects are providing habitat features consistent with the normative ecosystem within which the fish populations evolved. It is important to remember that the ecosystem benefits of the restoration projects extend far beyond those shown here for salmonids. Other native fish, wildlife, and plant species characteristic of ecosystems in the lower Columbia River should benefit from the projects as well.

Table 6. Habitat Potential (in Numbers of Adult Salmonids) of the Johnson Creek Watershed under Template, 2000, and 2009 Conditions

Evaluation	Coho	Steelhead	Chinook
Template (Johnson and Willamette)	5,227	1,016	1,523
2000 (pre-restoration projects)	103	67	57
2009 (with restoration projects)	134	96	62
Gain from 2000 to 2009	31	29	5
Gain as percentage of 2000	30%	43%	9%
2009 as percentage of template	2.6%	9.4%	4.1%

Note: Due to stochastic selection of life history parameters, EDT produces slightly different results each time a new life history trajectory set is created. As a result, there are small differences in results reported here between previous analyses (e.g., ICF International 2010) and elsewhere. These differences represent real variation in life history traits within the population and should not be interpreted as changes in conditions between runs.

Restoration Effectiveness with Planned Restoration Projects

This analysis evaluated results from projects that are expected to be implemented in the near future and builds from an assumed baseline of conditions in 2009. This includes the benefits of all the projects implemented between 2000 and 2009 and discussed in the previous report (ICF International 2010, Appendix A) The analytical design allowed us to evaluate the effect on each salmonid species for the future restoration actions independently and for all of the projects combined at the watershed scale. Projects were evaluated from two perspectives. First, each project was evaluated individually (Results by Project). In this exercise projects were evaluated one at a time with no other changes in the system. Second, projects were evaluated together in multiple groups in order to evaluate the combined effects of combined projects and phasing. This approach examines “synergistic” effects between projects. For example a habitat restoration project may show little or no benefit when examined in isolation in the context of the present system, perhaps because of fish passage blockages occurring downstream that prevent fish from reaching the restored habitat. Examining the combined effects of multiple restoration projects together with passage improvement projects may show dramatic differences in the projected benefit of the habitat restoration project. The sections below outline the results by individual projects and the combined effects of the multiple restoration actions.

Reading the Restoration Project Diagrams

The results of the analysis for each project are summarized in a series of diagrams similar to Figure 5. These diagrams illustrate three categories of information. The first is the change in habitat quality that is related to the improvement in individual attributes (e.g. Habitat Diversity) resulting from the restoration action. In interpretation of the diagrams it is important to understand the relationships exhibited by the attributes. For example, improvement in Temperature represents a decrease in summer water temperature while an improvement in Habitat Diversity represents an increase in structural habitat elements. Color-coded dots indicate the amount of improvement in each attribute relative to the 2009 base condition. The second category of information is the change in habitat quantity measured by the change in Key Habitat for the life stage. For example, pools represent Key Habitat for summer rearing for juvenile coho but riffles are Key Habitat for coho spawning. Color-coded triangles show the amount and direction (increase or decrease) in the change in Key Habitat relative to the 2009 baseline condition. While habitat quantity is related to habitat quality, the two parameters often move in opposite directions. For example, the quantity of pool habitat that forms key rearing habitat for juvenile coho salmon may decline, perhaps because a portion of it is modified to create riffles--key habitat for spawning. However, the quality of pool habitat may increase perhaps due to an improvement in water quality or temperature. The third category of information in the diagrams is the Life Stage Benefit Rank. In this case, the number 1 ranked life stage is the life stage that received the most benefit from the action. Note that only life stages of the species that occur in Johnson Creek are ranked and that all life stages are not present for each species. For example, ocean-type fall-run Chinook leave Johnson Creek during their first summer and do not display life stages such as over-wintering that occur in other species like coho. Hence, while there are thirteen possible life stages, fall-run Chinook only show rankings for the six life stages that occur in Johnson Creek, whereas steelhead display rankings for all thirteen life stages that occur in Johnson Creek.

Results by Project

When evaluated independently, each of the restoration projects planned by the City to be implemented after 2009 in Johnson Creek and Crystal Springs Creek would provide modest increases in habitat potential to support coho, winter steelhead and fall Chinook salmon. Overall, the largest increase is for Chinook, followed by coho and steelhead (Table 7). The projects in Johnson Creek have the greatest impact on Chinook and steelhead habitat potential, while the projects in the Crystal Springs Creek have the larger effect on coho.

The variation in species benefits among the projects reflects the differences in the distribution of the three indicator species with Johnson Creek; differences in the habitat benefits for each species provided by the restoration projects; and the variability in the habitat preferences amongst the species.

Table 7. Increase Habitat Potential (in Numbers of Adult Salmonids) from Future Planned Projects in Johnson Creek and Crystal Springs Creek

Evaluation	Coho	Steelhead	Chinook
Projects in Johnson Creek	18	14	19
Projects in Crystal Springs	14	6	17
Sum of gains from individual projects	32	20	36

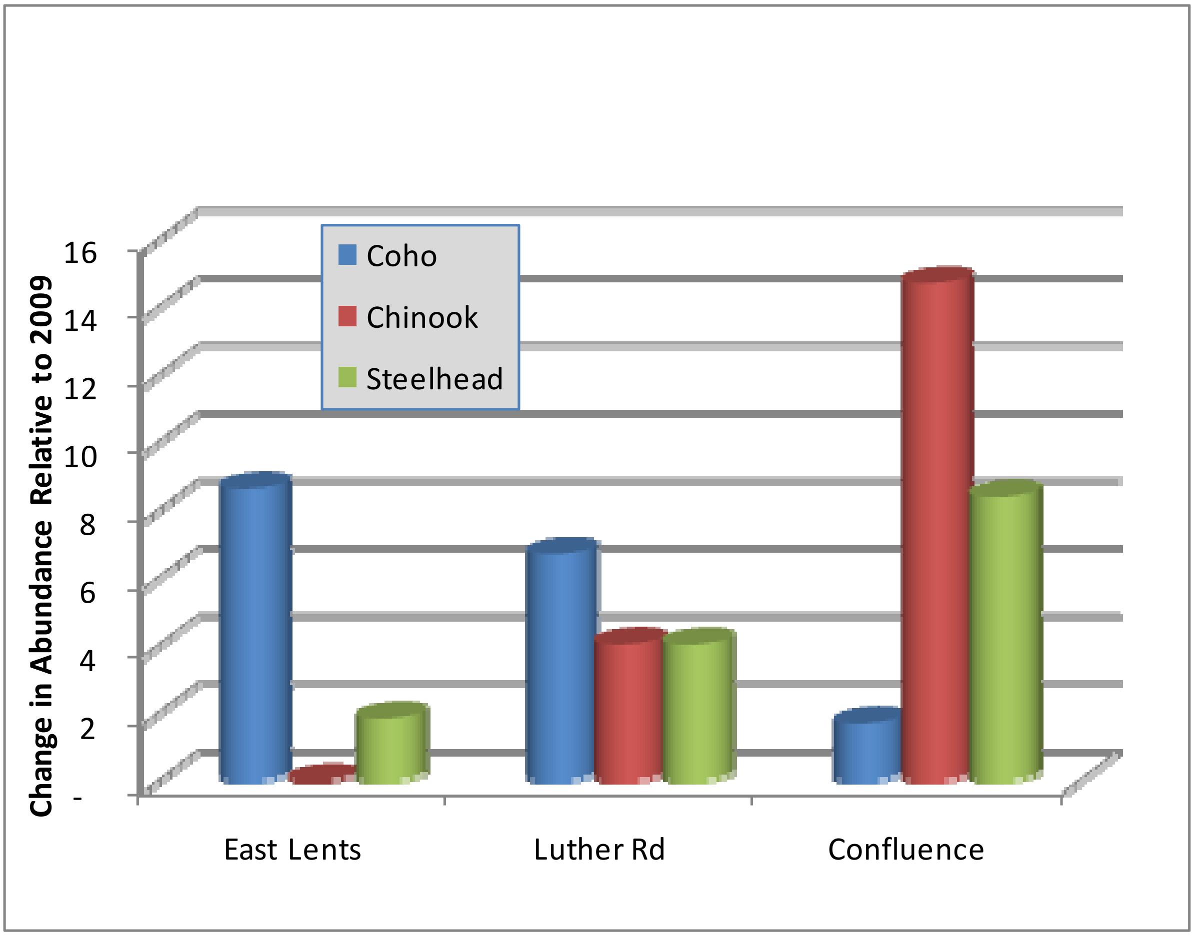
Projects in Johnson Creek

The increase in habitat potential from the three planned projects in Johnson Creek considered independently is shown in Table 8 and Figure 4. Overall, Coho benefited the most from the East Lents and Luther Road projects whereas fall Chinook benefited the most from the Johnson Creek Confluence project. These differences reflect the unique perspective of each species on habitat conditions as well as differences in the projects themselves. The biological and physical impacts of each project will be discussed below.

