Prepared for:

City of Burien
400 SW 152nd St., Ste. 300
Burien, WA 98166

Burien Comprehensive Plan Update
BEST AVAILABLE SCIENCE REVIEW

October 2011
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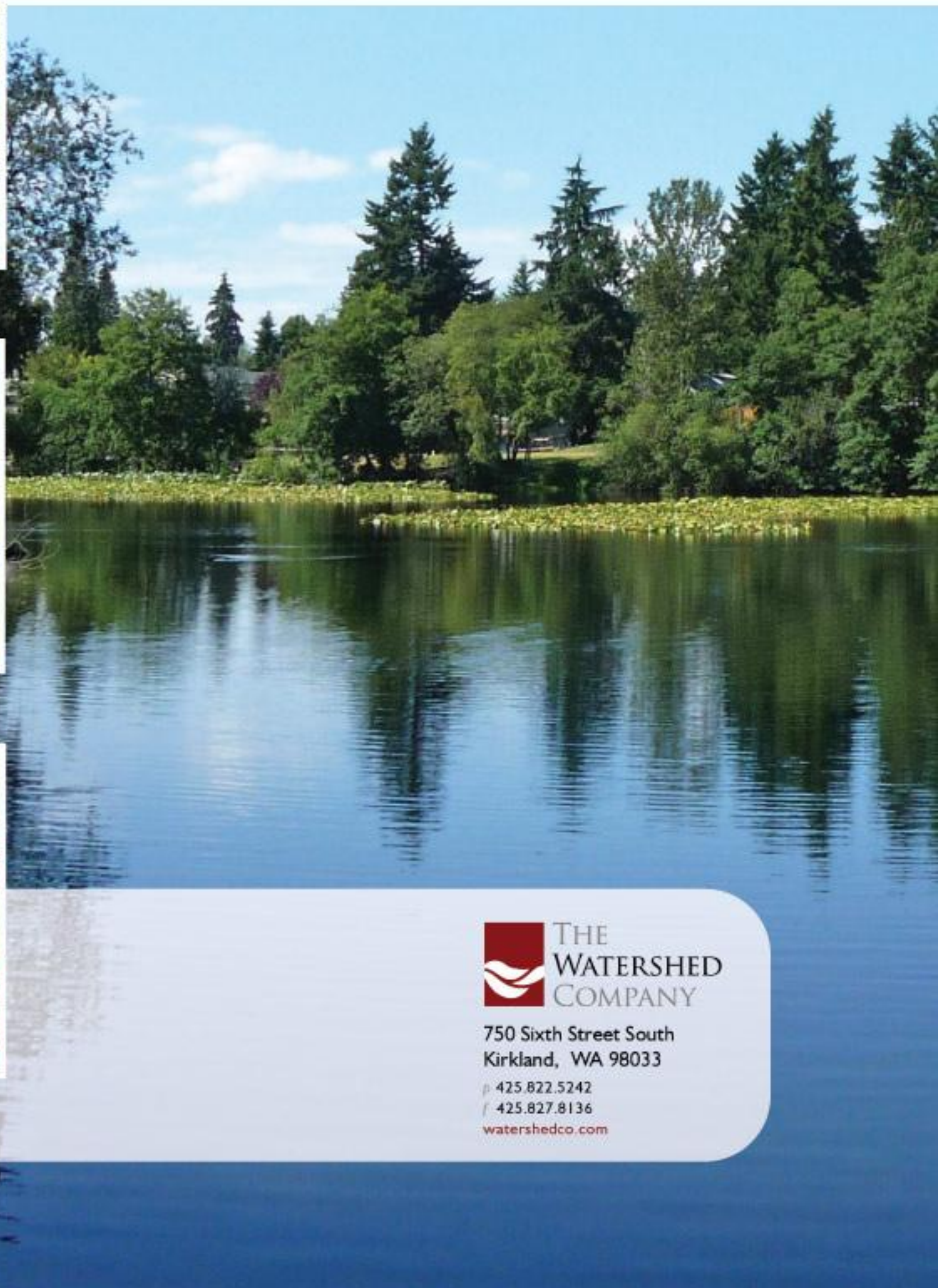

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BEST AVAILABLE SCIENCE REVIEW

CITY OF BURIEN COMPREHENSIVE PLAN UPDATE

1 INTRODUCTION

The Washington State Growth Management Act (GMA) mandates that cities and counties adopt policies and regulations to protect the functions and values of critical areas. Critical areas include geologically hazardous areas, frequently flooded areas, critical aquifer recharge areas, wetlands, and fish and wildlife habitat conservation areas (WAC 365-190-080). The GMA, as amended in 1995, further requires that cities and counties include best available science (BAS) in the development of such policies and regulations, as well as those measures taken to protect or enhance anadromous fisheries (WAC 365-195-900 *et sec*.). Inclusion of BAS in the development of locally appropriate policies and regulations must be balanced with the many other substantive goals and mandates of the GMA. Use of non-scientific information (e.g., social, legal, cultural, economic, or political) that results in departures from scientifically valid critical areas recommendations must be identified and justified, and potential consequential impacts must also be identified.

This report provides BAS for the planned update to the City of Burien Comprehensive Plan and will be incorporated by reference. This report briefly summarizes existing conditions within the City of Burien (City) and includes a BAS review of present critical areas beyond the jurisdictional area of Shorelines of the State; shorelines are covered under the City's Shoreline Master Plan (SMP). The description and analysis of existing conditions is limited to a paper review of critical areas mapping provided by the City and a brief targeted field review. There are five elements to this report: 1) geologically hazardous areas, 2) frequently flooded areas, 3) critical aquifer recharge areas, 4) wetlands, and 5) fish and wildlife habitat conservation areas.

This BAS review is intended to guide the development of policy in the Comprehensive Plan and new CAO language in the City of Burien Municipal Code (BMC, Chapter 19.40, Critical Areas). Local factors, including projected growth, the nature and intensity of land uses within the City, natural resources at risk, and the ability of the City to implement its CAO, should be considered during the update process (Ecology 2010).

2 GEOLOGICALLY HAZARDOUS AREAS

According to RCW 36.70A.030, Geologically Hazardous Areas are "those areas that are susceptible to erosion, sliding, earthquake, or other geological events and are not suited to the siting of commercial, residential, or industrial development consistent with public health and safety concerns". The four main types of geologically hazardous areas recognized in the GMA are 1) erosion hazard areas; 2) landslide hazard areas; 3) seismic hazard areas, and 4) areas subject to other geologic evens such as coal mine hazards and volcanic hazards.

In contrast to most other GMA-mandated critical areas, where the goal is to protect a valued resource like a wetland or stream, the purpose of regulating activities in geologically hazardous areas is not to protect the area, but to protect the public from the hazard represented by the area. These areas are subject to periodic events that can result in property damage, injury and the loss of life. Human activity in these areas can pose a safety concern, and, in some cases, may actually increase the potential for a hazardous event. Such hazard events have the potential to affect not just one property, but also the neighboring properties. For example, improperly clearing a parcel in a sloping landslide area may increase the potential for a landslide that could damage not only the cleared property, but also the neighboring properties above and below it. Therefore, it is important to identify where such hazard areas are, and to ensure that activities and development in those areas is appropriate.

GMA Guidelines indicate 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" [WAC 365-190-080(4)]. However, the same section of the code also states that "When technology cannot reduce risks to acceptable levels, building in geologically hazardous areas is best avoided."

The geology and topography within the City of Burien combine to create several of the types of geologically hazardous areas. Steep slopes in the glacial deposits in the western portion of the City pose a potential landslide hazard, while shoreline areas and areas adjacent to steep streams pose an erosion hazard. Seismically, hazards tend to be greater in soft, unconsolidated deposits of peat and other bog-like material, which are present within the City, and the shoreline may be subject to tsunamis. Coal mine and volcanic hazards, however, are unlikely in the Burien area, given the lack of exposed rock for mining and location of Burien relative to the Cascade volcanoes.

Steep slopes and other geologically hazardous sites that pose an erosion, landslide or seismic hazard should be included in critical area regulations to reduce potential risks to public health and safety. Mass wasting events can also be detrimental to habitat, particularly in-stream habitat. Landslide hazards include areas with all three of the following characteristics: slopes steeper than 15 percent, hillsides intersecting geologic contacts with relatively permeable sediment over relatively impermeable sediment or bedrock, and springs or groundwater seeps. Any areas where the slope is "40 percent or steeper and with a vertical relief of ten or more feet except areas composed of consolidated rock" is also deemed a steep slope which poses a landslide hazard (WDC 2003).

To reduce the risks associated with steep slopes, several local jurisdictions, including King and Snohomish Counties, require a 25-foot buffer from the top and toe of steep slopes. City of Burien currently requires a standard 50-foot buffer on steep slopes, which may be reduced by the Director if specific criteria are met (BMC 19.40.290). These regulations are consistent with literature, which suggests that buffers be established around mapped landslide hazard areas (DNR 1997).

2.1 Identification and Classification

2.1.1 Erosion Hazard Areas

Erosion Hazard is the susceptibility of the land to the prevailing agents of erosion (Houghton and Charman 1986). For Burien, such agents are primarily water action, in the form of streams and Puget Sound shoreline areas. The magnitude of the hazard is determined by a variety of factors, including the soil type, topography, vegetation, rainfall patterns, and basin-wide land use and development patterns. In a coastal setting, prevailing storm wind direction and fetch influence wave direction and size, and resulting erosion patterns (Easterbrook 1993).

Erosion hazard areas include areas likely to become unstable, such as bluffs, steep slopes, and areas with unconsolidated soils (WAC 365-190-120). Erosion hazard areas may also include coastal erosion areas mapped in the Coastal Zone Atlas (Washington State Department of Ecology).

Retaining healthy vegetation is one of the most effective ways to reduce the impacts of erosion. According to Shipman (2004) significant erosion in the region is typically limited to those areas where runoff has been concentrated by human activity or where vegetation has been removed from erodible soils. Such vegetation prevents a significant amount of rainfall from reaching the soil where it can cause erosion. In addition, the root structure of such vegetation mechanically binds the soil together, helping to further prevent erosion.

2.1.2 Landslide Hazard Areas

Landslides include a wide variety of processes that involve the downward and outward movement of slope-forming material by sliding, toppling, falling, or spreading (USGS, 2004).

Landslide hazard areas are well described in the WAC (365-190-120)

Landslide hazard areas include areas subject to landslides based on a combination of geologic, topographic, and hydrologic factors. They 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:

1) *Areas of historic failures, such as:*
    a. *Those areas delineated by the United States Department of Agriculture Natural Resources Conservation Service as having a significant limitation for building site development;*
    b. *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*
    c. *Areas designated as quaternary slumps, earthflows, mudflows, lahars, or landslides on maps published by the United States Geological Survey or Washington department of natural resources.*
2) *Areas with all three of the following characteristics:*
    a. *Slopes steeper than fifteen percent;*
    b. *Hillsides intersecting geologic contacts with a relatively permeable sediment overlying a relatively impermeable sediment or bedrock; and*
    c. *Springs or groundwater seepage.*
3) *Areas that have shown movement during the holocene epoch (from ten thousand years ago to the present) or which are underlain or covered by mass wastage debris of this epoch;*
4) *Slopes that are parallel or subparallel to planes of weakness (such as bedding planes, joint systems, and fault planes) in subsurface materials;*
5) *Slopes having gradients steeper than eighty percent subject to rockfall during seismic shaking;*
6) *Areas potentially unstable as a result of rapid stream incision, stream bank erosion, and undercutting by wave action, including stream channel migration zones;*
7) *Areas that show evidence of, or are at risk from snow avalanches;*
8) *Areas located in a canyon or on an active alluvial fan, presently or potentially subject to inundation by debris flows or catastrophic flooding; and*
9) *Any area with a slope of forty percent or steeper and with a vertical relief of ten 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 ten feet of vertical relief.

In the Puget Sound region, one of the more common settings for landslides is where relatively permeable materials such as sand and gravel overlies less permeable material, such as bedrock or dense silt and clay, especially where such materials are on a slope. Water that infiltrates through the upper layer, but cannot penetrate the lower layer as quickly, builds up at the interface between the two layers (Menashe 1993). This water adds weight to the slope and causes a loss of cohesion, which allows the slope to fail.

Vegetation can play a significant role in landslide potential. In areas described above, where permeable soils overlie less permeable substrate, dense vegetation can intercept a significant amount of rainfall, preventing it from infiltrating into the soil. Roots from vegetation also take up and transpire some of the water that does reach the soil.

The Coastal Zone Atlas (Washington State Department of Ecology) maps areas of instability, typically indicate erosion hazard areas, landslide hazard areas, or both. In a coastal setting, landslides may also be triggered by wave energy attacking the toe of a steep slope, removing material and causing the slope above to collapse, though extensive armoring of the marine shoreline in Burien makes this type of landslide event unlikely. During a storm event, with rain and wind combined, saturation of the permeable layer and wave attack of the toe of the slope may occur simultaneously.

The City's Critical Areas maps include a more comprehensive mapping of landslide hazard areas.

2.1.3 Seismic Hazard Areas

Per WAC, Seismic Hazard areas includes areas subject to severe risk of damage as a result of ground shaking, slope failure, settlement or subsidence, soil liquefaction, surface faults or tsunamis that are caused by an earthquake. It goes on to stipulate that ground shaking is the primary cause of earthquake damage in Washington, and that such shaking can cause the ground to settle. The strength of ground shaking is primarily affected by the magnitude of the earthquake, the distance from the source of the earthquake, the type or thickness of the surface materials, and the type of geologic structure affected (WAC 365-190-120 (7).

Western Washington is part of the "Ring of Fire", a series of tectonic plate boundaries that more or less outlines the Pacific Ocean. Where tectonic plates meet, they do one of three things: converge, diverge, or slide past each other laterally. In Western Washington, the last remnant of the Juan de Fuca plate is converging with the North American plate. The Juan de Fuca plate is an oceanic plate, while the North American plate is a continental plate. Oceanic plates are made of more dense material than continental plates, and where the two types of plates converge, the oceanic plate is driven under the continental plate. Such is the case in Western Washington, part of the Cascadia Subduction Zone, defined as the area affected by the subduction of the Juan de Fuca plate under the North American plate. This subduction is the primary driver of seismic activity in the Pacific Northwest.

Subduction zones are responsible for most of the largest magnitude earthquakes, including the recent Tohoku earthquake in Japan, (9.0 magnitude), the Alaskan earthquake in 1965 (9.2 magnitude) and Great Chilean earthquake of 1964 (9.5 magnitude). In the book *The Orphan Tsunami of 1700*, Brian Atwater, et al. (2005) provides evidence that a Cascadia subduction zone earthquake occurred on January 26, 1700 and was, per his estimate, in the 8.7-9.2 magnitude range. The precision of the date stems from records of a tsunami in Japan that was caused by the quake. There is geologic evidence for 13 or more of these "great quakes" in the Cascadia subduction zone, occurring at intervals ranging from 300-900 years apart.

In addition to these "great quakes", lesser, but still potentially damaging quakes occur in the region on a more frequent basis, including the 2001 Nisqually quake and the 1965 Olympia quake. These and other, smaller earthquakes are associated with smaller faults that occur in the Puget Sound region. One such fault is the Seattle Fault Zone, which runs roughly east-west from near Fall City to Hood Canal (Blakely et al. 2002; Blakely et al. 2009). Historical evidence indicates that the Seattle Fault has produced earthquakes of approximately magnitude 7. While a magnitude 7 earthquake releases only 1% of the energy of a magnitude 9 earthquake, the proximity of the smaller earthquakes and their shallower depth can produce a great deal of ground motion, especially on susceptible soils.

Unconsolidated material, either natural (i.e. river sediments) or artificial, tends to be affected more by ground shaking than consolidated material or rock. The thickness of such layers may also play a role in the amount of motion that the area experiences. In some cases, the frequency of the earthquake waves may create a resonance in a sediment layer of the proper thickness, creating greater ground motion in a localized area than in other nearby areas where the layer is more or less thick and resonance does not occur. Similarly, underlying geologic structures may serve to focus earthquake seismic waves, depending on depth and frequency (Langston and Lee 1983).

2.1.4 Other Geologically Hazardous Areas

Other geologically hazardous areas include areas subject to potential volcanic hazards, and areas where old coal mines may pose a hazard, per WAC 365-190-120 (8). Volcanic hazards can include pyroclastic flows, debris avalanches, debris flows, and flooding associated with volcanoes. Mine hazards can include areas that are underlain by mines, air shafts, etc. which can pose a threat of collapse and subsidence or simply a falling hazard.

Volcanoes in Washington are the result of the subsidence of the Juan de Fuca plate under the North American continent (see also 2.1.3 above). As the oceanic plate is forced under the continental crust, heat from the earth begins to melt the rock, starting with those minerals with the lowest melting point, such as quartz and feldspar. This melted material is less dense than the surrounding material and rises upward, and where it can reach the surface, a volcano is formed.

There are five Cascade volcanoes – Mt. Adams, Mt. St. Helens, Mt Rainer, Glacier Peak, and Mt. Baker. Of these, Mt. Rainier is in closest proximity to Burien at approximately 55 miles. The next closest is Glacier Peak, approximately 75 miles away. Lahars, which are mudflows or debris flows caused by the rapid melting of mountain snow from a volcanic eruption or other volcanic activity, have historically traveled similar distances – along the Green River from Mt Rainier, and along the Sauk and Skagit rivers from Glacier Peak. However, lahars are driven by gravity, and flow along the lowest ground. Burien, located on high ground west of the Green River valley, is therefore insulated from lahar hazards. Pyroclasitc flows and debris avalanches occur only within close proximity to their source, and are therefore not a hazard in Burien.

Coal, and therefore coal mines, generally occurs in Paleozoic era sedimentary rocks, primarily from the appropriately named Carboniferous period. Coal mining was once an important activity in Western Washington, with some of the larger mines around Black Diamond, Newcastle, Carbonado and Centralia (McCarty 2003). However, the Burien area is mantled in a deep layer of glacial sediments, with no known outcroppings of rock of any type, much less coal-bearing sedimentary rock. The lack of rock makes coal mine hazards inapplicable in Burien.

2.2 Functions and Values

2.2.1 Erosion Hazard areas

Erosion occurs when wind, streamflow, waves or even ice move particles from where they had previously rested. Erosion is part of the process that builds floodplains and beaches, enables channel migration on rivers and streams, and facilitates the recruitment of woody debris into streams and other bodies of water. Material that is transported via erosion is carried with the flow of the medium that caused the erosion until that medium no longer has sufficient energy to carry the material, at which point the material is deposited. In a stream, this results in the migration of sediment from upstream to downstream. In a beach setting, the waves create a back-and-forth movement of sediment, though over time the sediment will move laterally along the shoreline with the direction of the prevailing wave force in a process called longshore drift.

In an urban setting, erosion can become a hazard when structures are placed in areas susceptible to erosion, or land use actions cause formerly stable areas to begin eroding. Urban development such as parking lots, roads and buildings, prevent rain from infiltrating into the soil, generating more rapid runoff from the land into nearby streams and rivers. This results in an increase in peak flow volumes in the streams (Booth, 1991), which in turn produces higher energy and increases the potential for streambank erosion.

Removal of vegetation can also contribute to increased erosion potential in susceptible areas. Vegetation intercepts rainfall, preventing a significant portion of rainfall from reaching the ground where it can cause erosion (Watson and Burnett, 1995). In cleared areas, the impact of rain drops can initiate the erosion process, freeing small particles to be carried downslope. As water accumulated on the ground, it tends to concentrate in small channels, and as the water gains in depth and volume, larger particles can be mobilized by the flow. In this way, small channels or rills can eventually develop into gullies.

2.2.2 Landslide Hazard Areas

Landslides can occur in a variety of different ways, from fast to slow and deep to shallow, originating from the bottom of a slope or the top of a slope, or somewhere in between, and can range from being more water than earth to being more earth than water. A variety of classification schemes have been used to describe landslides. The classification by Varnes (1978) is likely the most widely used, and classifies slides by the type of movement and the material involve. A more simple classification, discussed in King County (2004), uses three basic types of landslides common to this area: 1) Rapid-Shallow, 2) Block Fall, and 3) Deep-Seated. As the names imply, a rapid-shallow landslide is one that does not extend deeply into the ground, and usually moves quickly down a slope. This is the most common type of landslide in the Puget Sound region, where the glacial deposits often result in surface layers that are more permeable then the deeper layers, causing water to build up on the interface between the two layers. The weight and pressure from the water causes the upper layer to fail, and slide over the deeper, more resistant layer. Block falls are common where erosion is occurring at the toe of a slope, either through wave energy or streamflow. As the toe is over-steepened, at some point the slope above the toe becomes unstable and the entire slope collapses as more-or-less a single unit. Deep-seated landslides are generally larger than the other types of landslide, and involve one or more large blocks of both soil and the underlying substrate moving together. Such slides can move extremely slowly, taking years, decades or longer to reach equilibrium. However, even moving slowly, such deep-seated landslides can cause significant damage to structures.

