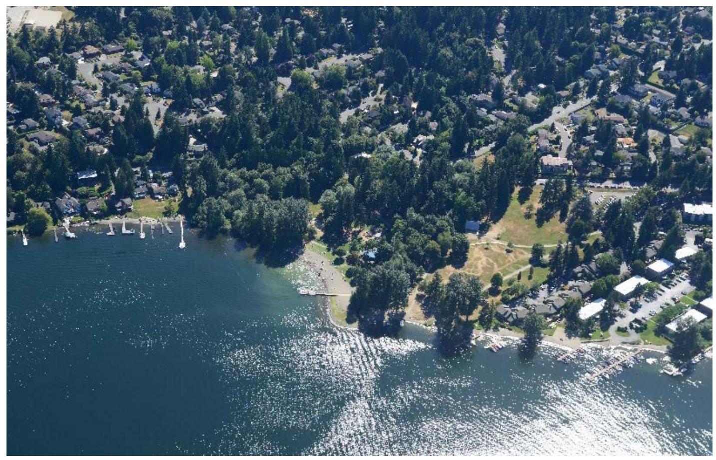
Best Available Science Summary Report

CRITICAL AREAS ORDINANCE UPDATE

CITY OF SAMMAMISH

October 2023



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DCG WATERSHED

Title-page image: Aerial Imagery from Department of Ecology Coastal Zone Atlas (2016-2017 Shoreline Photo)

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1 Introduction

1.1 Regulatory Framework

The City of Sammamish is in the initial phases of updating its Critical Areas Ordinance in conjunction with the periodic update of their Comprehensive Plan required by the Growth Management Act (GMA). To complete this effort, the City must review and incorporate best available science in development of policies and regulations as described in the Washington Administrative Code (WAC 365-195-900 through 920). The requirements for periodic updates include criteria for demonstrating 'special consideration' has been given to conservation measures necessary to preserve or enhance anadromous fisheries (WAC 365-195-925).

Critical areas defined under the Revised Code of Washington [RCW 36.70A.030(11)] subject to GMA requirements include the following areas and ecosystems:

a) Wetlands;
b) Critical aquifer recharge areas;
c) Fish and wildlife habitat conservation areas;
d) Frequently flooded areas; and
e) Geologically hazardous areas.

1.2 Best Available Science

This review of Best Available Science (BAS) was prepared to meet the GMA requirements and inform City staff of current BAS guidance for critical area management and protection.

BAS documents are prepared by qualified scientific experts and follow a valid scientific process. The scientific process, which produces reliable information, is generally characterized by peer review, standardized methods, logical conclusions and reasonable inferences, quantitative analysis, proper context, and references. Common sources of scientific information include research, monitoring, inventory, modeling, assessment, and synthesis (WAC 365-195-905).

The scientific process by design continues to grow and evolve as new studies are conducted and new technologies are employed. BAS provides information to support and guide development of polices and regulations. It does not always yield definitive direction on how to best manage and protect critical areas. In those cases, where incomplete scientific information or an absence of scientific information may lead to uncertainty about what actions could harm critical areas, a precautionary or no risk approach should be taken in accordance with WAC 365-195-920 until the uncertainty is resolved. An adaptive management program based on scientific methodology may also be used in those cases.

BAS documents cited here were selected based on their significance to conditions in the City of Sammamish, common use in each discipline, and relevance to current scientific practices or principles. This BAS review will be referenced as the City moves forward with their development regulations updates, including a CAO update.

1.3 Climate Change

Washington State recently adopted House Bill 1181 to improve the State's response to climate change by updating the State's planning framework. The bill requires local jurisdictions to ensure that comprehensive plans, regional policies, and development regulations adapt to and mitigate the effects of a changing climate to foster resiliency.

Anthropogenic global climate change is projected to impact climatic variation and natural resources in the Pacific Northwest. Climate models predict average annual temperatures in the contiguous United States to increase in the range of 2.5°F over the next few decades and, regardless of future emissions, increase by 3°F to 12°F by the end of the century (Hayhoe et al. 2018 in Kearl and Vogel 2023). Modeled changes include reduced regional snowpack, reduced summer water supply, a greater frequency and duration of extreme weather events including flooding and heat waves (Mauger et al. 2015). Climate change is projected to strain critical areas and the functions they provide; this poses a challenge for natural resource management (Mote et al. 2003; Dalton et al. 2013).

Climate change studies and modelling tools continue to provide information about what changes to expect globally and in the Pacific Northwest. However, climate change is a complex issue and BAS-based guidance on how best to manage critical areas in a changing environment continues to be developed. This BAS review addresses known climate change issues affecting each type of critical area and BAS-based recommendations to support resiliency in a changing climate.

1.4 Report Structure

This report features a section for each of the critical area types subject to regulation under the GMA. Each of the five critical area types in this report covers the following topics.

- Definition/description of the critical area;
- Functions and values provided by the critical area; and
- BAS-based protection measures, including resiliency strategies related to climate change.
    - Note: This section focuses on BAS-based guidance that is not already incorporated in the current City regulations under the Sammamish Unified Development Code, Chapter 21.03 Environment and Sustainability.

2 Critical Aquifer Recharge Areas

2.1 Definition

WAC 365-190-030 describes critical aquifer recharge areas (CARA) as,

"Critical aquifer recharge areas' are areas with a critical recharging effect on aquifers used for potable water, including areas where an aquifer that is a source of drinking water is vulnerable to contamination that would affect the potability of the water, or is susceptible to reduced recharge."

Aquifers are geologic formations that readily transmit water to wells or springs. Recharge of an aquifer usually occurs when water infiltrates the ground and flows to an unconfined aquifer. Aquifers can be either confined or unconfined. An unconfined aquifer is one in which the upper water surface elevation is the water table, with no significant aquitard (a geologic formation that does not readily transmit water) or aquiclude (a geologic formation that does not allow for the transmission of water) between the water and the ground surface. A confined aquifer is a deeper aquifer separated from the surface by an aquitard or aquiclude and is often under geostatic or hydraulic pressure, typically with increasing hydraulic heads with depth.

Groundwater recharge areas are characterized by decreasing hydraulic head with depth (direction of groundwater movement is downward). Local water-table aquifers are often relatively shallow (less than 100 feet below land surface) and unconfined. Regional aquifers are often deeper, semi-confined or confined, with recharge areas extending beyond jurisdictional boundaries.

One of the primary sources for potable water is from an aquifer. An aquifer is considered to be used for potable water if/when:

- It is being used for existing wells;
- It is in the identified protection area for an existing well;
- It is a sole-source aquifer;
- It is planned to be used for potable water in the future; or
- It is otherwise identified as an important water supply.

2.2 Functions and Values

The 2021 Washington State Department of Ecology (ECY) publication titled *Draft Critical Aquifer Recharge Areas Guidance* (#05-10-028) states that the functions and values of CARAs "are to provide the public with clean, safe, and available drinking water."

Aquifers play a pivotal role as sources of potable water as well as provide surface water flows, wetland recharge, and some attenuation of flood flows. Surface waters and groundwater are often interconnected when groundwater is the source for low flows in streams during hotter and drier periods, or the sole source for springs and wetland inflows. During dry periods a stream or wetland may be a groundwater discharge area and during periods of higher precipitation may be a groundwater recharge area. Under some conditions, this surface and groundwater continuity can attenuate surface water flows following storm events. Groundwater conditions can also influence geologic hazards, including landslide hazards and erosion hazards.

2.2.1 Water Quality

While aquifer recharge areas serve to replenish groundwater supplies, they can also serve as a conduit for the introduction of contaminants to groundwater. Aquifer susceptibility results from conditions in which water and pollutants can travel from the surface through the ground to reach the underlying aquifer. A shallow, unconfined aquifer in a gravel- substrate would be more susceptible to contamination than a deep, confined aquifer overlain by dense glacial till. Contamination loading potential refers to the quantity and types of pollutants present in the area, how they are handled, and the likelihood that they may reach a water source. The susceptibility of the aquifer and the contamination loading potential, or source loading (WDOH 2017, EPA 1995) are the two main parameters related to the overall risk of groundwater contamination or the vulnerability of the aquifer. A highly susceptible aquifer may have a low vulnerability if the land use within the area is primarily open space. Likewise, an industrial site with multiple leaking storage containers may not create significant vulnerability if it is separated from the nearest aquifer by several hundred feet of dense, glacially compressed clay.

Three key factors that can be used to assess the susceptibility of an aquifer (Morgan 2005) include:

1. The overall permeability of the vadose zone (the unsaturated material between the aquifer and the ground surface, through which any contaminants would need to pass to reach the aquifer)
2. The thickness of the vadose zone or depth to the aquifer,
3. The amount of recharge available.

Soil and surficial geology mapping can help estimate the permeability of the vadose zone while examining well logs within the vicinity of the study area can help determine the depth to an aquifer.

2.2.2 Water Quantity

Surface water and groundwater are often interconnected and can influence one another. Maintaining groundwater storage within an aquifer may support both pump volumes for potable water uses and water discharge for some landscape-scale habitat functions.

The water stored in aquifers is replenished by recharge and reduced by discharge. Aquifer recharge may come from rainfall, snowmelt, or seepage from lakes, rivers, streams or wetlands. Aquifer discharge may occur in seeps, springs, or wetlands, streams, lakes, estuaries, and shorelines. Wells are also considered an aquifer discharge.

Groundwater movement is driven, in large part, by gravity. An aquifer recharge area is typically at a higher elevation than its discharge area, therefore higher elevations tend to be recharge areas and lower elevations tend to be discharge areas. However, in some instances the subsurface conditions result in groundwater flow that does not reflect surface topography (Discoll 1986).

While changes in groundwater storage reflects movement of water, the amount of available water in an aquifer is a balance between recharge, storage, and discharge, which can be impacted by land use and development. Replacing forests with buildings, roads, driveways, lawns, and even pastures typically reduce recharge to underlying aquifers to varying extents, while increasing runoff to streams which, in turn, can lead to flooding and bank erosion. Some land uses can increase recharge rates. If homes in an area receive water from a river or lake and discharge that water into septic systems, the result can be an increase in recharge to the underlying aquifer, however this recharge water has potential for introducing contaminants such as household waste and yard chemicals (Dunne and Leopold 1978, Winter et al. 1998).

2.3 Protection Strategies

The City of Sammamish has had a water quality and flow monitoring program since 1999 for streams, rivers and other water bodies. More information about the history and the parameters of this water quality monitoring program can be found in the corresponding Existing Conditions Report. These studies, which are in cooperation with King County, are used to determine if the city's water bodies meet the state water quality standards and help to establish baseline conditions, ensure safe water for recreational activities, and monitor ecological changes. Measurements, including streamflow and water temperature, are collected from hydrology gauges in streams as well as from rainfall (City of Sammamish, n.d.). Streamflow, rainfall, and water quality data are used to monitor groundwater recharge and discharge. Water quality data from streams are used to assess groundwater discharge conditions during low flow periods and potential impacts due to groundwater recharge during high flow periods. Water temperature has a direct impact on the health of aquatic species and monitoring can help predict ecological changes and trends.

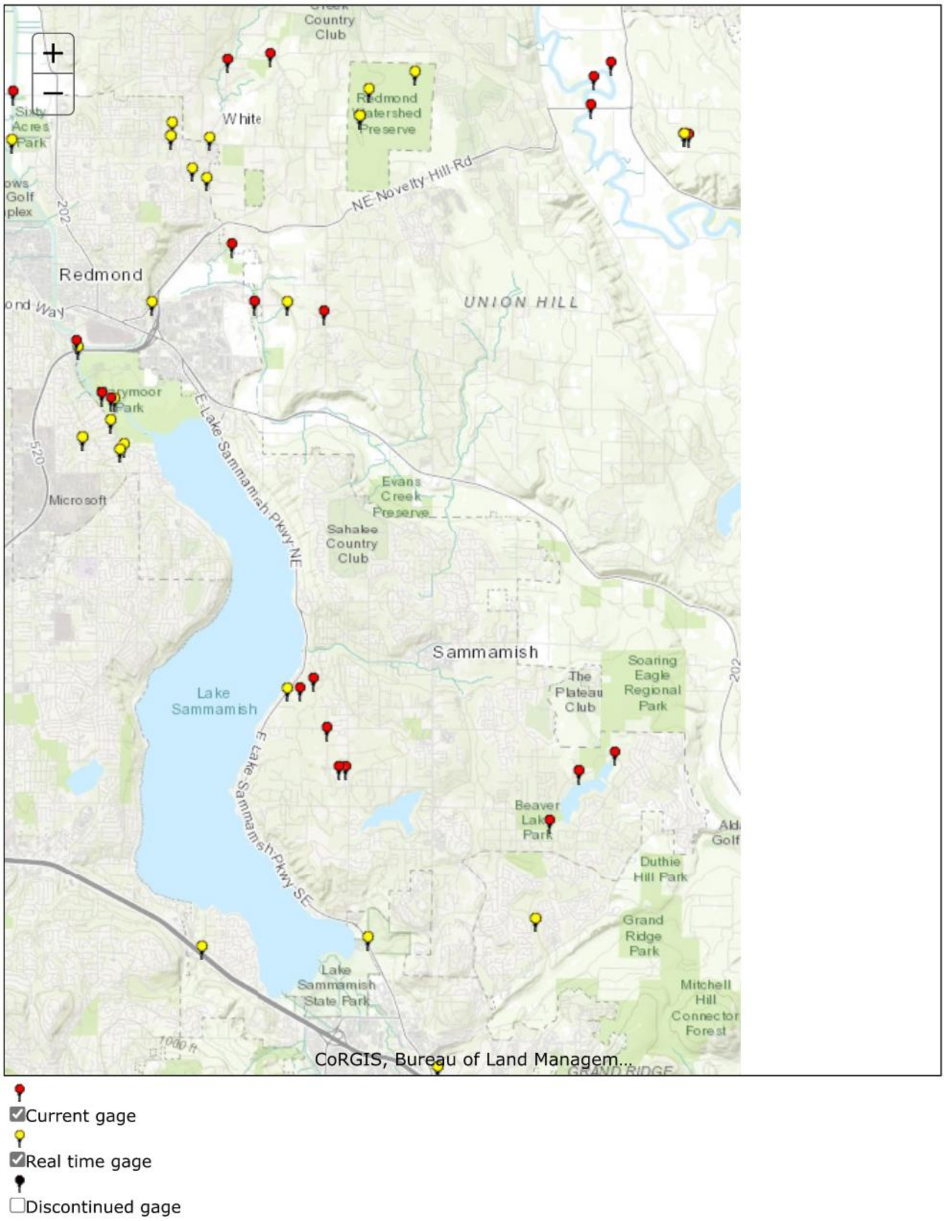

Figure 1. King County Water Quality Gauging Stations.

Citizens of Sammamish have also been given the opportunity to engage and participate in helping maintain water quality in the region by collecting water samples through the King County Small Lakes Program. This program allows volunteers to collect data on water level, precipitation, temperature, and water clarity which is then used to gauge the overall lake health and predict harmful algal blooms (City of Sammamish, n.d.).

King County, under an agreement with the City of Sammamish, performs a biweekly fecal coliform bacteria test at local swimming beaches, including Beaver Lake, Pine Lake, and Sammamish Landing, to ensure water quality conducive to this type of recreational use (City of Sammamish, n.d.).

Certain regulations have been put into place at the Federal, State, and local levels to help protect groundwater sources. A few of these regulations include (SPWSD, 2018);

Federal

- Safe Drinking Water Act
- Endangered Species Act
- Clean Water Act (Corps of Engineers permits for any work within wetland areas)

State

- Title 57 of the Revised Code of Washington
- Rules and regulations of the State Department of Ecology (ECY)
- Rules and regulations of the State Department of Health
- Coordinated Water System Plan of the East King County Regional Water Association
- City of Sammamish
- City of Sammamish Comprehensive Plan
- Development/Building Permits
- Right-of-Way Permits
- Fire Marshall Requirements
- Sammamish Fire Department & KCFD 10
- District Board of Commissioners Resolutions

Identifying and protecting CARAs through regulations and educational community outreach programs are the key protection strategies for CARAs. Current 2021 Ecology (ECY) CARA Guidance recommends the following eight steps to characterize and protect CARAs in a local community:

1. *Identify where groundwater resources are located.*
2. *Analyze the susceptibility of the natural setting where groundwater occurs.*
3. *Inventory existing potential sources of groundwater contamination.*
4. *Classify the relative vulnerability of groundwater to contamination events.*
5. *Designate areas that are most at risk to contamination events.*
6. *Protect by minimizing activities and conditions that pose contamination risks.*
7. *Ensure that contamination prevention plans and best management practices implemented and followed, including application of BMPs in the Stormwater Management and Site Development Manual for new developments in aquifer recharge areas. Review BMPs for infiltration designs with water quality treatment. Stormwater control usually affects the vadose zone and seasonal*

water tables with low risk to deeper water supply aquifers. Some exceptions are those glacial outwash plains with extensive deposits of coarse gravels near the surface.

8. *Manage groundwater withdrawals and recharge impacts to:*
9. *Maintain availability for drinking water sources.*
10. *Maintain stream base flow from groundwater to support in-stream flows, especially for salmon-bearing streams*.

Ecology Publication 05-10-028, Revised March 2021 provides detailed guidance on completing the above-mentioned eight steps (ECY, 2021a).

The Sammamish Plateau Water and Sewer District recognizes the importance of the City's groundwater resources and calls out specific actions the district is willing to take in order to accomplish protecting and preserving this resource. This includes (SPWSD, 2018);

1. Engage in proactive aquifer and water quality monitoring,
2. Maintain data on groundwater levels within the aquifers,
3. Monitor the water quality background of raw groundwater,
4. Be an advocate for groundwater interests and sustainability with land use and stormwater management agencies,
5. Monitor the codes and policies of the local land use agencies, and collaborate with those agencies on codes and initiatives which provide long term aquifer protection,
6. Collaborate with other water purveyors to advance city, county and state regulations and policies intended to protect groundwater and the aquifer from adverse impacts of development, stormwater management, and reclaimed water,
7. Be transparent and include regular outreach to inform customers, and
8. Engage its customers to solicit feedback and conservation regarding water quality.