Table 8. Increase in Habitat Potential (in Numbers of Adult Salmonids) with Johnson Creek Future Restoration Projects

Restoration Project	Coho	Steelhead	Chinook
Confluence	2	8	15
Luther Road	7	4	4
East Lents	9	2	0
Sum of gains from individual projects	18	14	19

Figure 4. Increase in Habitat Potential (in Numbers of Adult Salmonids) in Johnson Creek from Individual Planned Restoration Projects Relative to 2009 Conditions



Johnson Creek Confluence Restoration

The Confluence project has the greatest value for Chinook salmon followed by steelhead; the project provided small benefits to coho (Figure 4). For Chinook, the project primarily benefited the Adult Holding and Fry Colonization life stages (Figure 5). The project increased pool habitat by increasing Structural Diversity in a reach that is currently mainly large and small cobble riffle habitat. This resulted in an increase in habitat for Adult Migrants, Adult Holding and Fry Colonization but decreased the amount of habitat for Spawning and Egg Incubation for all three species but especially fall Chinook[2]. Steelhead benefited primarily from improved conditions for Spawning and 0-age[3] Summer Rearing life stages. Even though the quantity of spawning habitat for steelhead decreased, the quality of the remaining habitat increased resulting in a net benefit for steelhead. Spawning habitat quality for steelhead increased primarily due to improved temperature in this reach. This

[2] This is an example of the phenomenon discussed on page 29. The quantity of key habitat for Chinook spawning and egg incubation decreased because riffles (key spawning habitat) were modified to produce pools (key habitat for migration, adult holding and fry colonization) At the same time, quality of habitat improved due to changes in habitat diversity, temperature and other attributes.

[3] Life stage designations refer to age of juvenile fish. 0-age fish are less than one year old (e.g., 0-Summer Rearing refers to fish in their first summer), 1-age fish are one year old.

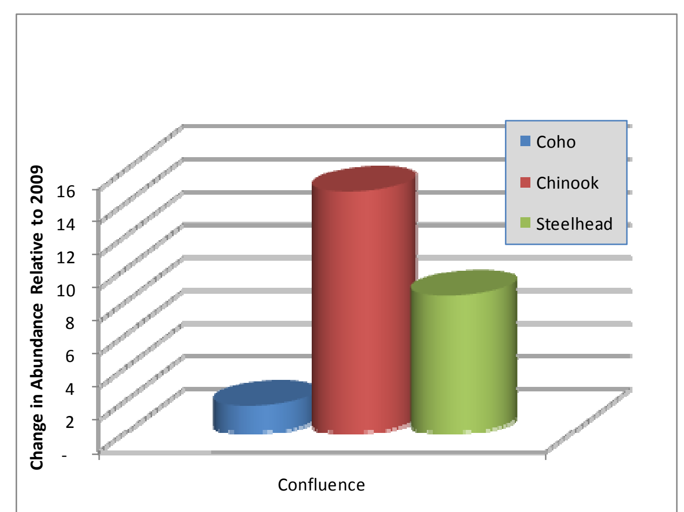
resulted from improved riparian condition and shade. The small benefit of the project for coho is because most spawning and rearing of coho occurs considerably upstream of the confluence. Life history trajectories passing through this reach are primarily migrating to and from upper reaches of Johnson Creek. Coho received a small boost in rearing for 0-age summer and 0-age winter life stages (Figure 5).

Figure 5. Results of Johnson Creek Confluence project on conditions in Johnson Creek Reach 1: Confluence Habitat Restoration vs. 2009 Condition; Increase in Habitat Potential (in Numbers of Adult Salmonids) in Johnson Creek from Planned Confluence Restoration Project Relative to 2009 Condition

JOHNSON CONFLUENCE	Lifestage Benefit Rank		
Life Stage	Coho	Chinook	Steelhead
Spawning	6	3	1
Egg Incubation	4	4	4
Fry Colonization	3	2	7
0-Summer Rearing	1		2
0-Summer Transients		5	
0-Migrants	8		9
0-Over Wintering	2		3
1-Summer Rearing	5		5
1-Migrants	9		8
1-Over Wintering			6
2-Rearing			10
2-Migrant			13
Adult Migrant	10	6	12
Adult Holding	7	1	11

Restored vs. Current

Most Variables	Key Habitat
>25% increase	>75% increase
5-25% increase	25-75% increase
1-5% increase	5-25% increase
<1% increase	<5% increase
Negligible change	Negligible change
<1% decrease	<5% decrease
1-5% decrease	5-25% decrease
5-25% decrease	25-75% decrease
>25% decrease	>75% decrease



Luther Road Habitat Restoration

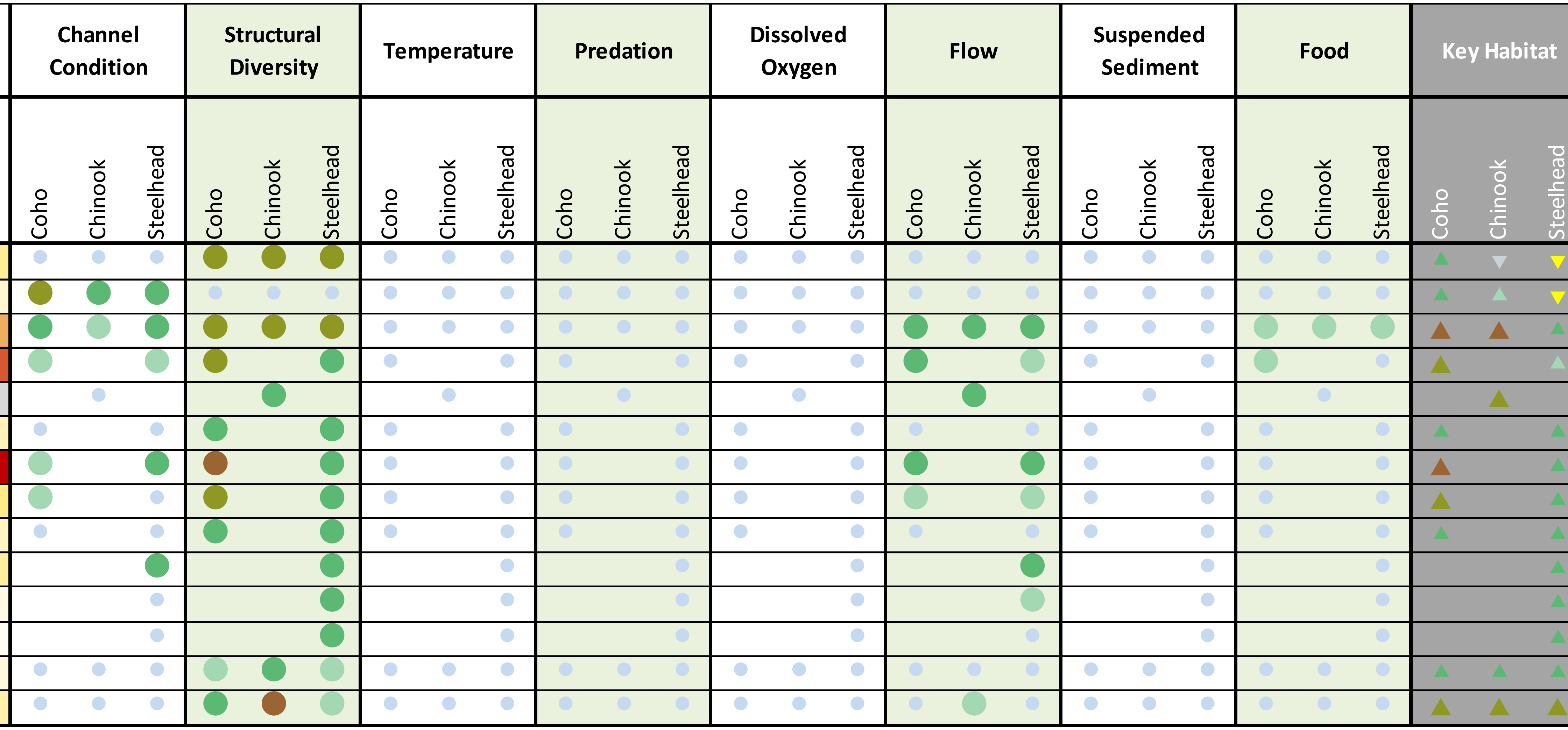
The Luther Road project is below the Interstate 205 Bridge and therefore benefited all three species (Figure 4). For coho and steelhead, the project primarily benefited 0-age summer rearing and 0-age overwintering life stages (Figure 6). These increases in habitat potential for coho and steelhead are especially the result of improvements in Structural Diversity due to the placement of large wood structures. The greatest benefits for fall Chinook were seen in Adult Holding and Fry Colonization life stages; the addition of structural elements providing cover was especially beneficial for overwinter survival of juvenile coho. The primary benefits of the Luther Road project for fall Chinook were due to improvement in conditions for adult holding. Again, the cover provided by structural elements improved habitat quality and quantity for Adult Holding. The Luther Road project removes much of the bank armoring currently present and reconnected the channel and floodplain. The resulting improved Channel Condition benefited juvenile life stages for all three species. In addition, the improved Channel Condition moderated the current low flow ratings resulting in improvement in the Flow attribute.

East Lents Habitat Restoration

The East Lents restoration primarily benefits coho with lesser benefits for steelhead (Figure 4). The project is above the assumed limit of fall Chinook distribution into Johnson Creek at Interstate 205; hence, the project provided no benefits to fall Chinook (Figure 7). The East Lents project provided benefits primarily for summer rearing of 0-age coho and overwintering of 0-age coho. Benefits to steelhead occurred primarily for 0-age winter rearing and for fry colonization. The increased habitat potential for both species was primarily because of improved structural diversity resulting from the addition of large wood (Figure 7). The addition of large wood was assumed to increase the population of benthic invertebrates resulting in an improved food supply as well. The project also improved Channel Condition by increasing sinuosity and decreasing bank angles. Although flow rate was not changed in this analysis, the benefit of existing flow increased because of the improved channel condition (Figure 7); the improved channel condition improved velocity and flow diversity with the current flow.