As with erosion hazard areas, activities associated with urban development, including vegetation removal, and increased impervious surfaces, can increase the hazard of susceptible areas. Vegetation can help reduce the amount of water reaching the soil, and can take up some of the water that does reach the soil (Watson and Burnett 1995), thereby reducing the amount of water that rests on the interface between the permeable and impermeable layer. 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.

Landslides deliver material from a higher elevation to a lower elevation. In most cases, landslides deliver material from the hillslopes into streams and rivers. Trees that are involved in the landslide often end up being delivered to these streams, rivers, and beaches, where they become important habitat. Such large woody debris (LWD) provides nutrients, shelter and shade, while helping to stabilize both stream channels and beaches.

2.2.3 Seismic Hazard Areas

In an earthquake, all the ground can be expected to move, but ground shaking is typically worse in areas where unconsolidated sediment, either naturally deposited or artificial, is present (Gerstel et al., 1997). However, in addition to the direct damage caused by ground shaking, a number of ancillary problems are also common with earthquakes.

Surface faulting is when movement along a fault causes a rupture in the ground surface. Such faulting can destroy buildings, make roads impassable, and sever underground utilities, including gas, electric, water, sewer, and communications. These utilities problems can lead to fires, flooding, sink holes, and contamination. Depending on the type of earthquake and the relative motion of the ground, movement along the faults can lead to subsidence and/or uplift along the fault line. During the 1964 Alaska earthquake, parts of the Gulf of Alaska were uplifted by 11 meters (36 feet) while other areas subsided by over 2 meters (Stover and Coffman 1993).

Ground shaking can also cause a number of different types of ground failure, including landslides, soil liquefaction, and settling (Keefer 1983). Landslides can be triggered when a marginally stable slope is subjected to ground shaking. Liquefaction occurs when saturated, loose, sandy soil is subjected to shaking.

Shaking causes the loose, sandy soil to compress, and if it is saturated (i.e. water fills all the spaces between soil particles), the water is displaced by the compressing particles and forced upwards. Under normal conditions, soil particles are in direct contact with each other, and that contact is what makes the soil capable of supporting a load like a building. But when liquefaction occurs, the pressure from the upward-migrating water breaks the contact between the soil particles, and the strength of the soil is lost, such that it behaves more like a liquid than a solid. Any buildings that rely on the soil for support (as opposed to pilings or other engineered structure) can essentially sink into the soil like quicksand. Where soils are not saturated, the compression can still lead to settling, which can break utility lines and, if such settling occurs unevenly under a building, may cause the foundation to break, or in severe instance, may cause the building to fail.

Tsunamis are another hazard associated with earthquakes. As was seen most recently in Japan, and before than in Indonesia, tsunamis can be as or more devastating than the earthquake that generated them. Tsunamis are simply fast-moving, long-wavelength waves in water that, when they approach land, can rise to great heights and wash inland for thousands of feet. They can be generated by rapid uplift or subsidence in the sea floor associated with an earthquake, or can be generated by large landslides, both above and below the water surface.

2.2.4 Other Geologically Hazardous Areas

Volcanic Hazards

The hazards associated with volcanoes include lava flow, volcanic gasses, lateral blasts, lahars, pyroclastic flows and surges, and tephra fall. Of these, only lahars and tephra fall can realistically be expected to impact an area as distant from a volcano as the City of Burien[1]. As discussed above, lahars are driven by gravity and follow river valleys, and are therefore unlikely to impact areas within the City of Burien, separated as it is from the Cascades by the Green River valley.

Tephra fall is the only volcanic hazard with the potential to impact the City of Burien. During the explosive eruptions typical of Cascade volcanoes, hot, pressurized volcanic gasses released by an eruption carry rock and ash into the

[1] Certain types of lava are hot enough and fluid enough to flow for several hundred miles. For example, the Grand Ronde group of the Columbia River basalts were extruded from volcanic vents in what is now the Tri-Cities area, and flowed from there to the Pacific Ocean (Lasmanis, 1991). However, that lava was basaltic, derived from mantle material, much like the volcanoes of Hawaii. By contrast, the Cascade volcanoes are derived from material melted as the Juan de Fuca plate is forced under the North American plate, and the resulting lava is considerably more viscous, so is unlikely to flow any great distance.

air. As the energy that carried the material upward dissipates, the particles begin to fall back to the ground, with the larger particles falling first and closest to the volcano, and the smaller particle being carried farther with the wind before depositing. The result is a thick deposit of coarse material nearest the site of the eruption, grading to thinner and finer deposits as the distance from the volcano increases (Wolfe & Pierson, 1995).

Prevailing winds in the vicinity of SeaTac Airport are from the south and SSW (Western Regional Climate Center), and as a result most tephra from Cascade volcanoes would not be carried to Burien. However, tephra is carried the direction of the wind at the time of the eruption, so if the eruption occurred during a time when the winds were blowing from the volcano towards Burien, tephra could be carried to the City of Burien.

2.3 Potential Impacts

The potential impact in geologic hazard areas is similar, regardless of the type of hazard – damage to property and/or people. Unlike other critical areas, where the potential impact is to a resource that is valued and being protected, with geologic hazards, the goal is to protect people and property from potential damage associated with the area.

2.3.1 Erosion Hazard Areas

The hazard from erosion-prone areas includes direct damage as a result of the erosion as well as increased risk from landslide as a result of erosion. During storm events and under other extreme conditions, erosion can happen very rapidly, putting at risk any structures located in the area being eroded, and potentially risking injury or death to people using such structures at the time of erosion.

Where erosion prone areas are on or adjacent to steep slopes, such as along a beach bluff or along a stream in a gully or ravine, erosion can remove enough material at the base of the slope to cause landsliding.

Along with erosion comes deposition. Erosion and deposition are natural processes for both streams and beaches, and the flora and fauna that use such areas are generally adapted to a certain level of erosion and deposition. However, excessive erosion, and resulting excessive deposition, can be harmful to stream channels, shorelines, and the plants and animals that use them. Erosion is one of the primary mechanisms for recruiting large woody debris to streams, and in Western Washington, such debris is highly beneficial to salmonids and other aquatic species. However, erosion also produces fine sediment, which can deposit in the gravels that many fish species use to spawn, causing eggs to suffocate and die.

2.3.2 Landslide Hazard Areas

The hazard associated with landslide prone areas includes damage to structures on the unstable slope, at the bottom of the slope where the material from a landslide deposits, and at the top of the slope that may be destabilized by the slide. During faster land sliding events, the danger of personal injury or death can be significant.

In addition to personal and property damage, landslides may have an adverse effect on plants and animals in the vicinity. Landslides, like erosion, are a natural phenomenon that is relatively common in the Pacific Northwest, and the flora and fauna of the region is adapted to landslides to a certain extent. However, persistent slides and an overabundance of slides can be harmful to a number of species. For example, landslides that produce abundant fine sediment can be damaging to fish that spawn in streams that receive the fine sediment.

2.3.3 Seismic Hazard Areas

Seismic hazards include both direct and indirect personal and property damage from earthquakes. Direct damage can vary from the relatively minor, such as broken glass, overturned furniture, and damage to brickwork (chimneys tend to be particularly vulnerable due to their height and narrow cross-section) and foundations to complete collapse of structures. Indirect damage can include fires triggered by broken gas and/or electric lines, loss of information from severed data lines, flooding from broken water lines, contamination and illness from leaking sewer lines, etc.

While in a large, subduction zone event, virtually all of Western Washington would be adversely impacted, those areas where soils and underlying geology would increase the magnitude of ground shaking would experience more severe damage. Ground shaking may also increase the hazard of landslide hazard areas by destabilizing marginally stable slopes, especially if the quake hits during or after a winter storm even when soil saturation levels peak.

2.3.4 Other Geologically Hazardous Areas

The only volcanic hazard likely to be experienced within the City limits is tephra fall. The major hazard potential from tephra fall are the impact from falling material, burial of structures and pathways, and the presence of abrasive materials in the air and water. Given the distance between Burien and any Cascade volcanoes, the impact potential is negligible, since larger particles fall nearest the volcano, and burial of structure would require a very severe eruption, since the depth of tephra decreases with distance from the volcano. However, volcanic ash can be problematic up to several hundred miles downwind of its source, causing eye and respiratory irritation, damaging engines on airplanes, automobiles, trucks, and trains, reducing visibility, and potentially shortcircuiting power transmission lines(King County, 2004). Such problems can occur during the initial ashfall, and later as wind and/or vehicles re-suspend ash particles. Additionally, wet ash on buildings can be heavy enough to cause roof damage or even collapse (Wolfe & Pierson, 1995). Ash suspended in water can also damage sewer treatment facilities.

2.4 Potential Protection Measures

A variety of measures can be taken to protect property and people from geologically hazardous areas. Careful planning and engineering can help to reduce the magnitude of, and maybe even prevent, certain erosion and landslide events from happening. Unfortunately, there is as yet no know way to prevent earthquakes or volcanic events, and even predicting such events is still a very imprecise endeavor. However, while such events cannot be prevented, the amount of damage that the events are likely to cause can be reduced or eliminated with proper planning and preparation. Identifying and mapping potential hazard areas is an important first step in developing protection measures.

2.4.1 Erosion Hazard Areas

Erosion Hazard Areas can be protected by promoting sound development practices. Temporary Erosion and Sedimentation Control (TESC) Plans and their associated Best Management Practices (BMPs) can be effective at preventing erosion associated with construction activities in erosion hazard areas.

Vegetation management is also an important component, since vegetation provides a good deal or protection against erosion (Fredricksen and Harr 1981, Gray and Sotir 1996, Menashe 1993). Vegetation protects soil on slopes from falling water, while the roots provide mechanical strength to the soil. On stream banks and shorelines, this root strength can protect against shear stress from waves and flow.

Development that concentrates flows or creates higher peak flows than in the pre-developed condition are likely to make erosion hazards more severe. This can be a localized effect (e.g. a homeowner that drains footings to a steep slope, causing erosion) or can be more drainage-basin in scale (e.g. parking lots in the upper basin causing higher peak flows downstream, increasing the potential for erosion from the parking lot outfall to all points downstream).

Erosion Hazard Areas should be mapped and classified based on their potential for erosion. King County hazard mapping includes the following 5 categories of hazard:

Slight. Indicates no appreciable erosion damage is likely to occur during and after the development or continuation of a particular land use under consideration. Soil conservation management should include simple practices such as rapid establishment of ground cover as soon as possible.

Moderate. Implies significant erosion may occur during development of a particular land use. Provided appropriate soil conservation measures are adopted during development, both short-term and long-term erosion problems may be avoided.

High. Implies significant erosion may occur. Intensive soil conservation measures are required to control erosion that will occur during development or continuation of a particular land use. Short-term measures are required in the initial stages of development. Long-term erosion control would involve intensive measures being implemented.

Very High. Implies that significant erosion will occur both during and after development of a particular land use is established, even with intensive soil conservation measures. Planning will need to carefully consider the balance between long-term erosion damage and the maintenance and repair needed to ensure the viability of the land use.

Extreme. Implies soil erosion will occur to such an extent that erosion control is impractical. These areas are best retained as green timber and not used. Where urban development proceeds in spite of this recommendation, detailed engineering, geotechnical and other studies will be necessary.

2.4.2 Landslide Hazard Areas

Buffers around landslide hazard areas, including the tops and toes of steep slopes, can be an effective way of preventing or limiting damage (Gerstel et al., 1997). If development is proposed within the buffer or slide area, rigorous design and construction standards should be adhered to in order to prevent the development from causing slope instability, either at the site or elsewhere on the slope. Any such development in the hazard area or its buffer should be evaluated on a site-specific basis by a licensed geotechnical engineer or engineering geologist. Data used in such analyses should be site-specific, and include subsurface exploration and testing of soils at an appropriate frequency across the site.

2.4.3 Seismic Hazard Areas

Given the difficulty in predicting where, when, and how large an earthquake will be, the safest course of action is to assume that a structure will at some point in its useful life be subjected to an earthquake. The Washington State Building Code (WAC 51-50) offers guidance from the 2009 International Existing Building Code with amendments specific to the State, including several directly related to seismic standards. Adherence to such guidance is an effective way to mitigate seismic hazards.

2.4.4 Other Geologically Hazardous Areas

King County has adopted a zonation approach to volcanic hazards, using three roughly circular zones that radiate outwards from volcanic centers, with each successively distant zone reflecting a lessening risk of hazard. All of the Burien city limits is in Zone 3, which is the least hazardous zone, where lahar deposits are the primary concern. As mentioned above, the risk of lahar deposits in any portion of Burien is negligible, given the vertical separation between the Green River, where such deposits would flow to, and Burien.

Tephra is essentially the only volcanic hazard that might face Burien. Zonation or mapping of such hazard areas is not necessary, since the entire City Limits would be equally prone to such a hazard.

2.5 Summary

Geologically Hazardous Areas within the City of Burien include areas of erosion hazard, landslide hazard, seismic hazard, and volcanic hazard. Unlike most other critical areas, the goal of regulating geologically hazardous areas is to reduce the risk of harm to people or property that are associated with such areas, rather than to protect those areas from being harmed or degraded.

The City has already identified landslide and seismic hazard areas on the April 2011 Critical Areas map. Erosion hazard areas may correspond with those or other mapped critical areas, but have not been specifically identified. Soil mapping typically gives a good estimation of erosion hazard areas.

Because the goal of identifying geologically hazardous areas is to protect human life and property, avoidance is often the best option. However, structural and engineering solutions can help to mitigate such hazards, if done appropriately and if properly maintained. Thorough geotechnical analysis and engineering design is critical to achieve such mitigation. Such analysis should include an assessment of the property in question as well as the properties surrounding the site. Also, since geologically hazardous areas are often interconnected, such analysis should include all the hazards likely to affect the site. For example, in a landslide hazard area on a slope above a creek, a proper analysis should include an assessment of the neighboring properties, as well as all the properties above and below the site on the slope, and should include an assessment of the potential for erosion from the creek at the bottom of the slope, as well as an assessment of the seismic stability of the site and the proposed structure.

It should also be mentioned that, unlike some other critical areas, off-site mitigation with respect to geologically hazardous areas does not generally make sense.

The only volcanic hazard that has the potential to impact the City is tephra fall from a Cascade volcanic eruption. No area within the City is particularly susceptible to such an event, nor are there areas within the City that are more likely than other areas to avoid impacts should such an event occur. Therefore hazard mapping of such areas is unnecessary. Prevailing winds and the infrequency of volcanic eruptions make such an event rather unlikely.

3 FREQUENTLY FLOODED AREAS

Frequently flooded areas are regulated to manage potential risks to public safety. Such areas also provide valuable habitat benefits in-streams and provide valuable downstream benefits as well. Flooding within the City of Burien, with its small to mid-sized streams, is most often triggered by heavy rains, and exacerbated by runoff from impervious surfaces related to development. Along the Puget Sound shoreline, high tides combined with low-pressure storm events can also cause flooding.

3.1 Identification and Classification

The City of Burien defines a flood as "a general and temporary condition of partial or complete inundation of normally dry land areas from: (a) the overflow of inland or tidal waters; and/or (b) The unusual and rapid accumulation of runoff surface waters from any source" (BMC 15.55.050(7)).

Expressed criteria for identification and classification of frequently flooded areas are provided in the Washington Administrative Code, WAC 365-190-110:

"Frequently flooded areas. Flood plains and other areas subject to flooding perform important hydrologic functions and may present a risk to persons and property.

(1) Classifications of frequently flooded areas should include, at a minimum, the 100-year flood plain designations of the Federal Emergency Management Agency and the National Flood Insurance Program.

(2) Counties and cities should consider the following when designating and classifying frequently flooded areas:

(a) Effects of flooding on human health and safety, and to public facilities and services;
(b) Available documentation including federal, state, and local laws, regulations, and programs, local studies and maps, and federal flood insurance programs, including the provisions for urban growth areas in RCW 36.70A.110;
(c) The future flow flood plain, defined as the channel of the stream and that portion of the adjoining flood plain that is necessary to contain and discharge the base flood flow at build out;
(d) The potential effects of tsunami, high tides with strong winds, sea level rise, and extreme weather events, including those potentially resulting from global climate change;
(e) Greater surface runoff caused by increasing impervious surfaces."

FEMA Mapping covering the City of Burien identifies Zone A floodplain in an area between SW 141st Street and SW 142nd Street, from approximately 6th Ave SW to Ambaum Boulevard. FEMA also identifies Miller Creek as Zone AE, and the lower portion of Miller Creek Tributary #1 as a Zone X Floodplain. The City's Critical Area map (updated April 19, 2011) includes those as "floodplain" areas mapped those areas identified as Zone A or Zone AE by FEMA, as well as the Puget Sound shoreline and the lower portion of Salmon Creek.

3.2 Functions and Values

Floods are a natural process, and the process by which floodplains are created. As a rule of thumb, a typical stream in equilibrium with its surroundings will tend to be sized so that it fills to the top of the banks about once per year (Leopold, 1994). As a result, when the stream flow is greater than the annual event, water will spill over the top of the banks. Streams carry sediment along with water, especially during flood events, and the amount of sediment that can be carried is a function of the velocity of the water. When water overflows the banks, its velocity slows compared to the water in the channel. As a result, the overbank flow drops its sediment load, which, over time, forms a flood plain.

Floodplains are dynamic and highly productive environments. Dynamic hydrologic processes, including mobilization of large woody debris and other allocthonous inputs, can be critical to the maintenance of fish and wildlife habitat. High flow channels carved into floodplains provide important habitat for a variety of fish species, creating areas of refuge from the high flows. Overbank flow serves as a short-term storage area for streams, helping to reduce the peak flood flows downstream of the flooding location. Some of the water on the floodplain infiltrates into the soil and contributed to aquifer recharge. According to the Washington State Department of Ecology (Ecology) such storage and infiltration may be a more cost effective way to address flooding problems than other structural solutions (Ecology 1991).

Frequently flooded areas are often regulated to reduce the risk to people and property (King County, 2004), typically by limiting development, requiring that structures be raised above flood levels, and requiring compensatory storage for any fill within the frequently flooded area. However, such areas often coincide with other critical areas, such as streams, wetlands, and aquifer recharge areas. Protecting frequently flooded areas therefore produces secondary benefits for habitat protection, especially when habitat is considered in locating, designing, installing, and maintaining flood control facilities (Bolton and Shellberg 2001).

3.3 Potential Effects of Development

As development occurs, stream channels are often straightened and armored to accommodate development within the urban grid. Flood protection measures, such as levees and dikes, may be built or maintained to protect structures and property in the floodplain from flooding events. These alterations impact floodplains and in some cases, disconnect them entirely from the stream they once served.

Increased impervious surfaces from buildings, driveways, roads, and the conversion of forest to lawn cause increases in peak flow magnitude and frequency (Booth 2002). These increases in surface water flow tend to scour or down-cut stream channels, which reduces floodplain connectivity and functions. (Bolton and Shellberg 2001). Such downcutting can, in some areas, lead to bank over-steepening, exacerbate erosion problems, and even increase the risk of landslide hazard. The stress on the bed of a stream caused by flow is a function of the flow velocity and the weight of the water pressing down on the bed, so as flow depths increase, the stress on the bed of the channel increases, and the channel downcuts. As the channel downcuts, the depth of the flow before it spills over the bank increases, which in turn increases the stress on the bed of the creek, setting up a negative feedback mechanism in which the more a stream downcuts, the more able it is to erode the bed. As a result, downcutting often continues until some other factor comes into play to stop it, such as the channel cuts down to a less erosive material (dense clay or rock), or is halted by woody debris, or some gradient control like a downstream culvert prevents further downcutting. Such downcutting can lead to bank over-steepening. This can exacerbate erosion problems in erosion hazard areas, and may also increase the risk of landslide hazard on a marginally stable slope. Coastal flooding areas are subject to somewhat different issues. WAC 365-190-110(2)(d) guides local jurisdictions to consider the effects of tsunami waves, high tides with strong winds, sea level rise, and extreme weather events, including such events that are generated by global warming.