2.4 Climate Impacts and Mitigation

Like other critical areas, CARAs can be impacted by changing climatic conditions. Changes to surface water flows will alter timing, frequency, and duration of surface water recharge which is expected to alter hydrologic patterns. Changes to surface and groundwater quality and quantity are dependent on regional trends and conditions and are summarized below.

- Hotter dryer summers will reduce surface saturation during the growing season. This is likely to reduce wetland areas and the groundwater recharge they provide.
- Changes to seasonal precipitation patterns may reduce groundwater recharge which in turn could reduce streams flows that are supported, in part, by groundwater.
- Wildfires will bring more particulates into the environment that settle onto surface water affecting water quality.

- Projected increases in winter runoff may overwhelm stormwater treatment facilities flushing contaminants into local streams and wetlands.

2.4.1 **Climate Change Stressors**

Climate change alterations in precipitation are projected to include earlier peak stream flows, increased frequency and extent of flooding, and reduced summer flows (Mauger 2015). However, groundwater may be more resilient under climate change stressors relative to surface water resources (U.S. EPA n.d.). Ecology notes in the Critical Aquifer Recharge Areas Guidance draft comment and response summary that groundwater impacts may occur with climate change. The primary stressors noted are changes in the timing and amount of groundwater recharge, and increased pressure to use groundwater as surface water conditions change. Ecology recommends focusing on water conservation (ECY 2021a) to address these stressors.

Other stressors on CARAs that may require further study include reclaimed water use and temporary construction dewatering. Ecology recommends that jurisdictions conduct a multi-year infiltration study to monitor use of reclaimed water. Another challenge presented by climate change is protecting CARAs from impacts due to increased intensity in land uses as urban areas see an increase in population. (ECY 2021a) The increase in land use intensity can exacerbate the effects of multi-year droughts which increase reliance on groundwater sources, lead to lower groundwater levels, and aquifer depletion. (Asinas, et al. 2022).

2.4.2 Resiliency Strategies

- Manage stormwater to maintain groundwater recharge in CARAs. Utilize 20-year planning horizon to manage supply and demand given climate trends and projections (Asinas et al 2022).
- Adaptive management of stormwater has the potential to better mimic natural systems and mitigate some of the functions lost elsewhere in the landscape due to changes in surface and groundwater inputs. For example, the use of roadside bioswales may be expanded. Stormwater treatment capacity may be increased as needed to protect water quality and manage water quantity.
- Planning for increased flooding can reduce the likelihood of contaminated runoff events.
- Preserve open space and restrict or condition high intensity land uses away from CARAs.
- If necessary, strengthen regulatory protection of CARAs. For example, the City may review CARA mapping, restrict or condition high intensity land uses with impervious surfaces that may reduce groundwater recharge or generate stormwater runoff, and prioritize protection of those areas. If stormwater from a high-intensity land use is proposed to be infiltrated on-site, the stormwater management plan should be reviewed for potential impacts to CARAs. The City can reduce the risk of groundwater contamination by prohibiting land uses that are high risk within

high priority areas. Public outreach education on best management practices (BMPs) for spills and leaks can also be improved.

- Continue to protect CARAs by maintaining updated CARA maps and classifications.
- Include a GIS map layer for CARAs within the Sammamish Property Tool. Review regulatory requirements for reclaimed water use and temporary dewatering during construction to ensure adequate protections are in place. This may involve additional City-specific studies and compliance with the Washington Department of Ecology (ECY).
- Continue to modify public outreach efforts to educate residents about best practices in CARAs and promote water conservation and water use efficiency programs.
- Promote and incentivize low impact development, specifically infiltration of clean runoff to support aquifer recharge.
- Balance growth and development with preservation and restoration of open spaces and native vegetation tracts.

3 Fish and Wildlife Habitat Conservation Areas

3.1 Definition

FWHCA are managed to maintain populations of species in suitable habitats within their natural geographic distribution so that the habitat available is sufficient to support viable populations over the long term and isolated subpopulations are not created.

City of Sammamish

Fish and Wildlife Habitat Conservation Areas (FWHCA) are defined as critical habitat and species federally and/or state listed as endangered, threatened, or sensitive. FWHCA also includes wetlands, streams and lakes, state natural area preserves, natural areas managed by the state Department of Natural Resources, and fish and wildlife habitat corridors (SMC 21.04.040.B.134).

Priority Habitats and Species

WDFW lists priority habitats and species (PHS) by county. City of Sammamish is located within King County. And though some of these species may not be present in Sammamish, any of the listed species below have a higher likelihood to be present within the King County area. Below is a summary of potential priority habitats and species present in City of Sammamish based on the WDFW King County Distribution PHS list. As WDFW notes, habitats and species can change over time as distributions expand or contract.

The City of Sammamish includes habitat types that are known to be used or could potentially be used by species of interest, including those species with State or federal status and WDFW priority species. A current list of priority habitats in King County is in the table below.

Table 1. Priority Habitats presumed present in Sammamish (source: WDFW PHS Distribution by County)

Terrestrial Habitats
Biodiversity areas and corridors
Herbaceous balds
Old-growth/mature forest
Oregon white oak woodlands
Westside prairie
Riparian
Aquatic Habitats
Freshwater wetlands & fresh deepwater
Instream
Puget Sound nearshore
Habitat Features
Caves
Cliffs
Snags and Logs
Talus

Table 2. Fish Priority Species List with state- and federal ESA-listings noted, limited to species with the potential to occur in the City of Sammamish (source: WDFW PHS Distribution by County).

	Common Name	State Status	Federal Status
Fish	Pacific lamprey		
	River lamprey	C	
	White sturgeon		
	Olympic midminnow	S	
	Bull trout/Dolly Varden	C	T
	Chinook salmon		T (Upper Columbia Spring run is Endangered)
	Chum salmon		T
	Coastal Res/Searun cutthroat		
	Coho salmon		T – Lower Columbia
	Kokanee		
	Pink salmon		
	Pygmy whitefish	S	
	Ranbow trout/Steelhead/Inland Redband trout	C	T
	Sockeye salmon		
Birds	Common loon	S	
	Marbled murrelet	E	T
	Western grebe	C	
	Great blue heron		
	Western high arctic brandt		
	W WA nonbreeding concentrations of: Loons, Grebes, Cormorants, Fulmar, Shearwaters, Storm-petrels, Alcids		
	W WA breeding concentrations of: Cormorants, Storm-petrels, Terns, Alcids		
	Cavity -nesting ducks: wood ducks, Barrow's Goldeneye, Common goldeneye, Bufflehead, Hooded merganser		
	W WA nonbreeding concentrations of: Barrow's Goldeneye, Common goldeneye, Bufflehead		
	Harlequin duck		
	Trumpeter swan		
	Tundra swan		
	Waterfowl concentrations		
	Golden eagle	C	
	Northern Goshawk	C	

	Sooty grouse		
	W WA nonbreeding concentrations of: Charadridae, Scolopacidae, Phalaropodidae		
	Band-tailed pigeon		
	Yellow-billed cuckoo	E	T
	Northern spotted owl	E	T
	Vault's swift		
	Black-backed woodpecker	C	
	Oregon Vesper sparrow	E	
Mammals	Roosting concentrations of: Big brown bat, Nyotis bats, Pallid bat		
	Townsend's big-eared bat	C	
	Fisher	E	
	Columbian black-tailed deer		
	Oregon spotted frog	E	T
Amphibians	Western toad	C	
	Oregon spotted frog	E	T
Reptile	Northwestern pond turtle (formerly Western pond turtle)	E	
Invertebrates	Blue-gray taildropper	C	
	Pacific clubtail	C	
	Beller's ground beetle	C	
	Hatch's click beetle	C	
	Western bumble bee	C	C
	Johnson's hairstreak	C	
	Valley silverspot	C	

Legend: C=Candidate species, E = Endangered, S=Sensitive species, T = Threatened.

3.2 Functions and Values

The critical areas and associated habitats of flora and fauna regulated as FWHCAs are interdependent. Natural disturbances, including floods, landslides, and channel migration, are part of temporal and spatial dynamics that supports formation of habitat niches and associated ecological diversity (Naiman, 1993). Land use can significantly alter the frequency and intensity of disturbance events (Nakamura, 1993); such events may be more or less common.

3.2.1 Ecosystem Processes

3.2.1.1 *Microclimate*

Forest canopy and riparian vegetation contribute to reduced stream temperatures and improved microclimate conditions, which are closely tied to each other. Factors influencing water temperature and microclimate include shade, orientation, relative humidity, ambient air temperature, wind, channel dimensions, groundwater, and overhead cover. Significant increases in maximum stream temperatures has been documented in association with the removal of riparian vegetation (Murray, 2000) (Moore, 2005) (Gomi T. R., 2006).

Salmon and other native freshwater fish require cool waters (55-68°F) for migrating, rearing, spawning, incubation, and emergence (EPA, EPA Region 10 guidance for Pacific Northwest state and tribal temperature water quality standards, 2003). Thermal tolerances differ by species; coho salmon prefer the coolest temperatures, whereas steelhead can tolerate higher temperatures. Riparian microclimate affects many ecological processes and functions, including plant growth, decomposition, nutrient cycling, succession, productivity, migration and dispersal of flying insects, soil microbe activity, and fish and amphibian habitat (Brosofske, 1997). Amphibians have narrow thermal tolerances, and they are particularly influenced by changes in microclimate conditions (Bury, 2008).

Several studies have documented significant increases in maximum stream temperatures associated with the removal of riparian vegetation (Beschta, 1987) (Murray, 2000) (Moore, 2005) (Gomi T. R., 2006).

A number of studies have considered the extent to which different riparian zone widths modulate stream temperature. In headwater streams in British Columbia, 10 m (33 ft) riparian zones generally minimized effects to stream temperature from timber harvest, although maximum daily temperatures reached 3.6°F higher than control streams (Gomi T. R., 2006). A comparative study of 40 small streams in the Olympic Peninsula found that mean daily maximum temperatures were 2.4°C higher in logged compared to unlogged watersheds, and that logged watersheds had greater diurnal fluctuations in water temperatures (Pollock et al. 2009). Another study of streams in Washington found that stream temperatures were most closely correlated with vegetation parameters associated with the riparian area, such as total leaf area and tree height, and that the effect of buffer width was less significant, particularly for buffers larger than 30 m (98 ft) (Sridhar, 2004). These findings are consistent with an earlier study relating angular canopy density, a proxy for shading, to riparian buffer width; which found that the correlation between shade and riparian buffer width increases up to around 30 m (98 ft) (Beschta, 1987). Therefore, for buffers less than 30 m (98 ft), buffer width is expected to be more closely related to shading and stream temperatures than buffers over 30 m (98 ft).

Riparian buffers necessary to maintain forest microclimate are controlled by edge effects, which tend to extend well into forested areas adjacent to clearings. However, riparian buffers ranging from 10-45 meters in width may minimize microclimate effects related to light, soil, and air temperatures. A study of small streams in Western Washington indicated that buffers greater than 45 m (147 ft) wide are generally sufficient to protect riparian microclimate in streams (Brosofske, 1997).

3.2.1.2 *Water Quality*

Water quality is characterized by several physical, chemical, and biological factors, including suspended sediment, nutrients, metals, pathogens, and other pollutants. Water quality characteristics are controlled by upslope, as well as riparian conditions. This section discusses how water quality is maintained under natural conditions. Water temperature is also a component of water quality, which is addressed separately.

When development results in reduced infiltration and increased surface flows, sediment and contaminants are transported more directly to receiving bodies without interfacing with natural soil filtration and flow attenuation processes. Because of this, urban areas tend to contribute a disproportionate amount of sediment and contaminants to receiving waters relative to the percentage of urbanized area within the watershed (Soranno, 1996). Heavy metals, bacterial pathogens, as well as PCBs, hydrocarbons, and endocrine-disrupting chemicals are aquatic contaminants that are commonly associated with urban and agricultural land uses.

The full suite of sublethal and indirect effects of these contaminants and combinations of contaminants on aquatic organisms is not fully understood (Fleeger, 2003). Likely some contaminants with potentially severe repercussions for fish and wildlife have yet to be identified. For example, research in the Puget Sound region had identified mature coho salmon that return to urban creeks and die prior to spawning, a condition called pre-spawn mortality (Feist, 2011) (Scholz, 2011). After a prolonged and diligent investigation, the specific cause of the condition has been recently attributed to 6PPD-quinone, not specifically a component of tire formulation but a breakdown product of tire wear (Tian, 2020). Coho pre-spawn mortality is positively correlated with the relative proportion of roads, impervious surfaces, and commercial land cover within a basin (Feist, 2011). A model of the effects of pre-spawn mortality on coho salmon populations indicates that, depending on future rates of urbanization, localized extinction of coho salmon populations could occur within a matter of years to decades (Spromberg, 2011). Hopefully, tires can be re-formulated in time to prevent this. This finding emphasizes the significance of efforts to address both point-source and non-point-sources of contaminants in the landscape.

The following water quality subsections closely follow those provided in *Riparian Ecosystems, Volume 1: Science Synthesis and Management Implications* from WDFW (Quinn, 2020).

Sediment

Excess inputs of fine sediments into stream channels reduce habitat quality for fish, amphibians, and macroinvertebrates. Highly turbid water can impair fertilization success in spawning salmonids (Galbraith, 2006) and interfere with the respiration and reproduction amphibians (Knutson M. W., 2004). Fine sediments that settle out of the water column can smother gravel and cobble streambeds that are essential habitat for salmonid spawning and for benthic macroinvertebrates. These fine sediments fill interstitial spaces of gravel in redds, reducing the flow of oxygenated water to developing salmonid embryos and reducing egg-to-fry survival (Jensen, 2009).

Excessive sediment loads can significantly degrade water quality and, furthermore, sediments tend to serve as a transport mechanism for other pollutants, carrying attached contaminants from upland sources to the stream channel. Suspended sediment can cause gill abrasion in fish and interfere with foraging and predator avoidance (Quinn, 2020).

Sediment input to streams is supplied by bed and bank erosion, landslides, and upland erosion processes. These processes occur naturally at background levels, but are also associated with and accelerated by forest practices and development activities. Other contaminants, including heavy metals and phosphorus, readily bind to suspended clay particles, and these contaminants are often transported with fine sediment in stormwater. Excess inputs of fine sediments into a stream channel reduce habitat quality for fish, amphibians, and macroinvertebrates. Fine sediment adversely affects stream habitat by filling pools, embedding gravels, reducing gravel permeability, and increasing turbidity. In salmon-bearing streams, fine sediment fills interstitial spaces in redds, reducing the flow of oxygenated water to developing embryos and reducing egg-to-fry survival (Jensen, 2009). Similarly, embedded, low-permeability gravel substrates reduce aquatic insect production, such insects being a primary food source for juvenile salmonid fish. Higher levels of fine sediment are also correlated with lower salmonid growth rates. Highly turbid water can impair fertilization success in spawning salmonids (Galbraith, 2006) and interfere with the respiration and reproduction of amphibians (Knutson M. W., 2004).

Vegetated riparian zones help stabilize stream banks and slow and filter overland flow, and temporarily store sediment that is gradually released to both seasonal and perennial streams. Sediment filtration is also high within intermittent and ephemeral streams, presumably because of the high interface with vegetative structures and the flux in water surface elevation, which allows for sediment storage along the streambanks (Dieterich, 1998).

Upland clearing and grading can result in long-term increases in fine sediment inputs to streams (Gomi T. D., 2005) (Jackson, 2007). Numerous studies have investigated the effectiveness of varying widths of buffers at filtering sediment. These studies have typically found high sediment filtration rates in relatively narrow buffer areas (Sheridan, 1999), reviewed in Wenger 1999, reviewed in Parkyn 2004, reviewed in Yuan et al. 2009 without a significant improvement in sediment retention beyond 15 meters (Abu-Zreig, 2004).

It is significant to note, however, that field plot experiments tend to have much shorter field lengths (hillslope length contributing to drainage) than would be encountered in real-world scenarios (*i.e.*, ~5:1 ratio of field length to riparian width for a field plot compared to 70:1 ratio in NRCS guidelines). Since water velocities tend to increase with field length, field plot experiments may suggest better filtration than would be encountered under real-world conditions. Additionally, field-scale experiments generally do not account for flow convergence, which reduces sediment retention (Helmers, 2005) or for stormwater components that bypass filter strips through ditches, stormwater infrastructure, and roads (Verstaeten, 2006). Therefore, the effectiveness of filter strips at filtering sediment under real-world conditions and at the catchment scale is likely to be lower than what is reported in field plot experiments.

Additionally, many studies on sediment retention in riparian zones consider sediment retention from one storm event, rather than accounting for sediment accumulation over time. Two studies used Cesium-137 to track the location of sediment deposition over many years (Wenger, 1999). Together these studies suggest that riparian zones from 30-100 m (98-328 ft) or more may be necessary to provide long-term sediment retention, and that studies of short-term sediment retention underestimate the riparian zone width needed for ongoing sediment filtration.

In addition to width, the slope, vegetation density, and sediment composition of a riparian area have significant bearing on sediment filtration potential (Jin, 2001). A recent model of sediment retention in riparian zones found that a grass riparian zone as small as 4 m (13 ft) could trap up to 100% of sediment under specific conditions (2% hillslope over fine sandy loam soil), whereas a 30 m (98 ft) grass riparian zone would retain less than 30% of sediment over silty clay loam soil on a 10% hillslope (Dosskey M. M., 2008) (Figure 1) . This study exemplifies the effects that soil type and hillslope have on sediment retention.