Figure 6. Results of Luther Road project on conditions in Johnson Creek Reach 7: Luther Road Habitat Restoration vs. 2009 Condition; Increase in Habitat Potential (in Numbers of Adult Salmonids) in Johnson Creek from Planned Luther Road Restoration Project

JOHNSON LUTHER RD.	Lifestage Benefit Rank		
Life Stage	Coho	Chinook	Steelhead
Spawning	5	4	5
Egg Incubation	4	3	10
Fry Colonization	3	2	3
0-Summer Rearing	2		2
0-Summer Transients		5	
0-Migrants	8		8
0-Over Wintering	1		1
1-Summer Rearing	6		4
1-Migrants	9		9
1-Over Wintering			6
2-Rearing			12
2-Migrant			13
Adult Migrant	10	6	11
Adult Holding	7	1	7



Relative to 2009 Condition

<u>Restored vs. Current</u>

Most Variables	Key Habitat
>25% increase	>75% increase
5-25% increase	25-75% increase
1-5% increase	5-25% increase
<1% increase	<5% increase
Negligible change	Negligible change
<1% decrease	<5% decrease
1-5% decrease	5-25% decrease
5-25% decrease	25-75% decrease
>25% decrease	>75% decrease

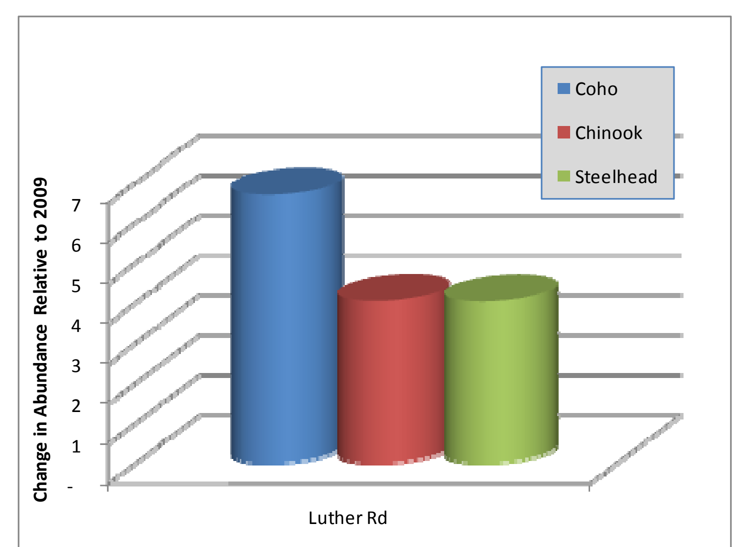


Figure 7. Results of East Lents project on conditions in Johnson Creek Reach 10. East Lents Habitat Restoration vs. 2009 Condition; Increase in Habitat Potential (in Numbers of Adult Salmonids) in Johnson Creek from Planned East Lents Restoration Project Relative to 2009 Condition

JOHNSON EAST LENTS

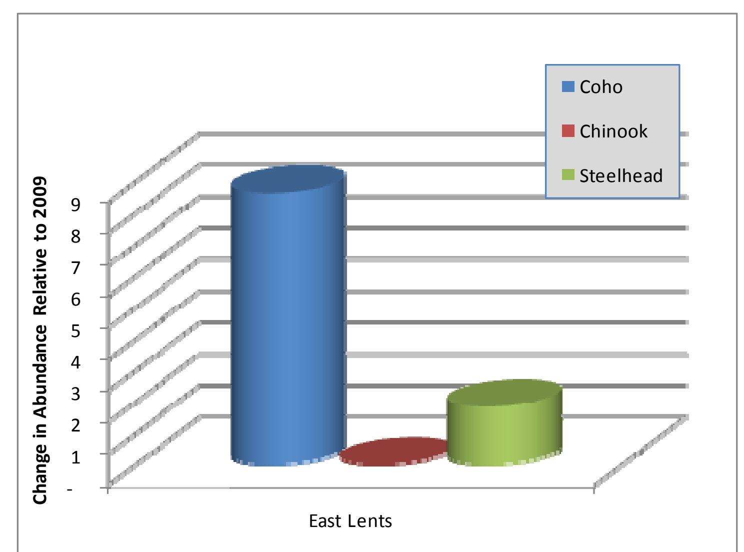
Life Stage	Lifestage Benefit Rank: Coho	Chinook	Steelhead	Channel Condition: Coho	Chinook	Steelhead	Structural Diversity: Coho	Chinook	Steelhead
Spawning	5		5	Negligible change		Negligible change	1-5% increase		5-25% increase
Egg Incubation	4		13	1-5% increase		<1% increase	Negligible change		Negligible change
Fry Colonization	3		2	<1% increase		<1% increase	1-5% increase		5-25% increase
0-Summer Rearing	1		3	<1% increase		<1% increase	1-5% increase		1-5% increase
0-Summer Transients									
0-Migrants	9		9	Negligible change		Negligible change	1-5% increase		1-5% increase
0-Over Wintering	2		1	<1% increase		<1% increase	5-25% increase		1-5% increase
1-Summer Rearing	6		4	<1% increase		Negligible change	1-5% increase		1-5% increase
1-Migrants	8		7	Negligible change		Negligible change	1-5% increase		1-5% increase
1-Over Wintering			6			<1% increase			1-5% increase
2-Rearing			11			Negligible change			<1% increase
2-Migrant			12			Negligible change			1-5% increase
Adult Migrant	10		10	Negligible change		Negligible change	<1% increase		<1% increase
Adult Holding	7		8	Negligible change		Negligible change	1-5% increase		<1% increase

Life Stage	Temperature: Coho	Chinook	Steelhead	Predation: Coho	Chinook	Steelhead	Dissolved Oxygen: Coho	Chinook	Steelhead
Spawning	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
Egg Incubation	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
Fry Colonization	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
0-Summer Rearing	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
0-Summer Transients									
0-Migrants	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
0-Over Wintering	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
1-Summer Rearing	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
1-Migrants	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
1-Over Wintering			Negligible change			Negligible change			Negligible change
2-Rearing			Negligible change			Negligible change			Negligible change
2-Migrant			Negligible change			Negligible change			Negligible change
Adult Migrant	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
Adult Holding	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change

Life Stage	Flow: Coho	Chinook	Steelhead	Suspended Sediment: Coho	Chinook	Steelhead	Food: Coho	Chinook	Steelhead	Key Habitat: Coho	Chinook	Steelhead
Spawning	<1% decrease		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change	5-25% increase		Negligible change
Egg Incubation	1-5% decrease		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change	5-25% increase		Negligible change
Fry Colonization	1-5% increase		1-5% increase	Negligible change		Negligible change	<1% increase		<1% increase	5-25% decrease		Negligible change
0-Summer Rearing	1-5% increase		<1% increase	Negligible change		Negligible change	<1% increase		<1% increase	<5% decrease		Negligible change
0-Summer Transients												
0-Migrants	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
0-Over Wintering	1-5% increase		1-5% increase	Negligible change		Negligible change	<1% increase		<1% increase	<5% decrease		Negligible change
1-Summer Rearing	<1% increase		<1% increase	Negligible change		Negligible change	<1% increase		Negligible change	<5% decrease		Negligible change
1-Migrants	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
1-Over Wintering			1-5% increase			Negligible change			Negligible change			Negligible change
2-Rearing			<1% increase			Negligible change			Negligible change			Negligible change
2-Migrant			Negligible change			Negligible change			Negligible change			Negligible change
Adult Migrant	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change
Adult Holding	Negligible change		Negligible change	Negligible change		Negligible change	Negligible change		Negligible change	<5% decrease		<5% decrease

Restored vs. Current

Most Variables	Key Habitat
>25% increase	>75% increase
5-25% increase	25-75% increase
1-5% increase	5-25% increase
<1% increase	<5% increase
Negligible change	Negligible change
<1% decrease	<5% decrease
1-5% decrease	5-25% decrease
5-25% decrease	25-75% decrease
>25% decrease	>75% decrease