Tsunamis are wave created by the abrupt displacement of large quantities of water, typically following a seismic or large landslide event. In the Puget Sound region, tsunamis are likely to be triggered by large subduction zone earthquakes generated as the oceanic Juan de Fuca tectonic plate is subducted under the North American plate (see also Section 2, above). Computer models indicate that tsunamis from such an event can be expected to hit the Pacific coast of Washington within 30 minutes of the earthquake, and reach a height of 30 feet or more (WMD 2010). In the more protected area of Puget Sound, waves would take longer to arrive and would be significantly smaller. However, an earthquake on the nearby Seattle Fault could arrive within minutes and reach heights of up to 20 feet (NOAA 2006).

It is now generally accepted that global climate change is occurring, and will contribute to sea level rise in the future, though estimates vary as to the magnitude of the rise. As global temperatures increase, the volume of water stored on continents as ice will decrease, contributing to sea level rise. Additionally, water expands when heated, and this thermal expansion will also contribute to sea level rise. Finally, tectonic forces change the relative sea level, as parts of the North American plate rise or fall relative to sea level. Mote, et al. (2008) predicted that the combined effect will be a rise in sea level of between 6 and 50 inches by the year 2100.

Along with rising sea levels, global climate change is predicted to alter weather patterns and produce anomalous storm events. Low atmosphere pressure that creates larges storm events also influences local sea level. Finlayson (2006) indicates that one storm in 1999 caused a 65 cm (25.6 inch) rise in sea level. The peak of that storm arrived during low tide, so was not as problematic, but had such an event occurred at high tide, damage could have been severe. More severe storms in the future could also result in significant damage to coastal areas.

3.4 Potential Protection Measures

The first step to protecting flood prone areas, or conversely to protect people and structures from flooding, is to identify such areas. The City has already mapped flood prone areas within the City limits, including those areas identified by FEMA as Zone A and Zone X flood areas, as well as other areas not identified by FEMA. The next step is to reduce the impact of, or to, the built environment.

Most current floodplain management strategies are premised on "no net impact" or "no adverse impact" (ASFPM 2003). Under such a strategy, the actions of one floodplain property owner does not adversely affect the flood risk of other property owners in terms of flood stage, flood velocities, increased flow volumes, or increased erosion risk. Regulatory actions to help achieve this goal include compensating for lost floodplain storage due to development and requiring no net increase in flood elevations. These strategies can be most effective at protecting not only development, but the natural processes of floodplains when they are combined with structural solutions such as setting back existing levees and reconnecting disconnected side channels.

The City can reduce hazards associated with frequently flooded areas by restricting development in mapped floodplains. Requiring compliance with stormwater design standards as specified in the Stormwater Management Manual for Western Washington (Ecology 2005) is another tool to protect floodplains from the impacts of urbanization. Additionally, some mapped floodplains overlap with other critical areas, such as wetlands and steep slopes and are therefore afforded some protection under those regulations.

3.5 Frequently Flooded Areas Summary

Frequently flooded areas are important to identify and protect both because they present a hazard and because they perform valuable hydrologic and habitat functions. The City Critical Areas mapping includes “floodplain” areas that correspond to frequently flooded areas, including coastal areas, riparian areas along Miller Creek, and a wetland area of off Ambaum Boulevard.

Development in and upstream of frequently flooded areas can have a negative impact, both to the area itself and to the development in and around the area. Historically, development has led to increased runoff to streams, as undetained flow from impervious surfaces increase the magnitude and frequency of peak flow event. This increase in flow often causes streams to downcut, which can separate the channel from the floodplain, making it more difficult for high flows to overtop the bank. This can lead to a negative feedback mechanism by which the downcutting worsens progressively until the channel can no longer downcut.

Development in frequently flooded areas generally needs to be protected from flooding by some means and can lead to increased flooding problems downstream. Natural floodplains store water during high flow events, releasing it back into the channel as the flow recedes. If the floodplain is blocked by a structure or a levee built to protect a structure, that storage capacity is lost, and downstream flooding is worsened.

Development in frequently flooded areas should be allowed only with no net loss, or no adverse impact, to both reduce the potential for damage to the resource and to prevent a worsening of flood impact. Development upstream of frequently flooded areas should employ mechanisms that ensure that peak flows to the creek are not increased. Again, such measures will not only help protect the resource of frequently flooded area, but will help protect people and structures from the hazard associated with flooding.

Coastal flooding involves extreme high tides, storm events, tsunamis global warming, and even plate tectonics. This makes for a complex set of issues. Coastal flooding areas in the City Limits correspond to either landslide hazard areas or seismic hazard areas, and therefore are offered some protection from those regulations.

4 CRITICAL AQUIFER RECHARGE AREAS

Washington State's Growth Management Act (RCW 36.70A) requires local government to designate and protect "Critical Areas" to protect natural resources, including those areas that have a "critical recharging effect on aquifers used for potable water" (RCW 36.70A.030(5)). Such areas are called Critical Aquifer Recharge Areas (CARAs), and the goal of establishing and protecting such areas is to protect the functions and values of a community's drinking water by both preventing the supply from being contaminated, and by maintaining the supply of water in the aquifer.

The Washington Administrative Code (WAC 365-190) further defines CARAs as;

> *Areas with a critical recharging effect on aquifers used for potable water are areas where an aquifer that is a source of drinking water is vulnerable to contamination that would affect the portability of the water.*

An aquifer is a geologic formation that readily transmits water to wells or springs. In the Burien UGA, where the surficial geology consists of glacial deposits, aquifers are typically the sand and gravel-dominated deposits where there is ample pore space for water to be stored and transmitted. By contrast, an aquitard is a geologic formation that does not readily transmit water. Aquitards in the Burien area will typically be compacted clay-rich till deposits.

An aquifer can be confined or unconfined. An unconfined aquifer is one in which the upper boundary is the water table, with no aquitard between the water and the ground surface. A confined aquifer is a deeper aquifer that is separated from the surface by an aquitard, and is often under pressure.

Aquifer recharge occurs when water flows into the ground to an aquifer. An aquifer recharge area, therefore, is an area where water from rainfall, snowmelt, lakes, rivers, streams or wetlands, flows into the ground to an aquifer. While such areas serve to replenish groundwater supplies, they can also serve as a conduit for the introduction of contaminants to the groundwater. Aquifer discharge areas are where water flows away from an aquifer to the ground surface. Such areas can include seeps, springs, wetlands, streams, lakes, estuaries, and shorelines. Wells are also considered an aquifer discharge.

Since groundwater movement is driven by gravity, an aquifers' recharge is always 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, subsurface conditions may result in groundwater flow that does not reflect surficial topography. The most reliable way to map recharge areas is to examine water levels in wells and use that data to map water levels or piezometric surfaces.

An aquifer is considered to be used for potable water if it has existing wells, or is in the identified protection area for an existing well; if it is a sole-source aquifer (i.e. supplies at least 50% of the drinking water for the region above the aquifer); is planned to be used for potable water in the future; or is otherwise identified as an important supply.

4.1 Identification and Classification

Identifying CARAs involves 1) identify aquifers used for potable water, and 2) identifying the areas that recharge those aquifers.

Both the Washington State Department of Health Source Water Assessment Maps and Department of Ecology Facility/Site Atlas (see References for websites) identify public water supply wells and their protection zones. No such wells are mapped in Burien at this time. Ecology requires well logs to be filed for all wells drilled in the state, and maintains a map of the location of each well logged (see Washington State Department of Ecology Well Logs in Section 7 for web address; http://apps.ecy.wa.gov/welllog/mapsearch.asp). Several water supply wells have been mapped in Burien, but there may be more wells than are shown. While well logs are required for all wells in the state, there are undoubtedly some that have not been properly logged. In some instances, the well log may not reflect the proper well location. Well logs are mapped as a point in the center of the reported quarter section. A quarter-section is a 40-acre square. Assuming that the well driller reported the correct quarter section for the well, the actual well location may be anywhere within that 40-acre area.

Recharge to an aquifer is dependent on precipitation and infiltration into the soil below the root zone. Infiltration below the root zone is controlled by a number of factors, including temperature, wind, soil type, geology, vegetation type, and land surface slope. The root zone is an important factor to consider, since evaporation and transpiration of water by plants reduces the water available for groundwater recharge, and can account for much or most of the rainfall during some months (SJC 2004).

Identifying the recharge area of an unconfined aquifer can be relatively simple. Since there is no barrier between the ground surface and the aquifer, the recharge area is typically the land in the vicinity of the aquifer. Surface water, in lakes, streams, and wetlands, may play a large role in both recharge to and discharge from unconfined aquifers, and the function may vary from season to season.

For a confined aquifer, more involved studies must be undertaken to understand the movement of subsurface water. Well logs from a given area can be used to map aquifers, and water elevations in the wells can be mapped to provide a piezomatic surface, which can then be used to determine flow direction in the aquifer.

The City of Burien Critical Areas mapping (updated April, 2011) includes a number of aquifer recharge areas. These areas are generally associated with various streams and wetlands.

Classification of CARAs is typically achieved by combining the susceptibility of the aquifer with the contaminant load in the recharge area. Susceptibility refers to how easily a contaminant can make its way to the aquifer, while contaminant load refers to the quantity and type of contaminants in the CARA and how likely it is for such contaminants to enter the ground.

Wellhead protection zones are defined as areas where a spill incident could result in contamination of the well within a specified time period, ranging from 6 months to 10 years. These time-of-travel zones are mapped, though with varying levels of accuracy. Some are mapped using groundwater modeling programs, while others are mapped by simply drawing circles of varying size around the wellhead.

4.2 Functions and Values

In the simplest terms, the functions and values of a CARA are to provide clean drinking water and to contribute water to streams and wetlands that support wildlife. Four water districts serve the City - Highline Water District, and King County Water Districts # 20, 54, and 125. Most of the water supplied by these districts comes from the Cedar River watershed via Seattle Public Utilities, but some is also derived from local wells. For example, the Highline Water Districts obtains 25% of its water from local wells, which are in medium to deep aquifers. These wells, and their wellhead protection areas, are outside the City, but there are numerous private wells throughout the City, some of which may currently be in use or may be used in the future.

Surface water and groundwater are constantly interacting. Streams can contribute to groundwater levels, and groundwater can contribute to stream flow. Often a stream will recharge an aquifer during wetter periods, and serve as a discharge during drier season. Likewise, wetlands can also serve recharge or discharge aquifers, with the function varying seasonally in some cases. Springs, which are simply locations where an aquifer intersects the ground surface, are common in coastal ravines underlain by glacial deposits such as those in Burien, and are also seen along the shoreline. Streams, wetlands, springs and seeps all provide critical habitat and resources for vegetation and wildlife, both aquatic and terrestrial.

These functions and values are dependent on both the quantity and quality of the water in the aquifer.

4.3 Potential Impacts

Impacts to CARAs can take two forms – impacts to water quality and impacts to water quantity.

4.3.1 Water Quality Impacts

The risk to water quality (groundwater contamination) is related to two main parameters: The susceptibility of the aquifer and the contamination loading potential or source loading. Susceptibility refers to how easily water and pollutants can move through the ground to reach the underlying aquifer. A shallow, unconfined aquifer in a gravel rich basin would be more susceptible to contamination than a deep, confined aquifer overlain by dense glacial till. Contamination loading refers to the quantity and types of pollutants present in the area, and how they are handled. Unmanaged open space would have a low contamination loading potential, while a light industrial area would likely have a higher loading potential, and an older industrial site with multiple leaking storage containers would have a high loading potential. Together, susceptibility and loading potential determine the vulnerability of an aquifer. A highly susceptible aquifer may have a low vulnerability if the land use within the area is primarily open space. Likewise the older 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.

The susceptibility of an aquifer can be assessed by looking at three critical factors (Cook, 2000):

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.

Permeability of the vadose zone can be estimated from soil and geologic mapping. The Washington Department of Natural Resources has an interactive web-based geologic map of the state which provides some insight into the permeability of the vadose zone (Washington State DNR/Geology; https://fortress.wa.gov/dnr/geology/?Site=wigm).

Depth to water can be determined by examining well logs in the vicinity. As mentioned above, well logs are available at the Department of Ecology website (see Washington State Department of Ecology Well Log in Section 7 for web address; http://apps.ecy.wa.gov/welllog/mapsearch.asp). In many cases, there may be several moderate to deep aquifers underlying a given location, and different wells in a given vicinity may be at widely varying depths if they are drawing from different aquifers.

Groundwater recharge rates can be estimated from soil permeability and rainfall data.

King County has mapped groundwater susceptibility to contamination. Areas within the County are mapped as one of three categories:

1) *Category I critical aquifer recharge areas include those mapped areas that King County has determined are highly susceptible to groundwater contamination and that are located within a sole source aquifer or a wellhead protection area.*
2) *Category II critical aquifer recharge areas include those mapped areas that King County has determined:*
   - *have a medium susceptibility to ground water contamination and are located in a sole source aquifer or a wellhead protection area; or*
   - *are highly susceptible to ground water contamination and are not located in a sole source aquifer or wellhead protection area.*
3) *Category III critical aquifer recharge areas include those mapped areas that King County has determined have low susceptibility to groundwater contamination and are located over an aquifer underlying an island that is surrounded by saltwater.*

This mapping can be viewed on King County's iMap system at the website listed in Section 7 (King County iMap/Groundwater): http://www5.kingcounty.gov/iMAP/viewer.htm?mapset=GroundWater.

Potential sources of groundwater contamination

Seawater Intrusion

Freshwater is less dense than saltwater, and therefore floats on top of salt water. In coastal areas where fresh groundwater and saltwater meet, the freshwater will lie on top of the saltwater. However, if too much freshwater is withdrawn from the aquifer, the interface between the freshwater and saltwater will rise. According to the USGS (2000) a 1 foot depletion in freshwater in an aquifer can yield a 40 foot increase in the transition zone between fresh and salt water. Global warming can also contribute to saltwater intrusion problems by raising the sea level, and with it, the transition from salt- to freshwater. In the Puget Sound region, tectonic forces from the subduction of the Juan de Fuca plate are causing the ground level to drop, which exacerbates salt water intrusion in coastal areas. Combined, global warming and tectonic forces are predicted to cause a relative sea level increase of between 6 and 50 inches by the year 2100 (Mote, et al. 2008).

Nitrate

Nitrate is a soluble form of nitrogen, which is stable, is not filtered by passing through soil, and which can cause health risks when it contaminates drinking water. Too much nitrate in drinking water can lead to, among other conditions, methemoglobinemia, or blue baby syndrome, in infants. This condition robs blood cells of their ability to carry oxygen, resulting in a bluish discoloration of the body. If not diagnosed and treated, this condition can lead to slow suffocation and possible death. To prevent this illness, the U.S. Environmental Protection Agency set the maximum contaminant level for nitrate at 10 mg/l.

Because of its solubility and stability, nearly all groundwater contains low levels of nitrate. Concentrations above 1mg/l are generally associated with anthropogenic sources, including sewage, fertilizers, livestock and pet waste.

Sewage Effluent

On-site sewage treatment can be an effective method for treating and disposing of sewage, if properly designed and maintained. As an additional benefit, such systems can be a source of aquifer recharge, with up to 85% of the treated effluent returning to groundwater (SJC 2008). However, on-site treatment does not typically remove nitrate, pharmaceuticals and many other chemical contaminants. Dilution usually reduces the concentrations of such contaminants, but is not always effective. In areas where the use of on-site sewage treatment is concentrated, groundwater contamination can result.

Chemicals and contaminants of concern

Chemicals and products that are used every day in an urbanized area have the potential to contaminate groundwater if improperly used. The activities and facilities that are likely to use such materials include, but are not limited to, the following:

Above/ underground storage tanks & lines
Airports
Automobile repair and body shops
Boat repair facilities
Construction
Food Processing
Funeral services/ taxidermy
Furniture repair/ refinishing
Machine/ metal fabricating shops
Marinas
Medical/ vet offices
Mines/ gravel pits
Office buildings/ strip malls
Pesticide operators
Photo processing facilities
Research laboratories
RV parks and facilities

Gas stations
Golf courses
Hardware/ farm/ auto parts stores
Landfills
Retail stores
Septage lagoons
Waste transfer/ recycling areas

The Department of Ecology requires pollution prevention plans for facilities that generate more than 2,640 pounds of hazardous waste per year, but these requirements apply only to waste products, and not necessarily to those products that are used as part of a process. Smaller businesses and homeowners are not required to provide prevention plans, and while larger farms and businesses may use potential contaminants more frequently or in greater quantity, groundwater is also subject to contamination by materials used by small businesses and households, especially those on septic systems or that store materials on the ground.

4.3.2 Water Quantity Impacts

The quantity of water available in an aquifer is a balance between recharge, storage, and discharge. Historically, native forests covered most of the area in Burien, and such forests are typically considered to be the baseline against which other land use conditions are measured. Replacing forests with buildings, roads, driveways, lawns and even pastures typically reduces the recharge rate of the underlying aquifers to varying extents, while simultaneously increasing the peak runoff rates to streams. In some rare instances, however, some land uses can increase recharge rates. For example, 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 rate to the underlying aquifer, albeit one that has potential for introducing contaminants.

On the discharge side of the balance, withdrawal of water via wells is the primary means of reducing groundwater quantity. Water rights help to regulate the amount of water withdrawn from an aquifer, but several exemptions exist, including;

- Water for livestock
- Water for non-commercial lawn or garden one-half acre or less
- Water for a single or group of homes, up to 5,000 gallons per day
- Water for industrial purposes, including irrigation, up to 5,000 gallons per day

While there are a handful of wells in the City, as mentioned above, most of the water used in the City is derived from Seattle Public Utilities or wells located outside the City limits.

4.4 Potential Protection Measures

Protecting these functions and values requires the following:

- Identifying where groundwater resources occur
- Determining how susceptible the groundwater resource is to potential contamination
- Identifying and quantifying the potential sources of contamination (contamination loading)
- Assessing the vulnerability of the water resources
- Classifying the risk potential by area
- Protect those areas that pose risks to the resource
- Ensure that protections are enforced
- Manage withdrawals to maintain future supply for both drinking water and for streams and wetlands

For public water supply wells, much of this work has already been done under the Safe Drinking Water Acts Source Water Protection Program, which identifies wellhead protection zones, determines the susceptibility of the well to contamination, and inventories contamination sources within the protection zone.

King County mapping classifies the susceptibility of groundwater, as well as the location of wells. This information, when supplemented with well location data from Ecology and he Department of Health can help to identify where non public wells are and how susceptible they might be to contamination. Zoning, business licenses, and Ecology data on existing pollution prevention plans can provide estimates of contamination loading.

Classifying the vulnerability of CARAs can be done in several different ways. For example, two methods suggested by Ecology (2005) include categorization by susceptibility alone and categorization by priorities and risk.

Categorization by susceptibility has the advantage that it can be accomplished through use of geologic mapping, soil mapping and well data, all of which are publically available. Once classified, decisions can be made to determine what activities should be allowed and what protections should be put in place for each category, regardless of the contaminant loading of the area. Such a categorization system might include the following categories, in order of decreasing susceptibility:

1. Water table sand and gravel aquifers
2. Deeper, less susceptible aquifers
3. Confined aquifers

A more targeted categorization system based on priorities and risk would assess what wells are the most important and provide the best protection for aquifers; travel time for contaminants could be used as a basis for the protection area. For example, such a prioritized list might include the following categories:

- Large public water supply systems one-year time of travel protection zone
- Densely populated areas that rely on ground water
- Medium public water supply system protection zones
- Rural areas with high dependence on groundwater
- Discontinuous local drinking water of limited extent
- Sole source aquifers.

Ecology (2005) recommends that local jurisdiction consider prohibiting certain high risk uses in high-priority CARAs. Such uses may include landfills, wood treatment facilities, metal plating facilities, tank farms, and any other facilities that treat, store, use, or transfer large quantities of chemicals. Moderate to low risk facilities may be acceptable in high-priority CARA's, provided that adequate pollution prevention plans and practices are in place and properly maintained, with appropriate contingency plans for emergency situations.