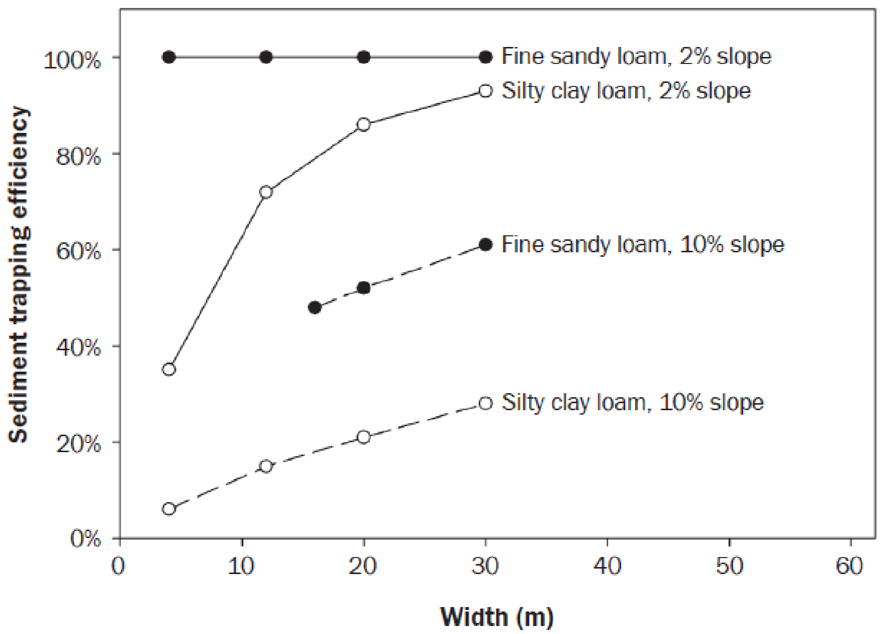

Figure 2. – Sediment trapping efficiency related to soil type, slope, and buffer width. (Figure from (Dosskey M. M., 2008)).

Multiple studies have found that larger particles tend to settle out within the first 3-6 m (10-20 ft) of the riparian zone, but finer particles that tend to degrade instream habitat, such as silt and clay, need a larger riparian zone, ranging from 15-120 m (49-394 ft), for significant retention (Parkyn, 2004).

Vegetative composition within the buffer also affects sediment retention. Vegetation tends to become more effective at sediment and nutrient filtration several years after establishment for both grass and forested buffers (Dosskey, 2007). Thin-stemmed grasses may become overwhelmed by overland flow while dense, rigid-stemmed vegetation provides improved sediment filtration that is expected to continue to function better over successive storm events (Blanco-Canqui, 2004) (Yuan, 2009).

Nutrients

Established vegetation in a dense composition can provide effective sediment and nutrient filtration (Dosskey M. K., 2007). Riparian zones can also reduce nitrogen pollution through nutrient uptake, assimilation by vegetation, and denitrification (Sobota, 2012). In excess concentrations, nitrogen and phosphorus can lead to poor water quality conditions, including reduced dissolved oxygen rates, increased pH, and eutrophication (Mayer P. S., 2005) (Mayer P. S., 2007). Excessive amounts of nitrogen and phosphorus speed up eutrophication and algal blooms in receiving waters, which can deplete the dissolved oxygen in the water and result in poor water quality and fish kills (Mayer P. S., 2005) (Dethier, 2006) (Heisler, 2008).

Riparian zones can reduce nitrogen pollution through nutrient uptake, assimilation by vegetation, and through denitrification (Sobota, 2012). The rate of nitrogen removal from runoff varies considerably depending on local conditions, including soil composition, surface versus subsurface flow, riparian zone width, riparian composition, and climate factors (Mayer P. S., 2005) (Bernal, 2007) (Mayer P. S., 2007). Nutrient assimilation is also dependent on the location of vegetation relative to the nitrogen source, the flow path of surface runoff, and position in the landscape (Baker, 2006).

Nutrients enter waterways through channelized runoff, groundwater flow, and overland flow. Nitrogen loading is often associated with agricultural activities, whereas low density residential development has been found to result in nitrate levels comparable to a forested basin (Poor, 2007).

Mayer et al. (2005, 2007) found that there was little relationship between riparian zone width and removal of *subsurface* nitrates. Subsurface nitrates were removed effectively regardless of riparian zone width. However, nitrate removal from *surface* runoff *was* related to riparian zone width, where 50%, 75%, and 90% surface nitrate removal was achieved at widths of 27 m (88 ft), 81 m (266 ft), and 131 m (430 ft) respectively (Mayer P. S., 2007). This suggests that surface water infiltration in the riparian zone should be a priority to promote effective nutrient filtration. Where soils are poorly drained and infiltration capacity is limited, the effectiveness of nutrient removal in riparian buffers may also be limited (Wigington, 2003).

The size and species composition of the riparian zone buffer also affects the efficiency of nutrient removal, but studies are conflicting as to whether grass, wetland, herbaceous, or forested buffers are most effective at removing nutrients (reviewed in Polykov 2005). Where nitrogen-fixing species predominate, such as red alder, these buffers tend to have higher soil nitrate concentrations (Monohan 2004).

Removal of phosphorus by riparian buffers is dependent on the form of phosphorus entering the buffer. Whereas phosphorus that is adsorbed by soil particles is effectively removed through sediment retention within a buffer, the retention of soluble phosphorus relies on infiltration and uptake by plants (Polyakov et al. 2005). One long-term study found that phosphorus uptake was directly proportional to the plant biomass production and root area over the four-year study period (Kelly et al. 2007). If a riparian buffer becomes saturated with phosphorus, its capacity for soluble phosphorus removal will be more limited (Polyakov et al. 2005). Another long-term study found that following a 15-year establishment period, a 40-meter (131 ft) wide, three-zoned buffer reduced particulate phosphorus by 22 percent, but dissolved phosphorus exiting the buffer was 26 percent higher than the water entering the buffer, so the buffer resulted in no net effect on phosphorus (Newbold et al. 2010).

In summary, most riparian zones reduce subsurface nutrient loading, but extensive distances are needed to reduce nutrients in surface runoff. Filtration capacity decreases with increasing loads (Mayer et al. 2005), so best management practices across the landscape that reduce nutrient loading will improve riparian function.

Metals

Although most metals can be toxic at high concentrations, cadmium, mercury, copper, zinc, and lead are particularly toxic even at low concentrations. Chronic and acute exposure to heavy metals have been found to impair, injure, and kill to aquatic plants, invertebrates, fish, and particularly salmonids (Grant, 2002) (Dethier, 2006) (Hecht, 2007) (McIntyre J. D., 2008) (McIntyre J. D., 2012). A review of contaminant effects on aquatic organisms summarized the factors affecting the toxicity of metals as follows:

- Duration and concentration of exposure
- The form of the metal at the time of exposure
- Synergistic, additive, or antagonistic interactions of co-occurring contaminants
- Species sensitivity
- Life stage
- Physiological ability to detoxify and/or excrete the metal

Metals are typically transported to the aquatic environment through fossil fuel combustion, industrial emissions, municipal wastewater discharge, and surface runoff. In general, heavy metals and hydrocarbons (e.g. leaked motor oil, polycyclic aromatic hydrocarbons) are found in road runoff, and these contaminants can reach the City's streams directly through existing stormwater systems. Stormwater systems that circumvent buffers limit the opportunity to filter runoff through adjoining soils and vegetation. Accordingly, stream buffers are typically underutilized for treatment of metals, hydrocarbons, and other pollutants found in typical stormwater runoff.

Copper brake pad dust has also been linked to chronically depressed Chinook salmon populations (EPA, 2007). The U.S. EPA is working to reduce the use of copper and other heavy metals in motor vehicle brake pads through the *Copper-Free Brake Initiative* (EPA, Copper-free brake initiative, 2015).

Pathogens

While not necessarily a problem for fish and other wildlife, waterborne pathogens associated with human and animal wastes are a concern for direct and indirect human exposure. Although pathogens include a suite of bacteria and viruses, fecal coliform bacteria, specifically E. coli, is typically used as an indicator of the possible or presumed presence of these pathogens. Fecal pollution tends to be positively correlated with human population densities and impervious surface coverage (Glasoe, 2004). The main sources of fecal pollutants include municipal sewage systems, on-site sewage systems, stormwater runoff, marinas and boaters, farm animals, pets, and wildlife (Glasoe, 2004). As municipal wastewater systems have improved treatment quality and capacity in recent years, increasingly, non-point source (septic systems, stormwater, wildlife, and pets) pollution is responsible for fecal contaminants in surface water (Glasoe, 2004).

Herbicides and Pesticides

Commonly used herbicides, pesticides, and other pollutants may also affect aquatic communities, and the acute and chronic effects of these chemicals or combinations of chemicals are not always well understood. Additionally, effects documented in the laboratory may differ significantly from effects identified in a field setting (Relyea, 2005) (Thompson, 2004). Despite our limited understanding, the effects of these chemicals may be long-lasting, as has been observed for legacy pollutants such as polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) in salmon, seabirds, and marine mammals in Puget Sound (Calambokidis, 1984) (O'Neill, 1998) (Ross, 2000) (Wahl, 2005) (Grant, 2002).

Herbicides and pesticides may reach aquatic systems through a number of pathways, including surface runoff, erosion, subsurface drains, groundwater leaching, and spray drift. Narrow hedgerows have been found to limit 82-97 percent of the aerial drift of pesticides adjacent to a stream (Lazzaro, 2008). In runoff, herbicide retention in a buffer is dependent on the percentage of runoff that infiltrates the soil (Misra, 1996). A study of herbicides in simulated runoff found that 6-meter-wide vegetated buffers were sufficient to reduce herbicide concentration exiting the buffer to zero (Otto, 2008). A meta-analysis found that filtration effectiveness increased logarithmically from 0.5 m to an asymptote at approximately 18 m (Zhang, 2010). In summary, relatively narrow vegetated buffers may be effective in limiting herbicides and pesticides from reaching aquatic habitats in surface runoff, erosion, and spray drift; however, transport via subsurface drainage and leaching are not affected by riparian buffers, and these processes are best managed through the use of best management practices in herbicide and pesticide applications to avoid contaminating groundwater (Reichenberger, 2007).

Pharmaceuticals

Pharmaceuticals are another class of contaminants, the effects of which remain poorly understood. Many commonly used pharmaceuticals are found in wastewater, particularly around more urban areas (Long, 2013). Many common pharmaceuticals have endocrine-disrupting properties, which can affect fertility and development in non-target aquatic species (Caliman, 2009). The existing and potential population-scale effects of these chemicals in the environment are not yet well-understood (Mills, 2005) (Caliman, 2009).

3.2.1.3 *Stream bank stabilization*

Vegetated riparian zones help to stabilize stream banks. Riparian vegetation helps provide bank stabilization through a complex of tree roots, brush, and soil/rock. Woody vegetation tends to provide greater bank stability than herbaceous vegetation because woody vegetation has larger roots that extend deeper into the streambank (Wynn, 2006).

Bank stabilization functions are at a higher risk of degradation in urbanized watersheds. As with sediment reduction, the streambank stabilization functions of vegetation increase with buffer width out to approximately 80 to 100 feet; after this point, disproportionately large increases are needed to improve riparian function (Castelle, 1998).

3.2.1.4 *Large woody debris / littoral inputs*

Large woody debris (LWD) plays a significant role in geomorphic functions such as directing stream flows to shape the channel form and influencing sediment storage, transport, and deposition rates. The many effects of large wood create a variety of channel morphologies—dam pools, plunge pools, riffles, glides, undercut banks, and side channels – which provide a diversity of aquatic habitats (Quinn, 2020). Instream large wood provides fish with cover from predators, and by increasing a water body's effective space, wood structures may increase fish densities (Bisson et al. 1987). Large wood provides the downward scour necessary for streams to create pools, and it provides protective cover for fish in those pools. Pools provide rearing habitat for juvenile fish and resting space for adults.

The collection of large woody debris and the subsequent entrapment of smaller branches, limbs, leaves and other material reduce flow conveyance in small streams and increase temporary flood storage (Dudley, 1998). By retaining smaller organic debris, LWD provides substrate for microbes and algae, and prey resources for macroinvertebrates (Bolton, 2001). Just as riparian areas have a more significant effect on smaller channels compared to larger channels (Vannote, 1980), the effects of LWD in small channels are particularly significant (Harmon, 1986). In small channels, LWD provides important structures in the stream, controlling rather than responding to hydrologic and sediment transport processes (Gurnell, 2002). For this reason, large wood is responsible for significant sediment storage in small channels (Nakamura, 1993) (May, 2003), thereby increasing channel stability (Quinn, 2020). The significant role of large wood for storing sediment is further revealed where wood has been experimentally removed from streams and sediment is mobilized and storage reduced (Bilby, 1987). Large wood that partially blocks flow can also help to encourage hyporheic flow through the streambed substrate (Poole, 2001) (Wondzell, 2009).

Instream large wood provides for a wider range of flow velocities, in turn resulting in a diversity of aquatic habitats – pool formation, streambed scour, sediment deposition, and channel migration (Quinn, 2020). As such, LWD plays an important role in forming complex in-water habitat structures that provide flow refugia and essential cover and improved foraging conditions for fish. Fausch and Northcote (1992) found that streams containing large amounts of LWD supported populations of juvenile cutthroat trout and coho salmon five times greater than streams within the same river system that had been cleared of LWD. Roni and Quinn (2001) found that winter densities of coho salmon, steelhead, and cutthroat trout were higher in streams where LWD had been added.

Large wood recruitment is often the result of bank erosion, windthrow, landslides, debris flows, snow avalanches, and tree mortality due to fire, ice storms, insects, and disease (Swanson, 1976) (Maser, 1988). Large woody debris can enter channels through individual trees falling into the stream, as well as through larger disturbances (Bragg, 2000). A comparison of 51 streams with varying channel form in mature forests of British Columbia found that of the approximately one-third of LWD pieces for which the source could be identified, tree mortality was the most common entry mechanism (Johnston, 2011). Streambank erosion and associated channel migration is a common method of wood recruitment in large alluvial channels (Murphy, 1989), whereas in smaller, steeper channels, wood recruitment predominantly occurs through slope instability and windthrow (May, 2003).

The probability of a tree entering the channel decreases with distance from the streambank (McDade, 1990), (Grizzel, 2000). Past research has found that most LWD originates within approximately 30 m (98 ft) of a watercourse (Murphy, 1989), (McDade, 1990), (Van Sickle, 1990), (Robison, 1990). In 90 percent of the 51 streams surveyed in British Columbia, 90 percent of the LWD at a site originated within 18 m (59 ft) of the channel (Johnston, 2011). May and Gresswell (2003) found that wood was recruited from distances farther from the stream channel in small, steep channels (80 percent from 50 m (164 ft) from the channel), compared to broad alluvial channels (80 percent from 30 m (98 ft) from the channel) because of the significance of hillslope recruitment in narrow valleys.

The likelihood of downstream transport of LWD is dependent on the length of wood relative to bankfull width of the stream (Lienkaemper, 1987). Wood that is shorter than the average bankfull width is transported more readily downstream compared to wood that is longer than the bankfull width (Lienkaemper, 1987). Therefore, large wood is rarely transported downstream from small channels less than 5 m (16 ft) in width (May, 2003).

3.2.1.5 *Beaver activity*

Beaver dams incorporate both small and large wood, and serve to slow water, retain sediment, and create pools and off channel ponds used by rearing coho salmon and cutthroat trout (Naiman, 1993), (Pollock, 2004). The removal of these structures throughout history has been linked to a significant reduction in coho salmon summer and winter rearing habitat in the nearby Stillaguamish River (Pollock, 2004). In finding 2012 c 167 § 1, the Washington legislature indicated that “beavers have historically played a significant role in maintaining the health of watersheds in the Pacific Northwest and act as key agents in riparian ecology.” They went on to state: “The benefits of active beaver populations include reduced stream sedimentation, stream temperature moderation, higher dissolved oxygen levels, overall improved water quality, increased natural water storage capabilities within watersheds, and reduced stream velocities. These benefits improve and create habitat for many other species, including endangered salmon, river otters, sandhill cranes, trumpeter swans, and other riparian and aquatic species." As such, beaver relocation can be a beneficial wildlife management practice and conditions for wild beaver release are given in RCW 77.32.585. Related to this legislation, WDFW has instigated a Beaver Relocation Program, which is described on their website.

3.2.1.6 *Urbanization and Ecosystem Processes*

As urban density continues to increase under the Growth Management Act, urban natural areas become increasingly valuable to both wildlife and humans. A growing knowledge base confirms what is best captured in the summary: "All urban areas have the potential to contribute to conservation of wildlife diversity" (Marzluff, 2008).

Habitat fragmentation is a consequence of urbanization. As land is developed, continuous tracts of native habitat are reduced to patches, which become progressively smaller and more isolated. Dale et al. (2000) found that ecologic impacts of development are often overlooked and landscape-scale changes, particularly habitat fragmentation, alter the structure and function of those ecosystems.

The performance of stream and wetland habitat functions is affected to varying degrees by the width and/or character of the surrounding buffers. Urbanization reduces wetland buffering and increases human encroachment. Disturbance vectors include noise; nighttime light; physical intrusion by equipment, people, or pets; and garbage. Each of these vectors can result in one or more of the following: disruption of essential wildlife activities, damage to native vegetation and invasion of non-native species, erosion or fill, among others. Semlitsch and Bodie (2003) found that upland areas surrounding wetlands are core habitats for many semi-aquatic species, such as amphibians and reptiles.

Cumulative impacts of direct and indirect riparian ecosystem alterations, including hydrologic changes, compromised water quality, and habitat fragmentation tend to reduce the habitat functions and values an urban wetland provides (Sheldon, 2005) (Azous, 2001).

Invasive plants and animals

Inadvertent or purposeful introduction and spread of invasive plant and animal species common to urban environments is a threat to biodiversity. Invasive species tend to be generalist that can proliferate under a wide range of conditions. They also tend to lack natural predators or competitors outside their native ecoregion. This causes displacement of native species and in some cases ultimately leads to extinction. Invasive species impact approximately half the plant and animal species listed as threatened or endangered under the U.S. Endangered Species Act (King County, n.d.).

3.2.2 **Wildlife Habitat**

Riparian ecosystems, including streams and associated riparian areas, including wetlands, provide important wildlife habitat within the landscape due to the presence of unique structures and processes. Ecological features that are linked to species richness and abundance in a landscape include structural complexity, connectivity to other ecosystems, plentiful sources of food and water, and a moist moderate microclimate (Knutson K. a., 1997). Riparian ecosystems, depending on site-specific conditions, landscape position, and surrounding land use, will have some or all of these habitat features.