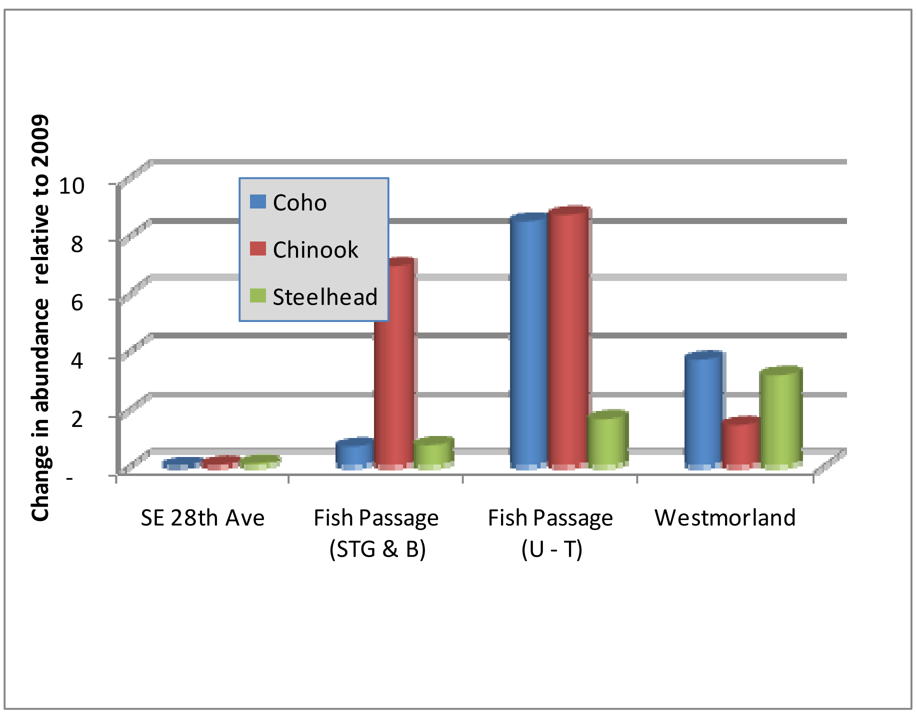
Projects in Crystal Springs

Projects in Crystal Springs include significant improvements to adult and juvenile passage in addition to improvements in habitat conditions at specific sites. Table 9 compares the increase in habitat potential for the two habitat restoration projects and two fish passage projects planned for Crystal Springs Creek. When considered individually, the sum of benefits from the Crystal Spring projects was greatest for Chinook salmon followed by coho with lesser benefits for steelhead (Table 9; Figure 8). There are no benefits from the SE 28th Avenue restoration project, which as noted below, is a result of downstream fish passage issues affecting the performance of the three indicator species. These differences reflect the unique perspective of each species on habitat conditions as well as differences in the projects themselves. The biological and physical impacts of each project will be discussed below.

Table 9. Increase in Habitat Potential (in Numbers of Adult Salmonids) with Crystal Springs Creek Future Restoration Projects

Restoration Project	Coho	Steelhead	Chinook
Fish Passage Improvements (, Tacoma, Glenwood, and Bybee)	1	1	7
Fish Passage Improvements (Umatilla to Tenino)	9	2	9
Westmoreland Pond	4	3	1
28th Avenue Habitat Restoration	0	0	0
Sum of gains from individual projects	14	6	17

Figure 8. Increase in Habitat Potential (in Numbers of Adult Salmonids) in Crystal Springs Creek from Individual Planned Restoration Projects Relative to 2009 Conditions



Fish Passage Improvements (Umatilla to Tenino)

The multiple fish passage projects provide access to underutilized habitats; projects were also assumed to provide some habitat change in the form of channel configuration and structure immediately at the project site. In isolation, the passage projects provided modest benefits, with the greatest value for coho and Chinook salmon followed by steelhead (Table 9). Without the benefit of improvement in passage at downstream sites, most of the benefit in shown in Table 9 relates to the local changes in channel configuration as well as improved life stage connectivity at each site. For all species, the access to new habitat primarily benefited the Adult Holding life stages (Figure 9). For coho the primary benefits resulted from increased access for the 0-age Overwintering life stages. Chinook benefited by increased access for the 0-age Summer Transient life stages. Access to spawning areas improved measures for the steelhead Egg Incubation life stage.

Westmoreland Pond Habitat Restoration

The creation of complex stream habitat in Westmoreland Pond and assumed improvements in water temperatures improved the habitat potential for all the indicator species, with the greatest effect on coho (Figure 10). The restoration of the pond created new stream channel habitat with spawning potential for all of the species. The new spawning habitat benefited the Adult Spawning life stage, with secondary benefits for the Egg Incubation life stage. The increased habitat potential for all species was primarily a result of improved channel condition, structural diversity, and water temperatures. Improved water temperatures benefited a range of steelhead life stages and the coho 0-age Summer Rearing life stage.

SE 28th Avenue Habitat Restoration

The SE 28th Avenue Habitat Restoration project at Reed College showed no increase in habitat potential for coho, steelhead and Chinook salmon when evaluated as an individual project (Figure 11). This is because downstream fish passage barriers prevent upstream fish access, which severely limits the habitat value to the fish populations. This site is near the headwaters of Crystal Springs and is above ten individual obstructions (street crossing and other barriers), each of which is believed to have a significant negative impact on adult passage. Thus, restoration of this site by itself has little or no benefit to the target species due to the cumulative impact of all downstream impediments to fish passage. As discussed below, once access to the site is restored the analysis showed benefits to all species from this project. The benefits resulted from improved habitat complexity, deeper pools and other factors, with the greatest benefits for the O-age coho Summer Rearing life stage, the 0-age steelhead Over Wintering life stage, and the Chinook Adult Holding life stage.

Figure 9. Results of Umatilla to Tenino project on conditions in Crystal Springs Reach 1C: Fish Passage Improvements (Umatilla to Tenino) Restoration vs. 2009 Condition; Increase in Habitat Potential (in Numbers of Adult Salmonids) in Crystal Springs Creek from Planned Fish Improvement Project (Umatilla to Tenino) Relative to 2009 Condition

CRYSTAL T-U PASSAGE	Lifestage Benefit Rank			Channel Condition			Structural Diversity			Temperature			Predation			Dissolved Oxygen			Flow			Suspended Sediment			Food			Key Habitat		
Life Stage	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead
Spawning	4	3	4	•	•	•	●	●	●	•	•	●	•	•	•	•	•	•	•	●	•	•	•	•	•	•	•	▼	▼	▼
Egg Incubation	6	6	2	●	●	●	•	•	•	•	•	●	•	•	•	•	•	•	●	●	•	•	•	•	•	•	•	▼	▼	▼
Fry Colonization	5	4	5	●	●	●	●	●	●	•	•	●	•	•	●	•	•	•	●	●	●	•	•	•	●	●	●	▲	▲	▲
0-Summer Rearing	3		3	●		●	●		●	●		●	•		●	•		•	●		●	•		•	●		●	▲		▲
0-Summer Transients		2			●			●			•			•			•			●			•			●			▲	
0-Migrants	8		9	•		•	●		●	•		•	•		•	•		•	•		•	•		•	•		•	▲		▲
0-Over Wintering	2		6	●		●	●		●	•		•	•		•	•		•	●		●	•		•	●		●	▲		▲
1-Summer Rearing	7		7	●		•	●		●	•		•	•		•	•		•	•		●	•		•	●		•	▲		▲
1-Migrants	10		10	•		•	●		●	•		•	•		•	•		•	•		•	•		•	•		•	▲		▲
1-Over Wintering																														
2-Rearing																														
2-Migrant			11			•			●			•			•			•			•			•			•			▲
Adult Migrant	9	5	8	•	•	•	●	●	●	•	•	•	•	•	•	•	•	•	●	●	•	•	•	•	•	•	•	▲	▲	▲
Adult Holding	1	1	1	•	•	•	●	●	●	•	•	•	•	•	•	•	•	•	●	●	•	•	•	•	•	•	•	▲	▲	▲

Restored vs. Current

Most Variables		Key Habitat	
●	>25% increase	▲	>75% increase
●	5-25% increase	▲	25-75% increase
●	1-5% increase	▲	5-25% increase
●	<1% increase	▲	<5% increase
•	Negligible change	•	Negligible change
●	<1% decrease	▼	<5% decrease
●	1-5% decrease	▼	5-25% decrease
●	5-25% decrease	▼	25-75% decrease
●	>25% decrease	▼	>75% decrease