4.5 Summary

Groundwater is a valuable source of drinking water as well as fresh water for stream, lakes, estuaries, wetlands and springs, and the habitat that such areas provide. Critical Aquifer Recharge Areas are meant to protect this resource by:

1. identifying aquifers that provide potable water, and
2. protecting those areas that provide water to such aquifers so that water quality and water quantity in the aquifer can be maintained.

The vulnerability of an aquifer is the product of its susceptibility to contamination and the contaminant loading. Susceptibility is determined primarily by how easily water passes from the ground surface to the aquifer. An aquifer that easily receives water is also highly susceptible to contamination. Contaminant loading is a measure of the quantity of contaminants in the recharge area. Contamination may include any number of chemicals used for a variety of industrial or household uses, as well as some natural sources, such as salt water intrusion.

A highly vulnerable aquifer is one with high susceptibility and high contaminant loading. A moderately vulnerable CARA may combine high susceptibility with low contaminant loading, or may combine low to moderate susceptibility with low to moderate contaminant loading.

Water quantity must also be considered when protecting CARA's. Water quantity is a function of the amount of water being taken into the aquifer (recharge) and the amount of water being taken out of the aquifer (discharge). Discharge can include both natural releases to streams, springs, lakes, wetlands, estuaries, and shorelines, as well as human withdrawals via wells. Development and associated increased impervious surfaces can decrease the amount of water reaching the aquifer by generating increased surface water runoff volumes.

Protecting CARA's involves identifying where they are, classifying them based on their vulnerability or some other rational method, and making appropriate land use decisions based on that classification. State and Federal laws regulate a number of activities and wellhead protection areas, but local jurisdictions may benefit from additional CARA protections.

5 WETLANDS

Wetlands were historically drained or filled to accommodate agriculture or development. However, today they are recognized as high functioning ecosystems what provide a wide range of valuable services, including flood control and wildlife habitat. As assessed in 2003, approximately 80 percent of buildable land with the City is already developed (Vanderburg 2003). The majority of remaining wetland areas appears to be shown on the City's Critical Areas Map (Burien Critical Areas Map, Ord. 394, October 2003, updated April 2011).

Major wetlands within the City include the headwaters of Walker Creek and Arbor Lake, which is a headwater of Miller Creek. Both of these wetlands are on City park land. Several smaller wetlands are present and many are associated with Lake Burien, Miller, Walker or Salmon Creeks.

5.1 Wetland Identification and Classification

Wetlands exhibit a diversity of characteristics, such as permanent or seasonal inundation, organic or mineral soils. Wetlands are distinguished from adjacent areas by anaerobic wet soil conditions within the root zone during the growing season, unique soil profiles, and water dependent or water tolerant plant species. Transitions between wetland and non-wetland or upland areas may be gradual or plainly defined, often by topographic breaks. Since interest in managing and protecting wetland resources began in the mid-fifties, ecologists have struggled to develop a wetland definition based on scientifically defensible criteria. Implementation of the 1977 Clean Water Act requires a scientifically based legally defensible wetland definition (Mitsch and Gosselink 2000).

The commonly used wetland definition as issued by the U.S. Environmental Protection Agency (EPA), the U.S. Army Corps of Engineers (Corps), Shoreline Management Act (SMA), Growth Management Act (GMA) and recorded in the Washington Administrative Code (WAC 173-22-030(10)) is:

> "Those 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 artificial wetlands intentionally created from non-wetland 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 non-wetland areas to mitigate the conversion of wetlands."

In accord with Washington State Legislature Senate Bill 5776, wetland determinations are made using methodology from the *Washington State Wetlands Identification and Delineation Manual* (State Manual) (Washington Department of Ecology [Ecology] 1997; Ecology Publication # 96-94). To address regional wetland characteristics and improve wetland delineation accuracy, the US Army Corps of Engineers (Corps) issued regional supplements to their Wetland Delineation Manual (1987) on which the State Manual is based. Therefore, current wetland methodology is based on the Manual and the *Regional Supplement to the Corps of Engineers Wetland Delineation Manual: Western Mountains, Valleys, and Coast Region (Version 2.0)* (Regional Supplement) (Corps May 2010). Both the State and Corps Manuals provide parameters and methods for determining presence or absence of jurisdictional wetlands within the landscape. Following this methodology, wetland determinations are based on an examination of vegetation, soils, and hydrology.

While some wetlands are inundated and obvious, many wetlands have little, no or only seasonal surface water. A scientifically sound wetland determination is one made by a qualified professional who can evaluate and document present or absence of the three wetland parameters, vegetation, soils and hydrology in a manner consist with current regulations and accepted BAS practices. Currently, there is no state licensing or certification requirement for soil and wetland science professions. However, bills HB 1313 and SB 5225, which would require professional licensing, have been introduced to the Washington State Legislature and may be adopted in the 2011-2012 session.

Once a wetland is identified, classification allows regulators to determine the relative rarity and functional value of an individual wetland feature. A wide range of tools and techniques have been used to categorize or manage wetland resources starting with gross scale National Wetland Inventory (NWI) mapping by the U.S. Fish and Wildlife Service using the Cowardin classification system (Cowardin et al. 1979). The Cowardin system is still widely used and has been incorporated into more recent tools, such as the Washington State Department of Ecology *Washington State Wetland Rating System for Western Washington* (Ecology Rating System)(Hruby 2004; Ecology Publication # 04-06-025).

The Ecology Rating System is the most commonly used and regionally-accepted wetland classification system. It is a four-tier wetland rating system, which grades wetlands on a points-based system in terms of functions and values. Ecology specifically developed this tool to allow for relatively rapid wetland assessment while still providing some scientific rigor (Hruby 1999). This rating system incorporates other classification elements, such as Cowardin (Cowardin et al. 1979), hydrogeomorphic (HGM) classifications (Brinson 1993), and special characteristics such as bogs and mature forests. As described in the Ecology Rating System guidance: "This rating system was designed to differentiate between wetlands based on their sensitivity to disturbance, their significance, their rarity, our ability to replace them, and the functions they provide" (Hruby 2004).

5.2 Wetland Functions and Values

Physical, chemical, and biological processes that occur within a wetland and the surrounding landscape are commonly referred to as wetland functions. Wetland scientists generally acknowledge that wetlands perform the following eight functions:

1) flood/storm water control,
2) base stream flow/groundwater support,
3) erosion/shoreline protection,
4) water quality improvement,
5) natural biological support,
6) general habitat functions,
7) specific habitat functions, and
8) cultural and socioeconomic values (Cooke Scientific Services 2000).

The capacity of an individual wetland to perform functions is dependent upon climate, geomorphic or topographic location, the hydrology source and hydrodynamics. Wetland functions also vary, both positively and negatively, due to processes or changes occurring at the watershed scale. The Bedford "process-structure-function" model is a tool for evaluating wetland functions and values at a greater landscape scale. This model assumes that land use choices affect processes key to wetland and other aquatic system functions (Sheldon et al. 2005). Additionally, a study conducted by Poiani et al. (1996) demonstrates that regional land uses, corresponding pollutant inputs, and watershed characteristics, such as soils and topography, effect wetland processes, particularly in regard to nitrogen cycling.

While wetlands perform many ecological functions, scientific literature acknowledges that the value assigned to any given wetland function is subjective. 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 practical applications, such as the Ecology rating system, wetland functional values are broadly grouped into three categories: 1) water quality functions, 2) flood storage or hydrologic functions, and 3) habitat functions (Sheldon et al. 2005).

5.2.1 Water Quality

Wetlands improve water quality by intercepting runoff, retaining inorganic nutrients, converting organic wastes, settling sediment and removing contaminants (Sheldon et al. 2005). The water quality functions provided by an individual wetland vary by site-specific characteristics including hydrogeomorphic (HGM) class and basin condition. Water quality functions are also dependent on several factors including residence time of polluted waters, vegetation structure and density, and soil composition. A longer residence time allows sediment and other solids to settle. Ungrazed vegetation acts as a filter to capture sediment particles entering the wetland (Hruby 2004). Research has shown that a vegetated wetlands and riparian buffers can be expected to capture more than 90% of sediment and other non-point source pollutants in runoff (Gilliam 1994). Due to the absorption properties of heavy metals, phosphorus, and some toxic compounds, sediment capture in wetlands also reduces these pollutants in downstream environments. According to Kerr et al. 2008, low oxygen concentrations that are common to wetland environments make them particularly good sinks for copper. The major processes by which wetlands reduce runoff pollutants are both biotic and abiotic and include sedimentation, adsorption, precipitation, oxidation, bio-degradation, and plant uptake (Adamus el al. 1991, ITRC 2003).

Nutrient uptake in wetland systems also protects down-gradient waters by preventing nutrient spikes that can disrupt trophic indices; such disruptions can cause eutrophication. The primary nutrients wetlands remove are nitrogen and phosphorus. 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). As noted above, phosphorus is captured in settled sediments; wetlands also remove phosphorus through adsorption, particularly to clay soils, and precipitation with calcium (Sheldon et al. 2005). However, phosphorus retention in wetlands is not permanent and seasonal fluctuations in phosphorus release have been documented in some studies (Aldous et al. 2005).

While wetlands are known to provide water quality functions, recent research indicates that household chemicals, pharmaceuticals and personal care products are entering our aquatic systems and negatively impacting fish and wildlife populations (Staples et al. 2004, Klaschka 2008, Fent 2008, Caliman & Garvilescu

2009); the ability of wetlands to neutralize these pollutants is unknown at this time.

5.2.2 Hydrology / Flood Storage

Primary hydrologic functions wetlands provide are peak flow reduction and flood-flow desynchronization, reduced downstream erosion, and groundwater recharge (Sheldon et al. 2005). As described by Hruby et al. 1991 and Adamus et al. 1991, flood-flow desynchronization is a landscape-scale process whereby stormwater is stored in wetlands across the watershed and slowly released down-gradient. Cumulatively this reduces the magnitude and intensity of peak flows (Sheldon et al. 2005). In turn, reducing the velocity of water flow across the watershed reduces downstream erosion (Reinelt and Horner 1995, Adamus et al. 1991). Wetlands also recharge groundwater to varying degrees based on site-specific conditions including groundwater flow rates, wetland storage capacity, landscape position or HGM class, and evapotranspiration rates (Adamus et al. 1991, Hunt et al. 1996).

5.2.3 Wildlife Habitat

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 and Naef 1997). Wetlands, depending on site-specific conditions, landscape position, and surrounding land use, will have some or all of these habitat features.

Wetlands provide habitat for a broad range of fauna including invertebrates, reptiles and amphibians, anadromous and resident fish, wetland-associated birds, and wetland-associated mammals. Aquatic invertebrates that depend on wetland ecosystems are important to aquatic trophic systems or food webs (Rosenberg and Danks 1987, Wissinger 1999, in Sheldon et al. 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 et al. 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 et al. 2005). Resident fish also inhabit wetlands. Waterfowl rely upon wetlands for all or part of their life cycle (Kauffman et al. 2001, in Sheldon 2005). Suitability of wetland 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 et al. 2005). Wetland-associated mammals, such as beaver and muskrat, also seek out well buffered vegetated corridors, interspersed habitat with open water, and a seasonally stable water level (Sheldon et al. 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.

Wetlands also provide habitat for many native plants species. Wetland characteristics that are correlated with plant richness are the hydro-period, duration of flooding, and variety of water depths (Schueler 2000 and Sheldon et al. 2005).

The performance of wetland functions described above is affected to varying degrees by the width and/or character of the surrounding buffer. Vegetated areas surrounding wetlands perform several important functions that in turn protect wetland functions. Widely recognized buffer functions include removing sediment, removing excess nutrients, removing toxic substances, influencing microclimate, maintaining adjacent habitat critical for wetland-dependent species, screening adjacent disturbances, and maintaining habitat connectivity (Sheldon et al. 2005).

5.3 Potential Effects of Development

Urbanization is known to have repercussions that impact both individual wetlands and broad-scale watershed processes. Land use changes typically involve wetland fill, loss of forest, modified drainage systems, increased pollutants, and more impervious surface (Sheldon et al. 2005).

5.3.1 Wetland Loss and Degradation

Due to the planned density that defines urban areas, impacts to natural areas including wetlands, are common. Nationally it is estimated that 85 percent of urban wetlands have been filled (Kusler and Niering 1998, in Sheldon et al. 2005). For example, linear improvement projects, public facility improvements, and legal lot requirements can each cause unavoidable wetland impacts, particularly in an urban core. To protect wetland resources under these conditions regulation of direct and indirect wetland impacts is necessary. Direct wetland impacts are activities that drain, fill or clear a wetland. Indirect impacts stem from changes in the surrounding landscape that degrade a wetland by altering the wetland hydroperiod, microclimate or habitat connectivity, for example (McMillan 2000). See section 5.4 below for further discussion of BAS mitigation tools.

5.3.2 Altered Hydrology

Urbanization typically alters wetland hydrology by increasing or decreasing flows that enter the wetland from the surrounding landscape (Sheldon et al. 2005). A Puget Sound wetland study found that even 4% urbanization can measurably alter wetlands and severe wetland degradation correlates with impervious cover in excess of 20% (Schueler 2000).

High impervious surface cover characteristic of urban areas leads to greater peak flows. In an urban setting, peak flow rates for a single storm event increase as much as five-fold relative to less developed areas (Booth 1991). Under these conditions, McMillan (2000) concludes that buffers are not likely to protect a wetland's hydroperiod if they are located in a basin with impervious surface exceeding 15 percent. While statistics on impervious cover within local City of Burien basins are not readily available, aerial photos clearly show impervious cover well above the 15 percent threshold, particularly in the Miller Creek basin (King County iMAP). These changes to flow conditions are known to increase erosion, down-cut stream channels, bury vegetation, increase depth of ponding, and alter seasonal water regimes (Sheldon et al. 2005).

Modified drainage patterns in urban areas are found to increase water level fluctuations (WLF) in wetlands by a foot or more; this stresses many native plant species and tends to result in more invasive or aggressive plant species establishment (Schueler 2000).

Other improvements typical of urban areas may reduce the amount of water entering a wetland. For example, stormwater management may have unintended consequences for wetland hydrology. When road ditches, drainage tiles or other stormwater features are installed down-slope wetlands may become drier (Wigington et al. 2005, Hogan and Walbridge 2007). As is typical of ecosystem processes, hydrologic maintenance is linked to many other wetland and buffer functions.

5.3.3 Water Quality Impacts

A negative correlation between urbanization and wetland water quality was found in a Puget Sound study (Schueler 2000). For example, increased water volumes within a wetland can alter plant communities and anaerobic soil processes thus diminishing water quality functions (Schueler 2000, Sheldon et al. 2005). A decrease in water entering wetlands results in less opportunity to provide water quality functions (Wigington et al. 2005, Hogan and Walbridge 2007). Urbanized watersheds also release more nutrients, sediment and toxins into wetlands (Sheldon et al. 2005), further straining systems that are already compromised.

5.3.4 Habitat Impacts

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.

Urbanization also 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 wetland 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. Additionally, Attum et al. (2007) concluded in their study of wetland-upland linkages that wetland surroundings and wetland areas are likely of equal importance to wildlife. Therefore, smaller habitat patches inevitably diminish habitat value.

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 a urban wetland provides.

5.4 Potential Protection Measures

As the City grows, a variety of BAS-based protection measures may be employed to maintain wetlands and the functions they provide.

5.4.1 Wetland Buffers

Protection of wetland functions from effects of surrounding land uses is most commonly achieved through fixed buffers. The factors that influence the performance of a buffer include vegetative structure, percent slope, soils, and buffer width and length. The scientific literature identifies four primary factors important in determining buffer width to adequately protect wetlands. These are 1) the functions and values of the subject wetland, 2) the characteristics of the buffer itself, 3) the intensity of surrounding land uses and their expected impacts and 4) the specific functions the buffer is intended to provide (Sheldon et al. 2005).

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). Water quality is the wetland function that has been studied most comprehensively in the context of adequate buffer width. Water movement and quantity, habitat, and disturbance protection functions have been addressed to a lesser extent. 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 5.1) 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. Even for sediment removal, effective buffer widths vary by particle size (Sheldon et al. 2005). Generally the minimum buffer deemed necessary to protect a wetland under most conditions is between (15-30 meters) 50-100 feet wide. To maintain conditions suitable for most wildlife, a minimum buffer of (60 meters) 197 feet is recommended (Granger et al. 2005). Table 5-1 summarizes general recommended buffer width ranges for protecting specified wetland buffer functions.

Table 5-1. Range of Effective Wetland Buffer Widths in Existing Literature for Applicable Functions

Function	Range (ft) of Effective Buffer Widths	Sources Consulted
Stormwater control (hydrology maintenance)	50-300 (generally); vegetative structure and impervious surface in basin are more important factors	Wong and McCuen 1982; McMillan 2000; Azous and Horner 2001
Erosion control	Unknown: wetland size and buffer type are more important factors	Cooke Scientific Services 2000; Kleinfelter et al. 1992, in McMillan 2000
Water quality	15-325	Horner and Mar 1982; Lynch et al. 1985; Lee et al. 1999; Shisler et al. 1987, in McMillan 2000; Dillaha and Inamdar 1997; Daniels and Gilliam 1996; Magette et al. 1989; Sheldon et al. 2005
Wildlife habitat	45-300	Castelle et al. 1992b; Desbonnet et al. 1994; Semlitsch 1998; Richter 1997, in McMillan 2000; Cooke 1992
Disturbance barrier	45-200	Cooke 1992; Shisler et al. 1987, in McMillan 2000; Desbonnet et al. 1994

Table 5-2 below categorizes buffer width ranges according to two primary functions, habitat and water quality. Water quality stressors are commonly inferred by categorizing the intensity of adjacent land use. In this model, land uses are deemed 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-density residential developments (1 unit/acre or less) and moderate-intensity open 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).

Table 5-2. Range of Effective Wetland Buffer Widths based on Habitat Functions and Land-Use (Sheldon et al. 2005)

Habitat functions	Adjacent Land Use	Range of Effective Buffer Widths (ft)
minimal	low-intensity	25 to 75
moderate	moderate- or high- intensity	75 to 150
high	low-, moderate- or high-intensity	150 to 300+

Determining set buffer widths for wildlife in general is difficult, due to variability among species (Sheldon et al. 2005). As habitat functions increase, effective buffer widths are increasingly contingent on life-history needs of wetland dependent species. Protecting wildlife habitat generally requires larger buffers than protecting water quality.

Table 5-3. Example Wetland Buffer Recommendations for Western Washington (Ecology 2010)*

Wetland Category	Standard buffer width (ft)	Additional buffer width (ft) if wetland scores 21-25 habitat points	Additional buffer width (ft) if wetland scores 26-29 habitat points	Additional buffer width (ft) if wetland scores 30-36 habitat points
Category I: Based on total score	75	add 30	add 90	add 150
Category I: Bogs	190	NA	NA	add 35
Category I: Forested	75	add 30	add 90	add 150
Category II (all)	75	add 30	add 90	add 150
Category III (all)	60	add 45	add 105	NA
Category IV (all)	40	NA	NA	NA

* Special wetland characteristics not present in the City of Burien were omitted. This Ecology reference, *Wetlands & CAO Updates: Guidance for Small Cities Western Washington Version*, is provided in Appendix A of this report.

As Tables 5-1, 5-2 and 5-3 above show, 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

Similar to stream systems, vegetated wetland buffers can affect water quantity and hydrology in the wetland by moderating the input of precipitation in a number of ways. Vegetation slows the movement of water from above and outside of the buffer, allowing the water to infiltrate into the soil and/or groundwater. Over time, this stored water will slowly be released 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). In either case, water quantity maintenance as related to buffer width has not been sufficiently studied. However, buffer characteristics that influence performance of this function are: "vegetation cover, soil infiltration capacity, rainfall intensity and antecedent soil moisture conditions" (Wong and McCuen 1982).

Upland buffers also function to control erosion by slowing water flow and allowing greater time for infiltration. Buffer vegetation can reduce sediment input to the wetland through soil stabilization by roots, and reduction in rain energy by 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).

The literature does not recommend a specific buffer size or range of buffer sizes for hydrology maintenance.

Water Quality Improvement

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). 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/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).

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.

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, 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.

5.4.2 Wetland Mitigation

Mitigation is a sequence of steps taken "to reduce the severity of an action or situation" (Ecology et al. 2006a). To bolster protection of our national wetland resources, a no net loss policy was adopted in 1988 by then president George H.W. Bush and has been upheld by all following presidents up through the present Obama administration.