These aquatic ecosystems provide habitat for a broad range of fauna including invertebrates, reptiles and amphibians, anadromous and resident fish, birds, and mammals. Aquatic invertebrates that depend on stream and wetland ecosystems are important to aquatic trophic systems or food webs (Rosenberg and Danks 1987, Wissinger 1999, both in (Sheldon, 2005)). Native frogs and salamanders require wetlands for breeding. Buffer condition, habitat interspersion, wetland hydro-period, and diameter of emerged plant stems are all important factors that impact amphibian richness and abundance (Sheldon, 2005). Wetlands with surface connections to salmon-bearing streams can provide backwater refuge for anadromous fish if they also have ponded water at least 18 inches deep, low flow conditions, and cover such as overhanging or submerged plants (Sheldon, 2005). Waterfowl rely upon riparian ecosystems for all or part of their life cycle (Kaufmann, 2012). Suitability of habitat for birds is dependent on buffer condition and width, presence of snags or other perches, corridor connections, open water, and forest canopy cover (Sheldon, 2005). Mammals typically associated with water, such as beaver and muskrat, also seek out well buffered vegetated corridors, interspersed habitat with open water, and a seasonally stable water level (Sheldon, 2005). According to a Washington Department of Fish and Wildlife (WDFW) study conducted by Knutson and Naef (1997)a predominance of terrestrial vertebrate species in Washington are dependent on streams and riparian areas, including wetlands.

3.2.2.1 *Habitat Composition and Structure*

Habitats are generally comprised of a mixtures of habitat types or plant stratum, including forested, shrub, emergent, and aquatic bed or open water. Habitat structure also varies depending on site specific characteristics such as forest canopy closure, forest age, amount of snags and large woody debris, and interspersion of vegetation types. Increased richness in structural diversity supports a greater number of habitat niches and species (Hruby 1999 in ECY 2014).

Ecosystem edge effects can occur through biotic or abiotic processes. Urbanization is the primary abiotic source of habitat patch edge area increases and associated habitat degradation. As habitat fragmentation occurs, habitat structure is impacted by site specific dynamics including habitat patch area, patch density, the amount of edge, shape complexity, and interspersion among patches (McGarigal and Marks, 1994 in Gregory et al. 2021). Habitat edge effects can alter population dynamics, influence plant and animal community structure, and facilitate the spread and establishment of invasive species (Watling and Orrock 2009).

Habitat Loss and Habitat Fragmentation

As discussed in Section 3.2.1.6 *Urbanization and Ecosystem Processes* above, habitat fragmentation is a by-product of urbanization. Habitat loss and fragmentation are among the primary drivers of wildlife declines. Carrying capacity and abundance are lowered as ecosystems are reduced to smaller patches. The species-area relationship dictates that species richness is also lower in small patches, although this is known to be influenced by patch composition and landscape context. There are numerous methods to measure the degree of fragmentation in a landscape, and spatial metrics commonly include core area, shape, proximity, contrast, and interspersion (Wang et al. 2014).

Urban developments present barriers to wildlife movement that prevent immigration and emigration among populations between individual habitat patches, particularly with roads, fences, and buildings. Insular populations have a greater probability of localized extinction due to natural stochasticity, an effect which is compounded by threats posed from urban development.

3.3 Protection Strategies

3.3.1 Riparian Management

FEMA Floodplain Habitat Assessments

In 2008, the National Marine Fisheries Service (NMFS) issued a Biological Opinion, which found that the implementation of the National Flood Insurance Program (NFIP) in the Puget Sound region jeopardized the continued existence of federally threatened salmonids and resident killer whales. As a result, NMFS established Reasonable and Prudent Alternatives to ensure that development within the Special Flood Hazard Area (100-year floodplain), floodway, Channel Migration Zone (CMZ), and riparian buffer zone do not adversely affect water quality, flood volumes, flood velocities, spawning substrate, or floodplain refugia for listed salmonids. Because the NFIP is implemented by the Federal Emergency Management Agency (FEMA) through participation by local jurisdictions that adopt and enforce floodplain management ordinances, FEMA has delegated responsibility to the local jurisdictions to ensure that development does not adversely affect listed species. Projects within FEMA-designated floodplains are required to prepare habitat assessments to ascertain their potential effects on federally-listed endangered species. In particular, floodplain storage volumes may not be decreased, nor base flood level elevations increased.

Buffers

For this narrative, clarification needs to be made between the terms “stream buffers” and “riparian management zones” (RMZs). WDFW current guidance (Rentz, 2020) for protection of riparian areas heavily emphasizes a shift in terminology from the concept of “stream buffers” to “riparian management zones” (RMZs). WDFW defines RMZ as the bounds of the riparian ecosystem; the area that has potential to provide full riparian functions (Rentz 2020). This differs from the use of “buffer(s),” as an RMZ is by definition wide enough to potentially provide full riparian function. Stream buffers are established through policy decisions and are clearly intended to protect streams but may or may not be intended to provide full riparian function or a close approximation of it.

Habitat types in Sammamish vary across the landscape. The City falls within the Puget Trough Ecoregion. This ecoregion tends to be forested except in areas cleared for agriculture or development. The Puget Trough Ecoregion is forested primarily with Douglas-fir (*Pseudotsuga menziesii*), western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*), and also includes bigleaf maple (*Acer macrophyllum*) black cottonwood (*Populus trichocarpa*) and red alder (*Alnus rubra*) along river channels more subject to disturbance. (LandScope Washington, 2022, http://www.landscope.org/washington/natural_geography/ecoregions/). The plant community and ecology of this region have important implications for how riparian buffers are established or RMZs defined.

WDFW's current recommendations for establishing RMZ widths are based primarily on a Site Potential Tree Height (SPTH) framework. WDFW defines SPTH as "…the average maximum height of the tallest dominant trees for a given site class" (Rentz 2020). Exceptions may occur where SPTH is less than 100 feet, in which case WDFW recommends assigning an RMZ width of 100 feet at a minimum based primarily on what is needed to provide adequate biofiltration and infiltration of runoff for water quality protection, but also in consideration of other habitat-related factors including shade and wood recruitment (Rentz, 2020). A 100-foot width buffer is estimated to achieve 95 percent removal of most pollutants, 85% for surface nitrogen (Rentz et al. 2020). WDFW recommends measuring RMZ widths from the outer edge of the Channel Migration Zone (CMZ), where present, or from the Ordinary High Water Mark (OHWM) where a CMZ is not present.

To apply their methodology, WDFW has developed a web-based mapping tool for use in determining SPTH in forested ecoregions of the state, such as occur in Sammamish. Where SPTH is 100 feet or more, WDFW recommends RMZ establishment within one SPTH, driven by the largest dominant tree species at any location. Acknowledging that establishing functional RMZs of these dimensions using these recommended methods may not be practical in many developed areas, WDFW recommends effective watershed management, preservation, and protection, resulting in as nearly full restoration of riparian ecosystem habitat functions as is feasible within existing constraints. WDFW RMZ establishment and management recommendations are detailed in their Riparian Ecosystems, Volume 2: Management Recommendations document (Rentz, 2020).

Below is a graphical representation of the Forest Ecosystem Management Assessment Team (FEMAT) curves, the same as or similar to that included in WDFW's recommendations for establishing the bounds of RMZs (Rentz, 2020). The curves show percentage of full function for various riparian habitat attributes with increasing distance from a stream. The WDFW recommendations show this graphic and these curves to support recommending one full SPTH for RMZ width to attain "full" riparian function. The SPTH is one point along a continuum of functional returns, with the highest rates of return on all habitat functions except root strength generally occurring within the inner buffer (Figure 2).

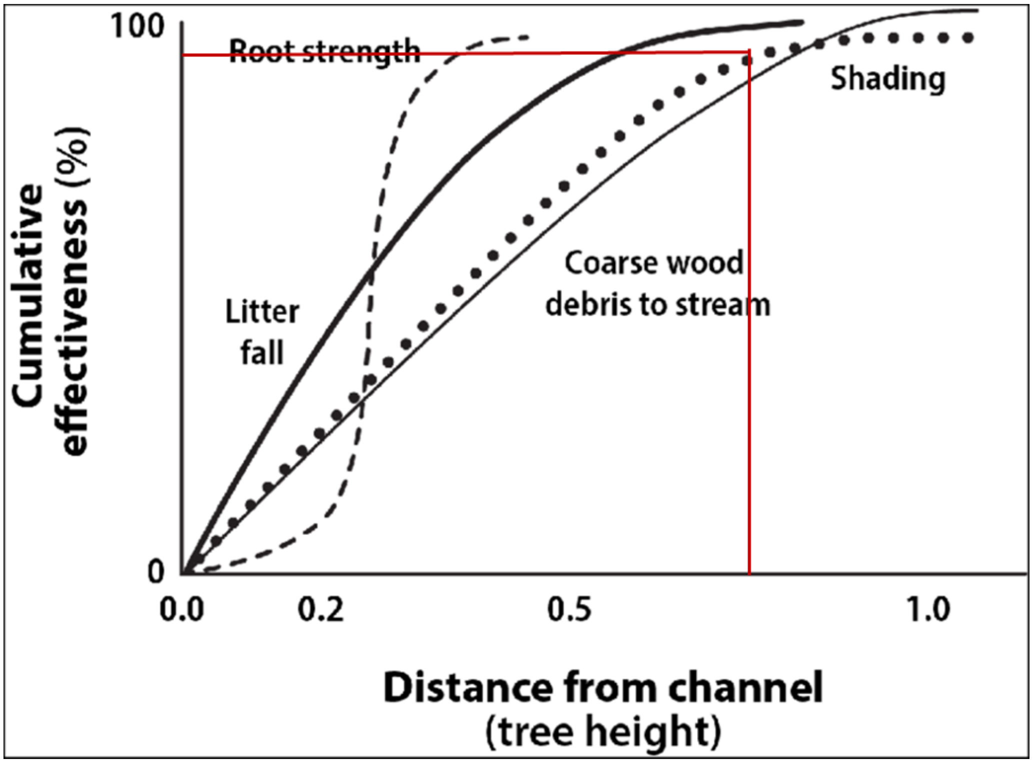

Figure 3. The "FEMAT Curves" (FEMAT 1993): Generalized conceptual model describing contributions of key riparian ecosystem functions to aquatic ecosystems as the distance from a stream channel increases. "Tree height" refers to average height of the tallest dominant tree (200 years old or greater); referred to as site-potential tree height (SPTH).

Using WDFW's on-line mapping tool yielded the following ranges of values for SPTH in feet for various dominant forest types throughout Sammamish. Douglas-fir was the predominant species, and red alder are present to some extent.

Douglas-fir	187-231 feet
Red alder	105 feet

This informal sampling indicates that the riparian buffer width in the current CAO for Type F streams (150 feet), tends to be moderately under the high end of the range for Douglas-fir. 150 feet falls above the SPTH range for red alder, but below the upper end of the ranges for Douglas-fir. As such, the current 150-foot fixed width is within the range of values expected from a custom delineation for an RMZ based buffer widths. As noted (SMC 21.03.020(AA)), Sammamish currently follows the WDFW recommendation of measuring stream buffer (or RMZ) widths) from the outer edge of the Channel Migration Zone (CMZ) where present. In those cases, effective or functional RMZ widths are often or typically wider than 150 feet as would be measured from the OHWM unless the current channel location abuts the outer CMZ boundary. Some widths determined using the SPTH mapping process are above and some below a 150-foot buffer width. Both methods result in a high level of riparian habitat protection.

Many scientific studies that examine the functions and values associated with riparian areas have been conducted in forested environments. However, there are fundamental differences between forested, agricultural, and urban areas, including land use and hydrology. Riparian studies often do not account for the contribution of engineering and public works projects, such as surface-water detention facilities, that can supplement natural riparian function in more urban settings. Thus, although stream and riparian conservation measures should be based in Best Available Science (BAS), some level of policy interpretation must be made by each local jurisdiction.

Sammamish currently assigns riparian buffers based on stream type ranging from 50-feet to 150-feet (SMC 21.03.020(AA)(1)(a)). BAS-based literature points to a range of recommended management measures and buffer considerations to help maintain habitat functions for fish and wildlife. Effective methods to reduce impacts from urbanization and manage associated runoff can include the following:

- Limiting development densities and impervious surface coverage;
- Limiting vegetation clearing and retaining forest cover;
- Concentrating impact activities, particularly roads and pollutant sources, away from watercourses;
- Limiting the total area of roads and requiring joint use of new access roads (This is tied to Public Works standards.);
- Protecting vegetation and limiting development on or near hydrologic source areas;
- Maintaining densely vegetated riparian buffers with native trees, shrubs, and groundcover species;
- Low impact development (LID);
- Municipal stormwater treatment;
- Public education.

In an analysis of riparian zone ordinances, Wenger and Fowler (2000) support using approaches that allow some flexibility in how policies are implemented on a parcel scale. Whereas variable-width policies provide greater flexibility and adaptability to address site-specific conditions, it is noted that fixed buffer widths are more easily established, require a lesser degree of scientific knowledge to implement, and generally require less time and money to administer (Castelle, 1998). Thus, although stream and riparian conservation measures should be based in Best Available Science, some level of policy interpretation must be made by a local jurisdiction.

If fixed-width buffers are implemented, buffers should be sufficiently wide to ensure that riparian buffers are effective under a range of variable conditions.

To achieve improved water quality in the City's streams, small lakes, and ponds, riparian buffer areas should be utilized effectively to provide both biofiltration of stormwater runoff and protection from adjacent land uses. Both goals can be achieved by providing dense, well-rooted vegetated buffer areas.

Biofiltration swales, created wetlands, and infiltration opportunities for specific stormwater runoff discharges can be utilized to intercept runoff before it reaches stream channels. Stormwater runoff that is conveyed through stream buffers in pipes or ditch-like channels and discharged directly to stream channels "short circuits" or bypasses buffer areas and receives little water quality treatment via biofiltration. In areas where stormwater flows untreated through riparian buffer areas, the buffer is underutilized and is prevented from providing the intended or potential biofiltration function.

3.3.2 Maintain Wildlife Habitat Corridors & Connections

Ecological corridors are a strategy to improve connectivity between habitat patches in the context of habitat loss and fragmentation. Mounting evidence suggests that the presence of ecological corridors improves ecological response variables such as species abundance, species richness, and inter-patch movement (Gilbert-Norton et al. 2010; Resasco 2019). While community ecological responses are positively correlated with corridor presence, species-specific interactions are complex and do not always follow these trends. For example, a study by Hadid et al. (2003) found that five of ten assessed species displayed increased abundance where corridors were preserved. Due to the varying responses, corridor management for individual species would benefit from species-specific analysis to determine corridor efficacy and management requirements. Meta-analytic studies have also found higher levels of wildlife movement through natural compared to manipulated corridors (Gilbert-Nortan et al. 2010).

Peer reviewed best management practices literature has been developed for corridor management such as the work completed by Gregory et al. (2021). This review discusses several dimensions urban development and identifies five general themes among the recommended best management practices: "*(1) minimize the number and intensity of human activities within, (2) maintain or re-create natural processes in linkages, (3) create buffers between linkage lands and human-use areas, and (4) help wildlife cross linear barriers, and (5) encourage recreationists and other people using the corridor to behave as well-informed stewards*."

The following list includes scientific knowledge gaps regarding corridor management and best practices (Gregory et al. 2021). These are relevant to the development of public policy and regulations because political decisions must be made in the absence of perfect information.

- "What Are Critical Dimensions of Corridors?"
- "Is There a Critical Threshold in Intensity of Land Use?"
- "How do Landscape Traits of Corridors Affect Different Species?"
- "How Far Away from the Linkage Edge Do We Need to Manage Human Uses?"

- "How Do Time Lags Affect Corridor Use?"
- "Which Governance and Management Activities Are Most Acceptable to People Living in or near Corridors and Which Policies Are Beneficial for Corridors?"

3.3.2.1 *Terrestrial and Aquatic Habitat Connectivity*

Habitat connectivity has become salient to the field of wildlife management and conservation as habitat loss and fragmentation increasingly limits wildlife movement across landscapes. Connectivity refers to the ease or difficulty of wildlife moment, or permeability, through a particular land area. Populations and communities residing in areas of poor connectivity, a near ubiquitous condition of urban landscapes, experience impacts to daily movement, dispersal, and migration. Other ecological interactions are numerous and include disruptions to predator-prey dynamics, seed dispersal, and inbreeding depression.

3.3.2.2 *Maintaining Sustainable Populations*

Habitat corridors are necessary to facilitate physical movement across the landscape and gene flow among plants and animals present in the ecosystem. "Ecological corridors are one of the best, and possibly only viable, management tools to maintain biodiversity at large scales and to allow species, and ecological processes, to track climate change" (Gregory et al. 2021).

3.3.2.3 *Urban Forestry*

Forest conditions throughout the City are important to the establishment and retention of wildlife corridors. Urban forest management contributes to habitat patch conditions and can support landscape-scale wildlife corridor functions.

Canopy Cover

Land cover analysis is a fundamental ecosystem parameter used to support many environmental applications. Some of these applications include forest and urban forest health (Lausch 2017, USDA 2019), habitat mapping (Lerman 2014), and urban infrastructure. At the planning level, urban forests are commonly measured using land cover analysis to determine tree canopy cover across geographical or physical boundaries. The City of Sammamish published a land cover analysis in 2018 in partnership with the University of Washington (Dyson 2018). Findings from this land cover analysis measured tree canopy within the city at 50% in 2015. This figure was further analyzed by Davey Resources in 2019 (Davey 2019) and was projected to potentially decline to 31% in 2025.

Urban canopy cover targets are a common tool used in long-range planning and policy across Washington. Targets for canopy cover in municipalities across the United States vary. A commonly used municipal canopy cover target of 40% established by the American Forests organization in 1997. This number has been refined in twenty years of urban forest research and planning, resulting in a current recommendation to stratify canopy cover percentages by existing zoning and policy considerations. U.S.

Forest Service Research Forester Greg McPherson of the Pacific Southwest Research Station is quoted, “Tree canopy cover targets are difficult to specify broadly because the opportunities to create canopy are highly variable among cities, even within a climatic region or land use class.”