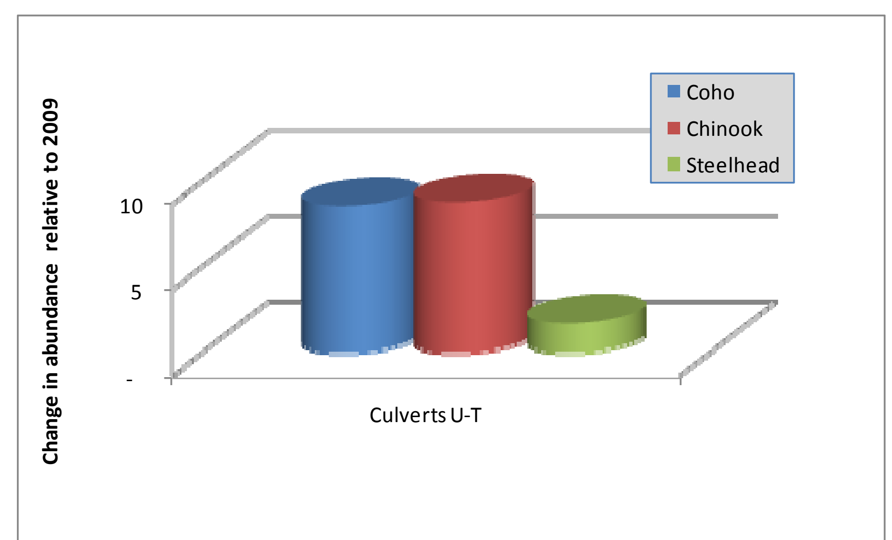
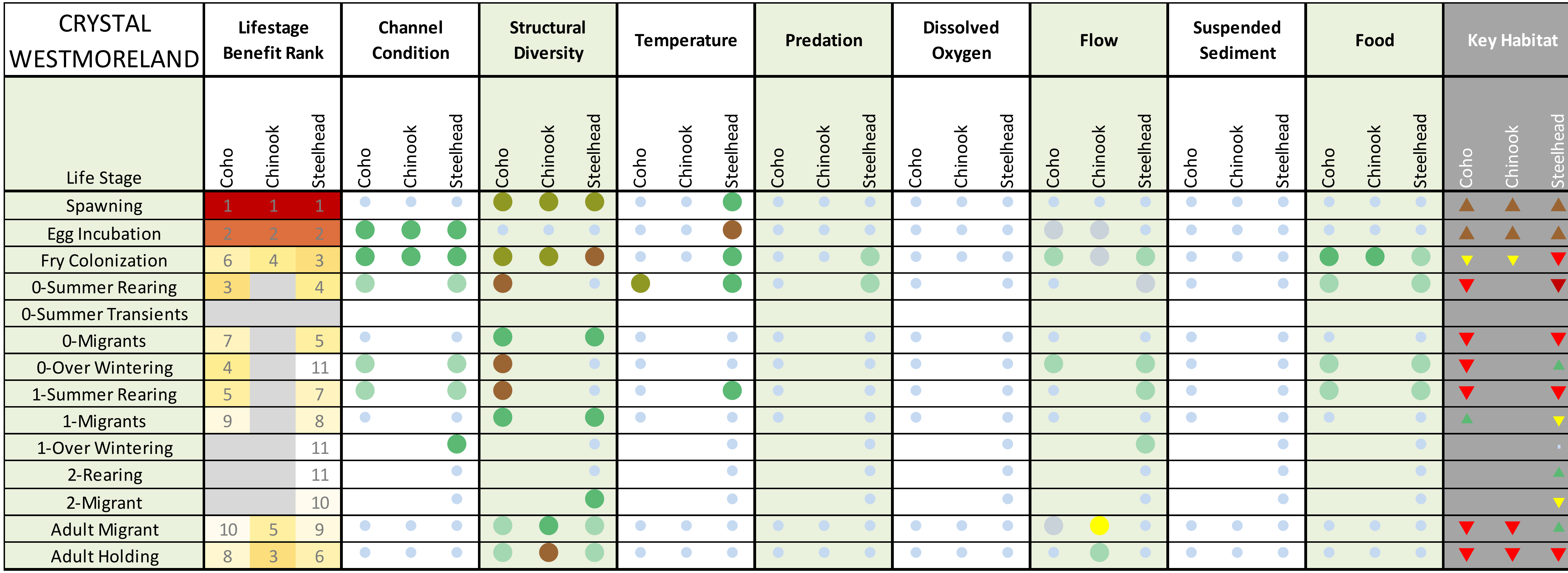


Figure 10. Results of Westmoreland Pond project on conditions in Crystal Springs 2APond: Westmoreland Pond Restoration vs. 2009 Condition; Increase in Habitat Potential (in Numbers of Adult Salmonids) in Crystal Spring Creek from Westmoreland Pond Restoration Project Relative to 2009 Condition



Restored vs. Current

Most Variables	Key Habitat
>25% increase	>75% increase
5-25% increase	25-75% increase
1-5% increase	5-25% increase
<1% increase	<5% increase
Negligible change	Negligible change
<1% decrease	<5% decrease
1-5% decrease	5-25% decrease
5-25% decrease	25-75% decrease
>25% decrease	>75% decrease

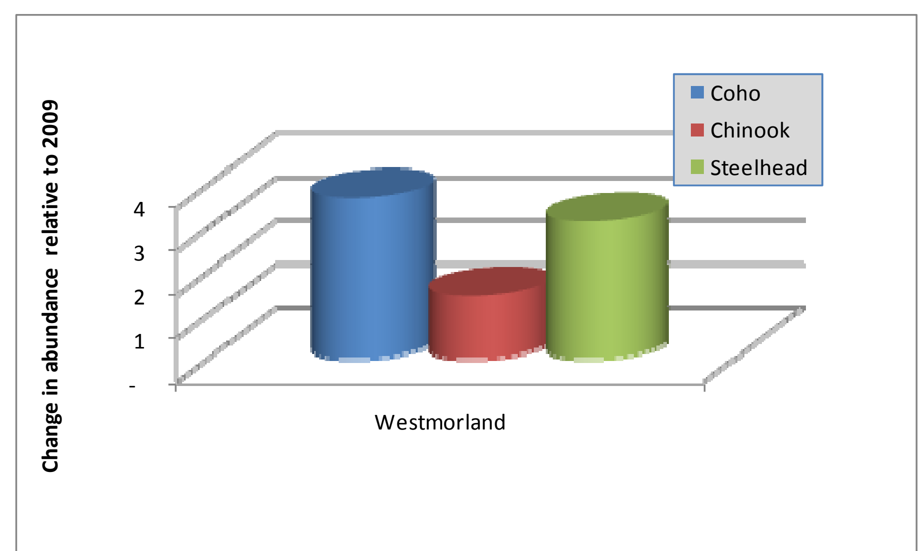
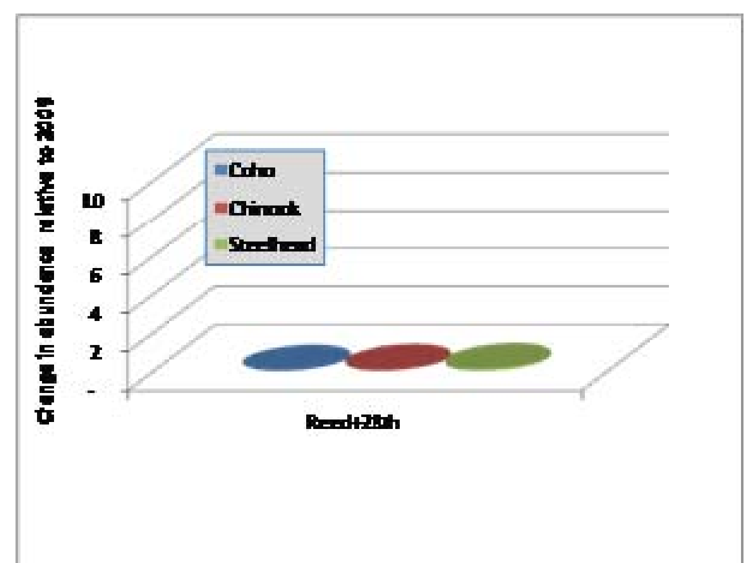


Figure 11. Results of Crystal SE 28th Avenue project on conditions in Crystal Springs Reach 4C: SE 28th Avenue Restoration vs. 2009 Condition; Increase in Habitat Potential (in Numbers of Adult Salmonids) in Crystal Spring Creek from SE 28th Avenue Restoration Relative to 2009 Condition

CRYSTAL SE 28th AVE	Lifestage Benefit Rank			Channel Condition			Structural Diversity			Temperature			Predation			Dissolved Oxygen			Flow			Suspended Sediment			Food			Key Habitat		
Life Stage	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead
Spawning	4	2	6	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▼	▼	▼
Egg Incubation	9	5	8	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▼	▼	▼
Fry Colonization	3	3	7	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▲	▲	▲
0-Summer Rearing	1		3	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▲		▲
0-Summer Transients																																	
0-Migrants	9		5	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▲		▲
0-Over Wintering	2		1	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▲		▲
1-Summer Rearing	6		2	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▲		▲
1-Migrants	8		12	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▲		▲
1-Over Wintering			4			●			●			●			●			●			●			●			●			●			▲
2-Rearing			9			●			●			●			●			●			●			●			●			●			▲
2-Migrant			13			●			●			●			●			●			●			●			●			●			▲
Adult Migrant	7	4	11	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▲	▲	▲
Adult Holding	5	1	10	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▲	▲	▲

Restored vs. Current

Most Variables	Key Habitat
>25% increase	>75% increase
5-25% increase	25-75% increase
1-5% increase	5-25% increase
<1% increase	<5% increase
Negligible change	Negligible change
<1% decrease	<5% decrease
1-5% decrease	5-25% decrease
5-25% decrease	25-75% decrease
>25% decrease	>75% decrease



Project Synergisms and Phasing

The benefit of projects undertaken in isolation are often limited by limiting factors elsewhere in the watershed such that projects conceived with the best of intentions may have limited biological value if overall limiting factors are not also addressed. The result of this is that multiple projects often have synergisms that result in considerable magnification of benefits relative to consideration of the project in isolation. The combined "portfolio" of multiple planned future restoration projects undertaken by the City in Johnson Creek and Crystal Springs Creek substantially increased the potential of Johnson Creek to support coho, fall Chinook, and winter steelhead. The planned restoration projects will have dramatic benefits for coho and Chinook salmon, and marked improvements in steelhead habitat potential (Table 10). Habitat potential for coho is projected to increase by 123%; winter steelhead by 52%; and Chinook salmon by 118%.

Table 10. Increase in Habitat Potential (in Numbers of Adult Salmonids) of the Johnson Creek Watershed with 2009 Conditions and the Future Planned Restoration Projects

Evaluation	Coho	Steelhead	Chinook
2009 existing condition	134	96	62
Planned future restoration (combined projects)	299	146	135
Gain from 2009 to future (difference)	165	50	73
Gain as percentage of 2009	123%	52%	118%

When the projects were considered in aggregate, the benefits were much greater than the total benefits of projects considered individually (Table 11). The difference in habitat potential when considering all projects together versus the summing of individual projects is a measure of the synergistic effects of implementing multiple restoration actions. Fish move through the system and occupy different habitats depending on the life stage (e.g., Adult Spawning or Juvenile Rearing) and restoration projects across the stream network provide overall benefits across the life cycle. The Johnson Creek EDT model captures the combined effects of restoration actions by moving fish across the entire life cycle, exposing the indicator species to cumulative effects of multiple projects.