On March 31, 2008, the U.S. Environmental Protection Agency (EPA) issued the Wetlands Compensatory Mitigation Rule. This rule emphasizes best available science to promote innovation and focus on results. *"Specifically, the rule:*

- *Emphasizes that the process of selection a location for compensation sites should be driven by assessments of watershed needs and how specific wetland restoration and protection projects can best address those needs;*
- *Requires measurable and enforceable ecological performance stands for all types of compensation so that project success can be evaluated;*
- *Requires regular monitoring to document that compensation sites achieve ecological performance standards;*
- *Clearly specifies the components of a complete compensation plan based on the principles of aquatic ecosystem science; and*
- *Emphasizes the use of science-based assessment procedures to evaluate the extent of potential water resource impacts and the success of compensation measures."*

Mitigation Sequencing

Wetland mitigation is typically achieved through a series of steps known as mitigation sequencing. Ecology recommends that the CAO contain clear language regarding mitigation sequencing. The mitigation sequence according to the implementing rules of SEPA (Chapter 197-11-768 WAC) follows:

(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.

The ABCs of mitigation sequencing are to Avoid, Buffer, and Compensate for impacts. The Ecology publication, *Wetland Guidance for Small Cities* (see Appendix B), provides sample code language for this approach.

Mitigation ratios are intended to replace lost functions and values stemming from a proposed land use while also accounting for temporal losses. Mitigation ratios recommended by Ecology can be found in Table 3 below. As noted above, the U.S. Army Corps of Engineers and Ecology have a mandate to maintain "no net loss" of wetlands. To that end, wetland creation and restoration are preferable to enhancement alone. Ecology guidance does allow for enhancement as sole compensation for wetland impacts at quadruple the standard ratio (Granger et al. 2005).

Per Ecology, compensatory mitigation should replace lost or impacted functions, unless out-of-kind mitigation can meet formally identified goals for the watershed. Ecology recommends prioritizing mitigation actions, location(s) and timing.

Mitigation Ratios

A relatively low success rate of wetland mitigation through both creation of new wetlands and restoration of historic wetlands (Castelle et al. 1992a; Johnson et al. 2002; NRC 2001) is generally acknowledged in the literature. Although more recent evaluations of wetland mitigation found that most wetland creation is at least moderately successful (Ecology 2008), the goal of no net loss is not being achieved (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, high replacement ratios, and greater expertise.

Mitigation estimates in the literature are most often based on temporal losses and known failure rates. Because compensatory mitigation implemented in the past has not fully replaced lost wetland area and functions, and because an immediate loss of habitat occurs when mitigation installation is delayed, compensation should never be made in less than a 1:1 ratio (Josselyn et al. 1990). Other research suggests that compensation should be made in substantially larger ratios to account for both the possibility of failure and the lapse of time between mitigation implementation and functionality; those mitigation ratios range from 1:1 (mitigation to impact) up to 10:1 (Josselyn et al. 1990; Willard and Hiller 1990). (Table 5-4).

Table 5-4. Suggested Wetland Mitigation Ratios and Sources

Recommended Ratio	Wetland and/or Mitigation Type	Source
1.5:1	Restoration (1:1 for completion prior to impact)	Kruczynski 1990
2:1	Creation (1:1 for completion prior to impact)	Kruczynski 1990
3:1	Enhancement (1:1 for completion prior to impact)	Kruczynski 1990
2:1	Creation	Kantor and Charette 1986
10:1	Low quality replacement wetlands	Zedler 1991
5:1	Moderate quality replacement wetlands	Zedler 1991
2:1	Compensation for projects needing a Hydraulic Approval Permit	WDW Wetlands Policy (POL-3025)
various	Creation	Ecology 2006

Ecology provides a range of mitigation ratio recommendations as listed in Table 5-5 below, which vary by impact wetland classification and type of mitigation (e.g. wetland creation, wetland enhancement, etc.). Ecology recommends the following wetland replacement ratios for local governments within Washington State: 6:1 for forested Category I wetlands, 4:1 for most other Category I wetlands, 3:1 for Category II wetlands, 2:1 for Category III wetlands, and 1.5:1 for Category IV wetlands. Ecology's *Guidance on Wetland Mitigation in Washington State* (Ecology et al. 2006a) also suggests criteria to be met in consideration of lowering or raising ratios on a project-specific basis.

Table 5-5. Ecology Recommended Mitigation Ratios (Granger et al. 2005)*

Category of Wetland Impact	Creation	Rehabilitation Only	Creation and Rehabilitation	Creation and Enhancement	Enhancement Only
Category IV	1.5:1	3:1	1:1 C and 1:1 RH	1:1 C and 2:1 E	6:1
Category III	2:1	4:1	1:1 C and 2:1 RH	1:1 C and 4:1 E	8:1
Category II	3:1	6:1	1:1 C and 4:1 RH	1:1 C and 8:1 E	12:1

Category of Wetland Impact	Creation	Rehabilitation Only	Creation and Rehabilitation	Creation and Enhancement	Enhancement Only
Category I: Forested	6:1	121:1	1:1 C and 10:1 RH	1:1 C and 20:1 E	24:1
Category I: Bog	Not possible	6:1 RH of a bog	Not possible	Not possible	Case-by-case
Category I: based on total score	4:1	8:1	1:1 C and 6:1 RH	1:1 C and 12:1 E	16:1 E

*This document, Appendix 8-C of *Wetlands in Washington State, Volume 2 – Protecting and Managing Wetlands* (Granger et al. 2005).
Legend: C = Creation, RH = Rehabilitation, E = Enhancement

Mitigation ratios are based primarily on area and do not account for specific functional losses. For example temporal functional loss is higher for slow growing coniferous forests than for more rapid growing deciduous forests and higher for forests than for shrub or emergent plant communities (Hruby 2011).

To give regulators and applicants a functions-based alternative to set mitigation ratios, the Washington State Department of Ecology recently developed a tool called the credit-debit method. This method, like the Ecology wetland rating form, is a peer reviewed rapid assessment tool. The credit-debit approach may be used to calculate functional gain of the proposed mitigation and functional loss due to proposed wetland impacts. This generates acre-points that can be compared in a balance sheet. Depending on specific site conditions, this may result in less or more mitigation than would be required under a set the standard mitigation ratio guidance (Hruby 2011).

Types of Compensatory Mitigation

Following mitigation sequencing, after demonstrating that a proposed wetland impact is unavoidable and has been minimized to the extent practical, compensatory mitigation is required by local, state and federal agencies. In general order of preference the agencies recommend wetland compensation in the form of: 1) restoration (re-establishment or rehabilitation), 2) creation (establishment), 3) enhancement, and 4) preservation (Ecology et al. 2006a).

Wetland restoration occurs when a historic or degraded wetland is returned to a naturally higher functioning system through the alteration of physical or biologic site characteristics. Restoration may involve re-establishment or rehabilitation. Re-establishment is typically achieved by modifying or restoring a hydrologic regime; this may include removing fill or plugging ditches. Rehabilitation is achieved by repairing or restoring historic functions. Restoring a floodplain connection by breaching a dike is an example of rehabilitation. Rehabilitation does not result in new wetland area.

Wetland creation or establishment is the development of a wetland at a site where a wetland did not naturally exist.

> "*Landscape position and proximity to a reliable water source are critical for the successful creation of wetlands. This cannot be over emphasized*" (Ecology et al. 2006a).

Both wetland enhancement and preservation result in a net loss of wetland acreage and are therefore, less preferable. Wetland enhancement typically increases structural diversity within a wetland, thus improving functions. Preservation of high functioning wetland systems in danger of decline may also be proposed as mitigation. While preservation does not increase wetland acreage, it may result in long-term functional gains (Ecology et al. 2006a).

There are several approaches that can fulfill the compensatory mitigation requirement, including advance mitigation, programmatic mitigation, or consolidated mitigation (Ecology et al. 2006a). Examples of a consolidated mitigation approach would be an in-lieu fee program or mitigation bank. Individual applicants may also partner on a mitigation project.

Mitigation Site Selection

The Agencies (Ecology, Seattle District U.S. Army Corps of Engineers, and the U.S. Environmental Protection Agency Region 10) recommend selecting mitigation sites based on proximity to the impact and potential ability to replace impacted functions. In order of preference, a mitigation site should be:

> *"in the immediate drainage basin as the impact, then the next higher level basin, then the other sub-basins in the watershed with similar geology, and finally, the river basin"* (Ecology et al. 2006a).

In the past decade, national and state policies have shifted toward using a broader scale approach for mitigation site selection. A recent forum convened by Ecology and comprised of regulators, businesses, and environmental/land use professionals recommend that local jurisdictions "establish an ecosystem- or watershed-based approach to mitigation" (Ecology 2008). Due to the limited success of on-site mitigation, particularly in highly developed areas, a broader watershed scale approach is increasingly desirable and is viewed by the regulatory agencies as more sustainable (Ecology 2008). To guide practical applications of BAS-based compensatory mitigation, the Agencies issued an Ecology publication, *Selecting Wetland Mitigation Sites Using a Watershed Approach* (Hruby et al. 2009). As noted by Azous and Horner 2001 (in Hruby et al. 2009), recreating or maintaining wetland functions in a highly developed landscape may not be sustainable. To account for this, the watershed approach may require a combination of on- and off-site mitigation to achieve functional gains equivalent to the proposed losses.

5.5 Wetland Summary

Wetlands are unique and potentially high functioning ecosystems. Many wetland functions such as water quality, flood control, and wildlife habitat, are valued in urban areas. As the literature documents, urbanization stresses and degrades wetland ecosystems. Through local planning and oversight, direct and cumulative impacts to wetlands can be reduced.

The primary wetland protection measure is buffering. The degree to which wetland functions are performed partially depends on the type and quality of buffer immediately surrounding the wetland. Preservation of fixed buffers is the most commonly used method of protecting wetland functional values. Existing science recommends buffer widths that vary widely depending on the specific wetland and functions to be protected, the characteristics of the buffer itself, and the proposed adjacent land use. Buffers perform four major functions in the protection of wetland functions: maintaining hydrology, preserving and improving water quality, providing fish and wildlife habitat, and protecting species from disturbance.

Water quality protection has been studied the most extensively in the context of protecting wetland function and buffer width, and recommended buffers in the literature vary generally from 10 to 200 feet for this function. The specific width at which a buffer is effective in protecting water quality function of wetlands depends on a number of factors, including the type of pollutant or sediment in question and the structure and composition of buffer vegetation.

Hydrologic maintenance, including stormwater and erosion control, is influenced by buffer and wetland vegetation and soil characteristics, rainfall, and soil moisture conditions. However, the literature does not provide a range of effective buffer widths. Of greater importance to a wetland's hydrologic regime is the percentage of development present in the wetland's drainage basin.

Similarly, effective buffer widths for protecting habitat depends upon which species are likely to be present and the life stages in which they use the buffer. Existing literature recommends a range of buffer widths from 50 to 300 feet for protecting most habitat functions.

Protection from disturbances such as noise, light, and physical intrusion may be achieved in a wetland by preserving buffers of 45 to 200 feet in width.

Stormwater management and watershed protection are large-scale, effective means of protecting wetlands.

Mitigation for wetland impacts can be achieved through wetland creation, restoration, and enhancement, and best available science recommends that it be implemented at greater than 1:1 ratios to compensate for the possibility of failure and any time lapse between wetland loss and equivalent functionality of the mitigation site.

A watershed and functions-based approach to mitigation that is based on BAS is recommended by the Agencies. Long-term sustainability of mitigation sites should be a consideration when designing, reviewing or approving compensatory mitigation.

BAS Based Regulatory Guidance

Wetland Classification

Protection of wetland functions, values, and uniqueness, as recommended by Washington Department of Commerce (WDC, formerly the Washington Department of Community, Trade and Economic Development) for compliance with the GMA, are to a large extent addressed under the Ecology system. Explicitly, WDC recommends use of the Ecology Rating System and urges the consideration of the following:

- Wetland functions and values;
- Wetland sensitivity to disturbance;
- Rarity of a wetland type; and
- The degree to which degradation or destruction of a wetland can be compensated.

A recently issued Ecology publication, which provides wetland guidance for CAO updates in small cities (Ecology Publication # 10-06-002, see Appendix B), also recommends the Ecology wetland rating system.

Wetland Buffers

Ecology and WDC suggest requiring wetland buffers based on either habitat scores (Table 5-3 above) and/or the intensity of proposed land use actions (Table 5-2 above). The Ecology-recommended standard buffer widths have been developed based on Ecology's review of the BAS for wetlands throughout the state. It is important to note that Ecology buffer recommendations assume the buffer is densely vegetated with native plants. Buffers not meeting these criteria should be enhanced with native plants or require a buffer width increase.

WDC acknowledges that the Ecology-recommended standard buffer widths may not be appropriate in non-rural and non-forested settings, and thus advised that local governments tailor them to meet specific needs in their jurisdictions. Some cities and counties throughout Western Washington have utilized a variable buffer width approach by assessing buffers based on habitat scores or combination of habitat score and land-use intensity.

Buffer averaging and buffer reduction with enhancement can be applied to the revised wetland buffer widths as incentive for landowners to improve buffer conditions. Both are standard practices in many jurisdictions.

Ecology and WDC guidelines allow for buffer width averaging, but recommend maintaining 75 percent of the standard buffer width at any given point. WDC also allows for buffer reduction with enhancement; again recommend requiring the buffer to be no less than 75 percent of the standard with or 35 feet, whichever is greater. To demonstrate how functions and values will be preserved, the Agencies recommend requiring all buffer averaging and reduction proposals to be submitted with a critical areas study that uses best available science. This Ecology guidance also recommended varying buffer widths based on the habitat score and water quality functions.

Wetland Mitigation

Ecology has identified key elements of successful wetland mitigation projects, resulting in the following five recommendations (Ecology 2008):

1) Reinforce importance of wetland impact avoidance and minimization to resources that are highly valuable or difficult to replace;
2) Establish an ecosystem or watershed-based approach to mitigation;
3) Develop and implement a wide variety of compensatory mitigation tools, including wetland banking, advance mitigation, and support development of a regional Puget Sound in-lieu fee program;
4) Develop coordinated, consistent review protocols for development projects and associated mitigation plans;
5) Support making mitigation work through standardized compliance monitoring and sufficient resourcing, adaptive management, and staff training or technical assistance.

Including options that may not be currently available to your citizens, such as in-lieu fee and mitigation banking, will enable the City to regulate use of those tools as needed in the future (Ecology 2010).

Watershed-based planning is a way for local jurisdictions to manage ecologic resources sustainably. Currently, the Washington State Department of Ecology (Ecology) is working on a Puget Sound Watershed Characterization project. This project seeks to provide a landscape-scale perspective to help planners in our region manage their wetland and wildlife resources.

Another planning strategy would be to conduct a comprehensive wetland inventory within City limits. Several significant wetland areas are already included on the City's current critical area map (see Appendix A). A wetland inventory would be a tool to help the City protect these resources in a consistent manner. However, many wetlands, particularly small wetlands, are on private property and therefore difficult to inventory. Also, wetlands that are not included in inventory mapping may be inadvertently overlooked.

6 FISH AND WILDLIFE HABITAT CONSERVATION AREAS

The City of Burien has limited Fish and Wildlife Habitat Conservation Areas (FWHCAs) as defined by the WAC. WAC 365-190-130 lists FWHCAs that must be considered for classification and designation. Non-shoreline and non-marine FWHCAs are:

- Areas where endangered, threatened, or sensitive species have a primary association;
- Habitats and species of local importance;
- Naturally occurring ponds and lakes less than 20 acres in size that provide fish or wildlife habitat;
- Waters of the State;
- Lakes, ponds, streams, and rivers stocked with game fish by a governmental or tribal agency; and
- State natural area preserves, natural resources conservation areas, and State wildlife areas.

State and Federally Listed species known to presently occur in the City are chum salmon (state candidate species, federal threatened species) and bald eagle (state sensitive species, federal species of concern). The City maintains no specific list of habitats and species of local importance. Lake Burien, which exceeds 20-acres, is the only Water of the State outside of the marine shoreline; Natural ponds less than 20-acres in size are classified as wetlands and addressed elsewhere in this document. No waterbodies in the City are stocked with game fish by a governmental or tribal agency; and there are no State natural area preserves, natural resources conservation areas, or State wildlife areas in Burien. Each of these WAC classifications can be more thoroughly described and protected by addressing the habitat types and features in the following sections, covering both species of special significance and habitat.

In addition to the criteria above, general habitat value provided by streams and riparian areas, ponds and lakes and associated upland habitat are discussed in this section. Major streams mapped wholly or partially within the City of Burien include Miller Creek, Walker Creek and Salmon Creek. The only lakes currently mapped within the City are Lake Burien and Arbor Lake; Hicks Lake is in the potential annexation area to the north.

6.1 Identification and Classification

6.1.1 Endangered, Threatened, or Sensitive Species and Species of Local Importance

Publically available information shows bald eagles (State sensitive species), chum salmon (summer run Hood Canal, federal threatened species), and coho salmon (Puget Sound/Strait of Georgia Coho Evolutionarily Significant Unit (ESU) are a federal Species of Concern), as potentially present in critical areas outside of Lake Burien and Burien's marine shoreline. The City's marine shoreline is also within the Puget Sound Chinook salmon ESU (federal threatened species).

WDFW Priority Habitats and Species (PHS) data documents one bald eagle breeding occurrence in Burien, and the presence of chum salmon in the lower reaches of Miller Creek, within Normandy Park, south of the City limits. Coho salmon presence has also been documented throughout most of Miller Creek (WDFW SalmonScape). Bald eagles likely also use a much wider area of Burien for foraging, perching and roosting than the shoreline area depicted on PHS maps.

Although the City of Burien does not maintain a list of habitat and species of local importance, the Burien Zoning Code (BZC) does include bald eagle habitat areas and heron rookeries and active nesting trees as FWHCAs (BZC 19.40.380). The Burien Critical Areas Maps shows one FWHCA, a bald eagle nest site and foraging area near and along the Puget Sound shoreline southwest of Seahurst Park Road. The source of the City information appears to be the PHS data for the same eagle(s). PHS data depict a great blue heron breeding area in the Seahurst Park area.

6.1.2 Streams and Riparian Areas

A stream is generally defined as a naturally occurring waterbody with seasonal or perennial flow sufficient to create a channel. This definition includes natural waterbodies that are conveyed in artificial channels, but generally does not include artificial irrigation channels (WAC 173-22.030(8)). Riparian areas are the vegetated margins of a waterbody. The City of Burien contains portions of Salmon Creek, Miller Creek, and Walker Creek; a few smaller tributaries also fall under Burien's jurisdiction.

Salmon Creek

Salmon Creek headwaters are reportedly at Hicks Lake. There are no recent records of anadromous salmonids in Salmon Creek, although they may have been present historically; a spawning survey recorded chum in two unnamed tributaries to the creek in 1956 (King County and Washington State Conservation Commission 2000). Today, a total anadromous fish passage barrier occurs at approximately RM 0.3. The King County/Washington State Conservation Commission Limiting Factors Analysis for WRIA 9 (WRIA 9 LFA) (King County and Washington State Conservation Commission 2000) rated the creek for habitat factors such as fine sediment, large woody debris, pool frequency and quality, riparian buffer width, floodplain, and water temperature and other water quality factors. Each factor was rated as poor, fair or good. Riparian vegetation was rated as fair in upper reaches, but overall considered to be not property functioning and a main limiting factor to natural salmonid reproduction. Other habitat parameters, including large woody debris recruitment, hydrology, bank stability, sediment condition, and water quality, were generally found to be impacted by urbanized conditions. The stream and its riparian zone within and beyond the City constitute a designated WDFW PHS Biodiversity Corridor (WDFW 2011). Biodiversity corridors form a network of connections between areas of high biological richness. These corridors allow essential daily and seasonal migrations of a variety of animal species and contribute to general ecosystem functions within the landscape.

Miller Creek

Miller Creek originates from Arbor Lake within the City of Burien. Migrating chum salmon are depicted in lower Miller Creek (WDFW 2011), and adult spawning Coho were observed in the creek in the 1990s (King County and Washington State Conservation Commission 2000) and are documented in the WDFW SalmonScape database. The Limiting Factors Analysis cites the observation of a single sockeye salmon in 1980. Fish passage barriers observed in the 1970s appear to have been removed as of 1999 (King County and Washington State Conservation Commission 2000); however, a total fish barrier is depicted in the WDFW SalmonScape database as occurring in the upper reaches of the creek within the City of Burien presently. While some reaches of the creek contain fair riparian habitat, riparian habitat overall was found to be a limiting factor to natural salmonid reproduction. (King County and Washington State Conservation Commission 2000). Potential for large woody debris recruitment was rated as poor, and impervious surfaces were found to contribute to high flow and sediment load and to impact water quality. The upper reaches are, however, part of a WDFW (2011) PHS Biodiversity Corridor.