The City of Sammamish Urban Forest Management Plan by Davey Resource Group outlines canopy cover projections per zoning type but does not specify recommended canopy targets per zoning type. An example of stratifying canopy cover targets by zoning type is included in Table 3 below. A different approach to urban canopy cover is addressing targets at a watershed or sub-watershed level. Canopy cover addressed at watershed levels allows for more discernable assessment of water quality and water quantity and permits a rapid assessment on watershed level planning.

Deployment of canopy cover data should be repeated every 5 to 8 years (USDA 2019). The higher the frequency of canopy cover studies the more suitable the data is for long-range planning. Data requirements for these studies can include satellite or fixed-wing natural color orthomosaic, high resolution LiDAR, near infrared (NIR), normalized difference vegetation index (NVDA) and hyperspectral imagery.

Table 3. Example Tree Canopy Cover Targets per Zone

Zone	**Tree Cover Goals**
Low Density Residential	60%
High Density Residential	50%
Mixed Use Town Center	35%
Commercial	45%
Industrial	25%

3.3.3 Protect Priority Species & Habitats

Effective BAS-based strategies can be applied to protect all Federal and State endangered or threatened species and WDFW-identified Priority Species and Habitats (PHS). Not all FWHCAs are water bodies or riparian areas associated with those water bodies.

Where species-specific management recommendations are available from WDFW guidance documents, those should be followed. Examples are the recovery plans for the Mazama pocket gopher (Stinson, 2020)(Stinson 2016; USFWS 2022) and Management Recommendations for Washington’s Priority

Species; Invertebrates (Larsen 2018); amphibians and reptiles (Larsen 1997); Birds (Larsen 2018); mammals (WDFW 2010). General recommendations for BAS-based strategies to protect terrestrial habitat are listed below.

General Terrestrial Habitat Management Recommendations

Generally, plan development to minimize fragmentation of native habitat, particularly large, intact habitat areas by incorporating mitigation sequencing standards into all development review. Where large forest stands exist, manage for forest-interior species and avoid fragmentation (Donnelly and Marzluff 2004, Diffendorfer et al. 1995, Mason et al. 2007, Orrock and Danielson 2005, Pardini et al. 2005 and others).

- Manage agricultural development to limit fragmentation and edge; preserve vegetative structural diversity whenever possible in agricultural areas by retaining hedge rows and areas of native vegetation (Southerland 1993).
- Protect priority habitats that have a primary association with an ESA-list species or species of local importance by continuing to regulate for adherence to WDFW management recommendations and other applicable regulatory requirements.
- Control invasive species where needed on a site- and species-specific basis. Address invasive species specifically addressed in areas where environmental conditions tend to promote infestation, including created edges, roadways, and riparian zones where they are contiguous with developed areas that may act as a seed source (Olden et al. 2004, Pimentel et al. 2005, McKinney 2002 and others).
- Protect, maintain, and promote habitat features such as snags and downed wood (Blewett and Marzluff 2005).
- Manage for increase native vegetative cover in landscaping and discourage lawns (Nelson and Nelson 2001).
- Plan habitat areas away from roads (Fahrig et al. 1995, Lehtinen et al. 1999).
- Promote buffers of adequate width to support wildlife guilds in adjacent habitat (Ficetola et al. 2008, Semlitsch and Bodie 2003, Crawford and Semlitsch 2007).
- Identify existing habitat patches and corridors and maintain connectivity with vegetated corridors to limit fragmentation and edge habitat (Gillies et al. 2008, Gilbert-Norton et al. 2010). Preserve habitat patches of at least moderate size 35 ha (86 ac) within developed areas (Kissling and Garton 2008).
- Promote restoration of FWHCAs, buffers, and other management zones through critical area regulations and public outreach. Encourage stewardship on a parcel by parcel and city-wide scale.

3.4 Climate Impacts and Mitigation

3.4.1 Climate Change Stressors

Changes in temperatures and seasonal precipitation patterns are projected to place additional stressors on FWHCAs. Some loss of riparian vegetation is anticipated due to the stresses of climate change, primarily warmer and drier summers. A reduction in riparian vegetation potentially triggers a cascading effect. A decrease in riparian vegetation would decrease shading, increase stream temperature, decrease detrital inputs, reduce available habitat structure, and reduce stream bank stability. Changes in seasonal hydrologic cycles may increase frequency and magnitude of flashy runoff events, mobilize greater volumes of sediments and pollutants into streams, and reduce groundwater recharge that supports base stream flows in summer. FWHCA Functions and Values, instream habitats are particularly negatively impacted by excess sediment discharge and deposition.

Hot dry summers are projected to reduce stream flow volumes and increase instream temperatures. This stressor is compounded by extreme precipitation events, flooding and erosion. All these stressors reduce instream habitat quality and stress salmonid populations, including Chinook salmon, the preferred food source for Orca whales. Climate change poses a threat freshwater fish habitat (Crozier et al. 2008).

3.4.2 Resiliency strategies

Strategies to manage climate change impacts to FWHCAs

The following actions or policies have the potential to reduce negative climate change impacts on FWHCAs (Redmond 2022).

- Citywide promote retention of significant trees and maintain tree replacement requirements.
- Encourage and incentivize enhancement and restoration of native forest patches throughout the City, particularly where connectivity to one or more FWHCAs is demonstrated. Both voluntary and required restoration planting should be paired with monitoring and maintenance that allows for dry season irrigation and adaptive management.
- Encourage the use of local nursery plant stock grown under current conditions to increase resilience of plant communities considering climate stressors.
- Manage stormwater infrastructure to avoid and minimize discharges of increased and/or untreated runoff to streams and thereby offset the anticipated increase in intensive rainfall events. Promote the use of LIDs as a tool to effectively manage stormwater for minimal downstream impacts.
- Update and maintain regulations for habitats and species of local importance. This may include adding mapping resources to help identify the locations of potential habitats and species requiring protection and management.

- Prioritize protection of streams and riparian corridors to reduce the stresses of climate change on native fish species and anadromous fish, such as chinook salmon.

4 Frequently Flooded Areas

4.1 Definitions

Frequently Flooded Areas (FFA's) are topographic features or landforms flooded by streams or rivers, waves or storm surges on freshwater or marine shorelines, high groundwater levels, or increased runoff from urban development. They usually overflow during times of high runoff, high tides, prolonged or intense rainfall and snowmelt, rising groundwater levels, or a combination of these conditions. Their hydrologic conditions vary with inflow, outflow, and storage of runoff, groundwater discharge, lake level changes, channel migration, and other variables. For purposes of Critical Area Ordinances, FEMA flood hazard areas mapped for flood insurance studies may be considered FFA's but should be augmented by delineations of other flood-prone areas. Flooding on small streams and wetlands are often included in wetland and Fish and Wildlife Habitat Conservation Area delineations. Flooding due to channel migration, landslide and slope failures, tsunamis, and seiches are often included in Geological Hazard Area delineations.

Sammamish Municipal Code Title 15, SMC Land Use Development Code (2023), recognizes 44 CFR 59.1 (Code of Federal Regulations) as the controlling definition of floodplains or flood prone areas as "any land area susceptible to being inundated by water from any source".

Elsewhere in Title 15, *Flood* or *Flooding* means:

a) A general and temporary condition of partial or complete inundation of normally dry land areas from:
    (1) The overflow of inland or tidal waters.
    (2) The unusual and rapid accumulation or runoff of surface waters from any source.
    (3) Mudslides (i.e., mudflows) which are proximately caused by flooding as defined in paragraph (a)(2) of this definition and are akin to a river of liquid and flowing mud on the surfaces of normally dry land areas, as when earth is carried by a current of water and deposited along the path of the current.

b) The collapse or subsidence of land along the shore of a lake or other body of water as a result of erosion or undermining caused by waves or currents of water exceeding anticipated cyclical levels or suddenly caused by an unusually high water level in a natural body of water, accompanied by a severe storm, or by an unanticipated force of nature, such as flash flood or an abnormal tidal surge, or by some similarly unusual and unforeseeable event which results in flooding as defined in paragraph (a)(1) of this definition.

The Sammamish Municipal Code Title 21 defines Frequently flooded areas as “those lands in the City in the floodplain subject to a one percent or greater chance of flooding in any given year and those lands that provide important flood storage, conveyance, and attenuation functions, as determined by the City in accordance with WAC 365-190-0803. Frequently flooded areas perform important hydrologic functions but may present a risk to persons and property developed too close to a source of flooding. Frequently flooded areas regulated by the current Critical Areas Ordinance include all areas of special flood hazards within the jurisdiction of the City of Sammamish.”

SMC Title 21 (Sammamish Municipal Code) defines floodplain as “the total area subject to inundation by the base flood”. The base flood is a 1% probability of occurrence flood, also known as the 100-year recurrence interval flood. The 1% probability of occurrence flood was intended to define flood risk for selling flood insurance policies. It has no unique geomorphic or environmental significance and is certainly not frequent in terms of frequently flooded areas. The 10% (10-year) and 50% (2-year) probability of occurrence floods are frequent and important for defining channel processes and ecological attributes of FFAs.

Frequently Flooded Areas (FFAs) are defined in WAC 365-190-030(8) as:

“Lands in the flood plain subject to at least a one percent or greater chance of flooding in any given year, or within areas subject to flooding due to high groundwater. These areas include, but are not limited to, streams, rivers, lakes, coastal areas, wetlands, and areas where high groundwater forms ponds on the ground surface.”

The WAC does not limit the recognition or delineation of FFAs as critical areas to just flood hazard areas defined by the FEMA National Flood Insurance Program and mapped on Flood Insurance Rate Maps (FIRMs). Other communities recognize channel migration zones and groundwater flooding areas as FFAs.

FFAs provide important hydrologic functions and ecological benefits and often serve as important habitat for fish and wildlife, including threatened and endangered species. Other FFA values and functions include: attenuation of peak flows and flood velocities to protect downstream areas, storage and bioaccumulation of fine sediment, nutrients, and organic wastes; refugia and both breeding and rearing habitat for fish and amphibians, band storage and groundwater seepage to help maintain baseflows, and carbon sequestration in floodplain vegetation. FFAs can also pose a risk to public safety when homes and commercial structures are built too close to the source of flooding. Potential FFAs in Sammamish include: high water areas on Lake Sammamish, Pine Lake, and Beaver Lake, and other small lakes and wetlands; riparian floodplain and channel migration zones within Sammamish city limits; floodplain areas and potential channel migration zones along 28 streams (named and unnamed) tributary to Lake Sammamish; depressional areas subject to groundwater flooding; and stormwater discharge areas (such as Flood Problem Flow Control Areas) where inflows exceed outlet capacities and subsequently flood roads or built up areas during prolonged rainfall, snowmelt, or intense rainstorms. Except for a few areas on the eastern shoreline of Lake Sammamish, none of these other areas are shown as FFAs in the Environmentally Sensitive Areas Map or listed in the current Critical Areas Ordinance for the City of Sammamish.

SMC Title 21 (Sammamish Municipal Code) does not include a definition of Frequently Flooded Areas for purposes of critical area designations under WAC 365-190-080 and the Purpose Statement doesn't include protecting environmental benefits or hydrologic functions of FFAs. Designation of flood hazard zones, for purposes of city administration of this chapter, includes an area of the floodplain (floodplain fringe) that can be filled or obstructed so long as the project doesn't increase the water surface elevation (WSEL) of the base flood more than one foot at any point. Floodplain fills for new foundations, bulkheads, boat ramps, or other developments in the floodplain around the lake would not likely increase the WSEL of the base flood on Lake Sammamish, and could be approved, as far as the requirements of current City regulation, regardless of potential adverse environmental impacts.

The City of Sammamish does consider areas within the area of special flood hazard, as outlined by FEMA in their report titled "Flood Insurance Study (FIS) for King County" and the corresponding flood insurance rate map (FIRM). The only mapped flood hazard zones within the City limits are along the Lake Sammamish shoreline (King County Regional Hazard Mitigation Plan 2020). The flood elevations, floodplain boundaries, and floodway delineations for the FEMA FIS and FIRM were developed in 1976 – 1977 and may not accurately reflect building and land development in Sammamish since then. The flood frequency analysis may also need to be updated due to changes in land use, particularly stormwater discharge, and floodplain alterations, over the last 40 years or more.

FEMA requires the city to ensure that development activities in the flood hazard zone along Lake Sammamish are consistent with Flood Damage Prevention standards contained within SMC Chapter 15.10. These standards include structural measures to reduce flood damage to residential or commercial properties. It is the purpose of the chapter (SMC15.10) to promote the public health, safety, and general welfare; reduce the annual cost of flood insurance; and minimize public and private losses due to flood conditions in specific areas by provisions designed to:

- Protect human life and health;
- Minimize expenditure of public money for costly flood control projects;
- Minimize the need for rescue and relief efforts associated with flooding and often undertaken at the expense of the general public;
- Minimize prolonged business interruptions;

- Minimize damage to public facilities and utilities, such as water and gas mains; electric, telephone, and sewer lines; and streets and bridges located in flood hazard areas;
- Help maintain a stable tax base by providing for the sound use and development of flood hazard areas so as to minimize blight areas caused by flooding;
- Notify potential buyers that the property is in a special flood hazard area;
- Notify those who occupy flood hazard areas that they assume responsibility for their actions; and
- Participate in and maintain eligibility for flood insurance and disaster relief. (Ord. 2400, 2020)

4.2 Functions and Values

Flooding is more than a water surface elevation from a fixed-bed hydraulic model. It is a three-dimensional process with overbank flow that mobilizes bed sediments, recruits large woody debris, and initiates channel migration. FFAs provide many functions and values to the environment and are dynamic in nature and ecologically productive. Dynamic processes can be critical to the maintenance of fish and wildlife habitat, including the mobilization of large woody debris and other allochthonous inputs (Naiman & Decamps 1997, Gurnell 2005). During periods of high-water flows, channels can be carved into the floodplain which can then provide important habitat for a variety of fish species and create areas of refuge. Sediment loading can also occur during periods of high flows when streams overtop their banks and deposit sediment in a new location. This cumulative process builds and alters the floodplain (Dunn & Leopold 1978, Knighton 1998). The floodplain can then in turn store and slow water during peak flows while contributing to soil infiltration and aquifer recharge. The Washington Department of Ecology has identified flooding as the costliest natural hazard (ECY 2021b, Publication # 21-06-019). This cost is associated with damage to structures and infrastructure but does not account for the loss of ecological and public benefits from floodplain degradation by fills, dredging, gravel removal, destruction of riparian areas, and other adverse effects of development in FFAs.

FFAs have historically been diked, leveed, and filled to provide for human developments and a variety of land uses including agriculture, residential development, and urbanization. As areas develop it has been standard practice for infrastructure to be placed in proximity to rivers and other large bodies of water as these locations proved to be advantageous to travel, transportation of goods, and to help eliminate waste generated from human activities. Development activities such as these within FFAs were thought of as “improvements” however they had negative impacts to downstream lands and land uses, and contributed to loss of riparian habitat and negative impacts on natural geomorphic processes (ECY 2021b).

Today, changing river dynamics, including sediment and large woody debris accumulation as well as increased flows due to upstream land use changes, may overwhelm aging flood control systems that have not been maintained or improved. The social, ecological, and economic costs of flooding have increased over the years with increasing populations and development and the failure to recognize long-term potential flooding or the ecological and public benefits of high flows in streams and rivers and natural inundation of wetlands, shorelines, and groundwater basins.

Urbanization and land development, which oftentimes involves stream channel straightening and armoring, can disconnect streams from their natural floodplain and associated wetlands (Booth 1990). Additionally, increased impervious surfaces and loss of forest within a basin increases peak flow magnitude and frequency (Booth 2002). Associated downcutting of stream channels further separates them from their floodplains, increases in-stream erosion, and deposits sediment in downstream environments leading to problems such as blocked culverts in some cases (Booth 1990). An integrated management approach to complex stream environments requires more detail than total impervious areas within stream basins (Booth et al. 2004). Urban development patterns including increased impervious surface area and its aggregation, or patch size, are relevant to watershed functions and directly impact stream ecosystems (Alberti et al. 2006. As demonstrated above, stream dynamics and floodplain functions are closely linked.

4.3 Protection Strategies

Many other communities in Washington regulate areas of special flood hazards using National Flood Insurance Program standards and deem this sufficient for the regulatory basis for frequently flooded areas codes (Commerce 2023). Washington State Department of Commerce (Commerce) notes that this approach can meet the minimum requirements if there are no special circumstances. However, Commerce also states that FEMA maps do not address all flood risk in communities and that the frequently flooded area designation should be based on BAS. As such, Commerce encourages local governments to consider additional flood risks in their communities and address related regulatory issues in their frequently flooded areas subsection. The Washington State Department of Ecology (ECY) encourages local governments to exceed FEMA minimum requirements for floodplain management (ECY n.d.).

The Flood Insurance Study (FIS) for King County, Washington and Incorporated Areas dated August 19, 2020, and Flood Insurance Rate Maps (FIRM) are adopted by reference in SMC 15.10.060 as areas establishing special flood hazard areas, see corresponding Existing Conditions Report. Further, this subsection describes that these maps shall be considered the basis for the best available until a new FIRM is issued. These maps delineate only a few FFAs along the eastern shore of Lake Sammamish where there is sufficient development to sell flood insurance. There are no other mapped or regulated FFAs in the City of Sammamish included in the FEMA Flood Insurance Study.

Because of their inherent limitations and inaccuracies, FEMA flood insurance maps, including floodway designations, generally have limited use for evaluating or protecting anadromous fish habitat, particularly maintenance of spawning gravels, instream refugia, and hyporheic flows. The City currently has guidance documents that inform property owners when a Floodplain Habitat Assessment is required for developments on certain shorelines of Lake Sammamish. There are currently no Floodplain Habitat Assessments required for developments in FFAs anywhere else in the city. The guidance documents reference that a Floodplain Habitat Assessment is needed in certain circumstances that meets the requirements of the FEMA Region X Guidance / Habitat Assessment Worksheet (v1.6 – November 2017).

Ecological restoration is a key tool to limit or reverse the damage caused by the use and development of lands in and around critical areas. In 2018, the City of Sammamish, along with a number of regional partners, sponsored the Zackuse Creek Fish Passage and Stream Restoration project to assist in the reestablishment of Zackuse Creek as a kokanee spawning area. The primary project objectives included replacement of the existing culvert under East Lake Sammamish Parkway (ELSP) and restoration of approximately 400 linear feet of Zackuse Creek upstream of the culvert. The replacement of the culvert ensured that the area is now fully fish passable and included design elements that emulate a natural stream bed.