The habitat potential for coho salmon clearly benefits the most from the synergistic effects, with adult habitat potential increasing dramatically (38 to 165), followed by steelhead (20 to 50) and Chinook (36 to 73). An evaluation of the relative contribution of planned restoration actions in

Table 11. Increase in Habitat Potential (in Numbers of Adult Salmonids) of the Johnson Creek Watershed with 2009 Conditions and the Future Planned Restoration Projects: Evaluation of Projects in Isolation vs. Multiple Projects

Evaluation	Coho	Steelhead	Chinook
2009 Existing Condition	134	96	62
Gain from 2009 with individual projects	38	20	36
Gain from 2009 to future with combined projects	165	50	73

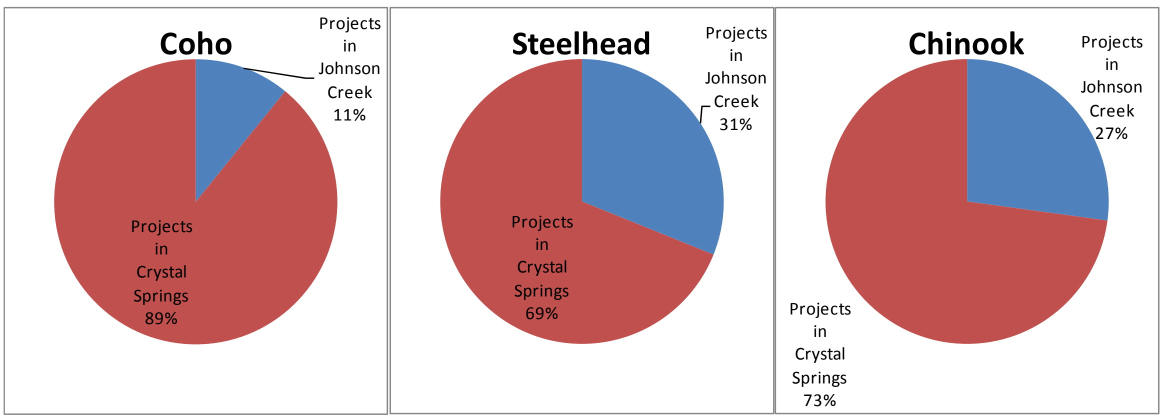
Johnson Creek and Crystal Springs Creek demonstrate the large differences in increased habitat potential for the two systems (Table 12). All of these actions result in much larger relative increases in habitat potential throughout Crystal Springs Creek in comparison to Johnson Creek (Figure 12).

The combined restoration projects in Crystal Springs Creek provide significantly greater benefits relative to Johnson Creek for Coho (148 to 18), steelhead (31 to 14), and Chinook (51 to 19).

Table 12. Relative Increase in Habitat Potential (in Numbers of Adult Salmonids) in Johnson Creek and Crystal Springs Creek from Multiple Planned Restoration Projects

Evaluation	Coho	Steelhead	Chinook
Combined projects in Johnson Creek	18	14	19
Combined projects in Crystal Springs Creek	148	31	51
Sum of gains from 2009 to future restoration	165	50	73

Figure 12. The Relative Percent Contributions to Increased Habitat Potential from Multiple Restoration Projects Allocated between Johnson Creek and Crystal Springs Creek



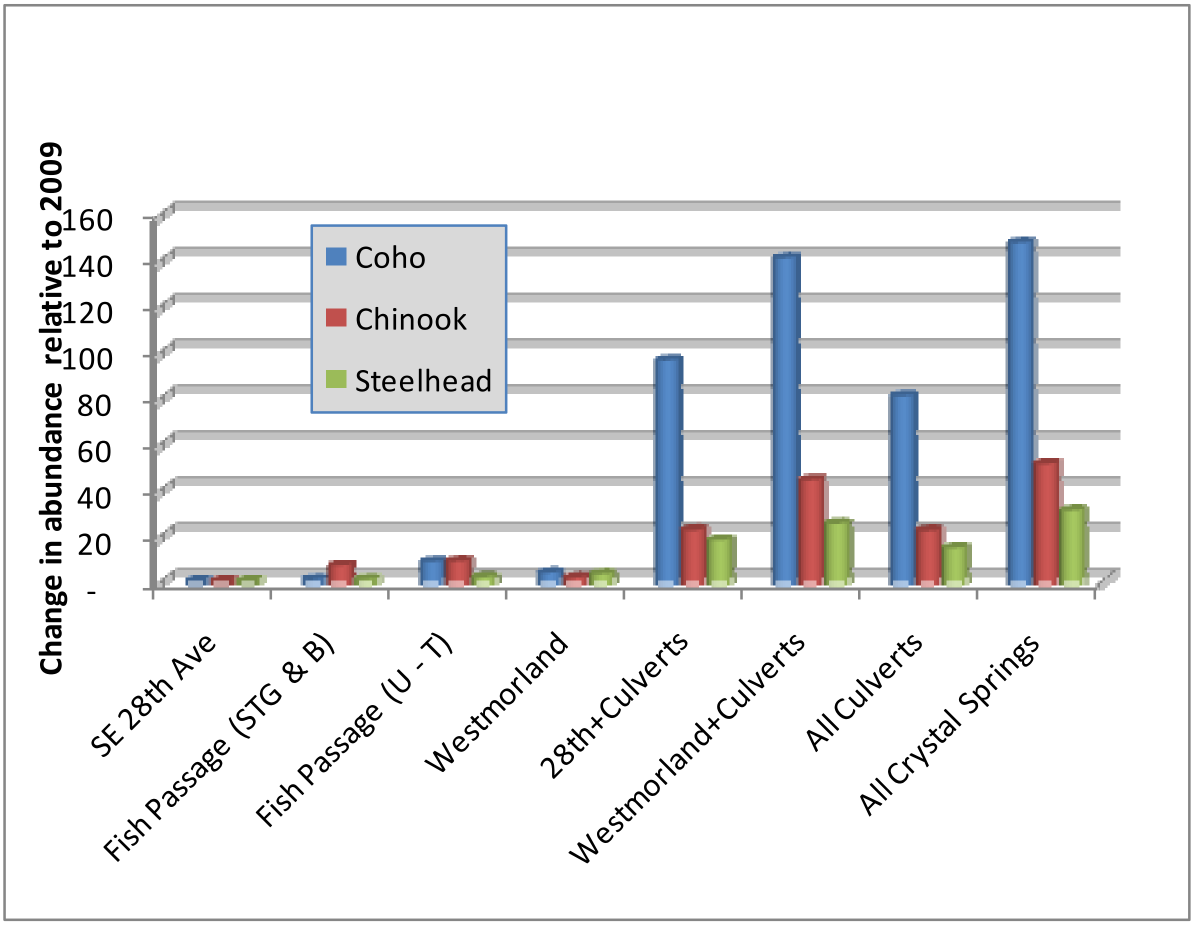
The dramatic gain in fish habitat potential in Crystal Springs Creek is a result of the multiple habitat restoration actions combined with improvements in fish passage (Table 13; Figure 13). The phasing and combining of habitat and fish passage projects will affect the overall increase in habitat potential. While multiple fish passage improvements increase the habitat accessible to the three indicator species, improving fish passage in combination with habitat restoration results in the most dramatic benefits. When evaluated in isolation, the Westmoreland Pond habitat restoration project resulted in modest benefits. Conversely, when combined with fish passage, restoration of the pond into complex stream habitat with water temperature improvements resulted in large increases in habitat potential across all three indicator species: coho (4 to 140); steelhead (3 to 25); and Chinook (1 to 44). The gains in potential habitat are even more dramatic for the 28th Avenue restoration project because it is at the upper end of the system with multiple downstream fish passage barriers: Without the fish passage improvements, the 28th Avenue project showed no increase in habitat potential.

Table 13. Increase in Habitat Potential (in Numbers of Adult Salmonids) in Crystal Springs Creek from Fish Passage Improvements and Multiple Habitat Restoration Projects

Evaluation	Coho	Steelhead	Chinook
Crystal Springs Westmoreland Pond with culverts	140 (4)	25 (3)	44 (1)
Crystal Springs SE 28th Avenue with culverts	96 (0)	18 (0)	22 (0)
Crystal Springs all fish passage	81 (10)	14 (3)	22 (16)
Crystal Springs projects combined	148 (14)	31 (6)	51 (17)

Note: Numbers in parentheses are for each project evaluated in isolation.

Figure 13. Increase in Habitat Potential (in Numbers of Adult Salmonids) in Crystal Springs Creek from Fish Passage Improvements and Multiple Habitat Restoration Projects



Multispecies Benefits

The overall results of the entire analysis of restoration project in Johnson Creek to date are summarized in Figure 14. This figure summarizes the improvements in habitat quality and quantity for individual life stages for three salmonid species due to changes attributes at the scale of the Johnson Creek watershed. At that scale, the combined projects provided the greatest benefit to spawning, egg incubation and adult holding for all three species due to improvements in Habitat Diversity and by increasing the quantity of Key Habitat for the spawning life stage (Figure 14).