Walker Creek

Walker Creek originates from a large wetland in the southeast corner of the City and continues westerly through Normandy Park en route to Puget Sound. Riparian habitat in the Creek has been impacted by agriculture and urban development, albeit to a lesser degree than Miller Creek (King County 2000). The headwater area is highly urbanized, and a culvert beneath Highway 509 likely acts as a fish passage barrier. The channel in this area also does not contain suitable fish habitat. Downstream of the headwater wetland, the creek runs through and along suburban development and roads, and through numerous undersized culverts. Where riparian vegetation exists in this reach, it is primarily young deciduous plants and often ornamental species and lawn. Homeowners have altered the channel in places. Substrate is sand and silt with occasional gravel and large woody debris is scarce. Lower reaches have somewhat better riparian habitat, but urban encroachment is also evident in the form of lawns, landscaping, and invasive plants. The lowest reaches, nearest Puget Sound, also exhibit a great deal of channel disturbance and alteration, with little natural riparian vegetation and high sedimentation (King County and Washington State Conservation Commission 2000).

Other Systems

Three additional small, non-salmonid stream systems are part of designated PHS Biodiversity Corridors. The Seahurst Park area includes two unnamed streams with several tributaries with a relatively intact corridor of native forest in ravines. The majority of the land is owned by the City of Burien and managed as a City park. A smaller corridor in private ownership extends from the shoreline eastward toward Lake Burien (but does not include the lake) and includes a habitat corridor of native forest vegetation, broken in a few areas by roads.

Stream Classification / Water Typing System

Streams are commonly classified based on flow conditions and fish use. The Department of Natural Resources (DNR) is encouraging all jurisdictions within the State to adopt the permanent water typing system upon completion of fish habitat water type mapping. The permanent system provides for four stream classes as listed in Table 6-1 below.

Table 6-1. Permanent Water Typing System (WAC 222-16-030)

Permanent Water Typing	Description
Type S	All waters, within their bank-full width, as inventoried as "shorelines of the state" under chapter 90.58 RCW and the rules promulgated pursuant to chapter 90.58 RCW including periodically inundated areas of their associated wetlands.
Type F	Segments of natural waters other than Type S Waters, which are within the bankfull widths of defined channels and periodically inundated areas of their associated wetlands, or within lakes, ponds, or

Permanent Water Typing	Description
	impoundments having a surface area of 0.5 acre or greater at seasonal low water and which in any case contain fish habitat or are described by one of the following four categories: (a) Waters, which are diverted for domestic use by more than 10 residential or camping units or by a public accommodation facility licensed to serve more than 10 persons, where such diversion is determined by the department to be a valid appropriation of water and the only practical water source for such users. Such waters shall be considered to be Type F Water upstream from the point of such diversion for 1,500 feet or until the drainage area is reduced by 50 percent, whichever is less; (b) Waters, which are diverted for use by federal, state, tribal or private fish hatcheries. Such waters shall be considered Type F Water upstream from the point of diversion for 1,500 feet, including tributaries if highly significant for protection of downstream water quality. The department may allow additional harvest beyond the requirements of Type F Water designation provided the department determines after a landowner-requested on-site assessment by the department of fish and wildlife, department of ecology, the affected tribes and interested parties that: (i) The management practices proposed by the landowner will adequately protect water quality for the fish hatchery; and (ii) Such additional harvest meets the requirements of the water type designation that would apply in the absence of the hatchery; (c) Waters, which are within a federal, state, local, or private campground having more than 10 camping units: Provided, That the water shall not be considered to enter a campground until it reaches the boundary of the park lands available for public use and comes within 100 feet of a camping unit, trail or other park improvement; (d) Riverine ponds, wall-based channels, and other channel features that are used by fish for off-channel habitat. These areas are critical to the maintenance of optimum survival of fish. This habitat shall be identified based on the following criteria: (i) The site must be connected to a fish habitat stream and accessible during some period of the year; and (ii) The off-channel water must be accessible to fish.
Type Np	All segments of natural waters within the bankfull width of defined channels that are perennial non-fish habitat streams. Perennial streams are flowing waters that do not go dry any time of a year of normal rainfall and include the intermittent dry portions of the perennial channel below the uppermost point of perennial flow.
Type Ns	all segments of natural waters within the bankfull width of the defined channels that are not Type S, F, or Np Waters. These are seasonal, non-fish habitat streams in which surface flow is not present for at least some portion of a year of normal rainfall and are not located downstream from any stream reach that is a Type Np Water. Ns Waters must be physically connected by an above-ground channel system to Type S, F, or Np Waters.

6.1.3 Ponds and Lakes

Open water features are a vital habitat component for the listed and significant species in Burien. Lakes and large rivers that support fish provide prey for bald eagle, osprey, great blue heron, and green heron. These species all rely on the proximity of these features for some or all of their lifecycle, and the presence of open water in the City of Burien is responsible for the ability of the species to live in City limits. Herons in particular often nest near open-water wetlands. Preservation of forest stands, native shrub, and large trees near open water is key to providing potential nesting habitat for these species as well. As well, any measures to enhance fish populations in Burien lakes would benefit herons and eagles.

Ponds and small lakes, (less than 20-acres in size) such as Arbor Lake, within the City of Burien are described as wetlands and are largely covered in the wetland section of this document. Lake Burien is a water of the state and is regulated as such. Lakes are generally defined as large areas of open water with average depths of 6.6 feet (2m) or more (Hruby 2004). Ponds are smaller shallower depressions with permanent inundation. Functions of ponds meeting wetland criteria are described in the wetland section of this document. Specific information on Burien lakes and ponds is limited.

6.2 Functions & Values

6.2.1 Streams & Riparian Areas

While the primary role of streams and rivers is to transport water, riparian areas interact with many other fluvial and landscape processes. These processes act in concert to support a wide diversity of aquatic and terrestrial plant and wildlife species. Under natural conditions, a dynamic equilibrium within riparian areas provides for continual environmental change, such as channel migration, but supports the stability of species which rely on those changes for survival. Thus, streams and rivers are included here as fish and wildlife habitat areas.

Natural Processes and Disturbance Events

Natural disturbances (e.g. floods, fire, landslides, and channel migration) lead to spatial heterogeneity and temporal variability, which lead to numerous habitat niches in non-equilibrium, leading ultimately to ecological diversity (Naiman et al. 1993; Gregory et al. 1991). Unmodified riparian corridors are characterized by high dynamism and disturbance events, which, in low-order[2] streams, consist primarily of landslides and debris flows. Higher-order streams are typically

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[2]Stream order refers to a classification system that groups streams based upon their relative size. By convention, first-order streams have no tributaries, as viewed on a map, typically a USGS 7 ½-minute topographic map; second-order streams result from the confluence of two first-order streams; third-order streams are produced when two second-order streams meet; and so on. Recognition that many intermittent and small perennial streams are not represented on USGS 7 ½-minute topographic maps has led some to use the term “zero-order” for such streams. Reliable classification of stream order requires field verification.

characterized by floods and channel migration (Naiman et al. 1993). The survival of many plant and animal species is dependent upon such dramatic changes to the environmental landscape.

Stream channel migration is a key environmental disturbance necessary for the sustainability and richness of species along the riparian corridors. Erosion processes that occur during flood events and subsequent changes in channel direction lead to improvements in large woody debris (LWD) recruitment, gravel and sediment transport, and nutrient supply. These processes can also form off-channel habitat such as oxbows and side channels or even smaller incremental changes such as lateral bank scour and pool/riffle formations (King County 2004). Off-channel and floodplain habitats are particularly significant for salmonid over-winter survival and growth (e.g., Solazzi et al. 2000; Sommer et al. 2005; Tschapalinski and Hartman 1983). Together, these structural changes can result in increased habitat quality and complexity for salmon spawning and rearing, as well as for other aquatic species.

Functional roles of riparian areas and the width of the riparian corridors are related to the position of the stream in the drainage, the hydrologic regime, and the local geomorphology (Naiman et al. 1993). Low-order streams typically occupy confined channels whose forms are dominated by hillslope rather than fluvial processes (Montgomery and Buffington 1997).

Riparian plant communities influence aquatic and terrestrial ecology (Gregory et al. 1991). Steep slopes may limit the extent of common riparian vegetation (Knutson and Naef 1997). Low-order streams flowing through unconfined reaches exhibit plant communities distinct from the surrounding uplands (Gregory et al. 1991; Naiman et al. 1998). In contrast, because of the dominance of hillslope process on channel form, riparian areas along confined headwater streams tend to be narrower and less distinct, and have been thought generally to contain vegetation similar to that of upland areas (Gregory et al. 1991). However, further studies of confined, intermittent streams and small, perennial streams have found significant differences between riparian and upland vegetation characteristics (Waters et al. 2001). These differences in vegetation characteristics are exhibited primarily in the groundcover and shrub vegetation layers of headwater channels (Waters et al. 2001). Vegetation characteristics are critical factors in the function of the riparian zone, including allocthonous input (litterfall, terrestrial insects) (Piccolo and Wipfli 2002) and wildlife habitat (Waters et al. 2001; O'Connell et al. 2000). Finally, riparian corridors can play an important role in plant dispersal due in large part to microclimate considerations (Gregory et al. 1991).

As documented in the literature, streams, associated buffers and riparian areas perform several important functions including water quality, bank stabilization, shade and temperature, microclimate, wildlife habitat, in-stream habitat and productivity.

Water Quality

Riparian areas have inherent water storage capabilities, which can serve to retain pollutants and nutrients in surface runoff; this is affected by soil permeability and type, surrounding land uses, slope, and drainage installations. Riparian forests are important for biotic accumulation of nutrients due to high transpiration rates (Naiman and Décamps 1997). Riparian zones reduce nitrogen pollution through nutrient uptake and assimilation by vegetation, and the transformation of dissolved nitrogen to nitrogen gas in a process called denitrification (Schwartz and Houser 2006). The effectiveness of filtration by the riparian zone depends on riparian zone density and composition, overland flow volume, hillslope, width of the protected zone, and sediment particle size (Osborne and Kovacic 1993). Complex buffers with multiple classes of vegetation may be most effective at removing a variety of contaminants. Indeed, Schultz et al. (1995) found that riparian buffers combining trees, shrubs, and groundcover vegetation were effective at significantly reducing a complex mix of agricultural pollutants and nutrients. Riparian buffers along smaller streams have greater potential to reduce pollutant load due to the lower water volumes in small channels, underscoring the importance of protecting such systems (Naiman and Décamps 1997).

Bank Stabilization

Riparian vegetation is commonly acknowledged as providing a bank stabilization function. This is accomplished through a complex of tree roots, brush, and soil/rock that protect streambanks from high velocity stream flows by slowing water currents (Spence et al. 1996). These structures create resistance to erosion while allowing moderate levels of dynamic channel change to occur.

In addition to bank vegetation and root structures, large woody debris (LWD) also plays a significant role in streambank stabilization, especially in headwater streams (Naiman and Décamps 1997). Beeson and Doyle (1995) concluded that major bank erosion is 30 times more likely on stream bends with bare banks compared to vegetated banks, and that densely vegetated banks are the most effective at resisting erosion. A study in Virginia found that woody vegetation provides greater bank stability than herbaceous vegetation because woody vegetation has larger roots extending deeper into the bank (Wynn and Mostaghimi 2006; Wynn *et al.* 2004). Another study on 1^{st}-3^{rd} order streams in the southeastern Cascades found that streams exhibited greater geomorphic complexity when flanked by scrub-shrub riparian vegetation (e.g. alder, vine maple, and dogwood) that formed the understory of Ponderosa pine forests compared to dense mature fir forests with little understory riparian vegetation (Liquori and Jackson 2001).

Due to a lack of stream power, LWD is relatively stable in small headwater streams, contributing to overall channel stability and the retention of sediment (Montgomery and Buffington 1997), both of which are critical factors in the distribution of salmonids (Montgomery et al. 1999). Ironically, the contribution of LWD to channel form in headwater streams is essential to the reduction in stream power that ultimately impedes the export of LWD from headwater systems. Thus, maintaining sufficient recruitment of LWD to headwater streams provides an effective mechanism for maintaining channel form.

Headwater Systems

Low-order streams (first- and second-order streams) account for more than 70 percent of the cumulative channel length in typical mountain watersheds of the Northwest (Benda et al. 1992). Similarly, intermittent streams on 13 national forests in the Northwest represented an average of approximately two-thirds of the estimated total channel length (FEMAT 1993). Headwater streams produce significant quantities of litterfall (Gomi et al. 2002) and invertebrates (Wipfli 2005; Wipfli and Gregovich 2002) that are transported downstream where they contribute to salmonid production. Riparian zones along small, low order streams have been found to be particularly effective at reducing downstream temperatures (Elliot 2003) and contaminants (Tomer et al. 2005). These factors are important when assessing potential impacts to anadromous fisheries, as it is noted that populations in lower order streams can show, on a relative basis, greater declines due to environmental changes. Riparian vegetation surrounding small, headwater streams contributes to riparian continuity at the watershed scale and can ameliorate water quality and habitat concerns, making downstream riparian zones more effective.

Shade & Temperature

Factors influencing water temperature include shade, relative humidity, ambient air temperature, wind, channel dimensions, groundwater, and overhead cover (Adams and Sullivan 1989; Mohseni and Stefan 1999). Overall, 60 to 80 percent shading throughout the day is recommended to maintain water temperature control (Knutson and Naef 1997). Steinblums et al. (1984) considered riparian width and shading for 40 streams in conifer-dominated areas of Oregon. They found that 120 ft wide riparian zones would generally result in 80% shade coverage, whereas a 25 ft and 50 ft riparian zone would result in 20% and 45% coverage, respectively (Steinblums et al. 1984). Beschta et al. (1987) reviewed literature on riparian zones and shading, concluding that in western Oregon, forested riparian zones wider than 98 ft maintain maximal shading and temperatures similar to natural forested conditions. Vegetated buffers up to about 25 meters (approximately 80 feet) provide significant shade production (Castelle and Johnson 1998). Besides shading, the next most important factor influencing stream temperatures is ambient air temperature, which is a function of microclimate (Mohseni and Stefan 1999; Poole and Berman 2001; Adams and Sullivan 1989).

Microclimate

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 habitat (synthesis provided by Brosofske et al. 1997). With the exception of wildlife habitat, riparian buffer widths necessary for microclimate control are generally much wider than those necessary for other functions. Microclimatic gradients appear in air, soil, and surface water temperatures as well as relative humidity (Naiman and Décamps 1997).

Wildlife Habitat

Streams provide breeding and foraging habitat for both green and great blue herons, as well as for numerous other birds and for fish, reptiles and amphibians. Where vegetated riparian zones exist along streams, they become an invaluable resource as travel corridors for birds and mammals.

Riparian corridors can serve as refuges and travel corridors for wildlife (Naiman and Décamps 1997). Riparian areas provide ready access to drinking water, nesting and foraging sites, and cover. The wildlife communities supported by large rivers can be dramatically different than those associated with small streams. Riparian habitat along smaller streams is generally insufficient to support large mammals, but it can provide habitat for a number of bird species (Bolton and Shellberg 2001). Natal dispersal of some bird species has been linked to riparian corridors (Machtans et al. 1996). Frogs and salamanders utilize riparian habitat at various stages of their lives; this use can be either permanent or transient (Brode and Bury 1984). Salamanders range widely from waterbodies, and utilize riparian areas as migration corridors (Maxcy and Richardson 2000; Semlitsch 1998; Brode and Bury 1984). Buffer strips that are inadequate for wildlife could impact the transfer of nutrients from aquatic to terrestrial systems (Willson et al. 1998).

In-Stream Habitat (Large Woody Debris)

As discussed above under "Shoreline Stabilization," LWD exerts a substantial influence on channel morphology for confined headwater streams. LWD and other debris are rarely transported in small streams, and the consequent obstructions formed by LWD alter hydrology and geomorphology (Knutson and Naef 1997). The collection of woody debris and the subsequent entrapment of smaller branches, limbs, leaves and other material has been found to significantly reduce flow conveyance (Dudley et al. 1998). Gregory et al. (1991) reviewed the literature and found that LWD has a greater influence in the development of geomorphic structures in headwater streams, than downstream channels. LWD also retains smaller organic debris and provides substrate for microbes and algae, supplying a resource base for macroinvertebrates (Bolton and Shellberg 2001). LWD results in longer water residence time, shortening the carbon-spiral length (Naiman and Décamps 1997).

In higher order streams, LWD plays an important role in forming complex in-water habitat structures (Bilby and Ward 1991; Montgomery and Buffington 1997; Pollack and Kennard 1998). These structures improve salmonid habitat by providing flow refugia and essential cover from predators as well as improved foraging conditions. LWD also traps smaller woody debris and organic matter which in turn contributes to additional enhancement of habitat conditions. The literature shows a strong correlation between the density of LWD in streams and salmonid production. Fausch and Northcote (1992) found that streams containing large amounts of LWD supported populations of juvenile cutthroat and coho salmon five times greater than streams within the same river system that had been cleared of LWD. Quinn and Roni (2001) found that winter densities of coho salmon, steelhead, and cutthroat trout were higher in streams where LWD had been added. Similarly, the removal of LWD from streams has been correlated with decreased salmonid abundance in the Pacific Northwest and southeast Alaska (Dolloff 1986; Elliot 1986; House and Boehne 1986).

Productivity

Small streams receive most of their energy from allocthonous input (litterfall, terrestrial insects) from the riparian zone. Allocthonous inputs account for 81-95% of primary production in first and second order streams; whereas 85-95% of production in fifth and sixth order streams is autochthonous (Conners and Naiman 1984). Small, headwater streams serve as food conduits for downstream, fish-bearing waters, significantly increasing the capacity of those waters to support salmon (Dodge and Mitas 2001; Piccolo and Wipfli 2002; Wipfli et al. 2002). Intermittent streams have been found to produce substantial numbers of macroinvertebrates, exceeding those of perennial streams in some cases (Muchow and Richardson 2000).

6.2.2 Ponds and Lakes

Ponds and lakes meeting wetland criteria may perform the wetland functions, which are discussed in Section 5 above. The open water of ponds and lakes also functions as a special habitat feature, providing an essential habitat component for many wildlife species.

Species of special concern and interest depend on ponds and lakes at some or all stages of their lifecycles. Bald eagles, green herons, and great blue herons, the species of importance covered in this document, all depend on open water for foraging. Green herons in particular feed almost exclusively on species found in ponds, lakes, and streams, as well as preferring nest sites near ponds and streams. The species depends on wetlands, ponds and streams for their prey, which is primarily small fish, but also includes crustaceans, insects, herpetiles and rodents. They typically nest in trees near water (Seattle Audubon 2005).

The open areas above ponds and lakes are ideal foraging habitat for a number of swift and swallow species. Bald eagles and peregrine falcons regularly forage on ducks and other birds that utilize open water. Reptiles and amphibians that breed and rear in ponds and lakes are important as primary and secondary prey species to a variety of wildlife, beyond the species of local importance mentioned here.

Preservation of forest stands, native shrub, and large tree buffers on ponds and wetlands is key to providing potential nesting habitat for the species that utilize open water. Vegetated buffers and riparian zones are also an invaluable resource as travel corridors, roosting areas, and resting cover for birds and mammals. Many studies address the importance of riparian corridors to wildlife, particularly in developed areas (Knopf et al. 1988, Gillies and St. Clair 2008). Similarly, pond and lake buffers provide cover for wildlife using the open water. The interface between open water and upland habitat is of great value to wildlife for these reasons, and any alteration in ponds, lakes and their buffers can affects all wildlife guilds in complex ways (Sheldon et al. 2005).

6.3 Potential Effects of Development

Recent science addresses measurable effects of urbanization on native habitat, and how animal populations and communities change in response. Emerging trends indicate repeatable and predictable changes to that may be expected. Generally, as buildings and paved surfaces increase, vegetation coverage decreases and remaining vegetation tends to be maintained and unnatural. Although habitat heterogeneity and wildlife species richness may increase temporarily as a result of increased habitat interspersion resulting from varying degrees of human disturbance (McKinney 2002), the end result is reduced vegetative richness and diversity at the urban core.