4.4 Additional BAS

New developments in GIS mapping of frequently flooded areas offer a comprehensive, geomorphic approach to the delineation of floodplains in alluvial basins (USGS et al. 2013). This basin-specific approach recognizes the geological and hydrological elements of sediment transport, large woody debris dynamics, and more frequent (2-year to 10-year recurrence interval) high-flow processes (Wald 2009). The use of spatial data, particularly LiDAR (Light Detection and Ranging) coverages, for mapping floodplains is a useful and applicable augmentation of hydraulic modeling used in Federal Emergency Management Agency (FEMA) flood insurance studies. Most frequently flooded areas can be delineated and mapped using LiDAR coverages available from the Washington Geologic Information Portal (DNR n.d.) and other sources. Integrating geospatial data to identify floodplain functions is a recommended strategy for protecting floodplains (NFFA & WMC 2023).

FFA’s are typically delineated using water level data for streams and lakes, relative elevations, geological controls, and watershed or drainage area characteristics. Geomorphic floodplains are mapped using a Geographic Information System (GIS) spatial data analysis to define channel and valley boundaries, coastal topography, and upland depressional areas. GIS delineation and mapping often uses LiDAR (Light Detection and Ranging) data available from the Washington Department of Natural Resources geological portal (https://lidarportal.dnr.wa.gov/#45.72344:-121.29238:12) and other sources.

Stormwater flooding areas are frequently included in management plans that identify problem areas where inflows may exceed conveyance or storage capacity. FEMA flood insurance rate maps include flood boundaries for a limited number of streams, lakes, and coastal areas. They need to be augmented with delineations on streams, lakes, wetlands, groundwater flooding areas, and marine shorelines not included in the FEMA maps.

4.4.1 Comprehensive Flood Control Management Plan (CFCMP)

Per WAC 173-145-040 a Comprehensive Flood Control Management Plan (CFCMP) must be approved by the Washington State Department of Ecology (ECY) in consultation with the Washington Department of Fish and Wildlife and must contain specific elements including:

- A determination of the need for flood control work based on known and potential flood damages;
- Alternative flood control measures;
- Consideration of instream and critical area impacts;
- Coverage area;
- Conclusion with recommendations; and
- Certification from the Emergency Management Division of the Washington State Military Department/local emergency management organization (ECY 2021b).

4.4.2 Integrated Floodplain Management

An Integrated Floodplain Management Plan (IFM) is a collaborative approach that brings together multiple stakeholders to develop strategies and actions that benefit people, fish and wildlife, community interests, and tribal rights while focusing on sustainability and economic costs. Jurisdictions are recommended by the Washington State Department of Ecology to develop and implement IFMs (ECY 2021b).

4.4.3 Development Restrictions

Washington State has implemented a No Adverse Impact (NAI) strategy to floodplain management which does not mean that development cannot occur, however it must be mitigated when it may impact the storage capacity and function of floodplains. (ASFPM 2003). This only applies to a few areas in Sammamish mapped for the FEMA NFIP.

The City of Sammamish can reduce loss of public values and ecological benefits in FFAs by restricting development in numerous natural areas that experience high water levels in the city. Local regulations that are commonly applied throughout the state include No-rise, designating floodplains as protected tracts on new land subdivisions, and compensatory storage on all of the streams in the city.

4.5 Climate Impacts and Mitigation

As climate change impacts precipitation and runoff in the Pacific Northwest, it is projected that the region will see wetter autumns and winters and drier summers (Mote & Salathe 2010). The Department of Ecology predicts that climate change will increase the frequency of floods as rainfall patterns change. This includes an increase in rainfall intensity and duration of rainfall events (ECY 2021b). With an increase in flooding the region could see an increase in sediment transport in winter and spring which can lead to a decline in water quality as well as maintenance issues involving urban infrastructure (Mauger et al. 2015). As seen in recent years heavy precipitation in the Pacific Northwest is commonly associated with atmospheric rivers and recent climate change models project an increase in the frequency of these extreme events (Mauger & Kennard 2017). Additionally, climate change is likely to drive flooding in shoreline and coastal areas due to sea level rise, high tides, storm surges and waves. These types of extreme flood events may impact instream habitats by mobilizing sediment and pollutants (Talbot et al 2018). Stream channel migration associated with climate change can also drastically alter food availability for some species (Mauger & Kennard 2017).

Federal Emergency Management Agency (FEMA) maps do not consider future flood risk, sea level rise, other climate change impacts, or channel migration zones (Commerce 2023).

4.5.1 Climate Change Stressors

Increased flood flows the floodplain boundaries has the potential to increase sediment deposition and may expand from the currently mapped areas. This may impact flood fringe areas and may put structures and lives at risk, while continuing to degrade the natural values and functions of FFAs.

4.5.2 Resiliency Strategies

- Complete and maintain a comprehensive flood control management plan (CFCMP) to support stormwater management, salmonid habitat, and streamflow planning for all the FFAs in Sammamish.
- Encourage and incentivize floodplain restoration actions to restore floodplain connectivity to streams, lakes, and wetlands and protect or restore riparian corridors to maintain microclimate.
- Utilize the FEMA Climate Resiliency approach to support flood hazard management planning and follow grant funding opportunities for more than just the few areas mapped in the Flood Insurance Study for Sammamish.

5 Geologically Hazardous Areas

5.1 Definition

Pursuant to WAC 365-190-120(1), geologically hazardous areas include areas susceptible to erosion, sliding, earthquake, or other geological events. These areas pose a threat to the health and safety of citizens when incompatible commercial, residential, or industrial development is sited in areas of significant hazard.

The four main types of geologically hazardous areas recognized in the GMA are (RCW 36.70A.030(9) and WAC 365-190-120):

1. Erosion hazard areas;
2. Landslide hazard areas;
3. Seismic hazard areas; and
4. Areas subject to other geologic events such as coal mine hazards and volcanic hazards including mass wasting, debris flows, rock falls, and differential settlement.

The definitions of each of these areas, as provided by the WAC 365-190-120, are described below.

5.1.1 Erosion Hazard Area

WAC 365-190-120(5) defines "erosion hazard areas" as "areas likely to become unstable, such as bluffs, steep slopes, and areas with unconsolidated soils. Erosion hazard areas may also include coastal erosion areas as found in the Washington State Coastal Atlas developed by the Washington State Department of Ecology. The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) soil survey may be used as a mapping resource to help identify erosion hazard areas." A description of erosion and the associated hazards posed by erosion is provided in Section 5.2.1.

5.1.2 Landslide Hazard Area

As defined in WAC 365-190-120(6), Landslide hazard areas include "*areas subject to landslides based on a combination of geologic, topographic, and hydrologic factors. Landslide hazard areas include any areas susceptible to landslide because of any combination of bedrock, soil, slope (gradient), slope aspect, structure, hydrology, or other factors, and include, at a minimum, the following:*

- *a) Areas of historic failures, such as:*
    - *i. Those areas delineated by the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) as having a significant limitation for building site development;*
    - *ii. Those coastal areas mapped as class u (unstable), uos (unstable old slides), and urs (unstable recent slides) in the Department of Ecology Washington Coastal Atlas; or*
    - *iii. Areas designated as quaternary slumps, earthflows, mudflows, lahars, or landslides on maps published by the United States Geological Survey (USGS) or Washington Department of Natural Resources (DNR).*
- *b) Areas with all three of the following characteristics:*
    - *i. Slopes steeper than 15 percent;*
    - *ii. Hillsides intersecting geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock; and*
    - *iii. Springs or groundwater seepage.*

c) *Areas that have shown movement during the holocene epoch (from 10,000 years ago to the present) or which are underlain or covered by mass wastage debris of this epoch;*
d) *Slopes that are parallel or subparallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials;*
e) *Slopes having gradients steeper than 80 percent subject to rockfall during seismic shaking;*
f) *Areas potentially unstable as a result of rapid stream incision, stream bank erosion, and undercutting by wave action, including stream channel migration zones;*
g) *Areas that show evidence of, or are at risk from snow avalanches;*
h) *Areas located in a canyon or on an active alluvial fan, presently or potentially subject to inundation by debris flows or catastrophic flooding; and*
i) *Any area with a slope of 40 percent or steeper and with a vertical relief of 10 or more feet except areas composed of bedrock. A slope is delineated by establishing its toe and top and measured by averaging the inclination over at least 10 feet of vertical relief.*"

The City of Sammamish has many slopes that meet the above definitions of a landslide hazard. The types of landslides and their associated landslide hazards as they apply to the City are discussed in detail in Section 5.2.2.

5.1.3 Seismic Hazard Area

Seismic hazard areas include areas that are subject to severe risk of damage as a result of earthquake induced ground shaking, slope failure, settlement or subsidence, soil liquefaction, surface faulting, or tsunamis, as described in WAC 365-190-120(7). Settlement and soil liquefaction conditions often occur in areas that are underlain by cohesionless soils of low density, typically in association with a shallow groundwater table. An indicator of potential for future earthquake damage is a record of earthquake damage in the past. Ground shaking is the primary cause of earthquake damage in Washington, and ground settlement may occur with shaking. The strength of ground shaking is primarily affected by:

a) *The magnitude of an earthquake;*
b) *The distance from the source of an earthquake;*
c) *The type or thickness of geologic materials at the surface; and*
d) *The type of subsurface geologic structure.*

The Puget Sound, which includes the City of Sammamish, is in an area with high seismic hazard. The geologic hazards that are associated with earthquakes are discussed in more detail in Section 5.2.3.

5.1.4 Other Geologic Hazards

WAC 365-190-120(8) defines other types of geologic hazard areas to include volcanic and mine hazard areas. The WAC defines volcanic hazard areas as *"areas subject to pyroclastic flows, lava flows, debris avalanche, or inundation by debris flows, lahars, mudflows, or related flooding resulting from volcanic* *activity."* Volcanic hazards such as pyroclastic flows and lava flows are typically associated with areas in close proximity to an active volcano. More far-reaching volcanic hazards are those associated with lahars, which are volcanic mudflows. In a lahar, the snow on a mountain rapidly melts and mixes with pyroclastic material, rocky debris, and water. This results in a slurry that flows into the valleys surrounding the volcano. For Mount Rainier, lahars from previous eruptions have flowed as far north as Kent in the Green River Valley. There is no data that would indicate that the active volcanos in Washington pose a threat to the City of Sammamish from the volcanic hazards defined in the WAC. Ash from an eruption is also a hazard; however, it is not included as part of the WAC definition of geologic hazards.

Mine hazard areas are defined as *"those areas underlain by, adjacent to, or affected by mine workings such as adits, gangways, tunnels, drifts, or air shafts. Factors which should be considered include proximity to development, depth from ground surface to the mine working, and geologic material."* Mine hazards typically consist of ground subsidence that occurs as soils above old mines fail and fill in the cavity that was formed as a result of mining activity. There is a deposit of coal mapped at the southern boundary between Issaquah and Sammamish along the Issaquah-Fall City Road. Old maps indicate that several mines were excavated within this deposit; however, the mapping appears to show these mines to be outside of the city limits of Sammamish (Northwestern Improvement Co., 1938).

5.2 Functions and Values

5.2.1 Erosion Hazard Areas

Erosion is the combination of physical processes by which rock and soil are removed and transported by natural forces from one location to another. Natural erosion is important for maintaining sediment processes in aquatic environments. Sediment that is transported by erosion activities can result in spawning substrate for salmon in streams and lakes and provides sediment that contributes to stream deltas.

Alternatively, excessive erosion and sediment deposition can result in negative impacts to receiving waters, shorelines, and the flora and fauna present. Anthropogenic effects such as clearing vegetation and creating additional impervious surface area can cause erosion events that exceed natural conditions and become damaging. Examples of the negative impacts of erosion include the movement of large amounts of soil downstream that can even result in flooding, or fine particles of eroded soils can cause siltation of adjacent waterbodies including wetlands, streams, lakes, and stormwater management systems.

When development encroaches into geologically hazardous areas, it also increases the probability that protective measures will be to prevent geologic movement and protect property, such as armoring or retaining walls. These preventative measures are likely to impact the ecosystem by interrupting natural geologic processes. When structures are placed in areas that are susceptible to erosion, or land use actions cause formerly stable areas to begin eroding, the risk of erosion increases for surrounding properties as well.

Vegetation can increase the stability of geologic hazard areas and reduces erosion by preventing a significant amount of rainfall from reaching the soil and physically binds the soil together with root materials (Booth et al. 2002, Niaman & Decamps, 1997). Subsequently, vegetation removal can contribute to increased erosion in susceptible areas. In cleared areas, rainfall tends to concentrate in small channels. As the water gains depth and volume, sediment can be eroded by the flow and eventually develops into gullies.

5.2.2 Landslide Hazard Areas

Sammamish is home to a variety of landslide hazards which include rockfalls, deep slope failure, and shallow debris flows. Gravity acting on a slope is the primary cause of landslides, but there are other important and dynamic factors that serve as triggers. Saturation of slopes by precipitation (rain or snowmelt) weakens soil and rock by reducing cohesion and increasing the pressure in pore spaces, pushing grains away from each other. Erosion and undercutting of slopes by streams or burst pipes increase slope angles and decrease slope stability. Ground shaking from earthquakes can also create stresses that weaken slopes and physically cause slope movement.

Landslides can occur in different forms at varying speeds and depths. Landslides can start from the bottom or top of a slope, or somewhere in between. The most common type of landslide in the Puget Sound region occurs in response to either heavy precipitation (Tubbs, 1974) or elevated groundwater conditions (Thorsen, 1987) in soil deposits derived from glacial deposits. Glacial deposits often result in surface layers that are more permeable than the deeper layers, causing water to perch at the contact between the two layers. The weight and increase in pore pressure from the water causes the upper layer to fail, and slide over the deeper, more resistant layer.

Activities associated with urban development, including vegetation removal, and increased impervious surfaces, can increase risk of a landslide in susceptible areas. Vegetation can significantly affect the potential for landslides by intercepting a substantial amount of rainfall. This action prevents precipitation from infiltrating into the soil and subsequently increasing the weight of the soil mass. Roots from vegetation take up and transpire a portion of water that reaches the soil and reduces the amount of water that rests at the contact between the permeable and impermeable layer (Watson & Burnett, 1995). A dense matrix of roots can also lend considerable strength to the soil on a slope (Schmidt et al. 2001), decreasing the likelihood of slope failure and shallow-rapid landslides.

Slope instability can also be induced by construction activities on or near a slope. This can be the result of excavations near the base of slopes that remove some of the materials that provide stability for the slope or placement of additional weight, such as fill materials at the top of a slope. As modifications to a slope due to construction activity can be evaluated and design can implement mitigation measures to provide adequate stability of the slopes, appropriate geotechnical studies should be performed for development in landslide prone areas.

5.2.3 Seismic Hazard Areas

As described in the City of Sammamish Jurisdictional Annex to the King County RHMP (2020), Sammamish ranked earthquake as the greatest threat to the City of Sammamish. The City is particularly at risk since it is threatened by several fault lines that can produce high magnitude earthquakes. A seismic event of a high magnitude would subject the City to violent shaking and ground movement. A significant seismic event is likely to also produce secondary hazards that may further result in loss of life, property, and critical infrastructure. Secondary hazards associated with seismic events include liquefaction of the soil, rockfall, landsliding, dam failure, levee failure, and tsunamis or seiches.

Best available science for evaluation of the seismic hazard associated with large ground motions is typically accounted for in the applicable building codes. These are updated from time to time, but typically include the International Building Code (IBC) and ASCE 7 for building design. The applicable Sammamish codes that regulate the approval of building permits incorporate these design standards and address the seismic hazard for most building sites.

Some sites have additional vulnerabilities associated with liquefaction, liquefaction induced settlement, and lateral spreading. These sites are typically located in alluvial basins and other areas adjacent to water bodies; however, some sites outside of these areas may also be susceptible to liquefaction. The IBC and ASCE 7 provide parameters for which to assess the potential for liquefaction to occur. Liquefaction potential is typically assessed using geotechnical in situ testing to determine the relative density or consistency of a soil. This typically includes using Standard Penetration Tests (SPT) or cone penetrometer testing (CPT). With the soils data, simplified procedures are commonly used to determine if a soil is considered liquefiable. The methods were originally developed by Seed and Idriss (1971), updated by Youd et al (2001), and by Idriss and Boulanger (2004, 2006, 2008). Once liquefaction susceptibility is evaluated, the magnitude of any liquefaction induced settlement and lateral displacement due to lateral spreading can be estimated. Depending on the magnitudes of the settlement and/or lateral movement, design can accommodate the movement or mitigation of the liquefiable soil can be performed to reduce or eliminate liquefaction. Mitigation methods include ground improvement methods such as excavating the liquefiable soils and replacing them with non-liquefiable soils, or installing stone columns, or performing deep soil mixing.

Some sites within the City also have a risk of experiencing surface rupture as a result of movement along the Seattle fault (USGS, n.d,). An EERI study from 2005 for a 6.7M event on the Seattle Fault indicates surficial uplift could be as much as 6.5 feet. It is difficult to predict where this would occur and if the ground rupture would manifest itself at the ground surface. Fault locations are provided in Figure 19 of the Existing Conditions Report. It should be noted that the dotted lines showing the fault locations indicate that the fault is moderately constrained and that there is still uncertainty as to the actual location of the faults. An evaluation to assess for signs of a surface expression of the fault should be considered as part of a seismic hazard assessment properties near mapped fault lines.

Lastly, there is potential for sites near Lake Sammamish to experience inundation from tidal waves. Seiches could also form if the Seattle Fault were to experience surficial fault rupture within the lake. Since the Seattle fault bisects the southern half of Lake Sammamish, a sudden elevation rise of nearly 7 ft would displace an enormous volume of water resulting in a seiche of the water body. Lake Sammamish is bordered by residential structures with limited access to vertically evacuate up the plateau if required. There has been no true study of the consequences of a seiche in Lake Sammamish, nor has modelling been completed to highlight vulnerabilities to infrastructure and property on the lakefront. If a seiche were to occur there would be limited to no time to alert and warn threatened populations, and lives and structures would be at risk. A seiche may also impact East Lake Sammamish Parkway, which is a primary transportation arterial of the jurisdiction.