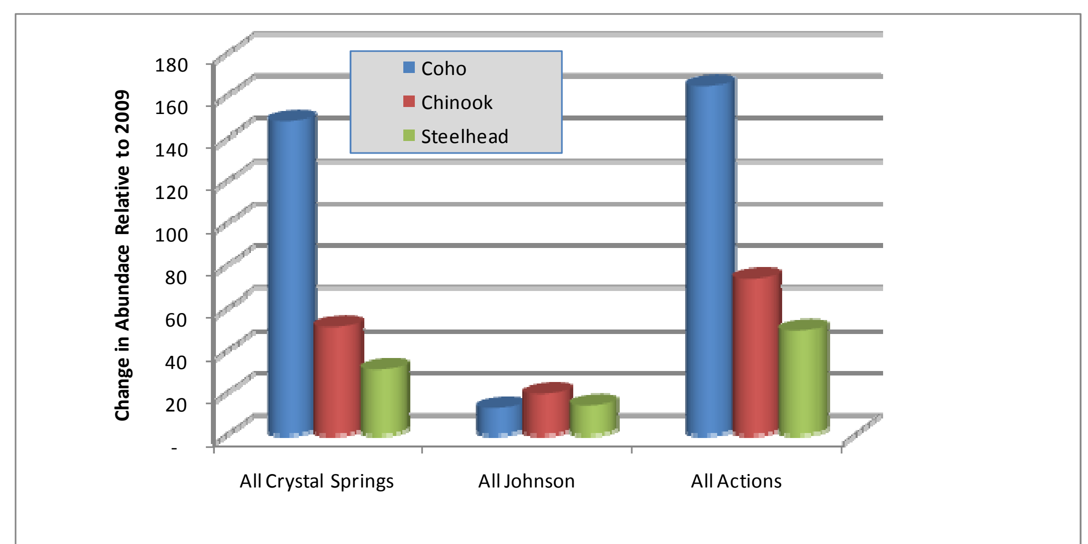
Spawning success for steelhead was also improved by improvement (lowering) in water temperature during early spring. Over-summer survival for coho and steelhead was also improved by improvements in Habitat Diversity and Temperature (lowering) during summer. The overall impact of the combined project is a substantial increase in salmonid habitat potential for all three species relative to the 2009 condition (Table 13).

Figure 14. Limitation of Salmonid Life Stages by Survival-Related Attributes in Johnson Creek and Crystal Springs Creek for All Future Restoration Projects vs. 2009 Condition; The Increase in Habitat Potential (in Numbers of Adult Salmonids) in Johnson Creek Watershed from All Evaluated Projects

FULL SYSTEM	Lifestage Benefit Rank			Channel Condition			Structural Diversity			Temperature			Predation			Dissolved Oxygen			Flow			Suspended Sediment			Food			Key Habitat		
Life Stage	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead	Coho	Chinook	Steelhead
Spawning	2	1	1	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▲	▲	▲
Egg Incubation	5	3	3	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▲	▲	▲
Fry Colonization	8	6	5	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▲	▲	▲
0-Summer Rearing	4		4	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▲		▪
0-Summer Transients		4			●			●			●			●			●			●			●			●			▲	
0-Migrants	9		10	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▪		▲
0-Over Wintering	3		6	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▲		▲
1-Summer Rearing	6		7	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▲		▪
1-Migrants	10		12	●		●	●		●	●		●	●		●	●		●	●		●	●		●	●		●	▪		▪
1-Over Wintering			9			●			●			●			●			●			●			●			●			▲
2-Rearing			11			●			●			●			●			●			●			●			●			▪
2-Migrant			14			●			●			●			●			●			●			●			●			▪
Adult Migrant	7	5	8	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▪	▪	▲
Adult Holding	1	2	2	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	▲	▲	▲

Restored vs. Current

Most Variables	Key Habitat
● >25% increase	▲ >75% increase
● 5-25% increase	▲ 25-75% increase
● 1-5% increase	▲ 5-25% increase
● <1% increase	▲ <5% increase
● <1% decrease	▼ <5% decrease
● 1-5% decrease	▼ 5-25% decrease
● 5-25% decrease	▼ 25-75% decrease



Conditions in the 2040s under Future Urban Development and Climate Change

Under the 2040 climate change scenario, increasing air temperatures and modified rainfall patterns would have significant impacts on future watershed processes within the Johnson Creek watershed, particularly on the flow and water temperature regimes. On the other hand, ICF concludes that future urban development of the watershed, consistent with current plan guidelines and with proper BMPs , will have minimal or net positive effects on the health of Johnson Creek. Recent studies provide additional support for the conclusion that climate change will have a greater impact on watershed processes than increasing urbanization. In an analysis of Portland-area urban flooding caused by the combined effects of climate and land use change, the increases in Johnson Creek flood frequency and variability are more sensitive to climate change than land use change (Jung et al. 2010). Because minimal impacts from future urban development are projected, the EDT analysis focuses only on the effects of climate change and the interactions with future restoration projects.

The EDT model results were used to evaluate the impacts of climate change on the Johnson Creek watershed under two conditions relative to 2009: 1) Conditions without planned restoration; and 2) with the planned restoration projects. Table 14 summarizes the impacts of climate change on habitat potential for the three indicator species without planned restoration. If the planned restoration projects are not implemented, there would be significant loss of habitat potential resulting from climate change, with the most significant losses for coho and steelhead. By the 2040s, the watershed-scale loss of habitat potential relative to 2009 would be 32% for coho, 17% for steelhead, and 5% for Chinook salmon.

Clearly, by the 2040s climate change would dramatically decrease the capacity of the Johnson Creek watershed to support salmonid populations, with the largest impact on coho and steelhead. Juvenile coho and steelhead reside in the system for significant periods and they would be the most affected by climate change-driven modifications of the water temperature and flow regimes. Chinook salmon, on the other hand, do not reside in the system as long as these other two species and they are less affected, particularly by increased summer water temperatures because they are out of the stream by this time.

Table 14. Change in Habitat Potential (in Numbers of Adult Salmonids) in the Johnson Creek Watershed from Climate Change Impacts Relative to 2009 Conditions without Restoration Projects

Evaluation	Coho	Steelhead	Chinook
2009 existing condition	134	96	62
Climate change scenario with no restoration	91	80	59
Loss from 2009 to future with climate change	-43	-16	-3
Loss as percentage of 2009	-32%	-17%	-5%

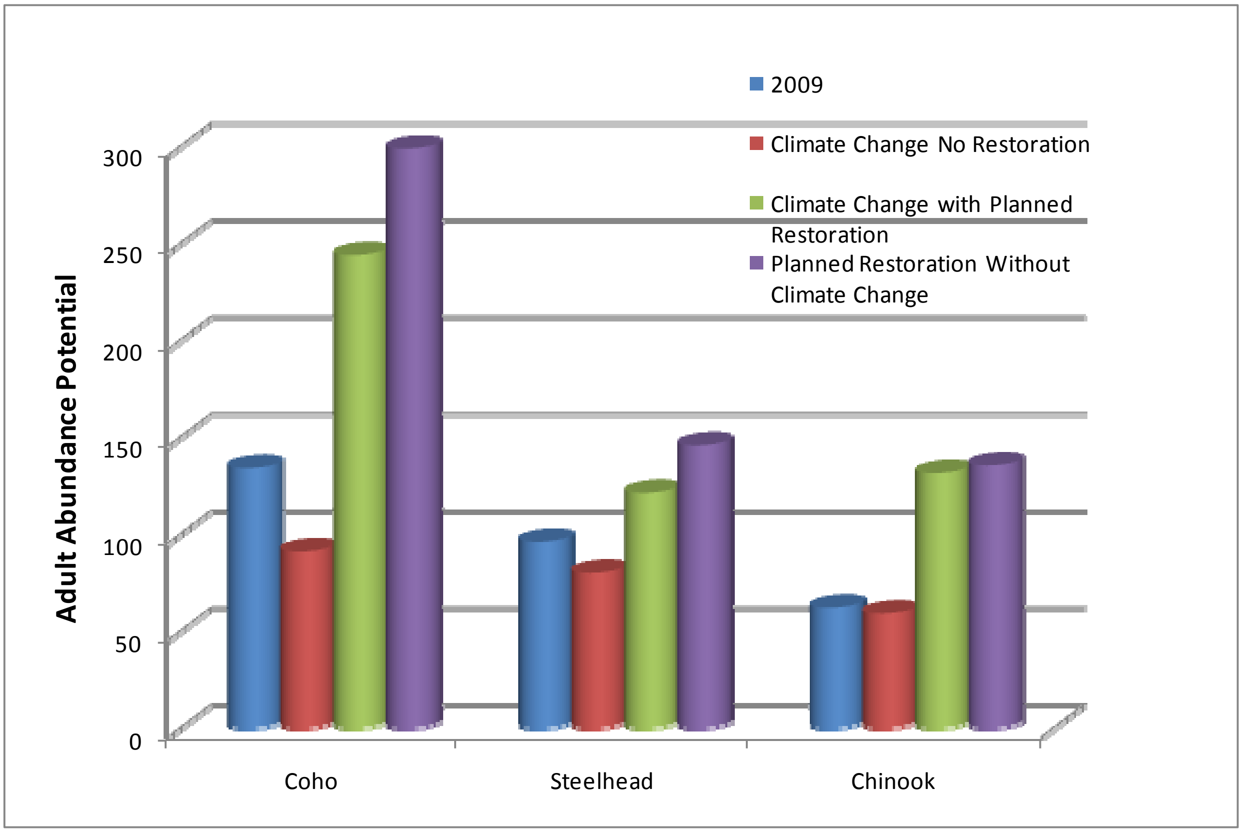
The restoration projects planned for the Johnson Creek watershed have potential to moderate the impacts of climate change. Despite the countervailing effects of climate change, the restoration projects would increase the habitat potential for all three species relative to 2009, albeit at lower levels than if climate change was not present (Table 15; Figure 15). Habitat potential under climate change would decrease very little for Chinook salmon. As stated above, Chinook do not reside long in the system and would be less exposed to changes in water temperatures and flow induced by climate change. Coho and steelhead would experience substantial reductions in habitat potential under the climate change scenario, with the most dramatic reductions in coho potential.