6.3.1 Changes in Vegetation

Land use changes from contiguous forest to single-family housing in developing Puget Sound cities resulted in significant declines in native tree and forb diversity as forest was lost in the last quarter of the 20th century (Robinson et al. 2005). Native shrub diversity also showed a downward trend. In this and other studies (Blair 1996, 2001; McKinney 2002), exotic ground cover vegetation increased significantly with development, and this in turn served to simplify and degrade ground cover (Reichard and White 2001), which can impact nest site selection and foraging availability. Both the number and proportion of non-native plant species changed from a few percent or less in rural areas to more than 50% at the urban core in the Midwestern U.S. (Whitney 1985). As the urbanization gradient progresses, the rate at which natural vegetation is lost increases (McKinney 2002). The replacement of native species by common non-native weeds presents the danger of habitat homogenization (Blair 2001). As well, vegetative structural diversity can be expected to decrease as forest is lost, although urbanization in former grasslands can actually increase structural diversity (Marzluff 2001). Scientists in the Pacific Northwest and elsewhere have investigated the impacts of these vegetation changes. These vegetation alterations have been shown to drive changes in animal populations and communities.

Loss of species richness in urban cores has been attributed to reduction in available habitat, measured as number of plants or area covered by plants, particularly in earlier works. Richness of birds (Shugart et al. 1975, Goldstein et al. 1986), mammals, and herpetiles (Dickman 1987) has been correlated with amount of available plant cover. In small study areas, such as urban parks, wildlife-habitat dynamics are also influenced by factors like juxtaposition of landscape features; locations of structures, roads, and other development; availability of adjacent habitat; presence of corridors; and other landscape-level characteristics.

Replacement of native vegetation with maintained lawns has been demonstrated to affect bird and butterfly abundance and species richness negatively (Nelson and Nelson 2001). Increased non-native vegetative cover, which can include ornamental species used in landscaping, was one of several factors that simultaneously led to reductions in the number and quality of urban songbird nest sites in several studies, and exotic shrub cover was correlated with an increased risk of nest predation (Marzluff 2001). Exotic ground and shrub cover was locally associated with a decrease in forest bird species and an increase in synanthropic species, or those that adapted readily to human presence, in the Seattle area, although whether these changes were also the result of other concurrent effects of other urbanization was unclear (Donnelly and Marzluff 2004). Ironically, dispersal of non-native plant species may be facilitated by birds in the urban landscape, leading to the propagation of discrete infestations (Reichard et al. 2001).

6.3.2 Fragmentation and Connectivity

A major effect of urbanization at both local and landscape levels is habitat fragmentation and loss of connectivity. As structures, roads, yards, and other man-made features perforate the landscape, remaining habitat becomes isolated in patches or fragmented, often to the detriment of wildlife (Marzluff and Ewing 2001). Isolated habitat fragments tend towards degradation and the establishment of non-native habitat (Marzluff 2001). Water flow is obstructed or redirected, nutrient cycling is disrupted, and ecological function may be interrupted or altered. Many taxa of wildlife are impacted by discontinuity of habitat as it affects travel between available patches.

Urban development tends to cause more persistent and drastic fragmentation than other land uses, such as forestry and agriculture, as fragments are commonly separated by impervious surface, structures, impassable barriers, and infrastructure used by vehicles and people. Subsequent impacts on wildlife and habitat can be extreme. Total habitat area is reduced; dispersal and travel by many wildlife species is altered or obstructed; and the processes of predation, parasitism and interspecies competition are affected (Marzluff and Ewing 2001).

Fragmentation affects species differently depending on the species' sensitivity to patch size, isolation, habitat within the patch, landscape characteristics surrounding patches, and species interactions with other wildlife using the landscape. Even small breaks between habitat patches can deter wildlife travel and, in some cases, directly impact wildlife abundance. Fahrig et al. (1999) documented a proportional increase in frog and toad mortality with traffic intensity on roads, and suggested that mortality contributed to decreased abundance in areas of high-intensity road use. The relatively small gaps from bridges, perhaps coupled with the disturbance of vehicles and noise, were associated with decreases in riparian bird species richness and density (Lens and Dhondt 1994, Machtans et al. 1996). Not surprisingly, urban-exploiters and species that nest in man-made structures increased with the same type of fragmentation and disturbance (Rottenborn 1999).

Patch size has been shown to exert an influence on bird populations. In Burien, habitat patches occur between and among manmade features like homes and roads and contiguous, naturally vegetated areas are limited outside of the larger stream corridors that have received PHS Biodiversity Corridor designation. Donnelly and Marzluff (2004) looked at habitat patch size impacts on avian species in a landscape context in the Seattle metropolitan area. Their results provide evidence that species richness increases with habitat patch size, as reported elsewhere in the literature, in all landscapes (urban, suburban, and rural) because large patches are able to support more species drawn from the regional pool. As well, larger patches can be expected to support greater habitat diversity and subsequently more niches for species to utilize. As reserve size decreased, those species depending on intact or expansive forest were the first to disappear. In summary, forest species occurrence decreased with decreasing habitat patch size, and synanthropic species occurrence increased with the amount of urbanization in the surrounding landscape. Non-native groundcover explained much of this variation: native forest species decreased and synanthropic species increased with the amount of exotic ground vegetation.

The complex juxtaposition of habitats in more urban landscapes seems to allow for the occurrence of synanthropic species in urban habitat patches.

Long-term viability of avian populations is lowered by reduced quality and abundance of native forest (Donnelly and Marzluff 2004). As well, native forest bird species are the first to be lost from urban areas. Therefore, large forest patches in the greater landscape may be important to adjacent developed areas in that they preserve species that may use urban areas but cannot exist without larger habitat patches in the greater vicinity. In contrast, fragmented habitat matrices are a major influence on urban habitat patches as a source of invasive plants and predators (McKinney 2002). These urban habitat patches may eventually become “sinks,” unable to support wildlife populations.

A review of collected literature found that terrestrial habitat islands are likely to support more species as the size of island increases (Adams 1994). This holds true for woodland birds, chaparral birds, land vertebrates, flies, and beetles.

One solution to the negative impacts of fragmentation is connectivity (Schaefer 2003). Connectivity refers more to the ability of an animal to traverse an area than any innate condition of the habitat itself. It can refer to the intactness of a patch or expanse of habitat (in contrast to fragmented habitat) or to a travel corridor between larger habitat patches. It is becoming increasingly apparent that landscape configurations are an important factor in species occurrence and distribution (Rodewald 2003), but it follows that different wildlife species perceive and use connectivity differently. Small, terrestrial organisms require separate consideration from more mobile large mammals and birds. Many small, less readily mobile species are typically associated with wetlands, streams and riparian zones, potential impacts to which are discussed in Section 6.3.5 and elsewhere in this document. Upland areas adjacent to streams and wetlands are crucial to the ability of many less mobile species to live, reproduce and travel (Calhoun and de Maynadier 2004). Thus, connectivity between upland habitat areas may aid in the movement and survival of some taxa. Lehtinen et al. (1999) found that road density in particular was associated with a decline in amphibian species richness. This argues for upland connectivity when preserving wetlands.

Less mobile species, such as invertebrates and small mammals, often exhibit a more profound response to development than more mobile species (Hansen et al. 2005), and might be expected to be more greatly impacted by fragmentation. Bird population dynamics may be related to amount of vegetated area available rather than configuration because birds are highly mobile and able to travel between disjunct patches (Marzluff 2005). However, some mobile species (e.g., songbirds) exhibit a preference for traveling between habitat patches through wooded areas compared to open gaps, even when the wooded route was up to three times longer than the gap (Desrochers and Hannon 1997).

6.3.3 Other Impacts

Ecological Processes

Human activities in urban areas impact a number of ecological processes. Altered flood regimes, increased and redirected stormwater flow, and changes in stream volumes and locations are all incurred with the construction and development of towns and cities. Subsequent changes in riparian and floodplain vegetation can change vegetative composition and structure in urban habitat. These areas are of particular importance because they tend to support rich wildlife communities (Knopf et al. 1988). Habitat degradation is just one of the impacts of stormwater sediment and pollution (Anthony et al. 1993, 1994), which result from increased impervious surface (NRDC 1999). Increases in impervious surface are a universal result of urbanization and ongoing development. This in turn may increase pollution and sedimentation in stormwater runoff, which typically lowers water quality in aquatic features, where it can impact biotic communities (Garrison and Wakeman 2000). Similar increases in nutrient load can impact the natural environment by promoting the growth of non-native species and lowering biotic diversity (Vitousek et al. 1997). Water quality and other impacts are further discussed Section 1.2.2.

Direct Human Disturbance

Habitat disturbance by humans results from the influx of people to newly developed areas and the activities of people in existing settlements. Noise, vehicular and foot traffic, litter and pollution, lighting, and pets all impact habitat to some extent. Passive and active recreation (Fraser et al. 1985, Stalmaster and Keiser 1998) put varying degrees of pressure on birds and other wildlife, as well impacting habitat with the addition and use of trails and other recreational facilities. The presence of humans along trails has been shown to impact adjacent use of habitat by birds (Miller et al. 1998).

6.3.4 Endangered, Threatened, or Sensitive Species and Species of Local Importance

Due to the limited presence of priority fish species beyond the shoreline jurisdiction areas, habitats of terrestrial species included as City of Burien FWHCAs are the focus of this section. The occurrences of non-shoreline fish species covered under Burien FWHCA regulations are confined to a few stream systems and associated with stream and riparian habitat, which are addressed in detail in Section 6.3.5.

Bald Eagle

Nesting bald eagles tend to choose sites close to open water in dominant tall trees of any species, usually providing line-of-sight to nearby water (Watson and Rodrick 2004). Individuals may forage in an area covering up to 5 square miles in a day. Their diet is primarily fish, both live and dead, as well as ducks, other waterfowl, and carrion. Mammals are taken on occasion.

In winter, birds congregated at feeding grounds along large rivers and roost sites in dense conifer stands in western Washington. Habitat for established pairs and potential breeding habitat for additional birds exists in Burien, and suitable foraging perch trees are present throughout the City.

The species often acclimatizes well to human development, although some individuals respond negatively to new disturbance and development (Stalmaster 1987). In developed and developing areas, they often forage and perch in highly developed and easily visible areas. However, even urban adapted individuals are sensitive to human activities during incubation and rearing. Noise, visual proximity to human activity, boating and other recreational uses, pets, and roads may all impact eagles in Burien. Loss of existing or potential habitat or individual trees may deter eagles from using an area. In addition to the direct impacts of human disturbance and habitat loss, disruption or modification of food sources also have the potential to impact the species indirectly.

Herons

Great blue herons are typically thought of as wading birds frequenting wetlands, rivers, ponds and lakes. They are common in these habitats year-round in the Burien area. In winter, however, they also hunt on land, foraging on small mammals, primarily voles (Seattle Audubon Society 2005). The species usually nests in tall trees, but may also utilize artificial structures and even shrubs. The availability of suitable nesting sites in proximity to foraging areas may limit the occurrence of the species, and a number of studies also show that human disturbance can affect colony success, although some birds may acclimatize to disturbance (Quinn and Milner 2004).

Green herons depend on wetlands, ponds and streams for their prey, which is primarily small fish, but also includes crustaceans, insects, herpetiles and rodents. They typically nest in trees or shrubs, singly or in colonies, near water. Although they breed in developed areas, they are a secretive species and susceptible to disturbance, development and habitat loss (Seattle Audubon Society 2005).

The nationwide population of Green Herons appears stable (Davis and Kushlan 1994; Seattle Audubon Society 2005), and their range appears to be expanding in this region. Threats to the population include predator control at fish hatcheries and disturbance during the nesting season. Pesticides appear to be less of a threat for Green Herons than for other heron species. As is the case with most wetland species, habitat loss and degradation are the primary concerns to the population.

6.3.5 Streams and Riparian Areas

The following review provides a background of both natural and anthropogenic-influenced processes to riparian areas, including in-stream habitat. In addition, a review of the available scientific literature is provided, assessing the effectiveness of the riparian buffers in an urbanized environment.

Effects of Development

A key feature of urban areas is impervious surface coverage. Increases in impervious surface coverage, and the consequent reduction in soil infiltration, have been correlated with increased velocity, volume and frequency of surface water flows. This hydrologic shift alters sediment and pollutant delivery to streams (Booth 1998; Arnold and Gibbons 1996). Increased surface water flows associated with impervious surface coverage of suburban areas (20-30%) has been linked to decreased bank stability and increased erosion (May et al. 1997a). Knutson and Naef (1997), in their literature review, concluded that as little as 10 percent impervious surface coverage is sufficient to alter bank stability and erosion. This increased erosion often simplifies stream morphology, leading to wider, straighter stream channels (Arnold and Gibbons 1996), or narrow incised channels (Booth 1998), depending upon position in the watershed. Additionally, changes in basin hydrology resulting from land use activities and stormwater conveyance can have a profound negative influence on channel stability (Booth 2000).

Changes in hydrology and stream morphology brought on by impervious surfaces have also been linked to shifts in macroinvertebrate community composition, which could have profound and far-reaching impacts on the productivity of a watershed (Pederson and Perkins 1986, as cited in Leavitt 1998). Changes in fish assemblages have been correlated with changes in stream temperature and base flow as a result of increased impervious surface coverage (Wang et al. 2003). Increases in flood frequency and volume have been correlated to declining salmon populations in some Puget Sound lowland streams (Moscrip and Montgomery 1997). Riparian areas can protect against these factors by moderating surface water and sediment inputs. While, impervious surface area alone is not the only component to predicting stream biological conditions (Booth et al. 2004), riparian quality has been shown to be inversely proportional to the level of urbanization (May et al. 1997b).

Many concerns have arisen in recent years over the impacts from the urbanization of predominantly forested areas, especially areas that contain erosion-susceptible geologic substrate and relatively high gradients (Booth and Henshaw 2001). Booth and Henshaw (2001) found that under highly susceptible conditions, post-development channel changes occur so rapidly that remediation efforts could only be successful if implemented prior to development. Booth et al. (2002) conclude that under typical rural land uses, impacts to watershed ecology from reduced forest-cover area can be as great or greater than similar increases in impervious area. Threshold levels of 10 percent impervious coverage and 35 percent deforested area have been found to mark a distinct transition towards severely degraded stream conditions (Booth 2000).

In general, development is known to have detrimental effects on salmonids, particularly with spawning abundance and success. Pess et al. (2002) found that wetland occurrence, local geology, stream gradient, and land use were significantly correlated with adult coho salmon abundance. While positive correlations were found between spawner abundance and forested areas, negative correlations were found between spawner abundance and areas converted to agriculture or urban development. Fish species diversity has been found to decline with increasing levels of urban development, while cutthroat trout (*O. clarki*) tend to become the dominant salmonid species (Lucchetti and Fuerstenberg 1993; Ludwa et al. 1997). Human impacts upon the landscape have altered natural and dynamic stream processes through the modification of water conveyance for flood control, agriculture, and other development, such that the protection and enhancement of both habitat and species is essential to their preservation.

Importance of Headwater Systems

Hydrologic connectivity is an important consideration in watershed management, and the basis for support of headwater-stream protection (Naiman et al. 1993). Headwater streams serve as important resource bases to subsidize downstream food webs, and much of the material for export originates in the riparian zone (Dodge and Mitas 2001; Piccolo and Wipfli 2002; Wipfli et al. 2002). Headwater streams also govern downstream water temperatures (Mohseni and Stefan 1999). Thus, disregard for headwater streams could have ramifications at multiple scales.

Water Quality

Sediment input to streams is supplied by both bank erosion and upland processes (Naiman and Décamps 1997). Sediment input to confined, low-order streams in unmodified watersheds is typically dominated by hillslope processes while sediment input within higher order streams is typically driven by fluvial processes (Montgomery and Buffington 1997). In unmodified watersheds, aquatic organisms are adapted to the natural rate of sediment input via disturbance and erosion. Changes to that natural rate of sediment input resulting from human activities stress aquatic systems (May et al. 1997b). Large storms and resulting high flows in urbanized watersheds result in elevated sediment transport and associated turbidity and nutrient concentrations, due to increased erosion, mass-wasting, and the mobilization of water-quality constituents accumulated on roads and other impervious surfaces. Construction sites are also potential sources for sediment (May et al. 1997b).

The reduction in forest cover and increase in impervious surface coverage typical of urbanized watersheds substantially impairs the storage capabilities of the watershed (Booth 2000; Sorrano et al. 1996). Stormwater systems often bypass riparian buffers, conducting nutrient- and sediment-laden water directly to receiving waters. The result is that urban areas contribute a disproportional amount of nutrients and other contaminants to receiving waters relative to the percentage of urbanized area within the watershed (Sorrano et al. 1996). Excessive nutrients in aquatic ecosystems can lead to poor water quality conditions including reduced dissolved oxygen rates, increased pH, and eutrophication (Mayer *et al*. 2005). Provided that they are not bypassed via a stormwater system, forested buffers can significantly reduce nutrient flux to receiving waters, but actual reductions are highly responsive to variations in precipitation (Sorrano et al. 1996). Chemical removal functions increase with buffer width out to 25 to 30 meters (approximately 80 to 100 feet); after this point, disproportionately large increases are needed to improve riparian function (Castelle and Johnson 1998).

Forested buffers of 100 to 150 feet are frequently recommended for sediment removal functions (Johnson and Ryba 1992). However, 50 percent removal efficiency is commonly attained in the first 30 to 100 feet (Daniels and Gilliam 1996, as cited in May et al. 1997b); however, the retention efficiency is highly dependent on site specific conditions. A recent model of sediment retention in riparian zones found that a grass riparian zone as small as 13 ft could trap up to 100% of sediment under specific conditions (2% hillslope over fine sandy loam soil), whereas a 98 ft grass riparian zone would retain less than 30% of sediment over silty clay loam soil on a 10% hillslope (Dosskey *et al.* 2008). For sediment reduction and chemical removal, disproportionately large increases in buffer width are needed beyond 80 to 100 feet to markedly improve buffer function; most benefits of riparian vegetation are realized in the first 15 to 80 feet. Palone and Todd (1997) report that buffers of 45 feet or more are effective at reducing pesticide contamination of streams. Most studies indicate that buffer widths of 50 to 100 feet are adequate for phosphorus and sediment removal, and that increasing widths beyond 150 feet does not significantly improve removal efficiencies (Palone and Todd 1997). While vegetative filter strips have been known to be an effective best management practice for controlling non-point source pollution (Dillaha et al. 1989; Magette et al. 1989; Young et al. 1980), Palone and Todd (1997) emphasize that a combination of grass filter strips and forested buffer is especially good at removing phosphorus and sediment.

Studies have considered the long-term effectiveness of sediment retention in riparian zones by considering the sediment condition downstream of a riparian zone. Meyer *et al*. (2005) estimated that reducing riparian zone width from 100 ft to 50 ft throughout a stream system would increase the fine sediment in spawning gravels by 11%. Based on the combined increase in fine sediment and stream temperature, Meyer *et al*. (2005) used a predictive spatial model to conclude that the reduced riparian zone size would result in an 81-88% reduction in juvenile trout biomass on a watershed scale.

In 2005, the U.S. EPA conducted an extensive review to investigate the qualities of a riparian zone that effectively limit nutrient pollution (Mayer *et al*. 2005). A meta-analysis of all of the studies revealed that riparian zones removed nutrients through subsurface flow more effectively than surface flow (Mayer *et al*. 2005). Riparian zones ranging from 3-675 ft generally removed 89% of subsurface nitrates regardless of riparian zone width (Mayer *et al.* 2005) (Fig. 5). On the other hand, nitrate retention from surface runoff was related to riparian zone width, where 50%, 75%, and 90% surface nitrate retention was achieved at widths of 110 ft, 389 ft, and 815 ft respectively (Mayer *et al.* 2005). Mayer *et al.* (2005) also found that the composition of the riparian zone affected the efficiency of nutrient removal. Forested riparian zones (ranging from 33 ft to 725 ft) removed subsurface flow more efficiently than grass riparian zones, and the nitrogen filtering capacity of grass and grass/forested riparian zones increased with width (Mayer *et al.* 2005).