5.3 Protection Strategies

The primary goal of protection measures for geologic hazards is to ensure adequate protection is in place for people and property. Although the general approach is to avoid disturbing geologic hazard areas, WAC 365-190-080(4) describes that "*some geological hazards can be mitigated by engineering, design, or modified construction or mining practices so that risks to health and safety are acceptable*."

Common protection strategies that are applied to geologic hazards, including use of Best Management Practices (BMPs), requiring site-specific evaluations by a licensed geotechnical professional, and establishing minimum buffer requirements and development standards for structures adjacent to geologically hazard areas. The primary mechanism for protecting people and property is reducing the overall risk by limiting the occupancy and citing of development, particularly of essential or hazardous facilities.

Erosion, landslide, and seismic hazards can be mapped and classified to ensure appropriate protections are applied. The classification systems can be used by regulatory authorities to determine appropriate site limitations and development requirements.

5.3.1 Report Requirements

If development is proposed within or adjacent to a designated erosion or landslide hazard area, rigorous design and construction standards should be applied to ensure that the existing slope stability is maintained or improved. Any development within a designated hazard area or its required buffer should be evaluated on a site-specific basis by a licensed geotechnical engineer or engineering geologist, as outlined above. Data used in such analyses should be site-specific and include subsurface exploration and testing of soils at an appropriate frequency across the site.

5.3.2 Development Restrictions

Following the Oso mudslide that occurred in Snohomish County in March 2014, the State Route (SR) 530 Landslide Commission prepared several findings and recommendations to aid in the regulation of land uses in geologically hazardous areas. The commission included that “the Legislature significantly expand data collection and landslide mapping efforts, which will provide the foundation for sound public and private land-use planning and decision-making” (SR-530 Landslide Commission 2014). The findings of the SR-503 Landslide Commission included that updates to critical areas regulations are recommended to improve identification of geologically hazardous areas and regulations for land uses. Jurisdictions are encouraged to consider requiring geologic risk assessments as part of subdivision permit application reviews, requiring slope-density regulations, conservation easements, and clearing and grading ordinances (SR-530 Landslide Commission 2014). Slope-density calculation is a method for determining the number of allowable development units of subdivisions that have geological hazards present. The greater the slope, the fewer buildings or units are allowed to be built on it. The exact slope at which building restrictions apply varies depending on local regulations and other site-specific factors.

The recommendations from the SR-530 Landslide Commission also include:

- Integrating and funding Washington’s emergency management system;
- Supporting a statewide landslide hazard and risk mapping program;
- Establishing a geologic hazards resilience institute;
- Conducting landslide investigations, and;
- Advancing public awareness of geologic hazards.

Integration of Washington’s emergency management system would connect, “*the Governor’s office, the [State] Legislature, tribes, county and municipal government, first responders, transportation agencies, non-government support agencies, the private sector, and members of the public*” (SR-530 Landslide Commission 2014). To improve the accuracy of landslide hazard mapping resources, it is encouraged to collaborate among agencies and landowners, in addition to completing risk prioritization and utilizing LiDAR mapping and GIS-based tools. Further, the Commission recommends the governor establish a geologic hazards institute focused on education, outreach, research needed, and best professional practice guidelines (SR-530 Landslide Commission 2014).

Seismic hazards can be managed by applying earthquake resistant building standards to areas that have been designated as at risk. The Washington State Building Code (WAC 51-50) offers guidance from the 2018 International Building Code (IBC) with amendments specific to the State, including several directly related to seismic standards. Additionally, jurisdictions could consider requiring that all new construction be designed to withstand the ground motion effects specified in the most recent versions of the International Residential Code (IRC) and International Building Code (IBC). The IRC and IBC specifications have been designed for a ground level acceleration of an earthquake that has a 1-in-2475 chance of occurring each year as mapped by the United States Geological Survey's National Earthquake Hazards Reduction Program. Adherence to these specifications can mitigate the risk from seismic hazards.

5.4 Climate Impacts and Mitigation

Geologically hazardous areas, particularly erosion hazard areas and landslide hazard areas, are vulnerable to impacts from changing precipitation patterns and associated stress on native trees, shrubs, and groundcover plants. When planning for geologic hazards, it is important to consider the impacts of climate change that may further increase the risk of geologic hazards. Geologically hazardous areas are likely to be impacted by increased flooding, sea level rise, and slope failures due to climate change. These risks are often exacerbated by increased occurrence of wildfires and erosion hazards (Commerce 2023).

5.4.1 Climate Change Stressors

Climate change models predict warmer, drier summers, and increased precipitation during other seasons. However, roughly the same amount of annual precipitation will occur, as heavy rains will be more common outside of the summer months (Dalton et al. 2013). Over-saturated soil from an increased magnitude and frequency of precipitation events will contribute to slope instability. Rainfall intensity and duration is considered a predictor for landslide events (Cheleborad et al. 2006, Washington DNR, 2020). Extreme precipitation events modeled by the UW Climate Impacts Group (CIG) are expected to increase in intensity and frequency as the climate changes (Morgan et al. 2021). Significant plant mortality from dry summer periods, in conjunction with heavy rains, will increase the risk of slope instability due to reduced vegetation rooted in hazard areas.

5.4.2 Resiliency Strategies

Strategies to mitigation climate change impacts for geologically hazardous areas may include:

- Encourage or require climate-informed design for development and infrastructure in or near geologic hazard areas (Washington DNR, 2020) including accounting for increased storm frequency.
- Require appropriate surface and ground water management practices for development near erosion and landslide hazard areas.
- Restrict vegetation removal within landslide hazard areas (Commerce 2023).

- Encourage utilization of soft shore protection strategies to the extent practicable.
- Identify and prioritize geologic hazards within the City, then update mapping as needed using current practices such as LiDAR and GIS database tools, and field observation.
- Keep in communication with the Governor's office to ensure the City is included in statewide collaborative efforts to manage geologic hazard area.

6 Wetlands

6.1 Definition

Wetlands are dynamic environments characterized by seasonally or permanently wet areas. Wetlands also have anaerobic hydric soil indicators and water dependent or water tolerant plant species. Implementation of the 1977 Clean Water Act amendment requires a scientifically based legally defensible wetland definition (Mitsch and Gosselink 2000).

The City of Sammamish defines wetlands (SMC 21.040.B.399) as those areas designated as wetland in accordance with the federal 1987 Wetland Delineation Manual (Environmental Laboratory, 1987) and the United States Army Corps of Engineers (USACE) Interim Regional Supplement for Western Mountains, Valleys, and Coast Region (USACE, 2010), or such other manuals adopted by the Washington State Department of Ecology (ECY) pursuant to RCW 90.58.380 and WAC 173-22-035, as amended.

> *Wetlands are areas that are inundated or saturated by surface or groundwater at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs and similar areas. Wetlands do not include those artificial wetlands intentionally created from nonwetland sites, including, but not limited to, irrigation and drainage ditches, grass-lined swales, canals, detention facilities, wastewater treatment facilities, farm ponds, and landscape amenities, or those wetlands created after July 1, 1990, that were unintentionally created as a result of the construction of a road, street, or highway. Wetlands may include those artificial wetlands intentionally created from nonwetland areas to mitigate the conversion of wetlands.*

6.2 Functions and Values

Wetland functions are the biological, chemical, and physical processes that occur within a wetland. Wetland values refers to the resources a wetland provides that are valued by society, either ecologically, economically, recreationally, or aesthetically.

The capacity of an individual wetland to perform functions is dependent upon multiple factors, including the wetland landform or hydrogeomorphic (HGM) class. For example, wetlands on slopes have less potential to store water relative to depressional wetlands. Wetland functions are dependent on the geomorphic and hydrologic characteristics of each wetland (Brinson 1993; Hruby 2014). Other factors that impact wetland functions are landscape setting, vegetation structure, hydroperiods, proximity to potential sources of pollution, and priority habitat corridors and connectivity. Wetlands naturally perform several functions at low-cost relative to engineered solutions, such as water storage, flood protection, water reserve, pollutant and nutrient retention, and provisional fisheries habitat; these are valued as human services (Hattermann et al. 2008).

For regulatory purposes, wetland functions and values are ranked in a rating system. The current BAS-based rapid assessment tool for wetland functions is the Washington State Wetland Rating System for Western Washington: 2014 Update (ECY Publication #14-06-029, Hruby 2014). The Ecology wetland rating system, broadly groups wetland functional values into three categories: 1) water quality functions, 2) flood storage or hydrologic functions, and 3) habitat functions (Sheldon et al. 2005; Hruby 2014). The functional score for each category is ranked as high, medium, or low. Each category assesses site potential to perform each function, relative to landscape setting, and value to society.

6.2.1 Water Quality Functions

Wetlands improve water quality by intercepting runoff, retaining inorganic nutrients, converting organic wastes, settling sediment and removing contaminants (Sheldon et al. 2005). Wetlands perform these functions to varying degrees depending on several factors including residence time of polluted waters, vegetation structure and density, and soil composition (Hruby 2014). Wetlands uptake nutrients, particularly nitrogen and phosphorus, and protect downstream areas from nutrient spikes. Wetland plants and microorganisms are known to uptake or remove nitrogen through the biochemical processes of nitrification and denitrification, which occur in aerobic and anaerobic conditions, respectively (Sheldon et al. 2005). According to Kerr et al. 2008, low oxygen concentrations that are common to wetland environments also make them particularly good sinks for copper. Studies of constructed wetlands has shown wetland plants remediate pharmaceuticals and personal care products (PPCPs) to various extents and provide some phytoremediation (Wang et al. 2019, Zhang et al. 2013).

6.2.2 Hydrologic Functions

Hydrologic wetland functions include groundwater recharge, reduction in peak surface water flows, reduced stream erosion, and flood-flow desynchronization (Sheldon et al. 2005). Flood-flow desynchronization is a landscape-scale process within a watershed where stored water is slowly released down-gradient after being retained in surface of groundwater (Hruby et al. 1991; Adamus et al. 1991). This has a cumulative impact on magnitude and intensity of peak flow events (Sheldon et al. 2005).

Urbanization, or increased impervious surface area within a drainage basin, commonly alters wetland hydrology by increasing or decreasing flows from the surrounding landscape (Sheldon et al. 2005). Those wetland hydrology changes are linked to other negative urbanization effects, such as stream channel erosion and downcutting, sediment deposition, and altered seasonal water regimes (Sheldon et al. 2005). Changes in wetland ponding depths, seasonal hydroperiods or water level flux can also impact wetland plant communities (Schueler 2000).

6.2.3 **Habitat Functions**

A diverse group of fauna depends on wetlands for at least a portion of their life cycle, including wetland-associated mammals, waterfowl, fish, invertebrates, reptiles, and amphibians (Kauffman et al. 2001, in Sheldon 2005). For example, the red-legged frog, a species withing a declining population throughout the Pacific Northwest, migrates from an aquatic habitat in late spring to adjacent woodlands in the summer (Van Staveren 2006). Several factors including buffer width and condition, vegetative structure, habitat interspersion, wetland hydroperiods, and landscape setting all impact wetland habitat functions (Hruby 2014).

Wetland habitat functions are also dependent on landscape-scale conditions. Several factors including buffer width and condition, vegetative structure, habitat interspersion, wetland hydroperiods, and connectivity between terrestrial and aquatic habitats in the landscape all impact wetland habitat functions (Hruby 2014). A study of wetland and non-wetland landscape matrix quality have on wetland vertebrates found that while species abundance generally increases in landscapes with more wetland areas, some species are more sensitive to the broader landscape condition, such as amphibians (Quesnelle et al. 2015). For example, native amphibian species richness has been negatively correlated with urban landscape attributes, including fragmentation (Guderyahn et al. 2016).

Cumulative impacts of direct and indirect wetland alterations, including hydrologic changes, compromised water quality, and habitat fragmentation tend to reduce the habitat functions and values an urban wetland provides (Sheldon et al. 2005, Azous and Horner 2010).

6.3 Protection Strategies

Wetlands are primarily protected through regulatory requirements at the local, state, and federal levels to avoid, minimize, and mitigate any impacts. Common BAS-based wetland protection strategies include regulatory protocols to identify and classify wetlands, assign buffer widths, and require impact avoidance and compensatory mitigation for any wetland or buffer impacts. Additionally, landscape-scale corridors can be protected by establishing corridor retention requirements for development proximate to a wetland complex.

6.3.1 Wetland Identification and Classification

To protect wetlands, they must first be identified by a qualified professional. Currently per SMC 21.04.040.B.399 and consistent with BAS, wetland delineations are conducted using the 1987 Corps of Engineers (Corps) *Wetlands Delineation Manual* (Manual) with the *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region Version 2.0* (Regional Supplement) (Corps 2010). The Regional Supplement provides greater detail on determining presence or absence of wetlands based on an examination of vegetation, soils and hydrology in our ecoregion.

The *Ecology Wetland Rating System for Western Washington* was first issued in 2004, annotated in 2006, and updated in 2014. Sammamish has adopted 2014 Ecology rating system in their current critical area regulations. The focus of the 2014 update was to change the scoring to a high, medium, or low ranking that better reflects the accuracy of this rapid assessment tool. Additional clarifications were added to the rating system guidance to incorporate annotations from the prior version (Hruby 2014).

Jurisdictional status of an area meeting wetland criteria according to the Manual and Regional Supplement can vary depending on the agency involved and the wetland definition applied. Wetlands are regulated at the local, state, and federal levels. For example, local and state agencies exclude constructed stormwater features. Whereas the Corps may still regulate certain features and conveyances to project water quality under the Clean Water Act.

The U.S. Supreme Court's Sackett opinion, release May 25, 2023, revised the definition of Waters of the United States (WOTUS) and impacts how the U.S. EPA and Corps determine jurisdictional wetland status. On August 29, 2023, the U.S. EPA adopted a final rule redefining WOTUS. However, Washington State Department of Ecology (ECY) continues to regulate wetlands, including isolated wetlands, under state laws, including the state Water Pollution Act and the Shoreline Management Act. Wetlands that are not regulated at the federal level will be reviewed and reviewed under State Administrative Orders (ECY n.d).

6.3.2 Wetland Buffers

Washington State Department of Ecology (ECY) defines a buffer as the land around a wetland that is capable of protecting the wetland from stressors present in the surrounding landscape (Hruby 2017). Wetlands are commonly protected from surrounding land uses through fixed buffer width requirements. Documented wetland buffer functions include moderation of stormwater inputs, sediment removal, pollutant settlement, microclimate, habitat for wetland-dependent fauna, habitat connectivity, and disturbance screening (Sheldon et al. 2005). Buffer functions vary depending on several factors, including the vegetation community present, gradient, soil conditions, and adjacent land use intensity (Sheldon et al. 2005). Ecology provides buffer width alternatives in *Appendix C: Wetland Guidance for Critical Areas Ordinance (CAO) Updates -Western and Eastern Washington* (ECY Publication

No. 22-06-014). The recommended buffer widths assume the buffer is vegetated with a native plant community appropriate to the ecoregion (Granger et al. 2005, modified 2018). Wetland buffer widths under current Sammamish Code (SMC 21.03.020(Y)) are based on wetland category, habitat functions score, and implementation of minimizations measures. This is similar to one of the BAS-based options in Appendix C of Ecology Publication No. 22-06-014.

A synthesis of scientific studies summarizing, among other wetland topics, effectiveness of various buffer widths relevant to Western Washington was published by the Washington State Department of Ecology (Sheldon et al. 2005). These studies focus on buffer widths relative to water quality functions, hydrologic maintenance, wildlife habitat, and disturbance barrier effectiveness. General studies on stream buffer widths were also deemed relevant to discussions of wetland buffer widths because a vegetated buffer often operates independently of the sensitive area it is intended to protect, particularly for "sink" functions such as sediment and pollutant removal. The effective buffer width ranges given below (Table 4) are broad and variations are largely dependent on buffer condition, landscape setting, and specific metrics. For example, buffer widths that can effectively maintain water quality functions differ for sediment removal, nutrient removal, and pathogen removal. Effective buffer widths for sediment removal vary by particle size (Sheldon et al. 2005). Generally, buffer widths recommended in the literature to protect a wetland varies depending on multiple factors, including land use intensity, habitat functions being protected, and pollutant removal necessary to protect water quality (Granger et al. 2005).

Current Ecology wetland guidance documents consistent primary factors to considers when determining buffer widths (ECY 2022):

- The wetland type and the functions needing protection (buffers filter sediment, excess nutrients, and toxics; screen noise and light; provide forage, nesting, or resting habitat for wetland-dependent species; etc.),
- The types of adjacent land use and their expected impacts, and
- The characteristics of the buffer area (slope, soils, vegetation)

As buffer determination options are reviewed, it is important to note that, "*Ecology's buffer width recommendations are based on the assumption that the buffer area is well vegetated with native species appropriate to the ecoregion*" (ECY 2022).

Three BAS-based wetland buffer alternatives are presented in Appendix C of Ecology Publication No. 22-16-014. Those buffer options are:

- Width Based on Wetland Category, Habitat Score, or Special Characteristics
- Width Based on Wetland Category and Modified by the Intensity of the Impacts from Proposed Land Use

- Width Based Only on Wetland Category

Ecology's latest wetland guidance for CAO updates was issued in October 2022 (ECY 2022). The guidance provides three BAS-based options for wetland buffer tables.

Ecology's preferred option, Option 1, provides the most flexibility and site-specific buffers. This option considers habitat score and includes the potential to reduce the buffer through provision of a habitat corridor and implementation of minimization measures to reduce the level of impact from the adjacent land use. Use of the lowest buffer widths under this option, shown in Table 4 below, requires the implementation of minimization measures. If an applicant chooses not to apply the applicable minimization measures, then an approximately 33% increase in the width of all buffers is required. Note that to use the reduced widths in Table 4, the protection of a wildlife corridor is also required between higher functioning wetlands that score six or more habitat points and certain other protected areas. If this cannot be provided, then a non-reduced (33% increase) buffer would be required for those higher functioning wetlands.