Under future restored conditions, a number of attributes would help buffer the system from the effects of climate change. The structural diversity of habitat, the availability of key habitat, and temperature would all help mitigate changes in the flow and water temperature regimes across a range of life stages (Figure 14). While these factors would help counteract the impacts of climate change, it is import to understand the context for the changing environment in the Johnson Creek watershed. There are three factors that influence how habitat potential in Johnson Creek will respond to climate change. First, Johnson Creek is a rain-dominated system, and thus already subject under current conditions to high water temperatures and low flows during the summer months. While climate change will affect this type of system, snow-dominated watersheds are much more susceptible to the climate change impacts resulting from reduced snow pack, which can dramatically increase peaks flows and water temperatures (Chang and Jones 2010). Second, Johnson Creek is an urban system that is already heavily affected by development. Despite significant improvements in the Johnson Creek watershed, the watershed as a whole is still greatly constrained and the system, like many others throughout the Pacific Northwest (ICF International 2010, Appendix A). Thus, climate change is affecting an already stressed system. Finally, and importantly for restoration strategy, key portions of the Johnson Creek watershed are less susceptible to climate change impacts. The upper portions of Johnson Creek, which certainly have potential for increased fish numbers from habitat improvements because of better habitat conditions and water temperature regimes, would experience fewer impacts from climate change. Similarly, Crystal Springs Creek, which is spring-fed, is buffered from increased water temperatures and changes in the flow regime because of the cool water sources and consistent flows.

Table 15. Change in Habitat Potential (in Numbers of Adult Salmonids) in the Johnson Creek Watershed from Climate Change Impacts Relative to 2009 Conditions with Planned Restoration Projects

Evaluation	Coho	Steelhead	Chinook
2009 existing condition	134	96	62
Climate change scenario with planned restoration	244	121	131
Gain from 2009 to future with climate change	110	25	69
Gain from 2009 to future without climate change	165	50	73
Net decrease from climate change	-55	-25	-4
Gain as percentage of 2009 with climate change	82%	26%	112%
Gain as percentage 2009 without climate change	123%	52%	118%

Figure 15. Habitat Potential (in Numbers of Adult Salmonids) in the Johnson Creek Watershed in 2009, with Planned Restoration and from Climate Change Impacts with and without Planned Restoration Projects



Conclusions and Recommendations

Conditions in Johnson Creek for native salmonids and for co-evolved fish, wildlife, invertebrate and plant species have changed dramatically since the advent of European development of the watershed. As Portland developed, the watershed was rapidly converted to meet a range of needs for the burgeoning human population. During much of the 20th century, this development occurred with little thought to the impacts on the biological community or on the ecosystem services provided by the stream including especially flood control. In the last few decades, the attitude of the City to Johnson Creek has markedly shifted. The City has undertaken significant actions to modify conditions in the creek to restore salmon and other species and to provide flood control based on normative stream function. The success of these and other actions will be affected to a significant degree by the impacts of climate change and by the ability of the City to limit the impact of future development on stream conditions.

Land use change and urban development since the early 1900s have warmed Johnson Creek and altered summer and winter stream flows. Climate change will amplify these trends. Under the 2040 climate change scenario, increasing air temperatures and changes in the distribution and intensity of rainfall will have significant impacts on future watershed processes within the Johnson Creek watershed. Summer flows are expected to decrease; lower stream flows, combined with warming and more frequent heat waves, will elevate water temperatures. The extension of drought periods and warming temperatures into the early fall will prolong the period of temperature stress on fish populations. The increased frequency of high intensity rainfall and associated flood events, combined with changes in the structure of the channel such as the WPA armoring, will exacerbate bed scour in Johnson Creek, with associated impacts on stream habitat.

Improvements in land management, planned stream restoration and natural revegetation of riparian areas will help to counteract the effects of climate change. Future urban development within the watershed, if done with the proper BMPs and land use practices in place, should have minimal effects on the health of Johnson Creek and could improve conditions, including enhancing groundwater recharge and riparian vegetation. The EDT analysis illustrates that climate change will affect fish populations, but the impacts will be moderated by comprehensive aquatic and riparian restoration.

This analysis demonstrated that the appropriate placement and sequencing of multiple restoration actions will enhance the biological benefits realized by the City's investments in watershed restoration. Strategic implementation of projects will also help the City accommodate and adapt to climate change with respect to restoration of streams and natural areas. When evaluated separately, individual projects have modest benefits for improved salmon and steelhead potential. However, the analysis of a combined "portfolio" of multiple projects demonstrates significant synergisms between projects that greatly enhance the biological value of restoration investments. The planned restoration projects will have substantial benefits for coho and steelhead even in the face of climate change, and some improvement in Chinook habitat potential. The most dramatic gain in future fish habitat potential is in Crystal Springs Creek because of the multiple habitat restoration actions combined with fish passage. Crystal Springs Creek, a spring-fed system, exhibits water temperature regimes that are initially colder than Johnson Creek, however, existing conditions along the stream result in significant warming. The planned restoration project in Crystal Springs help maintain cool water through the length of the stream and provide thermal refugia. These synergisms have been demonstrated in analysis of projects in Tryon Creek as well (ICF Jones & Stokes 2008). Synergisms occurring between restoration projects and the order of implementing projects should be an important consideration in planning stream restoration throughout Portland watersheds.

Evaluation of the biological value of stream restoration projects can only be made with reference to particular species or species groups. Each species will view the effects of restoration differently based on their unique biological requirements and scale of life history experience. In this analysis, variations in salmon and steelhead life history strategies and habitat requirements affected the response of the three indicator species to restoration actions and climate change. For example, in comparison to juvenile fall Chinook salmon that transition out of the system shortly after emergence, juvenile steelhead and coho remain in the system through the summer and are more affected by increased water temperatures and are expected to be more affected by climate change impacts.

Although predicting the local effects of climate change is challenging, this analysis demonstrated that the City's restoration strategies should help moderate the effects of climate change. Efforts to moderate stream temperatures by enhancement of riparian forests and storm water recharge of groundwater are examples of positive steps that the City can take to moderate the expected impacts of climate change. Extrapolating from climate change models, evaluating watershed-scale effects, and predicting salmonid species response with the model multiplies the uncertainties associated with exact predictions. In addition, fish population response is only one component of a broader ecosystem and there is a wide range of possibilities in the response of complex biological systems to climate change. Nonetheless, this analysis, along with a host of climate analysis conducted at regional, national and global scales, indicate that climate change is a significant factor that should be incorporated into planning and implementation of the City's restoration efforts.

Managing the Johnson Creek watershed to account for future climate change and the inherent uncertainties will be complex. There are, however, strategies to manage the system in the face of climate change and the uncertain future. The effects of climate change and the impacts of urban development can be moderated by policies and actions that foster ecological resilience (Hixson et al. 2010). As this analysis demonstrated, population resilience and productivity of native salmonids in Johnson Creek can be improved through restoration actions implemented with an eye toward synergisms and sequencing. Actions that target the most resilient parts of the system (for example the upper reaches of Johnson Creek and Crystal Springs Creek) will be the most effective in the long term. The effects of climate change will not be uniform across the watershed but will likely increase downstream. Cold water refuges created by spring flows or the exchange of stream flow with groundwater will become increasingly important. Crystal Springs Creek, a spring-fed system that potentially provides cool water and could moderate high and low flows, will likely be an important refuge habitat. Similarly, areas in the upper portions of Johnson Creek can provide cooler water. The potential for development of refuge habitat can be enhanced through actions that improve shade and cover and enhance groundwater recharge to directly moderate water temperatures. These actions include improved infiltration of storm water into the groundwater system, floodplain restoration, and riparian enhancement to improve stream shading. Habitat restoration actions that enhance cold water refuges, combined with fish passage and habitat complexity improvements, will provide benefits for coho, steelhead and Chinook salmon across all life stages, which will build resiliency into the system and moderate the impacts of climate change.

We conclude with recommendations for the City that emerge from our analysis. First, we encourage the City to continue its use of an analytical framework around which to structure and evaluate restoration. This framework clearly provides benefits in terms of illustrating synergisms and for planning of restoration strategies. The framework also allows the City to illustrate the contribution of restoration efforts to biological goals including recovery of ESA listed species as well as enhancing the value of streams like Johnson Creek to the overall character of Portland. Our second recommendation is to incorporate climate change into that analytical framework in order to build consideration of climate change into the fabric of City planning. The analysis reported here only illustrated the potential impacts of climate change and did not delve into the mechanistic relationships between climate change and stream conditions and the interactions with development activities. As the impacts of climate change accumulate the need for more sophisticated analysis will become apparent. Finally, our third recommendation is to merge the City's analysis of best management practices (BMPs) and effectiveness evaluation with the restoration analytical framework used in this analysis. This will provide much more detailed and realistic analysis of build-out and development in the context of climate change than was possible in this analysis.

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