Bank Stabilization

Bank stabilization functions are potentially subject to degradation in an urbanized watershed. Culp and Davies (1983) observed that a 33 ft riparian zone maintained bank stability in a 3rd order stream in British Columbia one year after logging. Another study suggested that larger riparian zones (>50 ft) were needed to adequately limit stream bank erosion (Whipple *et al*. 1981). In a study in northern California, Erman *et al.* (1977) found that stream channel stability (based on both bank and instream metrics), was reduced in clear-cut streams and streams with riparian zones less than 98 ft, whereas riparian zones over 98 ft maintained stream channel stability similar to unlogged streams. 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 and Johnson 1998).

Shade and Temperature

The loss of riparian forest cover and stream shading has been found to significantly increase stream temperatures (Brown and Krygier 1970; Beschta et al. 1987). While shade affects stream temperature more than most other factors, it may not play a significant role in short, headwater streams (Poole and Berman 2001). Intermittent streams, for instance, typically contain no flow during the hottest weather when the potential for warming would be the greatest. Thus, the level of shading to intermittent streams is often largely irrelevant with respect to temperature.

Additionally, studies of clear-cuts along forested streams in Oregon found incremental yet insignificant increases in stream temperature through short cleared reaches (Zwieniecki and Newton 1999). Ultimately, for short, headwater streams, groundwater temperature and the magnitude of groundwater inputs have the greatest influence on stream temperatures (Mohseni and Stefan 1999).

Microclimate

Altering riparian vegetation can change microclimate, leading to alterations in riparian functions (Brosofske et al. 1997). Stream temperatures are strongly influenced by riparian soil temperatures (Naiman and Décamps 1997), ambient air temperature, relative humidity, and wind speed (Mohseni and Stefan 1999). Changes to microclimate can effectively fragment riparian areas for those species unable to cope with altered conditions (Brosofske et al. 1997). While studies on small streams (approximately 7 to 17 feet wide) suggest that buffers greater than 45 meters (approximately 150 feet) are appropriate to protect riparian microclimate (Brosofske et al. 1997), buffers greater than 100 meters (approximately 328 feet) are generally required for full microclimate protection (Spence et al. 1996; Brosofske et al. 1997). Microclimate factors are potentially influenced by altered conditions to a distance of two to three site-potential tree heights from the streambank (Reid and Hilton 1998). Ledwith (1996) reported that the rates of change in ambient air temperature and relative humidity in forested buffers decreased beyond 30 meters (approximately 100 feet) from the stream, indicating that the inner 30 meters of buffer were the most critical for maintaining those factors.

Wildlife Habitat

Riparian zones play a critical role as wildlife habitat, and those buffer widths reported to fully protect wildlife habitat functions are exceeded only by those widths necessary to protect microclimate (Pentec 2001). Most studies report a range of 200 to 300 feet necessary to provide essential habitat for most species (Keller et al. 1993). However, it has been noted that even a narrow buffer will enhance the habitat of most species (Wenger 1999). Wildlife habitat value is determined by structural complexity, ecological connectivity, food and water availability, and moist and moderate microclimate (Knutson and Naef 1997). The wildlife-habitat functions of riparian buffers are intrinsically tied to the other functions discussed previously. Thus, alteration to any buffer function is likely to affect wildlife habitat. Development can fragment riparian connectivity, thereby reducing its value as habitat and travel corridor for wildlife (Armstrong et al. 1983). Based on songbird studies, while wide corridors are optimal, management efforts should focus on restoring or creating riparian areas along streams that lack vegetation, as even narrow buffers have been shown to enhance habitat for most species (Keller et al. 1993).

Many studies address the importance of riparian corridors to wildlife, particularly in developed areas (Knopf et al. 1988, Gillies and St. Clair 2008). They are particularly valuable in fragmented urban habitats because they facilitate travel among habitat patches for wildlife. For example, corridors are used more frequently than clearcuts by certain bird species for movement (Machtans et al. 1996). The number of wildlife species present is directly proportional to buffer width (Dickson 1989, as cited in Keller et al. 1993). Additionally, wildlife species respond to varying degrees of forest successional stages and are affected by the type, frequency, duration, and severity of disturbance (Naiman et al. 1998).

In-Stream Habitat (Large Woody Debris)

In the riparian zone, large woody debris (LWD) facilitates establishment and survival of plants, and provides cover for wildlife (Naiman and Décamps 1997). Recruitment of LWD is largely dependent on stand-age of the riparian forest (May et al. 1997b). Recruitment from alder-dominated stands tends to be faster than coniferous forests, but decomposition rates are higher (Bilby and Ward 1991). The probability of a tree entering the channel decreases as you move away from the stream (McDade *et al.* 1990; Naiman *et al.* 2002). A study in a redwood forest of Mendocino County, CA found that trees beyond one SPTH from a creek influence LWD indirectly by knocking down other trees closer to the stream when they fall (Reid and Hilton 1998). The implications of this study are that buffer strips need to be much greater than one site-potential tree height to maintain pre-harvest recruitment rates (Reid and Hilton 1998). Further investigation would be necessary before applying this concept to an urban environment. However, new developments requiring clear-cutting of forested areas should consider the effective reduction in buffer dimensions over time due to windthrow on buffer edges.

Productivity

Recent studies around the Puget Sound region have found stream health, as measured with the multimetric benthic index of biological integrity (B-IBI), to be closely associated with urban land cover with a reduction in biological integrity as the percentage of urban cover increases (Morley and Karr 2002). Studies have shown that 30-meter (approximately 100 feet) riparian buffers maintain natural rates of input of organic matter (Kiffney and Richardson *no date*). Other studies have suggested that beyond 80 feet, disproportionately larger buffers are needed to markedly increase allocthonous inputs (Castelle and Johnson 1998).

Riparian Functions and Buffer Widths

Upland changes that impact riparian areas are important in determining overall stream function, degradation and rehabilitation potential (Booth 1998). In addition to buffer width, several factors can influence the effectiveness of vegetative functions, including vegetative composition, riparian connectivity, stream size, hillslope, soils, and channel migration. See the Potential Protection Measures section 1.4.2 for a discussion of effective buffer widths.

6.3.6 Ponds and Lakes

Changes to ponds and lakes in the City of Burien from a natural state have been the result of urbanization. Increases in impervious surface, loss of vegetated buffers, human intrusion, and stormwater runoff all impact urban ponds and lakes by reducing habitat and altering water quality and quantity functions. Many of these impacts are addressed in detail in the preceding sections.

Generally, a loss of vegetated buffers and increase in impervious surface and ornamental and/or maintained vegetation accompanies development in urban and suburban areas. Such development is evident in Burien, where land uses surrounding ponds and lakes are largely residential. The expected and observed impact to habitat includes a reduction in area for water-dependent species, as well as lost habitat for terrestrial species due to narrow and scarce native buffers. Bald eagles and herons, of special importance in Burien, are largely limited to better protected riparian areas along the main streams in the City; occurrences of these species on ponds and lakes in Burien are not documented.

Specific information on Burien lakes and ponds is limited. A 2010 analysis report on Lake Burien (Herrera 2010) defined Lake Burien as a mesotrophic lake with an aquatic plant community that provides "excellent" fish and wildlife habitat. Potential invasion of non-native species was cited as a risk of public access. Other information specific to ponds and lakes in the City of Burien is not readily available.

6.4 Protection Measures

6.4.1 Endangered, Threatened, or Sensitive Species and Species of Local Importance

As noted in Section 6.3.4 above, fish species covered by City of Burien regulations are largely absent from the urban core, beyond shoreline jurisdiction areas. Potential protection measures for terrestrial priority species present in Burien are detailed here. General fish habitat and associated riparian habitat protection measures are detailed in Section 6.4.2 below.

Bald Eagle

WDFW has established guidelines and recommendations for activities near nests (Watson and Rodrick 2004). Recommendations pertinent to the City of Burien include disturbance control and buffering of nest trees during construction activities and protection of open water foraging areas from both disturbance and pollution to ensure an abundant and uncontaminated food source. Disturbance controls include timing guidelines and visibility/screening parameters. Direct protection of existing and potential nest trees can be accomplished by controlling removal and ensuring that buffers are adequate for protecting against tree loss due to windthrow.

Efforts to reduce contaminated stormwater and sedimentation will also benefit bald eagles by affecting water quality in foraging areas. Similarly, riparian protections have the potential benefit bald eagles by improving the quality of water that drains to eagle foraging sites, particularly nearshore Puget Sound.

WDFW no longer requires bald eagle management plans for activities near nests in Washington. Applicants are now referred to the U.S. Fish and Wildlife (USFWS) for guidelines on development activities in bald eagle management zones. USFWS provides information on buffers and protection methods.

Herons

WDFW management guidelines advise that protection of great blue herons is best approached through a comprehensive land use plan that addresses all species, or if not available, through a site-specific plan for activities proposed near nesting birds. Because nesting birds are less tolerant of disturbance than birds outside of the breeding season, nest buffers are recommended and guidelines for buffer widths provided in the WDFW PHS Management Recommendations Guidance (Quinn and Milner 1999). Foraging area protections are also advised, with a minimum radius of 4 km from colonies.

Management recommendations are not specified in the literature, likely due to the species' noted stability in western Washington. However, both green and great blue herons inhabit slow-moving salt or fresh waters and would benefit from protection of shallow bays, wetlands and streams, as they depend on these resources for food and nesting sites.

6.4.2 Streams and Riparian Areas

The literature includes a wide range of recommended buffer widths; those with smaller widths may be adequate provided the existing buffer is high-quality forest and/or the surrounding land use has low impact (May et al. 1997b). For most riparian buffer functions, much of the literature indicates that buffer widths of 100 feet (30 meters), and in some cases less, may be adequate to provide for fish and wildlife habitat if the buffer is of high quality (Knutson and Naef 1997).

Buffer width reduction with enhancement can be used by landowners to improve the functions of existing, degraded riparian buffers while also making effective use of their land. Both Larry Fisher and Tony Opperman of the Washington Department of Fish and Wildlife (pers. comm., 10 April 2002) concur that buffer averaging and reduction incentives are appropriate to encourage mitigation and enhancement that would improve buffer functioning beyond levels provided by existing buffer conditions. Narrow buffer widths may be adequate if such buffers are of high quality (May et al. 1997b; Castelle and Johnson 1998). Knutson and Naef (1997) have found that there are few studies that examine the effects of incremental changes in buffer widths. Buffers less than 10 meters in width (approximately 33 feet) are not generally considered functionally effective (review by May et al. 1997b; Johnson and Ryba 1992). Contiguous buffers along streams may be more important than increased width for achieving aquatic and terrestrial habitat goals, and smaller buffers may be adequate to protect small, first-order streams (Palone and Todd 1997). The continuity of the riparian corridor along a stream is at least as important as its width (Horner and May 1998; May et al. 1997a).

The removal of non-point source pollutants, including nutrients, sediment, and metals, is generally regarded as a valuable function of riparian buffers (May et al. 1997b). In general, hydrocarbons are found in road runoff and 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 hydrocarbons and other pollutants found in typical stormwater runoff.

In establishing the appropriate level of protection for different stream classes throughout the City, various inferences must be drawn. The majority of scientific studies that critically examine the functions and values associated with riparian areas have been conducted in forested environments. As such, fundamental differences between forested, agricultural, and urban areas, including land use and hydrology, are frequently overlooked. Moreover, Knutson and Naef (1997) have found that there is a limited body of literature on the effects of incremental changes in riparian buffer widths. Lastly, riparian studies often fail to 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.

Recent updates to critical area regulations within some other jurisdictions (e.g. King County, Thurston County, City of Redmond) have utilized a variable width approach based on best available science in which stream buffers may be larger/smaller depending upon connectivity to special aquatic areas such as Puget Sound or other Shorelines of the State. 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 and Johnson 1998). However, Haberstock et al. (2000) suggests utilizing conservative fixed buffer widths that are larger than the minimum needed for protection. Thus, deriving overall recommended buffer widths for application throughout a local jurisdiction is somewhat subjective. Table 6-2 notes the ranges of effective buffer widths (as outlined in each subsection) based on each function and some notes on the functions that were studied.

Table 6-2. Range of Effective Buffer Widths for Each Applicable Riparian Function

Function	Range of Effective Buffer Widths	Notes on Function
Water Quality (sediment and pollution removal)	80 to 150 feet	For 80% nutrient and sediment removal
Bank Stabilization (erosion control)	80 to 125 feet	Disproportionately large increases needed beyond 30 meters to improve function
Shade and Temperature	80 to 150 feet	Based on adequate shade
Microclimate	80 to 525 feet	Up to a distance of two to three site-potential tree heights (SPTH)
Wildlife Habitat	100 to 600 feet	Coverage not inclusive
In-stream Habitat (large woody debris – LWD)	33 to 200 feet	Up to 1 SPTH
Productivity	80 to 100 feet	Disproportionately large increases needed beyond 30 meters to improve function

To achieve improved water quality in the City's streams, riparian buffer areas should be utilized effectively to provide both biofiltration of stormwater runoff and protection from adjacent land uses. Both of these goals can be achieved by providing dense, well-rooted vegetated buffer areas. Forested riparian areas are known to reduce nutrient input into streams (Snyder et al. 1998). Additionally, biofiltration swales, created wetlands, and infiltration opportunities for specific stormwater runoff discharges can be utilized before they reach 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. Effective methods to reduce impacts from urbanization and associated runoff can include fencing, concentrating impact activities away from riparian areas, and densely planting riparian buffers with native trees, shrubs, and groundcover species.

6.4.3 Upland Habitat

The majority of wildlife habitat located within the City of Burien can be found within or adjacent to aquatic areas and thus would be afforded some level of protection through critical area and critical area buffer regulation. However, it is recognized that not only are there other wildlife habitats outside of these wetland and riparian areas, but that the need for wildlife habitat protection may extend much farther than any fixed-width stream or wetland buffer. The dynamics of wildlife use and landscape-scale changes make it difficult to create blanket regulations that would apply to all wildlife areas within the City. Protection of wildlife habitat regulated on a more site-specific basis is recommended.

Approaches to protecting and conserving species and their habitats have varied from protecting species only within clearly identified ecological reserves (Wright 1998) to protecting species regionally through enhancement of existing habitat and important wildlife needs (Morrison et al. 1998, as cited in King County 2004). Regardless of the approach, it is important to recognize the need to protect not only the existing habitats being utilized, but also alternative habitats which may be necessary for breeding, foraging, and sheltering (Bissonette 1997). In order to maintain viable wildlife populations, alternate habitats and features must be accessible (Marzluff and Ewing 2001).

Several generalizations regarding effective policies for wildlife and habitat conservation can be gleaned from the literature. For example, large habitat patches tend to support greater wildlife diversity than smaller patches (Brown 1985; Donnelly 2002), particularly for interior species. However, small, isolated patches of suitable habitat can both support species throughout critical life stages and provide cover for individuals moving between larger habitat patches (Fahrig and Merriam 1994).

Recent and ongoing research at the University of Washington’s College of Forest Resources (Marzluff and Ewing 2001; Marzluff and Donnelly 2002; Rohila and Marzluff 2002) addresses native forest species conservation in developed areas of the Puget Sound region. Recommendations stemming from this work that would apply to conditions in the City of Burien include maintaining mixed (at least 23 percent conifer) stands at a minimum tree density of four per acre and preserving trees of large diameter. Many recommendations in the available literature are species-specific. Thus, as mentioned previously, wildlife habitat is most effectively regulated on a site-specific basis.

In response to growing public interest in wildlife and its protection, as well as changing and expanding federal legislation regarding wildlife, and in order to be competitive for federal grant money, the Washington Department of Fish and Wildlife (WDFW 2005) produced a conservation strategy for the preservation and enhancement of state and federal threatened or endangered species. The resulting document, Washington's Comprehensive Wildlife Conservation Strategy, was created using six "guiding principles" to achieve its goals of healthy, diverse, and sustainable fish and wildlife populations, habitats and recreational opportunities. Table 5 summarizes these principles and how they are useful in the future development and refinement of wildlife habitat regulation in the City of Burien.

Table 6-3. Guiding principles used in development of Washington's Comprehensive Wildlife Conservation Strategy (CWCS)

Guiding Principle	Relevance to the City of Burien
Address all species and habitats, identifying those having the greatest need or lacking adequate documentation	This allows for emphasis on species regulated by state and federal government while addressing all wildlife species and habitat.
Summarize and use information gathered in collaborative conservation planning methods	The Washington GMA mandates the use of best available science in policy decision; the CWCS collates and utilizes recent knowledge gathered specifically for developing wildlife and habitat conservation strategies in Washington State.
Strengthen and expand conservation partnerships	Implementation of wildlife and habitat regulations and policies will be most successful with the cooperation of private, public, and non-government groups and individuals.
Emphasize conservation of biodiversity	In 2002, Washington State passed legislation calling for the development of state guidelines for conserving biodiversity. Best available science also emphasizes the need to address and conserve biodiversity.
Produce an understandable document available to the public	Providing a comprehensive, reader-friendly document will assist in gaining public support for proposed regulatory updates.
Produce a document that draws attention to important wildlife issues, particularly where decision-makers are concerned	Implementation of wildlife conservation strategies will require the support of both the public and decision-makers. Policy backed by best available science, detailed in a document highlighting wildlife issues, will facilitate acceptance and approval by concerned parties.

To incorporate BAS, Burien may consider including the following elements in its designation of FWHCAs:

- State Priority Habitats and Areas Associated with State Priority Species;
- Areas of Rare Plant Species and High Quality Ecosystems; and
- Land Useful or Essential for Preserving Connections Between Habitat Blocks and Open Spaces.

Inclusion of State priority habitats, state priority species, rare plants, and high quality ecosystems would substantially overlap the existing designation of "areas with which endangered, threatened, and sensitive species have a primary association." However, the habitat elements that do not overlap provide key foraging or breeding habitat (e.g., snags), support high species density and diversity (e.g., old-growth or mature forest), are difficult or impossible to replace (e.g., caves), and/or are limited in number (e.g., cliffs). While State or federally listed or sensitive species may not be directly associated with these special habitats or ecosystems, their preservation and protection may be key in preventing the addition of species to those lists. Further, existing and proposed performance standards for FWHCAs require coordination on a site-specific level with the WDFW and Washington Department of Natural Resources (among others), the agencies which manage the PHS program and the Natural Heritage Program (which maps rare plants and high quality ecosystems), respectively.

Maintenance of special habitats across the landscape is important in the short term, but long-term viability requires that species be able to move between patches to maintain genetic diversity, enable dispersal, and allow movement of species that require different habitat types for different life stages. The relative importance of safe corridors connecting patches is somewhat dependent on the particular species and the size and characteristics of the habitat patch. Accordingly, the City should consider including these elements in its definition of FWHCAs.

6.5 FWHCA Summary

FWHCAs in the City of Burien are: chum salmon, great bule heron, and bald eagle habitat; streams and riparian areas, with particular attention paid to Salmon and Miller Creeks; and ponds and lakes. PHS polygons in the City include a bald eagle breeding occurrence, chum salmon, Coho salmon, a great blue heron breeding area, and biodiversity corridors. Lake Burien is a Water of the State, but does not support salmonids and is not publically stocked.

Functions and values of FWHCAs in Burien focus on habitat and are diverse, varying among habitat types. Streams and riparian areas work through complex processes to sustain fish, terrestrial wildlife, and plant communities. Processes and functions performed by streams and riparian areas maintain and impact water quality, sedimentation and erosion, microclimate, stormwater flow, and terrestrial and aquatic habitat for many species. Ponds and lakes perform many of the functions of wetlands, as well as providing special habitat features for many wildlife guilds, including reptiles, amphibians, and species of local importance such as herons.

All FWHCAs in Burien are impacted by development through vegetation changes, fragmentation, human disturbance, and alterations in ecological processes. Impacts to stream and riparian areas include changes in hydrology, loss of bank stability, fish community alterations, flood frequency and volume changes, and water quality loss, all of which result in habitat impacts. Vegetated buffers play a role in maintaining habitat value amid land use changes in and near streams and riparian areas.

Ponds and lakes are impacted by development in much the same way as other FWHCAs in Burien. Potential impacts to bald eagles and herons include their exclusion from highly developed ponds and lakes; formal documentation of bald eagles and herons on Burien ponds and lakes does not exist.

Measures to protect FWHCAs in Burien include the application of specific WDFW management recommendations for PHS species; preservation and improvement of sufficient buffers on streams, ponds and lakes; protection and conservation of upland habitat; and adherence to the guiding principles in Washington's Comprehensive Wildlife Conservation Strategy.

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