Table 4. Ecology Buffer Option 1 - Wetland buffer width requirements, in feet, if Table 5 is implemented and a habitat corridor is provided.

Category of Wetland	Habitat Score 3-5 points (corridor not required)	Habitat Score 6-7 points	Habitat Score 8-9 points	Buffer width based on special characteristics
Category I or II: Based on rating of functions (and not listed below)	75	110	225	NA
Category I: Bogs and Wetlands of High Conservation Value	NA	NA	225	190
Category I: Interdunal	NA	NA	225	NA
Category I: Forested	75	110	225	NA

Category of Wetland	Habitat Score 3-5 points (corridor not required)	Habitat Score 6-7 points	Habitat Score 8-9 points	Buffer width based on special characteristics
Category I: Estuarine and wetlands in coastal lagoons	NA	NA	NA	150
Category II: Interdunal	NA	NA	NA	110
Category II: Estuarine and wetlands in coastal lagoons	NA	NA	NA	110
Category III: All types except interdunal	60	110	225	NA
Category III: Interdunal	NA	NA	NA	60
Category IV: All types	40	40	40	NA

Table 5. Impact minimization measures

Examples of disturbance	Activities and uses that cause disturbances	Examples of measures to minimize impacts
Lights	• Parking lots • Commercial/industrial • Residential • Recreation (e.g., athletic fields) • Agricultural buildings	• Direct lights away from wetland • Only use lighting where necessary for public safety and keep lights of when not needed • Use motion-activated lights • Use full cut-off filters to cover light bulbs and direct light only where needed • Limit use of blue-white colored lights in favor of red-amber hues • Use lower-intensity LED lighting • Dim light to the lowest acceptable intensity
Noise	• Commercial • Industrial • Recreation (e.g., athletic fields, bleachers, etc.) • residential • Agriculture	• Locate activity that generates noise away from wetland • Construct a fence to reduce noise impacts on adjacent wetland and buffer • Plant a strip of dense shrub vegetation adjacent to wetland buffer
Toxic runoff	• Parking lots • Roads • Commercial/industrial • Residential areas • Application of pesticides • Landscaping • Agriculture	• Route all new, untreated runoff away from wetland while ensuring wetland is not dewatered • Establish covenants limiting use of pesticides within 150 ft. of wetland • Apply integrated pest management (These examples are not necessarily adequate for minimizing toxic runoff if threatened or endangered species are present at the site.)
Stormwater runoff	• Parking lots • Roads • Residential areas • Commercial/industrial • Recreation • Landscaping/lawns • Other impermeable surfaces, compacted soil, etc.	• Retrofit stormwater detention and treatment for roads and existing adjacent development • Prevent channelized or sheet flow from lawns that directly enters the buffer • Infiltrate or treat, detain, and disperse new runoff from impervious surfaces and lawns

Examples of disturbance	Activities and uses that cause disturbances	Examples of measures to minimize impacts
Pets and human disturbance	• Residential areas • Recreation	• Use privacy fencing • Planet dense native vegetation to delineate buffer edge and to discourage disturbance • Place wetland and its buffer in a separate tract • Place signs around the wetland buffer every 50-200 ft., and for subdivisions place signs at the back of each residential lot • When platting new subdivisions, locate greenbelts, stormwater facilities, and other lower-intensity uses adjacent to wetland buffers
Dust	• Tilled fields • Roads	• Use best management practices to control dust

Ecology Buffer Option 2 is based on category and the level of impact from the adjacent proposed or existing land use. This option necessitates inclusion of a table with levels of impacts from proposed land use types.

Table 6. Ecology Buffer Option 2 - Width of buffers based on proposed land uses

Wetland Category	**Land Use Impact**		
	Low	**Moderate**	**High**
I	150 ft	225 ft	300 ft
II	150 ft	225 ft	300 ft
III	75 ft	110 ft	150 ft
IV	25 ft	40 ft	50 ft

Finally, Ecology Buffer Option 3 is based solely on the category of wetland. It is the simplest to administer, however it is the least flexible and differs the most from the system in the current code.

Table 7. Ecology Buffer Option 3 - Wetland buffer width requirements based on wetland category

Wetland Category	Buffer
I	300 ft
II	300 ft
III	150 ft
IV	50 ft

Buffer option 3 is the least flexible and most conservative option (Table 7). It is a simple model to apply, but it does allow for more detailed project impact considerations.

Buffers options 1 and 2 allow for a more detailed review of the proposed project relative to land use intensity and specific wetland functions. Buffer option 1 is the most complex and the most flexible. In buffer option 2, land uses are designated as high, moderate, or low intensity. Dense residential development (>1 unit/acre), institutional, commercial, and high use recreation (e.g., ball fields) are considered high-intensity impacts. Moderate-intensity residential developments (1 unit/acre or less) and moderate-intensity open/recreational space (parks with paved trails) are examples of moderate-intensity land uses. Low-intensity land use would be open spaces or natural areas with unpaved trails for low impact activities like hiking (Granger et al. 2005; ECY 2022).

Recommended buffer widths vary widely depending on individual characteristics such as adjacent stressors, targeted functions, buffer condition, and species-specific habitat niche requirements.

Hydrology Maintenance

Vegetated wetland buffers can affect water quantity and hydrology in the wetland by moderating the input of runoff in several ways. Vegetation slows the movement of water from above and outside of the buffer, allowing the water to infiltrate into the soil. This slows or desynchronizes hydrologic inputs into the wetland. Leaf and other vegetative litter on and in the soil also capture water and improve the soil's infiltration capacity (Castelle et al. 1992b). Depending on the size of the basin, the type of wetland, and the degree to which stormwater falling on impervious surfaces is routed away from the buffer (either directly to the sensitive area protected by the buffer, to a detention or infiltration pond, or to some other facility), the contribution of a specific buffer to water quantity maintenance in a wetland may be high or low (McMillan 2000). Buffer characteristics that influence performance of hydrologic maintenance are: "vegetation cover, soil infiltration capacity, rainfall intensity and antecedent soil moisture conditions" (Wong and McCuen 1982).

Buffers also function to control erosion by slowing water flow and allowing greater time for infiltration. Buffer vegetation can reduce erosion by capturing sediment before it enters the wetland, through soil stabilization by roots, and reduction in rain energy by both the vegetation canopy and organic material on the soil (Castelle et al. 1992b). The plant species growing in buffers are an important factor in the buffers' ability to perform this function. Plants with fine roots are most effective at preventing erosion by binding the soil (Kleinfelter et al. 1992, in McMillan 2000).

Water Quality Improvement

As detailed in Ecology's *Wetlands in Washington State, Volume 1: A Synthesis of the Science* publications, buffers protect water quality in wetlands through removal of sediment and suspended solids, nutrients, and pathogens and toxic substances (Desbonnet et al. 1994; McMillan 2000; Castelle et al. 1992b; in Sheldon et al. 2005). Performance of the water quality improvement function depends on a number of variables, including slope, vegetation composition, leaf and wood litter, soil type, and the type of pollutant (Desbonnet et al. 1994). In general, optimum performance could be achieved with a diverse mix of trees, shrubs and groundcovers; poorly drained clay-loam soils with organic content; abundant downed wood and leaf litter; and no slope. Sediment and pollutants can either be prevented from reaching the wetland through physical mechanisms, such as wood or leaf litter holding or binding these materials, or through chemical and biological means, such as breakdown or uptake of certain pollutants by root systems or microorganisms in the soil (Desbonnet et al. 1994; McMillan 2000; Castelle et al. 1992b). Buffer vegetation can reduce sediment input to the wetland through stabilization of soils by roots, and reduction in rain energy by the vegetation canopy and organic material on the soil (Castelle et al. 1992b). Shading and wind reduction by buffer vegetation also influences water quality by maintaining cooler temperatures. Water temperature in wetlands can be critical to survival of aquatic wildlife species, but more importantly from a water quality perspective, it helps maintain sediment-pollutant bonds, increases the water's dissolved oxygen capacity (McMillan 2000), and limits excessive algal growth (Castelle et al. 1992b; Sheldon et al. 2005).

Desbonnet et al.'s (1994) literature summary concluded that approximately 70 percent or greater sediment and pollutant removal was obtained at buffer widths between approximately 65 and 100 feet. Between 60 and 70 percent of sediment and pollutant removal, except for phosphorus, occurs in buffers between 25 and 50 feet (Desbonnet et al. 1994). Phosphorus removal efficiencies of 60 percent or more are found in buffers greater than 40 feet wide (Desbonnet et al. 1994). McMillan's (2000) summary analyzed a range of buffer widths by specific water quality function and identified the following effective buffers: 5 to 100 meters (16 to 330 feet) for sediment removal; 10 to 100 meters (33 to 330 feet) for nitrogen removal; 10 to 200 meters (33 to 656 feet) for phosphorus removal; and 5 to 35 meters (16 to 100 feet) for bacteria and pesticide removal (Sheldon et al. 2005).

Wildlife Habitat

Vegetated wetland buffers provide essential habitat for a wide variety of wildlife species, particularly those that are wetland-dependent, but require adjacent upland habitat for some part of their life cycle (e.g., some amphibians, waterfowl, some mammals). They also provide habitat for non-wetland-dependent species that prefer habitat edges, use the wetland as a source of drinking water, or use the protected buffer corridors to travel between different habitats. Studies have been done to determine necessary wetland buffer widths for wildlife in general, for particular species, and for particular life stages of particular species.

The recommended buffer widths range widely in the literature and are clearly species dependent. For example, a study conducted in urban King County (Milligan 1985) found that bird diversity was positively correlated with vegetated buffers of 50 feet or greater. One literature summary reports an effective buffer range of 50 feet (15 m) for many bird species up to 3,280 feet (1,000 m) for native amphibians (Milligan 1985 and Richter 2001, in Sheldon et al. 2005). A large number of studies recommend buffers between 150 and 300 feet (WDW 1992, in Castelle et al. 1992b). Triquet et al. (1990, in Desbonnet et al. 1994) recommend minimum buffer widths of 50 to 75 feet to provide general avian habitat. A minimum recommended wildlife corridor is 98 feet (Shisler et al. 1987, in McMillan 2000), although 490 feet was also recommended as a minimum travel corridor by Richter (1997). The generally recommended buffer widths for habitat protection range between 50 and 300 feet depending on factors including wetland habitat conditions, target species, buffer condition, and surrounding land uses (Sheldon et al. 2005).

Disturbance Barrier

Dense, vegetated buffers also provide a barrier between a wetland and the various vectors for human encroachment, including noise, light, trampling of vegetation, and the introduction of garbage and other pollutants. Buffer widths necessary to effectively reduce impacts vary by intensity of the adjacent land use. Buffer widths of 49 to 98 feet can effectively screen low-intensity land uses, such as agriculture and low-density residential. High-intensity land use, such as high-density residential (more than 1 unit/acre), commercial and industrial, require buffer widths of 98 to 164 feet (Shisler et al. 1987 in Sheldon et al. 2005). The buffer itself, and the functions that it provides, is subject to human-related disturbance. Cooke (1992, in Castelle et al. 1992a) found that buffers less than 50 feet wide experienced the most loss of buffer function related to human disturbance, and this loss is related to gradual reduction in buffer width as adjacent land uses encroach.

6.3.3 Mitigation

Mitigation Sequencing

Mitigation sequencing requires project applicants to first avoid all feasible wetland and buffer impacts, then to minimize unavoidable impacts, and lastly to mitigate unavoidable impacts. This is consistent with federal directives to achieve no-net-loss of wetland functions and values. Mitigation sequencing is also stated in the U.S. Environmental Protection Agency (EPA) issued 2008 Wetlands Compensatory Mitigation Rule and the WAC 197.11.768. As described in the *Wetland Guidance for Critical Areas Ordinance (CAO) Updates -Western and Eastern Washington* (ECY Publication No. 22-06-014), mitigation must be applied in the following order:

1. "Avoiding the impact altogether by not taking a certain action or parts of an action;
2. Minimizing impacts by limiting the degree or magnitude of the action and its implementation, by using appropriate technology, or by taking affirmative steps to avoid or reduce impacts;
3. Rectifying the impact by repairing, rehabilitating, or restoring the affected environment;
4. Reducing or eliminating the impact over time by preservation and maintenance operations during the life of the action;
5. Compensating for the impact by replacing, enhancing, or providing substitute resources or environments; and/or
6. Monitoring the impact and taking appropriate corrective measures." (ECY 2022)

Compensatory Mitigation

The loss of the entire wetland is not the only type of impact that requires compensatory mitigation; the area of impact, degree of alteration and degree of impacts compared to the overall size of wetlands can all adversely affect wetland functions which can have repercussions throughout the watershed (ECY 2021; Bendor 2009). Additionally, though federal agencies don't strictly regulate wetland buffers, any impacts to wetland buffers are indirect wetland impacts which can reduce the level at which a wetland performs functions, even if the wetland itself continues to meet wetland criteria (ECY 2021).

The current approaches to compensatory wetland mitigation include programmatic mitigation, such as wetland mitigation banks and in-lieu fee programs, and permittee-responsible mitigation. Required mitigation ratios are based on wetland category, function, special characteristics, risk and temporal loss (ECY 2022). Most ratios require a greater area for mitigation than the impacted wetland area, which is intended to help offset both the risk that the compensatory mitigation will fail and the temporal loss of functions that may occur (Ecology 2022). The requirements for any mitigation plan must demonstrate "no net loss" of ecological function in the project area. While preservation does not directly support the goal of "no net loss". Preservation is another method utilized to provide compensatory mitigation, usually in conjunction with other forms of mitigation activities (Hill 2013). Regulatory permits are issued with the view that wetland destruction and compensatory mitigation are concurrent and instantaneous, but delays are a common occurrence. However, recent studies suggest that the currently shortcomings of wetland permit systems is having no expectations to replace functions; the mitigation plan requirements target area over function (Adusumilli 2015). Delays initiating and completing restoration activities mean that large numbers of temporary wetland losses can compound into a consistent, temporary net loss of wetland acreage and function over time (Bendor 2009). The temporal lags slow the re-establishment of wetland functions. Any loss in wetland services over time is a function of the point at which one wetland is destroyed and the time taken for the mitigation wetland to attain full function (Bendor 2009). Both of these factors, as well as the inherent uncertainty in the outcomes of ecological restoration, influence the temporal net loss of function that occurs in the wake of mitigation projects (Bendor 2009). Hill et. al. (Hill 2013) studied the compensatory stream and wetland mitigation program for various sites to evaluate them for regulatory success. They found that the performance standards of mitigation plans often fell short of quantifying whether or not projects were on track to meet or had achieved the mitigation plan goals. They also found that preservation (which included the long-term protection of property with high-quality wetlands and streams) was the most successful mitigation activity for both wetlands and streams (Hill 2013).

In recent observations, Ecology is finding that wetland mitigation sites need to take steps to ensure long-term protection. Protection includes site ownership with legal mechanisms to prevent future development and buffers that serve to maintain wetland functions. Some examples of legal mechanisms to secure long-term protection are site ownership, deed restrictions and conservation easements (ECY 2022). The most effective long-term protection is to place the wetland and buffer in a non-buildable tract that is owned and maintained by an organization dedicated to protecting them. Delineation, recording, and signage clearly denoting the buffer and wetland area helps prevent degradation over time (ECY 2022).

Monitoring

Evaluations of wetland mitigation outcomes found that most wetland mitigation does not fully replace impacted functions and falls short of the goal of no net loss (ECY 2008; Johnson et al. 2002). The goal of no net loss of wetland function cannot be achieved through mitigation alone, but may be met through a number of factors, including adequate monitoring and maintenance and appropriate performance standards. NRC (2001) identifies factors that reduce the risk of mitigation failure, such as detailed functional assessment, high success standards, detailed mitigation plans, larger bonds with up-to-date market values, high replacement ratios, and greater expertise.

6.4 Climate Impacts

6.4.1 Climate Change Stressors

It has been suggested that if wetlands were part of the successional pathway from open water to uplands, there would be good reason to consider them as possible ecotones or transitional habitats in a generic sense. Despite the changing vegetation pattern in some wetland types or under certain conditions, wetlands do not typically evolve into uplands, unless the hydrology is modified by humans (or the area filled), by a climactic change, or by catastrophic events (Tiner 2016). Today, more uplands are probably becoming wetlands due to natural processes, which is primarily occurring along the coasts and in northern climes. Wetlands play an important role in creating and maintaining community and ecosystem resilience to climate change.

Wetlands help offset climate change through carbon storage. Wetlands store carbon both in organic soil and tree biomass. Carbon storage in undisturbed wetlands is approximately twice as high as carbon storage in wetlands disturbed by human-driven land use changes (Nahlik 2016, Ecology n.d.). Bogs are important carbon sinks that are highly sensitive to disturbance, particularly stormwater discharges and changes in pH.

Climate-driven changes in hydrologic patterns and temperatures may cause hydroperiods of saturation or inundation in wetlands to change. This may cause some wetlands to lose seasonal ponding characteristics or to dry up entirely, whereas other wetlands may experience increased ponding (Halabisky 2017, Ecology n.d.).

Although wetlands are dynamic by nature, their ability to adapt to change is limited. Alterations in stormwater runoff conditions and changes to seasonal wetland hydrologic cycles can reduce the ability of wetland soil bacteria and plants to retain, process, and sequester pollutants (U.S. EPA 2015, Ecology n.d.). Native plant species distribution is being impacted by climate change; adaptive potential and climate tolerance for native plant species are being studied in the scientific community (Vose et al. 2012).

6.4.2 Resiliency Strategies

- Continue to encourage and incentivize direct wetland impact avoidance to maintain existing carbon storage.
- Continue to regulate wetland buffers to encourage and require width retention/limitations and enhancement with native vegetation. Both voluntary and required restoration planting should be paired with monitoring and maintenance that allows for dry season irrigation and adaptive management.
- Continue to manage and regulate stormwater infrastructure to avoid and minimize discharges of untreated runoff to wetlands.
- Apply increased protections to bog wetlands and associated buffers to prevent stormwater impacts that could change pH and alter sensitive plant communities.
- Encourage use of native plant stock grown under local conditions to increase resilience under climate stressors.

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7.3.2 Climate Change

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7.4 Frequently Flooded Areas

7.4.1 General

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